Leibniz
Ferdinand-Braun-Institut

ANNUAL REPORT

MICROWAVE COMPONENTS & SYSTEMS
GAN ELECTRONICS
DIODE LASERS
GAN OPTOELECTRONICS
MATERIALS & PROCESSES
SCIENCE MANAGEMENT

2011

JAHRESBERICHT

Kleines ganz groß …

Sie sind so winzig, dass man sie leicht übersehen kann: Einige sind kaum reiskorngroß, andere haben die Größe einer Streichholzschachtel. Die miniaturisierten Halbleiterkomponenten aus dem Ferdinand-Braun-Institut sind zwar klein, haben es aber in sich! Seit zwei Jahrzehnten entwickeln wir nunmehr Bauelemente und -module wie Diodenlaser, Transistoren oder Leistungsverstärker. Vieles hat sich in diesem Zeitraum verändert und weiterentwickelt, gleich geblieben ist jedoch, dass viele Systeme ohne die kleinen Alleskönner nicht funktionieren oder deutlich größer gebaut werden müssten.

Wir erzielen exzellente Forschungsergebnisse, etwa auf dem Gebiet der Diodenlaser. Hier entwickeln wir nicht nur Chips mit den weltweit höchsten Effizienzen, sondern auch sehr kompakte, streichholzgroße Lasermodule. Diese können beispielsweise in der Displaytechnologie bei aufwändigen Großprojektionen in Planetarien oder Flugsimulatoren schrankgroße Lasertypen ersetzen. Ein Beispiel aus der Mikrowellentechnik sind Schaltverstärker (Klasse-S-Verstärker), die dank neuer Konfigurationen ein effizienteres Leistungsmanagement ermöglichen. Die Leistungsendstufen und damit die Leistungsverstärker neuer Mikrowellensysteme bestimmen die Effizienz des Gesamtsystems und damit auch den Energieverbrauch.

So leisten wir in zentralen Bedarfsfeldern wie der Kommunikation, Gesundheit, Energie und Sicherheit mit unseren Forschungsergebnissen und unserem langjährigen Know-how einen wichtigen Beitrag zur technologischen Zukunftsvorsorge in unserer modernen Gesellschaft. Das Spektrum reicht von der Grundlagenforschung bis zur Applikation. Qua Forschungsauftrag haben wir die Anwendung stets im Blick und kooperieren kontinuierlich und gleichzeitig mit über 50 Industrieunternehmen im Rahmen von FuE-Aufträgen und Forschungsdienstleistungen. Dazu gehören nicht nur zahlreiche internationale Kooperationen oder Industrieprojekte mit Global Playern wie Bosch, Infineon, NEC, TESAT Spacecom oder Trumpf. Ein wichtiges strategisches Ziel ist die nachhaltige Entwicklung industrieller Wertschöpfung in der Region. Zu diesem Zweck arbeiten wir mit Firmen vor Ort zusammen, wie JENOPTIK, OSA, Osram, Lumics oder SENTECH. Bei diesen Unternehmen ist das FBH ein wesentlicher Bestandteil der Wertschöpfungskette und hilft, deren Markterfolg zu sichern. Auch in regionalen Verbünden wie dem regionalen Wachstumskern ‚Berlin WideBaSe' engagieren wir uns – mit exzellenten Resultaten: Leuchtdioden für spezifische UV-Wellenlängen sind hier inzwischen verfügbar, deren Effizienz zu den weltweit besten gehört. Gleichermaßen erfolgreich sind wir beim Technologietransfer durch Ausgründungen: sechs Spin-offs hat das Ferdinand-Braun-Institut seit 1999 auf den Weg gebracht; zwei weitere sind derzeit in Vorbereitung.

Nicht nur bei Forschung und Entwicklung sowie deren Anwendungen, auch bei der Sicherung des akademischen und gewerblichen Nachwuchses sind wir aktiv. Zusätzlich zu den Lehrtätigkeiten an mehreren Universitäten schließen bei uns jährlich etwa fünf Promovierende und über zehn Masterstudierende ab. Pro Jahr bilden wir drei junge Leute zu Mikrotechnologinnen und Mikrotechnologen aus; in der Werkstatt des Instituts lernt außerdem ein Industriemechaniker. Die Abteilung Wissenschaftsmanagement bündelt verschiedene Initiativen zur Aus- und Weiterbildung, wie etwa das Ausbildungsnetzwerk Hochtechnologie Berlin, oder organisiert Veranstaltungen, die Mädchen verstärkt für Karrieren in MINT-Berufen werben.

Durch unsere vielfältigen Aktivitäten, von State-of-the-Art-Forschung und -Entwicklung über Wissens- und Technologietransfer bis hin zur nachhaltigen Qualifizierung des Nachwuchses, sichern wir die Kompetenz Deutschlands in der Mikrowellentechnik und Optoelektronik. Als Querschnittstechnologien sind die Entwicklungen unseres Instituts von zentraler Bedeutung: Sie verbessern die Leistungsfähigkeit bestehender Anwendungen und erschließen vollkommen neue Applikationen. Das macht die „Winzlinge" aus dem FBH auch im zwanzigsten Jahr des Bestehens ganz „groß" und für die internationale Wettbewerbsfähigkeit des Technologiestandorts Deutschland unverzichtbar.

Small size, big impact ...

Their size is so small that they can be easily overlooked: some are hardly as big as a rice grain; others feature the size of a matchbox. The dimensions of the miniaturized semiconductor components from the Ferdinand-Braun-Institut may be little, but have proven to be very capable! Since two decades, we meanwhile develop devices and modules such as diode lasers, transistors, and power amplifiers. A whole lot changed and progressed in this time period; what remains the same is that many systems would not work or would have to be constructed considerably larger without the tiny all-rounders from FBH.

We achieve excellent research results in the field of diode lasers, developing not only laser chips with the best efficiencies attained world-wide, but also very compact, sophisticated laser modules the size of a matchbox. In display technology, for example, advanced large-scale projections generate razor-sharp images in planetariums and flight simulators. FBH's small-dimensioned modules may replace bulky laser types the size of cubicles which are currently used for such applications. An example for outstanding results in microwave technology is switching amplifiers (class-S amplifiers). They are investigated and developed at FBH with a novel configuration, enabling to profit from a more efficient power management. The final output stage and thus the power amplifiers of new microwave systems determine the efficiency of the overall system. Accordingly, an improved efficiency leads to reduced energy consumption.

With our results and long-term know-how we therefore substantially contribute to the technological provisions for the future, hence securing today's society's needs in vital fields like communications, health, energy, and security. Our activities range from basic research to applications. Corresponding to our research assignment, we always make sure that FBH know-how and research comes into application. We therefore continuously cooperate with more than 50 companies simultaneously in the framework of R&D contracts and services. These comprise not only various international business relations and industrial contracts, but also long-term strategic collaborations which have been established with global players such as Bosch, Infineon, NEC, TESAT Spacecom, and Trumpf. Close cooperation with regional enterprises including JENOPTIK, OSA, Osram, Lumics, and SENTECH are a further core part of our value chain, supporting these companies to assure their commercial success. FBH also plays a vital role in networks, among them the regional growth core 'Berlin WideBaSe'—achieving excellent results: meanwhile, light emitting diodes for specific UV wavelengths have been developed delivering efficiencies among the world's best. In technology transfer we are similarly successful: six spin-offs have been brought on their way by the Ferdinand-Braun-Institut since 1999; two are currently being prepared.

Not only in research and development including the application, also in securing the academic offspring and industrial apprentices we are actively involved. In addition to teaching activities at several universities five PhD students and more than ten master students graduate on an annual average. We train three apprentices as microtechnologists per year; the institute's workshop additionally qualifies one industrial mechanic. On top of this, FBH's Science Management Department bundles various initiatives regarding education and training including ANH Berlin (Ausbildungsnetzwerk Hochtechnologie), and organizes events encouraging girls for a career in natural sciences.

By our multifold activities, from state-of-the-art research and development, know-how and technology transfer to sustainable qualification of next-generation's employees, we assure German technological excellence in microwave and optoelectronic research. As cross-sectional technology, the developments from our institute are of vital importance improving the capability of existing applications and opening up entirely new ones. This is what makes the "midgets" from the FBH in the twentieth year of the institute's existence persistently "big" and indispensable to maintain Germany's excellent technological competitiveness.

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PROFILE

PROFIL

Das FBH im Profil

Das Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik (FBH) erforscht elektronische und optische Komponenten, Module und Systeme auf der Basis von Verbindungshalbleitern. Diese sind Schlüsselbausteine für Innovationen in den gesellschaftlichen Bedarfsfeldern Kommunikation, Energie, Gesundheit und Mobilität. Leistungsstarke und hochbrillante Diodenlaser, UV-Leuchtdioden und hybride Lasersysteme entwickelt das Institut vom sichtbaren bis zum ultravioletten Spektralbereich. Die Anwendungsfelder reichen von der Medizintechnik, Präzisionsmesstechnik und Sensorik bis hin zur optischen Satellitenkommunikation. In der Mikrowellentechnik realisiert das FBH hocheffiziente, multifunktionale Verstärker und Schaltungen, unter anderem für energieeffiziente Mobilfunksysteme und Komponenten zur Erhöhung der Kfz-Fahrsicherheit. Kompakte atmosphärische Mikrowellenplasmaquellen mit Niederspannungsversorgung entwickelt es für medizinische Anwendungen, etwa zur Behandlung von Hauterkrankungen.

Das FBH ist ein international anerkanntes Zentrum für III/V-Verbindungshalbleiter mit allen Kompetenzen: vom Entwurf, über die Fertigung bis hin zur Charakterisierung von Bauelementen.

Seine Forschungsergebnisse setzt das FBH in enger Zusammenarbeit mit der Industrie um und transferiert innovative Produktideen und Technologien erfolgreich durch Spin-offs. In strategischen Partnerschaften mit der Industrie sichert es in der Höchstfrequenztechnik die technologische Kompetenz Deutschlands.

FBH at a glance

The Ferdinand-Braun-Institut, Leibniz-Institut fuer Hoechstfrequenztechnik (FBH) researches electronic and optical components, modules and systems based on compound semiconductors. These devices are key enablers that address the needs of today's society in fields like communications, energy, health and mobility. Specifically, FBH develops light sources from the visible to the ultra-violet spectral range: high-power diode lasers with excellent beam quality, UV light sources and hybrid laser systems. Applications range from medical technology, high-precision metrology and sensors to optical communications in space. In the field of microwaves, FBH develops high-efficiency multi-functional power amplifiers and millimeter wave frontends targeting energy-efficient mobile communications as well as car safety systems. In addition, compact atmospheric microwave plasma sources that operate with economic low-voltage drivers are fabricated for use in a variety of applications, such as the treatment of skin diseases.

The FBH is a competence center for III-V compound semiconductors and has a strong international reputation. FBH competence covers the full range of capabilities, from design to fabrication to device characterization.

In close cooperation with industry, its research results lead to cutting-edge products. The institute also successfully turns innovative product ideas into spin-off companies. Thus, working in strategic partnerships with industry, FBH assures Germany's technological excellence in microwave and optoelectronic research.

Leitbild

... translating ideas into innovation

- ➜ Wir erforschen Schlüsseltechnologien für innovative Anwendungen in der Mikrowellentechnik und Optoelektronik. Als Kompetenzzentrum für Verbindungshalbleiter arbeiten wir weltweit vernetzt und erzielen Forschungsergebnisse auf internationalem Spitzenniveau.

- ➜ Wir bieten Lösungen aus einer Hand: vom Entwurf bis zum lieferfähigen Modul.

- ➜ Wir setzen unsere Forschung in strategischen Partnerschaften mit der Industrie in praktische Anwendungen um und sichern so die technologische Kompetenz Deutschlands in der Höchstfrequenztechnik. Innovative Produktideen transferieren wir erfolgreich durch Spin-offs.

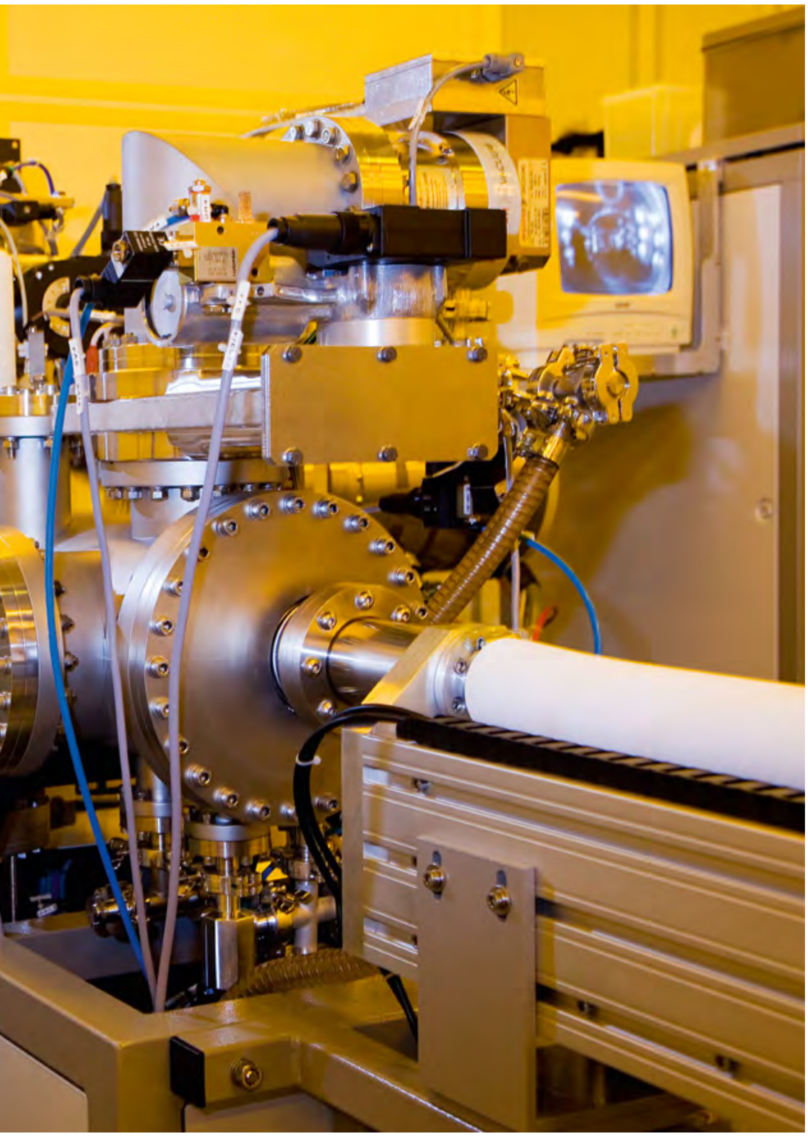
- ➜ Wir offerieren hochwertige Produkte und Services, die exakt auf die Anforderungen unserer Kunden zugeschnitten sind.

- ➜ Wir bieten unseren Mitarbeitern ein stabiles, attraktives und familienfreundliches Arbeitsumfeld mit reizvollen Aufgabenstellungen und Entfaltungsmöglichkeiten. Unsere Zukunft sichern wir durch die gezielte Förderung des wissenschaftlichen Nachwuchses und die Ausbildung technischer Fachkräfte.

- ➜ Wir haben es uns zur Aufgabe gemacht, den Anteil weiblicher Fach- und Führungskräfte im technischen und naturwissenschaftlichen Bereich gezielt zu erhöhen sowie ausländische Kolleginnen und Kollegen aktiv bei der Integration zu unterstützen.

Mission statement

... translating ideas into innovation



- We explore cutting-edge technologies for innovative applications in the fields of microwaves and optoelectronics. As a center of competence for III-V compound semiconductors, we are part of a worldwide network and achieve research results advancing the international state-of-the-art.

- We offer complete solutions as a one-stop agency—from design to ready-to-ship modules.

- In strategic partnerships with industry, we transfer our research results into cutting-edge products and thus ensure German technological leadership in microwaves and optoelectronics. By means of spin-off companies, we bring innovative product ideas into the market.

- We provide high-value products and services for our customers in the research community and industry which are tailored to fit their individual needs.

- We offer our employees an attractive and family-friendly working environment with interesting tasks and career prospects. To maintain top-level expertise we guide, assist, and encourage young scientists and train our staff.

- We specifically aim at increasing the proportion of female specialists and executive staff in the technical and scientific area and actively assist foreign colleagues with their integration.

Geschäftsbereiche & Forschung

Mikrowellenkomponenten & -systeme
➜ Frontends bis 100 GHz
➜ Leistungsverstärker bis 10 GHz
➜ Low-Noise-Komponenten
➜ Mikrowellen-Plasmaquellen
➜ Terahertz-Elektronik
➜ Leistungsmodule

GaN-Elektronik
➜ Mikrowellentransistoren & MMICs
➜ Leistungselektronik

Diodenlaser
➜ Breitstreifen & Barren (Spektralbereich 0,6 – 1,2 µm)
➜ Hochbrillante Laser (Linienbreiten < 10 MHz)
➜ Hybride Lasersysteme
➜ Lasersensorik
➜ Lasermetrologie

GaN-Optoelektronik
➜ UV-LEDs
➜ Nitrid-Laserdioden

Material- & Prozesstechnologie
➜ GaN-HVPE
➜ Optische Sonderbauelemente
➜ In-situ Kontrolltechniken bei MOVPE & HVPE
➜ Lasermikrostrukturierung

Wissenschaftsmanagement
➜ Technologietransfer & Marketing
➜ Bildungsmanagement

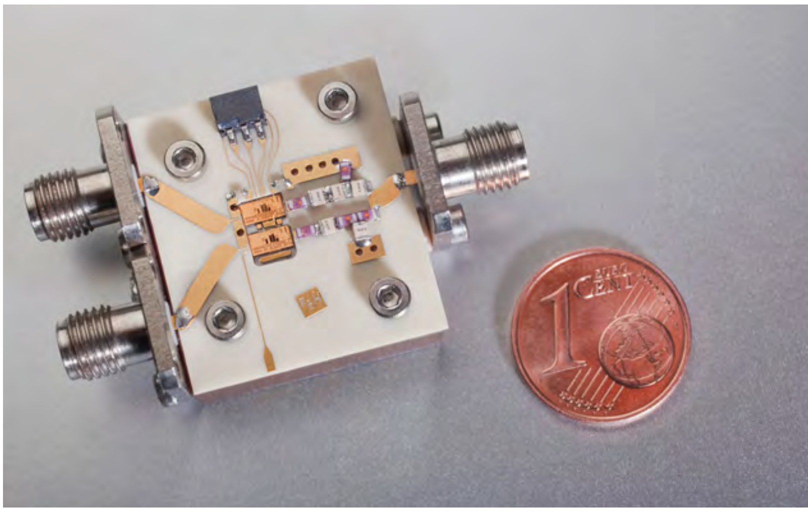
Lösungen & Services aus einer Hand

Für Partner aus Forschung und Industrie entwickelt das FBH hochwertige Produkte und Services, die exakt auf individuelle Anforderungen zugeschnitten sind. Seinem internationalen Kundenstamm bietet es Know-how und Komplettlösungen aus einer Hand: vom Entwurf bis zum lieferfähigen Modul.

Mikrowellenkomponenten und -systeme
➜ Galliumnitridelektronik: Transistoren und Verstärker (hybrid, MMIC) – Entwurf, Fertigung, Kleinserie
➜ Mikrowellenplasmen
➜ Elektromagnetische Simulation
➜ Hochfrequenz- und Leistungsmesstechnik

Hochleistungsdiodenlaser und LEDs
➜ Diodenlaser auf Galliumarsenid-Basis mit maßgeschneiderten Eigenschaften (Leistung, Wellenlänge, Linienbreite, Strahlgüte, Effizienz) – Entwurf, Fertigung, Kleinserie
➜ Hybride Lasersysteme im IR- und sichtbaren Spektralbereich
➜ Galliumnitrid-Laser und UV-LEDs
➜ Zuverlässigkeitsuntersuchungen

Prozesse und Materialien
➜ Entwicklung und Durchführung von Halbleiterprozessen (insbesondere III/V-Halbleiter)
➜ Epitaxie kundenspezifischer III/V-Halbleiter-Schichtstrukturen
➜ Optische Komponenten aus Galliumarsenid (Spiegel, Halbleiter-Scheiben, SESAMs)
➜ UV-Photodetektoren



Business areas & research

Microwave Components & Systems
- ➜ Front ends up to 100 GHz
- ➜ Power amplifiers up to 10 GHz
- ➜ Low-noise components
- ➜ Microwave plasma sources
- ➜ Terahertz electronics
- ➜ Power modules

GaN Electronics
- ➜ Microwave transistors & MMICs
- ➜ Power electronics

Diode Lasers
- ➜ Broad area lasers & bars (spectral range 0.6 – 1.2 µm)
- ➜ High-brightness lasers (linewidth < 10 MHz)
- ➜ Hybrid laser systems
- ➜ Laser sensors
- ➜ Laser metrology

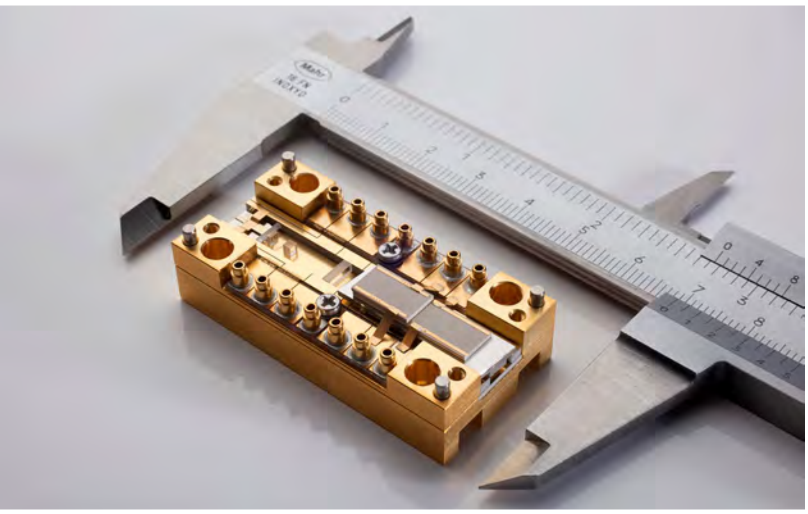
GaN Optoelectronics
- ➜ UV LEDs
- ➜ Nitride laser diodes

Materials & Process Technology
- ➜ GaN HVPE
- ➜ Special optical devices
- ➜ In-situ control techniques for MOVPE & HVPE
- ➜ Laser micro processing

Science Management
- ➜ Technology transfer & marketing
- ➜ Education & training management

Competence & comprehensive services

The FBH develops high-value products and services for its partners in the research community and industry which are tailored precisely to fit individual needs. The institute offers its international customer base complete solutions and know-how as a one-stop agency—from design to ready-to-ship modules.



Microwave Components and Systems
- ➜ Gallium nitride electronics: transistors and amplifiers (hybrid, MMIC)—design, production, small-scale series
- ➜ Microwave plasmas
- ➜ Electromagnetic simulation
- ➜ Microwave measurement and device characterization

High-Power Diode Lasers and LEDs
- ➜ Gallium arsenide-based diode lasers with customized properties (output power, wavelength, spectral line width, brightness, efficiency)—design, production, small-scale series
- ➜ Hybrid laser systems in the IR and visible spectral range
- ➜ Gallium nitride lasers and UV LEDs
- ➜ Reliability investigations

Processes and Materials
- ➜ Development and implementation of semiconductor processes (especially III-V semiconductors)
- ➜ Epitaxial growth of customized III-V semiconductor layers
- ➜ Optical components based on gallium arsenide (mirrors, semiconductor disks, SESAMs)
- ➜ UV photodetectors

Contact
Kontakt

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The institute in figures
Das Institut in Zahlen

Founded 1992 Gegründet 1992

	2010	2011
Staff / Team	220	240
Scientists / Wissenschaftlerinnen & Wissenschaftler	72	76
PhD students / Promovierende	38	38
Student assistants & diploma students / Studentische Hilfskräfte & Diplomierende	18	18
Trainees / Auszubildende	9	10

	2010	2011
Ongoing projects / **Laufende Projekte**	159	156
Publications (peer reviewed) / **Publikationen (referiert)**	78	64
Patents / **Patente**	126	148
Talks / **Vorträge**	90	108

Budget in million Euros — **Umsatz** in Mio. Euro

	2010	2011
Basic funding: State of Berlin and Federal Government / Grundfinanzierung durch das Land Berlin und den Bund	11.0	11.8
Public project funding / Öffentliche Drittmittel	5.8	7.7
Industrial contracts / Industrielle Auftragsforschung	2.7	2.4

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Forschungsverbund Berlin e.V.

Der Forschungsverbund Berlin e.V., zu dem auch das Ferdinand-Braun-Institut gehört, ist Träger von acht natur-, lebens- und umweltwissenschaftlichen Forschungsinstituten in Berlin. Alle Institute sind wissenschaftlich eigenständig, nehmen aber im Rahmen einer einheitlichen Rechtspersönlichkeit gemeinsame Interessen wahr. Als Forschungseinrichtungen von überregionaler Bedeutung und gesamtstaatlichem wissenschaftspolitischen Interesse werden die Institute im Rahmen der gemeinsamen Forschungsförderung von Bund und Ländern finanziert. Sie verfügen über eine gemeinsame Verbundverwaltung (Geschäftsführer: Dr. Falk Fabich) und gehören zur Leibniz-Gemeinschaft.

Die Direktoren der Institute und weitere leitende Wissenschaftler haben Professuren an den Universitäten in Berlin/Brandenburg inne und sichern so die enge Verbindung zu Lehre und Forschung in den Hochschulen.

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Organizational chart
Organigramm

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Director of the FBH

Science Management
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Business Areas				Departments			
Microwave Components & Systems Prof. Dr.-Ing. W. Heinrich	GaN Electronics Dr.-Ing. J. Würfl	Diode Lasers Dr. G. Erbert	GaN Optoelectronics Prof. Dr. M. Kneissl	Microwaves Prof. Dr.-Ing. W. Heinrich	Optoelectronics Dr. G. Erbert	Materials Technology PD Dr. M. Weyers	Process Technology Dr. O. Krüger
Frontend Power Amplifiers Low-Noise Components Microwave Plasmas Power Modules Terahertz Electronics	Microwave Transistors & MMICs Power Electronics	BA Lasers & Bars High-Brightness Lasers Hybrid Laser Systems Laser Sensors Laser Metrology	Nitride Laser Diodes UV LEDs	Electromagnetic Simulation Circuit Design Measurements & Packaging	Laser Design Laser Technology Mounting & Packaging Laser Measurements	Arsenides & Phosphides Nitrides Special Optical Devices Materials Analytics	Frontend Backend

University Cooperations
Prof. Dr.-Ing. G. Böck - Microwave Technology (TU Berlin) | Prof. Dr. M. Kneissl - Experimental Nanophysics and Photonics (TU Berlin) |
Prof. Dr. V. Krozer - Terahertz Photonics (Uni Frankfurt) | Prof. Dr. A. Peters - Optical Metrology (HU Berlin)

Forschungsverbund Berlin e.V.

The Forschungsverbund Berlin e.V. comprises eight research institutes in Berlin—one of them being the Ferdinand-Braun-Institut. The institutes are active in the fields of natural sciences, life sciences and environmental sciences. They pursue common interests within the framework of a single legal entity while preserving their scientific autonomy. As research institutes of national scientific importance, they are jointly funded by the German federal and state governments. The institutes share an administrative infrastructure (Common Administration, Head: Dr. Falk Fabich) and belong to the Leibniz Association.

The institute directors and other senior scientists hold chairs at the Berlin/Brandenburg universities, thus ensuring close contact with teaching and research in higher education.

HIGHLIGHTS

SCHLAGLICHTER

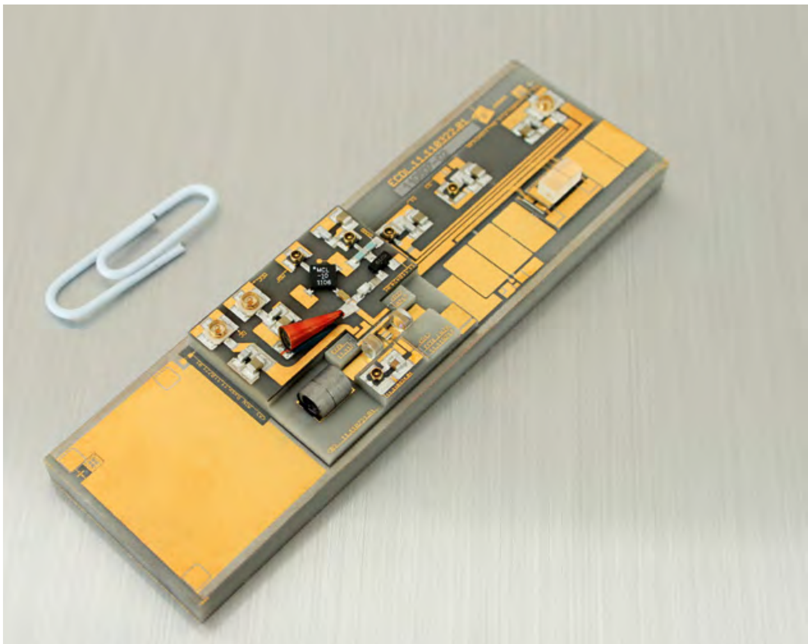
Gut positioniert: Kompetenz bei Weltraumanwendungen

In den vergangenen Jahren haben sich Weltraumanwendungen zu einem wichtigen Kompetenzfeld am FBH entwickelt. Mit seinen kompakten, effizienten und robusten Diodenlasern ist das FBH hier im Bereich der optischen Datenübertragung international seit vielen Jahren ausgezeichnet positioniert. 2008 wurde zudem die Gruppe Lasermetrologie geschaffen. Sie entwickelt die Lasertechnologie, die für weltraumgestützte Experimente benötigt wird. Dabei arbeiten Wissenschaftler des FBH und der Humboldt-Universität zusammen und verbinden so grundlagen- mit anwendungsorientierter Forschung.

Zahlreiche Laser haben die anspruchsvollen Tests der Europäischen Weltraumbehörde ESA für Weltraumapplikationen bereits bestanden und werden im All eingesetzt. Inzwischen laufen auch im Bereich der Mikrowellentechnik und der Galliumnitrid (GaN)-Leistungselektronik Projekte, bei denen robuste Transistoren und Komponenten für Radarsensoren aus dem Institut künftig im All zum Einsatz kommen werden.

Diodenlasermodule für die ultrapräzise Atomspektroskopie im Weltraum

In den vergangenen Jahren fanden verschiedene Grundlagenarbeiten für atomphysikalische Präzisionsmessungen am Fallturm ZARM in Bremen statt. Sie bereiten die Wissenschaftler auf den Start der Höhenforschungsrakete MAIUS vor, die 2013 abheben wird. An Bord soll ein quantenoptisches Experiment mit ultra-kalten Rubidium-Atomen durchgeführt werden. Damit kommt das Einstein'sche Äquivalenzprinzip auf den Prüfstand, demzufolge alle Massen im Gravitationsfeld gleich stark beschleunigt werden. Das FBH realisiert für diesen Zweck 40 Lasermodule mit sehr kleiner Linienbreite (DFB- und DBR-Laser, MOPAs, Extended-Cavity-Diodenlaser) auf mikrooptischer Bank. Verschiedene dieser Module haben die Vibrationstests für Raumfahrtanwendungen bis 8 g_{RMS} – dies entspricht den typischen Belastungen von Start und Flug – erfolgreich absolviert. Die Lasermodule zeigten dabei weder mechanische Beschädigungen noch Einschränkungen ihrer elektrooptischen Eigenschaften. Weitere Projekte beschäftigen sich mit quantenoptischen Experimenten mit ultrakalten Gasen (Bose-Einstein-Kondensat) und mit der optischen Datenübertragung großer Datenmengen im Weltraum und zur Erde.



Micro-integrated extended-cavity diode laser for the spectroscopy of ultra-cold atoms.

Mikrointegrierter Extended Cavity Diode Laser für die Spektroskopie an ultrakalten Atomen.

Erster europäischer GaN-Transistor im All kommt aus dem FBH

Wenn Mitte 2012 der Kommunikationssatellit Alphasat in eine geostationäre Umlaufbahn geschossen wird, ist auch ein Stück Hightech aus dem Ferdinand-Braun-Institut mit an Bord. Als erste europäische Galliumnitrid-Transistoren in einem Satellitenexperiment werden Transistoren aus dem FBH eingesetzt. GaN-Chips sind gegenüber Siliziumbauteilen besser für den Einsatz im Weltraum geeignet, da sie auf kleiner Fläche mehr Leistung bei hohen Frequenzen erzielen. Sie erlauben daher kleinere, leichtere sowie belastbarere Systeme und tolerieren zudem den Einfluss kosmischer Strahlung besser.

Wissenschaftler des FBH haben gemeinsam mit Kollegen der Universität Aveiro (Portugal) ein Modul zum Test von GaN-Anwendungen im Weltraum entworfen und gebaut. Das FBH fertigte speziell optimierte GaN-Bauelemente, die in ein 2 GHz-Oszillatorexperiment integriert werden. Alle notwendigen Tests, um mit der Installation an Bord des Satelliten zu beginnen, wurden im Mai 2011 erfolgreich abgeschlossen. ↓

Well-positioned: FBH competence in space applications

In recent years, space applications have developed into an important field of competence at the FBH. With its compact, efficient, and robust diode lasers, the FBH is world-wide recognized for years in the field of optical data transmission. Furthermore, the 2008 established laser metrology group develops the laser technology required for space-borne experiments. In this field, FBH and the Humboldt-Universität cooperate and thus combine basic with application-oriented research.

Numerous lasers have already passed the challenging tests of the European Space Agency ESA for space applications and are utilized in space. Meanwhile, also robust transistors and components for radar sensors based on microwave technology and gallium nitride (GaN) power electronics add to the portfolio and will be used there soon.

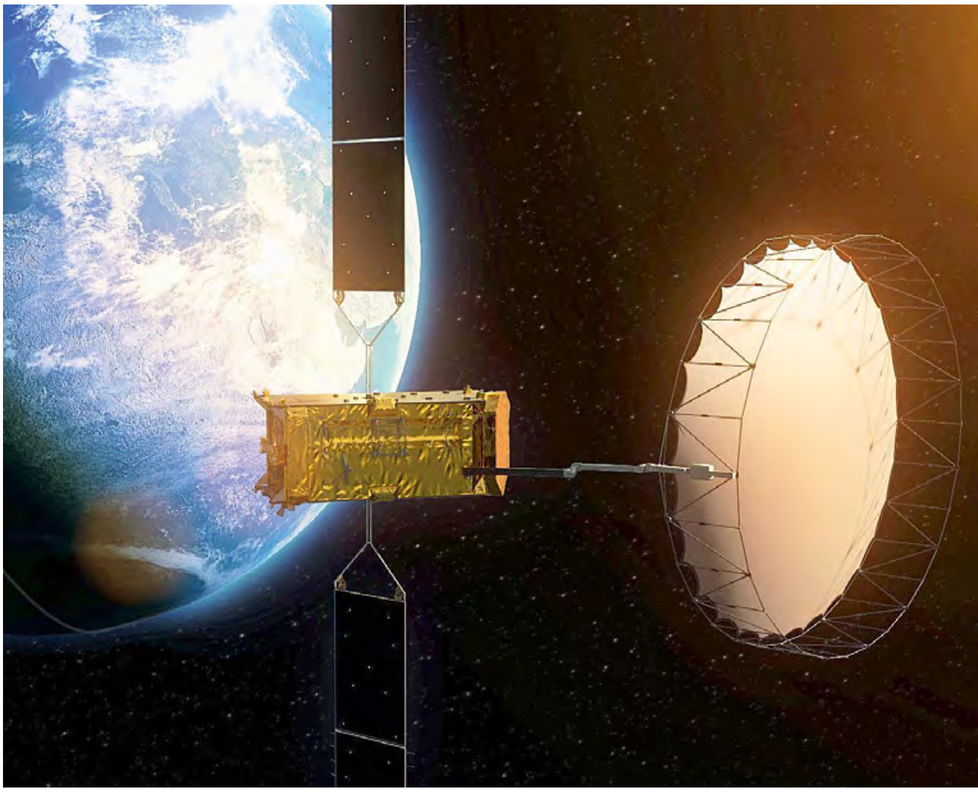
Diode laser modules for ultra-precise atom spectroscopy in space

In the last years, a number of basic research activities for atom-physical precision measurements have been executed at the Bremen drop tower ZARM. They prepare the scientists for the start of the sounding rocket MAIUS, taking off in 2013. A quantum-optical experiment with ultra-cold rubidium atoms shall be executed and hence reviews the Einstein equivalence principle claiming that all masses in a gravitation field are accelerated equally. For this purpose, FBH realizes 40 laser modules with very narrow linewidth (DFB and DBR laser, MOPAs, extended-cavity diode lasers) on a micro-optical bench. Some of these modules have already successfully passed the vibration tests with up to 8 g_{RMS} for space applications—this corresponds to the typical stress during start and flight. During testing, the laser modules showed neither mechanical damages nor limitations of their electro-optical properties. Further projects are concerned with quantum-optical experiments with ultra-cold gases (Bose-Einstein condensate) and with optical data transmission of high data rates in space and to the Earth.

First European GaN transistor in space comes from the FBH

When the Alphasat communication satellite will be launched in mid-2012, a piece of high-tech from the Ferdinand-Braun-Institut will be on board too. Hence, the gallium nitride transistors from the Ferdinand-Braun-Institut will be the first European ones ever used in a satellite experiment. In contrast to silicon-based devices, GaN chips are better suited for applications in space as they obtain more power at high frequencies from a smaller area. They enable smaller, more light-weighted and thus more reliable systems. Additionally, they can better deal with the influence of cosmic radiation.

Scientists from the FBH together with colleagues from the Aveiro University (Portugal) have designed and realized a module to test GaN applications in space. FBH produced specifically optimized GaN devices to be integrated into a 2 GHz oscillator experiment. All tests required to ↓



FBH gallium nitride transistors will soon be launched into space on board of the communication satellite Alphasat.

An Bord des Kommunikationssatelliten Alphasat starten bald Galliumnitrid-Transistoren des FBH ins All.

Das Experiment, das die Effekte der Weltraumumgebung verfolgen wird, ist für eine Missionsdauer von drei Jahren ausgelegt. In dieser Zeit werden kontinuierlich Daten bezüglich des Strahlungsumfeldes in geostationärer Umlaufbahn und dessen Auswirkungen auf GaN-basierte elektronische Komponenten aufgezeichnet und zur Erde gesendet. Diese Daten sind von besonderer Bedeutung für die weitere Optimierung der GaN-Elektronik für hochzuverlässige Weltraumanwendungen.

Bildgebung und Radarapplikationen für den Weltraum
Lande- und Andockmanöver von Raketen und Satelliten im Weltraum erfordern bildgebende und zielverfolgende Sensoren. Diese müssen unabhängig von der Beleuchtungssituation mit gleichzeitig guter Auflösung und räumlicher Lokalisierung sowie minimalen Datenraten arbeiten. Radarsensoren bei Millimeterwellen und Echtzeit-Bildverarbeitung erfüllen diese Anforderungen. Ihr Einsatz in Weltraummissionen wird am FBH anhand eines 3D-Bildgebungssystem mit Echtzeit-Datenverarbeitung für Abstände im Bereich unter 20 m und für ein Zielverfolgungsradar für Abstände bis 1000 m untersucht. Beide Systeme werden insbesondere hinsichtlich ihrer Weltraumtauglichkeit geprüft und optimiert.

Am FBH werden dazu Komponenten für die beiden Radarsysteme als integrierte Mikrowellenschaltungen (MMICs) entwickelt, die auf der am FBH vorhandenen Technologie für InP-Hetero-Bipolar-Transistoren (HBTs) basieren. Spannungsgesteuerte Oszillatoren (VCOs) und Leistungsverstärker im Frequenzbereich 70 bis 100 GHz sollen demonstriert werden. Der spezielle HBT-Prozess bietet unter anderem Vorteile bezüglich der Strahlungsunempfindlichkeit. Daher sind hervorragende Betriebseigenschaften der Schaltungen für den Einsatz im Weltraum zu erwarten.

Kompetenzen bündeln: Integration von Silizium- und III/V-Technologie für die Terahertz-Elektronik

Die CMOS-Halbleitertechnik bildet seit Jahrzehnten das Rückgrat der Mikroelektronik. Mehr als 95 Prozent aller digitalen oder analog-digitalen Schaltungen werden mit ihnen realisiert; sie sorgen beispielsweise in Computerprozessoren für immer höhere Integrationsdichten und kürzere Taktzeiten. Strebt man jedoch Frequenzen um 100 Gigahertz und darüber an, stoßen die CMOS-Schaltungen an ihre Grenzen. Um schneller zu werden, müssen sie immer weiter verkleinert werden. Mit steigender Betriebsfrequenz sinkt jedoch die Durchbruchspannung und damit auch die verfügbare Leistung signifikant.

Das FBH hat daher 2011 gemeinsam mit dem Leibniz-Institut für innovative Mikroelektronik (IHP) das Projekt „Silizium-III/V-Heterointegration für Terahertz-Elektronik" (HiTek) gestartet, um mit einem innovativen Konzept diese grundlegende Limitierung zu überwinden. Elektronische III/V-Bauelemente werden dabei so in eine Silizium-CMOS-Umgebung integriert, dass die Vorteile beider Materialsysteme miteinander kombiniert werden können. Auf einen traditionellen CMOS-Chip mit seiner hohen Integrationsdichte und damit Funktionalität wird in einer Art „Sandwich" eine Schaltung auf der Basis von Indiumphosphid aufgebracht. Dieses Materialsystem ermöglicht deutlich höhere Leistungen bei hohen Frequenzen. Um die Vorteile von Indiumphosphid-Schaltungen nutzen zu können, ohne auf die umfassende Funktionalität CMOS-basierter Schaltungen verzichten zu müssen, bedarf es neben der gemeinsamen Schnittstelle einer nahtlosen Verbindungstechnik. Diese wird im Rahmen des HiTek-Projekts bereitgestellt. Die Entwicklungen im laufenden Projekt zielen auf heterogen integrierte Schaltungen im Frequenzbereich zwischen 100 und 300 GHz.

Die beiden Leibniz-Institute in Berlin-Brandenburg – das FBH führend in der Entwicklung von III/V-Halbleitern, und der CMOS-Spezialist IHP – bringen europaweit einzigartige Kompetenzen zusammen, um die innovative Technologieplattform in einer institutsübergreifenden Prozessline zu implementieren. Künftige Anwendungen der superschnellen und leistungsfähigen Chips könnten bildgebende Systeme in der Medizin und Sicherheitstechnik oder im Mobilfunkbereich sein.

➜
Circuits based on indium phosphide in foil technology at FBH.
Indium-Phosphid basierte Schaltungen in Folientechnologie am FBH.

get started with the installation on board the satellite have been successfully completed in May 2011.

With the experiment, which is designed for three years mission duration, the effects of space environment on GaN-based electronic components will be tracked. During this time, data concerning the radiation environment in the geostationary orbit and its effects on the electronic devices will be recorded and constantly sent to Earth. These data are of particular importance to further optimize GaN electronics for highly reliable space applications.

Imaging and radar applications for space

Landing and docking maneuvers of rockets and satellites in space require imaging and target tracking sensors. They need to work independently from the respective illumination situation with good resolution and spatial localization at the same time. Additionally, they should work with minimal data rates. These requirements are fulfilled by radar sensors at millimeter waves and real-time image processing, which will be tested by means of a 3D imaging systems featuring real-time data processing. The setup is designed for both distances in the range of under 20 m and for a target tracking radar for distances up to 1000 m. Both systems will be especially examined regarding their space capability and accordingly further optimized.

