



Leibniz
Ferdinand-Braun-Institut



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JAHRESBERICHT



Dieser Jahresbericht gibt einen Überblick zu Forschungsprogramm und Status des Ferdinand-Braun-Instituts und zu seinen aktuellen Ergebnissen in Forschung und Technologietransfer. Als verlässlicher Partner für seine Kunden in Wissenschaft und Industrie ist das FBH integraler Bestandteil von Wertschöpfungsketten. Es steht damit für Innovationen und neue Anwendungen in der Optoelektronik und Mikrowellentechnik.

Mit seinen Forschungsarbeiten zu optoelektronischen und elektronischen Komponenten aus III/V-Halbleitern erzielt das Institut Resultate auf internationalem Spitzenniveau. Dazu gehören beispielsweise Weltbestwerte im Bereich der Hochleistungsdiodenlaser hinsichtlich Ausgangsleistung, schmaler Linienbreite und Effizienz. Galliumnitrid-Transistoren aus dem FBH haben kürzlich erfolgreich die anspruchsvollen Belastungstests für den Weltraum bestanden. Sie werden ihre Leistungsfähigkeit im kommenden Jahr an Bord einer Rakete im All unter Beweis stellen. Ein zentrales Verbundprojekt auf dem Gebiet der breitlückigen Halbleiter wurde mit dem Wachstumskern Berlin WideBaSe gestartet. Nicht nur in diesem Rahmen baut das FBH seine engen Kooperationen in Forschung und Industrie weiter aus.

Ich nehme diese Entwicklungen zum Anlass, um unseren Partnern und Kunden sehr herzlich für die oft langjährige und vertrauensvolle Zusammenarbeit zu danken. Ich freue mich auf viele weitere spannende Projekte, die wir gemeinsam mit Ihnen realisieren werden. Mein Dank gilt auch allen Mitarbeiterinnen und Mitarbeitern des Ferdinand-Braun-Instituts, ohne deren Engagement und Know-how unsere exzellenten Ergebnisse nicht zu schaffen wären.

Für die Zukunft sehen wir uns gut gerüstet, zumal es dem FBH in den vergangenen Jahren gelungen ist, sich in strategisch wichtigen Zukunftsfeldern zu positionieren. So hat sich etwa in dem 2008 gestarteten Bereich der Lasertechnologie die Projektlage sehr erfreulich entwickelt – sechs Vorhaben beschäftigen sich inzwischen mit schmalbandigen und höchststabilen Diodenlasern, die unter anderem für Präzisionsmessungen im Weltraum und zur optischen kohärenten Freiraumkommunikation eingesetzt werden. Auch bei hohen Frequenzen bis in den Terahertz-Bereich wurden erfolgreich erste größere Projekte eingeworben. Aktuell wird die Aufbau- und Verbindungstechnik zur Realisierung von MMICs für Frequenzen oberhalb 100 GHz am FBH etabliert. In der Galliumnitrid-Leistungselektronik verzeichnen wir ein großes Kundeninteresse, befördert nicht zuletzt durch den großen gesellschaftlichen Bedarf nach alternativen Konzepten in den Feldern Energie und Mobilität.

Dank umfassender Investitionen in die technische Ausstattung und Infrastruktur in den Reinräumen und Messlaboren wurden am Ferdinand-Braun-Institut in den letzten beiden Jahren die bereits sehr guten Bedingungen für unsere Forschung auf den neuesten technologischen Stand gebracht. Dies verdanken wir insbesondere unseren Zuwendungsgebern im Land Berlin und im Bund, mit deren finanzieller Unterstützung diese Maßnahmen erst möglich wurden. Ihnen gilt unser Dank für die großzügige Förderung.

Ich freue mich auf die weiterhin gute Zusammenarbeit mit Ihnen allen. Eine anregende Lektüre der Entwicklungen und Ereignisse des vergangenen Jahres wünscht Ihnen,
Ihr

Günther Tränkle



This annual report provides a current overview on the research program and status of the Ferdinand-Braun-Institut and its latest results in research and technology transfer. As a reliable partner for its customers in science and industry, the FBH is an integral part of the value added chain and thus stands for innovations and novel applications in optoelectronics and microwave technology.

With its research on optoelectronic and electronic components based on III-V semiconductors, the institute achieves international top-level results. In the field of high-power diode lasers, for example, FBH obtains world-wide record values with respect to output power, small linewidth and efficiency. Only recently, gallium nitride transistors from the Ferdinand-Braun-Institut have successfully accomplished the highly demanding load tests for space applications. They will demonstrate their capability on board of a rocket in space next year. With the regional growth core Berlin WideBaSe, a pivotal joint project in the field of wide band-gap semiconductors has been started. Not only in this framework, the FBH further extends its close cooperation within research and industry.

I use this progress as an opportunity to express my warmest appreciation to our partners and customers for the mostly long-term as well as trustful cooperation. Accordingly, I am looking forward to many further challenging projects to be realized jointly. I also like to thank the employees of the Ferdinand-Braun-Institut—our excellent results would be impossible without their dedicated involvement and know-how.

We therefore see ourselves well prepared for the future, especially considering that we managed to position FBH in major strategic cutting-edge areas during recent years. The project status in the field of laser metrology, for example, which has been started in 2008 shaped up well. Meanwhile, six projects deal with narrow-band and highly stable diode lasers to be used, amongst others, for high-precision measurements in space and for coherent optical free-space communication. Also in the high frequency range up to terahertz frequencies, first considerable projects have been successfully acquired. In gallium nitride power electronics, we observe a great market need, promoted not just by the high social demand for alternative concepts in the fields of energy and mobility.

During the last two years, the already excellent conditions for research at the Ferdinand-Braun-Institut have been brought on the latest technological level due to comprehensive investments in technical equipment and infrastructure in FBH's cleanrooms and measurement laboratories. We like to thank our funders from the State of Berlin and the Federal Government whose generous financial support enabled these future investments.

I am looking forward to further prosperous cooperation with all of our partners in the future and wish you an inspiring reading of last year's developments and events.

Yours sincerely

A handwritten signature in black ink that reads "Günther Tränkle". The signature is written in a cursive, slightly stylized font.

Günther Tränkle

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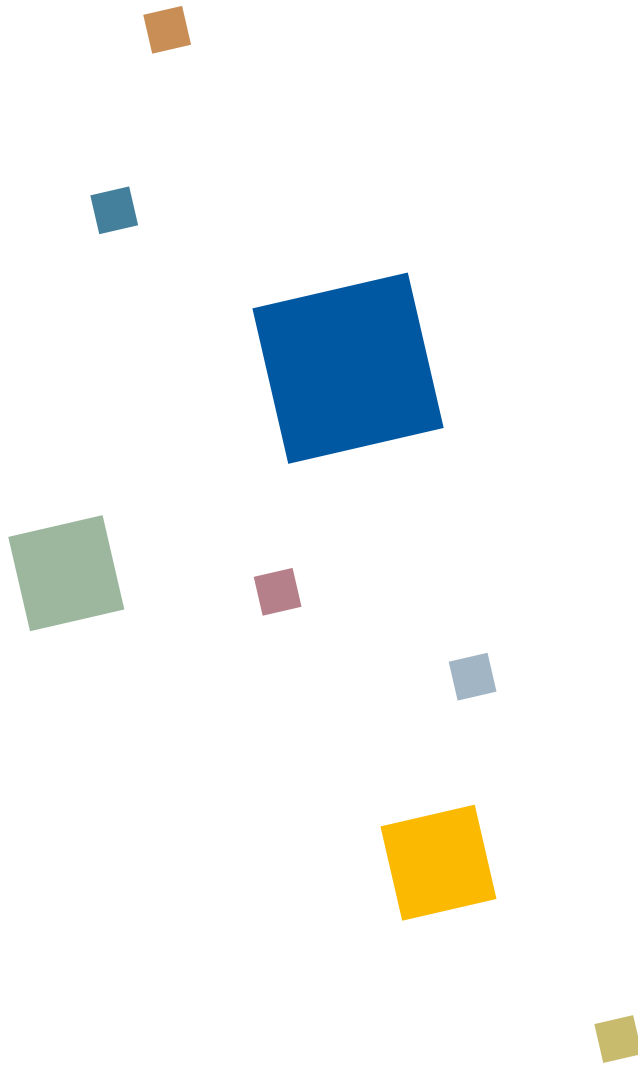
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Profile
» Profil



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 FBH 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, beispielsweise 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 for the treatment of skin diseases.

The FBH is a competence center for III-V compound semiconductors with 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 competence 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.

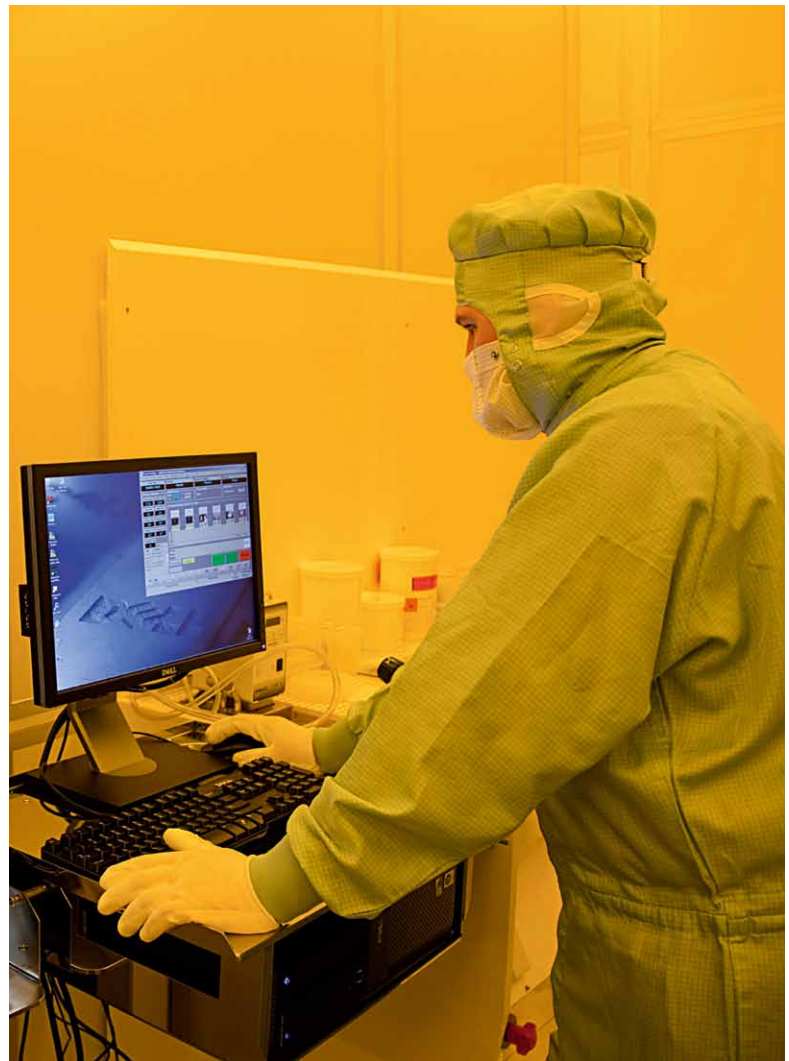
Wir bieten Lösungen aus einer Hand: vom Entwurf bis zum lieferfähigen Modul.

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 und 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

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-Hochleistungslaserdioden
- › Blaue & grüne Laserdioden
- › UV-LEDs

Material- & Prozesstechnologie

- › GaN-HVPE
- › Optische Sonderbauelemente
- › In-situ Kontrolltechniken bei MOVPE & HVPE
- › Lasermikrostrukturierung

Wissenschaftsmanagement

- › Technologietransfer & Marketing
- › Bildung

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 & -systeme

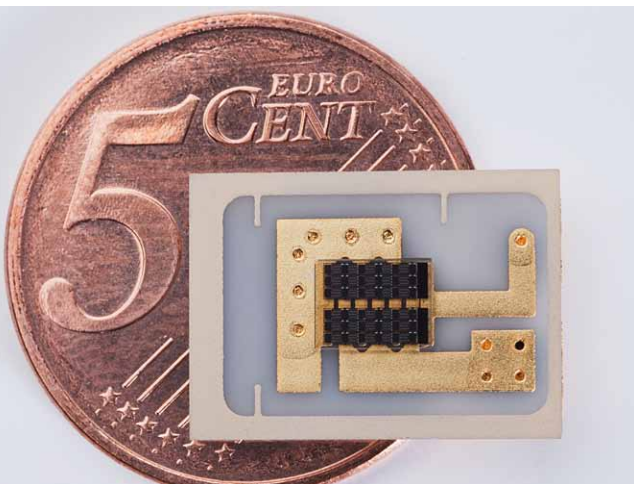
- › Galliumnitridelektronik: Transistoren und Verstärker (hybrid, MMIC) – Entwurf, Fertigung, Kleinserie
- › Mikrowellenplasmen
- › Elektromagnetische Simulation
- › Hochfrequenz- und Leistungsmesstechnik

Hochleistungsdiodenlaser & 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 & 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

GaN Electronics

- › Microwave transistors & MMICs
- › Power electronics

Diode Lasers

- › Broad area lasers & bars (spectral range 0.6- 1.2 μm)
- › High-brightness lasers (line width < 10 MHz)
- › Hybrid laser systems
- › Laser sensors
- › Laser metrology

GaN Optoelectronics

- › UV high-power laser diodes
- › Blue & green laser diodes
- › UV LEDs

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

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 & 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 & 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 & 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

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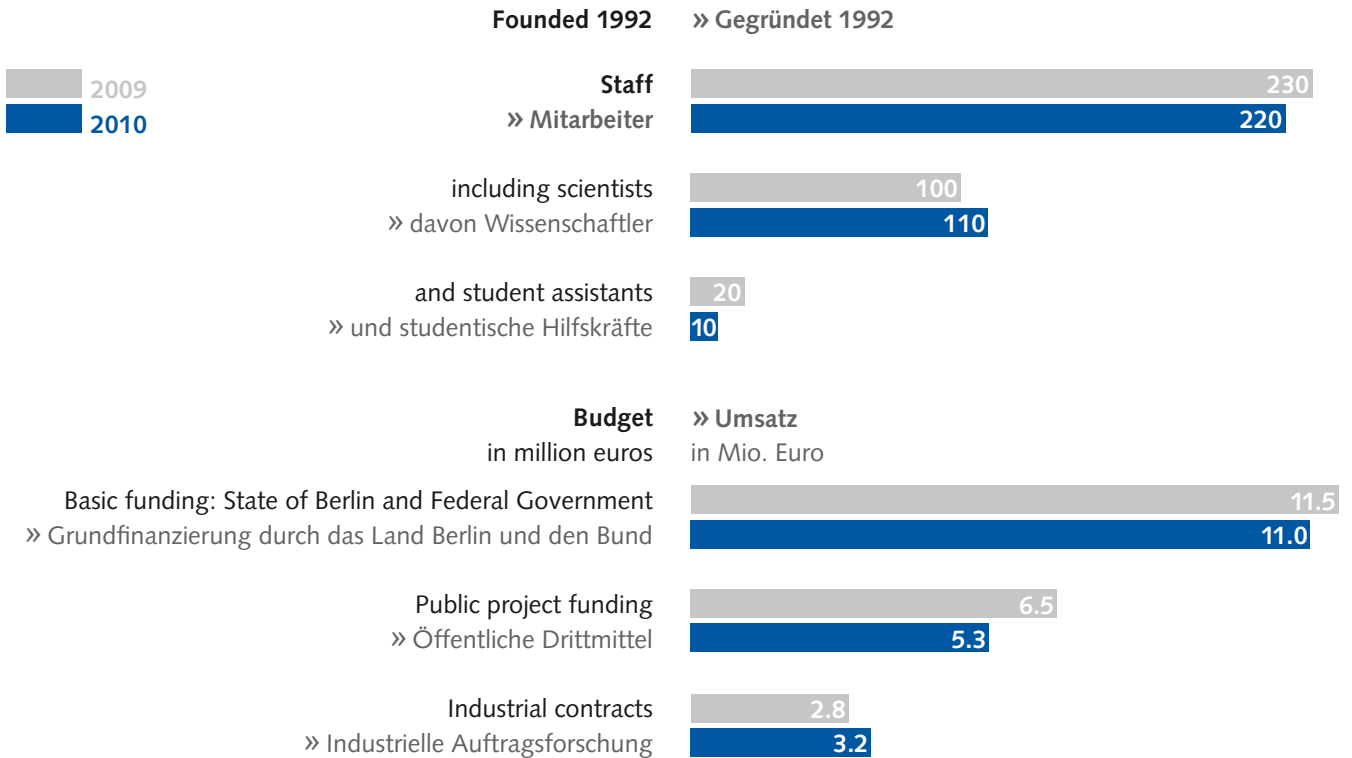
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The institute in figures Das Institut in Zahlen «



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The Forschungsverbund Berlin e.V. Der 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.

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.



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Highlights
» Schlaglichter



Gut vernetzt: FBH weitet seine Uni-Kooperationen erneut aus



Lasermetrologie

Achim Peters hat im Oktober 2008 die Professur „Optische Metrologie“ an der Humboldt-Universität zu Berlin übernommen – parallel leitet er am FBH den Bereich Lasermetrologie. Kooperationsmodelle dieser Art sind am FBH bereits in anderen Bereichen, etwa der GaN-Optoelektronik, etabliert und sichern die enge Zusammenarbeit zwischen grundlagen- und anwendungsorientierter Forschung sowie die enge Verzahnung mit Universitäten in der Region und bundesweit.

Auf dem Gebiet der Lasermetrologie entwickelt das FBH im Rahmen DLR- und EU-geförderter Projekte auf Diodenlasern basierende Lasersysteme für die höchstgenaue Atomspektroskopie. Bei den Experimenten geht es um die Untersuchung fundamentalphysikalischer Fragestellungen, z.B. um einen Präzisionstest des Äquivalenzprinzips, nach dem alle Körper im Schwerfeld der Erde gleich schnell fallen. Damit kommt nicht weniger als Einsteins Relativitätstheorie auf den Prüfstand. Die dafür genutzten Systeme müssen je nach Aufgabe Ausgangsleistungen von 50 mW bis 1 W bei einer Wellenlänge von 767 nm (Kalium) und 780 nm (Rubidium) erreichen. Die Herausforderung besteht darin, eine möglichst geringe Linienbreite (< 100 kHz, Präzision von neun Nachkommastellen!) sicherzustellen. Da diese hochpräzisen Experimente nur im Weltraum möglich sind, müssen die Systeme die Belastungen eines Raketenstarts funktionsfähig überstehen und unter extremen Bedingungen zuverlässig arbeiten.

Terahertz-Elektronik

Im Oktober 2009 wurde eine Stiftungsprofessur an der Goethe-Universität Frankfurt am Main im Bereich der Terahertz-Technologien (THz) eingerichtet, die vom Oerlikon-Konzern mitfinanziert wird. Sie ist mit der Leitung einer entsprechenden Arbeitsgruppe am FBH im Geschäftsbereich Mikrowellenkomponenten und -systeme verbunden. Auf diese Professur wurde Viktor Krozer berufen, der vorher einen Lehrstuhl für Mikrowellen- und Terahertz-Technologie an der DTU in Kopenhagen innehatte. In einem ersten Schritt wurde der am FBH entwickelte Transferred-Substrate-Prozess mit InP-HBTs (Transitfrequenzen > 400 GHz) an die neuen Bedingungen angepasst – er dient als Technologiebasis für den Höchsthfrequenzbereich. Zudem wird derzeit im Rahmen des EFRE-geförderten „Anwendungszentrums Höchsthfrequenztechnologien“ ein THz-Messplatz aufgebaut, der die on-Wafer-Messungen der MMICs im Frequenzbereich bis 300 GHz ermöglicht.

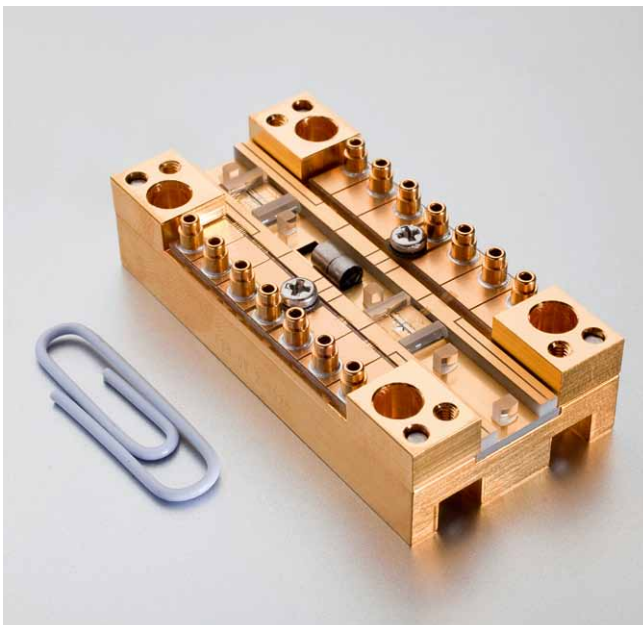
Erst kürzlich wurde auch ein gemeinsamer Projektantrag des FBHs und des Leibniz-Instituts für innovative Mikroelektronik (IHP) bewilligt. Elektronische III/V-Bauelemente sollen dabei in eine Silizium-CMOS-Umgebung integriert werden. Die Silizium-CMOS-Technologie bildet das Rückgrat der elektronischen integrierten Schaltungstechnik, hat jedoch eine klare Begrenzung: Mit steigender Geschwindigkeit und Integrationsdichte sinken nämlich die Durchbruchspannung und damit die verfügbare Leistung. Kombiniert man die Vorteile beider Materialsysteme, der III/V-Halbleiter- und der Siliziumtechnologie, wird ein Durchbruch bei der Realisierung von Terahertz-Systemen erwartet. Da eine solche Kombination bislang nicht existiert, betreten die Projektpartner technologisches Neuland. Erste Studien sollen zunächst Realisierungsmöglichkeiten für Bauelemente im Frequenzbereich zwischen 100 und 300 GHz aufzeigen. Dies soll unter anderem bildgebende Millimeterwellensysteme ermöglichen, mit denen ausgedehnte Areale auf sicherheitsrelevante Objekte untersucht werden können, etwa zur Terrorabwehr im öffentlichen Raum.

Well connected: FBH expands its university cooperation model

Laser metrology

In October 2008, Achim Peters was appointed on the chair of "Optical Metrology" at the Humboldt-Universität zu Berlin—he is additionally heading the Laser Metrology group at the FBH. Comparable cooperation models, for example in the GaN Optoelectronics field, have already been established before, ensuring close cooperation between basic and application-oriented research and thus close linkage between the institute and universities in the region and nationwide.

In the laser metrology field, FBH develops laser systems based on diode lasers for high-precision atomic spectroscopy within the framework of DLR- and EU-funded projects. Experiments target fundamental physical issues, for example precision tests of the equivalence principle, according to which all bodies experience the same acceleration by the earth's gravitation. Thus, not less than Einstein's theory of relativity is on the test bench. The systems used for this task have to provide an output power from 50 mW up to 1 W, depending on the respective task, at wavelengths of 767 nm (potassium) and 780 nm (rubidium). Particularly challenging is to achieve an extraordinarily small line width (< 100 kHz). As these high-precision experiments are only possible in space, the systems have to survive a rocket take-off and need to work reliably under extreme conditions.



Terahertz electronics

In October 2009, an endowed chair for terahertz (THz) technologies has been established at Goethe-Universität Frankfurt, financially supported by the Oerlikon group. The position is connected with an executive function in FBH's Business Area Microwave Components and Systems. Viktor Krozer was appointed to this position. He comes from DTU in Copenhagen, where he held a chair of Microwave and Terahertz Technologies. In a first step, FBH's transferred-substrate process with InP HBTs (transit frequencies > 400 GHz) has been adapted in order to serve as technology basis for the 100+ GHz frequency range. Additionally, THz measurement equipment allowing for on-wafer characterization of MMICs in the frequency range up to 300 GHz is currently built up within the EFRE-funded project "Applikationszentrum Höchstfrequenztechnologien".

Only recently, a joint project proposal of FBH and the Leibniz Institute for Innovative Microelectronics (IHP) to integrate electronic III-V devices into a silicon CMOS environment has been granted. Silicon CMOS technology forms the backbone of electronic integrated circuit technology, but also shows a clear limitation: With increasing speed and integration density, breakdown voltage scales down and thus available power decreases. By combining the advantages of both material systems, III-V semiconductor and silicon technology, a break-through regarding terahertz systems can be expected, significantly advancing the state-of-the-art. First studies are to evaluate possible solutions for devices in the frequency range between 100 and 300 GHz. Among other applications, they are supposed to enable millimeter-wave imaging systems with large spatial coverage. By detecting security-relevant objects they could be used for example in defense against terrorism in public space.

*Laser module for experiments in space.
» Lasermodul für Experimente im Weltraum.*



Berlin WideBaSe: Große Bandlücke – lückenlos vernetzt



Mit seinen Aktivitäten zu breitlückigen Halbleitern unter dem Stichwort WideBaSe (**Wide-Bandgap-Semiconductors**) war das FBH 2010 überaus erfolgreich. Das Institut hatte bereits zwei Jahre zuvor mit strategischen Arbeiten zur Vernetzung von Forschung und regionaler Wirtschaft begonnen. Diese werden seit Juli im Rahmen der Initiative „Innovative regionale Wachstumskerne“ drei Jahre lang vom BMBF gefördert und können weiter vorangetrieben werden. Zehn Unternehmen und drei Forschungseinrichtungen hatten das Konzept zur strategischen Zusammenarbeit entwickelt.

Berlin WideBaSe steht für die regionale Entwicklung, Herstellung und den Vertrieb von optoelektronischen und elektronischen Bauelementen auf der Basis von breitlückigen Halbleitern. Sie ermöglichen extrem kompakte und sehr schnelle Leistungsbaulemente sowie leistungsstarke LEDs für ultraviolettes Licht. Ziel ist es, die in Berlin vorhandene

technologische und wirtschaftliche Kompetenz bei Halbleiterbauelementen auf der Basis von Nitridhalbleitern (AlInGaN) zu nutzen und auszubauen. Unter dem Leitspruch „große Bandlücke – lückenlose Vernetzung“ soll die gesamte Wertschöpfungskette abgedeckt werden: vom Anlagenbau, über Substrate, Epitaxie, Bauelementprozessierung und Montagetechnik bis hin zum Systemeinsatz. Ziel ist es, für unterschiedliche Anwendungen die Position der beteiligten Unternehmen am Markt zu stärken und gleichzeitig die Forschung auszubauen.

Das Gesamtvorhaben wird mit 6,5 Millionen Euro gefördert – davon gehen 2,7 Millionen Euro an das FBH, das in sieben der acht Verbundvorhaben eingebunden ist. Beteiligt sind insbesondere die Abteilung Materialtechnologie sowie die Geschäftsbereiche GaN-Optoelektronik und GaN-Elektronik. Das Gesamtvorhaben wird von der Abteilung Wissenschaftsmanagement koordiniert.

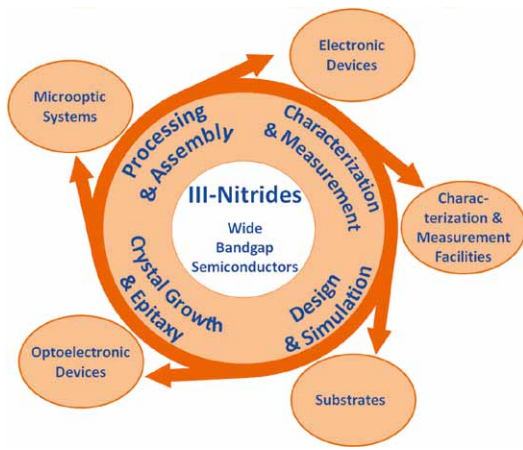
EFRE-Mittel: Anwendungszentrum Höchstfrequenztechnologien und Diodenlaser für Röntgenlaserprojekt



Für zwei Vorhaben sind Ende 2010 umfangreiche EFRE-Fördermittel bewilligt worden. Vier Millionen Euro stehen nun für den „Aufbau des Anwendungszentrums Höchstfrequenztechnologien“ zur Verfügung. Ziel ist es, energieeffiziente Leistungsverstärker sowie Laser und LEDs zur Anwendungsreife zu führen. Außerdem soll der Frequenzbereich zwischen 100 und 300 GHz für bildgebende Verfahren und die Sensorik erschlossen werden. In diesem Zusammenhang sind auch zentrale Geräteanschaffungen geplant, wie etwa ein Waferstepper für die Projektionslithografie, der die Reproduzierbarkeit und Volumentauglichkeit der Bauelemente sichert. Außerdem investiert das FBH in die Messtechnik zur Sicherung der Zuverlässigkeit und Fehleranalytik.