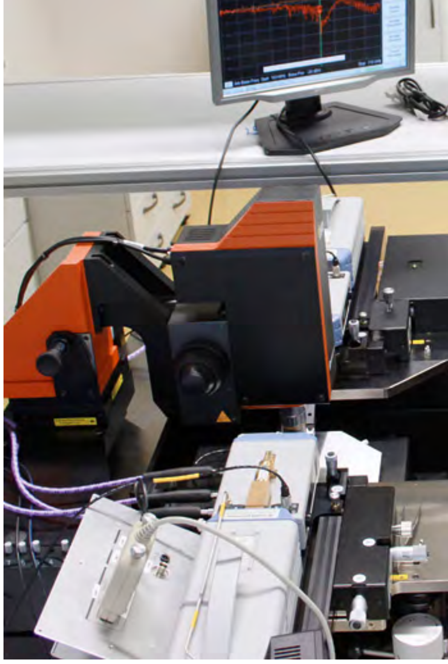
At FBH, components for both radar systems will be developed as integrated microwave circuits (MMICs) building up on FBH's technology for InP hetero bipolar transistors (HBTs). Voltage-controlled oscillators (VCOs) and power amplifiers in the frequency range of 70 to 100 GHz shall be demonstrated. The specific HBT process offers, among other things, advantages concerning radiation hardness. Thus, excellent operating properties of the circuits are likely to be expected for applications in space.

Bundling competencies: integration of silicon and III-V technology for terahertz electronics

Since decades, CMOS semiconductor technology builds the backbone of microelectronics. More than 95 percent of all digital or analogue-digital circuits are realized basing on this technology. It ensures, for example, increasingly higher integration densities and shorter cycle times in computer processors. However, when aiming at frequencies around 100 gigahertz CMOS circuits reach their limitations. They need to be more and more miniaturized in order to speed up. With increasing operating frequency, however, the breakdown voltage significantly decreases and thus also the available power.

To overcome this basic limitation, the FBH has started the project "silicon III-V hetero integration for terahertz electronics" (HiTek) in 2011. Hence, electronic III-V devices will be integrated into a silicon CMOS environment with an innovative concept that allows combining the advantages of both materials systems. In a sort of "sandwich", a circuit based on indium phosphide (InP) allowing for significantly higher output powers at high frequencies will be applied on a traditional CMOS chip featuring high integration density and thus functionality. In order to access the advantages of the InP circuits without abandoning the comprehensive functionality of CMOS-based circuits, a joint interface as well as a seamless connection technology is necessary. Both will be provided in the frame of the HiTek project. Current developments aim at heterogeneously integrated circuits in the frequency range between 100 and 300 GHz.

Both Berlin-Brandenburg Leibniz institutes, the FBH leading in the development of III-V semiconductors and the CMOS specialist IHP, bring together Europe-wide unique competencies in order to implement an innovative technology platform in an institute-spanning process line. Future applications for the ultrafast and powerful chips might be imaging systems in medical and security technology as well as in mobile communications.



Ausbau der Terahertz-Elektronik: Mikroelektronik für hohe Frequenzen

Anwendungen in der Robotik, der Materialanalyse und der Sicherheitstechnik sind integrierte Schaltungen mit Transitfrequenzen oberhalb von 400 GHz erforderlich. Diese sind als Halbleiterchips zunehmend verfügbar, die zugehörige Aufbau- und Verbindungstechnik lässt sich jedoch noch nicht wirtschaftlich realisieren. Die FBH-Forscher wollen daher eine kostengünstige, innovative Aufbautechnologie für Multi-Chip-Module bis in den Terahertz-Frequenzbereich entwickeln und demonstrieren. Diese vereinfacht den Modulaufbau bei hohen Frequenzen erheblich und führt zu hervorragenden elektrischen, thermischen und mechanischen Eigenschaften der Schaltungen. Diese Aktivitäten im Terahertz-Bereich ergänzen die Arbeiten in Kooperation mit dem IHP und wurden am FBH im Rahmen der Hochschulkooperationen ausgebaut.

Seit 2009 wird die Arbeitsgruppe Terahertz-Elektronik von Viktor Krozer geleitet, der zugleich an der Goethe-Universität Frankfurt eine Stiftungsprofessur innehat.

Derzeit wird insbesondere die erforderliche Aufbau- und Verbindungstechnik für integrierte elektronische Schaltungen aufgebaut. Diese ermöglichen kostengünstige Sensor- und Radarsysteme mit hoher räumlicher Auflösung. In diesem Zusammenhang wurden zwei Geräte, ein Netzwerkanalysator sowie die zugehörige Proberstation, am FBH installiert. Da das FBH mit seiner wachsenden Anzahl von Projekten und Mitarbeitern inzwischen an seine räumlichen Grenzen stößt, mussten im 2011 eröffneten „Zentrum für Mikrosysteme und Materialien“ auf dem Campus Adlershof zusätzliche Laborräume angemietet werden. Neben der Terahertz-Elektronik nutzt auch die Arbeitsgruppe Lasermetrologie des FBH Labore in dem Gebäude.

GloMic: Neues Spin-off für Mikrowellen-Leistungsmodule

Im Rahmen der Hochschulkooperation mit Georg Böck, dem Leiter des Fachgebiets Mikrowellentechnik an der Technischen Universität Berlin, wurde 2011 ein neues Spin-off aus dem FBH ausgegründet. Die GloMic GmbH baut auf den Forschungsaktivitäten des Instituts im Bereich der Mikrowellen-Leistungsmodule auf und soll Hochfrequenzbaugruppen und -systeme entwickeln, fertigen und vermarkten. Durch gemeinsame Forschungs- und Entwicklungsvorhaben, Know-how-Transfer und die gegenseitige Lizenzierung von Schutzrechten soll sich ein kontinuierlicher Technologietransfer etablieren, der die Forschungsarbeiten des FBH auf diesem Feld nachhaltig sichert. Das Spin-off kann zudem auf das Know-how des Vorläuferunternehmens Advanced Microwave Technologies GmbH aufbauen, das bereits erste Verstärker auf Basis der GaN-Technologie realisiert hatte. Dieses Portfolio soll mit GloMic um individuelle Verstärker-Lösungen in Einzel- oder Kleinserienprodukten erweitert werden. Das neue Unternehmen wird Leistungsverstärker-Produktfamilien in Form eines Baukastensystems definieren und diese mithilfe eines modularisierten Designprozesses entwickeln. Dadurch lassen sich der Entwicklungs- und Fertigungsaufwand beträchtlich reduzieren. Da auf vorgefertigte Module zurückgegriffen werden kann, sind Entwicklung und Fertigung eines vom Kunden individuell definierten Verstärkers binnen kürzester Zeit möglich. Damit können eine Vielzahl unterschiedlicher Verstärker aus einer geringen Anzahl von Funktionsblöcken zusammengesetzt werden. Dies führt zu großen Wettbewerbsvorteilen gegenüber anderen Anbietern.

Synergieeffekte ergeben sich auch aus der Zusammenarbeit mit einer weiteren FBH-Ausgründung, der BeMiTec Berlin Microwave Technologies AG. Das 2006 gegründete Unternehmen konzentriert sich auf effiziente und lineare Hochfrequenz-Leistungstransistoren und MMICs in GaN-Technologie. Derartige Bauelemente finden unter anderem Anwendung in hocheffizienten Mikrowellen-Leistungsverstärkern in der Mobilfunktechnik und der Satelliten-Kommunikationstechnik.

Viktor Krozer in the new terahertz electronics laboratory.
Viktor Krozer im neuen Terahertz-Elektronik-Labor.

Expansion of terahertz electronics: microelectronics for high frequencies

For applications in robotics, materials analytics, and security technology, integrated circuits with transit frequencies above 400 GHz are required. Such circuits are increasingly available as semiconductor chips, but the respective mounting and packaging technology can still not be implemented cost-efficiently. Thus, FBH scientists want to develop and demonstrate a reasonable, innovative assembling technology for multi-chip modules up to the terahertz frequency range. This technology will considerably facilitate the module setup at high frequencies and lead to excellent electrical, thermal, and mechanical properties of the circuits. These activities in the terahertz field complement the works executed in collaboration with IHP and have been expanded in the frame of FBH's university cooperations.

Since 2009, the Terahertz Electronics group is led by Viktor Krozer, who, at the same time, holds an endowed professorship at Goethe-Universität Frankfurt. Currently, the respective mounting and packaging technology for integrated electronic circuits is built up enabling cost-efficient sensor and radar systems with high spatial resolution. In this context, two tools, a network analyzer and the related prober station, have been installed at FBH. Due to its growing amount of projects and employees, laboratory and work space at FBH is confined. Thus, additional laboratory rooms had to be rented in the newly opened "Center for Microsystems and Materials" on the Adlershof campus. In addition to Terahertz Electronics, also FBH's Laser Metrology group uses laboratories in this building.

GloMic: new spin-off for microwave power modules

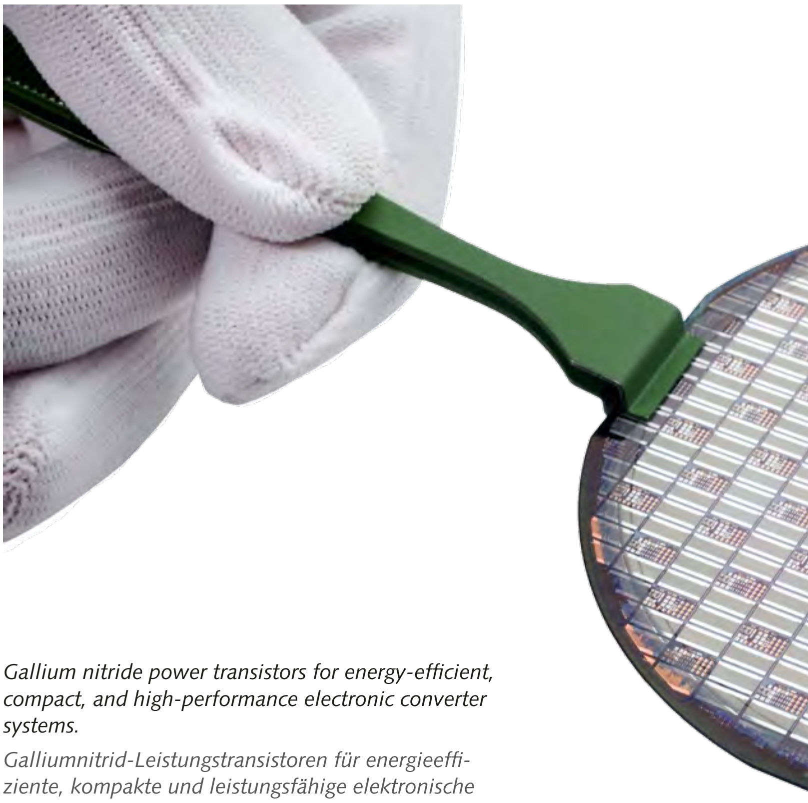
Within the context of the FBH university cooperation with Georg Böck, chair for microwave technology at Technische Universität Berlin, a new company has been spun-off from the institute in 2011. GloMic GmbH is based on FBH's research activities in the field of microwave power modules and develops, manufactures, and markets high-frequency devices and systems. By joint research and development projects, know-how transfer, and mutual licensing of property rights, a sustainable and continuous technology transfer of FBH's research activities shall be established in this field. Besides, the spin-off can build up on the know-how of Advanced Microwave Technologies GmbH, its predecessor company, which already realized first amplifiers in GaN technology. This portfolio shall be expanded with GloMic by individual amplifier solutions as single and small-series products. The young company will define product families in terms of a modular assembly system and will develop them by means of a modularized design process. Thus, development and manufacturing efforts can be significantly reduced. By making recourse on pre-fabricated modules, customized amplifiers can be individually defined, developed, and manufactured within an extremely short time. Thus, a great variety of different amplifiers can be built up from a small amount of functional building blocks, leading to relevant competitive advantages compared to other suppliers.

Synergy effects evolve from the cooperation with a further FBH spin-off, Berlin Microwave Technologies AG (BeMiTec). The company, which has been founded in 2006, focuses on efficient and linear high-frequency power transistors and MMICs in GaN technology. Such devices are used, among others, in highly efficient microwave power amplifiers in mobile communications and in satellite communication technology.

GloMic

EU-Projekt HiPoSwitch: Mehr Effizienz für die Leistungselektronik

In vielfältigen Anwendungen, etwa in der Informations- und Kommunikationstechnologie oder bei der Umwandlung von Solarenergie, kommen Leistungskonverter zum Einsatz. Niedriger Energieverbrauch, hohe Leistungen und eine kompakte Bauform sind die wesentlichen Anforderungen an moderne Konvertersysteme. Zentrale Bauelemente in derartigen Systemen sind Leistungstransistoren, die Gleich- und Wechselstrom auf unterschiedliche Spannungen transformieren. 2011 ist das vom Ferdinand-Braun-Institut koordinierte EU-Projekt HiPoSwitch gestartet, das sich mit neuartigen Galliumnitrid (GaN)-basierten Transistoren beschäftigt. Diese sollen bei künftigen Leistungskonvertersystemen für weniger Volumen und Gewicht bei gleichzeitig höherer Leistungsfähigkeit sorgen. 5,6 Millionen Euro fließen in den kommenden drei Jahren in das Verbundprojekt mit acht europäischen Partnern, die die komplette Wertschöpfungskette abdecken, von der Bauelemententwicklung bis zur industriellen Verwertung.



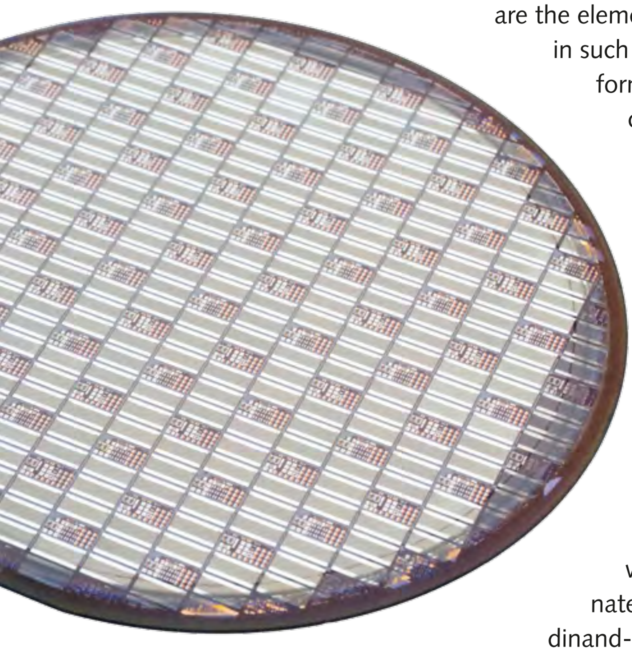
Gallium nitride power transistors for energy-efficient, compact, and high-performance electronic converter systems.

Galliumnitrid-Leistungstransistoren für energieeffiziente, kompakte und leistungsfähige elektronische Energiekonverter.

Die Effizienz derzeitiger Leistungskonvertersysteme wird in der Regel durch die verwendeten aktiven Schaltelemente begrenzt. Heutzutage kommen meist Komponenten auf der Basis von Silizium oder Siliziumkarbid zum Einsatz. Die Silizium-Technologie ist mittlerweile jedoch so weit fortgeschritten, dass das Material selbst an seine Grenzen stößt, oder, wie im Fall von Siliziumkarbid, sehr teuer ist. Bessere Materialeigenschaften verspricht Galliumnitrid. Mit GaN-basierten Bauelementen können Leistungsschalter bei deutlich höheren Frequenzen betrieben werden, ohne signifikante Schaltverluste in Kauf nehmen zu müssen. Grund ist der viel geringere Einschaltwiderstand von GaN-Leistungstransistoren, der zusammen mit den signifikant reduzierten Ein- und Ausgangskapazitäten zu einem deutlich verbesserten Schaltverhalten führt. Mit höherer Schaltfrequenz lässt sich zugleich die Größe der passiven Komponenten wie Spulen, Stromwandler und Kondensatoren reduzieren – die Baugruppe wird insgesamt kleiner. Die Transistoren werden auf kostengünstigen Silizium-Substraten realisiert und sind daher aus wirtschaftlicher Sicht sehr interessant, da sie längerfristig deutlich bessere technische Eigenschaften mit vergleichsweise günstigen Kosten verbinden.

Im Projekt entwickeln das Ferdinand-Braun-Institut und Infineon Technologies Austria gemeinsam selbstsperrende GaN-Leistungstransistoren in vertikaler Architektur. Der vertikale Aufbau ist eine der Voraussetzungen, um die charakteristischen Vorteile der GaN-Leistungselektronik wie hohe Leistungsdichte und effizientes Schalten bei hohen Frequenzen unmittelbar in innovativen Konvertersystemen umsetzen zu können. Die Prozessmodule aus dem FBH sollen dabei möglichst rasch auf einen massentauglichen Industrieprozess bei Infineon übertragen werden.

EU project HiPoSwitch: more efficiency for power electronics



Power converters are used in manifold applications, such as in information and communications technology as well as for the conversion of solar energy. Low energy consumption, high output powers, and a compact configuration are core requirements for modern converter systems. Power transistors are the elementary devices in such systems transforming continuous and alternating current into the effective voltages used by the systems. In 2011, the European project HiPoSwitch, which is coordinated by the Ferdinand-Braun-Institut, was launched focusing on novel gallium nitride (GaN)-based transistors. They are the key switching devices designed to ensure increased efficiency in future power converter systems and shall require less volume and weight along with enhanced performance. The joint project is funded with 5.6 million Euros for the coming three years, covering the full value chain from device development to industrial application.

Usually, the efficiency of present systems is largely limited by the active components used. Nowadays, they are mostly based on silicon which has now advanced to the point that the material itself is basically at its limits. Silicon carbide, on the other hand, is rather expensive and will thus prevent more widespread applications. With its superior material properties, GaN promises to be a suitable material for power switching. It is the basis for power switches operating at significantly higher frequencies without suffering from major switching losses. This is due to the drastically lower on-state resistance of GaN power transistors, combined with considerably reduced in- and output capacitances. The increase of switching frequency has also consequences for the passive components as the volume of inductors, current transformers and capacitors can be significantly reduced. Thus, the whole assembly itself becomes smaller and more light weighted. The transistors will be realized on cost-efficient silicon substrates and therefore become extraordinarily attractive from an economic point of view. In the long run, they will combine significantly improved technical properties with comparably low costs.

Throughout the project, normally-off GaN power transistors in vertical device architecture will be jointly developed by FBH and Infineon Technologies Austria. Such vertical architecture is one of the preconditions to directly access the characteristic advantages of GaN power electronics for innovative converter systems such as high power density and efficient switching at high frequencies. The process modules from the FBH shall then be transferred as soon as possible into a mass-compatible industrial process at Infineon.

Gut aufgestellt: Neues Cluster Optik in Berlin-Brandenburg

Berlins Wirtschaftssenator Harald Wolf und Brandenburgs Staatssekretär für Wirtschaft und Europaangelegenheiten, Henning Heidemanns, haben im Oktober 2011 das neue länderübergreifende Cluster Optik vorgestellt. Zugleich wurde das Cluster um die Querschnittstechnologie Mikrosystemtechnik erweitert. Damit fließen dort auch die Aktivitäten des am FBH angesiedelten Zentrums für Mikrosystemtechnik Berlin (ZEMI) ein. Clustersprecher ist der Direktor des Ferdinand-Braun-Instituts und Vorstandsvorsitzende von OpTecBB, Günther Tränkle. Im Rahmen der gemeinsamen Innovationsstrategie sollen die wirtschaftlichen und wissenschaftlichen Potenziale der Hauptstadtregion in diesem Zukunftsfeld weiter gebündelt werden. Forschung und Entwicklung gerade im Bereich der Schlüsseltechnologien Optik, Photonik und Mikrosystemtechnik gelten als Innovationstreiber. Der Anteil der Optischen Technologien am Wirtschaftswachstum in Berlin-Brandenburg soll weiter ausgebaut und die Internationalisierung des Clusters vorangetrieben werden.

Grundsteinlegung: Jenoptik erweitert Fertigungskapazitäten in Berlin-Adlershof

Im Beisein von rund 80 geladenen Gästen aus Wirtschaft, Politik und Industrie, legten Georg Schütte, Staatssekretär im Bundesministerium für Bildung und Forschung, Michael Mertin, Vorstandsvorsitzender der Jenoptik AG, Jürgen Sebastian, Geschäftsführer der Jenoptik Diode Lab GmbH und Günther Tränkle, Direktor des Ferdinand-Braun-Instituts im Dezember 2011 den Grundstein für den Erweiterungsbau der Jenoptik Diode Lab. Rund 10 Millionen Euro fließen in den Ausbau der Produktion am Standort in Adlershof. Die Fertigungskapazitäten sollen sich damit ab 2013 mehr als verdoppeln. Das 2002 gegründete Spin-off des Instituts, das zum Jenoptik-Konzern gehört, betreibt seit 2006 eine Halbleiterfabrik in Berlin-Adlershof und nutzt auch weiterhin Forschungsergebnisse des FBH für seine Diodenlaser.

Im Anschluss besuchte Staatssekretär Schütte die Labore des Ferdinand-Braun-Instituts. Er ließ sich dort hybride Diodenlasermodule zeigen, die in der Materialbearbeitung, der Sensorik, Medizintechnik und im Entertainmentbereich wie etwa der Displaytechnologie eingesetzt werden.

Laying of the foundation stone for Jenoptik Diode Lab's extension building in Berlin (FLTR: M. Mertin, G. Schütte, G. Tränkle, J. Leder, J. Sebastian).

Grundsteinlegung für den Erweiterungsbau der Jenoptik Diode Lab in Berlin (v.l.n.r. M. Mertin, G. Schütte, G. Tränkle, J. Leder, J. Sebastian).

Well positioned: new cluster optics in Berlin-Brandenburg

In October 2011, Berlin Economics Senator Harald Wolf and Brandenburg State Secretary for Economy and European Affairs, Hennig Heidemanns, presented the new cross-border cluster optics. Along with the foundation, the cluster adds microsystems technology as cross-sectional technology and thus integrates the activities of the Center for Microsystems Technology Berlin (ZEMI). Günther Tränkle, FBH's Director and Chairman of OpTecBB, has been appointed as its speaker. Aim of the cluster is to further bundle the economic and scientific potential of the capital region in the frame of the Berlin-Brandenburg joint innovations strategy. Research and development, especially in the field of the key technologies optics, photonics, and microsystems technology are considered as innovation drivers. Target is to expand the share of optical technologies of Berlin-Brandenburg economic growth and to promote the cluster internationally.

Laying of the foundation stone: Jenoptik expands its production capacities in Berlin-Adlershof

In the presence of 80 invited guests from economy, politics and industry, Georg Schütte, State Secretary from the Federal Ministry of Education and Research, Michael Mertin, Chairman of Jenoptik AG, Jürgen Sebastian, Managing Director of Jenoptik Diode Lab GmbH, and Günther Tränkle, Director of the Ferdinand-Braun-Institut, laid the foundation stone for the extension building of Jenoptik Diode Lab. Roughly 10 million Euros are invested to expand the production site at the Adlershof location. As of 2013, manufacturing capacities will thus more than double. The institute's spin-off, which has been founded in 2002 and is part of the Jenoptik group, runs a semiconductor plant in Berlin-Adlershof since 2006. The company still uses research results from the FBH for its diode lasers.

After the ceremony, State Secretary Schütte visited the laboratories at the Ferdinand-Braun-Institut. There, he has been showed hybrid diode laser modules that are used in materials processing, sensors, and medical technology as well as for entertainment applications such as in display technology.

State Sectretary Schütte (right) gets a demonstration of FBH's hybrid diode laser modules.

Staatssekretär Schütte (rechts) lässt sich die hybriden Diodenlasermodule des FBH zeigen.

Zukunft sichern: akademischen und gewerblichen Nachwuchs ausbilden

Der Bedarf an qualifizierten Mitarbeiterinnen und Mitarbeitern ist weiterhin sehr hoch, denn gut ausgebildete Fachkräfte sind eine wesentliche Voraussetzung für den wissenschaftlichen und wirtschaftlichen Erfolg. Viel Engagement des FBH steckt daher in der Aus- und Weiterbildung sowie der akademischen Qualifikation des wissenschaftlichen Nachwuchses. Zwölf Kolleginnen und Kollegen lehrten 2011 an Berliner und überregionalen Hochschulen.

Ausbildung des akademischen Nachwuchses

Das FBH kooperiert eng mit mehreren regionalen und überregionalen Universitäten. Nicht nur im Bereich der Forschung und Entwicklung arbeitet das Institut stark vernetzt, es ist auch aktiv in die Ausbildung des akademischen Nachwuchses eingebunden. Eine besonders enge Verbindung in den universitären Bereich besteht durch die zwei direkten Professuren des FBH mit der Technischen Universität Berlin. Neben Institutsdirektor Günther Tränkle und seinem Stellvertreter Wolfgang Heinrich, lehren noch zwei weitere Professoren (Georg Böck und Michael Kneissl) im Rahmen der Hochschulkooperationen des FBH an der TU Berlin. Drei Kollegen des FBH sind zudem über Lehraufträge eingebunden; ein Wissenschaftler lehrt an der HTW Berlin. Weitere Hochschulkooperationen laufen mit der Goethe-Universität Frankfurt und der Humboldt-Universität zu Berlin über zwei Professoren (Viktor Krozer und Achim Peters) und zwei Wissenschaftler, die gleichfalls akademischen Nachwuchs ausbilden. Diese langjährigen Aktivitäten zeigen sich nicht nur in wissenschaftlichen Ergebnissen, sondern spiegeln sich auch in den Abschlusszahlen wider: So wurden am FBH 2011 sechs Promotionen, vier Diplom- beziehungsweise Masterarbeiten und sieben Bachelorarbeiten abgeschlossen.

Gewerbliche Ausbildung am FBH

Im gewerblichen Ausbildungsbereich lernten neun Mikrotechnologinnen und Mikrotechnologen, ein Industriemechaniker und eine Kauffrau für Bürokommunikation am Institut. Zwei Kolleginnen engagieren sich zudem in diesem Bereich bei den regionalen Industrie- und Handelskammern (IHK): Birgit Stremlow, die am FBH im Bereich Personal arbeitet, sitzt bei der IHK Potsdam im Prüfungsausschuss für Kaufmann/-frau im Groß- und Außenhandel und kümmert sich dort unter anderem um die Auswahl der Prüfungsaufgaben. Marlies Gielow ist am Institut nicht nur verantwortlich für die gewerbliche Ausbildung, sondern auch Vorsitzende des IHK-Prüfungsausschusses für Mikrotechnologen/-innen in Berlin.

Skilled occupation with a future: microtechnologist.
Ausbildungsberuf mit Zukunft: Mikrotechnologe/-in.

Mikrotechnologinnen und Mikrotechnologen sind qualifizierte Facharbeiter für hochkomplexe und technisch anspruchsvolle Fertigungsverfahren in einer der Schlüsseltechnologien des 21. Jahrhunderts: Sie fertigen die reiskorngroßen Mikrochips, Halbleiterkomponenten und Mikrosysteme, die beispielsweise für Laser zur Materialbearbeitung oder als Sensoren in Airbags benötigt werden. Mikrotechnologinnen und Mikrotechnologen müssen nicht nur komplexe Arbeitsschritte ausführen, sondern auch abteilungsübergreifend ohne Reibungsverluste zusammenarbeiten. Kleine Unachtsamkeiten oder Missverständnisse im Verlauf der komplexen Prozessschritte können großen Einfluss auf die Ergebnisse haben. Daher gilt es, neben der fachlichen Qualifikation auch die persönlichen und kommunikativen Fähigkeiten zu schulen: Dazu bietet das FBH ein Mentorenprogramm, eine Vortragsreihe, die die Auszubildenden selbst gestalten, sowie Englisch- und Elektrotechnikunterricht nach Bedarf. ↓

Securing the future: teaching academic offspring and industrial apprentices

Well-educated skilled personnel are a core requirement for scientific and economic success. Thus, the demand for qualified staff remains very high, and a good deal of effort is invested in education and training at FBH along with academic qualification of the scientific offspring. In 2011, twelve colleagues were teaching at regional and further national universities.

Education of the academic offspring

FBH closely cooperates with several regional and trans-regional universities. The institute not only works intensely cross-linked in research and development, but is also actively involved in teaching the academic offspring. An especially intensive connection exists with Technische Universität Berlin due to two chairs held by FBH executives. In addition to the Director of the Institute, Günther Tränkle, and Deputy Director Wolfgang Heinrich, two other professors (Georg Böck and Michael Kneissl) teach within the framework of FBH's university cooperations at TU Berlin. Three colleagues from the FBH are additionally involved by teaching assignments; one scientist teaches at HTW Berlin. Further university cooperations are maintained via two professors (Viktor Krozer and Achim Peters) with Goethe-Universität Frankfurt and Humboldt-Universität zu Berlin—there, two further scientists also teach young academics. These long-time activities do not only manifest themselves by scientific results, but also by graduations: In 2011, six doctoral theses, four diploma or master theses, and seven bachelor theses have been completed at FBH.

Vocational training at the FBH

In the field of vocational training, nine microtechnologists, one industrial mechanic, and one management assistant in office communication were trained at the institute. Additionally, two colleagues are involved in this field at the regional Chambers of Industry and Commerce (IHK): Birgit Stremlow from FBH's human resources department belongs to the examination board for management assistants in wholesale and foreign trade at IHK Potsdam. Her tasks include, for example, selecting examination questions. And Marlies Gielow is not only responsible for industrial training at FBH, but also chairwoman of the IHK examination board for microtechnologists in Berlin.

Microtechnologists are qualified skilled workers for highly complex and technically challenging production processes in one of the key technologies of the 21st century: They manufacture grain-sized microchips, semiconductor components, and microsystems which are, for example, required for lasers used in materials processing and for sensors in airbags. Microtechnologists do not only have to execute complex working steps, they also need to collaborate with different departments and, above all, without friction losses. Even little inattention or misunderstandings during the sophisticated process steps can strongly influence the results. It is therefore also necessary to train personal and communicative skills: To achieve this, FBH offers a mentoring program, a series of lectures organized by the apprentices themselves, and English and electrical engineering lessons, whenever necessary.

Core contact for the soon-to-be microtechnologists is training officer Marlies Gielow, supported by colleagues such as Leonhard Weixelbaum and Dirk Rentner. ↓

Trainees in the FBH cleanroom.
Auszubildende im Reinraum des FBH.

Zentrale Ansprechpartnerin für die angehenden Mikrotechnologen ist Ausbildungsleiterin Marlies Gielow, die von Kollegen wie Leonhard Weixelbaum oder Dirk Rentner unterstützt wird. Sie registriert mit Besorgnis, dass sich immer weniger ausbildungsfähige Bewerberinnen und Bewerber um die jährlich drei ausgeschriebenen Ausbildungsplätze bewerben. Auch die Anzahl der Bewerbungen insgesamt geht zurück; nur noch 20 Lebensläufe sind für das letzte Ausbildungsjahr eingegangen – trotz ausgezeichneter beruflicher Perspektiven. Deshalb wird weiter direkt vor Ort bei den Jugendlichen, aber auch mit professioneller Netzwerk- und Lobbyarbeit geworben.

Ausbildungsnetzwerk bietet gezielte Unterstützung und Information

Im Ausbildungsnetzwerk Hochtechnologie (ANH) Berlin, das am Ferdinand-Braun-Institut angesiedelt ist, laufen vielfältige Aktivitäten zur Nachwuchsgewinnung und -sicherung zusammen. Das ANH-Team arbeitet seit 2007 daran, die Situation betrieblicher Ausbildung im Hochtechnologiebereich zu verbessern und die Anschlussfähigkeit von beruflicher und akademischer Ausbildung zu sichern. So unterstützt das Netzwerk Unternehmen und Forschungseinrichtungen in allen Aspekten beruflicher Ausbildung, von der Beratung über die Bewerbersuche und -auswahl bis hin zu Anmeldeformalitäten. Auch im Berufemarketing und in der Berufsberatung informiert ANH Berlin Schülerinnen und Schüler, Eltern, Lehrkräfte und Multiplikatoren über neue Berufsbilder und Zukunftsperspektiven in dualen Ausbildungsberufen, insbesondere im technisch-naturwissenschaftlichen Bereich. Ergänzt wird das Angebot durch Zusatzmodule mit praxisnah aufbereiteten Lehrinhalten, die die Aufstiegschancen nach der beruflichen Ausbildung verbessern sollen.

Ausgezeichnete Publikationen

Best Paper Award EUMW

Auf der European Microwave Week im Oktober wurden Franz-Josef Schmückle, Ralf Doerner, Gia Ngoc Phung und Wolfgang Heinrich für ihr Paper zur Kalibrierung und Modellierung von Koplanarleitungen im W-Band ausgezeichnet. Der Preis ist mit 5.000 Euro dotiert.

Preis der Chorafas-Stiftung

Für ihre hervorragende Dissertation erhielt Sina Riecke im Oktober 2011 den mit 4.000 US$ dotierten Chorafas-Preis der gleichnamigen Stiftung. Riecke hatte ihre Arbeit mit dem Titel „Flexible Generation of Picosecond Laser Pulses in the Infrared and Green Spectral Range by Gain Switching of Semiconductor Lasers“ an der Technischen Universität, dem Ferdinand-Braun-Institut und der PicoQuant GmbH angefertigt. Die von ihr untersuchten Pikosekunden-Laserpulse werden in der Materialbearbeitung, Telekommunikation und Spektroskopie genutzt. Die Chorafas-Stiftung zeichnet jährlich international Promovenden beziehungsweise Promovierte für ihre überdurchschnittlichen Forschungsarbeiten aus.

Gute Qualität: Integriertes Management-System erneut erfolgreich zertifiziert

Auch 2011 hat das FBH sein jährliches viertägiges Audit zum Integrierten Management-System ohne Abweichungen bestanden. Geprüft wurden die Bereiche Qualitätsmanagement, Umweltmanagement und Arbeitssicherheit nach den entsprechenden ISO-Normen und -Standards 9001, 14001 und 18001. Vor allem für Kunden aus der Industrie sind reproduzierbare und transparente Prozesse eine wichtige Voraussetzung für die langfristige Zusammenarbeit. Auch intern führt das Management-System dazu, dass Geschäftsprozesse über Kennzahlen systematisch gesteuert und mögliche Fehlerquellen bereits im Vorfeld schnell und effizient beseitigt werden können.

GL ISO 9001 ISO 14001 OHSAS 18001
GL Systems Certification

Marlies Gielow is very concerned that increasingly less educable candidates apply for the yearly three training positions. All in all, also the amount of applications decreases; only 20 CVs arrived for the past year's open vocational training positions, despite excellent career prospects. Hence, professional network and lobbying activities aim to promote the profession and inform adolescents, for example, in schools and at career fairs.

Training network provides targeted support and information
The training network ANH Berlin (Ausbildungsnetzwerk Hochtechnologie), which is located at the Ferdinand-Braun-Institut, bundles various activities regarding recruitment of junior personnel and securing next-generation employees. Since 2007, ANH is working on improving the situation of vocational training in the high-technology field and ensuring permeability between vocational training and academic education. The network supports companies and research institutions in all aspects of vocational education, from consulting to candidate search and selection to all formalities required. Also in vocational marketing and consulting, ANH informs pupils, parents, teachers, and multipliers about new occupational images and career prospects, in particular in the technical and natural sciences field. This is complemented by additional learning modules that are reviewed and edited in step with actual practice and targets to improve promotion prospects after vocational training.

Publication awards

Best Paper Award EUMW
In October, Franz-Josef Schmückle, Ralf Doerner, Gia Ngoc Phung, and Wolfgang Heinrich have been awarded as best paper at European Microwave Week for their publication "Radiation, Multimode Propagation, and Substrate Modes in W-Band CPW Calibrations". The prize is endowed with 5,000 Euro.

Prize of the Chorafas Foundation
For her excellent dissertation, Sina Riecke has been honored with the Chorafas Award by the identically named foundation. The prize is endowed with 4,000 US$. Riecke completed her thesis entitled "Flexible Generation of Picosecond Laser Pulses in the Infrared and Green Spectral Range by Gain Switching of Semiconductor Lasers" at Technische Universität Berlin, Ferdinand-Braun-Institut and PicoQuant GmbH jointly. Her work examines picosecond laser pulses that are used in materials processing, telecommuncations and spectroscopy. Every year, the Chorafas Foundation honors doctoral candidates and graduates world-wide for outstanding research works.

Good quality: integrated management system again successfully certified

In 2011, FBH again passed the yearly four-day audit in the frame of its integrated management system without deviations. Quality management, environmental management and occupational health and safety had been reviewed according to the respective ISO norms and standards 9001, 14001, and 18001. For industrial customers, in particular, reproducible and transparent processes are an important precondition for long-term cooperation. Also internal business processes can be systematically controlled via key figures by the management system. Thus, possible sources of error can be resolved quickly and efficiently already in advance.

EFRE-Mittel: Geräteausstattung auf neuestem Stand

Vor etlichen Jahren hat das FBH damit begonnen, seine apparative Ausstattung umfassend zu erneuern. Dank umfangreich bewilligter EFRE-Mittel wurden im letzten Jahr neue, leistungsfähigere Anlagen beschafft oder sollen 2012 aufgebaut werden. Leistungsstarkes technisches Equipment ist in vielen Bereichen die Voraussetzung für Forschungsergebnisse auf dem neuesten technischen Stand.

Alleine vier Millionen Euro fließen in das Anwendungszentrum Höchstfrequenztechnologien, das den Transfer wissenschaftlicher Ergebnisse zu Industriepartnern und Systemhäusern erleichtert. Das Anwendungszentrum optimiert Halbleiter-Fertigungsprozesse und trägt zur Qualitätssicherung von Höchstfrequenzbauelementen bei. Die Aufgaben umfassen neben der Verbesserung der Reproduzierbarkeit und Volumentauglichkeit von Prozessen vor allem die Erweiterung der Bauelementcharakterisierung einschließlich Fehleranalysen, Lebensdauer- und Zuverlässigkeitsprüfungen. Für diese Zwecke wurde neben Geräten für die Oberflächenkontrolle von Wafern insbesondere ein leistungsstarker Waferstepper für die Projektionslithografie bestellt, der 2012 installiert wird. Eine weitere zentrale Anschaffung ist ein leistungsfähiges Analytik-Tool zur Charakterisierung von Degradationsprozessen in Halbleiterbauelementen. Herzstück des Gerätes ist ein Rasterelektronenmikroskop mit thermischem Feldemitter zur hochauflösenden Abbildung von Oberflächen. Dieses Mikroskop ist mit verschiedenen Systemen zur Analyse der strukturellen und optischen Eigenschaften von Halbleiterschichten und Chips ausgerüstet. Die Leistungsfähigkeit des neuen Gerätes, das die apparativen Möglichkeiten zur Charakterisierung von Halbleiterschichtstrukturen und Bauelementen am FBH qualitativ deutlich verbessert, wurde anhand von Messungen belegt.

Im Rahmen des Anwendungszentrums wurde auch mit dem Aufbau von Messeinrichtungen zur Charakterisierung im Frequenzbereich über 110 GHz begonnen. Bei dieser Messtechnik fehlen bislang passende Kalibrierungstechniken sowie die von niedrigeren Frequenzen bekannte mechanische Präzision und Reproduzierbarkeit des On-Wafer-Equipments. Dazu wurde 2011 ein halbautomatisches System zur On-Wafer-Charakterisierung beschafft. Es basiert auf einem Vektor-Netzwerkanalysator, der mit nahezu voller Frequenzabdeckung bis zu 500 GHz betrieben wird und nur minimale Eingriffe des Maschinenbedieners erfordert. Das Messgerät bietet beste Voraussetzungen für die geplante Entwicklung der Kalibrierungsstandards und -techniken für die On-Wafer-Charakterisierung im Frequenzbereich über 110 GHz, die derzeit weltweit Gegenstand der Forschung sind.

In einem weiteren EFRE-geförderten Projekt, in dem gemeinsam mit dem Max-Born-Institut neuartige Kurzpuls-Hochleistungslaser entstehen, wurden die technologischen Voraussetzungen am FBH wesentlich verbessert. Für die Entwicklung und Herstellung der dafür benötigten Pumplaserdioden wurde ein neuer Ritz-und Spaltautomat beschafft. Dieses Gerät ermöglicht das automatische Zerlegen von voll prozessierten GaAs-Wafern in Diodenlaserchips mit hoher Präzision und Reproduzierbarkeit. Da die Kristallfacetten als Laserspiegel dienen, müssen sie atomar glatt und defektfrei sein. Andernfalls würde die auftretende Leistungsdichte des Laserlichts sofort die Facette und somit den Diodenlaser zerstören. Mit dem neuen Equipment konnte die Ausbeute an hochqualitativem Material für die Diodenlaser deutlich gesteigert werden. Das FBH verbessert damit seine Kompetenz als Forschungspartner über das konkrete Projekt hinaus, insbesondere für Aufgabenstellungen aus der Industrie.

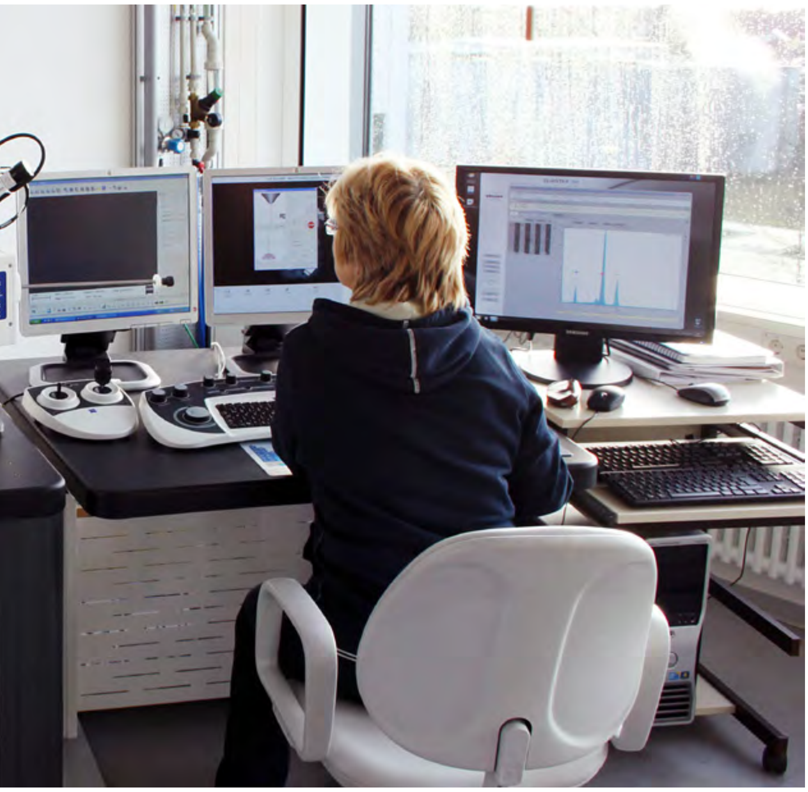
EFRE funds: bringing equipment up to date

Already some years ago, FBH started to modernize its technical equipment to a larger extent. Due to comprehensively conceded means from European Regional Development Fund (EFRE), during the last year novel and more efficient facilities have been acquired or will be established in 2012. Capable technical equipment strongly contributes in many areas to state-of-the-art research results.

Altogether four million Euros are provided just for the "Anwendungszentrum Höchstfrequenztechnologien", facilitating the transfer of scientific results to industrial partners and systems traders. The application center optimizes semiconductor production processes and contributes to quality assurance of high-frequency, laser and LED devices. Tasks include improving reproducibility and suitability to handle high volumes as well as to extend device characterization comprising failure analysis, lifetime and reliability testing. For these purposes, in addition to equipment for surface monitoring of wafers, especially a capable wafer stepper for projection lithography has been ordered, which will be installed in 2012. A further crucial acquisition is a powerful analytics tool to characterize degradation processes in semiconductor devices. Core piece of the equipment is a scanning electron microscope with thermal field emitter for high-resolution imaging of surfaces. This microscope is equipped with several systems to analyze the structural and optical properties of semiconductor layers and chips. The new facility proved its capability by means of measurements and thus significantly improves the technical infrastructure in terms of quality regarding the characterization of semiconductor layer structures and devices at FBH.

In the frame of the application center, the setup of measurement equipment for characterizations in the frequency range above 100 GHz has also begun. For such measurements, up to now an appropriate calibration technique has been missing as well as the mechanical precision and reproducibility of the on-wafer equipment known from lower frequencies. To solve these problems, a semi-automatic system for on-wafer characterization has been purchased in 2011. It bases on a vector network analyzer that can be run with almost full frequency covering up to 500 GHz and requires only minimum intervention of the operator. The measurement equipment offers best preconditions for the projected development of calibration standards and techniques for on-wafer characterization in the frequency range above 110 GHz, which is a research subject world-wide.

In a further EFRE-funded joint project with the Max-Born-Institut addressing novel short-pulse high-power lasers, the technological preconditions at FBH have been significantly improved. For development and manufacture of the required pump laser diodes, a new scribing and cleaving tool has been acquired. This equipment enables to automatically segment fully processed GaAs wafers into diode laser chips with highest precision and reproducibility. As the crystal facets are used as laser mirrors, they have to be atomically plain and defect-free. Otherwise, the emerging power density of the laser light would immediately destroy the facet and thus the diode laser. With the novel equipment, the yield of highly qualitative material for the diode lasers could be significantly enhanced. FBH thus also improves its competence as research partner exceeding the specific project, especially with regard to requirements from the industry.



Capable analytics tool to characterize degradation processes in semiconductor devices.

Leistungsfähiges Analytik-Tool zur Charakterisierung von Degradationsprozessen in Halbleiterbauelementen.

Messen & Veranstaltungen

Auch 2011 war das FBH wieder auf zahlreichen Veranstaltungen, Messen und Konferenzen vertreten. Vom Institut selbst wurden neben dem zweiten Mädchen-Technik-Kongress auch zwei Tagungen von der Abteilung Wissenschaftsmanagement organisiert.

Fachtagung „Trends in der Materialforschung für die Mikro- und Optoelektronik“
Fortschritte in der Forschung für Halbleitermaterialien standen im April 2011 im Mittelpunkt einer Fachtagung. Diese wurde vom Leibniz-Transferverbund Mikroelektronik veranstaltet, dessen Geschäftsstelle am FBH verortet ist. Forschungs- und Entwicklungsverantwortliche aus Unternehmen und Wissenschaftler aus Forschungseinrichtungen konnten sich über die Materialforschungen, unter anderem für die Oxidelektronik und für die siliziumbasierte Photovoltaik, informieren. Die Fachtagung stieß bei den 85 Teilnehmenden auf sehr positive Resonanz; insbesondere die Kontakte zwischen Forschungseinrichtungen und Unternehmen konnten intensiviert werden. Als Ergebnis befinden sich Kooperationsprojekte in Vorbereitung.

Tagung „Technologie und Anwendung von Nitrid-Halbleitern“
Im September 2011 fand die zweitägige Tagung „Technologie und Anwendung von Nitrid-Halbleitern“ in Berlin-Köpenick statt; Veranstalter war der Wachstumskern „Berlin WideBaSe“. Organisiert wurde die Tagung vom Ferdinand-Braun-Institut – dort ist auch die Geschäftsstelle des „Berlin WideBaSe“-Verbundes angesiedelt. „Berlin WideBaSe“ bündelt das Know-how und die technischen Ressourcen von zehn Unternehmen und drei Forschungseinrichtungen aus Berlin zur Entwicklung optoelektronischer und elektronischer Bauelemente auf der Basis von breitlückigen Nitrid-Halbleitern. Insgesamt 90 Teilnehmende tauschten sich über Stand und Anwendungspotenziale von Halbleitern mit großer Bandlücke aus und erarbeiteten Perspektiven für die weitere Forschungs- und Entwicklungsarbeit. Hauptanliegen der Tagung war die enge Wechselwirkung zwischen Entwicklern und Anwendern sowie potenziellen Kunden, um eine bedarfsgerechte Entwicklung zu sichern.

Galliumnitrid-Kristall – Grundmaterial für Bauelemente auf der Basis breitlückiger Nitrid-Halbleiter.

Fairs & events

Gallium nitride crystal—basic material for devices based on wide band-gap nitride semiconductors.

In 2011, the FBH was again represented at various events, fairs, and conferences. In addition to the second "Mädchen-Technik-Kongress", encouraging girls for a career in natural and technical sciences, two conferences were organized by the Science Management Department.

Symposium "trends in materials research for micro- and optoelectronics"

Advances in the research of semiconductor materials were in the focus of a symposium held in April 2011. The event was organized by the Leibniz Technology Transfer Association Microelectronics, whose office is located at the FBH. Persons responsible for research and development from companies and scientists from research institutions had the chance to gain an overview on materials research including oxide electronics and for silicon-based photovoltaics. The symposium met 85 participants with a positive response, especially contacts between research institutions and companies could be intensified leading to cooperation projects that are currently prepared.

Conference "technology and application of nitride semiconductors"

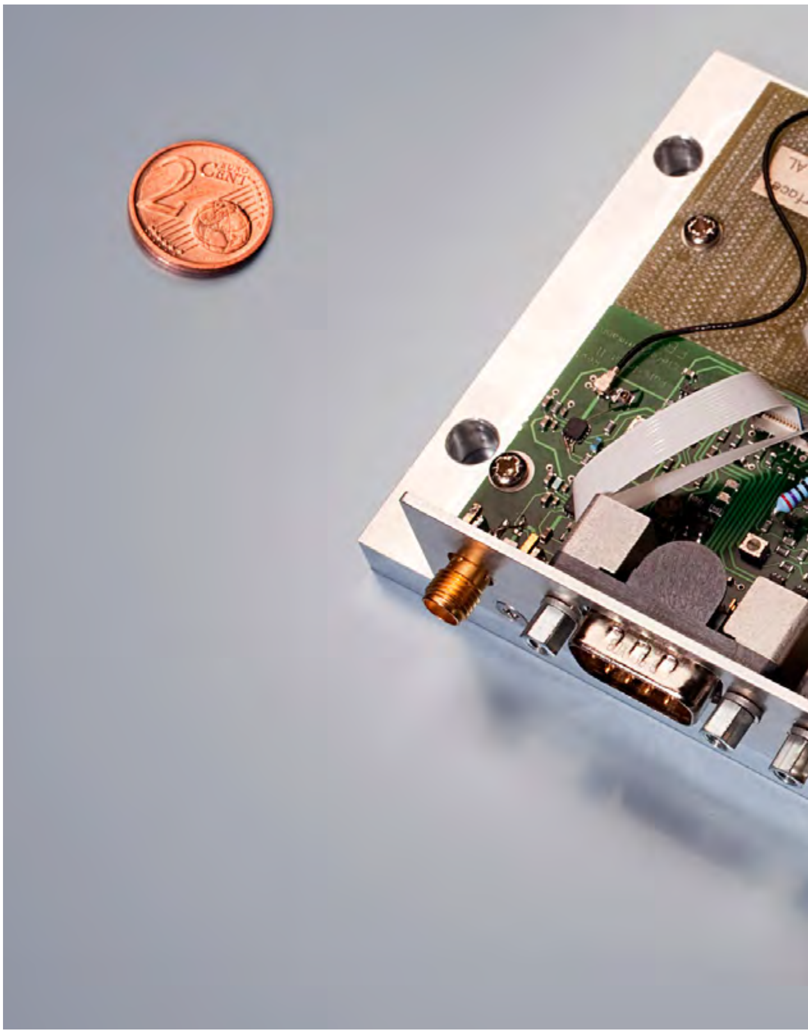
In September 2011, the two-day conference "technology and application of nitride semiconductors" took place in Berlin Köpenick, hosted by the growth core "Berlin WideBaSe". The event was organized by the Ferdinand-Braun-Institut where the office of "Berlin WideBaSe" is located. The network bundles the know-how and technical resources of ten companies and three research institutes from Berlin developing optoelectronic and electronic devices based on wide band-gap nitride semiconductors. 90 participants exchanged information on the latest state of technology and application potentials of semiconductors with wide band-gap, working out prospects for further research and development activities. Main objective of the conference was the close interaction between developers and users as well as potential customers to assure demand-oriented developments.

FBH für die Fachwelt

Entwicklungen aus dem Bereich Diodenlaser
Im Januar präsentierte das FBH auf der Photonics West aktuelle Forschungsergebnisse und Entwicklungen. Auf der weltweit größten Tagung zu optischen Technologien in den USA war das Institut gut sichtbar: Mit zehn Beiträgen waren FBH-Mitarbeiter als Erstautoren und an weiteren fünf Beiträgen als Co-Autoren beteiligt – darunter zwei eingeladene Vorträge.

Nur vier Monate später war das FBH mit einem Stand auf der Fachmesse Laser, World of Photonics und mit jeweils drei Vorträgen und Postern auf der Konferenz CLEO Europe (European Conference on Lasers and Electro-Optics) vertreten. Der Schwerpunkt lag bei Mikromodulen, die hochbrillantes Licht im nah-infraroten, roten sowie mittels Frequenzverdopplung auch im grünen und blauen Spektralbereich emittieren.

Entwicklungen aus dem Bereich Mikrowellentechnik & Leistungselektronik
Im Herbst präsentierte sich das FBH auf der European Microwave Week in Manchester mit einem eigenen Stand. Auf der führenden europäischen Veranstaltung, die eine Messe, drei Fachkonferenzen sowie Workshops und Seminare umfasst, stellte das Institut unter anderem seine neueste Generation von Galliumnitrid-Mikrowellentransistoren vor. Wissenschaftler des FBH wurden zudem mit dem Best Paper Award ausgezeichnet. Gleich im Anschluss beteiligte sich das FBH an der RadioTecC Transmit & Test Solutions 2011. Die Berliner Veranstaltung bietet einen Mix aus Workshops, Vorträgen, Diskussionen und Fachausstellung.

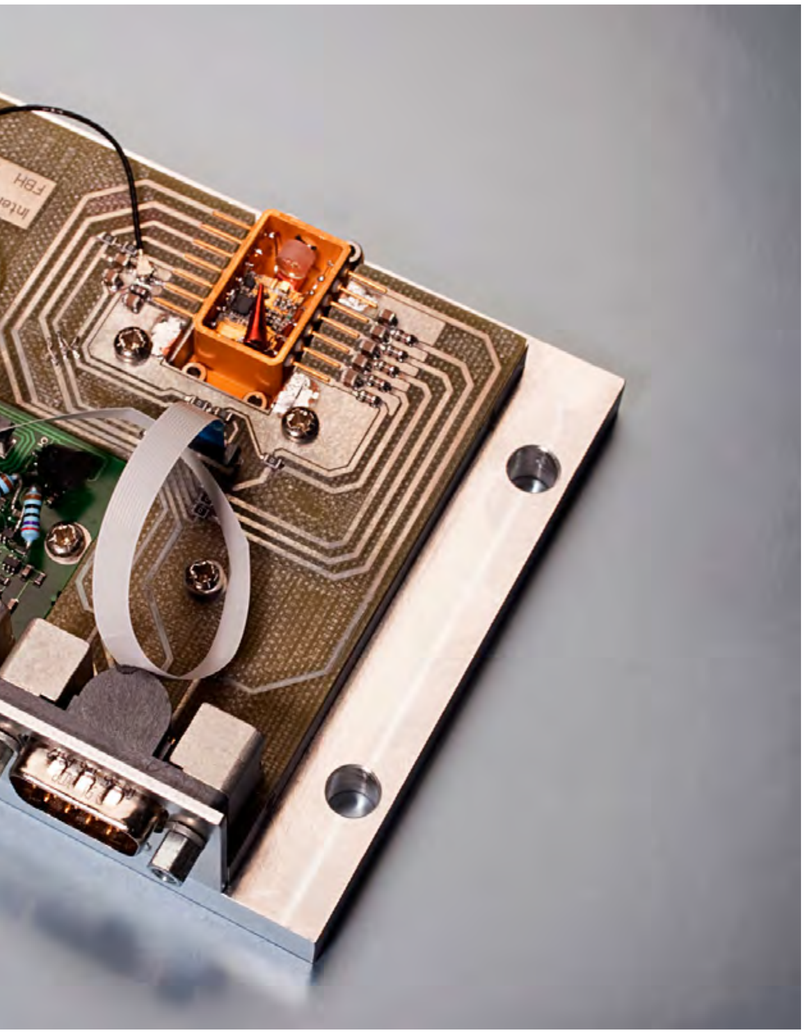


Eine von zahlreichen Neuentwicklungen aus dem FBH: Lasermodul mit elektronischer Ansteuerung zur Erzeugung von Nanosekunden-Pulsen.

FBH präsentiert sich der Öffentlichkeit

Wie bereits in den vergangenen Jahren, machte das FBH seine Forschungsthemen und -ergebnisse einer breiten Öffentlichkeit zugänglich. So informierte das Institut im Rahmen der Langen Nacht der Wissenschaften erneut 1.200 Besucherinnen und Besucher bei Führungen und Mitmach-Experimenten. Auch beim Girls' Day konnten Mädchen ab der 5. Klasse einen Blick hinter die Kulissen von Forschung und Entwicklung werfen. Zudem organisierte das am FBH angesiedelte Zentrum für Mikrosystemtechnik (ZEMI) den Mädchen-Technik-Kongress. Dieser fand bereits zum zweiten Mal statt und bot Mädchen ab der 7. Klasse die Gelegenheit, sich über technische Anwendungsfelder, Berufsbilder und Studienmöglichkeiten zu informieren. Erstmalig präsentierte sich das FBH 2011 zum Tag der offenen Tür beim Steinchen für Steinchen Verlag und stieß mit seinem Laserlabyrinth auf großes Interesse bei Kindern und Jugendlichen ebenso wie erwachsenen Besuchern. Im Jahr zuvor hatte das FBH im Mosaik-Comic des Verlags das Grundprinzip von Lasern erklärt.

FBH for the experts



One out of many new developments from the FBH: laser module with electronic control generating pulses in the nanosecond range.

Developments in the field of diode lasers
In January, FBH presented current research results and developments at Photonics West. The institute has been well visible at the world-wide biggest conference in the field of optical technologies in the USA: FBH scientists participated with ten contributions as lead authors and further five contributions as co-authors, among them two invited lectures.

Only four months later, FBH presented the institute with a booth at the trade fair Laser, World of Photonics. It was additionally represented at the CLEO Europe Conference (European Conference on Lasers and Electro-Optics) with three lectures and posters, respectively. The main focus of the presentation was on micro modules emitting high-brilliance light in the near infra-red, red, and also in the green and blue spectral range, which is achieved by means of frequency doubling.

Developments in the field of microwave technology & power electronics
In autumn, FBH presented itself at the European Microwave Week in Manchester with a stand. At the leading European event comprising a fair, three symposiums, workshops and seminars, the institute introduced, among others, its latest generation of gallium nitride microwave transistors. FBH scientists have additionally been bestowed with the Best Paper Award. FBH also participated at the subsequent RadioTecC Transmit & Test Solutions 2011 fair, offering a mixture of workshops, lectures, and discussions along with an exhibition.

FBH for the general public

Just like in recent years, FBH made its research topics and results available to a broad public. The institute, for example, informed again 1,200 visitors with guided tours and hands-on experiments at the Science Night. Also at Girls' Day, girls from 5th grade and higher gained an insight view behind the scenes of research and development. The Center for Microsystems Technology (ZEMI), which is located at the FBH, additionally organized the "Mädchen-Technik-Kongress". The event already took place for the second time offering girls from grade 7 and higher the opportunity to gain information on technical application fields, occupational images, and study options. For the first time, FBH presented itself at the Steinchen für Steinchen publisher's open day and attracted great interest from children and adolescents with its laser labyrinth. FBH had explained in the publisher's Mosaik comic the basic principle of lasers the year before.

MICROWAVE COMPONENTS & SYSTEMS

MIKROWELLENKOMPONENTEN & -SYSTEME

Mikrowellenkomponenten & -systeme

Der Schwerpunkt im Forschungsbereich Mikrowellenbauelemente und -schaltungen liegt auf Komponenten, die auf III/V-Halbleitern basieren – am FBH sind dies Galliumnitrid (GaN) und Indiumphosphid (InP) – sowie der zugehörigen Design- und Messtechnik-Kompetenz. Das FBH bietet daher die vollständige Wertschöpfungskette, von der Epitaxie und Prozesstechnologie bis hin zu CAD, Messtechnik und Chipaufbauten.

Im Mittelpunkt stehen Leistungsbauelemente für den Frequenzbereich von 2 bis 10 GHz. Dies wird ergänzt durch Aktivitäten zu MMICs für Frequenzen oberhalb 100 GHz, die in der Literatur häufig unter dem Schlagwort Terahertz-Elektronik firmieren. Als Basis dient dabei der am FBH entwickelte InP-HBT-Transfersubstrat-Prozess. Darüber hinaus bearbeitet das Institut Millimeterwellen-ICs im Frequenzbereich 10 bis 100 GHz, speziell für Low-Power- oder Radar-Frontends, wobei auf SiGe-HBT- und RF-CMOS-Prozesse von externen Foundries zurückgegriffen wird.

Im Einzelnen umfasst das Forschungsgebiet folgende Themen:

- ➜ GaN-Hochleistungs-Transistoren (HEMTs) und -MMICs für Frequenzen von 2 bis 10 GHz und den Leistungsbereich von 10 bis 100 W
- ➜ Robuste rauscharme GaN-MMIC-Verstärker
- ➜ InP-HBT-MMICs für Betriebsfrequenzen um 100 GHz und darüber
- ➜ Millimeterwellen-Frontends (24 und 77 GHz, RF-CMOS und SiGe-HBT)
- ➜ Integrierte Mikrowellen-Quellen zur Plasma-Erzeugung im 2 GHz-Band

Diese Aktivitäten adressieren Schlüsselkomponenten für die drahtlose Kommunikation wie Basisstationen für die Mobilkommunikation sowie für Radar- und bildgebende Systeme. Auch Mikrowellen-Plasmaquellen gehören zum Portfolio, für die Leistungs-Mikrowellenelektronik zusammen mit Strukturen zur Plasma-Anregung integriert wird.

Die zugehörigen GaN- und InP-Prozesse werden von den Technologie-Abteilungen des FBH beziehungsweise dem Geschäftsbereich GaN-Elektronik entwickelt und gepflegt. Reinraumlabore mit industriekompatiblem Gerätepark ermöglichen es, Bauelemente auf dem neuesten Stand der Technik herzustellen. Die Abteilung Mikrowellentechnik ist ein Kompetenzzentrum für Mikrowellen- und Millimeterwellen-Design inklusive der entsprechenden Aufbautechnik. Leistungsfähige Methoden zur dreidimensionalen elektromagnetischen Simulation, der Transistormodellierung und dem Schaltungsentwurf sind sowohl Forschungsgegenstand als auch Werkzeuge zur Entwicklung von Komponenten. Eine spezialisierte Messtechnik ermöglicht die Charakterisierung der Bauelemente bis zu Frequenzen von 110 GHz und darüber, ein Messplatz für S-Parameter-Messungen bis 500 GHz wird derzeit installiert.

Microwave Components & Systems

In line with the semiconductor technologies available at FBH, the focus in the field of microwave devices and circuits is on III-V semiconductor components—in this case, gallium nitride (GaN) and indium phosphide (InP) devices—and the corresponding design and measurement expertise. Thus, FBH offers the entire value-added chain from epitaxy and processing to computer-aided design, measurements, and packaging.

The core work is devoted to high-power discretes and MMICs for the frequency range between 2 and 10 GHz. This is complemented by activities on MMICs for frequencies beyond 100 GHz, commonly referred to as "THz electronics". They are based on the InP-HBT transferred-substrate process developed at FBH. An additional topic is millimeter-wave integrated circuits (10 to 80 GHz) with special emphasis on low-power and radar frontends. For this purpose, SiGe-HBT and RF-CMOS processes are applied, using external foundries.

In more detail, the topics of research include:

- ➜ GaN high-power transistors (HEMTs) and MMICs for 2 to 10 GHz with 10 to 100 W output power
- ➜ Robust low-noise GaN amplifier MMICs
- ➜ InP-HBT MMICs for operation at frequencies of 100 GHz and beyond
- ➜ Millimeter-wave frontends (24 and 77 GHz, RF-CMOS and SiGe-HBTs)
- ➜ Integrated microwave sources for plasma generation (2 GHz range)

The activities are focusing on key components for wireless communications, such as cellular radio basestations and radar and imaging systems. The portfolio also includes microwave plasma sources, integrating power electronics together with excitation structures for plasma generation.

The relevant GaN and InP processes are developed and maintained by FBH's technology departments and the Business Area GaN Electronics, respectively. Cleanroom laboratories with industry-level equipment offer the capability required for state-of-the-art device performance. The Microwave Department is a center of competence for microwave and mm-wave IC design and the respective packaging. Advanced methods for 3D electromagnetic simulation as well as transistor modeling and circuit design are both subject of research and routinely available as tools for component development. Dedicated measurement equipment allows characterization for frequencies up to 110 GHz and beyond, a 500 GHz S-parameter set-up is being installed.

(100 W) GaN-HEMT-based microwave power amplifier modules

Nowadays, highly efficient microwave power amplifiers are mandatory for a variety of systems. Applications range from microwave communication, radar, and measurement systems to safety and monitoring facilities. They are additionally required for industrial process technologies like heating, drying, and for plasma generation. GaN-HEMTs are the most suitable devices for these amplifiers because of their high power density and efficiency, high operating frequency, and excellent thermal properties. Moreover, they feature a potentially high robustness and reliability.

A common approach of efficiency enhancement is harmonic tuning. When applying this technique, the impedance matching at the source and load side of the transistor has to be performed not only at the fundamental frequency but also at their harmonics. Thus, current-voltage overlap at the intrinsic transistor is minimized and the transistor achieves its maximum efficiency. Unfortunately, high-power transistors require very low source and load impedances at the fundamental frequency. This fact, together with the tuning of the harmonic terminations, makes the corresponding network design a very challenging issue. Additionally, large transistors tend to oscillate. Therefore, nonlinear stability analysis and stability network design have to be integral parts of the design process, too.

Demonstrators with the described objectives are currently under development within the project work of "Berlin WideBaSe, Verbundprojekt 7, Hocheffiziente Mikrowellen-Leistungsverstärker und Oszillatoren". In collaboration with the project partners BeMiTec AG, GloMic GmbH, and SENTECH GmbH, one of the final goals of this project part is the demonstration of around 500 W of microwave output power with at least 60 % efficiency at 2.45 GHz.

In a first step, 50 and 100 W modules were developed using packaged BeMiTec GaN-HEMTs. Harmonic load-pull analysis has been accomplished to determine the optimum fundamental and harmonic load impedances. Lumped element and distributed approaches were investigated in order to realize the input and output matching networks, respectively. An additional stability network was combined with the input bias-t. Both designs provide unconditional stability with a stability factor > 1.3. The PAs were fabricated using a 0.51 mm thick dielectric substrate for

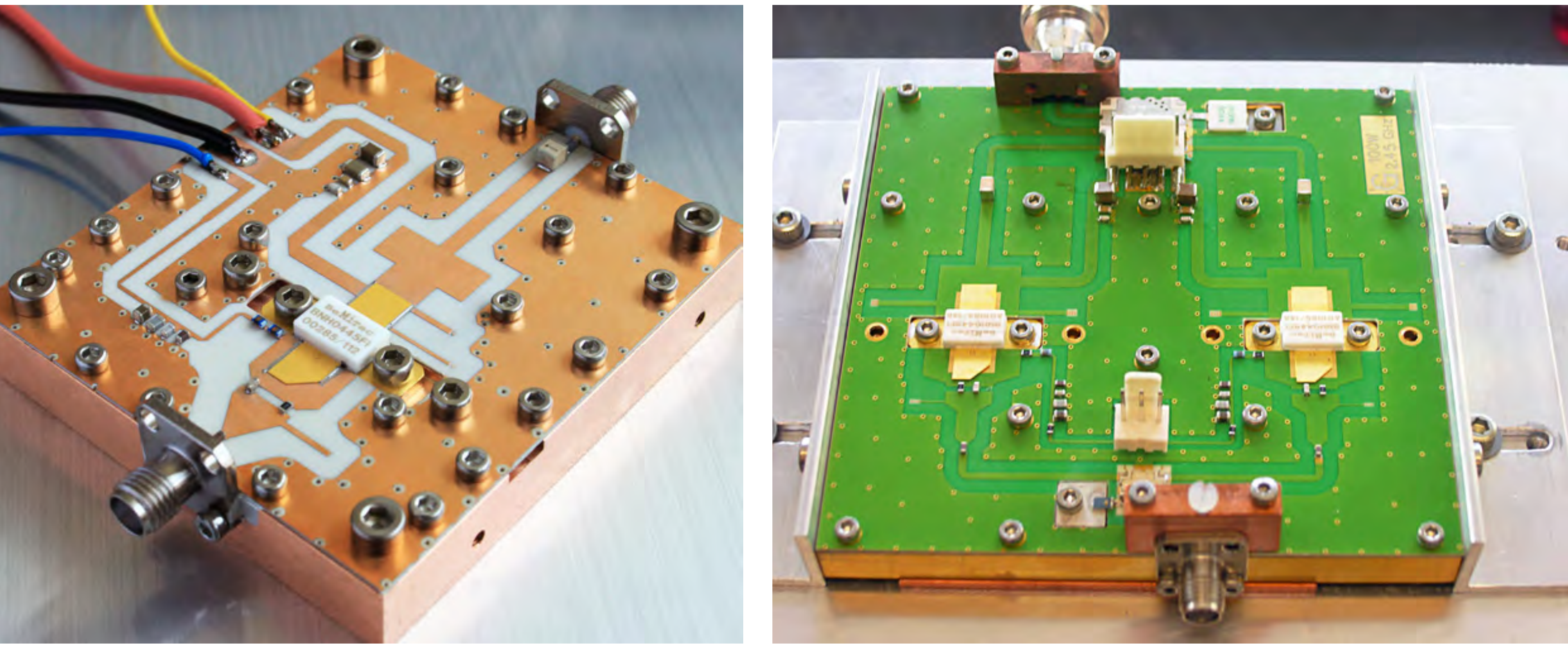


Fig. 1. 50 W (left) and 100 W (right), 2.45 GHz PA modules; V_{DD} = 28 V.

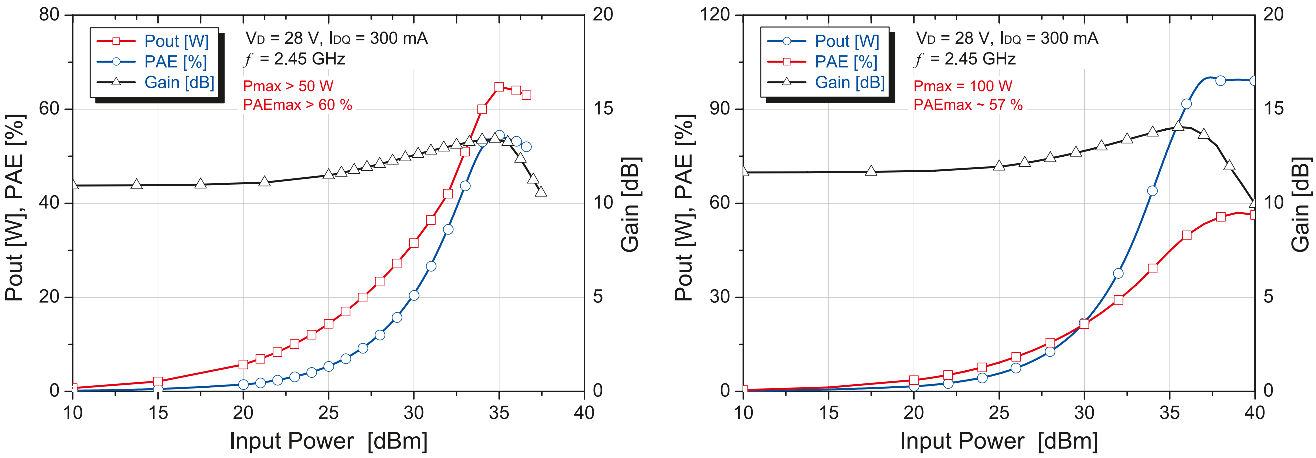


Fig. 2: Output power, PAE and gain of the 50 W (left) and 100 W (right) demonstrators; V_{DD} = 28 V.

the printed circuit board (PCB – RO4003C from Rogers, ε_r = 3.38). The sizes of the PCBs and the copper heat sinks were 60 × 60 and 90 × 90 mm² for both designs. The two prototypes are depicted in Fig. 1.

Fig. 2 shows output power, power added efficiency (PAE) and gain of both modules. The characterization was performed by applying a single-tone CW signal. The measured RF output powers were higher than 50 and 100 W, respectively. Both modules achieved a gain of > 13 dB and PAE values > 60 % (50 W) and 57 % (100 W) at 28 V supply voltage. Increasing supply voltages up to 50 V still lead to a higher output power at the cost of a slight efficiency drop.

The project objectives for 2012 are to double the output power along with sustaining efficiency and gain values. The final project goal is at least 500 W output power with > 60 % efficiency.

Hocheffiziente Mikrowellen-Leistungsverstärker werden in zahlreichen unterschiedlichen Systemumgebungen benötigt. Die Anwendungen reichen von Kommunikations- und Radarsystemen bis hin zur industriellen Prozesstechnik. Besonders eignen sich dafür GaN-HEMTs aufgrund ihrer hohen Leistungsdichte und ihrer herausragenden Effizienz. Um die potenziell hohe Effizienz des Bauelementes am fertigen Verstärker erzielen zu können, müssen Quellen- und Lastimpedanzen von Grundwelle und Harmonischen optimal ausgelegt sein. Zugleich muss die zeitliche Überlappung von Strom und Spannung am inneren Transistor minimiert werden. Besondere Herausforderungen beim Entwurf der Anpassungs-Netzwerke ergeben sich bei großen Transistoren aus den sehr niederohmigen Lastimpedanzen, dem gleichzeitig zu berücksichtigenden Abgleich der harmonischen Frequenzanteile und möglichen Oszillationen.

Im Rahmen des Wachstumskerns „Berlin WideBaSe" wurden in einem Teilprojekt erste Demonstratoren hocheffizienter Leistungsverstärker mit 50 und 100 W Ausgangsleistung bei 2,45 GHz entwickelt. Die dabei erzielten Wirkungsgradwerte lagen bei > 60 % (50 W) und 57 % (100 W). Beide Demonstratoren erreichten eine Verstärkung von mehr als 13 dB. Das Projektziel sieht 500 W Verstärker mit > 60 % Wirkungsgrad vor.

X-band power MMICs for communication and radar applications

Power amplifiers (PA) belong to the most critical components of any communication, radar or satellite system. As the last element in the transmitting chain before the antenna, they dominate the overall properties and usually also the power consumption. The most important figures of merit are maximum output power P_{max} and the power-added efficiency (PAE). Regarding semiconductor technology, this demands for a combination of high speed and high breakdown voltage, which common Si-based processes cannot offer. Therefore, either dedicated Si technologies such as LDMOS or III-V semiconductors, primarily GaAs, are dominating this field because of their material-related advantages. More recently, GaN has gained importance because of its superior high-power and high PAE properties.

There is a demand for efficient solid-state PAs in various frequency bands. The X-band (8…12 GHz) is of particular interest for radar and satellite communications. While in the 2 GHz band PAs are commonly realized as hybrid circuits, the situation at 10 GHz is different. Here, monolithic solutions (MMICs: Monolithic Microwave Integrated Circuits) become important because they offer lower interconnect parasitics than their hybrid counterparts. Such GaN PA MMICs are presently the subject of intensive research and development activities worldwide. The publications in journals and conference papers provide only a limited insight into the state-of-the-art here since many of these activities are performed under non-disclosure agreements.

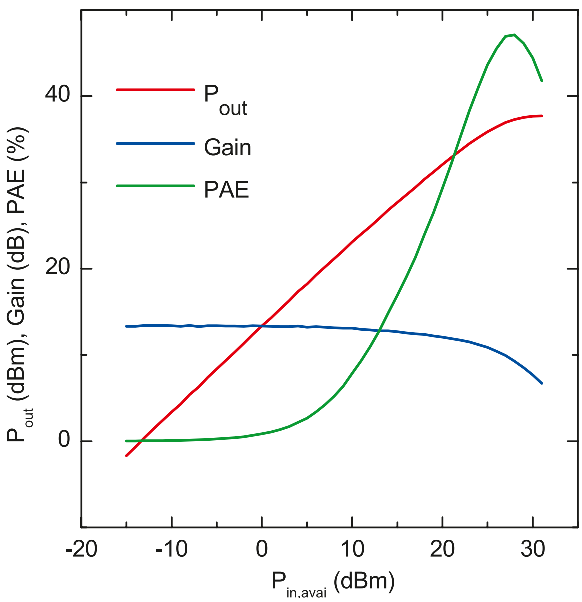


Fig. 1. Power measurement data for 12 × 125 µm transistor with field plate, matched for maximum PAE.

The challenge in developing such a high-efficiency power amplifier is twofold. First, one has to develop suitable basic transistor cells and, second, these cells need to be operated under optimum conditions within the circuit, which is the circuit-design part of the story. What makes the X-band special compared to lower-frequency bands is that the margin between the transistor's frequency limits and the operating frequency shrinks. Fig. 1 demonstrates recent results on a typical transistor available within the present 0.25 µm gate GaN MMIC process at FBH. The GaN-HEMT includes a source-connected field plate, which helps to mitigate the internal electric field peaking near the drain-edge of the gate. This results in improved RF properties of the transistor, especially regarding PAE. As depicted in Fig. 1, transistor versions with 12 × 125 µm gate width and field plate show state-of-the-art performance: an output power of 6.9 W, a PAE of 51%, and a linear gain of 12.8 dB under matching conditions for maximum P_{out} at 10 GHz in deep AB class.

Fig. 2 presents the chip photo of a recently realized power amplifier MMIC. In contrast to most of the other MMIC data published, this PA employs the coplanar instead of the microstrip technique. The circuit was designed targeting high PAE and high linear gain G, using a two-stage design. At the final stage, a 12-finger transistor with a gate width of 12 × 125 µm is chosen, resulting in 3 mm overall gate width of the final stage. Maximum output power reaches 40.5 dBm (11 W) at 10 GHz, and a final-stage PAE of almost 40% is achieved. The maximum linear gain is approximately 25 dB. Work is in progress to further optimize these results.

Leistungsverstärker gehören zu den entscheidenden Komponenten jedes Radar- oder Satellitensystems. Als letztes Element vor der Antenne bestimmen sie maßgeblich die Gesamteigenschaften des Systems, insbesondere dessen Leistungsverbrauch. Die Eigenschaften der Leistungsverstärker hängen stark von der verwendeten Halbleitertechnologie ab. Galliumnitrid zeigt auch im X-Band, dem Frequenzbereich von 8 bis 12 GHz, exzellente Leistungs- und Effizienzwerte. Am FBH wurde ein GaN-MMIC-Prozess mit 0,25 µm Gatelänge entwickelt. Die Transistoren liefern im AB-Betrieb Effizienzen bis 50 % (PAE) bei 10 GHz. Als Schaltungsbeispiel wurde ein zweistufiger Leistungsverstärker für 10 GHz realisiert. Die als koplanarer MMIC ausgelegte Schaltung liefert eine maximale Ausgangsleistung von nahezu 11 W, eine lineare Verstärkung von 25 dB und eine Effizienz von etwa 40 %.

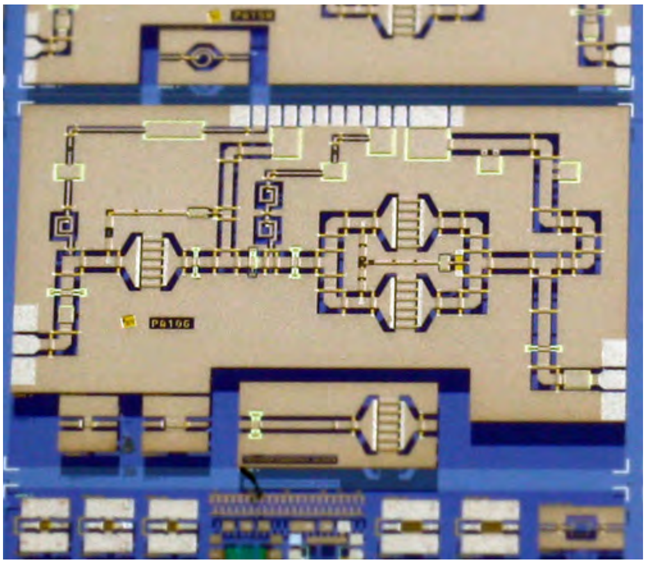


Fig. 2. Chip photo of an X-band power amplifier MMIC.

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➜ C. Meliani, E. Ersoy, N. Chaturvedi, S. Freyer, J. Würfl, W. Heinrich, G. Tränkle, **"A non-uniform GaN power TWA for 2 to 10 GHz suitable for square-wave operation"**, Radio Frequency Integrated Circuits Symposium, 2009, IEEE, Boston, MA, USA, pp. 591–594 (2009).

➜ E. Ersoy, C. Meliani, S. Chevtchenko, P. Kurpas, M. Matalla, W. Heinrich, **"A high-gain X-band GaN-MMIC power amplifier"**, German Microwave Conference Digest, paper 1561 (2012).

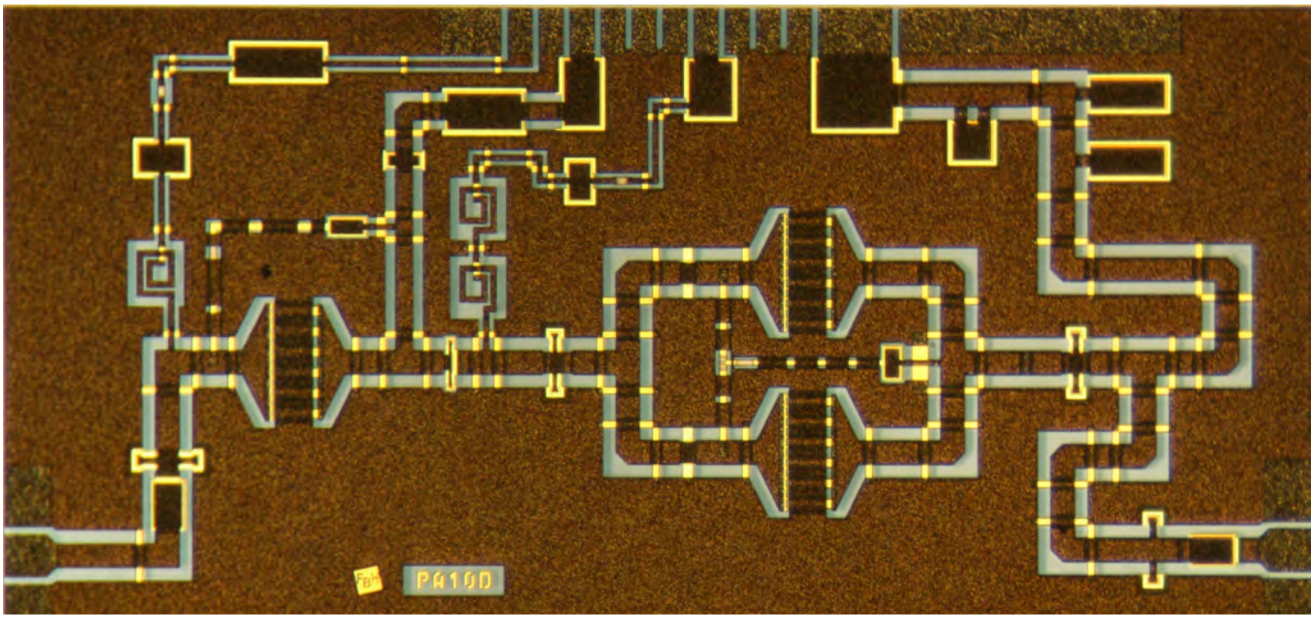


Fig. 3. The X-band PA of Fig. 2 during on-wafer measurements.

InP-HBT MMICs at 100+ GHz

Terahertz (THz) technology is on the verge of breaking through into major application fields such as medical technology, non-destructive materials testing, radar, security, food processing, and space. The FBH focuses on the development of microwave monolithic integrated circuit (MMIC) technologies at frequencies beyond the W-band, including the corresponding circuits, components, and modules. Power amplifiers, voltage-controlled oscillators, frequency multipliers, and mixers will soon be developed with operating frequencies up to 500 GHz. These devices shall be used to realize compact integrated front-end modules for radar and imaging systems.

The FBH activities in W-band and beyond were focusing on three topics in 2011:

➜ Developing power devices and amplifiers based on the in-house developed Transferred-Substrate-Process (TS process) for InP-HBTs. Work in 2011 concentrated on process optimization, device and circuit characterization, and investigations of which transistor periphery is optimum suited for high output power.

➜ Integrating the TS process with the SiGe-BiCMOS technology of the Leibniz Institute for Innovative Microelectronics (IHP). This was performed within the framework of the joint HiTeK project. HiTeK targets an InP-beyond-CMOS integration technology, which combines high-frequency power performance of InP with maturity, integration density, and low-power properties of BiCMOS.

➜ Setting up a measurement system for on-wafer characterization of S-parameters up to 500 GHz. In 2011, the required basic items have been purchased and installed.

Key to such circuit developments is the active device. Fig. 1 illustrates transistor results from a TS process run presenting S-parameters up to 110 GHz for a typical circuit transistor with two emitter fingers. Two observations should be mentioned: The forward gain S_{21} shows values of more than 10.5 dB at 77 GHz and still has more than 7 dB gain at 110 GHz. The output impedance in the frequency range 60 to 110 GHz is relatively close to 50 Ω, implying that it is easy to match the output whereas the input requires a bit more effort. The maximum short-circuit current gain frequency f_T and maximum frequency of oscillation f_{max} is close to 400 GHz. This, together with the relatively large emitter area, promises high-power operation beyond 100 GHz.

Also, power amplifier circuits were fabricated and characterized with regards to their power capabilities at 77 GHz. Fig. 2 shows the small-signal S-parameters for a typical circuit. In Fig. 3, output power and gain are plotted as a function of input power for another power amplifier from the same wafer. The 1 dB compression point is 9 dBm output-referred, with good input and output matching. A saturated output power of more than 14 dBm was achieved with optimized biasing. The goal of further work is to increase this output power to more than 23 dBm and to enhance efficiency.

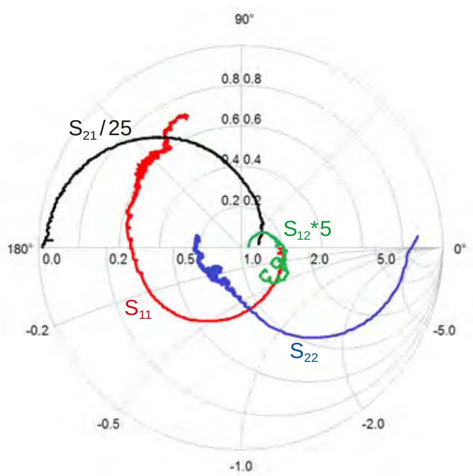


Fig. 1. S-parameters of an InP-HBT (TS process) as a function of frequency (0.05–110 GHz).