Ein weiteres EFRE-gefördertes Projekt ist ein neuer Table-Top-Röntgenlaser, der am Max-Born-Institut (MBI) entsteht. Kernstück sind 937 nm-Diodenlaser des FBH, die die kompakten Abmessungen des Röntgenlasers ermöglichen. Sie werden am FBH entwickelt und in Kooperation mit Jenoptik zu hocheffizienten Pumpmodulen aufgebaut. Circa 70 solcher Halbleiterchips bilden ein Pumpmodul, erste Prototypen sollen im ersten Quartal 2011 zur Verfügung stehen. Insgesamt fließen drei Millionen Euro an FBH und MBI, die Hälfte davon an das FBH.





Berlin WideBaSe: wide bandgap— gapless linked up

FBH's activities on **wide bandgap semiconductors** clustered in the Berlin WideBaSe initiative have developed very successfully in 2010. The network combines know-how and technical resources of ten enterprises and three research institutions in this field and started its strategic networking already two years ago. Due to a three-year funding within the framework of the "Innovative Regional Growth Cores" initiative which started in July, these activities can now be further advanced.

Berlin WideBaSe stands for regional development and marketing of optoelectronic and electronic devices based on wide bandgap semiconductors. Such devices enable extremely compact and very fast power devices as well

as powerful LEDs generating ultra-violet light. The aim is to join technological and economic forces to tackle semiconductor devices based on nitrides (AlInGaN) in Berlin in order to expand the existing activities. Following the motto "wide bandgap—gapless networking", Berlin WideBaSe covers the whole value chain: from equipment to substrates, epitaxy, device processing and mounting technology to systems integration. For a great variety of applications both the market position of the companies involved shall be strengthened and research is to be extended.

The overall project is funded with 6.5 million euros—2.7 million are assigned to the FBH, which is involved in seven of the altogether eight joint research projects. At the FBH, the Materials Technology Department and the Business Areas GaN Optoelectronics as well as GaN Electronics are particularly involved. The overall project is coordinated by the Science Management Department.

EFRE funds: "Anwendungszentrum Höchstfrequenztechnologien" and diode lasers for x-ray laser project

At the end of 2010, two of FBH's project proposals were granted comprehensive EFRE funding. Thus, four million euros are provided for the setup of the "Anwendungszentrum Höchstfrequenztechnologien" to further develop components such as energy-efficient power amplifiers as well as lasers and LEDs into marketable products. Additionally, the frequency range from 100 to 300 GHz shall be opened up for imaging techniques and sensor technology. Important equipment purchases are projected in this context, such as a wafer stepper for projection lithography, assuring reproducibility of the devices and being suitable for high volumes. The FBH additionally invests in measurement infrastructure for reliability testing and defect analysis.

The second EFRE project is a new table-top x-ray laser, which will be established at the Max-Born-Institute (MBI). Key parts of this laser system are 937 nm diode lasers from the FBH, which are the basis for the comparably small dimensions of the x-ray laser system. They are developed at the FBH and will then be assembled to high-efficiency pump modules in cooperation with Jenoptik. About 70 of such semiconductor chips form one pump module—first prototypes shall be available within the first quarter 2011. The overall funding amounts to three million euros, shared equally between FBH and MBI.

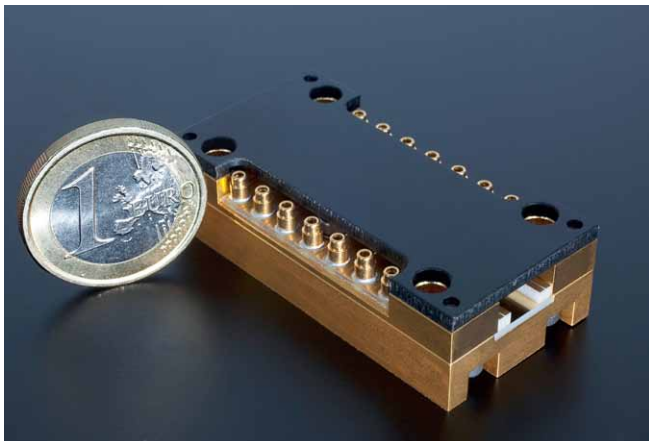
◀ Comprehensive investments in the newly founded „Anwendungszentrum“ enable FBH to continue developing state-of-the-art devices.
» Umfassende Investitionen in das neue Anwendungszentrum ermöglichen Entwicklungen auf dem neuesten technologischen Stand.



InnoProfile-Gruppe am FBH: eine Erfolgsgeschichte in rot, grün & blau



Seit vier Jahren entwickelt Katrin Paschke mit ihrem Team kompakte, leistungsstarke und hochbrillante Laserstrahlquellen für den sichtbaren Spektralbereich. Die Module emittieren Licht in den Farben rot, grün und blau und werden als hybride Diodenlasersysteme in der typischen Größe einer Streichholzschachtel realisiert. Um den raschen Technologietransfer zu sichern, bindet die durch das InnoProfile-Programm geförderte Gruppe kleine und mittelständische Berliner und Brandenburger Unternehmen frühzeitig mit in den Entwicklungsprozess ein. Industriepartner und Interessierte werden regelmäßig über Fortschritte und aktuelle Entwicklungen informiert. Vor allem bei den Statusseminaren zeigen sich das große Interesse der Industrie und damit gute Perspektiven für weitere Kooperationen. Alleine beim letzten Treffen nahmen mehr als zehn Unternehmen teil, mit denen Bedarf und Möglichkeiten für konkrete Entwicklungen diskutiert wurden. Von den Fortschritten überzeugte sich auch Hans-Peter Hiepe, Referatsleiter im BMBF und zuständig für regionale Innovationsinitiativen in den neuen Ländern, der sich neue Entwicklungen im Labor zeigen ließ.



*Microsystems light source for the red spectral region.
» Mikrosystemlichtquelle für den roten Spektralbereich.*

Ergebnisse

Im vergangenen Jahr ist die Übertragung eines Konzeptes für miniaturisierte Lasersysteme im Wattbereich von 488 nm auf andere Wellenlängen gelungen. Ein Watt Ausgangsleistung im Dauerstrichbetrieb (CW) wurde bei 532 nm Wellenlänge auf einer Mikrobank erreicht. Dabei ist eine möglichst weitreichende funktionale Integration (Chip, Optik, Temperaturstabilisierung) auf kleinstem Raum gelungen. Module dieser Wellenlänge eignen sich unter anderem zur großflächigen Anregung wie sie für die Ramanspektroskopie oder die Fluoreszenzspektroskopie benötigt werden, aber auch zum Pumpen von Femtosekunden-Titan-Saphir-Lasern. Damit erschließen sie eine Vielzahl von Anwendungen in der Medizintechnik, im Security-Bereich oder in der Grundlagenforschung.

Für ein Analytiksystem des Kooperationspartners Pico-Quant wurden bei gleicher Wellenlänge von 532 nm gepulste grün emittierende Laser im Pikosekundenbereich entwickelt. Diese liefern Spitzenleistungen von über fünf Watt und eignen sich für die Fluoreszenzspektroskopie, um beispielsweise die Wechselwirkung von Proteinen in lebenden Zellen zu verfolgen. Dafür werden benutzerfreundliche, kompakte Strahlquellen benötigt, die Pikosekundenpulse bei variabler Wiederholrate erzeugen. Die hybride Integration von Diodenlasern bietet hier hervorragende Möglichkeiten, nicht nur im grünen Spektralbereich.

Kompakte Lasermodule im grünen und blauen Spektralbereich mit Ausgangsleistungen von mehreren Watt werden auch im CW-Betrieb benötigt. Die Frequenzverdoppelung der nah-infraroten (NIR) Diodenlaser in einem Volumen-kristall bietet hier nicht die benötigte Konversionseffizienz. Nutzt man dagegen Wellenleiterstrukturen als konvertierendes Medium, erhöht sich die NIR-Laserlichtintensität im nichtlinearen Material und somit die Konversionseffizienz des nichtlinearen Prozesses. Die Herausforderung liegt in der optimalen Einkopplung des NIR-Laserlichts in den Wellenleiter. In einem Laboraufbau wurde eine Einkoppeleffizienz von 73% erreicht, was in einer Leistung von mehr als 1 Watt bei 532 nm mit einer opto-optischen Konversionseffizienz von 26% resultierte. Diese hohe Konversionseffizienz wirkt sich positiv auf die Gesamteffizienz des Moduls aus und minimiert den Energieverbrauch sowie die Wärmeentwicklung, was sowohl für Hersteller als auch Anwender äußerst relevant ist.

InnoProfile group at FBH: a success story in red, green & blue

For more than four years, Katrin Paschke and her team develop compact, powerful and highly brilliant laser sources for the visible spectral range. These modules are only the size of matchboxes and emit light in the colors red, green and blue. The group, which is funded by the InnoProfile program, involves small and medium enterprises already at an early stage into the development process in order to ensure rapid transfer of technology. Industrial partners and interested parties are regularly informed about progress and latest developments. Especially the status seminars reveal the strong interest of the industry and thus good prospects for further cooperation. More than ten enterprises participated in the last meeting, discussing market demands and approaches for practical developments. Hans-Peter Hiepe, Head of Division at the BMBF and responsible for the regional innovation initiatives in the newly-formed German states also assured himself of the group's advancements by reviewing latest developments in the laboratory.

Results

During the past year, a concept for miniaturized laser systems in the Watt range has been successfully transferred from 488 nm to other wavelengths. At a wavelength of 532 nm one Watt output power in cw operation has been achieved on a micro bench. Thus, the team managed to obtain extensive functional integration (chip, optics, temperature stabilization) within the smallest possible space. Modules of this wavelength are suitable for extensive excitation as required for Raman and fluorescence spectroscopy, but also for pumping of femtosecond titan sapphire lasers. Consequently, these lasers enable a variety of applications in medical technology, in security systems as well as in fundamental research.

For an analytics system of PicoQuant, one of FBH's cooperation partners, pulsed green emitting lasers in the picosecond range have been developed at the same wavelength of 532 nm. These lasers deliver peak powers of more than five Watt and are suited for fluorescence lifetime spectroscopy to track, for instance, the interaction of proteins in living cells. Therefore, user-friendly and compact beam sources are needed to generate picosecond pulses at a variable repetition rate. Hybrid integration of diode lasers offers here excellent possibilities even beyond the green spectral region.



*Katrin Paschke (r) informs Hans-Peter Hiepe (ctr) from the BMBF Ministry and Hartmut Paetsch (2nd from r) from the project executing organization PTJ about current developments.
» Hans-Peter Hiepe (m.) vom BMBF und Hartmut Paetsch (2. von re.) vom Projektträger Jülich informieren sich bei Katrin Paschke (re.) über aktuelle Entwicklungen.*

Compact laser modules in the green and blue spectral range with output powers of several Watt are also required in CW operation. Frequency doubling of near-infrared (NIR) diode lasers in a volume crystal does not provide the necessary conversion efficiency. When using waveguide structures as converting medium, NIR laser light intensity rises in the non-linear material and thus conversion efficiency of the non-linear process increases. Particularly challenging is the optimum coupling of the NIR laser light into the waveguide. In a laboratory setup a coupling efficiency of 75% has been achieved, resulting in an output power of more than one Watt at 532 nm with an opto-optical conversion efficiency of 26%. Such a high conversion efficiency positively influences the overall efficiency of the module and minimizes energy consumption as well as generation of heat, which are highly relevant aspects for both, manufacturers and users.



Simulation: Basis für exzellente Forschung am FBH



Wie viel Mathematik in wissenschaftlichen Entwicklungen steckt, sieht man ihnen nicht an. Am FBH ist die Simulation jedenfalls unverzichtbar, denn vor jeder Bauelemententwicklung – ob Leistungstransistor, Diodenlaser, Mikrowellenschaltung oder Mikrowellen-Plasmaquelle – stehen entsprechende Rechenmodelle. Sie bilden die Wirklichkeit nach und zeigen den Wissenschaftlern, ob sich ihre theoretischen Überlegungen praktisch umsetzen lassen. Später hilft die Simulation dabei einzelne Parameter anzupassen, um die gewünschten Ergebnisse zu erzielen.

Ein großer Teil der Simulationen am FBH beruht auf den Maxwell'schen Gleichungen. Sie beschreiben, wie elektromagnetische Felder durch Ladungen und Ströme erzeugt werden und wie sie sich räumlich und als Funktion der Zeit verändern. Bevor diese Gleichungen entdeckt wurden, waren Elektrizität, Magnetismus und Optik unabhängige Gebiete. Maxwell verband die Elektrizität mit dem Magnetismus und stellte fest, dass seine Formeln auch das Licht beschreiben. Je nach Frequenzbereich sind Vereinfachungen der Gleichungen sinnvoll und anwendbar. Dies führt auch zu unterschiedlichen Simulationsmethoden in der Hochfrequenztechnik und der Optik.

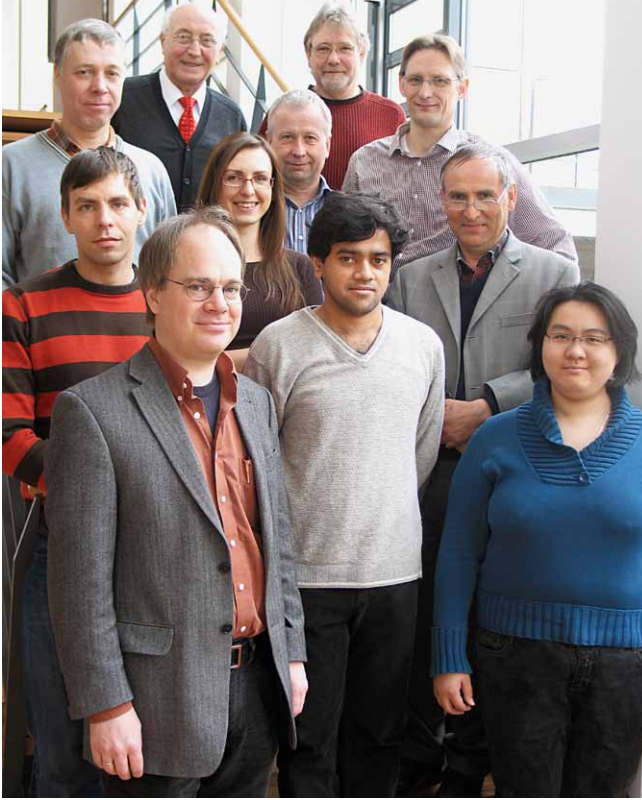
Im Bereich der Optoelektronik etwa gibt es Spezialisten wie Hans Wenzel, Karl-Heinz Hasler oder Agnieszka Pietrzak, deren Hauptaufgabe darin besteht, die Effizienz und Brillanz von Halbleiterlasern mit ihren Simulationen zu steigern. Das heißt, sie liefern die entscheidenden Hinweise, wie das Design aufgebaut sein muss, damit die Laser die gewünschten Anforderungen erfüllen. Dazu müssen weitere komplizierte Gleichungen gelöst werden, die den Stromfluss innerhalb des Lasers und die Erzeugung von Licht beschreiben.

Bernd Eppich dagegen kümmert sich vor allem darum, Laserstrahlen zu charakterisieren und zu formen. Er optimiert diese gezielt für verschiedene Anwendungen. Dazu nutzt er Modelle, die mögliche Schwachstellen eingrenzen, und rechnet Lösungsvarianten durch. Da diese Fragestellungen auch andere beschäftigen, hat er zwei kommerzielle Programme entwickelt, die inzwischen auch von anderen Unternehmen und Forschungseinrichtungen für ihre Laserentwicklungen genutzt werden. Das eine befasst sich mit der Analyse und Charakterisierung des Laserstrahls. Das andere ist ein sehr leicht bedienbares grundlegendes Simulationsprogramm, mit dem sich die Ausbreitung des

charakterisierten Strahls durch Linsen und andere optische Elemente berechnen lässt. Auf diese Weise können optische Systeme schnell und präzise ausgelegt werden. Ein grundlegendes Rechenmodell hat auch Reiner Güther entwickelt. Für die Frequenzverdoppelung, bei der infrarotes in blaues oder grünes Licht umgewandelt wird, gab es bislang keine Simulationslösung. Diese wird jedoch benötigt, um die komplexen Mikromodule auch theoretisch abbilden zu können. Derartige Lasermodule werden mit nicht-linearen Kristallen, Mikrolinsen und Optiken aufgebaut und kommen in der Lebensmittelanalytik oder Displaytechnologie zum Einsatz.

Auf dem Gebiet der Hochfrequenzschaltungen ist es dagegen oft notwendig für die Untersuchung und das Design eines Transistors oder Verstärkers unterschiedliche Simulationsprogramme einzusetzen. Um die auf Wafern hergestellten Barren mit Transistoren (Transistorarrays) beispielsweise als Produkt anbieten zu können, müssen diese in ein Gehäuse montiert und verdrahtet werden. Für den Kunden ist wichtig, wie die elektrischen Eigenschaften des Transistorarrays an den Gehäuseanschlüssen aussehen und ob die entstehende Wärme ausreichend abgeführt wird oder weitere Maßnahmen notwendig sind. Um die elektrischen Eigenschaften des Aufbaus zu bestimmen, führen Spezialisten wie Franz-Josef Schmückle elektromagnetische Simulationen des Gehäuses und seiner passiven Elemente durch. Diese umfasst sowohl die Details der Gehäusegeometrie als auch die Bonddrähte mit ihren Selbst- und Gegeninduktivitäten. An der Transistorsimulation arbeiten wiederum weitere spezialisierte Mitarbeiter wie Frank Schnieder oder Matthias Rudolph, die den aktiven Teil des Transistors beschreiben und ein komplexes Funktionsmodell erstellen, das auf gemessenen Daten beruht. Sie ermitteln zudem die Temperatur- und Wärmeverteilung durch Simulation des thermischen Verhaltens des Transistorarrays im Gehäuse und liefern dadurch wichtige Hinweise zum mechanischen Aufbau des gehäuseten Transistorarrays.

Darüber hinaus beschäftigen sich zahlreiche weitere Kollegen mit Simulationen, etwa von aktiven Verstärkerschaltungen oder dem Einkoppeln von Strahlungsfeldern in optische Wellenleiter. Das komplexe Zusammenspiel von Rechenmodellen und ihr Abgleich mit Messungen ist daher die unverzichtbare Grundlage, um Bauelemente permanent verbessern und die gewünschten Leistungsmerkmale erreichen zu können.



*A bunch of arithmetic power: simulation experts at the FBH.
 » Geballte Rechenkraft: Simulationsexperten am FBH.*

Simulations: basis for excellent research at FBH

One can hardly recognize how much mathematics is behind scientific developments. However, simulation is indispensable at FBH as corresponding calculation models are applied before each device development—no matter if it is a power transistor, diode laser, microwave circuit or microwave plasma source. Such models simulate reality and indicate whether the theoretical considerations can be practically implemented. They also subsequently help to adjust particular parameters to achieve the desired results.

Simulations at the FBH largely base on Maxwell's equations describing how electromagnetic fields are generated by charges and currents and how they behave, spatially and as a function of time. Before these equations had been discovered, electricity, magnetism and optics were independent fields. Maxwell connected electricity with magnetism and revealed that his formulae were additionally capable to describe light. Depending on the frequency range, simplifications of the equations are reasonable and applicable. This also leads to different simulation methods in microwave and mm-wave technology and in optics.

In the field of optoelectronics, for example, experts like Hans Wenzel, Karl-Heinz Hasler and Agnieszka Pietrzak are mainly concerned with increasing the efficiency and brilliance of semiconductor lasers. They provide their colleagues with clues how to optimize the laser design in order to meet the specific requirements. For this purpose, complex equations need to be solved describing the current flow inside the laser and the generation of light.

Bernd Eppich mainly deals with characterizing and forming laser beams in order to optimize them for various applications. He therefore uses models to limit potential

weaknesses and calculates possible solutions. As many users are concerned with comparable issues, Bernd Eppich developed two commercial programs which are meanwhile used by other companies and research institutions for their laser developments. One is about analytics and characterization of laser beams and the other a very easy-to-handle basic simulation program calculating the propagation of the characterized beam through lenses and other optical elements. Thus, optical systems can be constructed quickly and precisely. A fundamental calculation model has also been developed by Reiner Güther. For frequency doubling converting infrared into blue or green light no simulation solution has been available so far. Such a tool is required, however, to model the complex micro modules in theory, which are assembled with nonlinear crystals, micro lenses and optics and used for applications in food analysis and display technology.

In the field of RF circuits, on the other hand, it is often necessary to apply different simulation programs at the same time when designing a transistor or an amplifier. To offer transistor arrays as a product, they need to be mounted and packaged. In this regard, the electrical behavior at the external interconnects is of crucial importance for customers. But they also need to know if the heat generated can be sufficiently dissipated or further measures need to be taken. To determine the electrical properties of the assembly, specialists such as Franz-Josef Schmückle conduct electromagnetic simulations of the package and its passive elements. These simulations include the package structures as well as the bond wires with their self and mutual inductances. Transistor simulation, on the other hand, is conducted by further specialized FBH staff like Frank Schnieder and Matthias Rudolph who describe the active part of the transistor and establish a complex functional model, based on measurements. They additionally determine temperature and heat distribution by simulations of the thermal behavior of the packaged transistor array and thus give important hints for further mechanical setup.

Numerous further colleagues are additionally concerned with simulations as for example of active amplifier circuits and the coupling of radiation fields in optical waveguides. The complex interaction of calculation models and their verification by measurements is thus the indispensable basis to permanently improve devices in order to achieve the required performance features.



Vielfalt bereichert: Wissenschaftlerinnen und Wissenschaftler aus aller Welt am FBH



Fachkräfte sind gesucht und auch in Deutschland rar. So ist es wenig verwunderlich, dass immer mehr qualifizierte Frauen und Männer aus dem Ausland eingestellt werden. Bereits heute besitzen mehr als 10% der Kolleginnen und Kollegen am FBH nicht die deutsche Staatsbürgerschaft – diese Zahl wäre noch deutlich höher, würde man diejenigen mitzählen, die inzwischen eingebürgert sind oder ausländische Wurzeln haben. 22 verschiedene Nationalitäten von algerisch, britisch und chinesisch bis hin zu mongolisch, ukrainisch und vietnamesisch sind aktuell am Institut vertreten. Diese Zahlen sind in den vergangenen Jahren stetig gestiegen. Viele nutzen für den Auslandsaufenthalt Austauschprogramme des DAAD, immer häufiger jedoch bewerben sich Wissenschaftlerinnen und Wissenschaftler direkt am Institut. Kontakte entstehen durch internationale Konferenzen, Forschungskooperationen oder auch nach einer Internetrecherche zum eigenen Forschungsthema.

Berufliche Perspektiven bietet das FBH sowohl ausländischen Studierenden, die ihr Studium mit einer Diplom- bzw. Masterarbeit abschließen möchten, als auch Promovierenden und Postdocs, die länger am Institut forschen. Das zeigt auch, Forschung und Entwicklung werden immer internationaler und davon profitieren alle Beteiligten: Ausländische Wissenschaftlerinnen und Wissenschaftler bereichern mit ihren Erfahrungen die Forschung am Institut, diese wiederum können in ihren Heimatländern oder der nächsten Forschungsstation mit guten Kontakten und Auslandserfahrung punkten. Nicht zuletzt eröffnen sich dadurch Möglichkeiten, das Institut international noch besser zu vernetzen und den Kreis der Industriekunden und Kooperationspartner über die Landesgrenze hinaus auszuweiten.

*People from all over the world conduct research at the FBH. ►
» Menschen aus aller Welt forschen am FBH.*

Erfolgsgeschichte: Hochtechnologie-Ausbildung



Die Zwischenbilanz des Ausbildungsnetzwerks Hochtechnologie (ANH) Berlin kann sich sehen lassen: Wie geplant ist es dem Netzwerk seit 2007 gelungen, 60 zusätzliche betriebliche Ausbildungsplätze in der Region zu schaffen und mit geeigneten Bewerbern zu besetzen. Das im Frühjahr 2010 gestartete ANH-Anschlussprojekt setzt neue Schwerpunkte: Neben der Beratung von Unternehmen sowie Schülerinnen und Schülern in allen Fragen der beruflichen Bildung im Hochtechnologiebereich, entwickelt das Netzwerk Zusatzmodule. Damit sollen insbesondere Ausbildungsinhalte der Mikrotechnologie an veränderte betriebliche Anforderungen angepasst und zeitgemäße Modelle geschaffen werden, die für mehr Durchlässigkeit zwischen beruflicher und akademischer Bildung sorgen. So soll in Kooperation mit der Fachhochschule Brandenburg für Auszubildende in der Mikrotechnologie der Übergang in den Bachelor-Studiengang Mikrosystemtechnik und optische Technologien erleichtert werden. ANH Berlin ist ein Verbundprojekt mit der Lise-Meitner-Schule im Rahmen des Bundesprogramms JOBSTARTER – für die Zukunft ausbilden.

Mit „bottle neck“ ist Mitte 2010 auch eine „europäische Dimension“ hinzugekommen. In dem EU-geförderten Projekt geht es um innovative Inhalte, Methoden und Materialien für die berufliche Aus- und Weiterbildung in der Mikrotechnologie. Partner aus Deutschland, Dänemark, Belgien, Finnland und Großbritannien tauschen Informationen, Know-how und Good-Practice-Beispiele aus, um den langfristigen Fachkräftebedarf decken zu können.



Diversity enriches: scientists from all over the world at FBH

Skilled personnel is highly demanded and in Germany scarce too. Thus, it is nothing to be surprised about that qualified women and men are increasingly hired from abroad. Already today, the nationality of more than 10% of FBH's staff is not German—this number would even increase if those being naturalized in the meantime or with foreign roots were counted. Colleagues with 22 different nationalities, from Algerian, British and Chinese to



Mongolian, Ukrainian and Vietnamese are currently working at the institute. Many use exchange programs like DAAD for the stay abroad. However, scientists increasingly apply directly at the institute and additionally establish contacts at international conferences, via research cooperation as well as by searching the internet on corresponding research topics.

FBH offers career prospects to both foreign students completing their studies with a diploma or master thesis and Ph.D. students as well as post docs who like to pursue further research at the institute. This reveals that research and development increasingly become international and yield advantages for all parties: foreign scientists enrich FBH's research with their international experience and score at the same time with good contacts and work experience abroad in their home countries or their next research position. Not least, the increasing internationalization opens new possibilities to further cross-link the institute and extend the circle of customers and cooperation partners beyond national borders.

Success story: high-technology education

The "interim balance sheet" of ANH Berlin reveals results the high-technology education network can be proud of: As projected, ANH Berlin successfully created 60 additional vocational training positions in the region and matched them with appropriate candidates. The ANH follow-up project, which started in spring 2010, emphasizes new aspects: Beyond supporting research institutes and companies in all needs and questions concerning education in the high-technology area, the network develops additional modules. These specifically aim at adjusting training content in microtechnology to changing industry requirements and to establish up-to-date models, ensuring more permeability between vocational and academic education. Therefore, a cooperation with the Brandenburg University

of Applied Sciences shall facilitate the transition for trainees in microtechnology to the bachelor course in microsystems technology and optical technologies. ANH Berlin is a joint project of FBH and Lise-Meitner-Schule within the framework of the federal JOBSTARTER program.