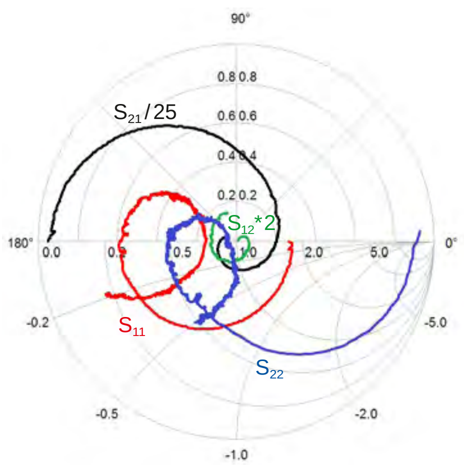
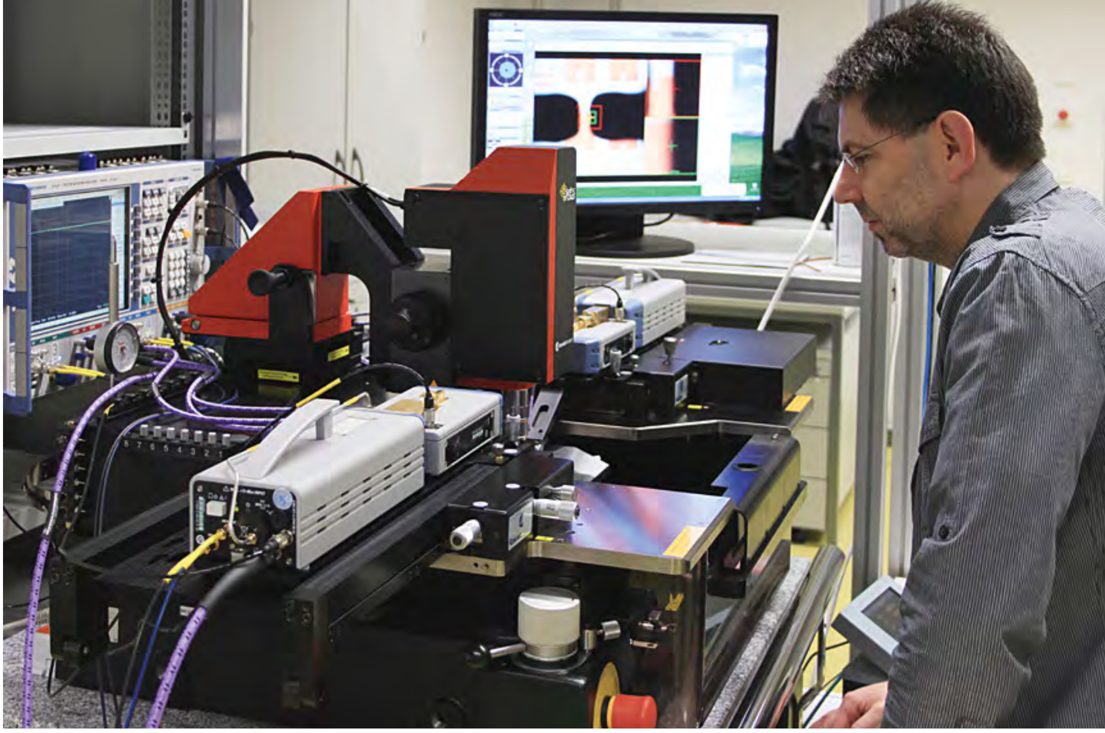


Fig. 2. Example of the S-parameters of a power amplifier MMIC as a function of frequency (0.05–110 GHz).

Fig. 4.
500 GHz measurement set-up showing the probe station with a set of frequency extender modules and the network analyzer. The fully automated probe station is equipped with a video camera and associated feature recognition software.



In terms of process integration, activities aim at integrating the FBH InP-DHBT-TS process with IHP's SiGe-BiCMOS process on circuit rather than device level. The first results of the integration efforts have shown that it is possible to implement a transition from the silicon CMOS wafer to the InP substrate with relatively low losses. Simulations of realistic structures were carried out indicating that transmission line losses of < 0.4 dB/mm up to 200 GHz can be achieved. Measurements of these transitions and transmission lines are ongoing. The necessary technological developments for the integration are currently focusing on the manufacturing of BCB layers on the already processed silicon BiCMOS wafer.

To support the activities mentioned above, an automated on-wafer S-parameter measuring facility for the frequency range up to 500 GHz is required. The implementation is pursued in close cooperation with the equipment manufacturers due to explorative issues inherent in measurements at such high frequencies. One target is to improve mechanical tolerances of the probe station in order to ensure measurement accuracy and repeatability. Another aim is to minimize losses between the frequency extenders and the probe tips, which will enhance on-wafer calibration procedures. The requirements to calibration procedures and techniques are also greatly increased and work has been initiated to fulfill these demands. By the end of 2011, the basic probe station and the network analyzer were successfully installed. Fig. 4 shows the set-up in the THz lab. For the higher frequency range, a set of exchangeable frequency extender modules—one set for each frequency band—is used.

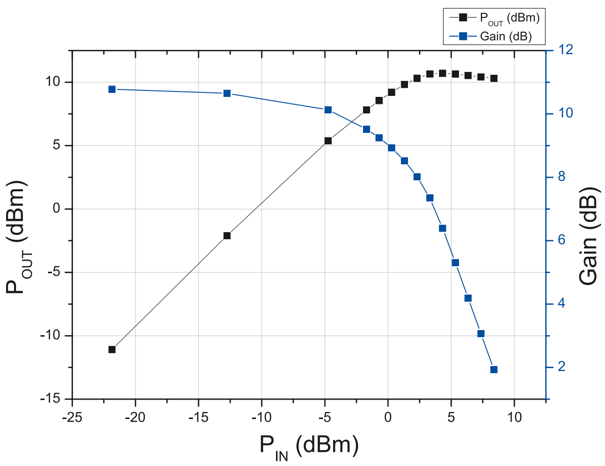


Fig. 3. TS-InP-HBT MMIC output power and gain as a function of input power at 77 GHz.

Der Frequenzbereich zwischen 100 GHz und 1 THz gewinnt derzeit international an Bedeutung. Die Hauptanwendungen für diese Frequenzen liegen bei bildgebendem Radar und in der Materialprüfung. Mit seinen Forschungsarbeiten konzentriert sich das FBH auf die Entwicklung integrierter Schaltungen (MMICs) oberhalb des W-Bands. Im Vordergrund stehen dabei Leistungsverstärker und Vervielfacher, die auf dem InP-HBT-Transferred-Substrat-Prozess des FBHs basieren. Dieser wurde 2011 weiter optimiert und soll auch in dem neu gestarteten HiTeK-Projekt genutzt werden. Ziel des gemeinsamen Projektes mit dem Leibniz-Institut IHP in Frankfurt/Oder ist es, den InP-HBT-Prozess mit der Silizium-BiCMOS-Linie des IHP zu integrieren. Die resultierende Technologie bietet eine ideale Kombination der Höchstfrequenz-Leistungsausbeute der InP-Transistoren mit der Integrationsdichte und Komplexität des BiCMOS-Prozesses. Dies erfordert eine entsprechende Messtechnik, weshalb 2011 mit dem Aufbau eines 500 GHz on-Wafer-Messsystems begonnen wurde. Die Grundkomponenten bis 110 GHz sind bereits installiert.

77 GHz radar for cars: chip package investigations

The market for automotive radars has seen steadily increasing activities in the last few years and offers interesting opportunities for companies working in this field. Various players worldwide are following different approaches to develop compact, reliable, and cost effective radars which become part of driver assistance systems. An important factor regarding pricing is packaging and module assembly.

Thus, the German company Infineon has developed the embedded wafer level ball grid array (eWLB) packaging process, which allows for a sophisticated layout, design, and packaging of radar systems in a user-friendly standard. The eWLB process uses low-cost plastic packaging. Furthermore, a redistribution layer allows to properly route signals from the motherboard to the radar chip. In the 77 GHz frequency range, Infineon has realized several packaged radar prototypes using this technology. The eWLB package and mounting scheme is shown in Fig. 1.

The work at FBH was focused on packaging design, for example, to optimize the layout of the package within the given limits of the eWLB process and the chip functionality. This means that the transmission-line structures and the signal propagation characteristics on the motherboard and the redistribution layer had to be altered within the technological limits. Proper design, optimization, and tolerance considerations lead to significant improvement in the way that the microwave signal is delivered from the motherboard to the radar chip. Here, FBH contributed with its experience in analyzing and understanding parasitic effects like radiation, coupling, and mode conversion. Another challenging aspect of the work was to deal with an electrically large overall structure, which, at the same time, had many details much smaller than the wavelength. The electromagnetic simulation method applied, the Finite-Difference-Time-Domain (FDTD) method, uses mesh cells to discretize the entire structure. Especially details in the interconnect region on the chip side need a fine spatial resolution so that a total mesh size of 10...20 million cells was quite a common number. Though time domain simulations run rather fast, such mesh sizes require dedicated hard- and software to stay within an acceptable CPU time range.

A major part of the investigations dealt with field distribution and wave propagation of certain modes in the different regions of the package. Due to the presence of metallization areas in the various layers, many types of Parallel-Plate-Modes (PPL) can propagate within the structure. This may lead to parasitic resonances and crosstalk, severely affecting the module performance. This is clearly an important factor for lines which are close together, but it may also be relevant for RF lines far apart on opposite sides of the chip. Proper shielding has thus to consider not only the electrical behavior, but should also include other functions such as heat sinking and mechanical stability.

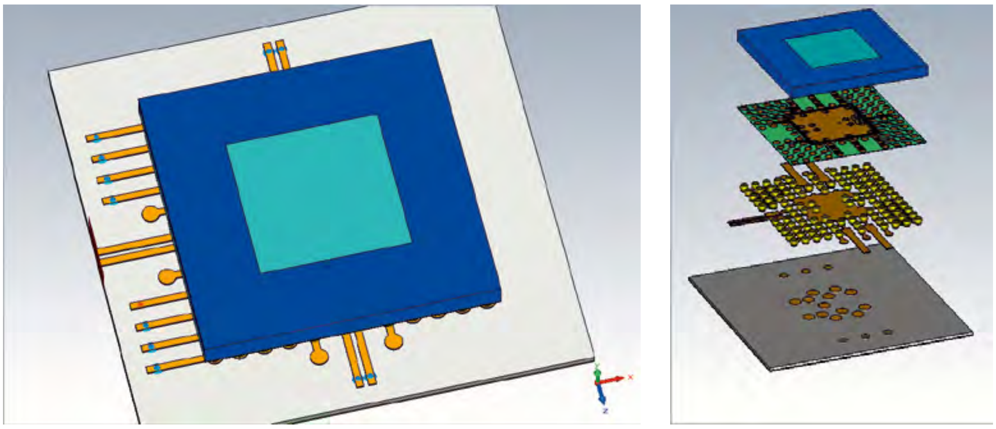


Fig. 1.
Model for the electromagnetic simulation of an eWLB package and radar chip for automotive radar applications in the W-band (77 GHz). The package is mounted on a motherboard in which vias realize the connections to the backside ground.

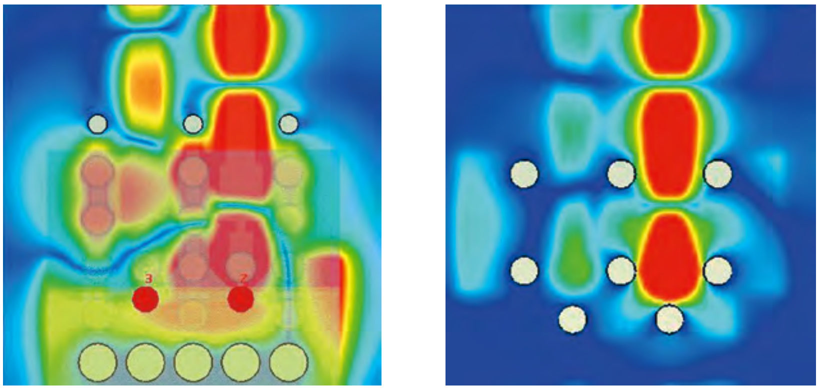


Fig. 2.
Electromagnetic wave in an initial package (left) and in an improved package with optimized placement of balls and vias.

Additionally, surface modes and radiation effects occur. Surface modes are mainly propagating in the motherboard and can be suppressed by vias which are positioned appropriately. Radiation effects appear in the motherboard, but also in the edge region of the mold. They cause losses and may lead to crosstalk as well. Here, some changes in the redistribution layer in each transition region were helpful to minimize radiation and to improve the behavior of the transitions itself. The investigations also involved checking the influence of various tolerances in the packaging process. It was found that nearly all of the tolerances that may appear in the different processes are uncritical, even those who, at a first glance, seem to have a strong impact like ball size and shape. However, the ball size in general is clearly one of the main factors limiting the high-frequency behavior. Simulations with smaller balls showed an increase in the upper frequency limit, which can be extended up to 110 GHz using the same mold package.

In general, it was found that a thorough design of the distribution and the layout of balls and vias are essential, as vias are realizing the ground connection in the motherboard carrying the package. In this way, one can reduce the coupling into neighboring line systems, suppress radiation, and improve the signal transition behavior. Fig. 2 illustrates how the proper placement of balls and vias improves transmission and suppresses unwanted couplings. All of the suggestions given keep the costs low and do not require basic process modifications. These results provide the manufacturer with simple rules and suggestions which help to improve the module performance when applied.

Radar-Anwendungen setzen sich in der Automobilbranche zunehmend durch. Um kostengünstige Geräte herzustellen, werden weltweit unterschiedliche Möglichkeiten im Aufbau der elektronischen Schaltungen, der Kapselung der Gesamtschaltung und Montage in der Karosserie verfolgt. Dies gilt speziell für den Frequenzbereich um 77-GHz-Bereich, in dem die meisten Radarapplikationen für die Fahrkontrolle angesiedelt sind. Beim Aufbau der elektronischen Schaltung setzt die Firma Infineon auf die von ihr entwickelte eWLB-Technologie. Dabei werden Chips in eine Plastikumgebung eingebettet und über eine Verteilerstruktur und ein Ball-Grid-Array auf einem Motherboard aufgebondet. Das FBH hat das hochfrequente Verhalten dieser Aufbauten untersucht. Die parasitären Effekte und ihr Einfluss auf das elektrische Verhalten standen dabei im Vordergrund. Mithilfe von Simulationen der elektromagnetischen Vorgänge konnten offene Fragen geklärt und Lösungsmöglichkeiten entwickelt werden. Alle Verbesserungsvorschläge zielen auf die einfache und kostengünstige Umsetzung.

BUSINESS AREAS & RESEARCH
GESCHÄFTSBEREICHE & FORSCHUNG

GAN ELECTRONICS

GAN-ELEKTRONIK

GaN-Elektronik

Die Entwicklung von Galliumnitrid (GaN)-Bauelementen für Anwendungen in der Mikrowellentechnik und der Leistungselektronik steht im Vordergrund der Arbeiten des Geschäftsbereichs GaN-Elektronik. Diese umfassen die anwendungsorientierte Konzeption der Bauelemente, die Entwicklung und Optimierung von geeigneten Prozessmodulen sowie deren Integration in einen Gesamtprozess. Die Aktivitäten decken die gesamte Wertschöpfungskette ab: von der Epitaxie bis hin zu fertig montierten Bauelementen, die reproduzierbar und lieferfähig zur Verfügung stehen.

Alle Entwicklungen beruhen auf dem synergetischen Zusammenwirken von physikalischer und thermischer Bauelementsimulation, Epitaxie, Prozesstechnologie, Mikrowellendesign und -Charakterisierung. Hinzu kommen Lebensdauermessungen und die Analyse von potenziellen Ausfallmechanismen. Die Arbeiten erfolgen in kontinuierlicher Abstimmung mit allen beteiligten Abteilungen und Geschäftsbereichen.

Am FBH verfügbar sind diskrete Mikrowellen-Leistungsbauelemente in 0,5 µm GaN-Technologie für verschiedene Leistungsklassen bis 100 W bei 2 GHz. Sie werden in kommerziell erhältliche Mikrowellengehäuse montiert und sind für eine Betriebsspannung von 60 V ausgelegt. Damit eignen sie sich für die Realisierung von hybrid aufgebauten Mikrowellen-Leistungsverstärkern. Weiterhin wurden GaN-Powerbars entwickelt für Leistungsbauelemente mit inhärent hoher Linearität und für robuste Leistungsbauelemente, die tolerant gegenüber einer hohen Fehlanpassung am Ausgang sind. Sie unterscheiden sich von den Standardbauformen durch den Aufbau der Epitaxieschichten und das laterale Design. Zudem ist ein 0,25 µm GaN-MMIC-Prozess verfügbar, der die Basis für eine Vielfalt von MMIC-Schaltungsentwicklungen bildet. Dazu gehören mehrstufige X-Band Leistungs-MMICs, Switchmode-Verstärker der Klasse S und robuste rauscharme Verstärker. Schnell schaltende, laterale Schottkydioden mit Schaltzeiten im ps-Bereich für den Einsatz in neuen Verstärkerarchitekturen erweitern den MMIC-Prozess.

2011 ist das Projekt „GaN-based normally-off high power switching transistors for efficient power converters (HiPoSwitch)“ gestartet. Das europäische Verbundprojekt wird vom FBH koordiniert und erweitert die bisherigen Aktivitäten des Instituts im Bereich GaN-Leistungselektronik. Im Fokus der Arbeiten stehen selbstsperrende Schalttransistoren für hohe Betriebsspannungen bis 1200 V bei gleichzeitig geringen Einschaltwiderständen von 50 mΩ. Die dynamischen Eigenschaften dieser Bauelemente bei hohen Schaltspannungen sind entscheidend für die angestrebten Systemanwendungen. Systematische, aufeinander abgestimmte Optimierungen, sowohl des epitaktischen Aufbaus als auch der lateralen Strukturen führten zu sehr guten Ergebnissen. Ein weiterer Entwicklungsschwerpunkt sind thermisch optimierte, skalierfähige Transistoren in quasi-vertikaler Bauweise. Sie ermöglichen es in der Leistungselektronik etablierte Montagetechniken einzusetzen und bieten darüber hinaus das Potenzial zur beidseitigen Entwärmung der Leistungs-Chips. Hocheffiziente, schnell schaltende GaN-Schottkydioden mit Sperrspannungen von über 1000 V runden das Portfolio ab.

Die Analyse der Zuverlässigkeit und die Identifikation von Degradationsmechanismen gewinnt bei allen Entwicklungen immer mehr an Bedeutung. Daher werden alle Entwicklungen von Zuverlässigkeitsmessungen begleitet, deren Ergebnisse iterativ in die Optimierung des Bauelementprozesses einfließen. Die Zuverlässigkeitsmessverfahren bestehen aus on-Wafer-Screening-Tests sowie thermisch aktivierten DC- und RF-Langzeittests.

Viele der Forschungs- und Entwicklungsaktivitäten zielen auf den raschen Technologietransfer, daher bestehen in diesem Bereich verschiedene strategische Kooperationen mit industriellen Partnern. Darüber hinaus läuft die Vermarktung von GaN-Prototypen über die BeMiTec AG (Berlin Microwave Technologies), einem Spin-off des FBH.

GaN Electronics

The Business Area GaN Electronics focuses on the development, fabrication, and characterization of GaN devices for microwave and power electronic applications. Activities are concentrated on application-oriented device designs, the corresponding development of process modules, and their integration in a complete process flow. They are covering the full value chain, from epitaxy to completely packaged devices, which are reproducibly available for delivery to customers.

All developments are based on the synergetic interaction between physical and thermal device simulation, epitaxy, processing technology, microwave design and characterization as well as lifetime measurements and the analyses of potential degradation mechanisms. These activities require an intensive interaction with all contributing departments and business areas.

At FBH, discrete microwave power devices in 0.5 µm GaN technology are available for different power classes up to 100 W at 2 GHz. They are mounted in commercially available microwave packages designed for up to 60 V operation voltage and thus suitable to realize hybrid high-power amplifiers. Furthermore, power bars have been developed for inherently higher linear behavior and for robust power devices being tolerant against high output mismatching. They differ from standard devices by their epi-layer design and device topology. FBH's 0.25 µm GaN MMIC process builds the foundation for various further circuit developments such as multistage X-band power amplifiers, class-S switch-mode amplifiers, and robust low-noise switch-mode amplifiers. Fast switching lateral GaN Schottky diodes are being integrated into the current GaN MMIC process in order to cope with the increasing demand for advanced amplifier topologies.

In 2011, the project "GaN-based normally-off high power switching transistors for efficient power converters (HiPoSwitch)" started. The European joint research project is coordinated by the FBH and expands the institute's activities in the GaN power electronics. Developments in this field focus on high-voltage normally-off transistors up to 1200 V featuring a simultaneously low on-state resistivity of 50 mΩ. The dynamic properties of these devices at high switching voltages are decisive for the targeted system applications. Systematic optimizations of both epitaxial design and technology and lateral structure design already led to promising results in this regard. Thermally optimized scalable devices in quasi-vertical technology are a further focus of development. They are compatible to established mounting schemes in power electronics and enable to dissipate heat from both sides. Highly efficient fast switching lateral GaN-Schottky diodes with blocking voltages above 1000 V complement the portfolio.

Reliability characterizations combined with identification and analyses of possible degradation mechanisms are routinely performed. The results feed back into technological development and therefore ensure continuous device improvement. Reliability testing techniques such as on-wafer robustness tests as well as long-term thermally accelerated DC and RF degradation tests are routinely performed.

Many of the research and development activities within this field are aiming to be transferred into an industrial environment. Hence, various strategic co-operations with industrial partners have been established. In addition, the FBH spin-off BeMiTec AG (Berlin Microwave Technologies) brings GaN prototypes to the market.

Highly efficient X-band GaN power devices in 0.25 µm gate technology

The realization of highly efficient high-power X-band 8 – 12 GHz monolithic microwave integrated circuit (MMIC) power amplifiers (PAs) based on AlGaN/GaN heterojunction field effect transistors (HFETs) offers attractive solutions for modern communication and radar systems. The most important MMIC building block is the GaN power transistor. It has to show a high output power level, combined with high power added efficiency (PAE) and high linear gain. Thus, the proper design of this device is a key prerequisite for highly sophisticated GaN HFET X-band power amplifiers. However, it is practically impossible to achieve record values for all key parameters simultaneously. Accordingly, GaN power transistors with optimum combination of output power, PAE, and linear gain are developed.

The development of GaN technology for high frequency applications includes the selection of a proper epitaxial structure, optimization of the fabrication process flow, and modifications of the transistor layout itself. For RF devices, the epitaxial structure has significant impact on output power and PAE. The most critical parameters of the epitaxial structure are Al mole fraction and thickness of the AlGaN barrier. In addition, the epitaxial structure determines the breakdown voltage of transistors, which should exceed the full RF voltage sweep for a particular drain bias (V_{DS}) of operation. On the processing side, the most important feature is the gate module. For X-band MMICs it features a typical gate foot print of 250 nm or even shorter. The modifications of transistors include, but are not limited to, various field plates, design of interconnection periphery, and management of thermal budget through the pitch variation and width of transistor.

FBH's X-band MMIC GaN technology is based on 0.25-µm-length gates defined by electron beam lithography and embedded in SiN_x. The gates are encapsulated by a 2nd SiN_x layer, which also serves as dielectric layer for thin film MIM capacitors. The process flow is optimized in such a way that any leakage current increase usually associated with the encapsulation of the gates is minimized. Furthermore, both device breakdown voltage and MIM capacitor breakdown voltage have to cope with the targeted device operation voltage and should be above 100 V for 30 V operation. Fig. 1 shows a scanning electron microscope image of a typical GaN-based HFET power cell used for the design of X-band MMIC power amplifiers.

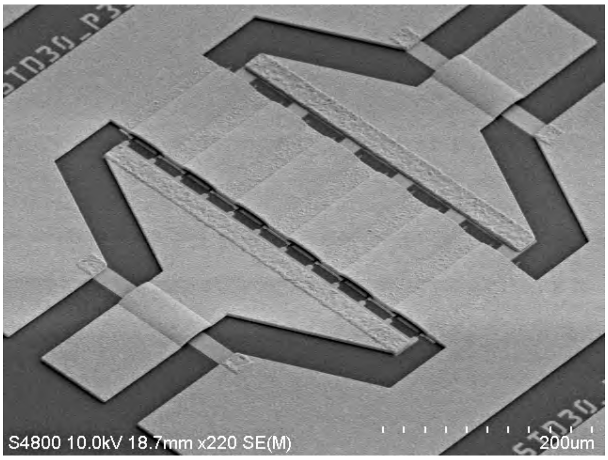


Fig. 1. Detailed view of a GaN-based HEFT used for the design of X-band MMIC power amplifiers.

Large periphery transistors with gate widths of 8 × 125 µm and 12 × 125 µm were fabricated on 4-inch GaN:Si/$Al_{0.25}$GaN/GaN epitaxial structures on semi-insulating SiC substrates using FBH's GaN MMIC process. The devices with various gate- and source-connected field plates as well as without field plates were characterized by load-pull measurements at different X-band frequencies and at different drain bias conditions. Subsequently, the results were compared. The best values of important parameters, i.e. output power, PAE, and linear gain, were obtained from a transistor variation with source-connected field plates. By analyzing the different field plate extensions to the drain side we arrived at a conclusion regarding the optimum design of the field plate. Fig. 2 shows an example of the load-pull measurements on a 12 × 125 µm field plated transistor. The load-pull measurements were conducted at 10 GHz, V_{DS} = 28 V and under optimum match for maximum PAE.

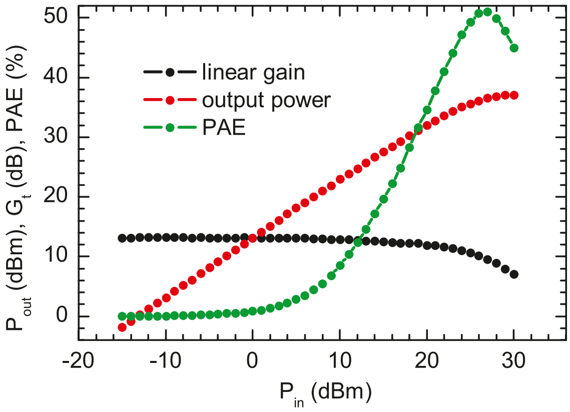


Fig. 2. Example of load-pull measurement for a 12 × 125-μm-wide transistor with maximum values of P_{out} = 5.1 W, PAE = 51 % and G_t = 13.2 dB. The measurements were conducted at f = 10 GHz, V_{DS} = 28 V and under optimum match for PAE_{max}.

For a number of measured 12 × 125 μm field plated transistors the average values of maximum output power of 5.9 W, power added efficiency of 46 %, and maximum linear gain of 13.2 dB were obtained for measurements conducted under optimum match for maximum P_{out}. The values obtained under optimum match for PAE_{max} were 5.0 W, 49 % and 12.8 dB correspondingly. In average, the improvement of efficiency up to 5 % and a linear gain up to 1.4 dB were observed for transistors with source-connected field plates as compared to the variation without field plates. The results of measurements for transistors with source-connected field plates at V_{DS} = 40 V show a maximum output power of about 7.5 W without degradation in efficiency and linear gain. Additional measurements at frequencies of 8 GHz and 9 GHz confirmed the trends observed at 10 GHz.

Effiziente X-Band Leistungsverstärker (8 – 12 GHz) ermöglichen attraktive Lösungen für moderne Kommunikations- und Radarsysteme. Schlüsselkomponenten sind monolithisch integrierte Mikrowellenschaltkreise (MMICs) mit GaN-Leistungstransistoren zur Erzeugung der Mikrowellenleistung. Das FBH führte eine umfassende Optimierung der gesamten Prozessierungskette zur Herstellung von 0,25 μm X-Band-MMICs durch: von der epitaktischen Struktur auf dem SiC-Wafer, dem Chiplayout, der Prozessführung bis hin zu Aufbautechnik und Charakterisierung. In diesem Zusammenhang wurden verschiedene Versionen Leistungstransistorzellen auf 100 mm GaN:Si/$Al_{0,25}Ga_{0,75}N$/GaN epitaktischen Strukturen prozessiert und vermessen. Dabei erreichten Layoutvarianten mit Sourcefeldplatte die besten Werte bezüglich der wichtigsten Parameter wie Ausgangsleistung, Wirkungsgrad und Mikrowellenverstärkung. Nach einer optimalen ausgangsseitigen Anpassung liefern typische Transistorzellen bei 12 GHz eine durchschnittliche maximale Ausgangsleistung von 5,0 W, eine Effizienz von 49 % und eine maximale lineare Verstärkung von 12,8 dB.

PUBLICATION

→ S. A. Chevtchenko, P. Kurpas, N. Chaturvedi, R. Lossy, J. Würfl, **"Investigation and reduction of leakage current associated with gate encapsulation by SiN_x in AlGaN/GaN HFETs"**, Int. Conf. on Compound Semiconductor Manufacturing Technology (CS ManTech 2011), Palm Springs, USA, May 16 – 19, pp. 237–240 (2011).

Lateral high-voltage GaN Schottky diodes

GaN high-voltage switching Schottky diodes are of particular interest for low loss freewheeling diodes in combination with efficient GaN-based high-voltage transistor switches for power conversion. In fact, in terms of switching speed they outperform Si- and SiC-based Schottky diodes at given high voltage capability. They are even suited for large signal microwave switching applications.

In general, ON-state conduction and switching losses as well as reverse bias leakage significantly limit the power switching performance of Schottky barrier diodes (SBD). GaN-based heterostructure SBDs are capable to shift these limitations and thus enable highly performing diodes in terms of low conduction and low switching losses. These properties are due to an efficient exploitation of the two-dimensional electron gas (2DEG) located at the heterojunction between GaN and AlGaN epitaxial layers. This region is characterized by high sheet carrier density and high mobility in the channel in conjunction with high breakdown field strength.

Lateral GaN based heterostructure SBDs grown on n-SiC substrate were manufactured at the FBH. These SBDs own very low onset voltage, $V_F = 0.43$ V, high reverse blocking $V_{BR} > 1000$ V, very low capacitive charge of 0.2 nC/A, and a very fast recovery time of $\tau = 10$ ps. These unique qualities are achieved by combining GaN:C back barrier epitaxial structure, fully recessed Schottky anode and slanted anode field plate in a robust and innovative process (shown in Fig. 1). The forward characteristics of planar diodes and of diodes with a recessed anode are depicted in Fig. 2. Anode recessing results in a strong reduction of the onset voltage from $V_F = 1.7$ to $V_F = 0.5$ V making the devices very efficient for rectifying and freewheeling applications. Naturally, the ON-state resistance is scaling with breakdown strength resulting in a trade-off between breakdown voltage V_{BR} and the ON-state resistance. This dependency is shown in Fig. 3 for lateral GaN SBDs with a scaled anode-cathode distance.

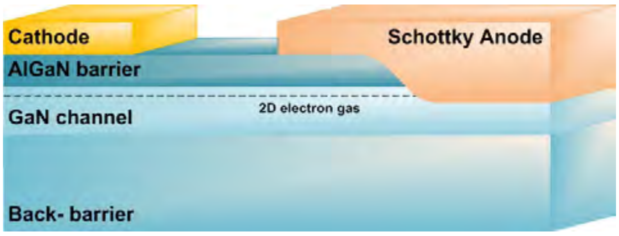


Fig. 1. Schematic sketch of the fully recessed Schottky barrier diode with slanted field plate lateral geometry.

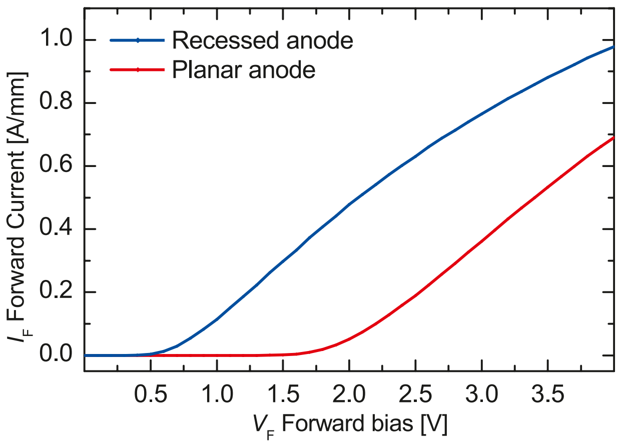


Fig. 2. Comparison of Schottky diode turn-on properties in dependence on different processing technologies (recessed and planar anode) applied.

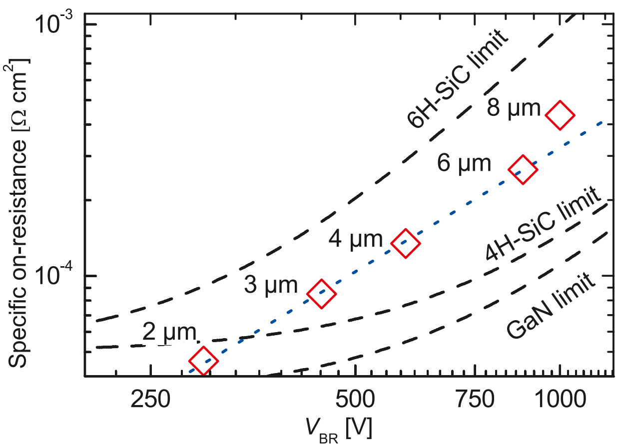


Fig. 3. Trade-off between breakdown voltage and specific ON-state resistance for diodes with different anode-cathode spacings.

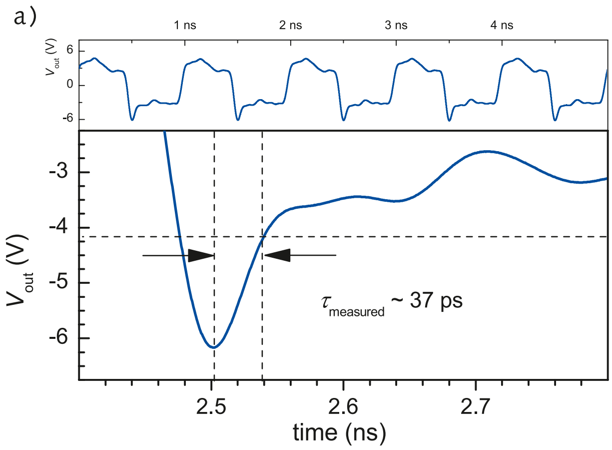
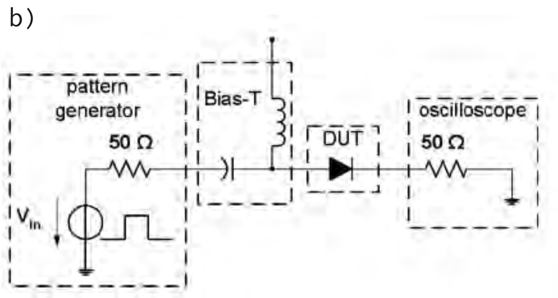


Fig. 4. a) Large signal switching measurement result for Schottky barrier diodes.



b) Measurement set-up.

Due to their lateral design principle, these SBDs feature low parasitic capacitances and therefore enable fast switching times. The typical small signal capacitance of a comparably large device designed for 2 A maximal saturation current is as low as ~1 pF at a reverse bias of 35 V. These diodes show a very low capacitive charge of 0.2 Nanocoulomb per Ampere current rating. They are therefore very competitive to even the best SiC Schottky diodes for the same current rating.

In order to investigate microwave switching properties under large signal operating conditions, a high frequency signal is applied at the input terminal. Its amplitude is set such that it completely switches ON and OFF the device. The large signal time constant of the SBD is measured in a 50 Ω environment according to the measurement system described in Fig. 4. Extracted from measurements, a de-embedded recovery time constant and capacitance of the diode, $\tau_{diode} \approx 10$ ps and $C_{diode} \approx 0.3$ pF has been found for a SBD with 250 µm width and 15 µm anode cathode separation respectively. This demonstrates the superior properties of these kinds of Schottky diodes for very fast switching applications.

Als Freilaufdioden für hocheffiziente Leistungsinverter in GaN-Technologie sind Schottkydioden mit extrem geringen Schaltverlusten unverzichtbar. Lateral aufgebaute GaN-Dioden nutzen die hohe Leitfähigkeit des zweidimensionalen Elektronengases (2DEG) an der GaN/AlGaN-Heterogrenzfläche und ermöglichen darüber hinaus extrem kapazitätsarme Schottkydioden. Durch speziell optimierte Prozessschritte sowie ein darauf abgestimmtes Design wurden GaN-Schottkydioden mit einer Einschaltspannung von etwa 0,5 V und einer Durchbruchspannung bis zu 1000 V realisiert. Die niedrige Einsatzspannung wird durch eine direkte Kontaktierung des 2DEG mit dem Anodenmetall erreicht. Hohe Durchbruchspannungen sind möglich, indem der Anoden-Kathodenabstand skaliert wird in Verbindung mit Anodenfeldplatten. Die so aufgebauten lateralen Schottkydioden zeichnen sich durch extrem geringe Speicherkapazitäten und damit durch ein exzellentes Schaltverhalten aus. Dadurch sind auch Anwendungen im Mikrowellenbereich möglich.

PUBLICATION

→ E. Bahat-Treidel, O. Hilt, R. Zhytnytska, A. Wentzel, C. Meliani, J. Würfl, G. Tränkle, **"Fast switching GaN based lateral power Schottky barrier diodes with low onset voltage and strong reverse blocking"**, IEEE Electron Devices Letters, vol. 33, no. 3, pp. 357–359 (2012).

GaN high-voltage power transistors with low on-state resistance

GaN-based high-voltage switching transistors enable particularly efficient power converters as a result of their low area-specific ON-state resistance and low gate capacitance. Due to lower losses per switching cycle, GaN-based converters can operate at higher frequencies than converters with Si-based switches, enabling more compact and light-weighted converters. Several 100 V blocking voltage and ON-state resistances of a few 100 mΩ or even less are needed for kW-range power converters. The required large device structures consume several mm^2 chip area and are thus challenging the quality of the epitaxial semiconductor layers grown on SiC- or Si-substrates as well as the device processing robustness.

Based on the FBH p-GaN-gate technology for normally-off GaN-HFETs, devices with +1.2 V threshold voltage have been realized with different buffer concepts using either AlGaN or carbon-doped GaN (GaN:C) as buffer material. The 200 V normally-off GaN-transistors with 113 mm gate width and solder bumps for flip-chip mounting are based on an $Al_{0.05}Ga_{0.95}N$ buffer grown on 3″ n-type SiC wafers. The devices control up to 50 A pulse current and feature 85 mΩ ON-state resistance as depicted in the output characteristics in Fig. 1.

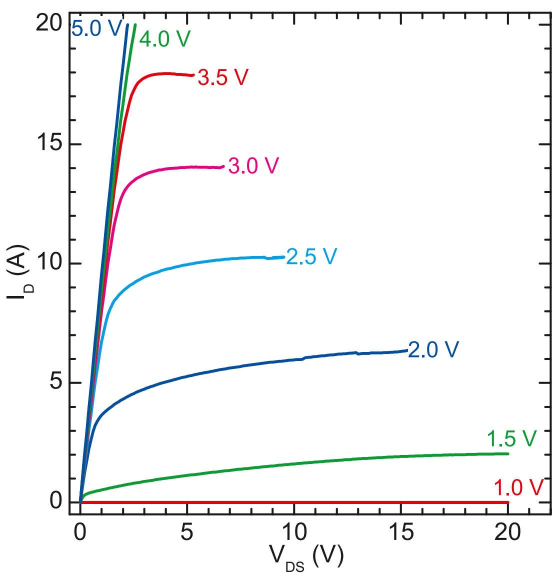


Fig. 1. Output characteristic measured up to 20 A of the 85 mΩ/ 200 V GaN switching transistors with AlGaN buffer. The gate bias is indicated.

With a chip size of 4.5 mm × 2.4 mm, a compact 156 mm wide normally-off transistor was realized using a GaN:C buffer with 2×10^{19} cm^{-3} carbon doping. The blocking strength is 600 V on insulating SiC as substrate and 300 V on conductive n-type SiC substrate. With 0 V gate bias the OFF-state leakage current is less than 50 µA. In ON-state condition at +5 V gate bias the device offers 80 mΩ ON-state resistance and > 40 A pulse current. Fig. 2 shows this wire-bonded transistor in an A0191 package.

Fig. 2. 80 mΩ/300 V GaN switching transistor with 4.5 mm × 2.4 mm chip size in an A0191-package.

The high blocking strength of the carbon-doped GaN buffer was used to develop a 1000 V normally-off GaN-transistor on SiC substrate for high-voltage applications. 800 mΩ ON-state resistance and 5 A maximum pulse current have been obtained with a device using 22 mm wide gates. The output characteristic is shown in Fig. 3. The OFF-state drain leakage at 0 V gate bias is less than 25 µA up to 1000 V, see Fig 4. Due to the good blocking properties of the p-GaN gate module, the gate leakage is less than half of the drain leakage.

When switching the transistor from high-bias OFF-state to ON-state, the dynamic ON-state resistance R_{ON} of GaN-HFETs often increases. To probe the dynamic R_{ON}, 0.2 µs pulsed ON-state IV curves were taken with different OFF-state drain voltages in-between the pulses. The R_{ON} ratio between 65 V and 0 V OFF-state drain voltage is then considered as increase in dynamic R_{ON} as shown in Fig. 5.

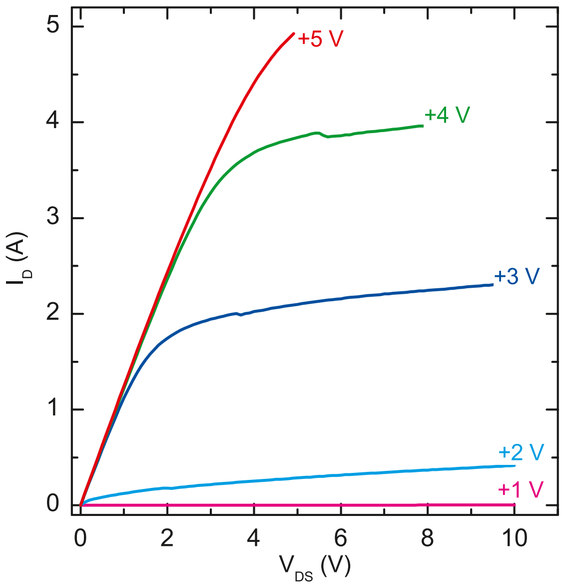


Fig. 3. Output characteristic of the normally-off 1000 V/5 A high-voltage GaN transistor with GaN:C buffer. The ON-state resistance can be read as 800 mΩ. The gate bias is indicated.

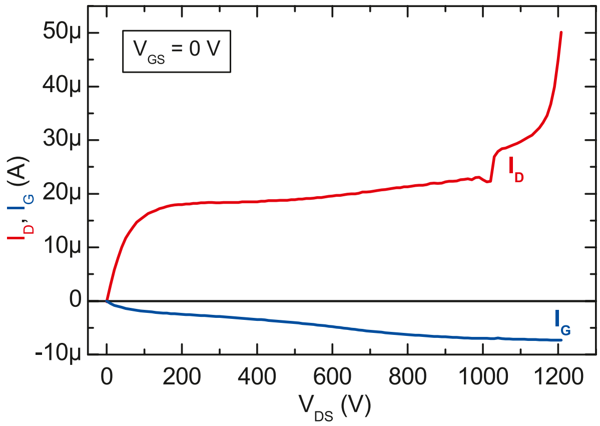


Fig. 4. OFF-state drain (red) and gate (blue) leakage-current at 0 V gate bias of the normally-off 1000 V/5 A high-voltage GaN transistor from Fig. 3.

This dispersion strongly depends on the buffer composition and a trade-off between voltage blocking strength and increase in dynamics R_{ON} is observed, see Fig. 5. For carbon-doped buffer, both dispersion and voltage blocking strength increases with doping concentration. A similar relation holds when comparing AlGaN-buffer-based devices grown on Si substrates or on SiC substrates, with the latter featuring reduced dispersion but also less voltage-blocking strength.

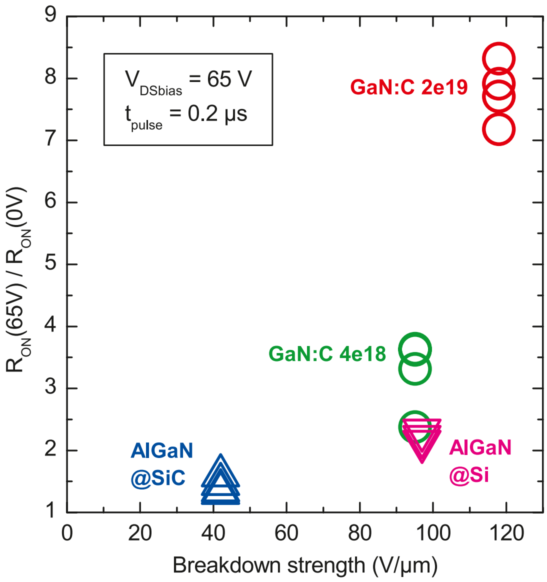


Fig. 5. Increase in dynamic ON-state resistance versus device breakdown strength for buffer compositions. Increase in dynamic R_{ON} is given as $R_{ON}(V_{DSbias} = 65\ V)/R_{ON}(V_{DSbias} = 65\ V)$ at 0.2 µs after OFF-state. Breakdown strength is per µm gate-drain distance.

Schalttransistoren mit mehreren 100 V Spannungsfestigkeit und nur wenigen 100 mΩ Einschaltwiderstand werden für den Einsatz in Leistungskonvertern im kW-Bereich benötigt. Solche Bauelemente belegen mehrere Quadratmillimeter Chipfläche. Daher stellen sie hohe Ansprüche an die Qualität der epitaktisch auf einem SiC- oder Si-Substrat gewachsenen GaN-basierten Halbleiterschichten. Selbstsperrende GaN-HFETs mit +1,2 V Einsatzspannung wurden mit einem AlGaN-Puffer und einem Kohlenstoff-dotierten Puffer realisiert. Die Spannungsfestigkeit lag dabei für unterschiedlich entworfene Transistoren zwischen 200 V und 1000 V und die Einschaltwiderstände zwischen 80 mΩ und 800 mΩ. GaN-HFETs leiden generell unter einer Erhöhung des dynamischen Einschaltwiderstands. Ausgangslinien, die in Tests mit 0,2 µs schnellen Pulsen erzeugt wurden, zeigten, dass je nach Zusammensetzung des Halbleiterpuffers eine hohe Sperrspannungsfähigkeit auch mit einer hohen Dispersion korreliert. Dabei weisen die AlGaN-Puffer-basierten Bauelemente generell eine geringere Erhöhung des dynamischen Einschaltwiderstands auf.

PUBLICATION

→ O. Hilt, F. Brunner, E. Cho, A. Knauer, E. Bahat-Treidel, J. Würfl, **"Normally-off High-Voltage p-GaN Gate GaN HFET with Carbon-Doped Buffer"**, Proc. Int. Symp. on Power Semiconductor Devices & IC's (ISPSD), San Diego, CA, May 23–26, pp. 239–242 (2011).

DIODE LASERS

DIODENLASER

Diodenlaser

Das Ferdinand-Braun-Institut ist eine der weltweit führenden Einrichtungen bei der Erforschung und Realisierung von hochbrillanten Diodenlasern auf der Basis von Galliumarsenid. Der Wellenlängenbereich reicht vom roten bis zum nahen infraroten Spektralbereich (630 nm...1150 nm). Die Einsatzgebiete umfassen Lasersysteme für die Materialbearbeitung, Laser für die Medizintechnik (Diagnostik, photodynamische Krebstherapie) und für die Displaytechnologie ebenso wie Hochleistungslasersysteme für die Grundlagenforschung (Röntgenlasersysteme, Teilchenbeschleuniger und laserinduzierte Kernfusion). Zudem entstehen neuartige, benutzerfreundliche und besonders kompakte Lasermodule durch die hybride Integration von maßgeschneiderten Diodenlaserchips mit aktiven und passiven Bauelementen auf einer mikrooptischen Bank. Mit seinen Kompetenzen deckt das FBH den gesamten Teil der Wertschöpfungskette ab: von Simulation und Entwurf über die technologische Realisierung der Halbleiterchips bis zum Aufbau einsatzfähiger Diodenlasermodule.

Die Schwerpunkte der Arbeiten im Jahr 2011 lagen bei Hochleistungs-Diodenlasern mit monolithisch integrierten Gittern sowie kompakten Lasermodulen mit schmalbandiger Laserstrahlung für Spektroskopie und Messtechnik. Auch verschiedene gepulste Lasersysteme für die Materialbearbeitung wurden entwickelt. Darüber hinaus konnte die technologische Basis im Forschungsbereich Diodenlaser durch die Qualifizierung und Verfahrensentwicklung einer neuen MBE-Anlage für die Facettentechnologie weiter verbessert werden.

Herausragende Ergebnisse des Jahres 2011 waren:

- ➜ Die Demonstration von Rekordwerten für 10 W Diodenlaser mit integriertem Gitter bezüglich Konversionswirkungsgrad und Zuverlässigkeit.
- ➜ Der Nachweis von Linienbreiten im Bereich um 1 kHz, die mit 780 nm Lasermodulen für die Spektroskopie von Rubidium erreicht wurden. Diese sind zentrale Bausteine für die Entwicklung extrem genauer Atomuhren.
- ➜ Die Entwicklung eines 633 nm Lasermoduls mit 1 MHz Linienbreite für die Längenmesstechnik.

In den Forschungsarbeiten, die in enger Kooperation mit Industriepartnern erfolgten, wurden Ausgangsleistungen von mehr als 100 W aus so genannten „low fill factor"-Barren erreicht. Das sind Laserbarren mit < 10 % Belegungsdichte. Darüber hinaus konnte die Zuverlässigkeit von 100 µm Standardlasern bei 15 W demonstriert werden. Mit diesen beiden Resultaten konnte das FBH die Leistungen um jeweils 50 % gegenüber dem gegenwärtigen industriellen Standard steigern.

Diode Lasers

The Ferdinand-Braun-Institut is one of the world leading institutions for the development and realization of high-brilliance diode lasers based on gallium arsenide, with programs spanning the wavelength range from 630 nm to 1150 nm. Applications of this technology include laser systems for material processing, lasers for medical (diagnostic, photodynamic cancer therapy) and entertainment (displays) applications as well as high-energy laser systems for basic research (x-ray laser systems, particle acceleration, laser-induced fusion). Hybrid integration of customized diode laser chips together with active and passive devices on a micro-optical bench leads to novel, user-friendly, and especially compact laser modules. The capabilities of the FBH cover the full value chain, from simulation and design to the technological realization of semiconductor chips through to the assembly of ready-to-use diode laser modules.

The focus of developments in 2011 has been on high-power diode lasers with monolithically-integrated gratings as well as on compact laser modules with small emission linewidth for spectroscopy and measurement applications. Additionally, various pulsed laser systems for materials processing have been developed. In further work, a newly purchased MBE system was qualified for use in facet passivation, enhancing the technological basis of FBH's diode laser research.

Outstanding results in 2011:

- ➜ Demonstration of record values for 10 W diode lasers with integrated gratings regarding conversion efficiency and reliability.
- ➜ Linewidths around 1 kHz achieved from 780 nm laser modules, as required for spectroscopy of rubidium. These laser modules are core components for the development of extremely accurate atomic clocks.
- ➜ Development of a 633 nm laser module with 1 MHz linewidth for highly accurate length measurements.

In further research conducted in close cooperation with our industrial partners, output powers of more than 100 W have been achieved from so called "low fill factor" bars. Such bars are manufactured with < 10 % fill factor. In addition, the FBH demonstrated that standard single emitters with 100 µm stripes operate reliably at a power level of 15 W. Both results represent a 50 percent improvement compared to current industrial standard values.

Compact customized ns light pulse sources with butterfly housing and integrated electronics

High-power diode lasers capable of generating spectrally stable nearly diffraction-limited optical pulses in the nanosecond range can be used in a variety of applications: analytics of materials and biological systems, free-space communication, metrology, and as seed sources for fiber lasers required for materials processing. Gain switching, in other words, modulating the laser gain by turning on and off the current injected into the cavity, offers a simple, cost-effective, and power-efficient possibility to generate optical pulses. Diffraction-limited emission is achieved by a proper design of the laser waveguide, so that only the fundamental transverse mode lases. Spectral stabilization can be realized with Bragg gratings integrated into the semiconductor chip.

Within the framework of the BMBF-funded project "FaZiT", the FBH developed distributed feedback (DFB) lasers specially optimized for emitting short pulses at the wavelength around 1064 nm. The epitaxial layer structure of the DFB lasers bases on an asymmetric super-large cavity, where the active region consisting of a double quantum well is placed asymmetrically in a 4.8 µm broad $Al_{0.35}Ga_{0.65}As$ waveguide core. Lateral optical confinement and p-contacting is provided by a ridge waveguide (RW) with a ridge width of 5 µm. The cavity has a length of 1 mm and anti- and high-reflection coated facets with reflection coefficients of 10^{4} and 0.95, respectively.

In order to evaluate the capabilities, the laser was soldered p-side up on a C-mount and attached to a test equipment suitable to transmit high-frequency electric fields. For amplification and control of the nanosecond current pulses, an electronic circuit was utilized comprising a high-frequency GaN transistor developed at the FBH. Fig. 1 shows the dependence of the maximum power of the optical pulses on the amplitude of the injected current pulses with a length of 4 ns and a repetition frequency of 250 kHz (4 µs period). A pulse power of 3.8 W was reached at the maximal injected current of 6 A. Fig. 2 shows the temporal behavior of an optical pulse measured using a 70 GHz sampling scope NRO 9000 (LeCroy) and a fast 25 GHz photo diode 1434 (New Focus) for a current of 6 A. The small peak appearing in the turn-on slope of the pulse is the first relaxation oscillation, which is typical

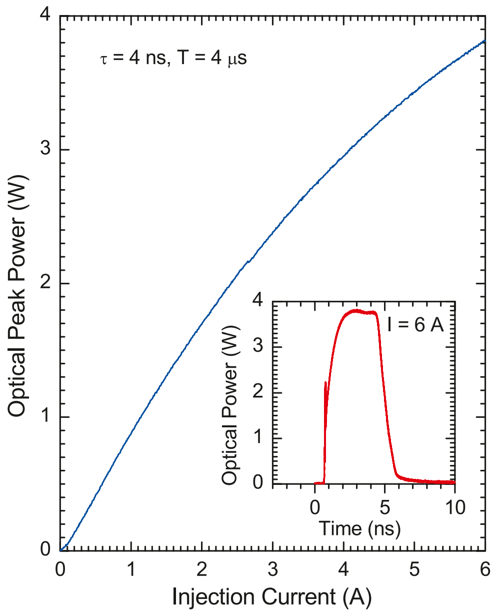


Fig. 1. Maximum power of the optical pulses emitted by a gain-switched DFB laser versus amplitude of the injected current pulses (blue curve). Inset: Temporal shape of the optical pulse for a current of 6 A (red curve).

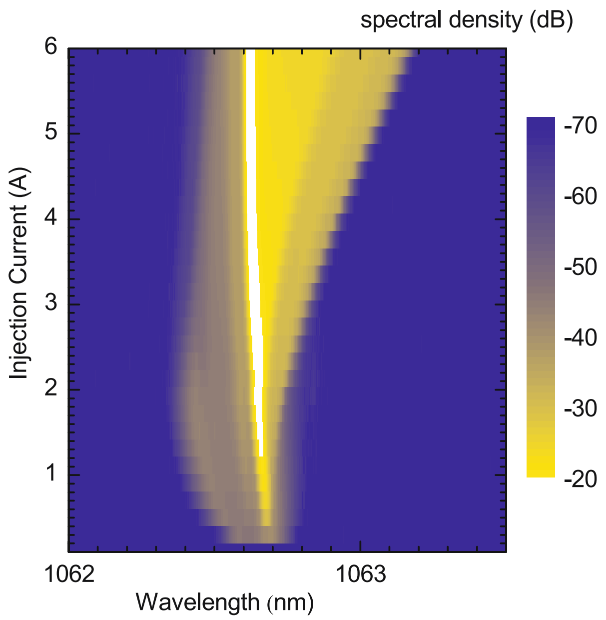


Fig. 2. Color-scale mapping of the optical spectrum as a function of the amplitude of the current pulse (vertical axis). White denotes highest, yellow medium, and blue lowest intensity.

for the turn-on behavior of the laser diode. The rise and fall times of 1.2 ns (excluding the first relaxation oscillation) correspond to those of the current pulses. Hence it can be ascertained that the optical pulse follows the electrical pulse.

Time-averaged optical spectra were measured using an optical spectrum analyzer Q8384 (Advantest) with a resolution of 10 pm. Fig. 2 shows a color-scale mapping of the optical spectrum of the pulses in dependence on the amplitude of the injected current pulses (and hence on the optical peak power). The spectra reveal that the gain-switched DFB laser operates in a single mode over the whole current range. The peak wavelength decreases slightly, an effect that might be caused by an increase of the carrier density in the active quantum wells. This behavior is also accompanied by a broadening of the spectrum at the longer wavelength side which indicates a thermal chirp occurring during the pulse.

Commercially available high-power DFB lasers operating in continuous-wave (CW) mode are typically provided in a Butterfly housing. However, due to the fact that this housing is not optimized for transmitting high-frequency electric fields, gain-switched operation is commonly reduced to longer pulses and small current amplitudes. In order to overcome these limitations, for the first time world-wide, a DFB laser was integrated together with control electronics into a Butterfly housing as can be seen in Fig. 3. Thus, by mounting ultrafast GaN high-power transistors developed at the FBH with corresponding drivers adjacent to the laser chip, it is possible to generate laser pulses with durations from 1 to 10 ns with a peak power in the Watt range. The beam emitted by the laser is collimated by a micro lens in order to facilitate the coupling into a single mode fiber as requested by most applications. A Peltier element and a thermistor regulate the temperature within the housing. An additional server board provides the necessary electrical voltages and forms the electrical pulses. Due to the specific mounting and the comprehensive circuit know-how, a very compact light source has been developed generating nanosecond pulses with repetition rates ranging from 10 MHz down to single pulses.

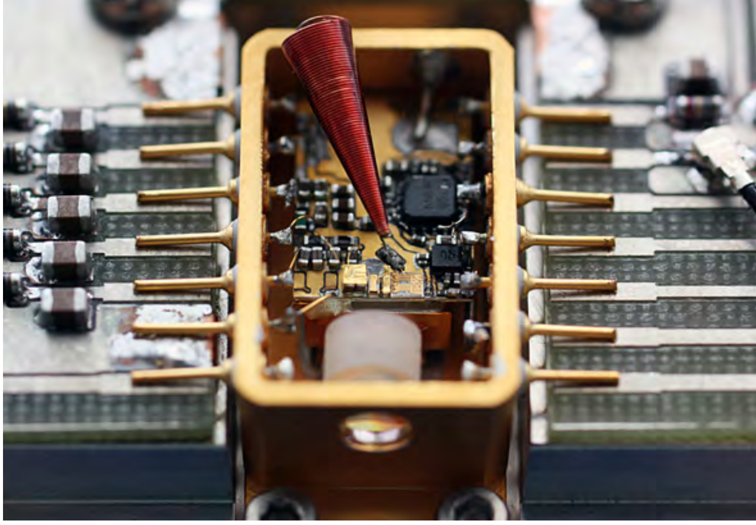


Fig. 3. Opened Butterfly housing comprising DFB laser, control electronics, as well as a micro lens for beam shaping.

Für Anwendungen, etwa in der Material- und Bioanalytik, der Freiraumkommunikation, der Metrologie und als Anregungslaser für Faserlasersysteme werden leistungsfähige Lichtquellen benötigt. Diese müssen spektral stabilisierte und beugungsbegrenzte Laserimpulse mit einer Zeitdauer im Nanosekundenbereich aussenden. Dazu werden am FBH entwickelte, gewinngeschaltete DFB-RW-Laserdioden und Verstärkerschaltungen, die auf ultraschnellen GaN-Transistoren basieren, eingesetzt. Bei einer Wellenlänge um 1062 nm konnten damit 4 ns lange Lichtimpulse mit einer Spitzenleistung von 3,8 W erzeugt werden. Um die Anwendbarkeit der Lichtquellen zu erleichtern, wurde weltweit erstmalig solch eine gewinngeschaltete Laserdiode mit Ansteuerelektronik in ein Butterfly-Gehäuse integriert. Die Strahlung wird mit einer Mikrolinse kollimiert – dies erleichtert die Einkopplung in eine Monomode-Glasfaser. Durch den speziellen Aufbau und das umfassende Schaltungs-Know-how am FBH ist eine kompakte Quelle entstanden, mit der maßgeschneiderte ns-Impulsfolgen im Bereich von 10 MHz bis hin zu Einzelimpulsen erzeugt werden können.

PUBLICATIONS

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→ H. Wenzel, A. Klehr, S. Schwertfeger, A. Liero, T. Hoffmann, O. Brox, M. Thomas, G. Erbert, G. Tränkle, **"Compact sources for the generation of high-peak power wavelength-stabilized laser pulses in the picoseconds and nanoseconds ranges"**, Proceedings SPIE, vol. 8241, p. 30 (2012).

New equipment for diode laser facet passivation successfully qualified

Proper facet passivation prior to optical coating of high-power diode lasers turns out to be mandatory to achieve minimum degradation during device operation and for maximum resistance of the facets to catastrophic optical mirror damage (COMD). In recent years, FBH developed a patented process for this purpose based on atomic hydrogen cleaning of the facets and their subsequent sealing with zinc selenide (ZnSe). The process is carried out on an experimental UHV setup delivering the desired process quality and device performance. However, due to low throughput and the absence of an automatic operation mode, the equipment provides only insufficient capacity to meet the growing quality and quantity demands.

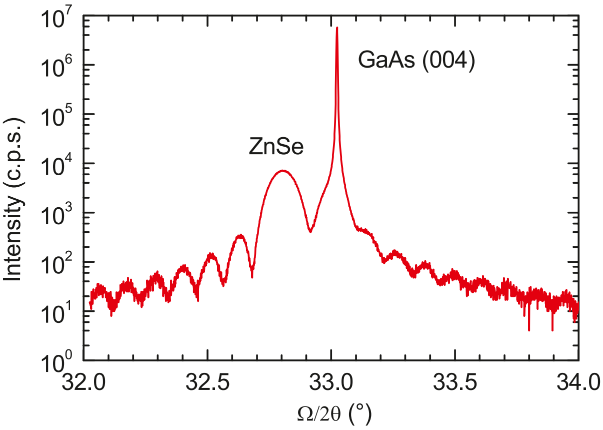
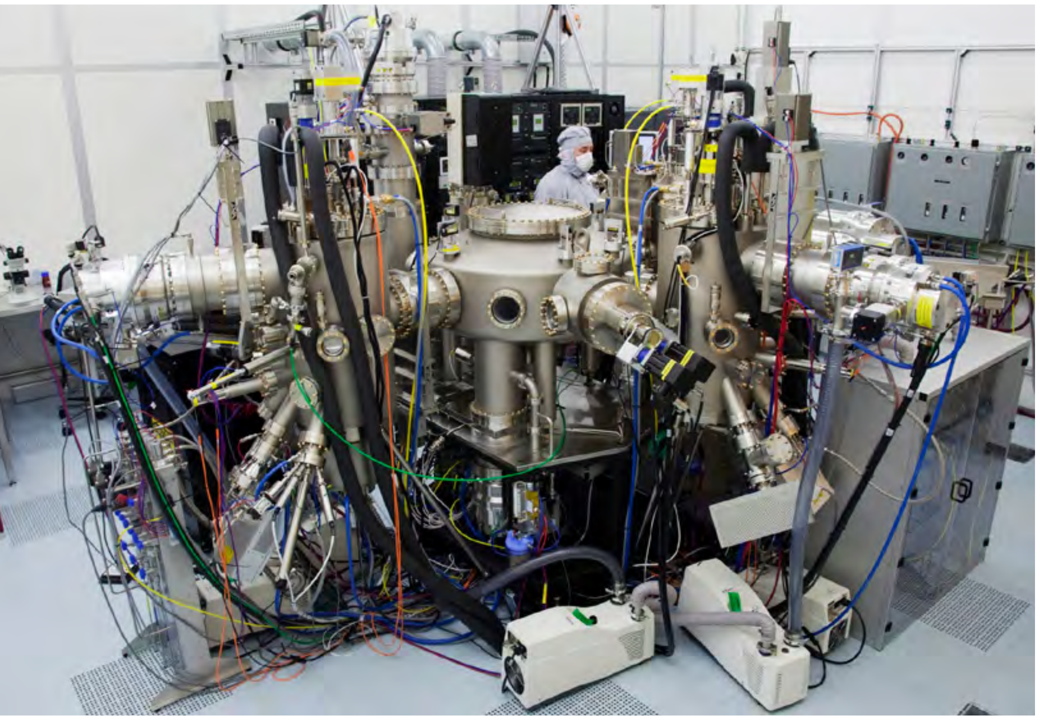


Fig. 2. High-resolution X-ray rocking curve of a GaAs (001) wafer piece cleaned with atomic hydrogen and coated with a 50 nm thick ZnSe layer.

As a consequence, FBH has recently installed a multi-chamber UHV system with automatic process control that is capable of doubling the throughput per run from 50 to 100 laser bars. In addition, its automatic control allows the system to be run in shift-mode, which further increases the daily throughput of processed devices. Fig. 1 shows the system after installation in the cleanroom. Grouped around a central handler are the process chambers as growth module, the preparation chamber, storage chamber, and load lock.

Atomic hydrogen cleaning of the facets is carried out in the preparation chamber, while the cleaned facets are sealed with ZnSe in the growth module. In contrast to the existing passivation tool, the new system is not equipped with only a single source for ZnSe growth from the compound, but has additional sources for elemental zinc and selenium. This allows us processing with a higher degree of control and should yield further improvement of the epitaxial quality of the ZnSe sealing layers.



After commissioning, the passivation process has been transferred from the existing passivation tool to the new system. For this purpose, process conditions have been established for ZnSe deposition from the compound source on atomic-hydrogen-cleaned GaAs wafers. Fig. 2 displays the high-resolution X-ray rocking curve of a respective GaAs (001) sample. Thickness fringes adjacent to the main GaAs and the ZnSe peak indicate good epitaxial growth of the ZnSe layer, which, in turn, confirms the successful process transfer.

Fig. 1. New multi-chamber UHV system for diode laser facet passivation.

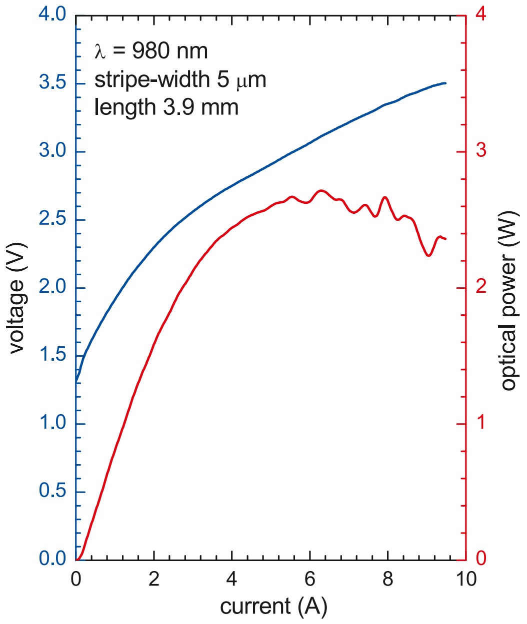


Fig. 3. P-U-I-characteristics of a ridge-waveguide diode laser processed with the new passivation tool.

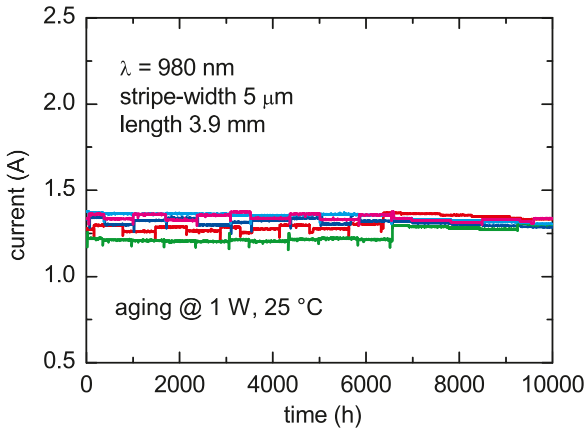


Fig. 4. Aging of ridge-waveguide diode lasers from the same charge (Fig. 3). All five diodes successfully passed the test scheduled for 10,000 h at 1 W, 25 °C.

Next, diode lasers have been passivated using this process. They have subsequently been optically coated with our standard ion-beam sputtering tool. Ridge-waveguide lasers (5 µm stripe width) with 980 nm wavelength exhibit a maximum optical output power of more than 2.6 W, being limited only by thermal roll-over (Fig. 3). Thus, the facet resistance to COMD achieved with the new system is at least comparable to that obtained with the existing passivation tool.

For final qualification of the new process tool, we have assessed the lifetime of further ridge-waveguide diode lasers identical to those used above for the COMD experiments. Fig. 4 displays the current dependence on time for five lasers aged at 1 W (25 °C), which is equivalent to a mean power density of 25 MWcm^{-2}. All diodes operated failure-free for a test duration of over 12,000 h. The life test is continuing. Degradation rates are all below 1E-5 h^{-1} with some diodes exhibiting negative values (i.e., their performance is gradually improving).

These results confirm the successful transfer of the FBH facet passivation technology to the new process tool. Due to its high throughput and automatic process control, FBH facet passivation technology now has a reliable technical foundation to serve the growing needs of in-house projects as well as from external partners. Further improvement of process quality and versatility will be demonstrated in the future based on the additional technical features of the new passivation tool.

Passivierung und optische Beschichtung der Facetten sind zentrale Prozessschritte bei der Herstellung von Hochleistungs-Diodenlasern. Sie sind entscheidend für eine minimale Degradation der Bauelemente und eine hohe Beständigkeit der Facetten gegen laserinduzierte Zerstörung (COMD). Das FBH verfügt über eine patentierte Technologie zur Facettenpassivierung, die auf einer Passivierungsanlage qualitativ hochwertig umgesetzt wird. Um die ständig steigenden Qualitäts- und Kapazitätsforderungen bewältigen zu können, wurde nun ein neues System für diesen Prozessschritt beschafft. Es ermöglicht einen doppelt so hohen Durchsatz, auch eine Weiterentwicklung des Verfahrens ist damit möglich. 2011 wurde zunächst die Technologie von der alten auf die neue Anlage transferiert und qualifiziert. Die Ergebnisse sind qualitativ mindestens gleichwertig, was nunmehr den uneingeschränkten Einsatz der neuen Anlage für die Facettenpassivierung des FBH erlaubt. Dank der ausgezeichneten technischen Leistungsmerkmale der Anlage sind künftig weitere Verbesserungen hinsichtlich der Prozessqualität und Flexibilität zu erwarten.

Stabilized diode lasers at 633 nm for precision distance measurements

The measurement of distances with a relative uncertainty of at least 10^{-6} is important for a variety of industrial processes. For instance, to determine distances of tens of meters with micrometer precision is needed in the aircraft industry, and the fabrication of optical components requires thicknesses of some millimeters to be measured with nanometer precision. Absolute distance interferometry (ADI) is particularly suitable for these applications thanks to the low measurement uncertainty and quick measurement times it yields. This method requires a single-mode, tunable laser as light source with a narrow linewidth, depending on the measurement range and/or the frequency stability. Visible wavelengths in the vicinity of 635 nm are particularly interesting for distance measurements due to eye safety regulations. Lasers with the above-named properties also fulfill the requirements for atomic spectroscopy ($^{127}I_2$ spectroscopy for instance).

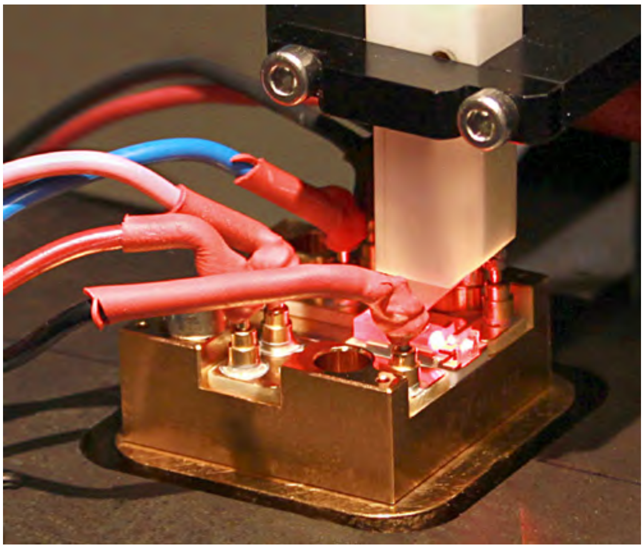


Fig. 1. Red-emitting diode laser module under test conditions.

Within the framework of the BMBF-funded project DuMiDiL, the FBH has developed a micro-integrated external cavity diode laser (ECDL) emitting at 633 nm (see Fig. 1) that meets the requirements for implementation in an industrial ADI setup. The targeted specifications for the laser beam are as follows: 5 mW output power in a single, longitudinal mode with a linear tunability of 25 GHz and a linewidth smaller than 10 MHz. Moreover, the laser should contain no moving parts to avoid misalignments during operation in harsh industrial environments.

The gain medium of the device is a laser diode emitting in the vicinity of 633 nm. The optical resonator is formed between the front facet of the laser diode and the surface of a reflection Bragg grating (RBG) acting as external resonator mirror. Two gradient-index lenses, GRIN 1 and 2, collimate the beam inside the resonator and at the output of the device, respectively. The whole device is mounted on an AlN base plate featuring a footprint of 10 mm × 5 mm. Thermal management is carried out on-board with a micro-Peltier element. A scheme of the micro bench is shown in Fig. 2. The device is mounted partly by passive alignment and bonding using a flip-chip bonder (rails, Peltier element, sub-mounts, laser, thermistor, and glass blocks) and partly by active alignment and gluing with UV-cured adhesive (lenses, RBG). The active alignment of the optical elements was made by applying the independent positioning of all 6 degrees of freedom, with a resolution of 100 nm for translation and 2 µrad for rotation.

The optical characterization of the ECDL is depicted in Fig. 3. As shown in Fig. 3a), the ECDL has a threshold current of 43 mA and a slope efficiency of 0.30 W/A averaged over the whole current range above threshold. A maximum output power of 10 mW was demonstrated at an injection current of 80 mA. From Fig. 3b) it can be

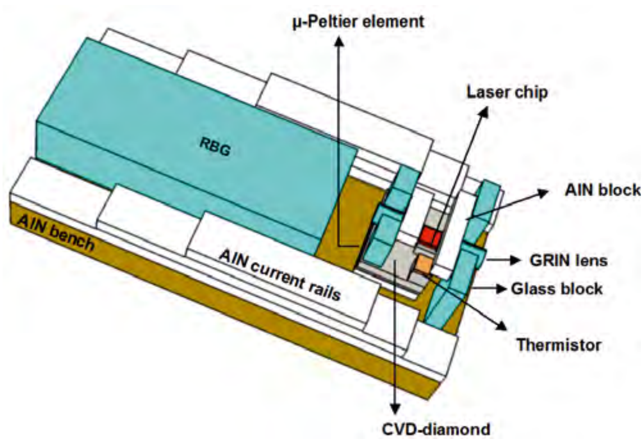


Fig. 2. Model of the micro bench.

seen that the wavelength is centered around 633 nm and tunable without mode hops over a span of approximately 34 pm, corresponding to a frequency scanning range of 25 GHz. The laser linewidth of the ECDL is measured using a self-delayed heterodyne technique. As shown in Fig. 3c), the laser linewidth at an output power ≤ 8 mW in the regions where no mode hops occur is smaller than 10 MHz. The experimental results confirm that the requirements for ADI are fulfilled by this laser.

The ECDL concept can be extended to other wavelengths, and the tuning range can be adapted simply by using shorter laser chips and lenses. Moreover, the whole optical setup can be embedded in a silicone gel in order to improve robustness and shield against humidity. However, preliminary experiments with a protective silicone gel have shown that the tuning range is reduced to 20 GHz and the linewidth broadens to > 15 MHz for a maximum output power of 6.8 mW. An alternative could be to integrate the micro-optical bench into a butterfly package.

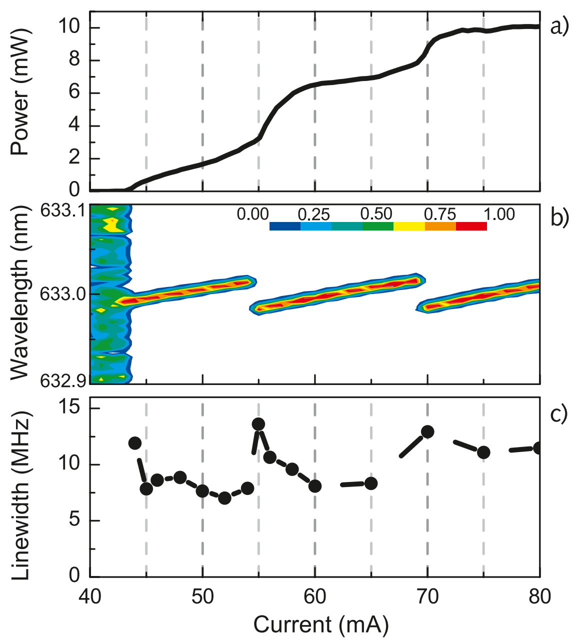


Fig. 3. a) Power-current characteristics,
b) optical spectrum and
c) linewidth of the ECDL at injection currents up to 80 mA.

Im BMBF-Projekt „Durchstimmbarer-Mikrosystem-Diodenlaser“ wurden Wellenlängen-stabilisierte hybrid-realisierte Lichtquellen entwickelt, die für die absolute optische Distanzmessung im Nanometerbereich nutzbar sind. Sie wurden auf diese Anwendung hin optimiert und erreichen Ausgangsleistungen von ca. 5 mW. Die Lichtquellen basieren auf einem Laser im externen Resonator, sind ohne bewegliche Teile über einen Spektralbereich von 25 GHz durchstimmbar und zeigen eine Linienbreite kleiner als 10 MHz. Das gesamte System ist auf einer nur 10 mm × 5 mm großen AlN-Platte aufbaut; Kernstück ist eine Halbleiterlaserdiode für den Spektralbereich um 633 nm. Der Resonator wird von der Frontfacette des Diodenlasers und einem hochreflektiven, spektral schmalbandigen Bragg-Gitter gebildet. Alle Komponenten werden mit einer Präzision im Bereich unterhalb 100 nm bzw. 2 µrad auf der AlN-Platte justiert und fixiert. Erprobt wurde dabei auch die hermetische Verkapselung der Bauelemente in einem Silikon-Gel zum Schutz vor Umwelteinflüssen.

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→ B. Sumpf, A. Bawamia, G. Blume, B. Eppich, A. Ginolas, S. Spießberger, M. Thomas, G. Erbert, **“Continuously current-tunable, narrow line-width miniaturized external cavity diode laser at 633 nm”**, SPIE Photonics West Conference, lecture 8277–40, San Francisco, California, USA (2012).

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Beam characterization for single-mode fiber coupling of tapered lasers

Tapered lasers deliver a much higher output power than ridge-waveguide (RW) lasers and a significantly better beam quality than broad area lasers at the same power level. Incorporation of spectral selective components, such as DBR sections, may even produce very small bandwidths. Hence, as efficient and high-brilliance beam sources they show a high market potential for many applications. One important precondition for broad industrial application is the possibility for efficient coupling of the lasers into fibers with as few as possible guided modes. The lower the number of guided modes, the better is the beam quality at fiber output. Hence, coupling into single-mode fibers is targeted, since the beam at the fiber exit then is nearest to the best physically possible beam quality.

In comparison to other lasers, tapered lasers have a more complex beam structure. The capability of simpler lasers to be coupled into fibers can easily be estimated by the beam propagation ratio M^2, whose definition and measurement procedure are both defined in the international standard ISO 11146. But for tapered lasers this is not sufficient. A more comprehensive beam characterization is necessary, which can be accomplished by measurements of the Wigner distribution function (WDF). In a simplified picture, the WDF can be considered as giving the fraction of beam power emitted, for example, from the laser facet, as a function of the transverse source point position and the direction angle of radiation. The WDF is a general and complete description of partially coherent beams, such as the fields of tapered lasers. Knowledge of the WDF is the basis for calculating the beam propagation through complicated systems in general. In particular, it allows for calculating coupling efficiencies into fibers, regardless if they are single-mode, few-mode, or multi-mode fibers. It is thus possible to calculate the upper limit of the power that can be coupled into a given fiber as well as the coupling efficiency that will be obtained with a predefined optical system.

Hence, the experimental determination of the WDF allows for

- ➜ reliable qualifying of lasers with respect to fiber coupling,
- ➜ determination of optimum operating conditions,
- ➜ optimization of the optical system for fiber coupling, considering predefined conditions (space requirements, adjustment tolerances, available lenses).

The measurement procedure for obtaining the WDF resembles the method for determining the beam propagation ratio M^2. An accessible beam waist is created using suitable lenses, and then beam profiles are acquired with a CCD camera at many different axial positions in the range of the beam waist. From the measured beam

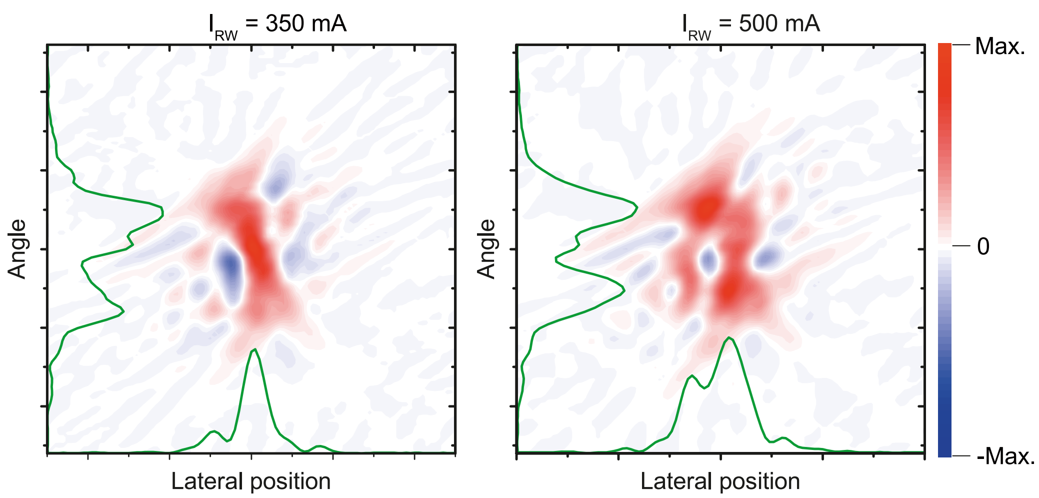

Fig. 1. Measured lateral WDFs of a tapered laser at two different RW currents together with near field (bottom) and far field (left) intensity distributions.

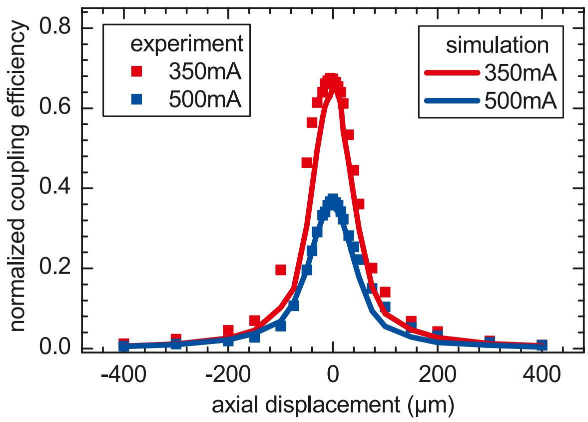

Fig. 2. Coupling efficiency as a function of the axial displacement of the fiber position for two different RW currents, measured (dots) and calculated from measured WDFs (lines).

profiles a numerical algorithm retrieves the WDF. Object of a current investigation is to evaluate the accuracy of predictions of fiber coupling efficiencies based on this method. For this purpose, WDFs of various tapered lasers under different operating conditions have been measured, the coupling efficiency into a given single-mode fiber using a predefined optical system has been calculated, and the results have been compared to the corresponding experimental realization.

Amongst others, tapered lasers with separated contacts have been investigated allowing for an independent control of the current in the RW section and the tapered section of the lasers. Keeping the current through the tapered section constant, the beam properties still depend on the current though the RW section. Measurements illustrate, that the beam propagation ratio varies only slightly from $M^2 = 4.2$ to $M^2 = 5.0$ at RW currents of 350 mA and 500 mA, respectively. But the calculations based on the measured WDFs, as shown in Fig. 1, reveal a much higher difference in the expected coupling efficiencies, which is also verified by the experiments. In Fig. 2 the coupling efficiency as a function of the axial displacement of the fiber position is shown for both RW currents. The shape of the curves for each RW current as well as the big difference in the coupling efficiencies for both operating conditions are in good agreement with the predictions. Hence, it is demonstrated that only the additional information contained in the WDF allows evaluating the potential of a laser to be coupled into single-mode fibers. The knowledge of the beam propagation ratio M^2 alone is not sufficient. Thus, the precise measurement of the WDF may support the development of tapered lasers with efficient coupling into single-mode fibers and open the market of this promising diode laser type as a consequence.

Trapezlaser erzeugen deutlich höhere Leistungen als RW-Laser und wesentlich bessere Strahlqualitäten als BA-Laser der gleichen Leistungsklasse. Als hochbrillante Strahlquellen verfügen sie daher über ein hohes Marktpotenzial für sehr viele Anwendungen. Eine wichtige Voraussetzung für die breite industrielle Anwendung ist jedoch, dass der Laserstrahl sehr effizient in Glasfasern eingekoppelt werden kann. Angestrebt sind Monomodefasern, da hier die Strahlungsfelder die Faser mit der bestmöglichen Strahlqualität verlassen. Da Trapezlaser eine komplexe Strahlstruktur aufweisen, kann die Einkoppelbarkeit nicht anhand der Beugungsmaßzahl M^2 abgeschätzt werden. In einem laufenden Projekt konnte gezeigt werden, dass die umfassendere Charakterisierung der Strahleigenschaften durch Messung der Wigner-Verteilung diesbezüglich eine verlässliche Vorhersage erlaubt. Die präzise Messung der Wigner-Verteilung mit einem relativ einfachen Messverfahren schafft somit die Voraussetzungen, um effizient fasergekoppelte Trapezlaser zu realisieren und damit ihr großes Marktpotenzial zu erschließen.

PUBLICATION

→ M. Uebernickel, B. Eppich, B, C. Fiebig, K. Paschke, G. Erbert, **"Wigner distribution function of DBR tapered diode lasers"**, Proceedings of SPIE, vol. 7918, no. 79180C (2011).

Micro-integrated master-oscillator power-amplifier laser modules for Rubidium precision spectroscopy in space

Cold atom-based quantum sensors are currently moving into the focus of various fields like precision time keeping, navigation, exploration, and fundamental physics tests. Optical clocks, for example, are meanwhile outperforming microwave atomic clocks that still officially define the unit time, in terms of accuracy and stability. Cold atom matter wave interferometers can be used for inertial navigation and specifically work in an environment, where a GPS-type of navigation is not possible. This applies, for example, under water and on deep-space satellite missions. Cold atom-based matter wave interferometers are also considered for precision tests of the equivalence principle. In 2011, ESA selected STE-QUEST, a proposal for a **S**pace-**T**ime **E**xplorer and **QU**antum **E**quivalence Principle **S**pace **T**est, as one of four candidates for a medium-size M3 satellite mission within the Cosmic Vision 2015–2025 framework. On the national level, the German Space Agency DLR is supporting activities that will lead to the first-time ever demonstration of a Bose-Einstein-Condensate-based atom interferometer onboard a sounding rocket in 2013 (QUANTUS family of projects). Cold atom quantum sensors like optical clocks or matter wave interferometers need ultra-stable lasers to reach their ultimate performance. For example, optical clocks require optical local oscillators with a relative stability at the 10–17 level and below: on a time scale of 13 billion years, the age of the universe, this would correspond to an uncertainty of only 4 seconds!

Currently, only very few lasers are space-qualified, and only one of these, a solid-state laser operating at 1064 nm, can provide the required spectral stability in principle. Lasers for quantum sensor applications in space however do not only have to provide radiation at the right wavelength with appropriate power levels, they also have to be very robust, compact, reliable, and power-efficient.

The FBH is currently developing a technology platform that will meet the requirements of quantum sensor applications in space. Currently, laser modules are developed for application to Potassium (767 nm) and Rubidium (780 nm) Bose-Einstein condensation and atom interferometry.