Since August 2010, a European dimension has been added to these activities with "bottle neck". The EU-funded project deals with innovative content, methods and material for vocational training and further education in microtechnology. Partners from Germany, Denmark, Belgium, Finland and Great Britain exchange information, know-how and good-practice examples in order to meet the long-term need for skilled personnel.

◀ *Career with good prospects: microtechnology trainees in FBH's cleanroom.*
» *Beruf mit Zukunft: Auszubildende in der Mikrotechnologie im Reinraum des FBH.*



Auszeichnungen



Preisträger 2010: „wissen.schafft.arbeit“ für erfolgreichen Technologietransfer

Das Institut für Experimentelle Physik der Otto-von-Guericke-Universität Magdeburg, die LayTec GmbH und das Ferdinand-Braun-Institut sind als Team die Sieger 2010 im Wettbewerb „wissen.schafft.arbeit“, den die TU Chemnitz und die Deutsche Postbank zum dritten Mal ausgelobt haben. Der mit 20.000 Euro dotierte Technologietransfer-Preis wurde für die Entwicklung und den erfolgreichen Transfer einer Krümmungsmesstechnologie vergeben, mit der die Qualität und die Ausbeute bei der Herstellung von LED-Bauelementen deutlich gesteigert werden konnten. Am FBH wurde dieser in-situ Krümmungssensor erprobt und weiterentwickelt.

Eine wesentliche Schwierigkeit bei der Herstellung von Galliumnitrid-Bauelementen besteht nämlich darin, dass

sich die Halbleiterscheiben, auf denen sie entstehen, stark durchbiegen. Die Höhe der Durchbiegung hängt dabei von den Dicken der Halbleiterschichten (wenige Mikrometer) sowie von der Größe und Dicke der verwendeten Substrate ab. Daher ist das Verständnis und die Kontrolle der Waferdurchbiegung im gesamten Herstellungsprozess, von der Substratauswahl über die Schichtherstellung bis zur Bauelemente-Prozessierung, von zentraler Bedeutung.

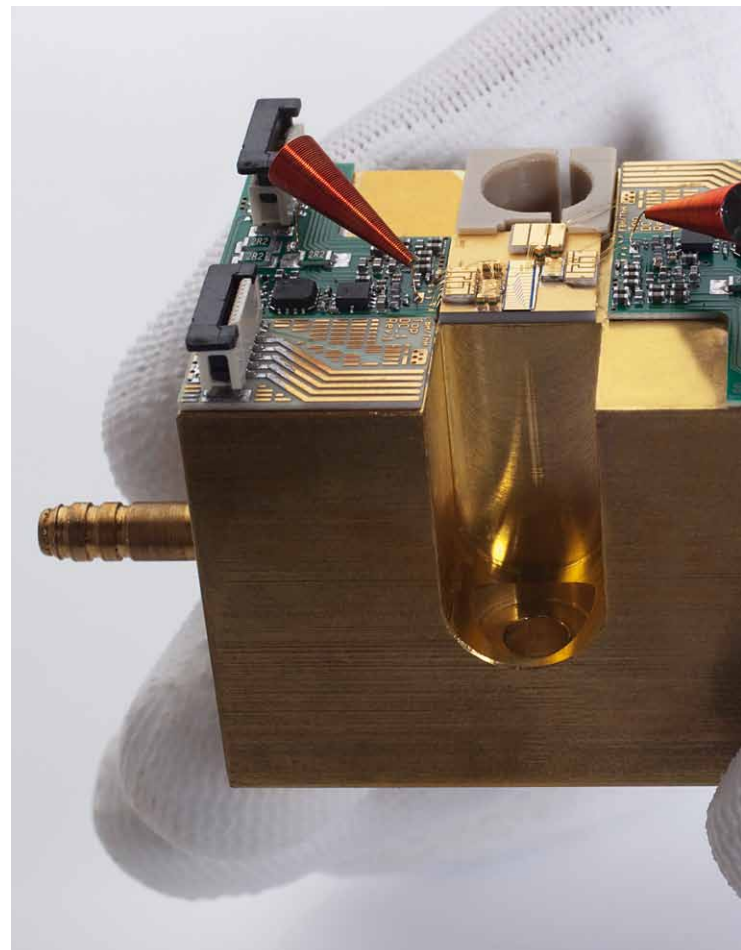
Chorafas-Preis

Für seine Dissertation über das Wachstum von nicht- und semipolaren Galliumnitridschichten erhielt Tim Wernicke am 19. Oktober an der Technischen Universität Berlin (TU) den Chorafas-Preis. Tim Wernicke hatte zuvor seine Promotion in Physik an der TU bereits mit Auszeichnung abgeschlossen.

Wege in die Zukunft: erste FBH-Forschungskonferenz



Im Sommer hat das FBH erstmalig eine Forschungskonferenz organisiert, bei der alle Gruppen aus den verschiedenen Geschäftsbereichen und Abteilungen ihre Themen und Ergebnisse kurz präsentierten. Ziel war es, an insgesamt drei Tagen allen Mitarbeiterinnen und Mitarbeitern einen umfassenden Überblick über die verschiedenen Arbeitsfelder zu geben und gemeinsam neue Ansätze für die Zukunft zu entwickeln. Die Forschungskonferenz zeigte zugleich die Entwicklung, die das FBH in den vergangenen Jahren genommen hat: Die Bearbeitung vielfältiger Themen mit exzellenten Ergebnissen – über den Halbleiter hinaus bis hin zu Modulen und ersten Systemen. Bei Diodenlasern mit hoher Leistung ist das FBH in Europa die erste Adresse und eines der führenden Institute weltweit. Auch in der Höchstfrequenztechnik bis zum Terahertzbereich strebt das Institut in die „Champions League“.



Awardee 2010: „wissen.schafft.arbeit“ for successful technology transfer

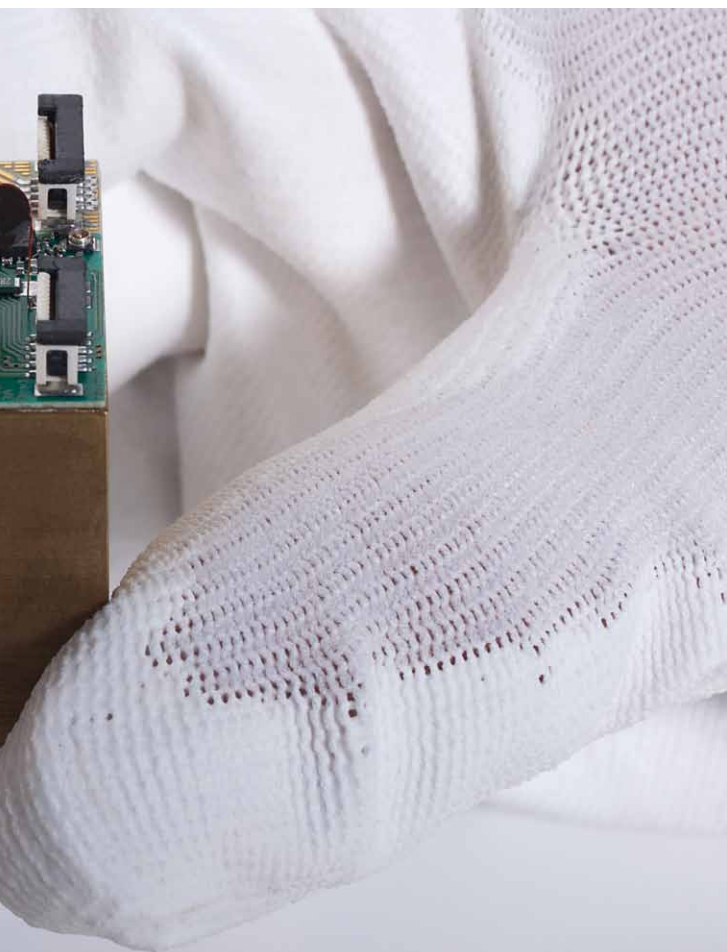
The Institute for Experimental Physics at Otto-von-Guericke-Universität Magdeburg, LayTec GmbH and the Ferdinand-Braun-Institut jointly won the “wissen.schafft.arbeit” competition, which has been tendered for the third time by TU Chemnitz and Deutsche Postbank. The technology transfer prize is rewarded with 20.000 euros and has been assigned for the successful transfer of a curvature sensor technology which significantly enhances quality and yield of LED devices. This in-situ curvature sensor had been tested and further developed at the FBH.

One of the major problems is that the manufacture of gallium nitride devices is troubled by a considerable bow

of semiconductor wafers which are the basis for such devices. The amount of bow depends on the thickness of the epitaxial layers (some micrometers) as well as the size and thickness of the used substrates. Therefore, a deep understanding and control of the wafer bow is highly relevant within the overall manufacturing process, ranging from substrate selection and layer deposition to device processing.

Chorafas prize

In October 2010, Tim Wernicke has been awarded with the Chorafas prize at the Technische Universität Berlin (TU) for his thesis on the growth of non- and semi-polar gallium nitride layers. Before, he had already completed his doctoral thesis at the TU in physics with distinction.



Paths into the future: first FBH research conference

For the first time, FBH organized a research conference bringing together all work groups from various business areas and departments to briefly present their topics and results. Aim of the three-day event was to give all employees a comprehensive overview on the different working fields and to jointly develop new approaches for the future. The conference at the same time revealed FBH's progress within the last years: handling versatile topics with excellent results—beyond the semiconductor to modules and first systems. FBH ranks as the first address in Europe for diode lasers with high output power and among the world-wide leading institutes in this field. The institute also targets the “champion league” in microwave and mm-wave technology up to the terahertz range.

- ◀ *This device unites competencies from optoelectronics and microwave technology: picosecond light source with hybrid-integrated electronics.*
- » *Hier fließen Kompetenzen aus Optoelektronik und Mikrowellentechnik zusammen: Pikosekunden-Lichtquelle mit hybrid integrierter Elektronik.*



Auch 2010 Zukunftsinvestitionen aus dem Konjunkturprogramm II



Nach umfassenden Investitionen in die Energie- und Medienversorgung des Reinraums und Geräteanschaffungen in 2009, hat das FBH 2010 erneut mehr als 1,2 Millionen Euro aus dem Konjunkturprogramm der Bundesregierung erhalten. Hierdurch wurde unter anderem der Bereich der Aufbau- und Verbindungstechnik auf den neuesten Stand gebracht. Räume wurden neu aufgeteilt und Lüftung, Gassystem sowie die Elektroinstallation modernisiert. Eine neue Klimatisierung und Medienversorgung schaffen stabile

Arbeitsbedingungen für die Montage der Bauelemente und verbessern die Arbeitsabläufe erheblich. Dabei konnten die Lieferverpflichtungen der laufenden FBH-Projekte trotz des Umbaus eingehalten werden. Das FBH hat zudem Planungsmittel für einen Erweiterungsbau mit Büro- und Laborflächen in Höhe von 420.000 Euro erhalten – die abschließende Finanzierung des Gebäudes steht noch aus.

Geräteanschaffungen verbessern zusätzlich die Ausstattung des FBH und erweitern die Prozessmöglichkeiten. So sichert ein neues automatisches Belackungs- und Entwicklungssystem die Weiterentwicklung und Optimierung von Bauelementen auf neuestem technologischem Stand. Um die am FBH angestrebten höheren Leistungen und Frequenzen erzielen zu können, müssen Wafer mit hohen Topologien durch Spraybelackung homogen beschichtet werden. Mit der automatischen Anlage zum Belacken, Tempern und Entwickeln von Wafern können Lacke nun sowohl mittels Spin- als auch Spray-Coating aufgetragen werden.

Im Bereich der Aufbau- und Verbindungstechnik wurde ein neues Barrenlötgerät angeschafft, das höchste Präzision und Flexibilität bietet. Durch die permanente Weiterentwicklung der Diodenlaser hoher optischer Leistung und Brillanz müssen immer längere Chips auf Wärmesenken platziert, gelötet und kontaktiert werden. Dies war mit der vorhandenen Infrastruktur nicht möglich. Die wichtigste Eigenschaft des neuen Gerätes ist die automatische und mikrometeregenaue Einstellung der Planparallelität zwischen dem Chip und der Wärmesenke vor dem Lötprozess. Mit weiteren Tools und Vorrichtungen für die Bauteilaufnahme kann die große Vielfalt verschiedener Diodenlaserchips, die an einem Forschungsinstitut wie dem FBH anfallen, verarbeitet werden.



Qualitätsaudit erneut erfolgreich bestanden



Auch 2010 hat das FBH sein 4-tägiges jährliches Audit zum Integrierten Managementsystem erfolgreich bestanden – dieses umfasst Qualität, Umwelt und Arbeitssicherheit. Erstmals ist das FBH im Bereich Qualitätsmanagement 2004 zertifiziert worden, die Bereiche Umwelt- und Arbeitssicherheitsmanagement folgten ab 2006 bzw. 2007. Das effiziente und

prozessorientierte System unterstützt das FBH darin, seine Geschäftsprozesse im Bereich von Forschung und Entwicklung sowie beim Technologietransfer zu steuern und systematisch zu organisieren. Dadurch gelingt es dem FBH seine führende Position zu sichern und international konkurrenzfähig zu bleiben.

Further future investments in 2010 from the economic stimulus package II

After comprehensive investments in the cleanroom's energy and media supply along with equipment purchases in 2009, the FBH again received more than 1.2 million euros from the economic stimulus package of the Federal Government. This enabled FBH to bring its mounting and assembling technology up to date. Rooms have been rearranged and ventilation, gas system as well as electrical installation were modernized. A new air conditioning and media supply provide the basis for a stable working environment for device mounting and significantly improve the workflow. Despite renovation, all delivery commitments of the ongoing projects could be fulfilled. Moreover, FBH received planning costs for an annex building with additional office and laboratory space in the amount of 420.000 euros—the final funding of the building is not yet determined.

Equipment purchases additionally improve FBH's infrastructure and extend the institute's processing capacities. A new automated cluster system for photolithography processing ensures further development and optimization of devices on state-of-the-art level. In order to achieve the desired higher output powers and frequencies, wafers with high topologies need to be coated homogeneously by means of spray coating. With the automatic equipment for wafer coating and developing, photoresist can be applied by either spin or spray coating.

In the area of mounting and assembling, a new soldering system for laser bars has been acquired allowing for highest precision and process stability. Due to persistent further development of diode lasers with high optical output power and brilliance, increasingly larger chips have to be mounted and soldered on heat sinks. The existing

equipment has no longer been capable to cope with these demands. The most important feature of the new tool is its ability to automatically adjust plane parallelism with sub-micrometer accuracy between chip and heat sink before the soldering process. Further tools and instruments help to handle the great variety of different diode laser chips resulting from activities of a research institute like the FBH.



Excellent working conditions after comprehensive construction works at FBH's mounting and packaging area.

» Umfassende Umbauten in der Aufbau- und Verbindungstechnik schaffen ausgezeichnete Arbeitsbedingungen.

Quality audit again successfully passed

Also in 2010, FBH successfully passed the four-day yearly audit of its integrated management system, comprising the modules quality, environment and occupational health and safety. FBH's quality management has been certified for the first time in 2004, the other two categories followed in 2006 and 2007. The efficient and process-oriented system supports FBH to systematically organize and manage all

business processes in research and development as well as in technology transfer. This allows FBH to ensure its leading position and to remain internationally competitive.



Gut informiert: Kommunikation aus dem FBH



Entscheiderkommunikation off- und online – neues Format: frequent

Um Entscheider aus Industrie, Politik und Verbänden zielgerichtet über aktuelle Entwicklungen und Ergebnisse auf dem Laufenden zu halten, hat das FBH 2010 ein neues Format entwickelt. Die frequent ist neben dem Jahresbericht das zentrale Medium, mit dem das Institut zwei Mal jährlich kompakt zu einem Schwerpunktthema informiert, ergänzt durch Kurznachrichten aus Forschung und Produktentwicklung. Bislang sind zwei der 8-seitigen Hefte erschienen: (1) Mikrowellenplasmaquellen und (2) Hochleistungsdiodenlaser. Die frequent gibt es sowohl in gedruckter Form als auch auf der Website – dort findet sich außerdem ergänzendes Material wie Publikationen, Vorträge oder Hinweise auf Projekte:
www.fbh-berlin.de/frequent

Laser kinderleicht – FBH erklärt das Grundprinzip im „Mosaik“-Comic

Im Rahmen der Medienkooperation zwischen dem Steinchen für Steinchen Verlag und Instituten der Leibniz-Gemeinschaft hat das Ferdinand-Braun-Institut im „Mosaik“-Novemberheft allgemeinverständlich das Grundprinzip eines Lasers erklärt. Seit Herbst 2009 widmet sich „Mosaik“ der Wissenschaft und begleitet Gottfried Wilhelm Leibniz und die Abrafaxe durch Europa. Unter der Rubrik „Auf Leibniz' Spuren: Die schlaunen Leute von heute“ erklären Leibniz-Institute leicht verständlich verschiedene wissenschaftliche Phänomene. „Mosaik“ ist das älteste und mit einer Auflage von etwa 100.000 pro Heft zudem auflagenstärkste deutsche Comic.

Neue Zielgruppen erschließen – FBH twittert

Mit den modernen Kommunikationsformen im Web 2.0 lassen sich schnell und unbürokratisch große Zielgruppen erreichen – damit steigt ihre Bedeutung auch für die Außendarstellung. Seit August 2010 nutzt das FBH daher Twitter als zusätzliches Kommunikationsmedium und informiert in 140 Zeichen über aktuelle Nachrichten aus der Forschung, Publikationen, Stellenangebote und Termine des Instituts: http://twitter.com/FBH_News.



Well informed: communication from the FBH

Off- and online communication for decision makers— new format: frequent

In order to provide decision makers from industry, politics and organizations with target-oriented information on up-to-date developments and results, FBH designed a new format in 2010. Along with the annual report, frequent is the institute's core medium informing biannually about a particular key issue, completed with short news from research and product development. Up to now, two of the eight-page booklets have been published: (1) microwave plasma sources and (2) high-power diode lasers. frequent is available as printed version and on the website—there, additional material such as publications, lectures and project references is offered: www.fbh-berlin.de/frequent

Laser as easy as pie—FBH explains basic principle in the „Mosaik“ comic

Within the framework of a media cooperation between Steinchen für Steinchen Verlag and institutes of the Leibniz Association, the Ferdinand-Braun-Institut explained intelligible to all the basic principle of a laser in the “Mosaik” November issue. Since autumn 2009, “Mosaik” is dedicated to science and accompanies Gottfried Wilhelm Leibniz and the Abrafaxes across Europe. Under the column “following Leibniz’ traces: smart people from today”, Leibniz institutes explain various scientific phenomena the easy way. “Mosaik” is the oldest German comic and with a 100.000 edition per issue also the one with the widest circulation nationwide.

Opening up new target groups—FBH tweets

With new ways of communication offered by web 2.0 applications, major target groups can be addressed quickly and unbureaucratically. Thus, their relevance in creating a public image increases. Since August 2010, FBH uses Twitter as additional communication channel and informs in 140 characters about latest news such as research results, publications, job offers and current events of the institute: http://twitter.com/FBH_News.

AUF LEIBNIZ' SPUREN:
DIE SCHLAUEN LEUTE VON HEUTE

HEUTE: DAS FERDINAND-BRAUN-INSTITUT, LEIBNIZ-INSTITUT FÜR HÖCHSTFREQUENZTECHNIK

50 Jahre Laser – ein Grund zu feiern und genauer nachzufragen, was das ist. Laser ist eine Abkürzung und steht für „light amplification by stimulated emission of radiation“. Übersetzt heißt das: Lichtverstärkung durch stimulierte Emission von Strahlung. Das klingt komplizierter, als es ist!

Alles, was wir sehen oder anfassen können, besteht aus unzähligen winzigen **Atomen**. Die setzen sich aus noch kleineren Teilen zusammen: einem **Kern** und einer **Hülle** darum. Auf dieser Hülle bewegen sich **Elektronen** in verschiedenen Ebenen. Kommt **Energie** in Form von Licht oder Strom hinzu, werden die Atome angeregt. Das heißt, die Elektronen hüpfen eine Ebene höher. Auf dem Weg zurück geben sie **Lichtteilchen** (Photonen) ab. Trifft ein solches **Photon** auf ein ebenfalls angeregtes Atom, gibt dieses ein neues Photon ab, das dem ersten vollkommen gleich ist. Es hat die gleiche Farbe und die gleiche Richtung. So geht das immer weiter und das nennt man dann „**stimulierte Emission**“. Sperrt man diese Emission zwischen zwei **Spiegel**, läuft das Licht so lange hin und her, bis die Energie groß genug ist und der **gebündelte** Laserstrahl austritt. Wichtig ist, dass einer der Spiegel teilweise durchlässig ist, damit das Laserlicht heraus kann.

1 **2** **3**

Die **kleinsten** Lasertypen sind reiskorngroße **Halbleiterlaser**, die zum Beispiel am Ferdinand-Braun-Institut hergestellt werden. Im Prinzip funktionieren sie aber genauso wie größere Gas- oder Festkörperlaser. Hier ist der Halbleiterlaser im Vergleich zu einer 1-Cent-Münze zu sehen.

WAS MACHT LASERLICHT SO BESONDERS?

Normales Licht (wie **Sonnenlicht** oder Glühlampen) besteht aus vielen unterschiedlichen **Wellenlängen** und Farben und leuchtet in ganz verschiedene Richtungen. So kann mit dem **gestrauten** Licht ein ganzer Raum ausgeleuchtet werden. Laserlicht dagegen lässt sich **gut bündeln**. Es besteht aus Wellen, die alle in die gleiche Richtung gehen, im **Gleichtakt** schwingen und genau die gleiche Farbe haben. Deshalb lässt es sich besonders gut steuern und kann für viele verschiedene Dinge genutzt werden: im **CD-Spieler**, in der Supermarktkasse oder beim Schweißen von Blechen. Auch **Ärzte** nutzen Laser für heikle Augenoperationen oder schmerzarme Zahnbehandlungen.

Nie direkt ins Laserlicht schauen, weil es sehr intensiv ist und die Augen verletzen kann!



Messen & Veranstaltungen



Auch 2010 war das FBH wieder auf vielen Messen, Fachkonferenzen und Veranstaltungen vertreten. Ins Jahr gestartet ist das Ferdinand-Braun-Institut mit einem wissenschaftlichen Kolloquium mit dem Titel „high-power diode lasers – achievements and challenges“ anlässlich des 60. Geburtstags von Götz Erbert. Es folgten zahlreiche „Pflichtveranstaltungen“ der Branche wie Photonics West oder CLEO. Zwei Veranstaltungen wurden 2010 von Kolleginnen und Kollegen des FBH selbst organisiert: die German Microwave Conference (GeMiC) und der erste Mädchen-Technik-Kongress.

German Microwave Conference (GeMiC)

Mit Wolfgang Heinrich, Georg Böck und Matthias Rudolph haben drei Chairmen aus dem FBH und seinem Umfeld die größte deutsche Mikrowellenkonferenz German Microwave Conference (GeMiC) organisiert. Sie fand an der TU Berlin statt und wurde vom 15. - 17. März von 160 Teilnehmern besucht, davon etwa 20% internationales Fachpublikum. Die steigenden Teilnehmerzahlen und qualitativ hochwertigen, internationalen Beiträge belegen, dass sich die GeMiC zunehmend als Forum der deutschen Mikrowellenforschung etabliert. Das FBH war beim wissenschaftlichen Programm mit vier Vorträgen und einem Poster präsent. Erstmals fanden außerdem BMBF-Statusseminare, Industrieworkshops sowie Sessions der Informationstechnischen Gesellschaft im VDE im Rahmen der Konferenz statt.

Leibniz auf der Hannover Messe

2010 hat sich die Leibniz-Gemeinschaft erstmals mit einem Gemeinschaftsstand auf der Hannover Messe präsentiert. Zusammen mit fünf weiteren Leibniz-Einrichtungen, stellte das Ferdinand-Braun-Institut sich und seine Entwicklungen vor. Mit dabei war auch der im Jahr zuvor gegründete Leibniz-Transferverein Mikroelektronik, dessen Geschäftsstelle am FBH angesiedelt ist. Der Verbund bündelt das Know-how und die Ressourcen von derzeit sieben Leibniz-Instituten und der TU Berlin. Er entwickelt marktorientierte Forschungs- und Dienstleistungsangebote, die auf den Bedarf von Unternehmen zugeschnitten sind und neue Märkte für Innovationen erschließen sollen.

Erster Mädchen-Technik-Kongress Berlin-Brandenburg organisiert

Mädchen ab der 7. Klasse hatten in Berlin und Brandenburg erstmalig die Möglichkeit, spannende Einblicke in Naturwissenschaften und Technik zu gewinnen und Karriereperspektiven in MINT-Berufen auszuloten. 125 Mädchen nutzten diese Chance und nahmen am ersten Mädchen-Technik-Kongress teil, der im Rahmen des ZEMI-Projekts mst|femnet organisiert wurde. Ziel war es, dem weiblichen Nachwuchs mit abwechslungsreichen Angeboten Berufs- und Arbeitsfelder in den MINT-Fächern (Mathematik, Informatik, Naturwissenschaften und Technik) näher zu bringen. Die Resonanz von Schülerinnen, Lehrkräften und Beteiligten war so positiv, dass im nächsten Jahr erneut ein Mädchen-Kongress stattfinden wird.

FBH für alle:

Lange Nacht der Wissenschaften & Girls' Day

Auch im Jahr 2010 öffnete das FBH seine Türen für die interessierte Öffentlichkeit. Mehr als 1.200 Besucherinnen und Besucher zog das Programm zur Langen Nacht der Wissenschaften in das Institut. Neben dem Girls' Day, bei dem Mädchen ab der 5. Klasse einen Blick hinter die Kulissen von Forschung und Entwicklung werfen können, ist dies die wichtigste Veranstaltung des FBH für die allgemeine Öffentlichkeit.



Berlin Secretary of Commerce Harald Wolff (r) and René Gurka (l), Managing Director of Berlin Partner, visit the Leibniz stand at Hannover Messe 2010.

» Der Berliner Wirtschaftssenator Harald Wolff (re.) und René Gurka (li.), Geschäftsführer von Berlin Partner, besuchen den Leibniz-Stand auf der Hannover Messe 2010.

In 2010, the FBH was again represented at many fairs, conferences and events. Ferdinand-Braun-Institut started the year with a colloquium entitled “high-power diode lasers—achievements and challenges” on the occasion of the 60th birthday of Götz Erbert. This celebration was followed by many “must-attend events” of the branch such as Photonics West and CLEO. Two conferences in 2010 have been organized by colleagues from the FBH themselves, the German Microwave Conference (GeMiC) and the first “Mädchen-Technik-Kongress” aiming to get girls involved in science and technology.

German Microwave Conference (GeMiC)

With Wolfgang Heinrich, Georg Böck and Matthias Rudolph three chairmen from the FBH and its close environment organized the major German Microwave Conference (GeMiC). The event attracted 160 participants—20% of which were international professional attendees—and took place from 15th to 17th March at the TU Berlin. The increasing number of participants and high-rank international contributions proved that GeMiC increasingly establishes itself as a panel for German microwave research. FBH participated in the scientific program with four lectures and a poster. For the first time, BMBF status seminars, industry workshops as well as sessions of the Information Technology Society of VDE were additionally organized within the framework of the conference.

Leibniz at Hannover Messe

In 2010, the Leibniz Association was represented for the first time with a joint stand at the Hannover Messe. Together with five further Leibniz institutions, the Ferdinand-Braun-Institut introduced the institute and its developments. Also on board was the Leibniz Technology Transfer Association Microelectronics, which has been founded one year ago and whose office is located at the FBH. The transfer association bundles know-how and resources of currently seven Leibniz institutes and the TU Berlin. It develops market-oriented offers in research and related services which are tailored to meet enterprises' needs and shall open up new markets for innovations.



Warm-up for the “Mädchen-Technik-Kongress”: kick-off event in Berlin.

» *Warmlaufen für den Mädchen-Technik-Kongress: Eröffnungsveranstaltung in Berlin.*

First Mädchen-Technik-Kongress Berlin-Brandenburg organized

For the first time, Berlin and Brandenburg girls from 7th grade and higher had the possibility to gain fascinating insights in natural science and technology and to explore career prospects in MINT professions. 125 girls took their chance and participated in the first girls' technology congress, which was organized within the framework of the ZEMI project *mst|femnet*. Aim was to give the female offspring an understanding of occupational areas and fields of work by a diversified offer in MINT subjects (mathematics, informatics, natural sciences and technology). As the response of the students, teachers and other participants was very positive, it was decided to project another girls' congress for the following year.

FBH for everybody: Science Night & Girls' Day

Like any other year, FBH opened its doors for the general public in 2010. During Science Night, more than 1,200 visitors were attracted by the institute's program. Apart from Girls' Day, allowing girls from 5th grade and higher to gain an insight view behind the scenes of research and development, the Science Night is FBH's most important event for the interested public.



Gleichstellung & Familienfreundlichkeit



FBH zum dritten Mal familienfreundlicher Betrieb Treptow-Köpenicks

Erneut wurde das Ferdinand-Braun-Institut für seine familienfreundlichen Maßnahmen vom Bezirk ausgezeichnet. Bezirksbürgermeisterin Gabriele Schöttler überreichte im Rahmen des Unternehmer- und Ausbildungstages Süd-Ost im September 2010 den ersten Preis an Günther Tränkle, Direktor des FBH. Zuvor hatte das FBH diesen Preis schon 2006 und 2009 erhalten. In ihrer Rede hob Schöttler die beispielhaften Leistungen des FBH bei der Vereinbarkeit von Familie und Beruf hervor, die Vorbildcharakter für andere Unternehmen bzw. Einrichtungen haben sollten. Mit der Auszeichnung ist ein Preisgeld in Höhe von 500 Euro sowie eine Acrylglas-Skulptur der Liechtensteiner Künstlerin Evelyne Bergmann als Wanderpreis verbunden.

Gut unterstützt: Väter, Mütter & Kinder am FBH

Die Elternzeit wurde in den beiden vergangenen Jahren am FBH gut angenommen. 19 Mütter und Väter haben seither eine Auszeit für die Kinderbetreuung genommen, darunter zehn junge Männer, die zwischen ein und vier Monaten Reinraumlabor gegen Wickelkommode getauscht haben. Das Angebot, die Arbeitszeit zu reduzieren oder während der Elternzeit stundenweise zu arbeiten, nehmen insbesondere Mütter gerne an. Das FBH sieht die flexiblen und auf individuelle Bedürfnisse abgestimmten Vereinbarungen mit seinen Mitarbeiterinnen und Mitarbeitern als ideales Zukunftsmodell für die Vereinbarkeit von Kindern und Beruf.

Die Kinderbetreuung spielt dabei eine wesentliche Rolle. Daher hat das FBH Ende 2010 einen Vertrag mit einer neu geschaffenen Kindertagesstätte auf dem Campus Adlershof geschlossen – ein Angebot, das die bereits vorhandenen Möglichkeiten zur Kinderbetreuung, wie etwa das institutseigene Kinderzimmer, frei abrufbare Betreuungskontingente im Kinderhotel oder individuelle Arbeitszeitmodelle ergänzt. Die Kita betreut Kinder ab acht Wochen flexibel von 6 bis 20 Uhr und bietet zudem eine bilinguale Erziehung (Deutsch-Englisch). Das Institut finanziert derzeit zwei Betreuungsplätze, die für Kinder von Mitarbeiterinnen und Mitarbeitern des Instituts reserviert und auch bereits besetzt sind.

Equal opportunity & family friendliness

FBH is family-friendly workplace in Treptow-Köpenick for the third time

The Ferdinand-Braun-Institut has again been awarded with the first prize for its family-friendly measures by the district Treptow-Köpenick. The honoring comprises 500 euros prize money and a challenge cup trophy, an acrylic sculpture designed by the Liechtenstein artist Evelyne Bergmann, which District Mayor Gabriele Schöttler handed to FBH's Director Günther Tränkle. Schöttler described FBH in her speech as a role model for other companies and institutions and emphasized the exemplary achievements helping employees to combine family and career. In 2006 and 2009, the institute has already been awarded with this prize.

Well supported: fathers, mothers & children at the FBH

Parental leave is an offer, which has been widely used at the FBH within the last two years. Since then, 19 mothers and fathers took a time out for childcare reasons, including ten young men who exchanged the cleanroom laboratory

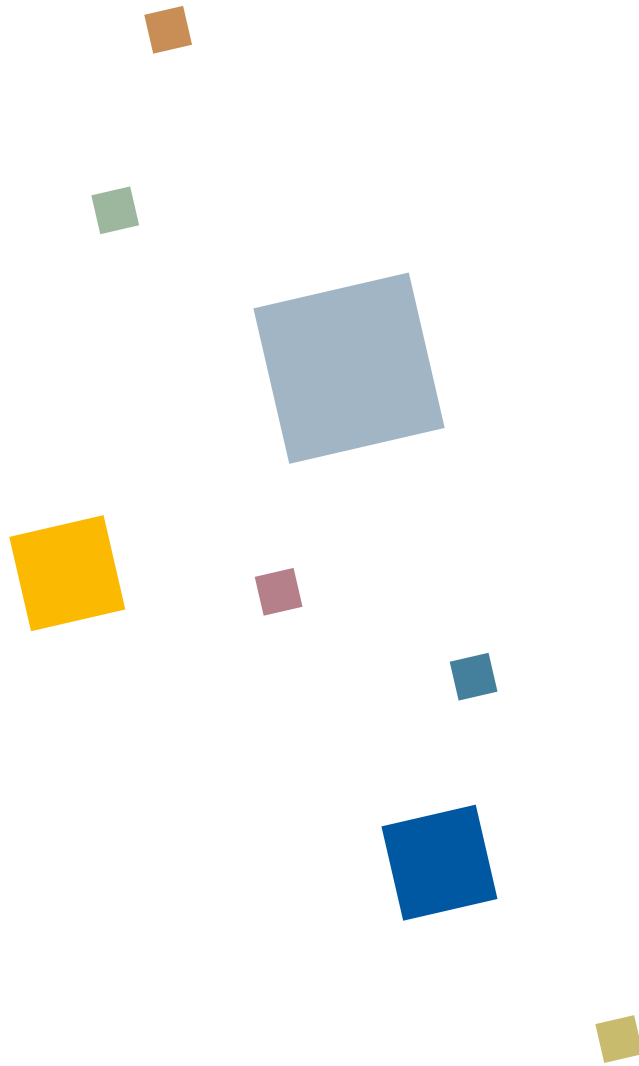
for a diaper changing unit. Especially mothers appreciate the offer to cut working hours or to work part-time during parental leave. FBH regards its flexible agreements, which are adapted to the individual needs of its employees, as a model for the future to combine family and career.

Childcare is an important issue in this context. At the end of 2010, FBH therefore signed an agreement with a newly founded day-care center on campus Adlershof. The new institution takes care of children aged eight weeks and older from 6:00 am to 8:00 pm and additionally offers a bilingual education (German and English). Currently, the institute finances two places reserved for children of FBH's employees; both childcare places were occupied instantly. This offer complements the already existing possibilities, such as the institute's children room, a need-based available number of hours at the "Kinderzeit" children hotel with its 24-hour service as well as individual working hour models.



Günther Tränkle (l) receiving 2010's award as family-friendly workplace.

» Günther Tränkle (li.) nimmt die Auszeichnung als familienfreundlicher Betrieb 2010 entgegen.



BUSINESS AREAS & RESEARCH

Microwave Components & Systems **» Mikrowellenkomponenten & -systeme**

GESCHÄFTSBEREICHE & FORSCHUNG



Mikrowellenkomponenten & -systeme



Die Arbeiten des FBH im Bereich der Mikrowellenbauelemente und -schaltungen umfassen die vollständige Wertschöpfungskette von der Epitaxie und Prozesstechnologie bis hin zu CAD, Messtechnik und Chipaufbauten. Aufgrund der am FBH verfügbaren Technologien liegt der Schwerpunkt auf III/V-Halbleitern – in diesem Falle der GaN-Elektronik – und der zugehörigen Design- und Messtechnik-Kompetenz. Hier stehen Leistungselemente für den Frequenzbereich 2 bis 10 GHz im Vordergrund. Darüber hinaus werden Millimeterwellen-ICs im Frequenzbereich 10 bis 100 GHz bearbeitet, speziell für Low-Power- oder Radar-Frontends. Dabei wird mittlerweile ausschließlich auf SiGe-HBT- und RF-CMOS-Prozesse zurückgegriffen (externe Foundries). Unter dem Schlagwort THz-Elektronik befinden sich Aktivitäten zu MMICs für Frequenzen oberhalb 100 GHz im Aufbau. Als Basis dient dabei der am FBH entwickelte InP-HBT-Transfersubstrat-Prozess.

Bauelemente aus dem FBH sind Schlüsselkomponenten für die drahtlose Kommunikation (Basisstationen für die Mobilkommunikation, Breitband-Richtfunk) und die Sensorik (Radarsensoren im Automobil, Sensor-Netzwerke). Auch Mikrowellen-Plasmaquellen gehören zum Portfolio, für die Leistungs-Mikrowellenelektronik zusammen mit Strukturen zur Plasmaanregung integriert werden.

Im Einzelnen umfasst das Forschungsgebiet folgende Themen, die gemeinsam von den Geschäftsbereichen Mikrowellenkomponenten und -systeme sowie GaN-Elektronik bearbeitet werden:

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

Die zugehörigen GaN-Prozesse werden von den Technologie-Abteilungen des FBH bzw. dem Geschäftsbereich GaN-Elektronik entwickelt und gepflegt. Ein Reinraum-Labor mit industrie-kompatiblen Gerätepark ermöglicht es, Bauelemente entsprechend dem neuesten Stand der Technik herzustellen. Die Abteilung Mikrowellentechnik ist ein Kompetenzzentrum für Mikrowellen- und Millimeterwellen-Design sowie die entsprechende Aufbautechnik. Leistungsfähige Methoden zur dreidimensionalen elektromagnetischen Simulation für die Transistormodellierung und den 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 – die Erweiterung zu höheren Frequenzen ist derzeit in Vorbereitung.

Microwave Components & Systems

The FBH research activities in the field of microwave devices and circuits cover the entire value-added chain from epitaxy and processing to computer-aided design, measurements, and packaging. As a consequence of the technology available at FBH, the focus is on III-V semiconductor components—in this case GaN devices—and the corresponding design and measurement expertise. Here, FBH mainly targets power components (discretes and MMICs) for the frequency range between 2 and 10 GHz. An additional topic are millimeter-wave integrated circuits (10 to 100 GHz), with special emphasis on low-power and radar frontends. For this purpose, SiGe-HBT and RF-CMOS processes are applied, using external foundries. Emerging are activities on MMICs for frequencies beyond 100 GHz, commonly referred to as “THz electronics”. This work is based on the InP-HBT transferred-substrate process developed at FBH.

The devices developed at the FBH represent key components for wireless communications (cellular radio base-stations, broad-band radio links) and sensors (automotive radar, sensor networks). Also in the portfolio are microwave plasma sources, integrating power electronics together with excitation structures for plasma generation.

In detail, the main topics of research in this field include:

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

These activities are pursued jointly with the Business Area GaN Electronics. The relevant GaN processes are developed and maintained by the FBH technology departments and the Business Area GaN Electronics, respectively. A clean-room laboratory with industry-level equipment offers the capabilities 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, which presently is being extended to higher frequencies.

Large-signal characterization of microwave power transistors

One of the target applications for GaN-HEMT transistors developed at FBH is power amplifiers (PAs) for telecommunication systems. Modern telecommunication systems use relatively wideband radio channels and complex modulation schemes to increase the data transfer rate. The PAs therefore have to work over a large bandwidth with high peak-to-average power ratio (PAPR) signals. Since the instantaneous power in the amplifier changes continuously and it still has to operate in a linear region, the overall efficiency of the PA becomes very low, ranging from 5 to 15% for the modulated signal. Dedicated measurement setups, known as source- and load-pull systems, allow for analyzing and improving the trade-off between linearity and efficiency. This is accomplished by providing a similar environment to the transistor as present in a power amplifier. The dynamic voltage and current waveforms can also be analyzed under large-signal conditions and the transistor behavior can be determined under multi-tone or modulated carrier excitation. Since 2009, both measurement capabilities were established at FBH. The findings lead to improved circuit designs and advances in device technology.

Time-domain waveforms

The time-domain waveforms are measured with a large-signal network analyzer (LSNA). Voltage and current waveforms are determined at a calibrated reference plane using harmonic sub-sampling with frequency domain correction. The transistors are mainly characterized on-wafer with de-embedding to the probe interface. Intrinsic

dynamic mechanisms are visualized and can be analyzed as seen in Fig. 1. The results enable the study of dynamic voltage-breakdown effects and analysis of alternative stress mechanisms, e.g. thermal versus field breakdown.

Modulated measurements

Modulated measurements are conducted using either simple two-tone modulation for intermodulation distortion (IMD) analysis or more complex digital modulation schemes. Two-tone IMD analysis is mainly performed for technology comparison and improvement. With a complex modulation similar to the standards used in applications such as WCDMA, WLAN and long-term evolution (LTE), the transistor performance for a typical signal can be measured and compared to the specifications. Moreover, complex modulations provide deeper insight into the non-linear characteristics of the transistor. Gain and phase distortion from modulated signals represented as AM/AM and AM/PM graphs give additional information about so-called memory effects in the transistor, as shown in Fig. 2. Therefore, wideband complex signals can be used for both benchmarking and technology improvement. Modulated measurements place specific demands on the measurement setup, which is shown in Fig. 3. All parts of the system have to be well characterized. Non-linear effects at the input of the device under test (DUT), have to be compensated using linearization. At FBH, complex modulated measurements are conducted in a load-pull system, which is linearized by means of an in-house developed digital pre-distortion (DPD) software.

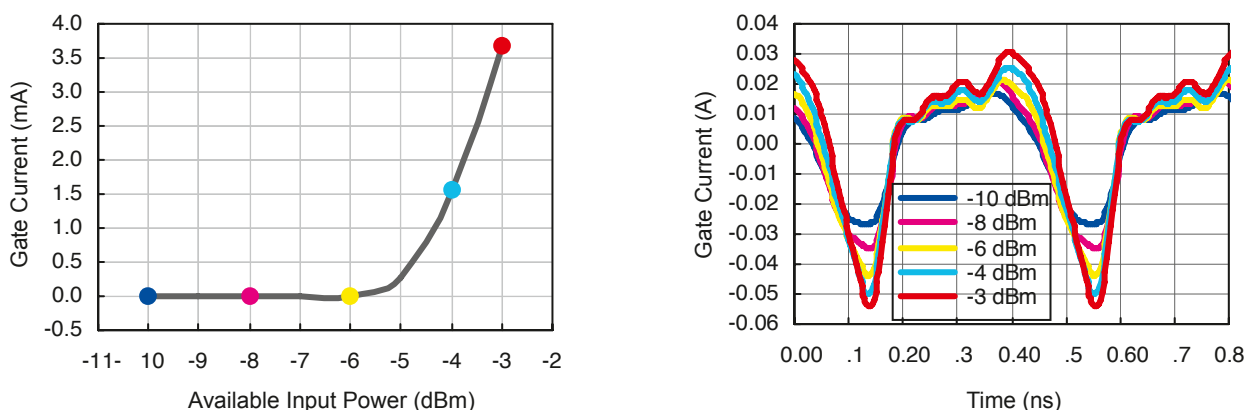


Fig. 1. Time-domain waveforms show the influence on gate current with increasing input power for a GaN-HEMT transistor biased in deep class-AB.

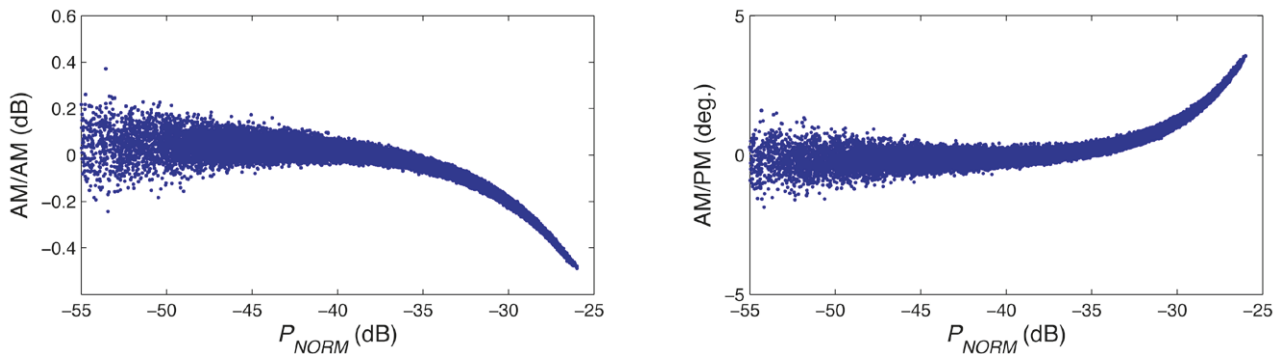


Fig. 2. Typical measured gain distortion (left) and phase distortion (right) for a pre-amplifier used in the measurement setup.

Publications

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Moderne Kommunikationssysteme benötigen höhere Bandbreiten und komplexe Modulationsverfahren. Dafür entwickelt das FBH GaN-HEMTs, die in Leistungsverstärkern eingesetzt werden. Diese müssen Signale mit hohem Dynamikumfang über einen weiten Frequenzbereich verarbeiten. Da diese Verstärker trotz wechselnder Leistungsanforderungen linear bleiben sollen, liegt ihre Effizienz nur um 10% für modulierte Signale.

Um Effizienz und Linearität beurteilen und optimieren zu können, kommen spezielle Messaufbauten zum Einsatz, die die Bedingungen eines Leistungsverstärkers nachbilden. Unter solchen Großsignalbedingungen werden die Wellenformen von Strom und Spannung, aber auch das Verhalten der Transistoren bei Anregung mit unterschiedlichen Signalen analysiert. Die daraus gewonnenen Erkenntnisse fließen ins Schaltungsdesign ein und führen letztlich zu verbesserten Bauelementen. ■

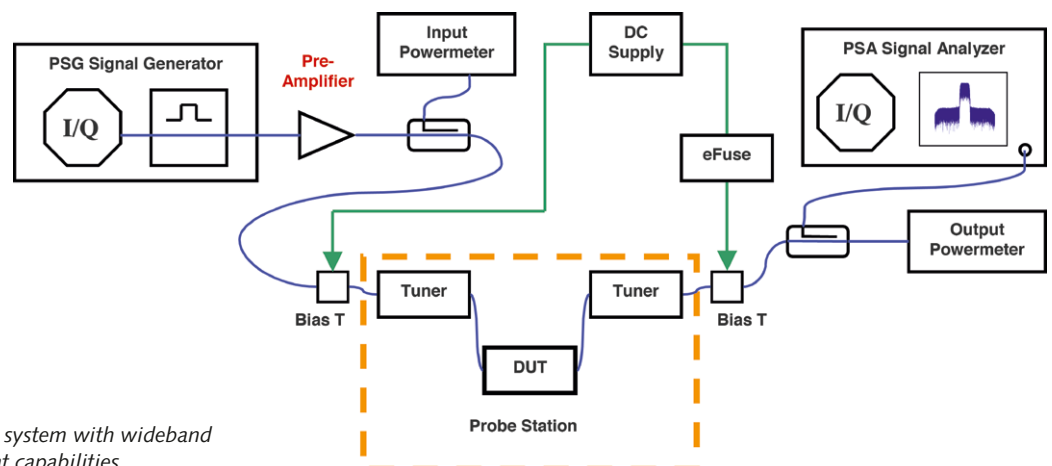


Fig. 3. Load-pull measurement system with wideband modulated measurement capabilities.

State-of-the-art RF class-S power amplifiers

Along with the introduction of new modulation schemes in today's wireless communication infrastructure (3G, 4G), the efficiency requirements on the power amplifier (PA) will strongly increase. As a consequence of the bandwidth-optimized modulation schemes, the PA has to operate at high peak-to-average power ratios (PAPR), which significantly reduces efficiency when using a common linear PA such as class-AB. The switch-mode concepts class-E, -F, and -J offer better efficiencies but still do not meet the requirements for high PAPR ratios. Hence, the Doherty concept or a type of envelope tracking is preferred.

At FBH, a special switch-mode version, the class-S concept, is being explored for the microwave range focusing on the frequency band around 450 MHz so far. One characteristic feature of this approach is that it uses digital signals throughout the signal path except for the filter at the output. For ideal devices, the class-S concept yields high efficiency, independently of the PAPR. As one needs very fast and broadband power transistors, however, most of the realizations so far are limited to audio frequencies.

Fig. 1. Voltage-mode class-S amplifier.



On the basis of highly efficient GaN power switches, current-mode (CMCS) and voltage-mode (VMCS) class-S PAs were designed, fabricated and optimized in the course of this work at FBH. Figs. 1 and 2 show the realized amplifiers.

The results obtained advance the state-of-the-art in class-S in the RF range. Using a single-tone band-pass delta-sigma (BPDS) bit sequence at the input, the CMCS PAs achieve output powers up to 9 W (at 34% drain efficiency) and maximum drain efficiencies of over 40% (2 W). With half the final stage transistor gate width, the VMCS amplifiers deliver up to 3.4 W (38%) output power and reach maximum efficiencies around 50% (1 W). For a 10 dB power back-off input signal, the drain efficiencies decrease further to less than 10%. This data clearly needs to be improved to be competitive with the well-known concepts like Doherty, especially at power back-off.

Looking for reasons for the low efficiency, the band-pass delta-sigma coding scheme used was identified to be a major obstacle. Thus, further investigations focused on optimizing the coding scheme. Using a periodic square-wave signal with maximum coding efficiency instead, the same VMCS and CMCS amplifiers deliver up to 7 W with 64% efficiency and 19 W output power with 59%, respectively, which is almost double the BPDS values.

Consequently, in order to enhance efficiency at PAPR, a special pulse-width modulation (PWM) was investigated for coding the amplitude. For the maximum amplitude of the encoded signal (full-scale) the resulting PWM waveform is exactly that of the square-wave case and hence gives maximum coding efficiency. This PWM can be combined with pulse-position modulation to reproduce also the phase-modulation part of the input signal. Thus, in contrast to the BPDS case with a fixed bit rate, the resulting coding is a binary but time-continuous signal. Tests with such a pulse-width modulation for the amplitude show significant enhancements in maximum output power compared to BPDS. Drain efficiency at 10 dB power back-off is improved

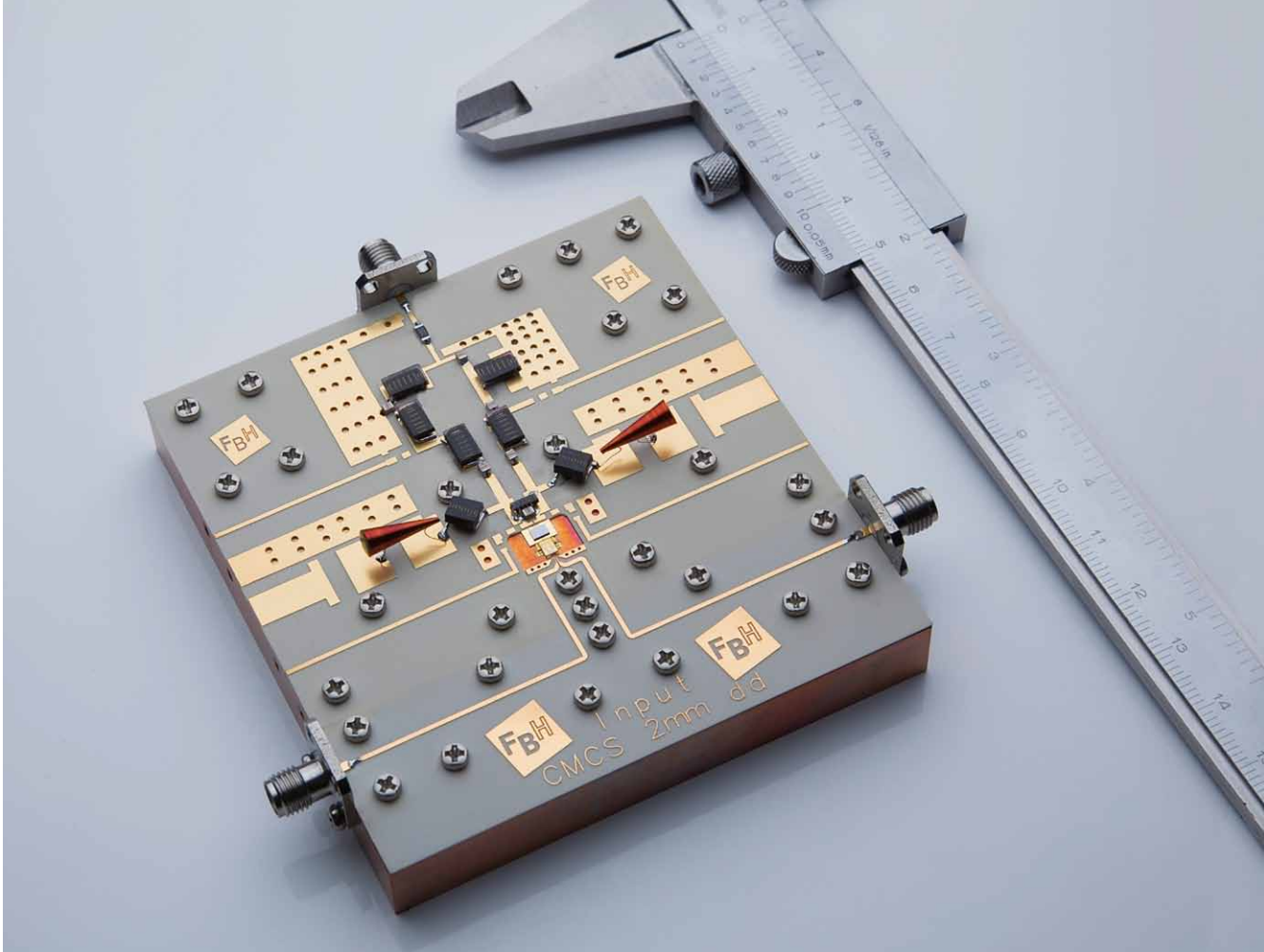


Fig. 2. Current-mode class-S amplifier.

from 10% to 40% (VMCS) and to 20% (CMCS), respectively. These results document the potential of the class-S PAs realized and prove that suitable coding is essential to achieve state-of-the-art results with microwave class-S amplifier architectures.

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Um den Wirkungsgrad von Hochfrequenz-Leistungsverstärkern auch bei einem hohen Verhältnis von Spitzen- zu Mittelwert der Leistung (PAPR) zu optimieren, wird am FBH im Frequenzband um 450 MHz das Klasse-S-Konzept untersucht. Ein Vorteil dieser Architektur ist, dass sie bis zum Ausgang der Endstufe komplett digital arbeitet.