For quantum sensor applications requiring a relatively high optical power (1 W level) at a modest spectral linewidth (100 kHz FWHM Lorentzian), the hybrid integration of a low-power, narrow-linewidth DFB (or DBR) master laser and of a high-power trapezoidal power amplifier (master-oscillator power-amplifier, MOPA) provides the best performance. Fig. 1 shows one of the first MOPA modules that also includes a basic electronic interface. All components, comprising two GaAs "laser" chips, micro lenses, a micro-optical isolator, micro-temperature sensors, and discrete electronic components, are integrated on a galvanically structured aluminum nitride ceramic body, the footprint of which is only 25 x 80 mm^2. The MOPA includes an electronic interface that supports injection current modulation by means of an integrated transistor (DC up to a few tens of MHz) and—through an integrated bias-Tee—modulation at microwave frequencies. The current modulation provides fast frequency control for frequency stabilization of the laser. The electronic interface also contains three temperature sensors providing information of the module temperature close to the two GaAs chips as well as of the module itself with mK resolution.

Depending on the integrated GaAs chips, these modules deliver an output power of up to 1 W and more. The module shown in Fig. 1 provides an output power of 415 mW at a FWHM linewidth of 1.2 MHz (10 µs time scale) and a Lorentzian FWHM linewidth of 281 kHz. The wavelength can be tuned by more than 500 GHz to reach the Rubidium D2 line at 780.24 nm. This module has also

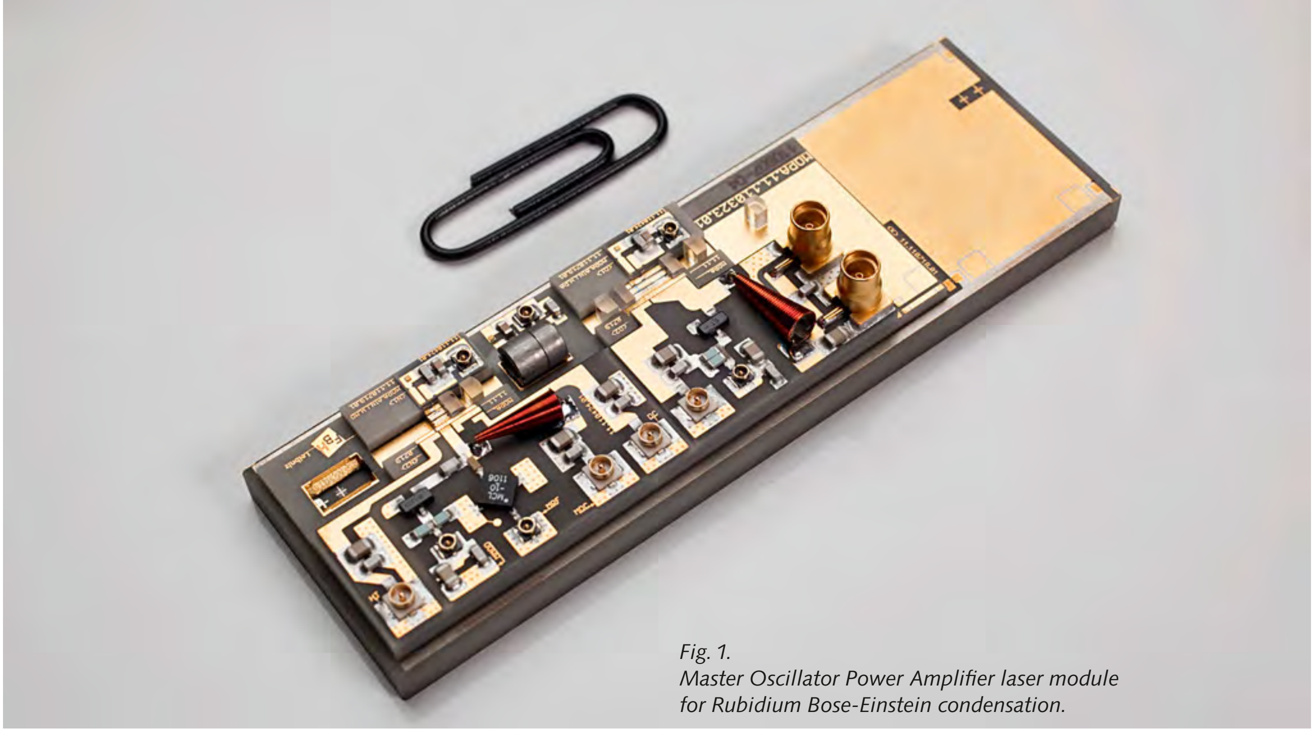

Fig. 1.
Master Oscillator Power Amplifier laser module for Rubidium Bose-Einstein condensation.

successfully, that is without any degradation of its power and spectral performance, passed vibration tests which simulate the launch of a sounding rocket (Fig. 2). These modules will be operated onboard a Quantus rocket in 2013.

FBH is preparing onboard fiber coupling, extension of the modulation capabilities, and integration of the laser module into a hermitically sealed package. Future vibration tests will subject the module to a mechanical load of up to 29 gRMS and 1500 g pyro-shock. This technology can be transferred to other wavelengths between 630 nm and 1100 nm.

The work is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant numbers 50YB0810, 50WM0940, and 50WM1134. The project iSense acknowledges the financial support of the Future and Emerging Technologies (FET) programme within the Seventh Framework Programme for Research of the European Commission, under FET open grant number 250072.

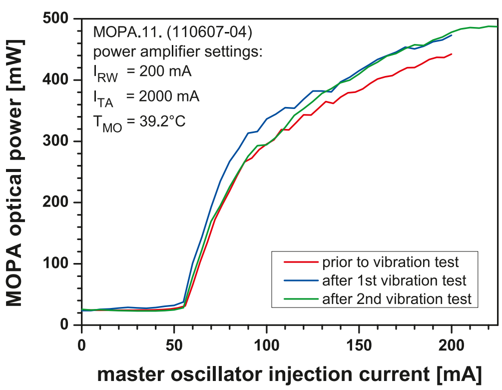

Fig. 2. Optical power of the MOPA vs. injection current of the master oscillator before, after the first, and after the second vibration test.

In Gebieten wie der Präzisionszeitmessung, der Navigation oder zum Prüfen fundamental-physikalischer Fragestellungen gewinnen Quantensensoren, die auf kalten Atomen basieren, zunehmende Bedeutung. Quantensensoren wie etwa optische Uhren und Materiewelleninterferometer benötigen ultra-stabile Lasersysteme, um die notwendige hohe Empfindlichkeit zu erreichen. Das FBH entwickelt zurzeit eine Technologieplattform für Lasersysteme, die für die Bose-Einstein-Kondensation und für die Atominterferometrie im Weltraum benötigt werden. Dafür werden schmalbandige DFB- (oder DBR-) Master-Laser geringer Leistung mit leistungsstarken Trapezverstärkern zu MOPAs (Master-Oszillator Power-Amplifier) kombiniert. Sie liefern die geforderten optischen Ausgangsleistungen von 1 Watt und mehr bei zugleich geringer Linienbreite und sind zudem sehr robust, kompakt, zuverlässig und energieeffizient. Erste Vibrationstests, die den für 2013 geplanten Raketenstart einer Höhenforschungsrakete simulieren, wurden erfolgreich absolviert. Diese Lasertechnologie ist auf andere Wellenlängen zwischen 630 nm und 1100 nm übertragbar.

PUBLICATIONS

➜ C. Kürbis, A. Kohfeldt, E. Luvsandamdin, M. Schiemangk, S. Spießberger, A. Wicht, A. Peters, G. Erbert, G. Tränkle, **"Mikrointegrierte Lasersysteme für die höchstauflösende Atomspektroskopie und die kohärente Nachrichtenübertragung im Weltraum"**, DGLR (2011).

➜ A. Wicht, E. Luvsandamdin, A.Kohfeldt, M. Schiemangk, S. Spießberger, A. Sahm, F. Bugge, J. Fricke, H. Wenzel, A. Peters, G. Erbert, G. Tränkle, **"Micro-integrated, high power, narrow linewidth diode lasers for precision quantum optics experiments in space"**, Photonics West (2012).

10 W reliable 975 nm DFB-BA lasers

Our work focuses on the development of spectrally stabilized high-power, high-efficiency broad area (BA) lasers. Such devices are suitable for pumping narrow absorption peaks in solid state and fiber lasers and for dense spectral multiplexing in direct applications. In addition to narrow spectral width operation, wall-plug efficiencies ~ 60 % and reliable CW powers ~ 10 W are required for use in real applications—a performance level that has not to date been reported.

We use buried distributed feedback (DFB) gratings for wavelength stabilization and fabricate them on the basis of a two-step epitaxy and lithographic structuring techniques. However, it is technologically challenging to introduce these nanostructures without adding additional optical loss, series resistance, and material defects. This is particularly challenging in modern high-power laser designs that use AlGaAs, which oxidizes rapidly and where defects are highly mobile. A technological process, newly developed by FBH scientists, overcomes these limitations by making use of an optimized semiconductor layer structure in the grating region and in-situ etching of the pre-structured grating inside the epitaxy reactor. In this approach, the in-situ etching transfers the surface corrugation into the underlying layers and removes oxygen contamination at the growth interface. 975 nm BA lasers with DFB gratings, constructed with the new grating technology, achieve the highest reported powers and efficiencies.

The DFB grating layers are grown using low-pressure metal organic vapor phase epitaxy (MOVPE) within the p-type waveguide of the laser structure. At the end of the first epitaxy step, a 10 nm InGaP layer is grown on top of AlGaAs and finished with a 25 nm GaAs cap-layer. Then, outside the epitaxy reactor (ex-situ), a grating mask is selectively wet-etched into the GaAs cap-layer, as schematically illustrated in Fig. 1a). Afterwards, the wafers are returned to the epitaxy reactor and the surface corrugation is transferred via in-situ etching with carbontetrabromide (CBr4) into the 10 nm thin InGaP layer beneath. The InGaP is completely removed between the grating stripes and the underlying AlGaAs is exposed, as shown in Fig. 1b). After overgrowth with AlGaAs, a thin floating grating is formed, consisting of InGaP grating ridges (with GaAs caps) buried in AlGaAs as depicted in Fig. 1c). The second order DFB grating has a period of 285 nm and a duty cycle of ~ 25 % after all etching. Figs. 1d) and e) show a tunneling electron microscope (TEM) micrograph and the indium-specific signal from an energy-dispersive X-ray spectroscopy (EDXS) of the same region, respectively. Both measurements indicate that the grating stripes are fully enclosed in AlGaAs and no residual layer from InGaP remains. Also no crystal defects are observed in the TEM micrograph. Secondary ion mass spectrometry (SIMS) measurements show that oxygen-contamination in the grating region is $< 1 \cdot 10^{17}$ cm^{-3} after in-situ etching.

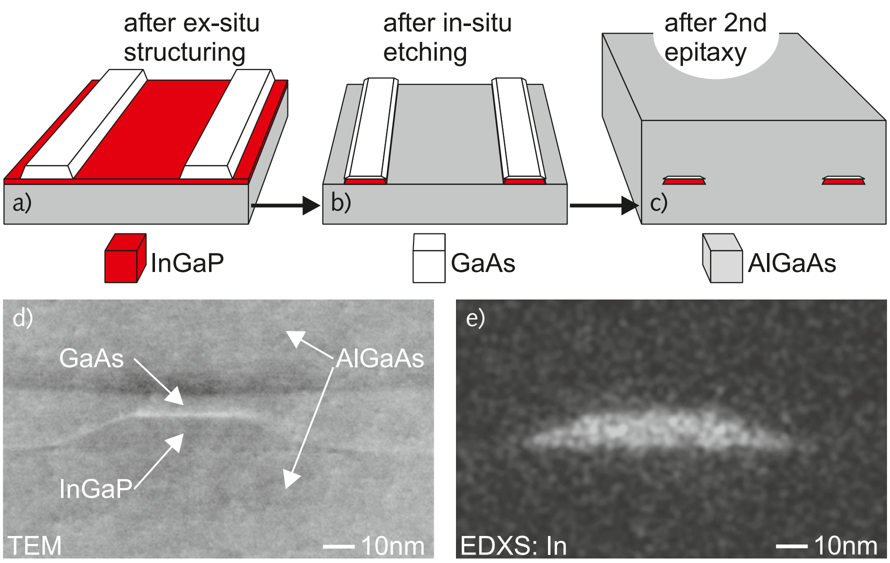

Fig. 1.
a) Grating region after ex-situ structuring,
b) after in-situ etching,
c) after overgrowth with AlGaAs,
d) TEM micrograph of a grating stripe,
e) In-specific EDXS signal, same region.

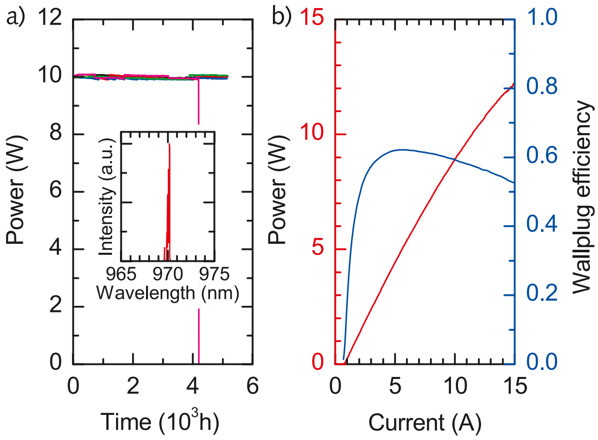

Fig. 2. a) CW output power of five DFB-BA lasers as a function of time, stabilized at 10 W. Inset: spectrum at 10 W, b) CW power and wall-plug efficiency of a DFB-BA laser at 25 °C heat-sink temperature.

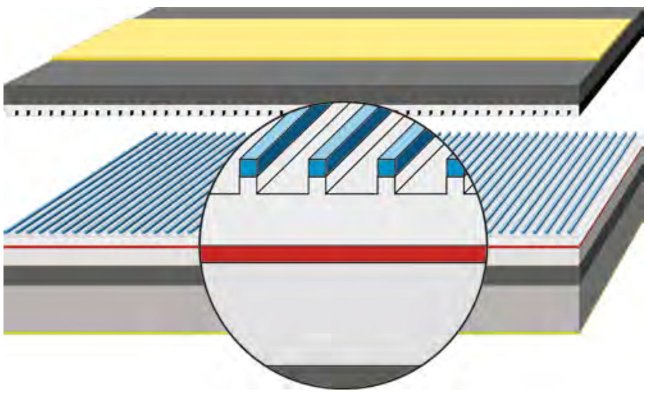

Fig. 3. Scheme of a DFB-BA laser with buried DFB grating.

DFB-BA lasers from this material are found to have the same optical loss and voltage characteristics as Fabry-Pérot reference lasers, grown in a single epitaxy process without the grating layers, confirming that the grating material is of very high quality. 3 mm long BA lasers with a contact stripe width of 100 µm and AR (< 0.1 %) / HR (98 %) coated front and rear facets reach record high peak wall-plug efficiency of 62 % and 12 W optical output power (15 A) at 25 °C heat-sink temperature under continuous wave (CW) measurement conditions. At 10 W CW optical output, 59 % wall-plug efficiency is reached.

Five DFB-BA lasers were life-tested at 10 W CW optical output over 5000 h. In Fig. 2a), the normalized injection current is depicted and Fig. 2b) shows that, for the first time, the optical output of four of five lasers was successfully stabilized at 10 W over 5000 h. One device failed at a non-grating-related defect.

In Summary, novel technology developed at the FBH has enabled wavelength stabilized diode lasers to achieve the highest reported reliable power and efficiency. A patent for this technology is pending (German patent application No.: 102011086744.9).

Das FBH entwickelt spektral stabilisierte, leistungsstarke und effiziente Breitstreifenlaser. Diese sollen künftig als Pumpquellen für schmale Absorptionsbanden in Festkörper- und Faserlasern oder direkt eingesetzt werden. Zur spektralen Stabilisierung werden DFB-Gitter mithilfe einer Zwei-Schritt-Epitaxie in den Wellenleiter aus AlGaAs eingebettet. Eine am FBH entwickelte Technologie ermöglicht es, diese Gitter in die Epitaxiestruktur zu integrieren, ohne Sauerstoff einzubauen und zusätzliche optische Verluste oder einen erhöhten Serienwiderstand hervorzurufen. Dadurch werden zusätzliche optische Verluste oder auch ein erhöhter Serienwiderstand vermieden. Die Gittertechnologie beruht auf einem Ätzprozess, der innerhalb der Epitaxieanlage stattfindet. Auf dieser Grundlage hergestellte DFB-Laser erzielen hohe optische Ausgangsleistungen bis zu 12,5 W und eine Konversionseffizienz von bis zu 63 %. Erstmals wurde für diese spektral stabilisierten Laserdioden eine Lebensdauer über 5000 h bei einer optischen Leistung von 10 W nachgewiesen.

PUBLICATIONS

→ P. Crump, C.M. Schultz, H. Wenzel, S. Knigge, O. Brox, A. Maaßdorf, F. Bugge, G. Erbert **"Reliable operation of 976 nm High Power DFB Broad Area Diode Lasers with over 60 % Power Conversion Efficiency"**, Proc. SPIE 7953, 79531G (2011).

→ P. Crump, J. Fricke, C.M. Schultz, H. Wenzel, S. Knigge, O. Brox, A. Maaßdorf, F. Bugge, G. Erbert, **"10-W Reliable 100-µm wide broad area lasers with internal grating stabilization"**, Proc. SPIE 8241, 82410N (2012).

High-power bipolar cascade diode lasers

Semiconductor diode laser bars are enabling devices for efficient solid-state laser systems. Such bars with an emission wavelength of 808 nm are used, for example, to pump Nd:YAG lasers. Scaling of the optical output power is usually achieved by increasing the overall device area, thus increasing the overall drive current of the pump lasers. For applications where current drive capabilities are limited, an alternative approach is to operate several diode lasers in series, which increases supply voltage rather than drive current. The most cost-effective realization is to stack several lasing stages monolithically on top of each other resulting in a Bipolar Cascade Laser (BCL) diode (Fig. 1).

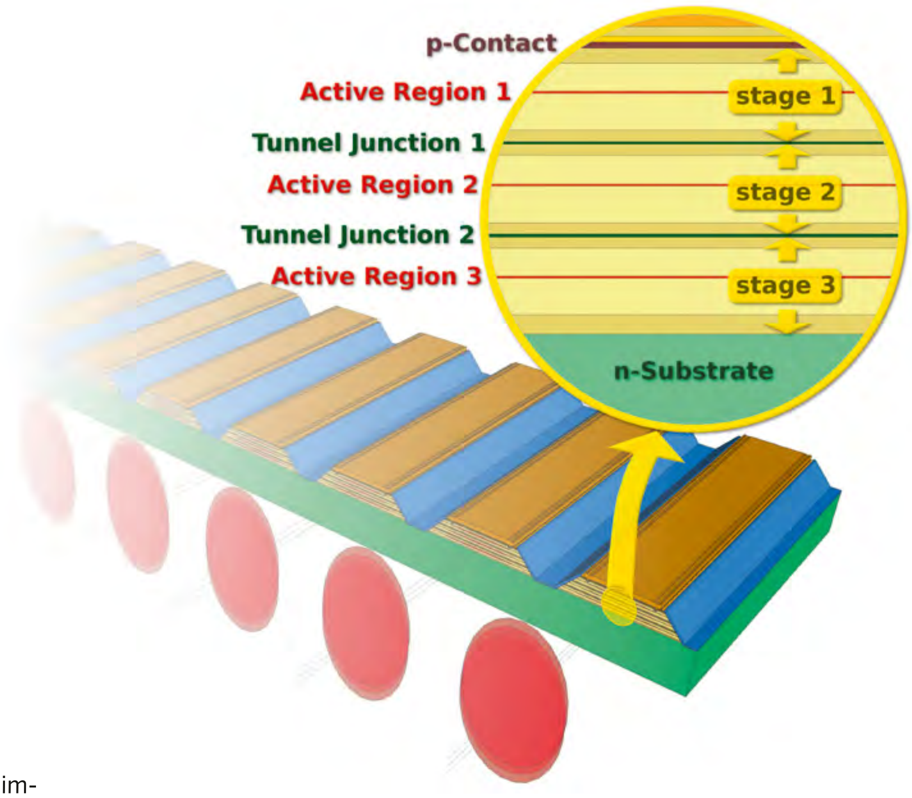

Fig. 1.
Schematic drawing of a 3-stage BCL bar. The inset illustrates the principal vertical layer sequence including the n-GaAs substrate at the bottom, three lasing stages along with 2 tunnel junctions, and the p-GaAs contact layer on top.

Each lasing stage comprises n- and p-side cladding and waveguide layers, as well as the active region which is located at the pn-junction of the respective stage. Between two adjacent stages, a reverse biased pn-junction is formed under normal device operation. To make this reverse biased pn-junction highly conductive, a tunnel junction diode is required. At this junction, valence band electrons from the p-side of one stage are injected into the conduction band of the n-side of the next stage leaving a hole on the p-side. This way, the electrons injected from the n-substrate are recycled for the following stage of the laser diode cascade.

The tunnel junction diode developed at FBH is based on GaAs with the p- and n-side being doped as high as possible. While this is easily achievable for the p-side using GaAs:C, heavily n-type doped GaAs is more challenging due to saturation of the incorporation of the standard dopant Si as substitutional donor. The use of selenium as n-dopant turns out to be the better choice for MOVPE-grown 808 nm BCLs resulting in almost no impact of the tunnel junctions on the overall series resistance.

BCLs require a thick layer stack (for example of ~ 8 µm for a 3-stage BCL). For such thicknesses, the slight lattice mismatch between AlAs and GaAs (~ 1400 ppm) results in significant wafer bow. A BCL for 808 nm stacking three stages with standard layer sequence for single stage emitters has a convex wafer bow of 125 µm over 3" making optical lithography difficult. Additionally, such heavy bow results in a bow of thinned 10 mm wide laser bars of 30 µm. This exceeds the bow of a single stage bar by a factor of 3 and causes severe problems during mounting. By modifying the design of the individual stages and including AlGaAsP strain management layers into the claddings, the convex bow for the 2-stage BCL was reduced to 11 µm.

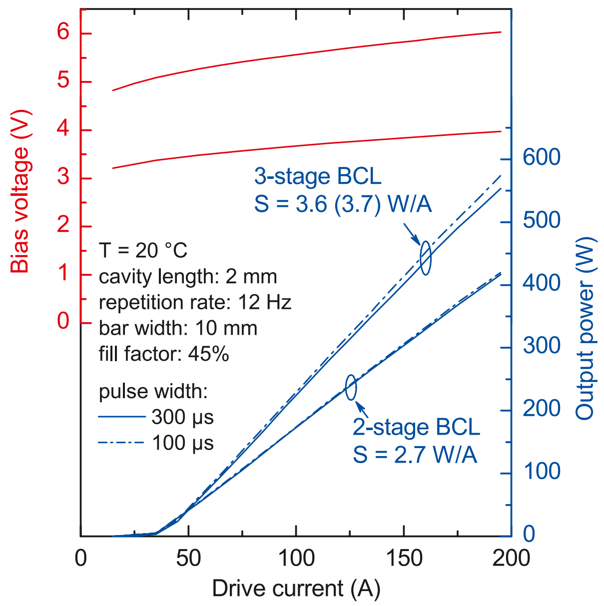

Fig. 2. PUI characteristics of 2-stage and 3-stage BCLs.

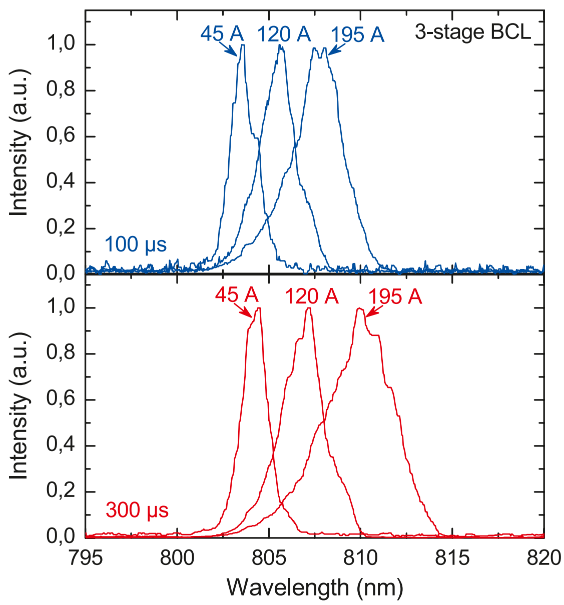

Fig. 3. Emission spectra at three different operation points for the 3-stage BCL from Fig. 2; top -100 µs pulse width; bottom -300 µs pulse width.

Fig. 2 shows the output power and the necessary drive voltage over the drive current of a 2-stage and a 3-stage 808 nm BCL. For the 2-stage device, the slope efficiency of 2.7 W/A is doubled in comparison to a similar single-stage laser (~ 1.4 W/A), yielding an output power of 415 W@195 A. Adding a third stage increases the drive voltage by about 2 V and allows for a maximum output power of 575 W@195 A (for 100 µs pulses). The slope of a 3-stage BCL already shows a noticeable dependence on the pulse width, indicating that heat removal from such thick layer stacks has to be taken into consideration. This can also be seen from the increasing spectral width at higher drive currents (Fig. 3).

For short-pulse operation, the high output power at strongly reduced drive current and device area shows the great potential of this concept in comparison to conventional single-stage emitters.

PUBLICATION

→ A. Maaßdorf, M. Hoffmann, M. Weyers **"Growth and characterization of heavily selenium doped GaAs using MOVPE"**, Journal of Crystal Growth 315, 57–60 (2011).

Kantenemittierende Halbleiter-Laserdioden-Barren sind wichtige Komponenten in effizienten Festkörper-Lasersystemen. So werden beispielsweise Barren mit einer Emissionswellenlänge von 808 nm zum optischen Pumpen von Nd:YAG-Lasern verwendet. Höhere Pumpleistungen werden üblicherweise durch eine größere aktive Fläche des Barrens und einen höheren Betriebsstrom erreicht. Für Einsatzszenarien, bei denen der maximale Betriebsstrom limitiert ist, können alternativ mehrere Laserdioden in Reihe betrieben werden. Die kosteneffizienteste Lösung besteht im monolithischen Stapeln von Laserdioden zu bipolaren Kaskadenlasern (BCL). Da die direkte Halbleiter-Halbleiter-Verbindung zweier leitender pn-Laserdioden im Normalbetrieb gesperrt wäre, setzt man hier eine Tunneldiode als verbindendes Element ein. Die am FBH entwickelte Tunneldiode besteht aus GaAs mit sehr hoch dotierten n- und p-Gebieten. Während eine p-Dotierung bis zu $p = 1 \times 10^{20}\,cm^{-3}$ in GaAs mit Kohlenstoff einfach zu realisieren ist, ist die erreichbare n-Dotierung mit Silizium auf $n = 2-3 \times 10^{18}\,cm^{-3}$ begrenzt. Verglichen damit erlaubt Selen die doppelte n-Dotierung und damit einen geringeren Gesamtserienwiderstand. Ein 2-facher Kaskadenlaser erzielt eine Ausgangsleistung von 415 W@195 A bei 808 nm, ein 3-fach Kaskadenlaser erreicht 575 W@195 A.

GAN OPTOELECTRONICS

GAN-OPTOELEKTRONIK

GaN-Optoelektronik

Der Geschäftsbereich GaN-Optoelektronik beschäftigt sich mit der Entwicklung innovativer Lichtquellen auf Basis des Halbleitermaterials Galliumnitrid (GaN) und seiner Legierungen AlGaN und InGaN. Diese Materialbasis ist die Grundlage für hocheffiziente Lichtemitter in einem Spektralbereich, der den gesamten sichtbaren und große Teile des ultravioletten (UV) Spektrums abdeckt. Die Forschungs- und Entwicklungsarbeiten am FBH konzentrieren sich auf Laserdioden mit Emissionswellenlängen im Bereich von 390 bis 450 nm, Leuchtdioden (LEDs) für den gesamten UV-Spektralbereich und UV-Photodetektoren. Die Laserdioden mit kundenspezifischen Wellenlängen zielen unter anderem auf den Einsatz in der Atom- und Molekülspektroskopie, während die UV-LEDs für Anwendungen wie die Wasserdesinfektion oder die Phototherapie interessant sind.

Die Bauelemententwicklung reicht von der Modellierung der optischen und elektrischen Eigenschaften von GaN-basierten Schichtstrukturen, dem Wachstum mittels Metallorganischer Gasphasen-Epitaxie (MOVPE) bis hin zur Chipherstellung im Reinraum. Abschließend werden die Chips auf Wärmesenken bzw. in Gehäuse montiert und die Bauelemente elektrooptisch charakterisiert. Das FBH arbeitet dabei eng mit der Arbeitsgruppe „Experimentelle Nanophysik und Photonik" der TU Berlin zusammen. Im Rahmen des regionalen Wachstumskerns „Berlin WideBaSe" gibt es auf dem Gebiet der GaN-Optoelektronik zudem enge Kooperationen mit einer Reihe Berliner Firmen wie etwa Osram, Jenoptik, OSA Opto Light und eagleyard Photonics.

Das Jahr 2011 war von Fortschritten bei der Bauelementeherstellung geprägt. Im Bereich der Chiptechnologie von Rippenwellenleiter-Laserdioden wurde die komplette Prozesskette entwickelt: von der Herstellung schmaler Rippen, dem Spalten von Laserbarren und der Facettenbeschichtung bis hin zu gelöteten Chips auf Submounts. Blaue Laserdioden mit einer Rippenwellenleiterbreite von 1,5 µm zeigen im CW-Betrieb Schwellenströme von 80 mA und Ausgangsleistungen von bis zu 40 mW. Im Bereich der UV-LEDs wurden sowohl die Materialien als auch die Chiptechnologie weiter optimiert und das verfügbare Wellenlängenspektrum erweitert. Für Anwendungen in mobilen batteriebetriebenen Geräten zur Analyse von Körperflüssigkeiten, insbesondere für At-Home-Bluttests, wurden fokussierbare Top-Emitter-LEDs bei 360 nm entwickelt. Die Auskopplung des Lichts erfolgt durch semi-transparente Vorderseitenkontakte. Hier konnten erste LED-Chips mit 0,3 mW Ausgangsleistung bei geringen Strömen von 10 mA realisiert werden. In Kooperation mit der TU Berlin wurden das Design und die Epitaxie der UV-B-LEDs deutlich verbessert, sodass nun LED-Heterostrukturen im Bereich 305–325 nm mit „on-Wafer" gemessenen Ausgangsleistungen von mehr als 1 mW zur Verfügung stehen.

GaN Optoelectronics

The main objective of FBH's Business Area GaN Optoelectronics is to develop innovative light sources based on the semiconductor material gallium nitride (GaN) and its alloys AlGaN and InGaN. This material system opens up the possibility to fabricate highly efficient light emitters in a broad spectral region comprising the entire visible range and large parts of the ultraviolet (UV) spectrum. Research and development at FBH focus on laser diodes emitting in the 390 nm to 450 nm wavelength range, light emitting diodes (LEDs) covering the entire ultraviolet (UV) spectral range as well as deep UV photodetectors. Custom laser diodes with tailored wavelengths find application in, for example, atom and molecule spectroscopy, whereas UV LEDs are interesting for applications in water disinfection and phototherapy.

Device development includes the modeling of optical and electrical properties of GaN-based layer heterostructures, growth by metal organic vapor phase epitaxy (MOVPE), and chip fabrication in a cleanroom environment. These chips are then mounted onto heat sinks or into packages, and the devices are finally electro-optically characterized. FBH collaborates closely with the "Experimental Nanophysics and Photonics" group at TU Berlin. Within the framework of the innovative regional growth core "Berlin WideBaSe", the Business Area GaN Optoelectronics at FBH closely cooperates with numerous companies in Berlin such as Osram, Jenoptik, OSA Opto Light, and eagleyard Photonics.

The year 2011 was characterized by advances in device fabrication. In chip technology of ridge waveguide laser diodes, the complete process chain has been developed, from the fabrication of narrow ridges, cleaving of laser bars, facet coatings to complete chips soldered onto submounts. CW operation of blue laser diodes with a ridge waveguide width of 1.5 microns with threshold currents of 80 mA and output powers of up to 40 mW has been demonstrated. In the field of UV-LEDs, both the materials and the chip technology have been further optimized, and the available wavelength range has been extended. For applications in mobile battery-powered devices for the analysis of body fluids, especially for at-home blood tests, focusable top emitter LEDs have been developed at 360 nm. The out-coupling of light was facilitated by semi-transparent conductive oxide top contacts. First LED chips with 0.3 mW output power at low currents of 10 mA have been realized. In cooperation with the TU Berlin, design and epitaxy of UV-B LED heterostructures were significantly improved. Thus, LEDs in the range from 305 nm to 325 nm are available now with "on-wafer" measured output powers of more than 1 mW.

Low-threshold GaN-based laser diodes for atom spectroscopy

Gallium nitride (GaN) based laser diodes emitting at 405 nm and in the blue spectral range, have been on the market for already some years. However, companies have so far been focusing on mass-market applications, such as Blu-Ray disk drives and RGB laser projectors. Therefore, only laser diodes with specific characteristics and emitting at a limited number of wavelengths are currently available. Within the innovative regional growth core Berlin WideBaSe, the FBH together with Technische Universität Berlin and the company eagleyard Photonics develops laser diodes with customized wavelengths for use in atom spectroscopy. The current focus is on the mercury lines at 404.7 nm and 435.9 nm. These laser diodes will be operated in an external cavity which involves a diffraction grating to ensure a narrow emission linewidth and to precisely adjust the lasing wavelength.

Ridge waveguide laser diodes with ridge widths of 1.5 µm and resonator lengths of 600 µm have been fabricated. A narrow ridge is essential to assure transversal single-mode operation and an optimum beam quality. The chip process comprises plasma etching of the ridge, chemical vapor deposition of an isolating layer, mechanical thinning of the GaN substrate and several metallization steps. Individual laser chips are obtained by scribing and cleaving the wafer and depositing alternately SiO_2/Ta_2O_5 layers of varying number and thickness on the facets to adjust the reflectivity to < 0.1 % for the front facet and 97 % for the rear facet. All technological steps have been optimized in terms of stability and precision to ensure sufficient yield of the fabrication process. The laser diode chips have been mounted on both copper heat sinks and ceramic submounts, as shown in Fig. 1. Due to the superior thermal conductivity of the GaN substrate, the chips were mounted p-side up rather than p-side down.

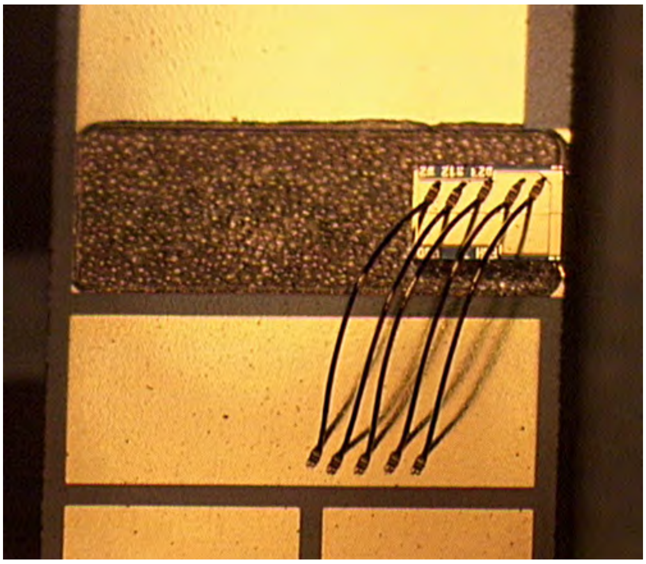

Fig. 1. Top-view of a GaN laser diode mounted p-side up on a ceramic submount by hard soldering.

Threshold currents as low as 40 mA have been obtained for devices with a ridge width of 1.5 µm and a length of 600 µm emitting around 41x nm. The threshold voltage and slope efficiency in pulsed operation for such devices were 7.5 V and 0.5 W/A, respectively. Under continuous wave operation, the output power of 40 mW has been reached (in Fig. 2, an L-I curve for a device emitting at 440 nm).

To implement the devices in real-world applications, efficiency and particularly driving current are crucial parameters. A systematic study of numerous laser diodes has shown that the lasing threshold not only depends on the design of the epitaxial layer structure and its structural quality, but the chip design is just as important, most notably the geometry of the ridge waveguide. The almost square-sectioned ridge waveguide is formed by etching several hundreds of nanometers deep into the semiconductor surface. The purpose of the ridge is to provide an index step in the lateral effective refractive index profile, which confines the optical mode. At the same time, the vertical current path between the p-contact and the active region is laterally confined.

Fig. 3 shows the threshold current density as a function of the ridge width for two batches of laser diodes whose etching depth of the ridge differs only by 175 nm. Although the impact of the ridge depth on the threshold vanishes when the ridge width increases, narrow ridge lasers exhibit more than a factor of two higher threshold current densities in case of shallow etched ridges. Since the intended application of the laser diodes requires

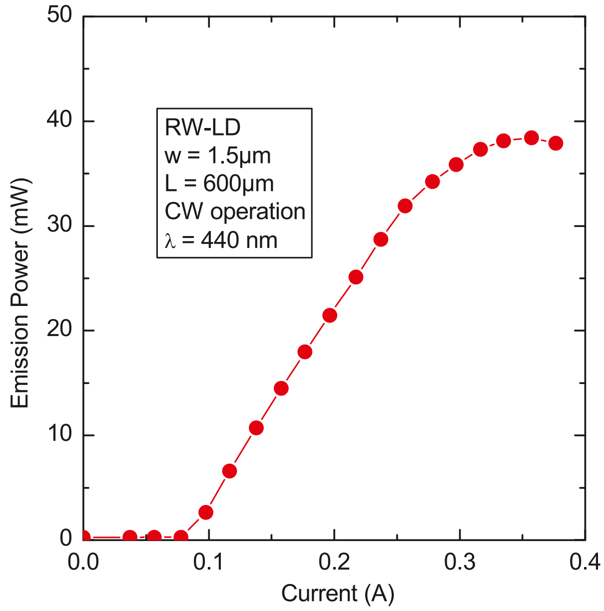

Fig. 2. Current light power characteristic of a 44x nm RW laser diode with a ridge width of 1.5 µm under CW operation.

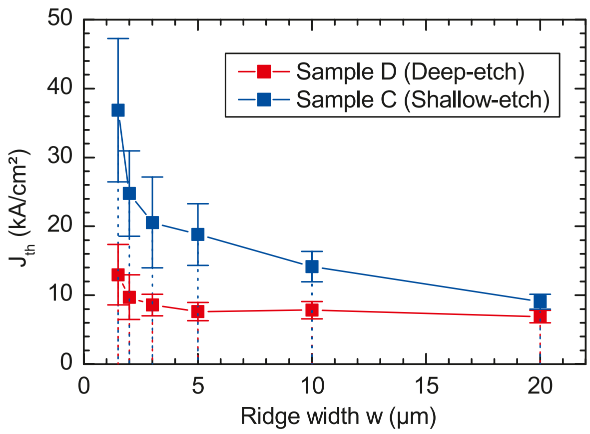

Fig. 3. Threshold current density versus ridge width for laser diodes which differ only in the etching depth of the ridge.

single-mode lasers, i.e. narrow ridges, the investigation of the effect is particularly important. Although known in the scientific community for some time, no comprehensive explanation for this effect has yet been found.

Systematic two-dimensional electro-optical simulations of the devices have been started in collaboration with the NUSOD institute and the TU Berlin. The anti-guiding effect originating from a high carrier density during lasing, optical absorption in the region of the lateral mode tails, and lateral current spreading have been considered. A comparison with experimental data, in particular the far-field and the near-field patterns as well as the distribution of the spontaneous emission through the substrate below and above threshold, shows that none of these contributing factors could be ruled out completely. However, preliminary results from comparison with numerical modeling reveal that lateral current spreading and lateral mode absorption alone cannot explain the findings. Further investigation are currently being undertaken to study the role of anti-guiding effects.

Laserdioden auf der Basis von GaN sind heute nur für eine begrenzte Anzahl von Wellenlängen kommerziell verfügbar. Zusammen mit der TU Berlin und der Firma eagleyard Photonics entwickelt das FBH Laserdioden mit speziellen Wellenlängen im blauen Spektralbereich für den Einsatz in der Atomspektroskopie. Für Bauelemente, die bei 41x nm emittieren, wurden Schwellenströme von nur 40 mA erreicht. Aufgebaute Bauelemente zeigen im Dauerstrichbetrieb (CW) eine maximale optische Leistung von 40 mW bei 440 nm. Die Laserschwelle der Dioden hängt sehr stark von der Ätztiefe der Wellenleiterrippe auf dem Chip ab. Mithilfe von systematischen Nah- und Fernfeldermessungen sowie zweidimensionalen elektrooptischen Simulationen wurde in Kooperation mit dem NUSOD Institute begonnen, die optimale Rippengeometrie für niedrige Schwellenströme zu bestimmen.

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Focusable UV-A LEDs for at-home blood screening

For applications in medical technology, gas sensing, and security focusable and efficient light sources in the ultraviolet-A (UV-A) spectral region (320–380 nm) are needed. UV light emitting diodes (LEDs) are highly desirable since they can be easily integrated into measurement systems, require only low operating power, and are environmentally friendly as well as long-lasting. In addition, shaping the radiation pattern by using LED chips is fairly straightforward since the LED acts as a point light source emitting from a small area. If a hybrid lens is mounted onto such a chip, the collimation of the radiation could already be realized on chip level. Within the innovative regional growth core Berlin WideBaSe, the FBH together with the TU Berlin and the companies Jenoptik Polymer Systems and Sentech have developed focusable LEDs emitting near 360 nm. Those LEDs are suited for use in mobile battery-powered devices to analyze bodily fluids, particularly for at-home blood testing.

In order to be useable for this application, the LEDs have to be very efficient. The efficiency of LEDs, in turn, is mainly determined by the internal quantum efficiency, i. e. by the fraction of the charge carriers which recombine radiatively. Particularly the active region of an LED has to be optimally designed and requires a high structural perfection to minimize any non-radiative recombination. Fig. 1 shows an example for such an optimization. The presented light-current characteristics correspond to test LEDs with GaN/AlGaN single quantum wells (SQWs) of different thicknesses emitting near 360 nm. Both the slope efficiency in the linear part of the curve and the maximum optical power are largest for the thickest wells. Similar studies have been done for other design parameters such as the number of quantum wells and the layout of the p-side of the epitaxial structure.

Besides the internal quantum efficiency, the extraction efficiency of the light out of the chip is of similar importance. Whereas in a bottom-emitting LED light is extracted through the substrate, light is emitted through the top of the epitaxial structure in a top-emitting LED. If the emission wavelength is near 360 nm, bottom-emitting LEDs require optically transparent AlGaN buffer layers. So far, the work has been focused on top-emitting LEDs. Here, the active region can be epitaxially grown on GaN buffer layers which, in comparison to AlGaN buffer layers, are easier to fabricate with a reasonably low dislocation density. Low resistance but optically transparent contacts to the top p-side of the diode had to be developed. Indium tin oxide (ITO) was found to be a feasible contact material once its deposition procedure and subsequent thermal treatment had been optimized properly. Fig. 2 shows that

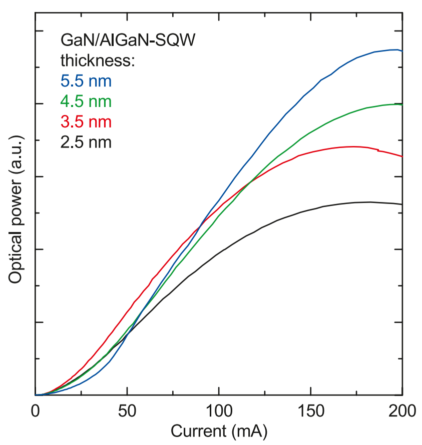

Fig. 1. Light power-current characteristics of top-emitter LEDs which contain GaN/AlGaN SQWs of different thicknesses.