Es wurden Verstärker sowohl vom Current-Mode- als auch vom Voltage-Mode-Typ realisiert und charakterisiert. Bei Verwendung der bei Klasse-S üblichen Bandpass-Delta-Sigma-Modulation erhält man jedoch zu geringe Effizienzen, speziell für hohe PAPR-Werte. Dies lässt sich durch Optimierung der Modulation verbessern. Für eine spezielle Pulsweitenmodulation (PWM) steigen die Effizienzen deutlich an (z.B. von 10% auf 40% bei 10 dB PAPR). Die erreichten Resultate zeigen das große Potenzial der realisierten Klasse-S-Verstärker und belegen, dass die Kodierung des Eingangssignals ein wichtiger Faktor bei der Optimierung ist. ■

GaN transistors for high-current switching laser driver

Diode lasers are used in a variety of applications offering powers up to several tens of Watt for a single laser structure. For many applications it is necessary to reach high optical power densities under pulsed conditions. These include fluorescence spectroscopy and metrology, micro-machining, biomedical systems, optical free-space communications and nonlinear optics.

Key element of such a pulsed laser source is the driver circuit. The challenge is to combine high peak current with fast switching. GaN transistors are well known to offer benefits for microwave devices if high power together with high-voltage operation is required. However, due to the high 2D electron density, GaN is also capable of providing large output currents for a given transistor size. In the end, GaN transistors offer a current density at least twice as high (i.e. 1-2 A/mm) as that of GaAs with switching speeds at least one third of GaAs-based ones.

Circuit design of such high-current switch drivers involves several challenges:

- Due to the low input impedance of the diode laser, it is hardly possible to use impedance-matched transmission lines as interconnects between the diode and the final

driver stage. Thus, one needs to keep the parasitics of the interconnects at an absolute minimum, particularly the inductances. Moreover, an optimized board design with chips directly bonded to the board is mandatory, as is careful simulation of the 3D structure.

- The large current capability of the final stage transistor means that there is a large gate capacitance at the input. As a consequence, the driver stage needs to be integrated with the final stage as close as possible to keep parasitic inductances low and to ensure fast switching behavior.

A further problem is the characterization of the switching behavior. Since the diode is current-driven, the output current is the decisive quantity to be measured. However, measuring fast switching of high currents in a miniaturized environment is very difficult. Therefore, we extract the transient current behavior from the optical output signal. Fig. 1 shows one of the laser drivers realized, including GaN driver and final stages, laser diode and storage capacitor.

Fig. 2 presents measured results showing the envelope of free running laser pulses passing an optical laser amplifier which is driven by the current switch described above.

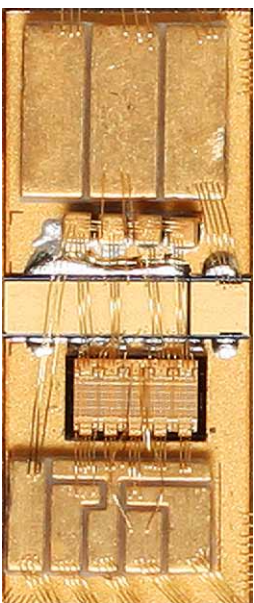


Fig. 1. Driver and final stage of the GaN transistor.

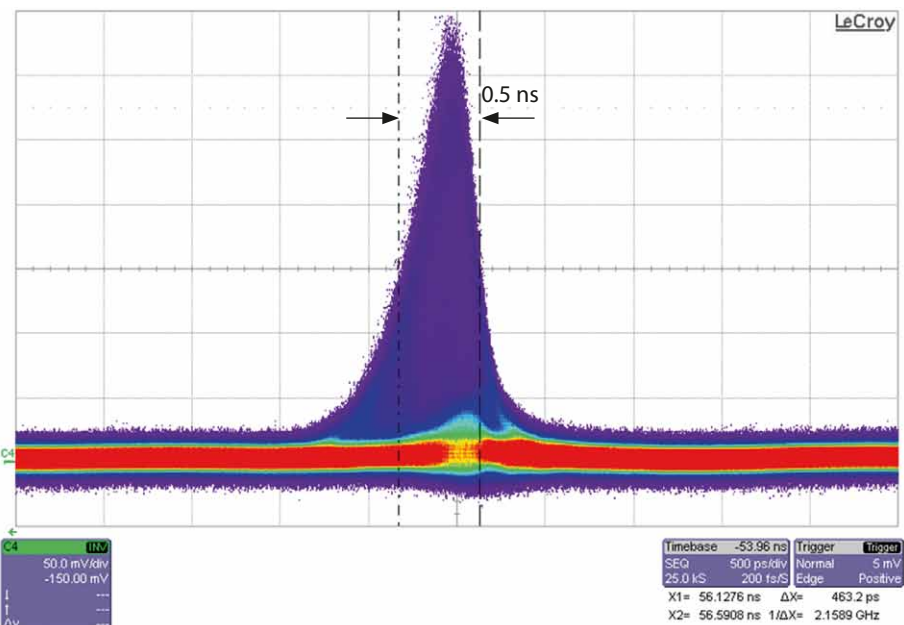


Fig. 2. Envelope of the optical output signal.

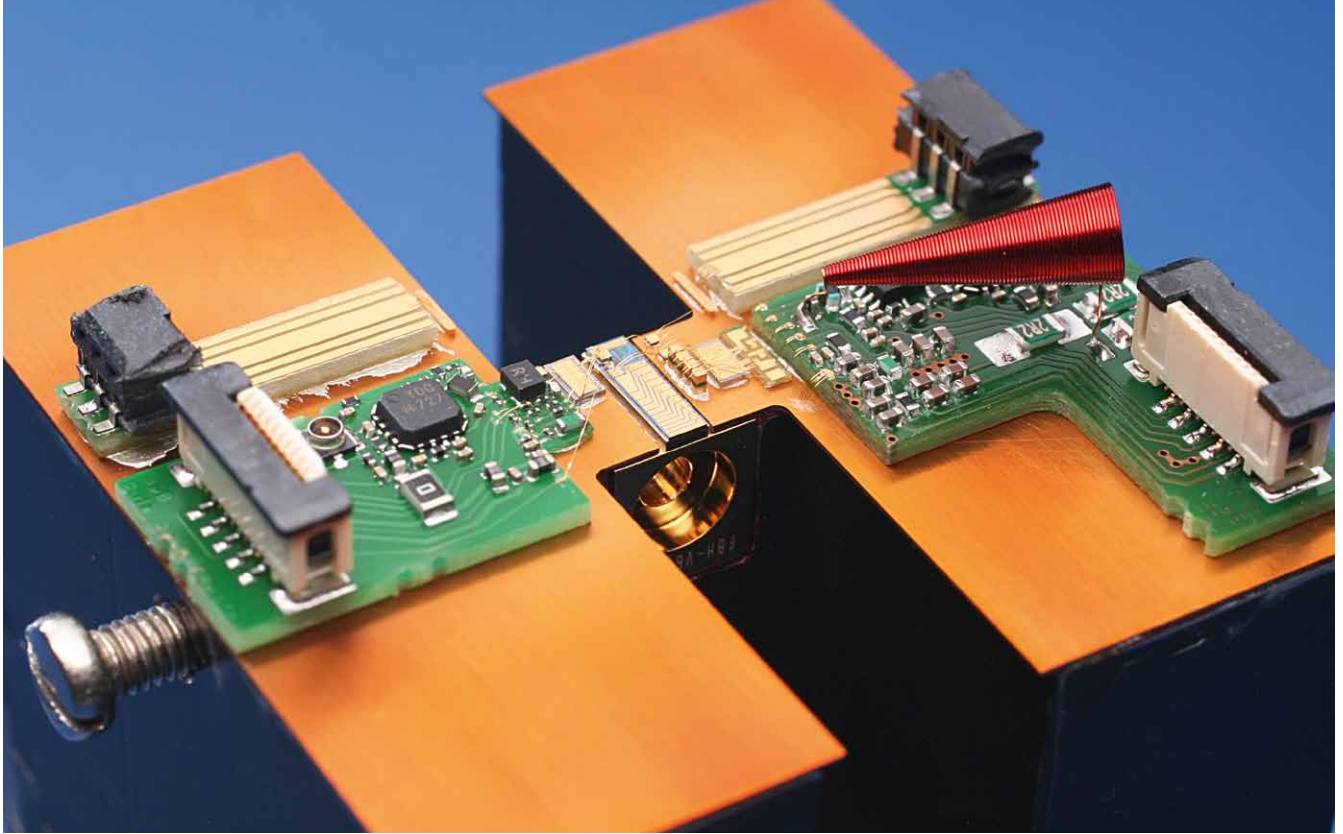


Fig. 3. Optical test fixture with a fast and a high-current switch.

The results demonstrate that a pulse width below 2 ns is achieved with rise and fall times in the 0.5 ns range. The GaN-based driver circuit is capable of delivering these short current pulses at 20 A peak current.

Using these fast driver building blocks one can realize a variety of laser assemblies. Fig. 3 shows a test fixture with two optical amplifiers/switches. A pulse train with laser bursts from an external laser can be fed through the optical gates so that one can separate single laser pulses.

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Diodenlaser, die einige zehn Watt Laserleistung aus einzelnen Strukturen erzeugen, werden für die verschiedensten Anwendungen eingesetzt. In vielen Fällen ist es jedoch notwendig, diese hohen optischen Leistungsdichten unter gepulsten Bedingungen zu erzeugen. Zu solchen Applikationen zählen die Fluoreszenz-Spektroskopie, biomedizinische Systeme, optische Freiraumkommunikation sowie die nichtlineare Optik.

Das Schlüsselement einer solchen gepulsten Laserquelle ist die Treiberstufe, die hohe Spitzenströme mit kurzen Schaltzeiten liefern muss. GaN-Transistoren haben ihr Hauptanwendungsgebiet bei Mikrowellen-Leistungsverstärkern. Wegen ihrer hohen 2D-Elektronendichte eignen sie sich aber auch für schnelle Hochstromschalter. Der Aufbau ist durch die extrem niedrige Impedanz der Laserdioden kritisch und erfordert sehr kurze und induktivitätsarme Leitungsstrukturen. Demonstriert wurde ein Schaltverhalten von 20 A in 2 ns. ■

Progress on microwave plasma sources

Atmospheric plasma sources

In 2010, the IMAPlaS (Integrated Microwave Atmospheric Plasma Source) was further developed in cooperation with FBH's industrial partner Aurion Anlagentechnik GmbH. Activities focused on industrial applications and small-series production. Thus, tests for several applications were performed such as the activation of high-voltage transformers prior to grouting. Moreover, systems were shipped to customers and research partners for evaluation and process development.

Further activities addressed the use of IMAPlaS for medical skin treatment. Results on nitric oxide and ozone generation capabilities and related biological effects were published. Also, the IMAPlaS source was exhibited at several trade shows and conferences such as Hannover Messe and Semicon Europe.

Low-pressure plasma sources

In a joint project with the Berlin company Sentech GmbH, microwave microplasma sources for low-pressure applications are being developed. Goal is a downstream source for the generation of activated species. Several versions of capacitively and inductively coupled plasma resonators were investigated and characterized. Fig. 1 shows an inductively coupled plasma resonator exciting a plasma inside a ceramic tube. For a better and faster optimization process of such devices, new methods of in-situ characterization were evaluated and installed.

Automated electrical characterization of microwave plasma resonators

In the first stage of the development of an integrated plasma source, a plasma coupling structure (antenna) has to be designed which, at the same time, acts as resonator for the necessary impedance transformation. For electrical circuit design of the oscillator, one needs to know the characteristics of this resonator with and without plasma

Fig. 1. Inductively coupled low-pressure downstream plasma.



To achieve this, an automated measurement setup was developed. It consists of a vector network analyzer (VNA), a power amplifier, directional couplers and control software. The VNA acts as signal generator and drives the amplifier. The direction coupler is placed between power amplifier and plasma resonator to measure voltage, current, and thus impedance. In a first step, the frequency response of the resonator is measured under small-signal conditions without plasma. These data is fed into an electrical circuit model of the resonator. Now, the plasma is ignited at the resonance frequency of the plasma resonator. After plasma

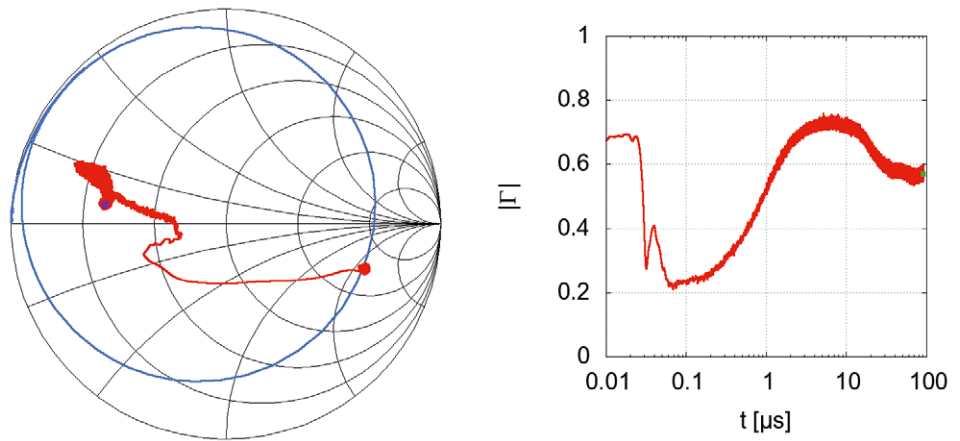


Fig. 2. Time-resolved reflection coefficient and plasma impedance during ignition.

ignition, a numerical algorithm tunes the frequency to the resonance frequency of the resonator under plasma conditions. In this way, the functionality of an oscillator circuit is simulated and the resonator is operating under realistic conditions. A mathematical calculation using the circuit model delivers the actual electrical values, in particular, consumed power, power loss, plasma power and electrical efficiency of the coupling structure.

Another setup is used to measure the transient wave voltages at the output of the directional coupler using a high-speed oscilloscope. A mathematical calibration, de-embedding and transformation algorithm was developed to obtain the transient reflection coefficient and the transient plasma impedance before, during and after ignition with a bandwidth limited only by the microwave frequency used to drive the plasma (Fig. 2). This delivers important data for the design of oscillator circuits as well as insight into the physical effects during plasma ignition. Interesting results were obtained, the interpretation of which needs further efforts.

Publications

S. Kühn, N. Bibinov, R. Gesche, P. Awakowicz, "Non-thermal atmospheric pressure HF plasma source: generation of nitric oxide and ozone for bio-medical applications", *Plasma Sources Sci. Technol.*, vol. 19, no. 015013 (2010).

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R. Gesche, S. Kühn, H.-E. Porteanu, J. Scherer, R. Kovacs, "Characterization of a Microwave Microplasma Source Using an Auxiliary Electrode", *SVC 53rd Annual Technical Conference Proceedings*, Society of Vacuum Coaters (2010).



2010 sind die Entwicklungen bei Mikrowellen-Plasmaquellen deutlich vorangekommen. So wurde die IMAPlaS (Integrated Microwave Atmospheric Plasma Source) in Zusammenarbeit mit dem Projektpartner Aurion Anlagentechnik GmbH weiter entwickelt. Erste Kleinserien wurden gefertigt, die derzeit zur Applikationsentwicklung bei potenziellen Kunden eingesetzt werden. Zusammen mit der Sentech GmbH wurden Mikrowellen-angeregte Niederdruck-Plasmaquellen entwickelt. Diverse induktiv und kapazitiv koppelnde Plasmaresonatoren wurden dazu aufgebaut und hochfrequenz- sowie plasmatechnisch charakterisiert.

Zur mikrowellentechnischen Untersuchung von Plasmaresonatoren wurde zudem ein automatisierter Messaufbau entwickelt. Dieser ermöglicht es, das Verhalten eines Oszillators zu simulieren und im Großsignal-Plasmabetrieb Spannungen, Ströme und Impedanzen zu messen. Diese Messungen erlauben es unter anderem, den Verlauf der Lastimpedanz bei der Plasmazündung zeitaufgelöst zu erfassen. ■



BUSINESS AREAS & RESEARCH

GaN Electronics » GaN-Elektronik

GESCHÄFTSBEREICHE & FORSCHUNG



GaN-Elektronik



Der Geschäftsbereich GaN-Elektronik entwickelt GaN-Bauelemente für Anwendungen in der Mikrowellentechnik und der Leistungselektronik. Die Aktivitäten decken die gesamte Wertschöpfungskette von der Epitaxie bis hin zu fertig montierten Bauelementen ab. Im Vordergrund stehen die anwendungsorientierte Konzeption der Bauelemente, die Entwicklung und Optimierung von geeigneten Prozessmodulen sowie deren Integration in einen Gesamtprozess. Dieser steht dann stabilisiert und reproduzierbar zur Verfügung.

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

Folgende Mikrowellen-Leistungsbaulemente werden gegenwärtig entwickelt:

- › Kompakt aufgebaute Mikrowellen-Leistungsbarren in thermisch und elektrisch optimierten Gehäusen für Ausgangsleistungen von bis zu 100 W bei 2 GHz
- › Leistungstransistoren für Hochstrompulse im ns-Bereich
- › Hochleistungs-Bauelemente mit optimierter Linearität
- › MMICs für Switchmode-Verstärker (Klasse S), auch kombiniert mit integrierten schnellen Schutzdioden
- › Mehrstufige X-Band-Leistungs-MMICs

Die Arbeiten zu GaN-basierten Hochleistungs-Schalttransistoren konzentrieren sich auf:

- › Normally-off-Schalttransistoren für hohe Betriebsspannungen (bis 1000 V) mit geringen Einschaltwiderständen und hoher Stromtragfähigkeit (bis 150 A). Hier konnten mit p-dotierten Gatestrukturen Weltbestwerte erreicht werden.
- › Hocheffiziente schnelle GaN-Schottkydioden mit Sperrspannungen von über 1000 V und einer Flussspannung von nur 0,5 V
- › Skalierfähige, thermisch optimierte Transistordesigns für die Flip-Chip-Montage auf Aluminiumnitrid-Submounts

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

Da viele der Forschungs- und Entwicklungsaktivitäten auf den raschen Technologietransfer zielen, kooperiert das FBH in diesem Bereich mit verschiedenen strategischen Partnern aus der Industrie. Darüber hinaus läuft die Vermarktung von GaN-Prototypen über die BeMiTec AG (Berlin Microwave Technologies), einem Spin-off des FBH.

The Business Area GaN Electronics focuses on the development, fabrication and characterization of GaN devices for microwave and power electronic applications. Activities cover the full value chain from epitaxy to completely packaged devices and aim at application-oriented device designs, the corresponding development of process modules and their integration into a complete process flow. This process will then be available in a stabilized and reproducible manner.

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

With respect to microwave power applications, the following devices are being developed:

- › Compact power bar devices including thermally and electrically optimized packaging for output power levels up to 100 W at 2 GHz
- › Power transistors for high current pulsing in the ns range
- › High-power devices with engineered linearity
- › Switch-mode amplifier MMICs (class-S), also combined with integrated fast Schottky protection diodes
- › Multistage X-band power MMICs

Activities concerning GaN-based high-power switching transistors focus on:

- › Normally-off switching transistors for high voltages (up to 1000 V) with low on-state resistance and high current capability (up to 150 A). World's best values could be obtained here with p-doped gate structures.
- › Highly efficient and fast GaN Schottky diodes with blocking voltages above 1000 V and a turn-on voltage of 0.5 V
- › Scalable thermally optimized transistor designs for flip-chip mounting on aluminum nitride submounts. These developments set the base for power switching transistors with very high current capability.

Reliability characterization combined with analysis and understanding of possible degradation mechanism gain in importance. The results feed back into technological development cycles 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.

As many of the research and development activities within this field are aiming to be transferred into an industrial environment, 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.

GaN HEMT processing optimization for power devices and MMICs

Stable and robust device processing is of crucial importance to establish a mature AlGaIn/GaN HEMT technology. Due to the still research-grade GaN material qualities and unsolved device issues this task is currently a world-wide challenge. The already developed baseline processing was further improved and stabilized at FBH with respect to the main goals: high performance, high yield and processing reproducibility.

The first aspect of device performance improvement was to reduce leakage currents observed in the MMIC processing variant. Previously, high gate-source leakage current in the range of 10^{-3} ... 10^{-2} A/mm was seen after the second SiN_x device passivation which is required for MIM capacitor fabrication. Systematic investigations targeting the origin of this effect revealed the decisive importance of local strain distribution in the gate vicinity to achieve low leakage

currents. In fact, by changing the processing scheme and after layout optimization the gate leakage current was decreased by 5 orders of magnitude to the very low level of 10^{-8} ... 10^{-7} A/mm (Fig. 1).

Furthermore, reliability and breakdown strength of the MIM capacitors have also been improved by tailoring the MIM layout, and by optimizing the MIM base-plate metal and the SiN_x dielectric layer itself. Routinely breakdown voltages of more than 180 V at a capacitance load of 300 pF/mm² are obtained which render these MIMs compatible for the higher voltage requirements of GaN-based MMICs.

The second activity focuses on the development of a 250 nm gate technology. These tiny gate dimensions are now available at FBH after installation of a new electron-

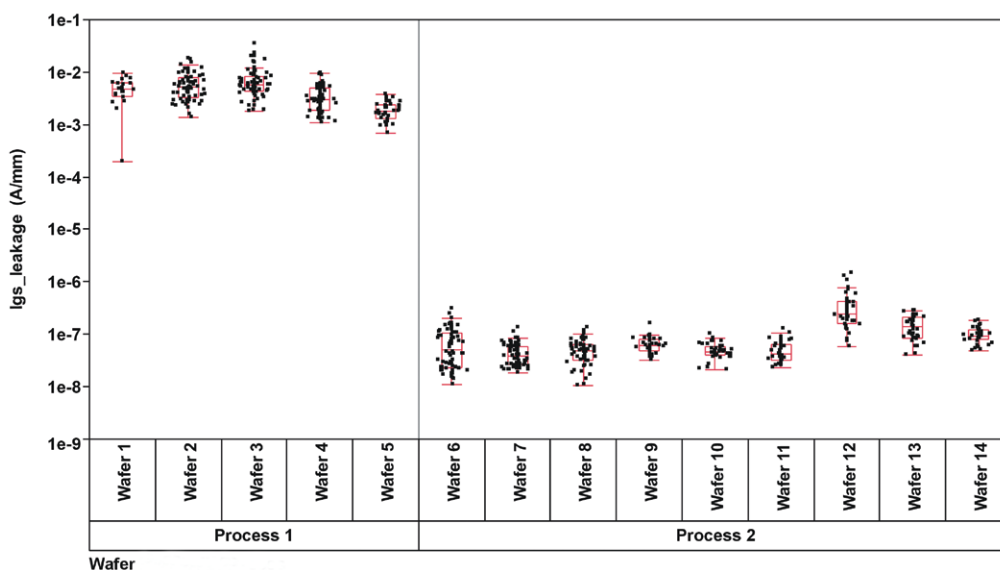


Fig. 1. Gate leakage current reduction after 2nd passivation achieved by optimized processing scheme and device layout (process 2).

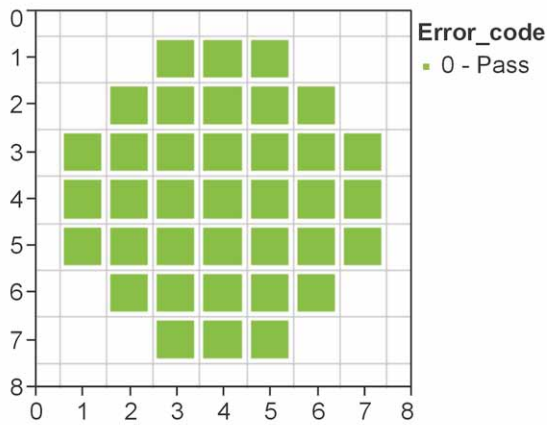


Fig. 2. Results from function testing by on-wafer mapping of 8 x 125 μm X-band power GaN-HEMTs with 250 nm gate showing no failed devices.

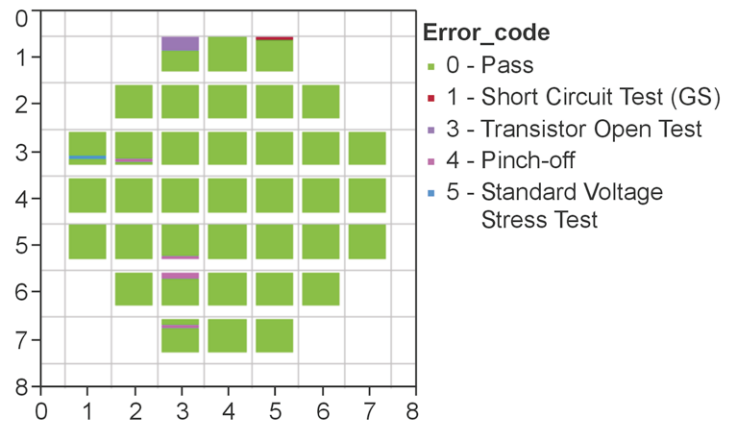


Fig. 3. Results from function testing by on-wafer mapping of 11 x 8 x 250 μm powerbars. The resulting yield is 97% for single cells and 81% for powerbars consisting of 11 cells each.

beam-based lithography system (Vistec SB251). However, basic lithography and system developments had to be performed in order to adapt this technology to GaN-HEMT structures on 75 mm SiC substrates. Fig. 2 shows the excellent yield of X-band power devices fabricated with 250 nm gate technology. The reduction of gate length from 500 nm to 250 nm allowed to increase the device's transit frequency f_T from 24 to 41 GHz and the maximum oscillation frequency f_{max} from 74 to 91 GHz, respectively.

For high yield and reproducible processing the parameters of critical processing steps have been stabilized. The gate module has been significantly improved by increasing the reproducibility of gate nitride thickness deposited by PECVD and by optimizing trench etching. A low-bias process has been developed allowing for less etching damage to the device channel as demonstrated by a 25% increase of the maximum device current compared to previously fabricated devices applying gate trench etching at higher bias levels. The minimized surface damage due to low-bias trench etching further decreases burn-in effects and improves bias point stability of the devices.

However, other processing steps are not less important for high-yield processing. Therefore, ohmic contacts with improved morphology after annealing were introduced in order to improve resist uniformity for gate formation. Fig. 3 verifies the success of the focussed processing optimization showing the excellent yield obtained on S-band powerbar devices for output power levels of 60 ... 100 W at 50 V.

Publication

S. A. Chevtchenko, P. Kurpas, N. Chaturvedi, R. Lossy, J. Würfl, "Investigation and reduction of leakage current associated with dielectric gate encapsulation in AlGaIn/GaN HFETs", accepted for Int. Conf. on Compound Semiconductor Manufacturing Technology (CS ManTech 2011), Palm Springs, USA, May 16-19 (2011).



Ein stabiler und robuster Herstellungsprozess von Bauelementen ist die Basis für eine marktreife AlGaIn/GaN-HEMT-Technologie.

Am FBH wurde nun ein entsprechender Basisprozess weiter verbessert und stabilisiert. Durch Optimierung von Prozessmodul und Bauelemententwurf konnte der Leckstrom um bis zu 5 Größenordnungen auf das Niveau von 10^{-8} ... 10^{-7} A/mm reduziert werden. Ferner wurden die Zuverlässigkeit und die Durchbruchfestigkeit der MIM-Kondensatoren so verbessert, dass eine hohe Durchbruchspannung von über 180 V reproduzierbar erreicht wird.

Ein besonderer Schwerpunkt lag auf der Entwicklung der Technologie für 250 nm Gates. Die Ausbeute an Bauelementen für den HF-Betrieb im X-Band konnte dabei signifikant gesteigert werden: Aufgrund der Verringerung der Gatelänge von früher 500 nm bieten diese jetzt deutlich höhere Grenzfrequenzen: f_T bis zu 41 GHz und f_{max} bis zu 91 GHz. Die Optimierung weiterer Prozessschritte – wie etwa ohmscher Kontakte mit verbesserter Morphologie – trägt dazu gleichfalls bei. Die exzellente Ausbeute an komplexen 100 W Leistungszellen bestätigt den Erfolg der fokussierten Prozessoptimierung. ■

AlGaN/GaN microwave power transistors: optimization of linearity and efficiency

The linearity of AlGaN/GaN heterojunction field-effect transistors (HFETs) is one of the key parameters in modern telecom systems. This parameter along with an improved efficiency needs to be optimized to design RF circuits fulfilling the requirements. GaN-based amplifiers are of practical interest not only for terrestrial but also for spaceborne communication applications. At FBH, the ESA-funded project "Linearity Assessment of GaN Technology" investigates possible approaches in epitaxy, processing and transistor design to optimize linearity at transistor level. Accordingly, GaN power devices with optimized inherent linearity properties are developed. This will reduce linearizing efforts in microwave power amplifiers and thus increase energy efficiency at a given linearity level. Together with its partners TESAT Spacecom GmbH & Co. KG, QinetiQ Ltd. and Technical University of Denmark (TUD), the institute aims at delivering highly linear C- and L-band amplifier prototypes for space applications.

The primary goal of the first project phase has been a cross-comparison of epitaxial structures supplied by FBH and QinetiQ with particular emphasis on linearity. The investigated epitaxial structures examine different buffer versions and diverse design concepts of the active transistor layers. In detail, the GaN standard buffer has been compared to other buffer variations including reduced thickness, structures encompassing an AlGaN potential back-barrier and GaN:Fe buffer in combination with an UID GaN channel. The AlGaN barrier composition and thickness variations in the active transistor layers as well as the GaN cap layer have been investigated in terms of linearity and efficiency. Linearity performance was evaluated by means of two-tone intermodulation distortion (IMD) measurements at different classes of amplifier operation (class-A, -AB and -B). The third order intermodulation ratio (C/I3) was calculated from the two-tone measurements. Transistors on different epitaxial structures were classified by using C/I3 as a parameter.

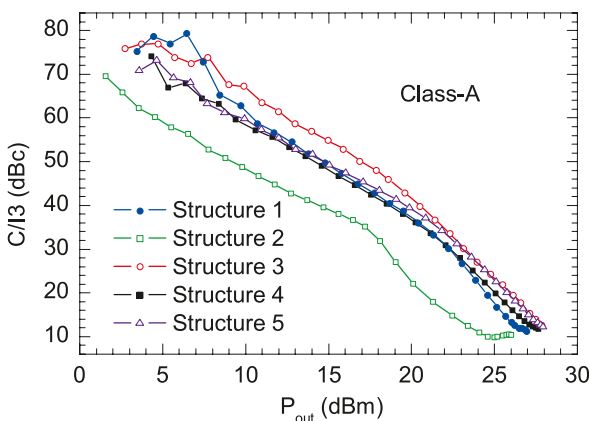


Fig. 1. Third order intermodulation distortion ratios versus output power measured around class-A bias point for $2 \times 125 \mu\text{m}$ wide transistors fabricated on different epitaxial structures.

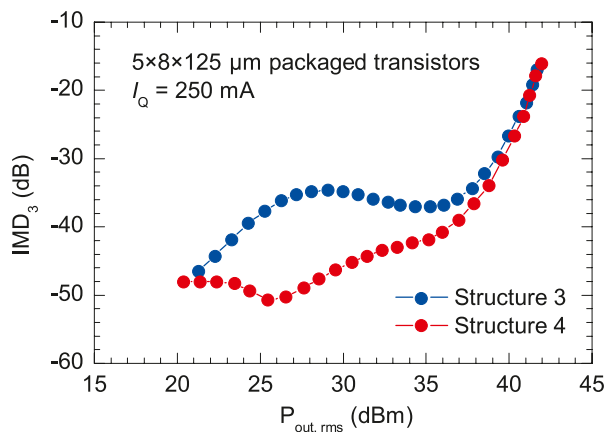
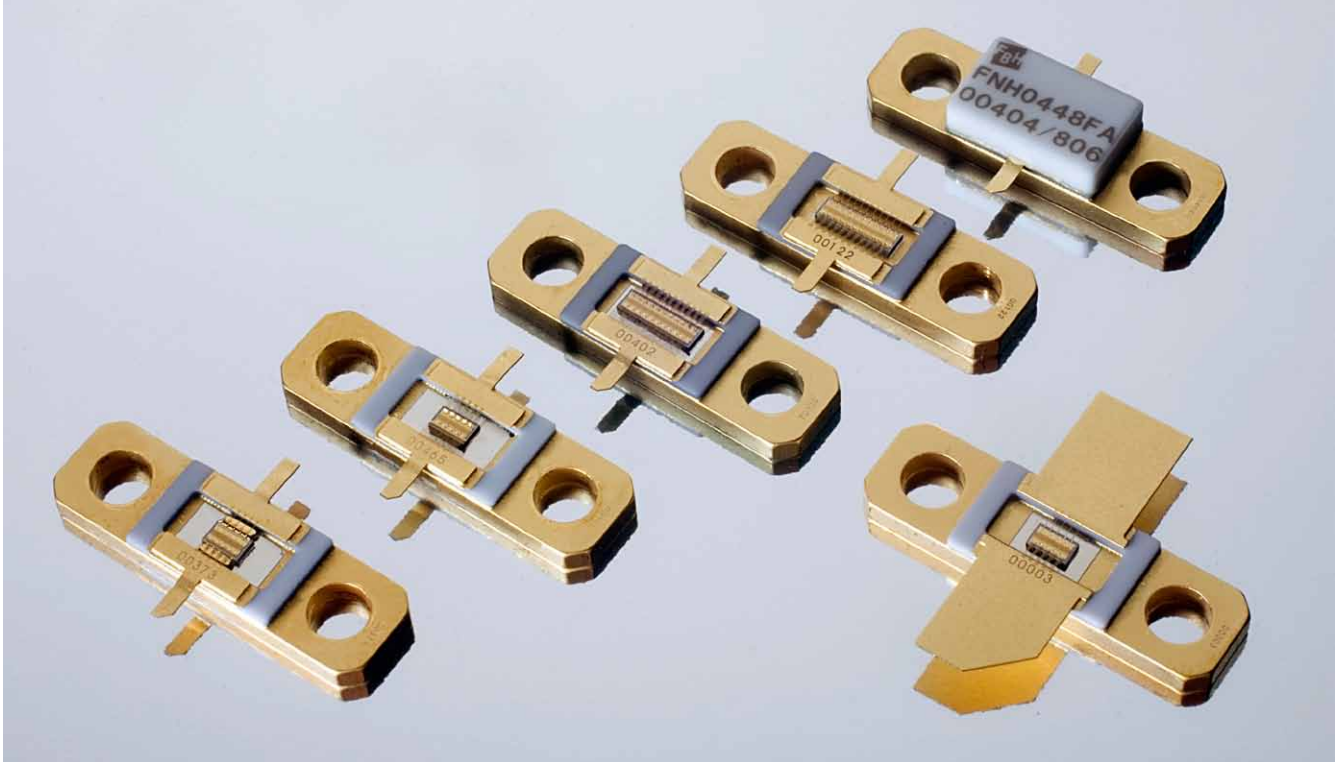


Fig. 2. Levels of IMD at $I_Q = 250 \text{ mA}$ for 20 W, 2 GHz power transistors on different epitaxial structures. Devices from epitaxial design 4 delivered significantly higher linearity values at lower power levels compared to design 3. Measurements performed by TUD.



Various nitride-based HFET transistors with improved linearity and efficiency.

The linearity results strongly depend on the specific epitaxial designs. In this connection, Fig. 1 compares the C/I3 ratio of devices from different epi-designs in dependence on output power level for class-A operation. It is evident that for given power levels the linearity can be improved up to 20 dB by selecting the proper epitaxial design. This also means that for a given linearity value the amplifier efficiency can be significantly increased by using optimized epi-designs. Therefore, this approach is considered to be extremely attractive for future amplifier concepts showing good linearity and high efficiency at the same time.

The measurements being performed on individual power cells, which were then combined to larger power bars showing power levels of typically 20 W to 40 W at 2 GHz at $V_{DS} = 28$ V depending on the gate width. Fig. 2 illustrates examples of two-tone IMD measurements for packaged $5 \times 8 \times 125 \mu\text{m}$ power bars. This class of power devices is designated for subsequent demonstrator amplifiers which are scheduled for the final phase of the project.

Publications

S. A. Chevtchenko, O. Bengtsson, F. Brunner, E. Bahat-Treidel, J. Würfl, "Two-tone intermodulation distortion characterization of AlGaIn/GaN HFETs fabricated on different epitaxial structures", Pro. 34th Workshop on Compound Semiconductor Devices and Integrated Circuits (WOCSDICE 2010), Darmstadt, Germany, May 17-19 (2010).

S. A. Chevtchenko, O. Bengtsson, F. Brunner, E. Bahat-Treidel, J. Würfl, M. J. Uren, A. Barnes, "Linearity evaluation of AlGaIn/GaN HFETs fabricated on different epitaxial structures", Proc. 5th Space Agency – MOD Round Table Workshop on GaN Component Technologies, Noordwijk, The Netherlands, September 02-03 (2010).

Die Linearität von AlGaIn/GaN-Heterojunction-Feldeffekttransistoren ist eine der Schlüsseleigenschaften, die diese Bauelemente für den Einsatz in Hochfrequenzschaltkreisen moderner Kommunikationssysteme qualifiziert. Derart optimierte Leistungsbauelemente sind von großem Interesse nicht nur für terrestrische sondern auch für weltraumgestützte Kommunikationssysteme.

In dem ESA-geförderten Projekt „Linearity Assessment of GaN Technology“ untersucht das FBH Möglichkeiten, die Linearität von GaN-Leistungstransistoren durch eine gezielte Optimierung von Epitaxie, Prozesstechnologie und Transistorlayout systematisch zu erhöhen. Die erste Projektphase konzentrierte sich auf vergleichende Untersuchungen von Transistoren auf epitaktischen AlGaIn/GaN-Schichten verschiedener Hersteller (FBH und Qinetiq) mit einem besonderen Schwerpunkt auf der Linearität.

Die Epitaxiestrukturen unterscheiden sich durch systematische Variationen des Pufferaufbaus und der aktiven Transistorstruktur. Wie die Ergebnisse zeigen, hängt die Linearität sehr stark vom Design der Epitaxieschichten ab. Messungen an gehäuteten $5 \times 8 \times 125 \mu\text{m}$ und $5 \times 8 \times 250 \mu\text{m}$ Powerbars, die in der Endphase des Projekts als Demonstratoren geliefert werden sollen, zeigen Ausgangswerte bis zu 40 W bei 2 GHz @ $V_{DS} = 28$ V. ■

Normally-off high-voltage GaN transistors for power switching applications

AlGaIn/GaN HEMTs are ideal switching transistors in power converters due to their low on-state resistance combined with high breakdown strength. They therefore promise low conduction as well as switching losses and thus aim at AC/DC or DC/DC converter markets where blocking voltages up to 1200 V and current capabilities of some 10 A are required. For safety reasons, transistors for power switching applications have to be completely turned off when the control electrode is unbiased. This requirement calls for normally-off transistor behavior instead of the default normally-on properties of standard GaN HEMTs.

The normally-off p-GaN gate technology developed at FBH combines low leakage currents for the unbiased gate (0 V) in the off-state with high currents and low resistances in the on-state. Additionally, the gate leakage current remains small. In contrast to normally-on GaN HEMTs with their Schottky-type metal gates, the transistor gates are made of p-type GaN which efficiently depletes the transistor channel in case of zero gate bias. The turn-on voltage is around 1.5 V.

For high-voltage GaN transistors blocking up to the kV range a special carbon-doped GaN buffer has been introduced to keep the electrons well confined in the transistor channel made of undoped GaN. Additionally, the carbon-doped GaN buffer is very resistive for any injected electrons

and thus prevents parasitic current flow. Both, the lateral source-drain leakage and the vertical buffer leakage to the conductive substrate is thus minimized and high blocking voltages for small lateral geometries have been obtained.

Recently, the p-GaN gate technology for normally-off transistors and the carbon-doped buffer structures enabling high breakdown devices have been combined for normally-off high-voltage transistors with blocking voltages of 1 kV and more. A blocking voltage of 1000 V has been obtained with a gate-drain distance l_{gd} as short as 6 μm giving rise to a low on-state resistance $R_{ON} = 7.3 \Omega\text{mm}$. Fig. 1 shows the output characteristic of such a device with a maximum drain current of 0.50 A/mm for +5 V gate bias and a clear off-state condition for +1 V gate bias. The threshold voltage is $V_{th} = +1.1$ V. At 0 V gate bias and 1000 V drain bias the leakage current is 20 $\mu\text{A}/\text{mm}$. Fig. 3 shows a processed 3" wafer with more than 200 normally-off GaN transistors for 45 A maximum current capability and 600 V continuous device operation.

In GaN transistors, the breakdown strength increases approximately linearly with the gate-drain distance. However, the on-state resistance increases as well. Therefore, a trade-off between breakdown voltage and on-state resistance is evident as seen in Fig. 2. One major benefit of using GaN:C instead of AlGaIn as buffer material for the

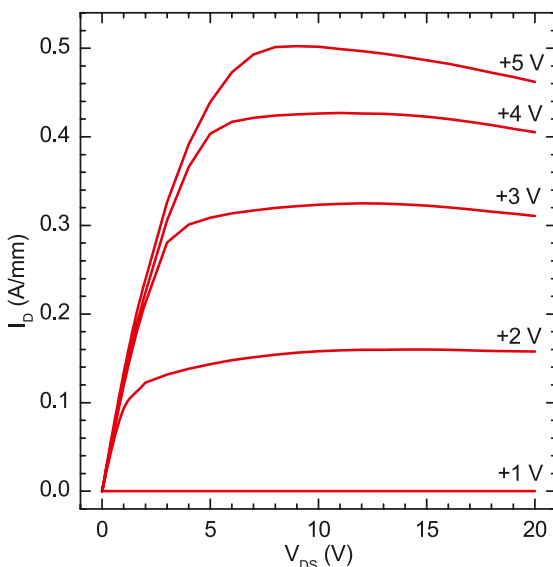


Fig. 1. Output characteristic for a 0.25 mm wide p-GaN gate transistor with 1000 V breakdown strength. The gate-drain distance is 6 μm . The gate bias is indicated.

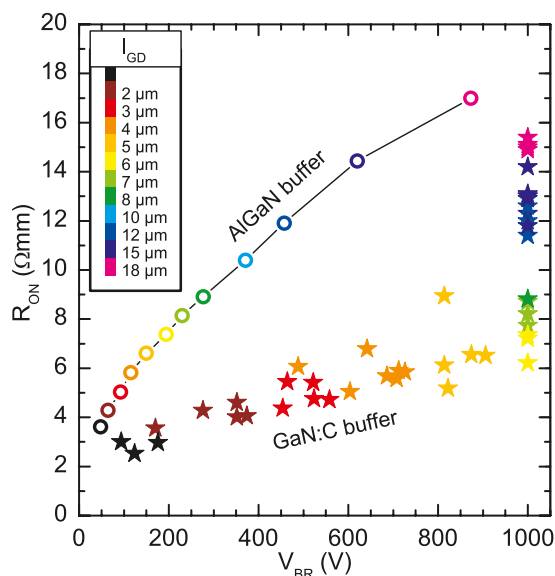


Fig. 2. On-state resistance vs. breakdown strength at different gate-drain spacing (color) for the former AlGaIn buffer and the new GaN:C buffer. 1000 V was the detection limit.

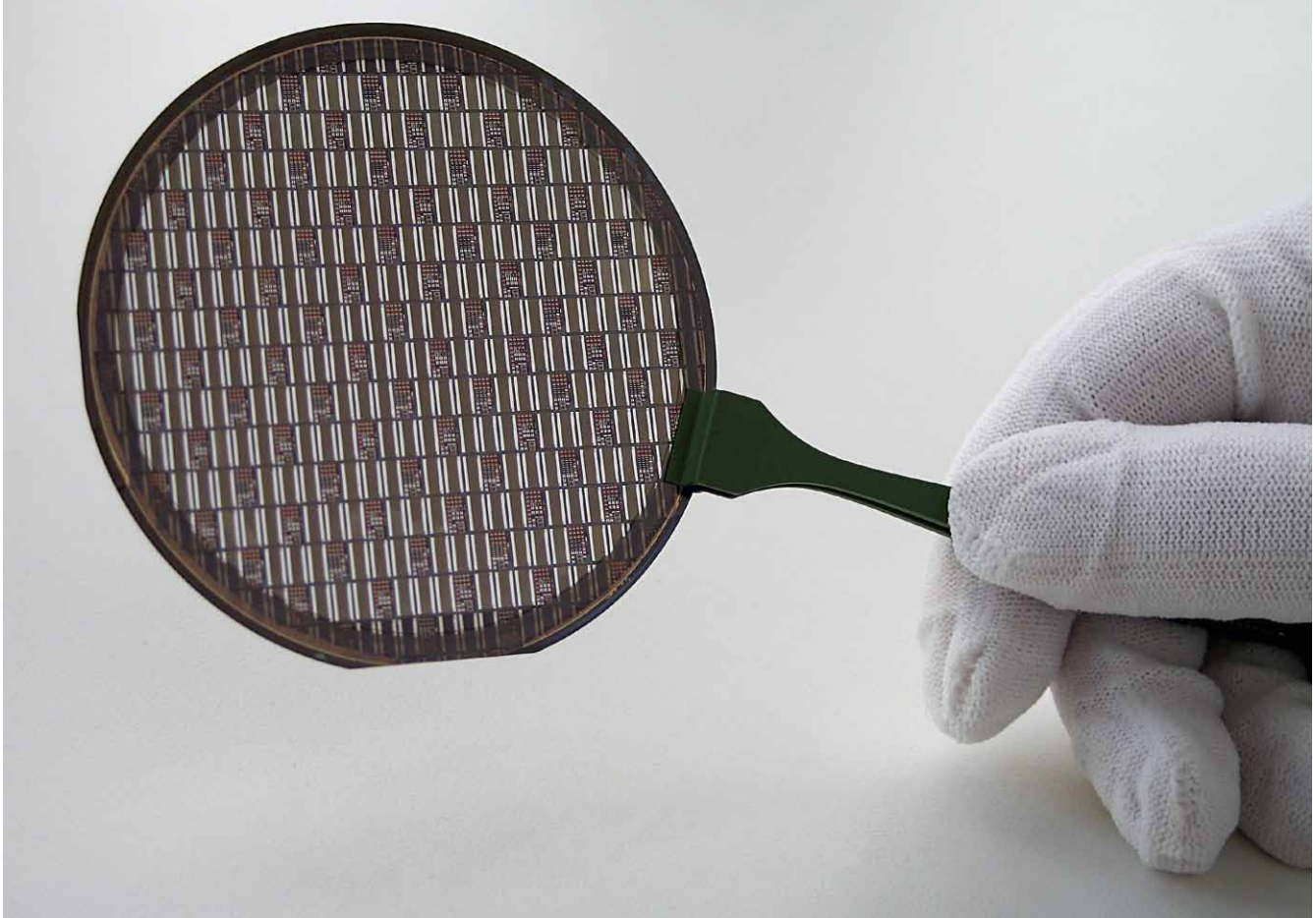


Fig. 3. Processed 3" wafer with more than 200 normally-off p-GaN gate 45 A/600 V power transistors.

p-GaN gate transistors is that the slope of the breakdown voltage with increasing gate-drain distance is more than three times higher without paying a price in R_{ON} . This is displayed in Fig. 2 where the relation between the on-state resistance and the breakdown strength for different gate-drain distances is plotted for p-GaN gate transistors with AlGaIn buffer and with GaN:C buffer. The obtained V_{BR} -to- R_{ON} ratio surpasses the performance of silicon-based devices and ranks among the best normally-off GaN devices world-wide.

Publications

E. Bahat-Treidel, F. Brunner, O. Hilt, E. Cho, J. Würfl, G. Tränkle, "AlGaIn/GaN/GaN:C back-barrier HFETs with breakdown voltage of over 1 kV and low $R_{ON} \times A$ ", IEEE Transactions on Electron Devices, Vol. 57, no. 6, pp. 3050-3058 (2010).

O. Hilt, A. Knauer, F. Brunner, E. Bahat-Treidel, J. Würfl, "Normally-off AlGaIn/GaN HFET with p-type GaN Gate and AlGaIn Buffer", Proceedings of the 22nd International Symposium on Power Semiconductor Devices (ISPSD), Hiroshima, pp. 347-350 (2010).

E. Bahat-Treidel, O. Hilt, F. Brunner, V. Sidorov, J. Würfl, G. Tränkle, "AlGaIn/GaN/AlGaIn DH-HEMTs Breakdown Voltage Enhancement Using Multiple Grating Field Plates (MGFPs)", IEEE Transactions on Electron Devices, Vol. 57, no. 6, pp. 1208-1216 (2010).



Selbstsperrende AlGaIn/GaN-HEMTs sind wegen ihrer Kombination aus niedrigem Einschaltwiderstand und hoher Durchbruchspannung ideale Schalttransistoren für Leistungsumrichter. Die am FBH entwickelte p-GaN-Gate-Technologie für selbstsperrende GaN-Transistoren verbindet niedrige Leckströme im ausgeschalteten mit geringen Leitungswiderständen im eingeschalteten Zustand.

Für GaN-Hochspannungstransistoren, die bis in den kV-Bereich sperren, wurde am FBH parallel eine spezielle kohlenstoffdotierte GaN-Pufferschicht entwickelt. Diese verhindert ein Ausbrechen der Elektronen aus dem Transistorkanal auch bei sehr hohen Drainspannungen. Inzwischen wurden beide Technologien in einem Bauelement kombiniert, was zu selbstsperrenden GaN-Hochspannungstransistoren mit 1000 V Spannungsfestigkeit und 1,1 V Einsatzspannung führt. Das Verhältnis aus Durchbruchfestigkeit zu Einschaltwiderstand ist dabei höher als bei Si-basierten Transistoren und gehört damit zu den weltweiten Bestwerten für selbstsperrende GaN-Transistoren. ■

Reliability of GaN-HEMT power bars and their optimization

Reliability of electronic devices can be determined by failure statistics. For the investigation of lifetime or reliability it would be desirable to operate a larger amount of devices under proper operation conditions and let them run until failure occurs. As most applications request a long lifetime, often exceeding a decade, this approach is not practicable. Thus, acceleration of aging is essential. This is typically achieved from tests at elevated temperatures. In many cases, aging mechanisms exponentially increase with temperature and can subsequently be treated mathematically using the Arrhenius relationship. The lifetime of devices at different temperatures then fits on a straight line as shown in Fig. 1. Thus, lifetime of devices at a given channel temperature can be estimated by extrapolating the straight line. In order to provide reliable data, the channel temperature at aging conditions has to be known exactly. At FBH, the channel temperature measurements are calibrated by using high-resolution Raman measurements at Bristol University. As shown in Fig. 1 the current FBH GaN technology demonstrates a lifetime of 5×10^6 (more than 500 years) if operated at a channel temperature of 125°C .

For electronic devices in GaN technology a systematic improvement of reliability, especially at higher temperatures and operation voltages, still needs to be undertaken. This requires investigation and interpretation of

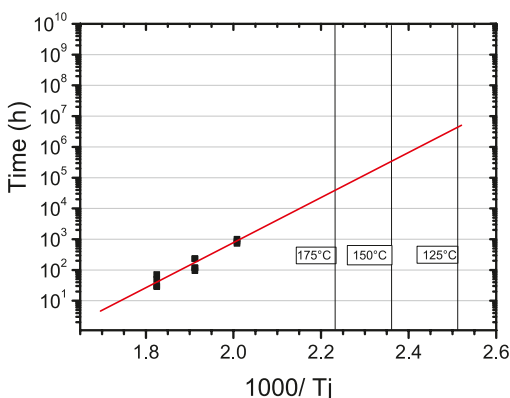


Fig. 1. Arrhenius plot from accelerated lifetime measurements and extrapolation of expected lifetime for channel temperatures of 175°C , 150°C and 125°C .

degradation mechanisms which may be detected by electrical, optical and microstructural methods. Out of these approaches, electroluminescence (EL) is a non-destructive method that provides locally resolved information.

Significant degradation effects may take place even when the devices are biased in off-state. As an example, transistor operation from moderately open channel condition to hard pinch-off ($V_{GS} = -20\text{ V}$) and back to open condition using a total of 7 steps is investigated. Electrical stress is accompanied by observation of electroluminescence from backside (Fig. 2). EL is documented using a color sensitive CMOS sensor detecting from backside. During open channel condition (step 1) strong emission along the gate fingers is visible being associated to the current flowing from source to drain (intra-band transitions in the 2DEG region of the device). Switching to pinch-off condition results in much lower light emission (step 2). Individual light spots become brighter while driving the gate voltage more negative. At -20 V gate stress light emission near the mesa edge shows high intensity. Comparison of light emission before and after highest gate stress (-20 V) is performed for -5 V gate voltage (step 2 and step 6). Clearly, a stronger emission after applying highest gate stress is visible. The increased light emission in step 6 is also accompanied by higher gate current which indicates strong degradation on light emitting spots.

Emission spots that evolve during the test indicate areas of weak material that are probably located at crystallographic defects. EL emission in these regions are triggered by parasitic electron currents along defective device regions. It is most probable that extended defect zones are generated in high field regions of the devices during stress. This may lead to degradation by multiplying the number of possibly already existing defects by various physical mechanisms such as inverse piezoelectric effect and hot electron injection. A second important example for detection of degradation behavior is the comparative study of EL from two different epitaxial structures (Fig. 3). Structure A consists of a non-doped GaN buffer with AlGaIn barrier. Structure B has an AlGaIn back-barrier with a GaN channel-layer and

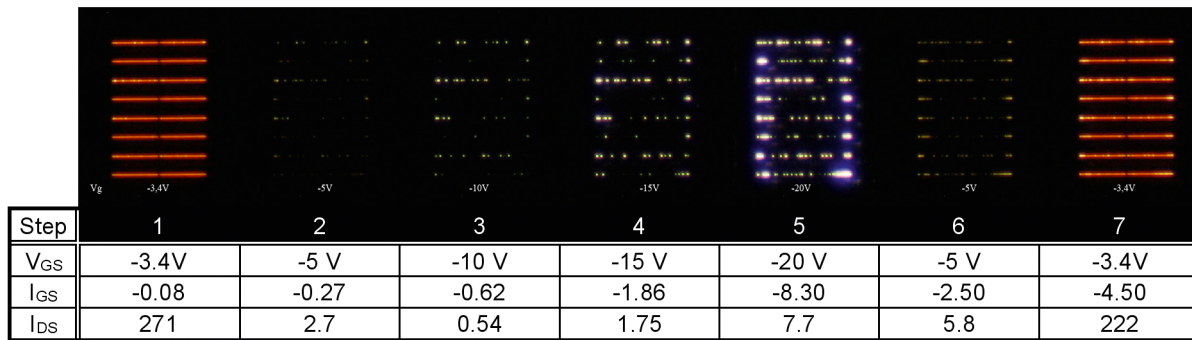


Fig. 2. Luminescence for shown bias conditions during stress cycle (I_{GS} and I_{DS} in mA, @ 28 V_{DS}).

AlGa_N barrier on top. Views of optical and EL images in pinch-off condition are shown superimposed. The EL signal from top-side view is taken with a panchromatic detector. Device A with GaN buffer has already some bright spots from the start and after stressing the number and size of bright spots increase with the stressing condition. Device B with AlGa_N back-barrier has no emission spots before stress. Due to low leakage, step stressing could be increased up to 120 V_{DS} and even after stressing up to 120 V no spots appear.

The back-barrier transistor confines the electron much better in the conducting 2DEG and the maximum electrical field in this configuration is lower compared to the standard type. This is mainly due to the modified band structure in presence of an AlGa_N back-barrier. There is

strong indication that the observed degradation of GaN buffer device A occurs in the high field region of the gate. The better device performance for devices with back barrier may in part be attributed to local E-field reduction in the gate vicinity. Additionally, the presence of a bulk AlGa_N back-barrier reduces the tensile strain in the AlGa_N barrier layer as compared to GaN buffer and thus shifts the relaxation limit of the AlGa_N barrier to higher Al values.