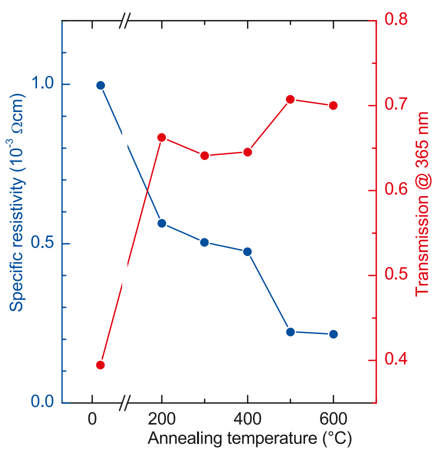

Fig. 2. Specific resistivity and optical transmittance at a wavelength of 365 nm of ITO in dependence on the annealing temperature.

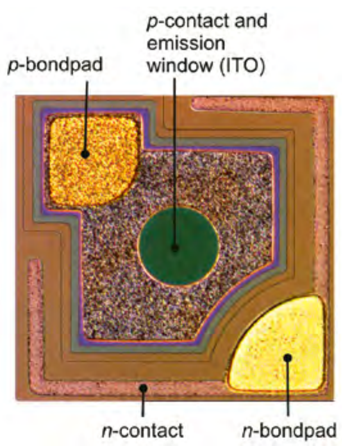

Fig. 3. Top-emitter LED chip (400 µm x 400 µm) with ITO emission window.

thermal annealing at elevated temperature is favorable to minimize absorption and heat losses in the ITO. Moreover, Ni/Au layers of only a few nanometer thickness, which were annealed under oxygen ambient, were found to reduce the operating voltages of the LEDs when inserted between the ITO and the p-type GaN.

Mountable top-emitting LEDs were fabricated as shown in Fig. 3. In these LEDs, the light is emitted through a small area in the ITO contact on the chip front side. The area through which the current flows in the LED was defined in different ways. In one case, insulating layers were inserted between ITO and semiconductor surface. In another case, a large area contact of the ITO to the semiconductor was formed, but the current path was spatially limited by subsequent ion implantation. Fig. 4 shows light-current-voltage (L-I-V) characteristics for a 360 nm top-emitter LED with a homogeneous emission over a circular aperture of 90 µm in diameter. The optical power is 0.3 mW at a diode current of 10 mA, which corresponds to an external quantum efficiency of about 0.9 %. The optical power varies by ± 20 % across the wafer. The operating voltage at 10 mA was 4.1 V resulting in an overall power consumption of 41 mW for the required output power of 0.3 mW.

Obtaining low power consumption is critical for battery-powered devices, and the current performance already enables first mobile applications. In a next step, it is intended to further increase the optical power by optimizing the light extraction efficiency. Moreover, procedures to mount optical lenses on the chip will be developed which should limit the angle of radiation to less than 90°.

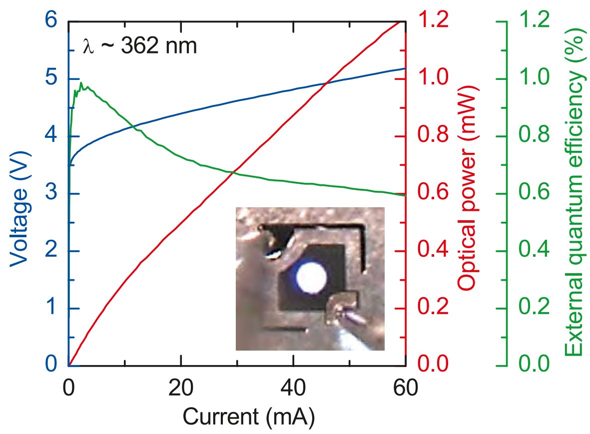

Fig. 4. Light power-current-voltage characteristics of a top-emitter LED. The emission comes through a circular aperture with a diameter of 90 µm (see photo inset).

Im Rahmen des regionalen Wachstumskerns Berlin WideBaSe hat das FBH in Kooperation mit der TU Berlin und den Firmen Jenoptik Polymer Systems und Sentech fokussierbare LEDs entwickelt. Diese emittieren im UV-A-Spektralbereich nahe 360 nm und können dank ihrer Fokussierbarkeit hohe Bestrahlungsdichten erzielen. Dadurch ermöglichen sie eine hohe örtliche Auflösung und Genauigkeit, die für Anwendungen in der sensorischen Messtechnik benötigt werden. Sie sollen künftig beispielsweise in batteriegetriebenen Messgeräten zum Einsatz kommen, mit denen Patienten ihre Blutparameter selbständig überwachen. Die LEDs emittieren durch eine UV-transparente Indiumzinnoxid-Schicht, deren elektrische und optische Eigenschaften optimiert wurden. Die Abstrahlung erfolgt durch eine kreisförmige Öffnung von 90 µm Durchmesser mit einer Lichtleistung von 0,3 mW bei einem Strom von 10 mA. Indem eine hybride Linse direkt auf dem Chip montiert wird, soll der Abstrahlwinkel auf 90° begrenzt werden.

Milliwatt power LEDs in the UV-B spectral range

Ultraviolet (UV) light can be used for numerous applications, depending on the exact wavelength. At wavelengths in the UV-B region near 310 nm, UV light can be employed for phototherapy such as treatment of psoriasis and UV curing of polymers. At even shorter wavelengths, UV light can be used for the disinfection of air, water, and medical instrumentation. Although UV light around a wavelength of 265 nm is optimal to damage or destroy the DNA or RNA of bacteria, viruses, and spores, UV-B light can also be employed. Currently, mainly mercury discharge lamps are used for such germicidal applications but may be replaced, at least partially, by UV-light emitting diodes (LEDs) in the long term. Compared to mercury lamps, UV LEDs are smaller, more robust, and do not require a high-voltage power supply. Moreover, the wavelength can be tailored to the needs of the application. LEDs emitting in the visible range exhibit a higher efficiency and a longer lifetime than discharge lamps. It can be anticipated that UV LEDs offer similar advantages once they are fully optimized. Within a collaboration of the Ferdinand-Braun-Institut and the Technische Universität Berlin, large efforts are devoted to improving the efficiency of UV LEDs and to shifting their emission towards shorter UV wavelengths. Moreover, the practical application of UV LEDs is studied. Only recently, we were able to successfully demonstrate the disinfection of small water volumes with UV-B and UV-C LEDs. All UV LEDs are based on the group III-nitride material system, covering the spectrum from 400 nm to 200 nm.

The design of the diode structures has been optimized with respect to the envisaged wavelength in order to ensure efficient current-injection, radiative recombination in the active region, and extraction of the light out of the semiconductor chip. Efficient current-injection requires sufficiently high densities of free electrons and holes in the semiconductor layers, particularly AlGaN. Unfortunately, the ionization energies of the doping impurities in AlGaN rise with increasing bandgap energy. Shorter wavelengths, for example, result in increased series resistance and carrier leakage due to electron overshoot over the active region. In optimized LED heterostructures, the electron leakage current has been significantly reduced by the insertion of a large bandgap electron blocking layer (EBL) between the active region and the p-type layers. In addition, p-doping of the EBL has been optimized in order to enable efficient hole injection. Finally, epitaxial growth parameters such as growth rate, reactor pressure, and dopand flows for the AlGaN EBL have been optimized for LEDs emitting in the UV-B spectral range. Since the light of the UV-B LED is emitted through the sapphire substrate, efficient light extraction requires a low absorption loss in the epitaxial AlGaN layers. Therefore, the active region of the LEDs has to be grown on AlGaN buffer layers with an average aluminium mole fraction larger than 40 %. Those layers are difficult to grow with a reasonably low density of threading dislocations. With the introduction of thick AlN buffer layers grown at high temperatures and the use of short-period superlattices made of AlN/GaN or AlN/AlGaN in

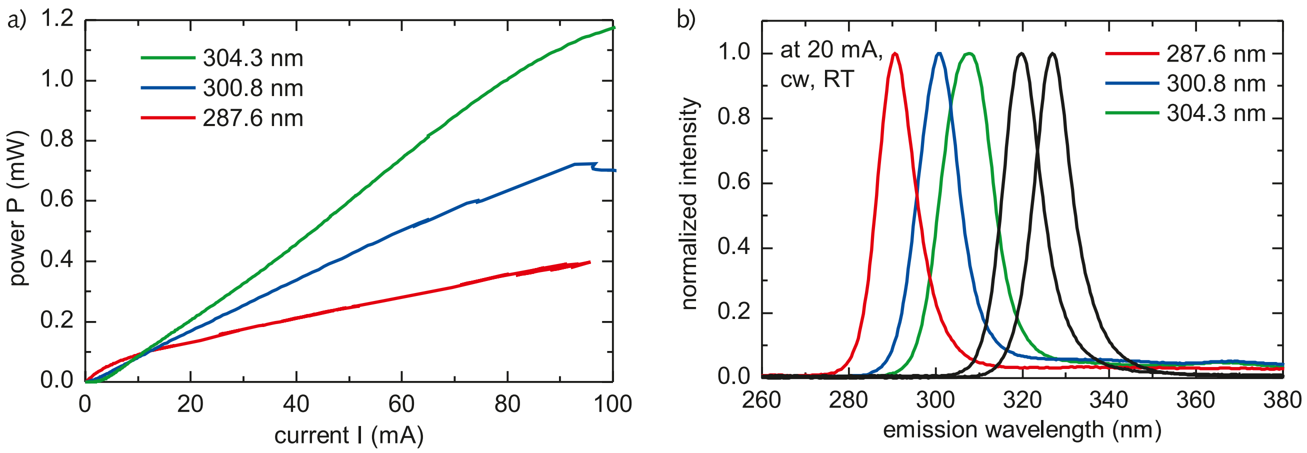

Fig. 1. Light output characteristics (a) and normalized emission spectra at 20 mA (b) for UV LEDs.

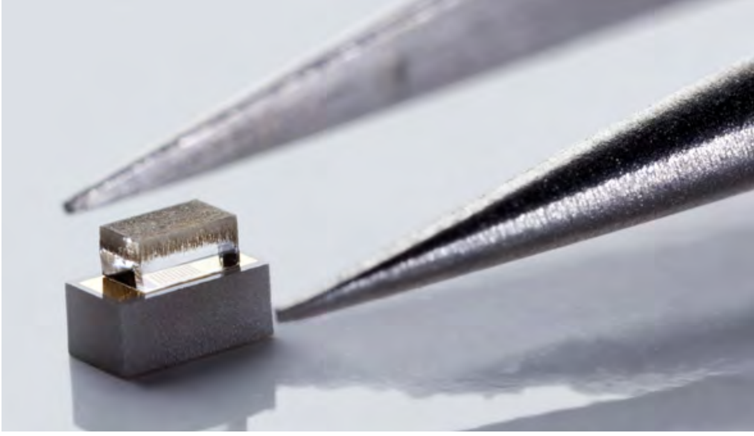

Fig. 2.
UV-B LED flip-chip mounted by AuSn soldering on a structured AlN submount.

combination with thick Si-doped AlGaN buffer layers, we were able to significantly reduce the threading dislocation density in the active region in the range of $10^9\,cm^{-2}$.

Full LED heterostructures have been fabricated with emission wavelengths ranging from 325 to 288 nm. The layer structure currently used for our UV-B LEDs consists of an AlN buffer layer, AlN/AlGaN superlattices, a 4 µm thick n-type $Al_{0.5}Ga_{0.5}N$ buffer layer, an active region of three AlGaN multi-quantum wells, a p-type $Al_{0.6}Ga_{0.4}N$ EBL, a p-type AlGaN/AlGaN superlattice, and a p-type GaN contact layer. As shown in Fig. 1a, on-wafer tests feature an optical output power of more than 1.2 mW for LEDs emitting at 305 nm and about 0.4 mW for the LEDs at 288 nm. The decrease in light output power with shorter emission wavelength can be partly attributed to a reduced injection efficiency due to an unoptimized EBL. Fig. 1b shows the emission spectra of different UV-B and UV-A LEDs. These LEDs exhibit a single peak emission with an FWHM of 10 nm indicating efficient blocking of electron leakage currents and a good spatial uniformity of the quantum wells. Further experiments to enhance the external quantum efficiency of the LEDs are ongoing including the realization of flip-chip mounted LED devices as shown in Fig. 2.

Ultraviolettes (UV) Licht wird unter anderem bei der Wasserdesinfektion, in der Phototherapie und zur Härtung von Lacken verwendet. In enger Kooperation mit der TU Berlin entwickelt das FBH Leuchtdioden (LEDs) auf der Basis von (Al,Ga)N, die in den Wellenlängenbereichen UV-A (320–380 nm) bzw. UV-B (280–320 nm) emittieren. Langfristig können diese LEDs in einigen Bereichen Gasentladungslampen ablösen, da sie kleiner und robuster sind. Zudem benötigen sie keine Hochspannungsquelle und ihre Wellenlänge kann frei eingestellt werden. Im vergangenen Jahr wurden deutliche Fortschritte bei der Erhöhung der Effizienz und der Verringerung der Wellenlänge erzielt. Nachdem das Design der Schichtstrukur sowie deren epitaktische Wachstumsbedingungen optimiert wurden, konnten UV-B LEDs mit einer Emissionswellenlänge von 305 nm und einer maximalen optischen Leistung > 1 mW bei einem Betriebsstrom von 100 mA realisiert werden. Die Bauelemente mit einer Emission bei 288 nm zeigten immer noch eine optische Leistung von 0,4 mW.

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MATERIALS & PROCESSES

MATERIALIEN & PROZESSE

Materialien & Prozesse

Der Schwerpunkt der Aktivitäten in Technologieentwicklung und Materialforschung am FBH liegt auf der Vorlaufforschung zu Materialien und Prozessen. Hier werden die technologischen Voraussetzungen für die gezielte Entwicklung von Bauelementen in den anderen Geschäftsbereichen geliefert. Intensiv wird an Materialien auf der Basis von Galliumnitrid gearbeitet, die in Leistungsbauelementen für Mikrowellen- und Leistungs-Schaltanwendungen, ultravioletten Leuchtdioden (UV-LEDs), Laserdioden und UV-Photodetektoren zum Einsatz kommen. Ein Beispiel für die Materialforschung ist die Entwicklung von Schichtstrukturen für GaN-basierte Hochvolt-Leistungstransistoren, die auf der Entwicklung entsprechender metallorganischer Gasphasenepitaxie(MOVPE)-Prozesse basiert. Zur Herstellung der nitridischen Epitaxieschichten für Bauelemente mittels MOVPE stehen zwei Mehrscheiben-Epitaxieanlagen (AIX 2600 G3 HT) und eine kleinere Einzelwafer-Anlage für explorative Untersuchungen zur Verfügung. Damit können insbesondere Prozesse für bipolare Bauelemente mit p-Dotierung (LEDs, Laserdioden) von solchen für unipolare Bauelemente (GaN-HFETs, Photodetektoren) getrennt bearbeitet werden. Auch an defektarmen AlN- und AlGaN-Schichten als Grundlage für UV-LEDs wird geforscht. Sie sind von zentraler Bedeutung, insbesondere für GaN-basierte Laserdioden. GaN-Kristalle, aus denen solche Substrate herausgeschnitten werden, werden am FBH mittels Hydride Vapor Phase Epitaxy (HVPE) gezüchtet. Diese Technik wird auch eingesetzt, um dicke AlGaN-Schichten als Unterlage für UV-LEDs abzuscheiden.

Im Bereich der Prozesstechnologie konzentrierten sich die Arbeiten auf die Optimierung und Entwicklung von robusten Prozessmodulen für die Fertigung von GaN-basierten Hochleistungstransistoren. Angestrebt sind dabei vor allem eine hohe Reproduzierbarkeit, Ausbeute und Zuverlässigkeit. Bei UV-LEDs und Lasern auf GaN-Basis wurden insbesondere Verfahren für die Herstellung von Ohmschen Kontakten zu p-GaN und n-AlGaN entwickelt. Ein weiterer Schwerpunkt lag auf der Vereinzelung dieser Bauelemente.

2011 wurden zahlreiche vielversprechende Projekte gemeinsam mit Forschungspartnern bearbeitet: So wurde beispielsweise die Entwicklung der (Al)GaN-basierten UV-Photodetektoren fortgeführt. Ziel ist die Weiterentwicklung der Bauelemente sowie ihr Einsatz als Werkzeug zur Materialcharakterisierung. Außerdem zeigte die F&E-Kooperation zur Herstellung von UV-Photodetektoren auf Basis von Siliziumkarbid (SiC) weitere Erfolge. Sie führte zu signifikanten Umsatzsteigerungen beim Industriepartner. Aus der Zusammenarbeit mit der TU Dresden und den Fraunhofer-Instituten IZFP-D und IPMS entstand der Demonstrator eines neuartigen Röntgendetektors. Kernstück sind direkt wandelnde GaAs-Zeilensensoren aus 1024 Pixeln, die am FBH hergestellt wurden. Weiterhin sind GaAs/AlGaAs-Quantenkaskadenlaser für 4,7 THz erfolgreich auf Heterostrukturen des Paul-Drude-Instituts prozessiert worden. Durch optimiertes thermisches Management wird ein Betrieb der Laser oberhalb von 80 K für spektroskopische Anwendungen angestrebt.

InP-basierte Heterobipolartransistoren (HBTs) wurden 2011 in Transfer-Substrat-Technologie realisiert. Sie bilden die Grundlage für die Verifizierung, Anpassung und Erweiterung der Modelle für die Entwicklung von Oszillatoren und Leistungsverstärkern. Diese adressieren z.B. Anwendungen für bildgebende Verfahren bei 70 – 300 GHz. Im SAW-Kontext (Senatsausschuss Wettbewerb der Leibniz-Gemeinschaft) bearbeitet das FBH gemeinsam mit dem Leibniz-Institut für innovative Mikroelektronik (IHP) ein risikoreiches Projektvorhaben zur dreidimensionalen Heterointegration von InP-HBTs in einen Silizium-CMOS-Prozess. Dazu wird ein am FBH entwickeltes Transfer-Substrat-Verfahren adaptiert; zusätzlich ist eine präzise Wafer-zu-Wafer-Ausrichtung erforderlich. In diesem Zusammenhang laufen grundlegende Forschungsarbeiten zu Planarisierungs-, Verbindungs- und Via-Technologien.

Darüber hinaus bietet das FBH weitere externe Dienstleistungen wie Lieferung von Epitaxiewafern, Analytik von Schicht- und Bauelementstrukturen sowie diverse Waferprozesse für Kunden aus Forschung und Industrie an.

Materials & Processes

Activities in development of materials and technology are focused on exploring materials and process modules paving the way for the fabrication of advanced devices. The Materials Technology and Process Technology Departments provide the technological preconditions for the development of devices that are realized in the respective Business Areas. Materials on the basis of gallium nitride (GaN) are subject of intensive research and are utilized for power transistors for microwave and power switching applications as well as laser diodes, UV LEDs, and UV photodetectors. For example, the development of epitaxial layers for GaN power transistors for high operating voltages is based upon the development of corresponding processes in metalorganic vapor phase epitaxy (MOVPE). The variety of different device structures is grown in two multiwafer reactors (AIX 2600 G3 HT) and a smaller single wafer machine for explorative work. This allows separating the work on bipolar devices with p-doped layers (LEDs, laser diodes) from that on unipolar devices (GaN-HFETs, UV photodetectors). Also, AlN and AlGaN layers with reduced defect density for UV LEDs are being developed. They are of pivotal importance, especially for GaN-based laser diodes. At FBH, GaN crystals for such substrates are grown using hydride vapor phase epitaxy (HVPE). This technique is also applied for thick AlGaN layers as basis for UV LEDs.

In device processing, activities were focused on optimization and development of robust and reliable process modules for fabrication of GaN-based high-power transistors with high reproducibility, yield, and reliability. Regarding UV LEDs and GaN laser diodes, process developments for the formation of ohmic contacts to p-GaN as well as to n-AlGaN were in focus. Another important issue was chip separation of LEDs and GaN laser diodes.

In 2011, further promising joint projects have been worked on together with research partners. For instance, the development of (Al)GaN photodetectors both as device and tool for the characterization of epitaxial layers has been continued. Another R&D cooperation on fabrication of UV photodetectors based on silicon carbide (SiC) has been successfully continued and significantly increased the sales volume of our industrial customer. In collaboration with TU Dresden and the Fraunhofer institutes IZFP-D and IPMS, a demonstrator of a novel X-ray detector using directly converting GaAs line sensors with 1024 pixels has been developed. The GaAs chips were processed at FBH in a 4-level process on 4″ wafers. Additionally, FBH has successfully processed GaAs/AlGaAs quantum cascade lasers for 4.7 THz on heterostructures grown at Paul-Drude-Institute. Due to optimized thermal management these lasers are targeted for spectroscopic applications at operation temperatures above 80 K.

InP-based hetero bipolar transistors (HBTs) have been processed in transferred substrate technology. They are now available for evaluation, modification, and extension of models for the development of oscillators and power amplifiers. The devices address, for example, imaging applications at 70–300 GHz. In the context of SAW (Senate Competition Committee of the Leibniz Association), FBH and Leibniz-Institut für innovative Mikroelektronik (IHP) collaborate in a high-risk project on three-dimensional hetero integration of InP-HBTs into a silicon-CMOS process. To this end, the transferred substrate technology developed at FBH is adapted to the precise wafer-to-wafer alignment necessary for this integration scheme. Basic research on planarization, assembling, and via technologies is additionally underway.

Besides basic developments in epitaxy and process technology, external services such as delivery of epitaxial wafers, customer-related wafer processes, and analysis of device structures continued to be an integral part of FBH's work in the materials and processes field.

Boule-like growth of GaN by HVPE

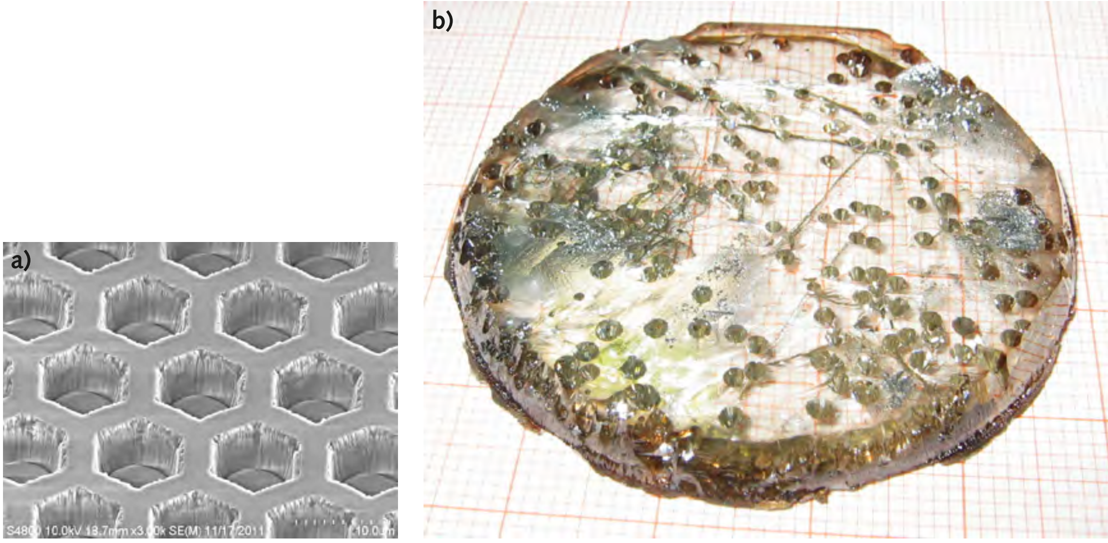


Fig. 1. SEM micrograph of patterned sapphire substrate (PSS) surface a) as used for subsequent growth of a 4.2 mm thick, undoped GaN boule shown as a photo in b).

Gallium nitride (GaN)-based devices are essential components in a great variety of modern applications. Blue-violet laser diodes, for example, are used for data storage (blu-ray discs) as well as for novel entertainment technologies like RGB laser projection. Ultra-high brightness LEDs are employed for solid-state lighting, and power transistors based on GaN are core devices in electric power converters that are integrated in practically every electric and electronic system. Such highly efficient power converters help us to cut the usage of energy and are therefore indispensable for energy-efficient conversion. Applications range from converters in solar systems, wind power stations, and modern electric vehicles (green car) to power supplies in mobile base stations and computer systems. No matter how different these applications are, they are all based on high-end group III-nitride devices. Their realization requires or can essentially profit from the growth on a native GaN substrate with a very low threading dislocation density (TDD) and a high thermal conductivity.

Hydride vapor phase epitaxy (HVPE) of GaN is an established method towards high-quality GaN substrates since they cannot yet be produced by standard crystal growth techniques. In HVPE, the formation of GaN bases on the chemical reaction of gallium (Ga) with hydrogen chloride (HCl) followed by the reaction with ammonia (NH_3). The technique provides a sufficiently high growth rate and good scalability. In order to take full economic and technical benefit from the HVPE method, leading manufacturers are shifting currently from wafer-by-wafer production to cutting substrates from several mm thick GaN crystals which show an improved structural quality. However, due to the lack of commercially available equipment and corresponding fully developed growth procedures, this approach using extended HVPE processes is no mature technology yet.

The FBH has thus supported the development of a vertical HVPE reactor by AIXTRON from the first prototype to the current production type model. In the past, processes for GaN starting layers on sapphire by metal organic vapor phase epitaxy (MOVPE) and boule-like GaN crystals of about 50 mm in diameter and more than 6 mm length have already been developed at FBH. The respective HVPE process uses a growth rate of 450 µm/h and produces GaN crystals with excellent material properties. The investigation and optimization of these processes has been continued in 2011. This included in-depth analysis of different defect types and their origins as well as the development of patterned sapphire substrates to reduce the defect formation during boule growth (Fig. 1) and the introduction of doping with silicon (Si) targeting the fabrication of n-type wafer material (Figs. 2 and 3). Fig. 1a contains a SEM micrograph of a patterned sapphire substrate (PSS) surface and Fig. 1b shows a 4.2 mm thick non-intentionally doped GaN boule grown on such a PSS. Fig. 2a depicts an intentionally Si-doped 7 mm thick GaN boule with a free electron density of about 1×10^{18} cm^{-3} together with one of the unpolished, near 2″ wafers in Fig. 2b, which have been cut out of this crystal by a partner. The diagram in Fig. 3 summarizes data of carrier concentration, mobility, and in-plane lattice constants (determined by X-ray diffraction) obtained from 1 mm thick Si-doped GaN layers which prove that high mobilities without significant incorporation of in-plane strain have been achieved. Tensile in-plane lattice strain is below $+10^{-4}$ as long as the measured lattice constant is below the dashed red line in the graph. This is an important result

Fig. 2a. 7 mm thick Si-doped, n-type GaN boule.

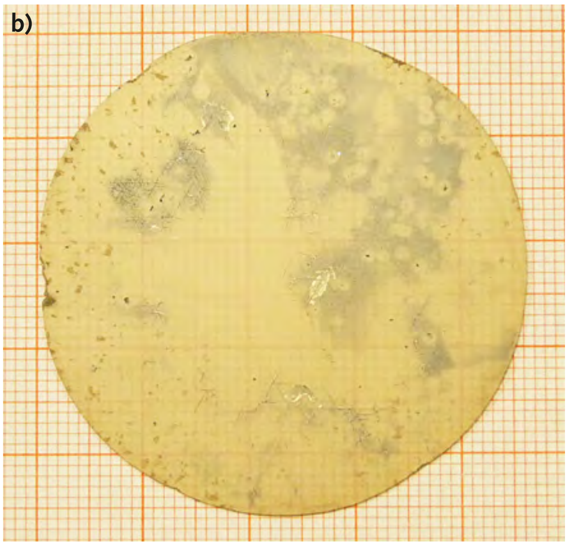


Fig. 2b. Near 2-inch unpolished substrate cut (by FCM) from GaN boule shown in 2a).

since Si as a dopant for GaN is currently generally discussed. Si is suspected to be the reason of observed tensile strain, i.e. values of in-plane lattice constants remarkably above the red dashed line in Fig. 3, resulting in early and detrimental crack formation in GaN layers grown by different epitaxial techniques. Although there is still a number of issues for further improvement, our experimental results support a dislocation-related model for the strain in Si-doped GaN layers and demonstrate the suitability of Si for GaN boule growth at high rates.

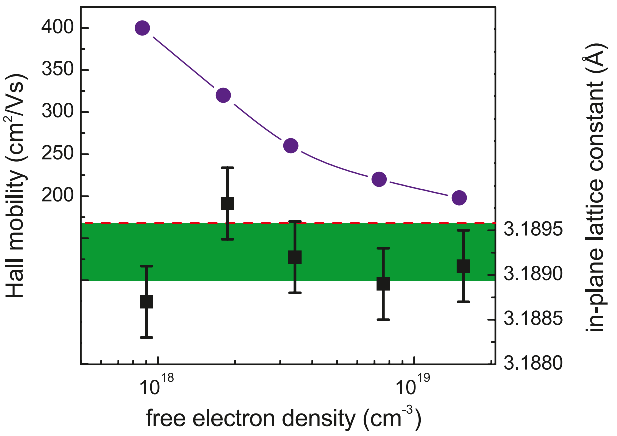


Fig. 3. Mobility and in-plane lattice constants vs. free electron density at room temperature. Green band: relative deviation of the ideal lattice constant within $\pm 1 \times 10^{-4}$; red dashed line: upper limit for material with negligible tensile strain.

Blau-violette Laserdioden für Datenspeicherung und Laserprojektion, sparsame LEDs zur Beleuchtung und effiziente Leistungsschalter für Elektroautos sollen helfen, den allgemeinen Energieverbrauch zu senken. Die Effizienz solcher GaN-basierter Bauelemente kann durch GaN-Substrate mit geringer Defektdichte erhöht werden. Allerdings sind derartige Substrate mit gängigen Kristallzüchtungsmethoden derzeit nicht herstellbar. Daher wird die Hydrid-Gasphasenepitaxie (HVPE) zur Herstellung dicker Schichten genutzt, die jeweils ein Substrat liefern. Weltweit wird daran gearbeitet, GaN-Kristalle zu züchten, aus denen dann viele Substrate herausgeschnitten werden können. Das FBH hat seine Arbeiten auf diesem Feld auf die Herstellung von n-dotierten Kristallen ausgedehnt. Neben den dabei erzielten guten elektrischen Eigenschaften ist ein wichtiges Ergebnis, dass mit dem üblichen Dotierstoff Silizium auch Kristalle mit mehr als 6 mm Dicke ohne erhöhte Verspannung und Rissbildung hergestellt werden können.

PUBLICATIONS

→ E. Richter, M. Gründer, B. Schineller, F. Brunner, U. Zeimer, C. Netzel, M. Weyers, G. Tränkle, **"GaN boules grown by high rate HVPE"**, Phys. Status Solidi C 8, 1450 (2011).

→ E. Richter, M. Gründer, C. Netzel, M. Weyers, G. Tränkle, **"Growth of GaN boules via vertical HVPE"**, J. Cryst. Growth, vol. 350, no. 1, pp. 89-92 (2012).

Steps towards $Al_xGa_{1-x}N$ substrates grown by HVPE

In the last years, the epitaxial growth of $Al_xGa_{1-x}N$-based light emitting diodes for the ultra-violet spectral range (UV LEDs) became increasingly attractive. This interest is mainly raised by the potential of UV LEDs to replace toxic mercury vapor lamps for applications like water purification and UV curing. Unfortunately, their efficiency is highly affected by material imperfections. Applying a high-quality substrate as starting material with an in-plane lattice constant similar to that of the active $Al_xGa_{1-x}N$ region of the device structure can lower strain-induced imperfections and therefore enhance the light output efficiency of the LEDs. Ideal substrate materials are GaN, AlN, and $Al_xGa_{1-x}N$. Until now, such substrates cannot be fabricated by conventional methods like pulling from the melt. GaN and AlN substrates can both be grown by hydride vapor phase epitaxy (HVPE). Hence, HVPE is also expected to permit growth of thick $Al_xGa_{1-x}N$ layers, e.g. in a medium composition range (x ~ 0.5), that may serve as lattice-matched substrates especially for LEDs emitting in the UV-B spectral range between 290 nm and 340 nm.

Only about four groups worldwide investigate the growth of $Al_xGa_{1-x}N$ by HVPE. Information about growth setup and properties of the grown layers are rare. Hence, the growth of thick $Al_xGa_{1-x}N$ is a challenging task, but offers the possibility to provide improved substrate material that could help to enhance the efficiency of UV LEDs. In our HVPE reactor (Fig. 1) $Al_xGa_{1-x}N$ layers are deposited by the reaction of $AlCl_3$ and GaCl with NH_3 on a sapphire substrate. Besides a lot of preferable properties of sapphire like transparency to UV light, temperature stability, and its low costs, the main disadvantage is a relatively high lattice mismatch towards $Al_{0.5}Ga_{0.5}N$ of about 13 %.

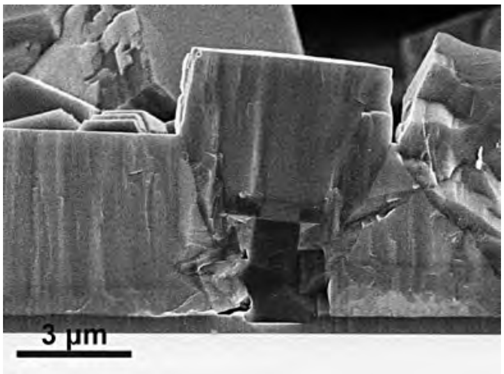


Fig. 2. $Al_{0.45}Ga_{0.55}N$ with AlN buffer layer grown on planar sapphire.

We investigated the growth of 5 µm thick $Al_{0.45}Ga_{0.55}N$ grown at 30 µm/h on sapphire substrate. Due to the high lattice mismatch at the interlayer, the $Al_{0.45}Ga_{0.55}N$ layers grown directly on sapphire show extended cracks, a rough surface, and a poor crystal quality. Furthermore, a lateral inhomogeneity in the composition caused by the formation of GaN-rich areas was detected by a reduced transmissivity for wavelengths shorter than 360 nm. From literature an AlN buffer layer introduced before $Al_xGa_{1-x}N$ growth is known to improve the $Al_xGa_{1-x}N$ quality by changing the strain in the layer. Hence, a high temperature AlN buffer layer of 500 nm thickness was introduced at the growth start. The introduction of the AlN buffer leads to an improved $Al_{0.45}Ga_{0.55}N$ crystal quality. In particular, extended cracks are avoided and a homogeneous composition distribution is reached. Unfortunately, the surface of that layer is disturbed by misoriented crystallites, like shown in the cross section in Fig. 2, leading to a polycrystalline surface when growing thicker layers. One possible reason is that microcracks that are decorated by

Fig. 1. HVPE reactor for $Al_xGa_{1-x}N$ growth.

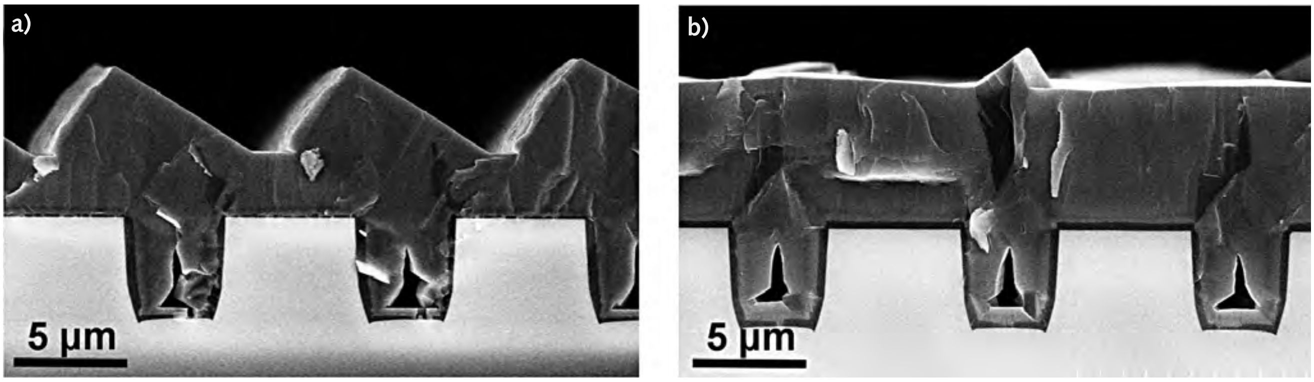


Fig. 3. $Al_xGa_{1-x}N$ layers grown at a total pressure of 800 hPa a) und 400 hPa b) on trench patterned sapphire.

tilted material occur in the AlN buffer layer. Consequently, to avoid microcracks, an additional strain relief is necessary. Therefore, the epitaxial lateral overgrowth (ELO) of patterned sapphire was studied.

Growth of isolated islands on the pattern that only later coalesce to a closed layer reduces the strain between epitaxial layer and substrate. The pattern with 4 µm deep and 4 µm wide trenches is etched into the sapphire substrate leaving 6 µm wide ridges. $Al_{0.45}Ga_{0.55}N$ layers with AlN buffer layer were grown on that pattern under the same conditions as used before for planar growth. The overgrowth of the trenches results in the surface structure shown in Fig. 3a. $Al_xGa_{1-x}N$ growth takes place on the sidewalls of the trenches. This growth of misoriented material on the sidewalls is dominant over the growth on the ridges and leads to the saw tooth-like surface. From GaN growth an impact of the total pressure on the habit of the ELO-grown material is expected. The cross section images in Fig. 3 illustrate that with reduction of the total pressure from 800 hPa to 400 hPa much smoother layers are achieved. At 400 hPa the growth from the ridges dominates over the sidewall growth. No cracks were found in the layer.

By introduction of an AlN buffer layer and a trench-patterned substrate, 6 µm thick $Al_{0.45}Ga_{0.55}N$ layers without cracks can be grown that are transparent for light with wavelengths longer than 290 nm. With further improvement in morphology, such layers can be used as templates for LEDs emitting in the 300 nm wavelength region.

Leuchtdioden (LEDs), die ultraviolettes Licht erzeugen, könnten giftige Quecksilberlampen in vielen Anwendungen ersetzen. Dank dieses Potenzials ist das Interesse an derartigen UV-LEDs in den vergangenen Jahren deutlich gestiegen. Insbesondere $Al_xGa_{1-x}N$ im mittleren Kompositionsbereich (x ~ 0.5) mit hoher Materialqualität wäre ein ideales Ausgangsmaterial für die Herstellung von UV-B-LEDs mit höherer Effizienz. Am Ferdinand-Braun-Institut wird daher das Wachstum geeigneter $Al_{0.45}Ga_{0.55}N$-Schichten untersucht. Auf Saphir-Substraten werden dabei verspannungsinduzierte Materialdefekte in den Schichten beobachtet. Das Einfügen eines AlN-Puffers, die Verwendung eines strukturierten Saphir-Substrats und die Optimierung des Prozessdrucks verbessern die Materialqualität jedoch erheblich. Mittels dieser Optimierungsschritte wurden rissfreie AlGaN-Schichten von 6 µm Dicke gewachsen, die transparent für Licht mit einer Wellenlänge größer 290 nm sind und sich damit als Unterlage für LEDs mit Emission um 300 nm eignen.

PUBLICATION

➜ S. Hagedorn, E. Richter, D. Prasai, W. John, M. Weyers, **"HVPE of $Al_xGa_{1-x}N$ layers on planar and trench patterned sapphire"**, submitted to Journal of Crystal Growth (2012).

UV-C AlGaN photodetectors for disinfection and medical applications

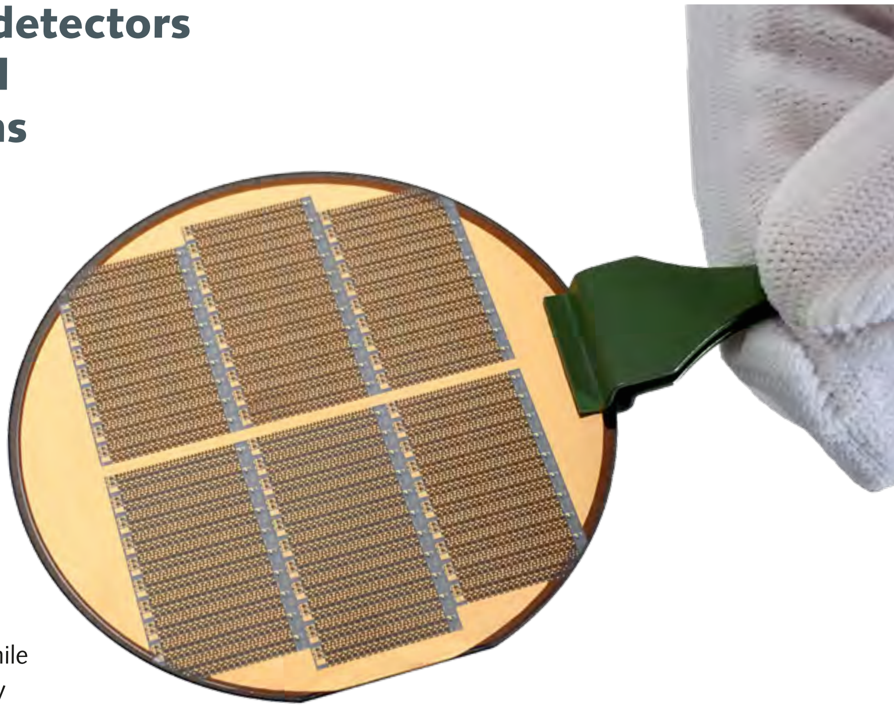


Fig. 2. Sapphire wafer with AlGaN photodetectors with interdigital structures.

Photodetectors for the UV spectral region are required to control high-power UV lamps, UV LEDs, and excimer lasers. Applications range from UV lithography, disinfection to medical utilizations. For water purification, the wavelength range between 240 nm and 290 nm is relevant (see Fig. 1). Shorter wavelengths are absorbed in water while longer wavelengths have minor germicidal effect. Any monitoring detector thus must be blind above 290 nm. SiC photodetectors have an intrinsic cut-off wavelength of 400 nm and require expensive and unreliable optical filters to suppress the biological ineffective UV-A and UV-B light. Using AlGaN, the direct band gap can be adjusted by the aluminum composition to obtain the required sensitivity characteristics.

The FBH develops solar blind, UV-C AlGaN MSM (metal-semiconductor-metal) photodetectors. These devices have two interdigitated Schottky contacts on non-intentionally doped absorber layer and require only few processing steps. The metal contacts are built as interdigital structures with 400 µm finger lengths, 2 µm finger width and different finger distances. For UV-C photodetectors 1.4 µm thick AlGaN absorber layers with 40 % aluminum were deposited by MOVPE on sapphire substrates with AlN buffer layers. Platinum, titanium, and gold are used for Schottky metallization (Fig. 2).

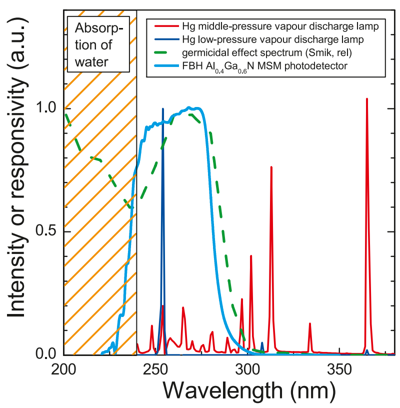


Fig. 1. For water disinfection: spectra of Hg lamps, germicidal effect (data from JENOPTIK Polymer Systems GmbH), and AlGaN MSM photodetectors.

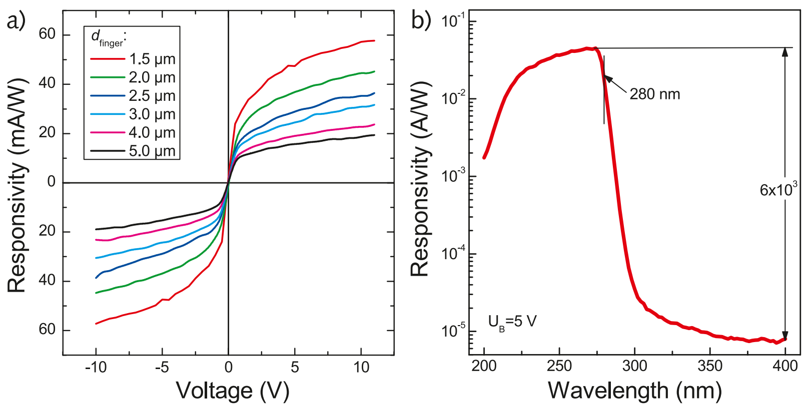


Fig. 3. Responsivity of MSM photodetectors with $Al_{0.4}Ga_{0.6}N$ absorber layer a) in dependence on the bias voltage for different finger distances and b) spectral behavior.

MSM photodetectors with different finger distances were analyzed in dependence of the bias voltage. As seen in Fig. 3a, the responsivity R for light with 275 nm wavelength increases with the bias voltage. For a fixed bias the responsivity is higher for smaller finger distances, which is caused by a short carrier lifetime in comparison to the transit time and low carrier mobility in such highly Al containing AlGaN absorber layers with relatively high defect densities. With X-ray diffraction measurements the edge dislocation density is estimated to be about 10^{10} cm^{-3}. Nevertheless, the responsivity of the MSM-detector with 2 µm finger distance is 45 mA/W at a bias voltage of 5 V commonly used for MSM photodetectors. The responsivity spectrum has a broad plateau for the desired spectral range from 240 nm to 290 nm (Fig. 3b). This detector is solar blind and the ratio between the responsivity at 275 nm and visible light (above 400 nm) is higher than 10^3. Additionally, the photocurrent linearly increases with the incident power density and the responsivity is independent from the incident power up to the measurement limit of 35 µW/cm^2.

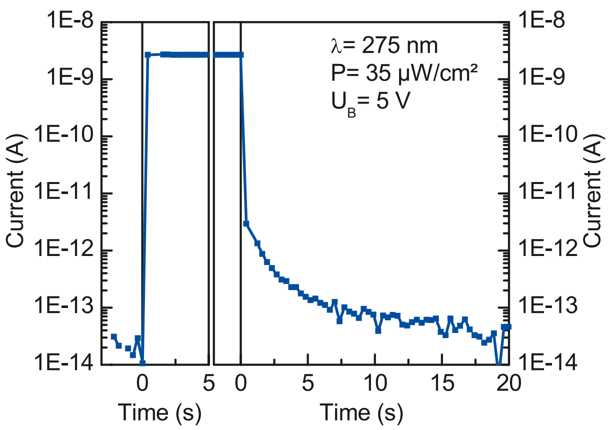


Fig. 4. MSM photodetectors with $Al_{0.4}Ga_{0.6}N$ absorber layer: time transients for switching on and off the illumination.

Fig. 4 shows the time transients for switching such detectors. Before illumination, the dark current is lower than 100 fA. By starting the illumination, the photocurrent increases to the ON-level within one measurement interval of 300 ms. After switching the illumination off the photocurrent drops about three orders of magnitude in 300 ms. The remaining photocurrent decreases due to persistent photo conductivity (PPC) with time constants of several seconds, caused i.e. by charging/decharging of traps in the material or at the surface. The level of PPC and the involved time constants are found to vary significantly for different detector configurations and are subject of ongoing studies. However, the photodetectors for the 240–290 nm wavelength region show dynamics that are sufficiently fast for the targeted applications.

The AlGaN photodetector activities are funded by the BMBF within the Berlin WideBaSe initiative (03WKBT02C).

Photodetektoren für den UV-C-Spektralbereich werden zur Überwachung von Hochleistungs-UV-Lampen, -LEDs und Excimerlasern benötigt. Sie kommen in der UV-Lithographie, bei der Desinfektion und in medizinischen Anwendungen zum Einsatz. Für die Wasserdesinfektion etwa ist der Wellenlängenbereich von 240 nm bis 290 nm besonders interessant. Licht mit kürzerer Wellenlänge wird im Wasser absorbiert, für Licht längerer Wellenlängen sind Mikroben unempfindlich. Bisher verwendete SiC-Detektoren haben eine Kantenwellenlänge von 400 nm und benötigen zur Unterdrückung der Spektralbereiche UB-A und UV-B relativ teure, nicht langzeitstabile Kantenfilter. Das FBH entwickelt derzeit AlGaN-Photodetektoren, bei denen die Kantenwellenlänge direkt über die Al-Komposition eingestellt werden kann. Diese neuen solarblinden UV-C-Photodetektoren vom Typ MSM zeichnen sich durch einen sehr geringen Dunkelstrom und eine hohe, von der überwachten Lichtleistung unabhängige Empfindlichkeit aus. Die derzeit nachgewiesene Antwortzeit der Detektoren ist bereits für die meisten Anwendungen ausreichend.

Line sensors for novel X-ray detectors

Modern production methods such as automated handling systems for automobile manufacture commonly use X-ray detectors for quality surveillance. Such systems require line sensors to monitor, for example, welded joints and residual stress of complex components. The FBH developed line sensors for innovative X-ray detectors in close cooperation with the Electronics Packaging Laboratory (IAVT) of the Technical University Dresden. In 2011, a new generation of directly converting line detectors has been demonstrated. These devices eliminate the disadvantages of present sensor systems that utilize scintillator and photo detector. Key benefits of the GaAs-based sensors are a very low cross-talk between adjoining pixels, their simple construction, and an extended lifetime of the detector chips. Within the system demonstrated, the sensors directly convert X-ray photons into charge carriers with a lateral resolution of 100 µm per pixel.

Between top and bottom contacts of the GaAs sensor, an operation voltage of up to 400 V is applied. As depicted in Fig. 1, charge carriers created by X-rays are separated by the electrical field and induce current pulses. Using integrated circuitry the pulses are evaluated and the number of counts per pixel can be read out. The demonstrator shown in Fig. 2 comprises a sensor with 1024 pixels and has been set up with the Fraunhofer Institutes IZFP-D and IPMS that developed amplifier and evaluation electronics.

At FBH, a 4-level process for chip fabrication has been developed and realized on 4″ GaAs wafers. The basic device comprises 32 pixels formed by 80 µm wide pads of Schottky contacts featuring a pitch of 100 µm on top (Fig. 3). A continuous ohmic contact is made on the bottom side. To achieve supply voltages of up to 400 V, a passivation layer was deposited on the top side and the back contact was adapted to chip size. The contact design with circular openings of the passivation layer on the pads allows both wire bonding and flip-chip mounting.

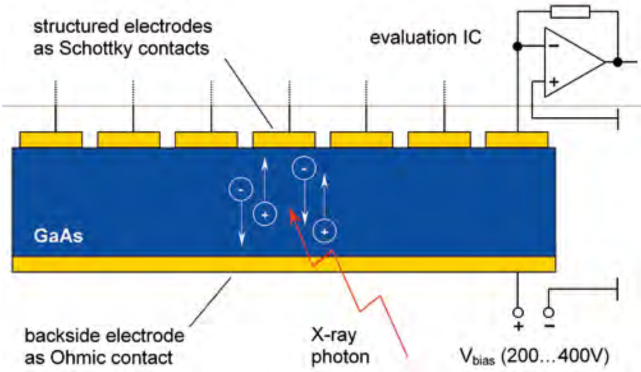


Fig. 1. Working principle of a directly converting sensor.

The building blocks of the devices with 32 pixels were precisely assembled to about 10 cm long line sensors with 1024 pixels. A constant pixel grid pattern of 100 µm was formed. As an important prerequisite a reliable gap of 20 µm between adjacent pixels at the assembling position had to be obtained. Thus, the processed wafer had to be separated accurately into single chips. Conventional wafer dicing like wafer sawing turned out not to be appropriate for this application due to unpredictable abrasion of the dicing blades during processing, which has to be taken into account already in the wafer layout.

At FBH, edge-emitting laser devices are separated by scribing with diamond and subsequent breaking. This method yields flat,

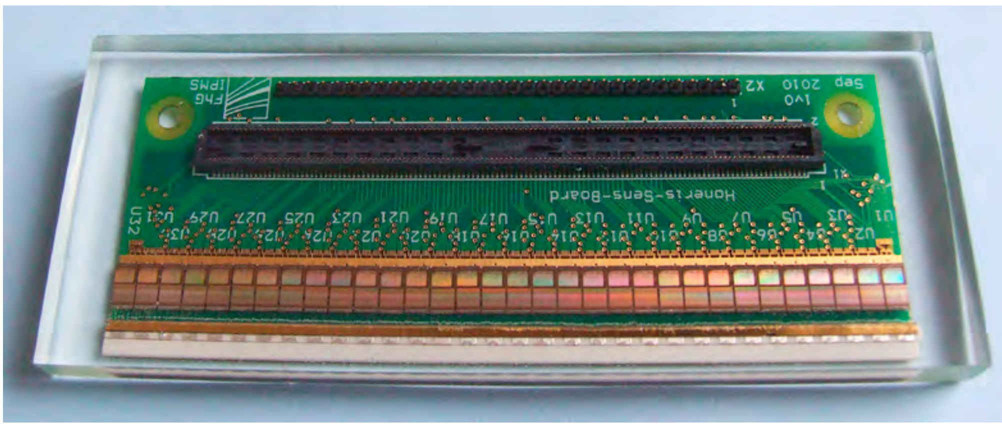


Fig. 2. Directly converting line detector with 1024 pixels and a lateral resolution of 100 µm.

reflecting facets without any loss of material and makes it thus interesting for chip separation for the X-ray detectors, too. In this case, an exact alignment of the wafer layout with respect to the orientation of the crystal structure is essential. This requires a precisely fabricated wafer flat by the manufacturer as it indicates the orientation of the crystal.

Chip separation by scribing and breaking has been successfully demonstrated for single detectors. Single chips have been assembled without difficulties. The width of only 10 µm for cleaving is determined by a passivation layer to prevent short circuits at the sensor's ends. In this particular design, the passivating layer exceeds the contact area by 5 µm and leaves 10 µm wide cleaving streets between the single chips uncovered (Fig. 3). Thus, scribing and breaking has to be performed very accurately because scratching or scribing the passivation layer leads to flaking and damaged breaking edges. By using this separation technology, sensor chips with 512 pixels featuring a length of about 5 cm and a width of 1.4 mm were manufactured. In this case, only two chips had to be assembled to yield a 1024 pixel line sensor, which simplifies the fabrication significantly.

Current research is focusing on direct converting X-ray line detectors for real-time X-ray scanners that non-destructively inspect and evaluate electronic and pharmaceutical packages. Such fast, reliable, and low-cost systems are also interesting for quality control, e.g., in food industry to check for unwanted bone fragments after meat processing and to detect shards and metal fragments in food cans. Building blocks of 32 or 512 pixels could also be arranged in a curved way so that radiation can be detected directionally. One can further think of very long line detectors for special applications in research and industry. For this reason, detectors with more than 10,000 pixels and a length of up to one meter are projected. Besides, different packaging concepts are under investigation to increase radiation hardness of the whole system by shielding the X-ray sensitive evaluation electronics and use devices that are resistant to X-rays.

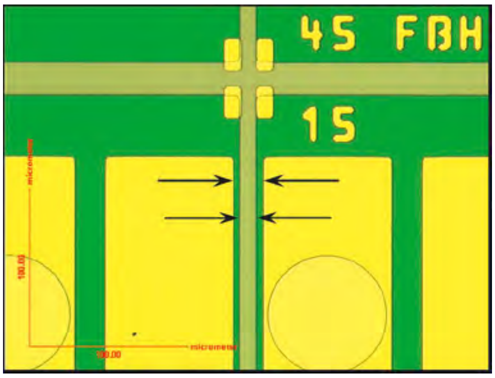


Fig. 3. Detail of a 32 pixel chip before separation (pixel distance: 20 µm, width of cleavage line: 10 µm).

In enger Zusammenarbeit mit Forschungspartnern entwickelte das FBH Sensorstreifen für neuartige Röntgendetektoren, die beispielsweise in der industriellen Fertigung für Materialprüfungen genutzt werden. 2011 wurde eine neue Generation direkt wandelnder Zeilensensoren demonstriert, die die Nachteile bisheriger Sensoraufbauten beseitigen. Vorteile sind insbesondere ein sehr geringes Übersprechen zwischen benachbarten Pixeln, der einfachere Aufbau sowie eine längere Lebensdauer der Detektorchips. GaAs-Sensoren wandeln hierbei Röntgenphotonen mit einer lateralen Auflösung von 100 µm je Pixel direkt in Ladungsträger um. Am FBH wurden die Sensorstreifen auf 4" GaAs-Wafern hergestellt. Mittels strukturierter Kontakte auf der Vorder- und Rückseite der Chips werden die erzeugten Ladungsträger detektiert. Die Kontakte sind so konzipiert, dass die Anbindung sowohl über Gold-Bonddrähte wie auch über Flip-Chip-Montage möglich ist. Ein besonderes Augenmerk galt der präzisen Vereinzelung der Sensoren durch Ritzen und Brechen, um die separierten Chips mit einem konstanten Kontaktabstand wieder aneinander reihen zu können. Detektoren mit 10.000 Pixeln und bis zu einem Meter Länge, die z.B. bei der Echtzeitüberwachung in der Lebensmittelverarbeitung benötigt werden, sind in Planung.

InP high-speed transistors and integrated circuits in transferred substrate technology

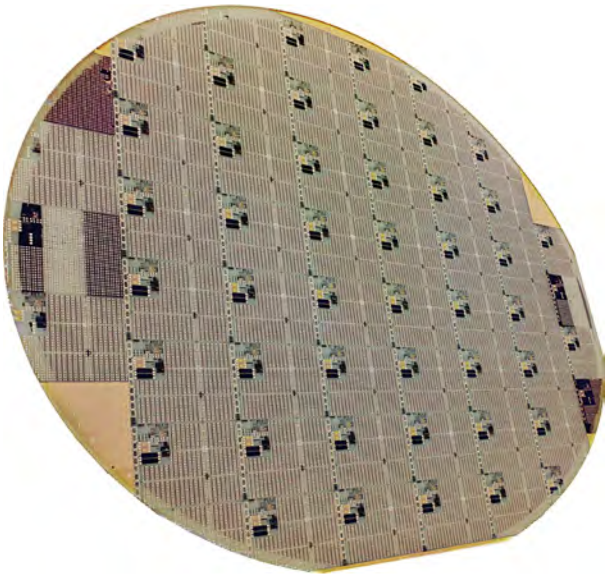
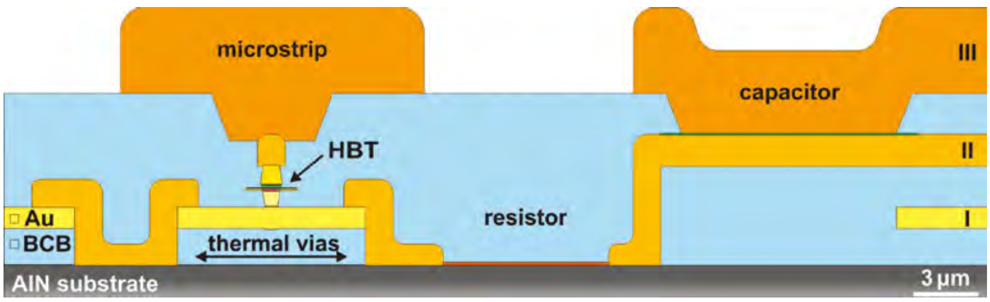


Fig. 2. Homogeneous and void-free 3″ wafer bond of fully processed InP-HBTs and integrated circuits on AlN substrate in transferred substrate technology.

Research on high-speed transistors is driven by applications for imaging and wide band communications. Recent technical advances of InP-based transistors with several hundred gigahertz (GHz) operating frequencies together with their outstanding material properties qualify them for key components in such systems. The long-term goal is to unlock the "terahertz gap"—the almost unutilized range between optics and electronics from 0.1 to 3 THz of the electromagnetic spectrum. This range of millimeter und sub-millimeter wavelengths provides wider bandwidth and improved spatial resolution. Concealed objects can be detected due to specific absorption and transmission properties. Imaging systems are projected in medical, security, and industrial inspection. Further applications comprise wireless high bit-rate and secure short-range communications.

In transistors, signal currents are generated by modulating the electron flow through depletion regions. The resulting displacement currents are coupled to the periphery via metal to semiconductor contacts. Device bandwidth is thus determined by depletion layer transit times and capacitances, by bulk and contact resistivities, and by current handling capabilities as well as device heating. Consequently, bandwidth is increased by lithographic scaling of junction dimensions, thinning of epitaxial layers, and by reducing ohmic as well as thermal resistances. At FBH, a transferred substrate technology has been established to address these issues with little compromise in order to open up the THz gap. The 3″ wafer-level process enables lithographic access to both the front- and backside of the heterojunction bipolar transistors (HBT) aligned to each other. The resulting linear device set-up in Fig. 1 eliminates dominant transistor parasitics and relaxes design trade-offs. The essential step for gaining frontal access to

Fig. 1. Schematic cross-section of the transferred substrate technology platform ready for MMIC processing.



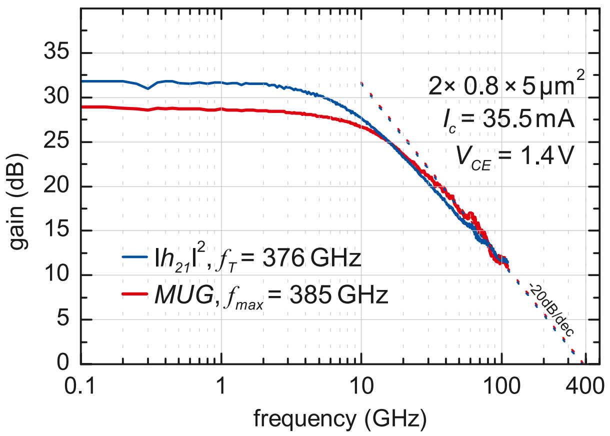


Fig. 3. *Short circuit current gain $|h_{21}|^2$ and maximum unilateral gain (MUG) with extrapolated f_T and f_{max} of a 2 × 0.8 × 5 µm² emitter area of an InP transferred substrate HBT.*

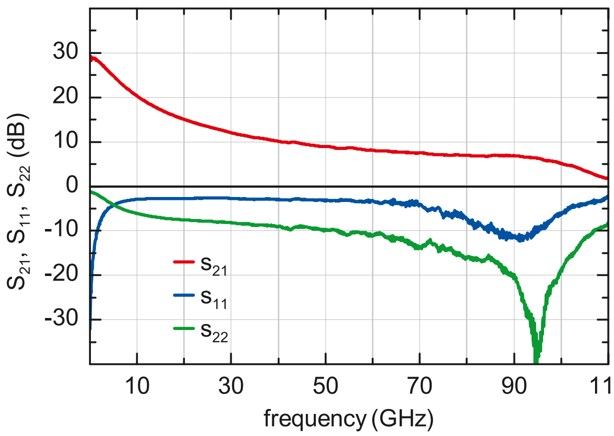


Fig. 4. *S-parameter measurement of a power amplifier in transferred substrate technology designed for 90 GHz operation.*

both sides of the epitaxial structure is the transfer of the substrate. Therefore, a robust adhesive wafer bonding procedure via benzocyclobutene (BCB) has been developed. It yields a homogenous, crack- and void-free composite matrix of transistors transferred on a wafer-level scale, which is shown in Fig. 2. Along with the innovative transistor set-up, a three-dimensional integration scheme supports functionality of the active devices and paves the way towards multi-functional composite electronics. For example, 3D heterogeneous integrated circuits of InP-HBT with BiCMOS technology are currently under development in an ongoing project.

The optimized device topology manifests in excellent HBT performance. Transistors of 2 × 0.8 × 5 µm² emitter area in Fig. 3 feature f_T = 376 GHz and f_{max} = 385 GHz at breakdown voltages BV_{CEO} > 4.5 V. They combine high frequency performance with saturated output power P_{out} > 14.2 dBm @ 77 GHz and an inherently good matching to 50 Ω. The highly scalable device architecture is capable to even further increase high frequency as well as power performance in the future. In addition, power amplifiers have been designed and realized in transferred substrate technology for 90 GHz operation. Their S-parameter measurements shown in Fig. 4 confirm good agreement with modeling.

The transferred substrate approach relaxes design trade-offs, offers excellent performance, and serves as a technology platform for complex 3D microintegration. The presented results prove the availability of the transferred substrate technology for advanced millimeter-wave circuit design.

Transistoren mit mehreren hundert Gigahertz (GHz) Betriebsfrequenz erschließen neue Anwendungen in der breitbandigen Datenübertragung und bei bildgebenden Systemen. Dank ihrer hervorragenden Materialeigenschaften nehmen InP-basierte Transistoren hier eine Vorreiterrolle ein. Am FBH wurden deren Höchstfrequenzeigenschaften mittels einer 3″ Substrat-Transfer-Technologie optimiert. Diese ermöglicht es insbesondere, die Bauelemente durch den lithographischen Zugang sowohl zu deren Vorder- als auch Rückseite linear aufzubauen.

Die optimierte Bauelementtopologie schlägt sich in exzellenten Leistungsmerkmalen nieder: Transistoren mit einer Emitterfläche von 2 × 0.8 × 5 µm² weisen ein f_T = 376 GHz und f_{max} = 385 GHz und eine Durchbruchsspannung von BV_{CEO} > 4.5 V auf. Bei guter inhärenter 50 Ω-Anpassung liefern die Transistoren eine Ausgangsleistung P_{out} > 14.2 dBm @ 77 GHz im Sättigungsbetrieb. Messungen an Leistungsverstärkern bestätigen die gute Übereinstimmung mit dem 90 GHz-Schaltungsentwurf.

PUBLICATIONS

→ T. Kraemer, M. Rudolph, F. J. Schmueckle, J. Wuerfl, G. Traenkle, **"InP DHBT process in transferred substrate technology with f_t and f_{max} over 400 GHz"**, IEEE Trans. Electron Devices, vol. 56, no. 9, pp. 1897–1903, (2009).

→ T. Kraemer, C. Meliani, F. J. Schmueckle, J. Wuerfl, G. Traenkle, **"Traveling wave amplifiers in transferred substrate InP-HBT technology"**, IEEE Trans. Microw. Theory Tech., vol. 57, no. 9, pp. 2114–2121, (2009).

BUSINESS AREAS & RESEARCH

GESCHÄFTSBEREICHE & FORSCHUNG

SCIENCE MANAGEMENT

WISSENSCHAFTSMANAGEMENT

Wissenschaftsmanagement

Die Abteilung Wissenschaftsmanagement bietet umfassende Dienstleistungen in den Bereichen Strategie, Technologietransfer und Marketing sowie Bildung. Strategisch berät und unterstützt die Abteilung die Institutsleitung sowie Wissenschaftlerinnen und Wissenschaftler am FBH bei Industrieprojekten, Fördervorhaben und beim Aufbau von F&E-Kooperationen. Sie positioniert das Institut in lokalen, regionalen, nationalen und internationalen Netzwerken und erhöht so die öffentliche Sichtbarkeit des Ferdinand-Braun-Instituts. Auch Forschungs- und Unternehmenspartner des FBH profitieren von den Aktivitäten des achtköpfigen Teams. Die interdisziplinär aufgestellte Gruppe übernimmt administrative und nicht-wissenschaftliche Arbeiten, die bei der Beantragung komplexer Verbundvorhaben, der Koordination nationaler und internationaler Projektverbünde oder bei der Entwicklung und dem Management solcher Vorhaben anfallen.

Durch das im Oktober 2011 neu ausgerufene Cluster Optik Berlin-Brandenburg und die Ernennung von Prof. Tränkle zum Clustersprecher der Länder übernahm die Abteilung eine Reihe neuer Aufgaben im Clustermanagement. Die Kompetenzen aus der Mikrosystemtechnik sollen zudem in das gemeinsame Cluster integriert werden; dies wird durch die Abteilung im Rahmen der ZEMI-Geschäftsstelle gesteuert.

Die Koordination von EU-Vorhaben bildet einen neuen Schwerpunkt: Seit Herbst 2011 koordiniert das FBH das Vorhaben HiPoSwitch, ein Verbundvorhaben mit acht Partnern aus fünf Ländern. Die Abteilung Wissenschaftsmanagement unterstützt den fachlichen Koordinator in allen organisatorischen Belangen. Hierzu gehören die Vorbereitung der Projektmeetings, der Aufbau und die Pflege der Webseite und das Erstellen von Vorlagen für die operative Arbeit im Projekt. Dadurch können sich der Koordinator, die wissenschaftlichen Kolleginnen und Kollegen aber auch die Projektpartner auf die technischen Projektinhalte und -ziele konzentrieren.

Weiterhin werden die Geschäftsstellen des Zentrums für Mikrosystemtechnik Berlin (ZEMI), des innovativen regionalen Wachstumskerns Berlin WideBaSe und des Ausbildungsnetzwerks Hochtechnologie Berlin (ANH Berlin) in der Abteilung Wissenschaftsmanagement geführt. Das Institut profitiert vor allem von der engen Vernetzung mit den Partnern und der verstärkten Sichtbarkeit innerhalb des jeweiligen Themenfeldes.

Zusätzlich organisierte die Abteilung im Jahr 2011 drei wissenschaftliche Veranstaltungen: Im Rahmen des Leibniz-Transferverbunds Mikroelektronik brachten sich 85 Vertreterinnen und Vertreter aus Wirtschaft und Wissenschaft im Frühjahr auf den neuesten Stand bei „Trends in der Materialforschung für die Mikro- und Optoelektronik". Im Herbst fand im Kontext des regionalen Wachstumskerns Berlin WideBaSe die Tagung „Technologie und Anwendungen von Nitrid-Halbleitern" statt. Der Fokus lag auf den Anwendungsfeldern von Halbleitern mit großer Bandlücke. 94 Teilnehmende aus wissenschaftlichen Einrichtungen und Unternehmen nutzten die zweitägige Veranstaltung, um sich zu informieren und fachlich auszutauschen. Bereits zum sechsten Mal wurde 2011 die Microsystems Summer School Berlin veranstaltet. Unter dem Motto „Energieeffizienz durch Mikrosystemtechnik" präsentierten sich die ZEMI-Partnereinrichtungen gemeinsam mit Unternehmen. Bei der einwöchigen Veranstaltung boten sie Einblicke in den aktuellen Stand der Forschung und die spezifischen Anwendungsmöglichkeiten zur effizienten Nutzung von Energie.

Im Bereich Bildung stehen die Aktivitäten rund um die Nachwuchswerbung und -förderung im Vordergrund. Mit der Organisation und Durchführung des zweiten Berlin-Brandenburger Mädchen-Technik-Kongresses engagierte sich das FBH, um insbesondere junge Mädchen für Qualifizierungs- und Karrieremöglichkeiten im Hochtechnologie-Sektor zu begeistern. Mit dem Vorhaben bottle neck wurde ein internationales Dialogforum auf den Weg gebracht, bei dem sich Partnereinrichtungen aus fünf Ländern über Good-Practice-Beispiele austauschen und weitere Initiativen anstoßen.

Science Management

The Science Management Department offers comprehensive services in the areas of strategy, technology transfer and marketing as well as education. Tasks include strategic advice and support for FBH's director and scientists in industrial and public-funded projects and the development of R&D collaborations. One of the main objectives of the team is to position the institute in local, regional, national, and international networks and to increase the public visibility of the Ferdinand-Braun-Institut. Research and business partners of the institute also benefit from the activities of the interdisciplinary eight-person team. The group takes over administrative and non-scientific work resulting from the application of complex collaborative projects, the coordination of national and international joint projects, and their respective development and management.

In October 2011, the new cluster Optics Berlin-Brandenburg with Prof. Tränkle as cluster speaker was proclaimed. The Science Management Department took over a number of new management tasks in this context. The competencies of microsystems technology shall also be integrated into the joint cluster, a task that will be managed by the department within the scope of the ZEMI branch office.

The coordination of EU projects forms a new focus: Since autumn 2011, the FBH has been coordinating HiPoSwitch, a joint project with eight partners from five countries. The Science Management Department supports the technical coordinator in all organizational matters including preparation of project meetings, establishment and maintenance of the website, and creation of templates for the operational work within the project. This allows the coordinator and the scientific colleagues, but also the project partners, to concentrate on the technical project content and aims.

Furthermore, the branch offices of the Centre for Microsystems Technology Berlin (ZEMI), the innovative regional growth core Berlin WideBaSe, and the Training Network ANH Berlin are administrated by the Science Management Department. The institute benefits from the close networking with the partners and the increased visibility within the respective topic.

In addition, the department organized three scientific events in 2011. As part of the Leibniz Transfer Network for Microelectronics, 85 representatives from industry and the scientific community were informed about the "Trends in Material Sciences for Micro- and Optoelectronics". In fall, the conference on "Technology and Applications of Nitride Semiconductors" took place in the context of the regional growth core Berlin WideBaSe. The focus was on the application fields of semiconductors with wide band gap. 94 participants from research institutions and companies used the opportunity to gain information and to profit from the professional exchange during the two-day event. For the sixth time, the Microsystems Summer School Berlin was organized by ZEMI in 2011. "Energy Efficiency through Microsystems Technology" was the motto of the event. During the one-week event, the ZEMI partners together with companies offered insight views of the current state of research and specific applications for the efficient use of energy.

In the training and education field, activities dealing with the promotion of young people are getting more and more important. Therefore, the second Berlin-Brandenburg Technology Congress that specifically addressed girls was organized by the ZEMI branch office. The congress aims to inspire young girls, in particular, for training and career opportunities in the high-tech sector. With the bottle neck project an international dialogue forum was also brought on its way encouraging partners from five countries to exchange good practice examples and to launch further initiatives.

Creating value from know-how, research results, and intellectual property

With MedUSe, FBH started a project in spring 2011 to further increase industrial cooperation. MedUSe, funded by the BMBF, aims to develop, implement, and professionalize a valorization concept. The focus is on a sectoral-oriented valorization of FBH's know-how, research results and intellectual property in three application fields: medical, environmental, and sensor technology. By collaborating with Ascenion GmbH, a company advising public research institutions in all aspects of intellectual property asset management, the valorization of research results shall be improved. Ascenion is a specialized technology marketer with strong roots in life-sciences. The company has more than ten years' experience in commercial technology transfer of attractive inventions and know-how to suitable industrial partners. As evaluated in a screening, numerous potential applications exist in the targeted application fields in at least three out of four FBH business areas. This is the result of a technology audit in three selected fields of research and an additional analysis of the patent portfolio. Thus, FBH provides a good base for successful valorization bridging the gap between science and industry.

Application laboratory: from components to systems

The FBH achieves excellent research results. To transfer these results into marketable products, further efforts and developments are necessary. Experiences in technology transfer have shown that output gained during research—like diagrams, characteristics, and laboratory samples—is often not applicable for marketing purposes. By establishing an application laboratory in 2009, FBH met this challenge und could broaden its range of R&D services.

The application laboratory is based on existing skills in optoelectronics and microwave technology and further develops laboratory models into functional models for practical usage. It complements the institute's expertise in specific technologies and components by competencies in systems.

One example for a current project is the development of a stand-alone pulse laser system comprising a picosecond light source with integrated pulse picker for a free choice of repetition rate and an amplifier element for pulse amplification.

FBH pulse laser system comprising the main control unit (left) and the optical component (right).

The FBH Application Laboratory is one of 13 laboratories associated under the label "Leibniz Applikationslabore". They act as central contact points for companies, universities, and institutes and provide extensive support for product and process developments.

Berlin WideBaSe: the whole value chain

The network Berlin WideBaSe continued its research and development activities on wide bandgap semiconductors in 2011. Berlin WideBaSe joins forces of ten enterprises and three research institutions in the Berlin Brandenburg region and covers the whole value chain in this application field. FBH is involved in seven of a total of eight projects, specifically with its Materials Technology Department and the Business Areas GaN Optoelectronics and GaN Electronics. The overall management and coordination is located within the Science Management Department.

One main activity in 2011 was to organize the conference "Technology and Application of Nitride-Semiconductors" that was attended by 94 representatives from science, economy, and politics. The participants gained information about the status quo and the application potential of wide bandgap semiconductors.

Representatives from science, economy, and politics attending the "Technology and Application of Nitride-Semiconductors" conference.

Leibniz Association Microelectronics: high-tech network
In 2009, the Leibniz Technology Transfer Association Microelectronics was founded by FBH and three other Leibniz institutes in collaboration with the TU Berlin. During the last two years, the number of members increased to ten institutes. The association bundles research and development in micro- and optoelectronics and initiates application-oriented cooperation with companies. It enables the involved institutes to coordinate their research topics according to demand-oriented needs of companies and to organize joint value.

Leibniz Association Microelectronics at SENSOR+TEST fair 2011 in Nürnberg.

In April 2011, FBH and the Leibniz Association Microelectronics organized an expert conference on trends in materials research for micro- and optoelectronics. Scientists from six Leibniz institutes presented current high-tech research topics and pointed to cooperation potentials. The program of the conference met with good response by more than 80 company representatives, scientists, and students. The event corresponded to the association's target to facilitate the communication of research and development performances and to manage access to new markets.

MIDIS: microsystems technology for ambient assisted living
As a technology partner, the ZEMI office cooperated within the Ambient Assisted Living (AAL) collaborative project MIDIS (service innovations for elderly people with microsystems technology). The project was funded by the BMBF and successfully completed in October 2011. Aim was to achieve an independent living for seniors by using intelligent technical products. Thus, ZEMI has identified the potential of both microsystems technology to resolve respective problems and corresponding AAL solutions, products, and research activities. The result of MIDIS is a practice-oriented guideline for manufacturers of microsystems technology solutions facilitating to cooperatively develop and successfully market new demand-oriented services.

Der Transfer wissenschaftlicher Ergebnisse gewinnt zunehmend an Bedeutung. Die Abteilung Wissenschaftsmanagement hat 2011 daher ihre Dienstleistungen weiter ausgebaut. Durch neu initiierte Kooperationen mit der Wirtschaft stärkt die Abteilung den Technologietransfer am FBH. Neben strategischen Verbünden und Vorhaben wurden vom Wissenschaftsmanagement neue Vorhaben initiiert, die vor allem auf die Verwertung von Forschungsergebnissen abzielen:

- ➜ Mit **MedUSe** startete das FBH die Zusammenarbeit mit einer externen, fachlich spezialisierten Verwertungsagentur, um neue Anwendungsfelder und Märkte für seine Forschungsergebnisse in Medizintechnik, Umwelttechnik und Sensorik zu erschließen.
- ➜ Der **Leibniz-Transferverbund Mikroelektronik** konnte auf zehn Institute ausgebaut werden. Er vernetzt die FuE der Institute in der Mikroelektronik und initiiert verwertungsorientierte Kooperationen mit Unternehmen.
- ➜ Das **Leibniz-Applikationslabor** am FBH ist eine Anlaufstelle für Unternehmen, Hochschulen und Institute. Vor dem Hintergrund einmaliger Forschungs- und Technologiekompetenz sowie modernster Laborausstattung bietet es umfangreiche Unterstützung für Produkt- und Verfahrensentwicklungen.
- ➜ Im 2011 abgeschlossenen Verbundvorhaben **MIDIS** entwickelte das FBH Konzepte zum Einsatz von Mikrosystemtechnik für ein selbständiges Leben in einer alternden Gesellschaft.

Fit for the future: training & education for skilled personnel

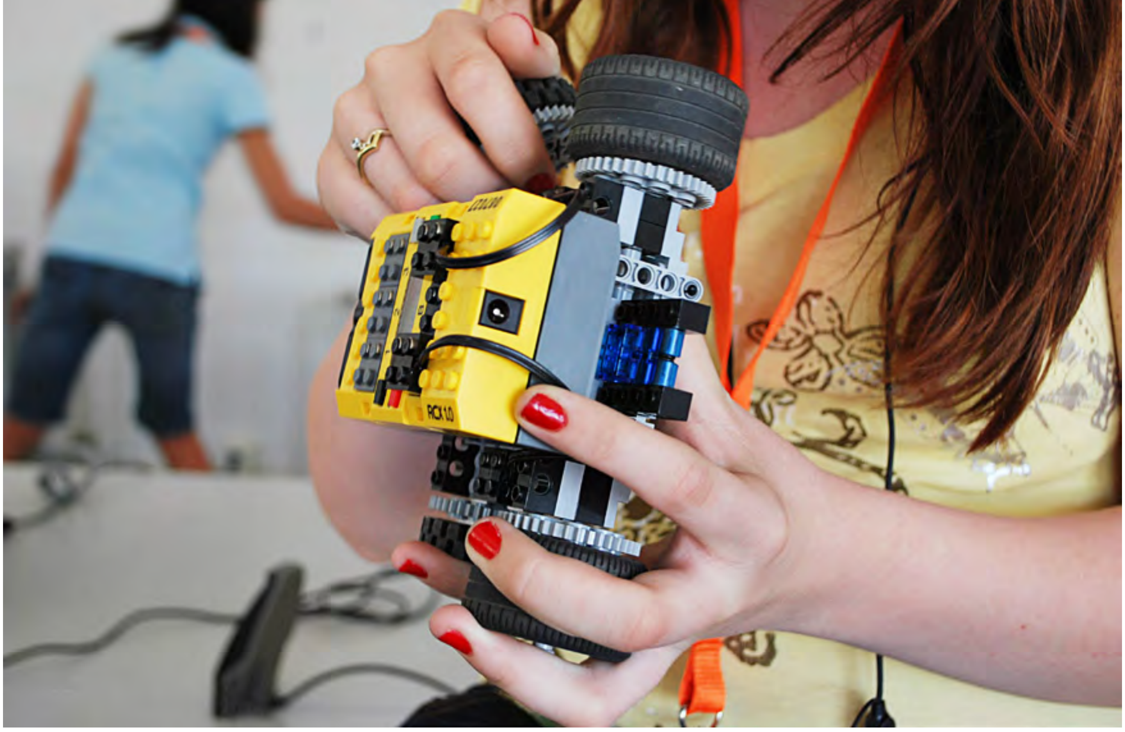
Skilled personnel at all educational levels is needed to avoid delays in transfer and implementation of new technologies into industrial applications. The current training situation in microsystems, optical and nanotechnologies can thus be described as a bottle neck. Therefore, vocational education and training has to face new challenges. Based on many years of experience, FBH helps to improve training in the field of high technology to meet the needs of companies and research institutions.

Das FBH arbeitet mit der Geschäftsstelle des Zentrums für Mikrosystemtechnik Berlin (ZEMI) seit vielen Jahren daran, Akteurinnen und Akteure im Bereich der beruflichen Ausbildung zu vernetzen sowie Nachwuchs für den Hochtechnologiebereich zu gewinnen. Mit dem Ausbildungsnetzwerk Hochtechnologie Berlin (ANH Berlin) unterstützt das FBH, in enger Zusammenarbeit mit der Lise-Meitner-Schule, Unternehmen wie Schüler/-innen, Lehrkräfte und Eltern in allen Fragen der beruflichen Ausbildung. Dadurch wurden mehr als 80 zusätzliche Ausbildungsplätze von 2007 bis 2011 geschaffen, die mit geeigneten Bewerberinnen und Bewerbern besetzt wurden. Um die berufliche und akademische Bildung attraktiver zu gestalten und die Durchlässigkeit zwischen verschiedenen Bildungsebenen zu verbessern, hat ANH Berlin passende Bausteine konzipiert. So wurden in 2011 Zusatzmodule und in Kooperation mit der Fachhochschule Brandenburg ein Modell für die Anerkennung von Ausbildungsinhalten der dualen Berufsausbildung für den Bachelorstudiengang Mikrosystemtechnik und optische Technologien entwickelt. Damit kann die Ausbildungszeit um bis zu 1,5 Jahre verkürzt werden. Mit dem zweiten Mädchen-Technik-Kongress für Berlin und Brandenburg organisierte das FBH eine Plattform, die 135 Mädchen nutzten, um sich über Karrierechancen im MINT-Bereich zu informieren. Auf internationaler Ebene sorgte das europäische „bottle neck"-Projekt für den transnationalen Erfahrungs- und Informationsaustausch zur Verbesserung der beruflichen Aus- und Weiterbildung. Ziel ist es dabei auch, neue Initiativen zur Sicherung von Fachkräften anzuregen. Entsprechende Workshops fanden 2011 in Kopenhagen (Dänemark), Oulu (Finnland) und bei IMEC in Belgien statt.

ANH Berlin: high technology training network

With its training network ANH Berlin (Ausbildungsnetzwerk Hochtechnologie), the FBH has been promoting vocational education and training (VET) for many years (funded by the Federal Program JOBSTARTER). ANH supports research institutes and companies in all needs and questions concerning education potential in the rapidly changing high technology area. Since ANH's foundation in 2007, 78 additional apprenticeships have been initiated; this number shall be increased to 100 within the next two years. In close cooperation with the Lise-Meitner-School, FBH is currently developing innovative content and training infrastructure, especially in the field of microtechnology, in order to make VET more attractive. New flexible training modules are designed, for VET as well as for further training to meet changing skills needs in research and industry. These modules for photovoltaics and vacuum technology will be tested and evaluated in 2012 within the initial vocational training for microtechnology as well as for physics laboratory assistants. In cooperation with the Brandenburg University of Applied Sciences, ANH Berlin opens new pathways for young people from an apprenticeship in microtechnology to a bachelor degree by recognizing skills and competences from VET for further studies at colleges and universities. In addition, the network offers a wide and practice-oriented range of services for vocational education: encouraging young people to opt for a career in natural and technical sciences and advising companies on all questions concerning VET. Therefore, ANH informed teachers, pupils and parents about training courses, professions and career options at several educational fairs (i.e. Einstieg Abi, vocatium, parentum).

Einstieg Abi, Berlin 2011: ANH presents training concepts and career options in the field of high technology.



Girl testing her technical skills at the second girl's congress.

Bottle neck: european dimension in education and training in microtechnology

Tackling high-level skills challenges in science, technology, engineering and mathematics is the shared responsibility of professional institutions, employers and universities as well as governments all over Europe. With the partnership project "bottle neck", FBH together with ZEMI Berlin initiates a transnational dialog in order to exchange know-how and experiences and to stimulate transfer of good practice. The partnership project, funded for two years within the EU program Leonardo da Vinci, started in August 2010 and brings together partners from Belgium, Denmark, Finland, UK, and Germany. In 2011, three project meetings in Denmark, Belgium and Finland have taken place giving staff from all partner organizations excellent opportunities for exchange of information and know-how.

bottle neck
bottle neck (2010-2012)
Leonardo da Vinci Partnership

Lifelong Learning Programme

mst|femNet meets Nano and Optics: encouraging girls and young women for a career in MINT

The proportion of girls and young women in high technology professions such as engineering, physics, and informatics is still low. This issue is gaining even more importance as Germany, at the same time, is facing a lack of skilled personnel and a decreasing number of inhabitants. FBH has been engaged in this matter for many years by starting the former regional MST Education and Training Network AWNET. Currently, the nationwide network mst|femNet meets Nano and Optics brings together representatives from public administration, politics, industry, research and education in order to develop appropriate solutions to inspire a rising number of girls for technical professions. Within this network, Mädchen-Technik-Talente-Foren in MINT (MÄTA) were organized by six partners from different federal states. Each partner implemented a roundtable to bundle regional activities in subjects like mathematics, physics and chemistry with technology congresses "for girls only" as regional highlights. In 2011, on the second girl's congress in the Berlin-Brandenburg region, 131 girls from 7th to 12th grade had the chance to taste MINT and to test own technical talents. In addition to hands-on experiments, the girls gained comprehensive information about training opportunities in VET and at universities. Staff from the FBH supported the congress by presenting role models who were answering all questions concerning career opportunities and work tasks. As the event format had been very positively acknowledged by the participating girls and thus proved to be very successful, ZEMI has submitted a project proposal to carry on with the congresses. FBH, in close cooperation with other institutes within the Centre for Microsystems Technology Berlin (ZEMI), also succeeded in building a sustainable network with regional partners over the past few months.

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