Publication

P. Ivo, A. Glowacki, E. Bahat-Treidel, R. Lossy, J. Würfl, C. Boit, G. Tränkle, "Comparative study of AlGa_N/GaN HEMTs robustness versus buffer design variations by applying electroluminescence and electrical measurements", *Microelectronics Reliability* 51, pp. 217-223 (2011).

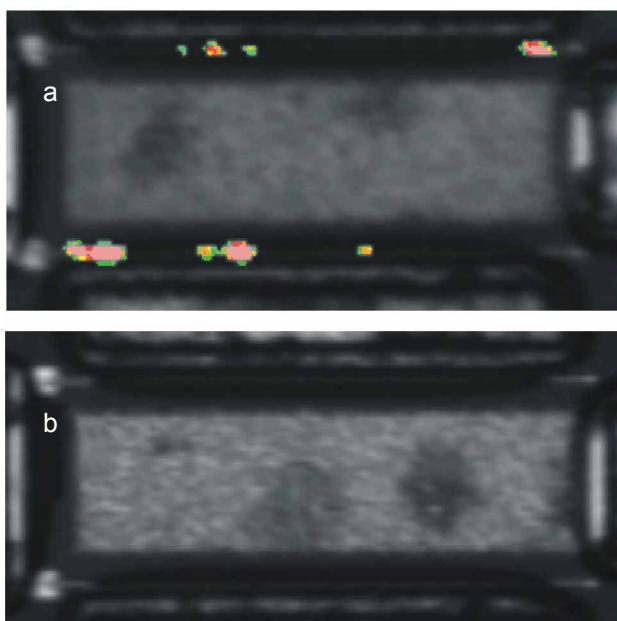
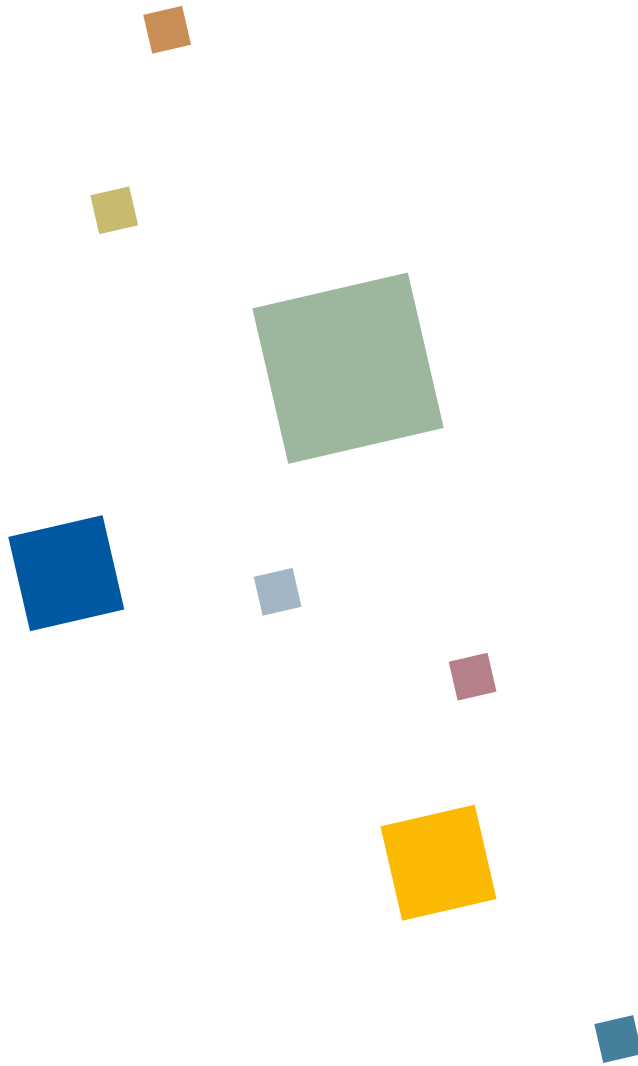


Fig. 3. Electroluminescence from 2-finger transistor of different epitaxy; a) standard epitaxy stressed up to 35 V_{DS} ; b) back-barrier design. This device could be stressed up to 120 V_{DS} without showing any signs of degradation.



Die Lebensdauer elektronischer Komponenten kann über beschleunigte Alterungsmethoden und Extrapolation der Daten auf lange Zeiträume bestimmt werden. In der Regel sind Degradationsprozesse thermisch aktivierbar und steigen exponentiell mit der Temperatur. Dies erlaubt Alterungstests bei hohen Temperaturen und die Übertragung der Ergebnisse auf typische Betriebstemperaturen. Damit konnten an GaN-Mikrowellentransistoren Lebensdauern von mehr als 5×10^6 Stunden bei 125°C Kanaltemperatur nachgewiesen werden. Die physikalischen Ursachen von Degradationseffekten werden über abgestimmte elektrische und optische Verfahren sowie Untersuchungen der Mikrostruktur analysiert.

Eine zerstörungsfreie Methode ist die Elektrolumineszenz, die orts aufgelöste Informationen über den Alterungsvorgang gibt. Wird das Material großen elektrischen Belastungen ausgesetzt, zeigen sich im Transistorkanal Bereiche mit veränderter Emission, die eine beginnende Degradation des Halbleitermaterials zeigen. Anhand vergleichender Untersuchungen von unterschiedlich hergestellten Halbleiterschichten können wichtige Zusammenhänge identifiziert und so iterativ belastbarere Material- und Transistorkombinationen realisiert werden. ■



BUSINESS AREAS & RESEARCH

Diode Lasers » Diodenlaser

GESCHÄFTSBEREICHE & FORSCHUNG



Diodenlaser



Das Ferdinand-Braun-Institut ist eine der weltweit führenden Einrichtungen bei der Erforschung und Realisierung von hochbrillanten Diodenlasern auf der Basis von Galliumarsenid vom roten bis zum nahen infraroten Spektralbereich (630 nm...1150 nm). Die Einsatzgebiete umfassen Lasersysteme für die Materialbearbeitung, Laser für die Medizintechnik (Desinfektion, photodynamische Krebstherapie) und die Unterhaltungstechnologie (Displays) ebenso wie Hochleistungslasersysteme für die Grundlagenforschung (Röntgenlasersysteme, Teilchenbeschleuniger und laserinduzierte Kernfusion). Diese Diodenlaser sind daher Schlüsselkomponenten für die optischen Technologien. Mit seinen Kompetenzen deckt das FBH den gesamten Teil der Wertschöpfungskette ab: von Simulation und Entwurf über die technologische Realisierung bis zum Aufbau einsetzbarer Diodenlasermodule.

Basierend auf einer maßgeschneiderten Chipentwicklung gewinnt zudem die hybride Integration von aktiven und passiven Bauelementen auf einer mikrooptischen Bank an Bedeutung. Auf diese Weise entstehen neuartige, benutzerfreundliche und kompakte Laserstrahlquellen hoher Brillanz. Sie zeichnen sich durch geringe Abmessungen, einen hohen Konversionswirkungsgrad und damit geringen Energieverbrauch aus.

Die Fortschritte im Jahr 2010 manifestieren sich insbesondere in neuen Ergebnissen bei monolithischen Hochleistungs-Diodenlasern, der Erzeugung von Laserstrahlung im sichtbaren Bereich durch nichtlineare optische Prozesse (SHG) sowie bei kompakten Modulen für gepulste Lasersysteme und für leistungsstarke, extrem schmalbandige Laserstrahlung.

Bei Hochleistungsdiodenlasern mit einer Standard-Aperturbreite von 100 μm wurden mit Simulationen die Voraussetzungen geschaffen, die Leistungsfähigkeit dieser Laser weiter zu erhöhen. Die Ausgangsleistung soll damit auf 15 W bei nahezu unveränderter Konversionseffizienz von 65% gesteigert werden. Bisher erreichte experimentelle Ergebnisse von 63% bis 64% bei 12 W liegen bereits nahe dieser Zielmarke.

Mittels monolithischer hochbrillanter Diodenlaser (DBR-MOPA-Strukturen) konnte durch SHG die optische Ausgangsleistung im grünen Spektralbereich auf nahezu 2 W erhöht werden. Lasermodule mit hybrid integrierten Oszillator-Verstärker-Anordnungen wurden sowohl für die Erzeugung kurzer Impulse im ns- und ps-Bereich als auch für leistungsstarke schmalbandige Strahlquellen erstmalig experimentell umgesetzt. Die Impulsspitzenleistungen erreichten Werte jenseits 50 W und machen diese Lasermodule zu attraktiven Seedquellen in Lasermaterialbearbeitungssystemen. Schmalbandige Laserstrahlung mit Linienbreiten kleiner 10 kHz und einer Ausgangsleistung größer 1 W konnte auf dieser Plattform ebenfalls realisiert werden. Die Kenndaten beider Module stellen im Übrigen Spitzenleistungen dar, die bisher nur vom FBH erreicht und publiziert wurden.

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 (disinfection, 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 nuclear fusion). In essence, diode lasers are key enabling components for the optical technology industry. The core competences of the FBH cover the entire diode laser value chain, from concept development and simulation through technological realization to the construction of fully qualified laser modules ready for use.

The construction of hybrid-integrated modules is of increasing importance. These modules combine customized semiconductor devices with passive components to form miniaturized micro-optic systems. As a result, novel, compact, user-friendly laser sources of extremely high brilliance are produced. Such sources are of small physical size and have high conversion efficiency, that is, they operate with very low power consumption.

Progress within the year 2010 includes new results in monolithic high-power diode lasers, the generation of laser light in the visible range through non-linear optical processes (SHG) as well as the development of compact modules for pulsed laser systems and for high-power laser sources with very narrow optical spectra.

In the case of high-power diode lasers, theoretical studies have laid the foundations for further improvements in the high-power capability of devices with a standard aperture of 100 μm . Optical output powers of up to 15 W with virtually unchanged power conversion of 65% should now be possible. Experimental results to date have demonstrated efficiencies of 63 - 64% at an emission power of 12 W, values that approach the 65% target.

For the first time in 2010, an optical output power of over 2 W has been demonstrated in the green spectral range. This was achieved by frequency converting the output of monolithic high-brilliance diode lasers (DBR-MOPA structures) using SHG techniques. Also, for the first time, novel laser modules have been experimentally realized, that use a hybrid integrated "oscillator-amplifier" configuration. These modules have been used in two configurations, firstly to generate high-power pulses with pulse widths in the ns to ps range and secondly to produce high powers with extremely narrow spectral widths. Short pulse modules have now achieved peak pulse powers of 50 W, making them attractive as seed lasers for industrial material processing systems. In addition, narrow spectral width modules have demonstrated output powers of over 1 W within a spectral width of less than 10 kHz. In both cases, the performance level demonstrated at the FBH is the highest achieved yet world wide, especially in regard to the peak power levels.

Pulsed diode laser systems with high output powers and stabilized emission wavelength

Pulsed laser sources find many applications in fields such as material processing, sensors and analytics (e.g., fluorescence spectroscopy) and therefore offer a big market potential. With diode lasers short light pulses down to the picosecond range can be easily generated by injecting short current or voltage pulses into the cavity. The semiconductor technology utilized to fabricate diode lasers additionally enables cost-effective mass production. However, for many applications the peak power in the Watt range generated with diode lasers is too small. In order to reach optical powers in the kW range, diode lasers are used as master oscillators in MOPA systems with laser-active fibers and crystals.

Within the framework of the BMBF-funded projects "FaZiT" and "INDILAS", the FBH particularly develops pulsed diode-laser based systems for pulse durations in the time range from 100 ns down to 500 ps, in the range around 100 ps

and below 10 ps. The laser diodes are edge emitters operating in the fundamental spatial mode with integrated wavelength stabilization (Bragg grating). Their low beam divergence enables efficient coupling into single-mode fibers. In order to increase the pulse energy, amplifiers, also based on edge emitters, are realized. The laser diodes and amplifiers are hybridly integrated with micro lenses for optical beam shaping on a microbench with a footprint of 4 cm x 5 cm. They are either assembled with electrical circuits (Fig. 1) based on GaN power transistors which have also been developed at the FBH or electrical power supply (Fig. 2).

The mounting of the components requires a precision in the sub- μm range. At first, the multi-section laser diode (2 mm) and the tapered amplifier (4 mm) are soldered on gold-plated carriers made from aluminum nitride ceramics. These subassemblies are then soldered together on a larger carrier of the same material. The radiation emitted by the laser diode is coupled by a 4.4 mm long graded-index lens into the amplifier. In order to keep the loss of radiation as low as possible, the laser diode and the amplifier must be adjusted to each other within a tolerance of $4\ \mu\text{m}$. After attaching the power supply lines, the coupling lens is adjusted and glued with a precision of $0.5\ \mu\text{m}$ and better into all three spatial directions while operating the laser diode and the amplifier. Additional micro lenses at the output serve to transform the divergent radiation emitted by the amplifier into a collimated beam.

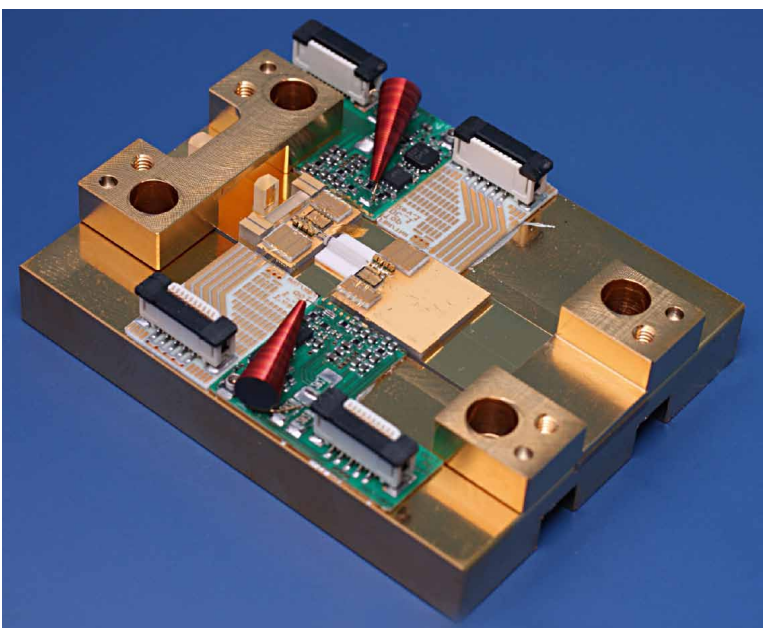


Fig. 1. Optical microbench for Q-switching with electrical circuits developed at FBH.

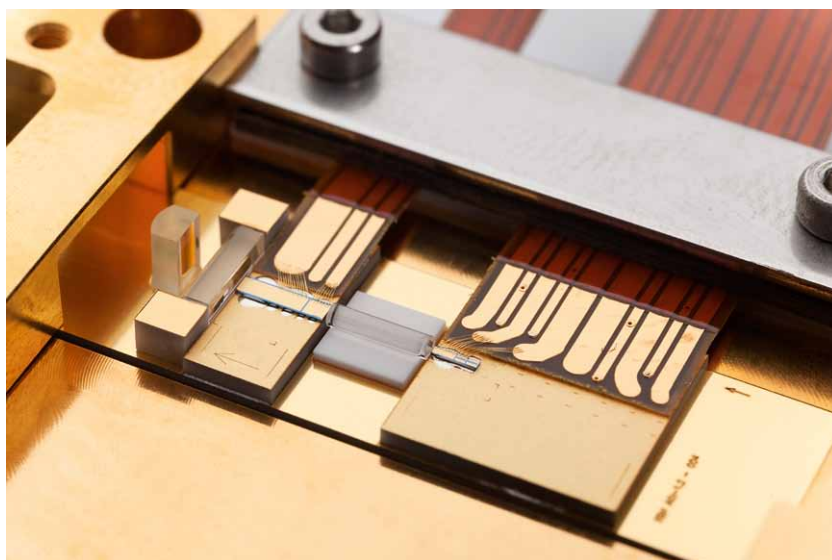


Fig. 2. Magnified view of an optical microbench showing the multi-section laser diode, the graded-index lens, the tapered amplifier and the micro lenses at the output (from right to left).

Fig. 3 shows the temporal shape of the light pulses emitted by the diode laser system and the corresponding optical spectrum, respectively. The light pulses were generated by a Q-switched operation of the laser diode where short electrical pulses switch a light absorbing section periodically transparent. The full width at half maximum of the light pulse is 80 ps and peak power amounts to 35 W. The optical spectrum shows a spectral line near 1067 nm. The spectral power density of the background caused by spontaneous emission is by a factor of 10,000 (40 dB) smaller than the power density of the line. These results have been achieved due to the integration of a Bragg grating into the multi-section laser diode which successfully stabilizes the emission wavelength.

Thus, FBH succeeded to develop tailored, miniaturized, pulsed diode laser systems for the desired applications by precision mounting of opto-electronic and optical devices on a joint platform. Due to their high optical output power of several tens of Watts and the stabilized emission wavelength they are ideally suited as seed lasers for pulsed fiber lasers and in MOPA systems. Further applications are in sensor technology and non-linear frequency conversion.

Publication

A. Liero, A. Klehr, S. Schwertfeger, T. Hoffmann, W. Heinrich, "Laser Driver Switching 20 A with 2 ns Pulse Width Using GaN", IEEE MTT-S Int.Microw.Symp. Dig., Anaheim, CA, May 25-27, pp. 1110-1113 (2010).

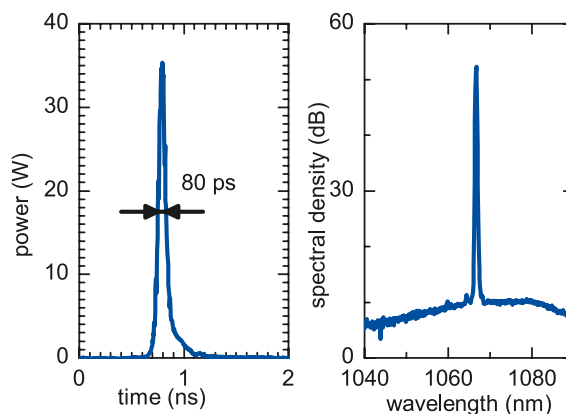


Fig. 3. Optical power versus time (left) and optical spectrum (right).



Gepulste Laserstrahlquellen besitzen ein großes Anwendungs- und Marktpotenzial in der Materialbearbeitung, Sensorik und Analytik.

Mit Diodenlasern lassen sich durch geeignete Strom- oder Spannungsimpulse relativ einfach kurze Laserlichtimpulse bis in den Pikosekunden-Bereich erzeugen.

Im Rahmen des Verbundprojektes „FaZiT“ entwickelt das FBH maßgeschneiderte gepulste Diodenlasersysteme für Pulsdauern im Zeitbereich von 100 ns bis 500 ps, im Bereich um 100 ps und unterhalb von 10 ps. Dazu werden im Grundmodebetrieb arbeitende Laserdioden mit inte-

grierter Wellenlängenstabilisierung (Bragg-Gitter) und optische Halbleiterverstärker auf einer Mikrobank hybrid integriert. Zusammen mit Mikrolinsen zur optischen Strahlformung und elektrischen Ansteuerschaltungen bzw. Anschlussleitungen werden sie auf einer Grundfläche von nur 4 cm x 5 cm aufgebaut. Dies erfordert die präzise Montage der einzelnen Komponenten im Submikrometerbereich. Die Module emittieren Pulse mit Spitzenleistungen bis 50 Watt und einer spektralen Breite von weniger als einem Nanometer. ■

Pulsed lasers for bioanalytics

Pulsed laser sources are used in various analysis methods in life sciences such as optical coherence tomography or two-photon spectroscopy. One particularly exciting method is time-domain fluorescence lifetime spectroscopy which uses a picosecond pulsed laser of moderate power to excite fluorescence in biological samples. In combination with a fast and sensitive single photon counting system, this allows the measurement of fluorescence decay lifetime which is in the range of a few nanoseconds. For many fluorophores, this lifetime depends on properties of the molecule's environment such as pH value and Na^+ concentration. Therefore, fluorescence lifetime spectroscopy allows the real-time monitoring of biological processes in living cells (Fig. 1).

For optimum fluorescence lifetime measurements, the excitation pulse length has to be much shorter than the fluorescence decay time, typically below 200 ps, while the pulse intervals have to be much larger. In order to adjust the repetition rate to different lifetimes and to avoid damaging the sample by excessive illumination, variable excitation pulse repetition rates in the megahertz range are preferred.

In the red and blue spectral range, such pulses can be readily generated by gain switching of single ridge-waveguide laser diodes. Green excitation sources are equally required, but directly green emitting laser diodes so far exist only as laboratory samples with limited lifetime. Therefore, second harmonic generation (SHG) is the method of choice to generate green picosecond pulses

In the past year, the second harmonic generation (SHG) of green picosecond pulses has been investigated in detail at Ferdinand-Braun-Institut. To start out, we studied the gain-switching behavior of infrared distributed feedback (DFB) lasers with the goal of generating spectrally narrow picosecond pulses with a high peak power. In order to achieve this, several design parameters of the laser diodes had to be optimized, in particular the grating reflectivity and the spectral overlap between grating and gain spectrum. This optimization was done both experimentally and numerically using a customized rate-equation model with good agreement between measurement and simulation. Close to the optimum, infrared laser pulses with a spectral width of below 0.15 nm and a peak power of 1 W have been generated.

In order to increase the conversion efficiency into the green spectral range, various media for optical amplification of these pulse have been investigated. These include a fiber amplifier and a tapered semiconductor amplifier in both bench-top hybrid and monolithically integrated setups. With both semiconductor-based setups, the infrared pulses could be boosted to an energy of more than 3 nJ while retaining their narrow spectral and temporal width. The monolithic DFB tapered master oscillator power amplifiers (MOPAs) are especially well suited for life science applications due to their superior compactness and ruggedness. Including beam shaping optics and pulse-generation circuitry, they have been assembled on a footprint of $2.5 \times 2.5 \text{ cm}^2$ (Fig. 2).

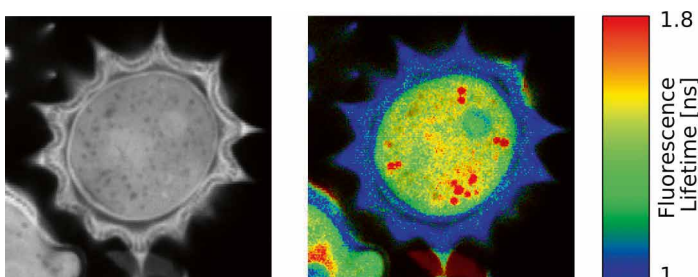


Fig. 1. Fluorescence images of a daisy pollen. Left: fluorescence intensity, right: fluorescence lifetime, color coded. The red areas carry no contrast in the fluorescence intensity image. Image: courtesy of PicoQuant GmbH.



Laserstrahlquellen mit kurzen Pulsen im sichtbaren Spektralbereich werden in Mikroskopen und Spektrometern bei Fluoreszenz-Experimenten in den Lebenswissenschaften benötigt. In Verbindung mit Lichtdetektoren mit sehr hoher zeitlicher Auflösung ermöglichen die miniaturisierten Quellen die Fluoreszenzanalyse in Echtzeit. Laserdioden haben den Vorteil, dass sie klein, robust, zuverlässig und effizient sind. Eine Herausforderung stellt dabei jedoch der grüne Spektralbereich dar, da die Zuverlässigkeit direkt emittierender Laserdioden – soweit verfügbar – noch sehr begrenzt ist. Deshalb ist die Frequenzverdopplung von nah-infraroten,

gepulsten Diodenlasern die Methode der Wahl, um grüne Pikosekundenpulse zu generieren.

Forschern des FBH ist es im letzten Jahr gelungen, kompakte Module ($2,5 \times 2,5 \text{ cm}^2$) mit monolithisch integrierten DFB-Pumplasern und optischen Trapezleistungsverstärkern zu entwickeln, die Pikosekundenpulse im nahinfraroten Bereich mit Peakleistungen von über 10 W erzielen. Damit konnten in einem Laborexperiment 2,3 W Pulsspitzenleistungen mit einer Pulsbreite von 112 ps erzielt werden. Das entspricht Pulsenergien bis 250 pJ bei 531 nm. ■

Using the semiconductor MOPAs as the fundamental source, the second harmonic generation of green picosecond pulses has been studied. Both with a benchtop and a monolithic fundamental source, pulse energies above 250 pJ at 531 nm have been obtained (Fig. 3). Due to pulse shaping both during amplification and SHG, the green pulse shape is nearly independent of the seed input signal. The deconvoluted peak power of 10 W exceeds previous realizations by more than an order of magnitude. The high pulse energy combined with their excellent extinction ratio makes these pulses ideally suited for fluorescence lifetime spectroscopy.

Publications

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S. M. Riecke, H. Wenzel, S. Schwertfeger, K. Lauritsen, K. Paschke, R. Erdmann, G. Erbert, "Picosecond spectral dynamics of gain-switched DFB lasers", *J. Quant. Electronics*, vol. 47, no. 5, pp. 715 - 722 (2011).

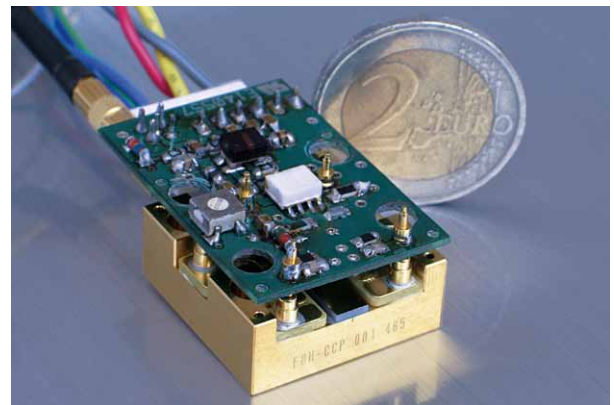


Fig. 2. Monolithic integrated DFB MOPA with control electronics (in cooperation with PicoQuant) emitting picosecond pulses with an energy of up to 3 nJ.

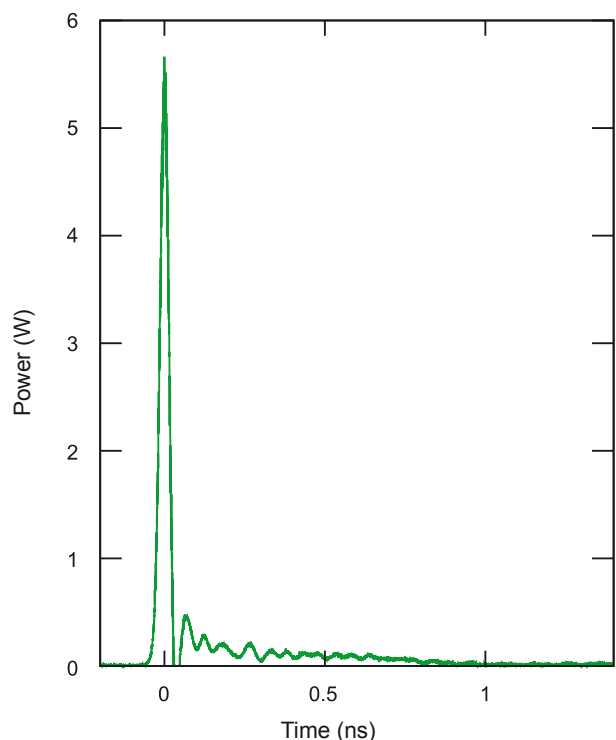
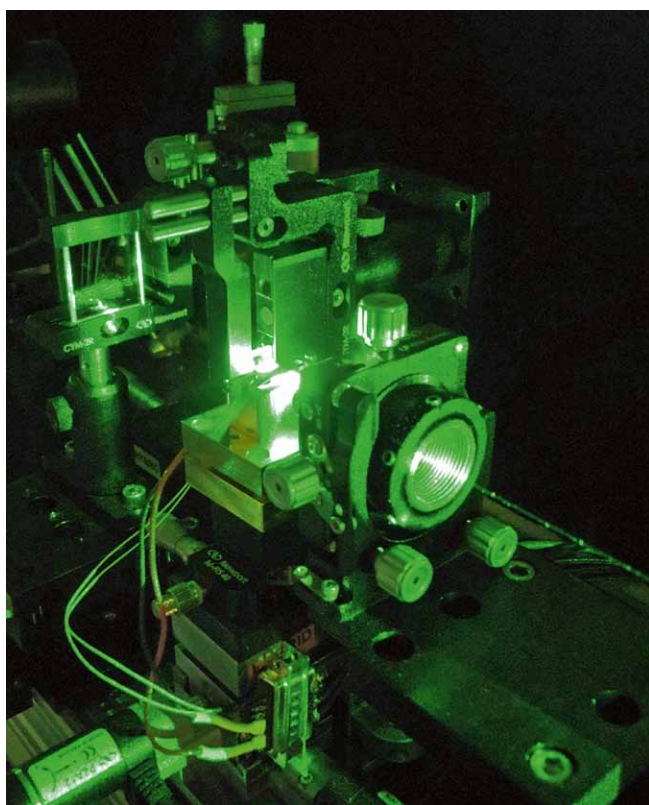


Fig. 3. Green picosecond pulse with an energy of 250 pJ—ideally suited for fluorescence lifetime spectroscopy.

Waveguide frequency doubling of NIR diode lasers

Visible laser light sources are desired in the fields of biotechnology, spectroscopy and display technology. Flow cytometry and Raman spectroscopy are only some example applications requiring compact, robust and efficient high-power visible laser modules. Since commercially available GaN diode lasers emitting continuous-wave (CW) radiation in this spectral range still exhibit drawbacks such as limited power or insufficient wavelength purity, other solutions enabling essential miniaturization are required. Frequency doubling of near-infrared (NIR) high-power GaAs diode lasers is a promising concept to realize such devices.



For second harmonic generation (SHG), the diode laser radiation passes through a nonlinear crystal, for example a bulk lithium niobate crystal, in a single-pass configuration. Due to a nonlinear interaction between NIR laser light and nonlinear crystal, laser radiation with a doubled frequency in the visible spectral region is generated. More efficient frequency doubling of NIR diode lasers can be achieved in nonlinear crystals with waveguide structures. In this approach, diode laser light is coupled into a waveguide manufactured from a nonlinear material where it experiences confinement in either two directions (channel waveguide) or one direction (planar waveguide). This results in higher NIR intensity in the nonlinear medium compared to bulk crystals and in a corresponding higher conversion efficiency. At high power levels the intensity in a channel waveguide can reach a level at which a saturation of the nonlinear process is observed. Therefore, planar waveguide structures are the preferable geometry for efficient high-power frequency doubling of NIR diode lasers in a single-pass configuration.

At the Ferdinand-Braun-Institut, frequency doubling of NIR diode laser radiation in bulk crystals, channel and planar waveguides is studied in-depth with regard to the optimal beam and crystal parameters. Recently, efficient frequency doubling of a DBR tapered diode laser in a planar waveguide structure has been achieved in a laboratory setup (Fig. 1). Focusing parameters were adjusted according to simulations to enable a high coupling efficiency (73%) into the waveguide and to achieve a high opto-optical conversion efficiency (26%). A maximal CW power of 1.07 W at 531 nm was reached (Fig. 2) which resulted in a electro-

Fig. 1. Laboratory setup for frequency doubling of NIR diode lasers.

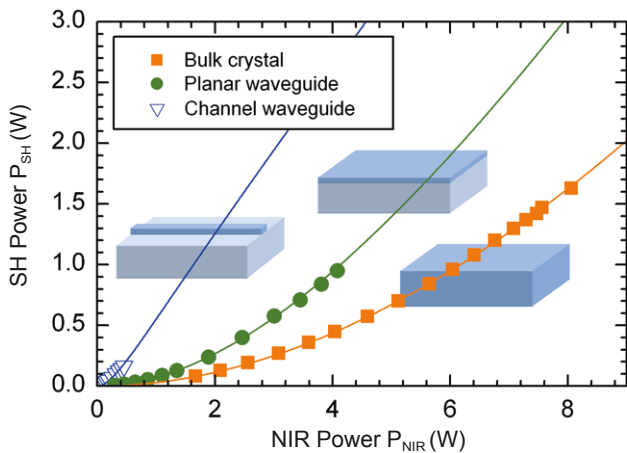


Fig. 2. SH power dependence on NIR power during frequency doubling in a bulk crystal, a planar and a channel waveguide.

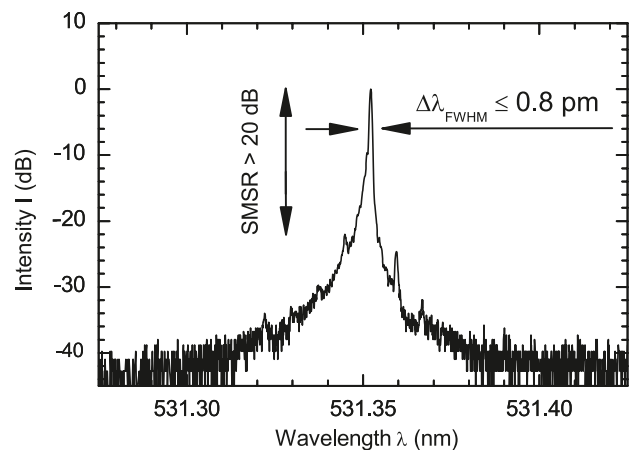


Fig. 3. SH spectrum at the maximum output power of 1.07 W.

optical conversion efficiency of 8.4%. The generated SH laser light is well-suited for spectroscopic applications due to high spectral purity (spectral linewidth $\Delta\lambda < 0.8$ pm FWHM) and a high side mode suppression ratio (SMSR) of more than 20 dB (Fig. 3). No saturation of the visible power was observed in the examined power range (Fig. 2), which indicates that even higher output power and conversion efficiency are feasible in future. Furthermore, the presented concept is well-suited for miniaturization and thus offers an opportunity to assemble a compact visible laser light module emitting several Watt with an electro-optical conversion efficiency of more than 10%.

The presented results have been achieved within the InnoProfile initiative "Hybride Diodenlaser-Systeme" of the German Federal Ministry of Education and Research (BMBF).

Publications

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D. Jedrzejczyk, R. Güther, K. Paschke, G. Erbert, "1 W at 531 nm generated in a ppMgO:LN planar waveguide by means of frequency doubling of a DBR tapered diode laser", *SPIE Proc.* 7917-2 (2011).

» Kompakte, robuste und effiziente Hochleistungs-Diodenlasermodule im sichtbaren Spektralbereich werden für die Biotechnologie, Spektroskopie und Displaytechnologie benötigt. Da die Leistungsfähigkeit bzw. die spektrale Reinheit kommerziell verfügbarer, GaN-basierter Diodenlaser im Dauerstrichbetrieb bislang nicht ausreicht, ist die Frequenzverdopplung von nah-infraroten (NIR) Diodenlasern auf GaAs-Basis eine vielversprechende Alternative.

Das FBH untersucht daher systematisch die Frequenzverdopplung in nichtlinearen Kristallen. Planare Wellenleiter aus einem nichtlinearen Material bieten gegenüber Volumenkristallen und Kanalwellenleitern die Möglichkeit, hohe Leistungen bei hohen Umsetzungsrate zu erzielen. In einem Laboraufbau wurden 1,07 W bei einer Wellenlänge von 531 nm über einen einfachen Durchgang durch einen planaren Wellenleiter erzielt. Als NIR-Diodenlaser wurde ein am Institut entwickelter DBR-Trapezdiode verwendet. Im Experiment wurde eine opto-optische Konversionseffizienz (Verhältnis der sichtbaren Leistung zur NIR-Leistung) von 26% erreicht; die daraus resultierende elektro-optische Konversionseffizienz (Verhältnis der sichtbaren Leistung zur elektrischen Leistung) betrug 8,4%. Das Konzept ist daher ideal geeignet für die Realisierung kompakter Strahlquellen im sichtbaren Bereich mit Ausgangsleistungen von mehreren Watt und einer elektro-optischen Konversionseffizienz von mehr als 10%. ■

1 W master oscillator power amplifier laser modules with narrow linewidth emitting at 1060 and 780 nm

Narrow-linewidth high-power lasers find application in a variety of fields like coherent optical communication, precision measurements, spectroscopy and laser cooling.

Due to their compactness, low weight, high efficiency and good mechanical stability, semiconductor lasers are usually favored over optically pumped solid-state and fiber lasers in respective applications. However, solitary semiconductor lasers do not feature stable narrow-linewidth operation at the 1 Watt level as a result of mode instability and reliability problems. A monolithic master oscillator (MO) power amplifier (PA) configuration can provide high-power single-mode operation at high output power. However, such devices suffer from optical feedback from the amplifier to the oscillator which broadens the linewidth. A standard hybrid bench-top MOPA configuration including an isolator might be used to suppress optical feedback though the advantage of compactness and mechanical stability gets lost. The FBH succeeded to realize a compact and rugged micro-integrated MOPA that features both narrow-linewidth and high-power operation.

The MOPA emits 1 Watt optical power at a wavelength near 1064 nm (the desired wavelength for replacing optically pumped solid-state lasers used in coherent optical free-space communication) with a -3 dB linewidth below 100 kHz. The oscillator is a distributed Bragg reflector laser which is optimized for narrow-linewidth operation, and the amplifier consists of a tapered amplifier with a ridge waveguide entry section. Optical feedback from the amplifier to the oscillator is suppressed by a micro isolator. All semiconductor components and optics are integrated on a footprint of $50 \times 10 \text{ mm}^2$ (Fig. 1). The output power of the module exceeds 1 Watt with a conversion efficiency of 25%. Fig. 2 depicts the optical spectrum of the MOPA module in dependence on the injection current into the tapered section of the amplifier. The module features single-mode operation over the entire current range (0-2000 mA). To our knowledge this is the first time that a micro-integrated narrow-linewidth MOPA concept has been realized.

For MOPA modules at 780 nm utilizing the same technology exists a dedicated application in cold atom experiments to cool, coherently manipulate, and detect atoms. These cold atoms can be used as quantum sensors to evaluate fundamental laws of physics. The corresponding project aims at testing the weak equivalence principle on a space mission. The modules presented here will be used in preliminary experiments at the ZARM drop tower in Bremen. The next step towards space mission is an already scheduled sounding rocket mission that will be equipped with next generation MOPA modules which are just being prepared at the FBH.

These MOPA modules at 780 nm show a behavior comparable to those at 1060 nm. The output power of these modules also exceeds 1 Watt but with a slightly smaller conversion efficiency. To ensure the mode hop free tunability, required for the desired application, we use a (1.5 mm long) DFB diode as master oscillator. Since the linewidth is preserved during amplification, we reach an intrinsic linewidth (excluding technical noise) of 140 kHz and a -3 dB linewidth of 1.3 MHz at an output power of 1 W.

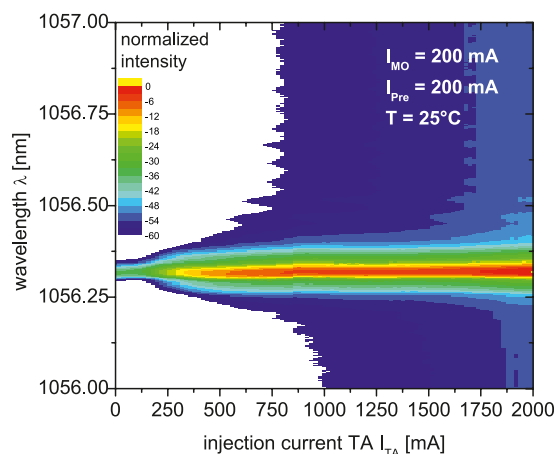


Fig. 2. Optical spectrum vs. injection current into the tapered amplifier section of a micro-integrated MOPA module. The injection current into the MO and into the ridge waveguide entry section is 200 mA.

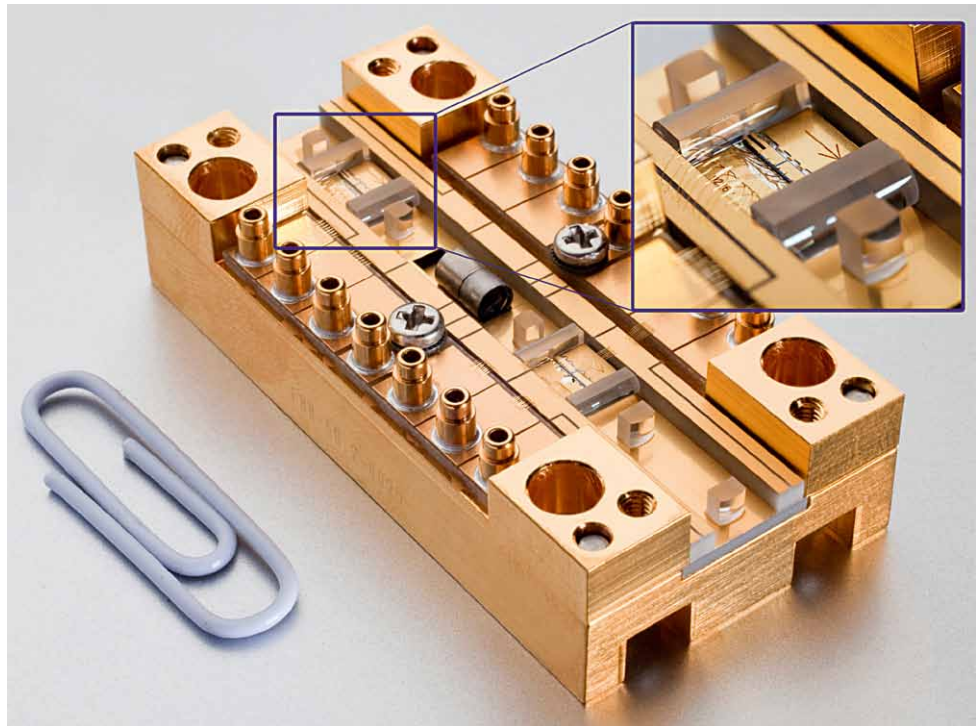


Fig. 1.
Micro-integrated MOPA module consisting of a DBR laser as a master oscillator and a tapered amplifier. Beam forming is realized by micro lenses.

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S. Spießberger, M. Schiemangk, A. Wicht, G. Erbert, "Compact narrow linewidth laser sources for coherent optical communication", Laser Optics Berlin, Berlin (2010).

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S. Spießberger, M. Schiemangk, A. Wicht, H. Wenzel, G. Erbert, G. Tränkle, "DBR laser diodes emitting near 1064 nm with a narrow intrinsic linewidth of 2 kHz", submitted for publication (2011).

S. Spießberger, M. Schiemangk, A. Sahm, A. Wicht, H. Wenzel, A. Peters, G. Erbert, G. Tränkle, "Micro-integrated 1 Watt semiconductor laser system with a linewidth of 3.6 kHz", Optics Express, vol. 19, no. 8, pp. 7077 - 7083 (2011).

S. Spießberger, M. Schiemangk, A. Sahm, A. Wicht, H. Wenzel, J. Fricke, G. Erbert, "1 W semiconductor based laser module with a narrow linewidth emitting near 1064 nm", Photonics West, SPIE, vol. 7953, no. 795311 (2011).

S. Spießberger, M. Schiemangk, A. Sahm, A. Wicht, H. Wenzel, J. Fricke, G. Erbert, G. Tränkle, "1 W narrow linewidth semiconductor-based laser module emitting near 1064 nm for coherent optical communication in space", IEEE ICSOS (2011).



Das FBH hat kompakte mikro-integrierte Master Oscillator Power Amplifier (MOPA) Module realisiert, welche sich durch eine exzellente spektrale Stabilität und eine hohe Ausgangsleistung auszeichnen. Die Module sind für Anwendungen wie die kohärente optische Freiraumkommunikation oder für Präzisionsmessungen im Weltall interessant. Die Halbleiterkomponenten (Master Oszillator und Verstärker) sowie alle optischen Elemente (Linsen, Mikroisolator) sind auf einer Fläche von 50 x 10 mm² aufgebracht. Optische Rückkopplung von nachfolgenden Komponenten in den Oszillator

wird durch einen Mikroisolator unterdrückt. Die erreichte Ausgangsleistung beträgt 1 Watt bei einer -3 dB Linienbreite von 100 kHz.

Es wurden Module bei einer Wellenlänge von 1064 (kohärente Freiraumkommunikation) und bei 780 nm (Experimente mit kalten Atomen) realisiert. Das Konzept lässt sich allerdings auch auf jede andere mit Halbleiterlasern zugängliche Wellenlänge übertragen. Soweit uns bekannt, ist dies das erste mikro-integrierte MOPA-Konzept mit geringer Linienbreite und hoher Ausgangsleistung weltweit. ■

Fabrication of Bragg gratings for wavelength stabilization

At the FBH, for wavelength stabilization of laser diodes, beside external stabilization methods such as volume Bragg gratings, mainly Bragg gratings are implemented into the semiconductor during the manufacturing process. Thus, costly mounting and adjustment which are necessary when using external gratings can be avoided. In wavelength stabilization both the exact realization of a given wavelength with narrow linewidth and the reduction of wavelength shift with changing operating temperature of the laser diode which occurs, for example, in response to changing operating currents must be understood.

When implementing Bragg gratings into the laser diode, essentially two established methods are equally applied at the FBH. For the fabrication of DFB (distributed feedback) laser diodes two-step epitaxy is used. Here, the epitaxial growth of the vertical laser structure at a specific position in the p-waveguide is interrupted. A periodic resist mask is then generated by means of holographic exposure or e-beam lithography and subsequently transmitted in a wet-chemical etching step into the vertical structure. By overgrowing the gratings with a second epitaxy the vertical structure is completed. In the case of passive gratings,

which are often used for DBR (distributed Bragg reflector) lasers, surface gratings can be used instead. This fabrication method avoids epitaxial overgrowth and is therefore well suited for cost-efficient high volume manufacturing.

In order to enable a high extent of automation, the resist pattern is realized by I-line wafer stepper lithography. Due to the resolution limit of the optical exposure system, the grating periods of the resist pattern must be higher than 700 nm. Corresponding to this value, the order of a Bragg grating must be 5 or higher. Simulations of such passive gratings with a mode matching tool have been carried out. The calculated reflectivity spectra show high values when the duty cycle (= non etched / period of Bragg grating) extends the value 0.9. Such a high duty cycle, however, can not be realized by the optical lithography tool. An improvement can be achieved by optimizing the etching process of the gratings. By forming a V-shaped etch profile a continuous increase of the duty cycle with advancing etch depth can be realized (Fig. 1). Such a profile provides a high duty cycle even at positions with high intensity of the optical mode.

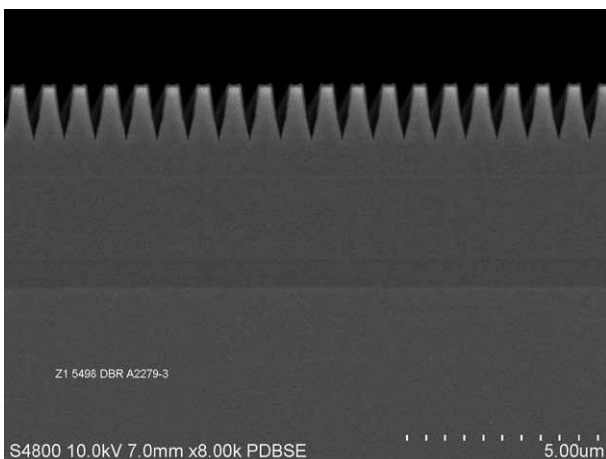


Fig. 1. SEM picture of a 6th order surface Bragg grating.

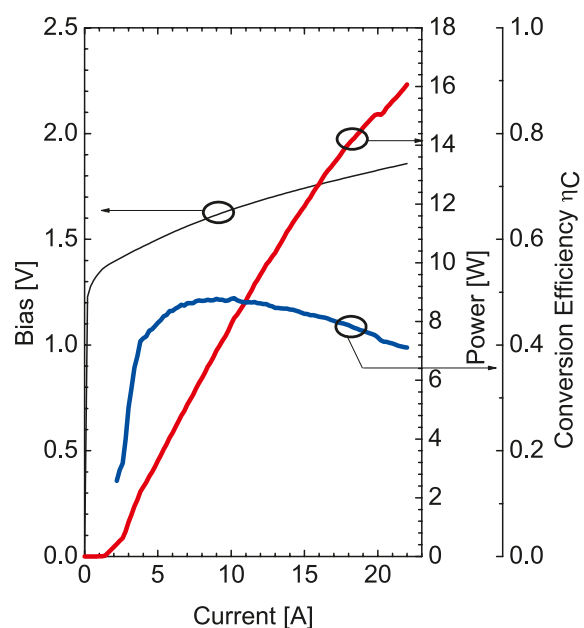


Fig. 2. PUI characteristic under CW condition of a 4 mm DBR laser with 6th order grating at 25°C.



Zur Wellenlängenstabilisierung der am FBH gefertigten Laserdioden werden Gitter eingesetzt, die während des Herstellungsprozesses direkt in den Halbleiter integriert werden. Wellenlängenstabilisierung bedeutet dabei sowohl eine vorgegebene Wellenlänge mit schmalen Linienbreiten exakt zu realisieren als auch die Wellenlängenverschiebung bei sich ändernder Arbeitstemperatur der Laserdiode zu reduzieren, beispielsweise bei wechselnden Betriebsströmen.

Eine kostengünstige Herstellungsmethode ist das Ätzen der Gitter mittels RIE, wobei ein nachfolgendes Überwachen der Gitter nicht erforderlich ist. Die Ätzmaske wird mithilfe eines Wafersteppers bei 635 nm erzeugt und kann deswegen nur mit Gitterordnungen > 5 realisiert werden. DBR-BA- sowie DBR-Trapezlasers, die mit dieser Technologie wellenlängenstabilisiert werden, erreichen Ausgangsleistungen von deutlich über 10 Watt. ■

Etching of surface Bragg grating is carried out with reactive ion etching (RIE). The Sentech system used provides direct He-backside cooling of the wafer for stable conditions during the whole etch process. An interferometer enables precise in-situ control of the etch depth. By controlling the sidewall angle of the grooves a variation of their depth from 1 μm to 2 μm is possible without requiring an additional hard mask. Laser diodes with such implemented Bragg gratings have been fabricated at the Ferdinand-Braun-Institut. 6 mm long DBR tapered lasers emitting at 1064 and 976 nm achieved maximum output powers of more than 10 W with a linewidth below 100 pm.

Wavelength-stabilized high-power broad area lasers are needed for efficient pumping of fiber lasers. The high absorption near 980 nm permits efficient pumping over a short device length. As this absorption band is quite narrow, the wavelength of the pump lasers must remain nearly constant during various injection currents to maintain the high efficiency of the fiber lasers over the full power range. For laser diodes with a length of 4 mm and 90 μm stripe width an output power of more than 15 W (CW) and

23 W (QCW with 300 μs pulses) at about 50% conversion efficiency have been demonstrated (Fig. 2). The spectral width is in the power range up to 16 W below 1 nm with 95% power inclusion and the maximum wavelength shift is 2.7 nm in the CW case (Fig. 3). Subject of current research is to optimize the design to achieve efficiencies above 60%.

Publications

B. Sumpf, K.-H. Hasler, P. Adamiec, F. Bugge, J. Fricke, P. Ressel, H. Wenzel, G. Erbert, G. Tränkle, "1060 nm DBR tapered lasers with 12 W output power and a nearly diffraction limited beam quality", Proc. SPIE, vol. 7230, no. 72301E (2009).

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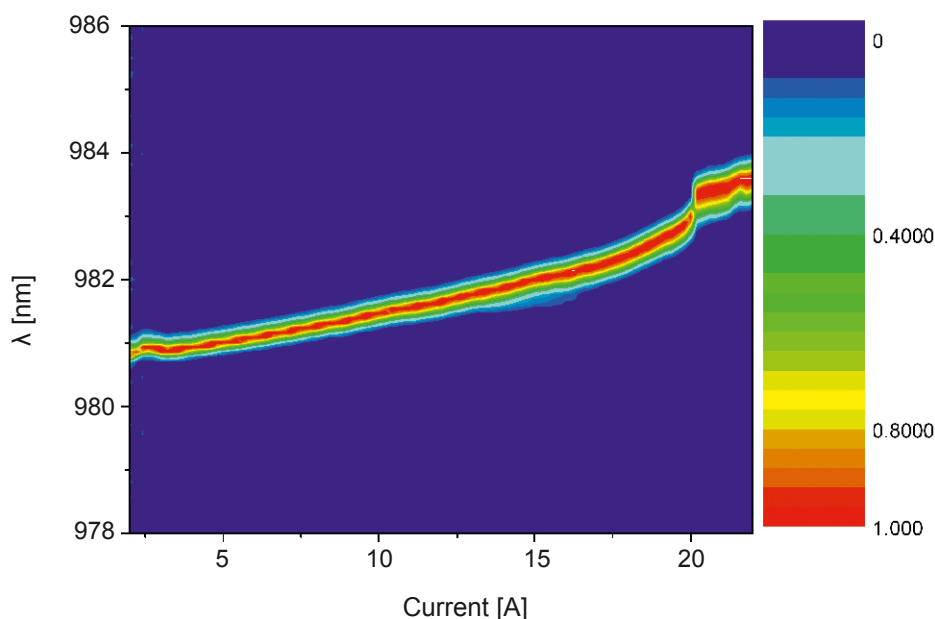


Fig. 3. Spectra mapping under CW operation of a 4 mm DBR laser with 6th order grating at 25°C.

660 nm high-power tapered diode lasers

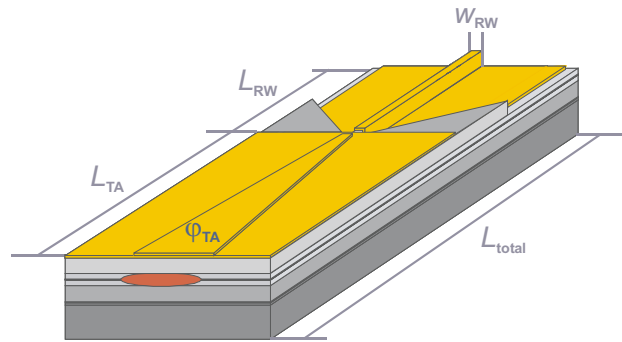


Fig. 1. Layout geometry of the tapered lasers.

High-power lasers in the red spectral range are suitable light sources for medical applications like photodynamic therapy (PDT), analytic methods (e.g., fluorescence imaging) and laser projection systems. Whenever the laser beam has to be propagated through an optical system (fiber, microscope or scanning mirror) a nearly diffraction-limited beam is required for optimum transmission. While ridge waveguide (RW) lasers provide lateral single mode emission (beam propagation factor $M^2 = 1$) their output power is limited to several tens of mW because of catastrophic optical mirror damage (COMD). Commercial products are available with output powers in the range of 100-200 mW.

To obtain nearly diffraction-limited laser radiation in the range of Watts, tapered lasers can be used. They consist of a RW section for the generation of single-mode emission and a taper amplifier (TA) to increase the output power (Fig. 1). Tapered lasers are less susceptible to COMD because the lateral beam waist lies inside the taper amplifier, i.e., the beam is already widened when it passes the front facet. The highest previously reported output power of a red tapered laser is 1.0 W at 670 nm with a beam quality of $M^2(1/e^2) = 1.7$ and was achieved at FBH in 2007. We now succeeded to improve the performance to $M^2(1/e^2) = 1.5$ at a power of 1.5 W.

In order to achieve this, we experimentally investigated how the optical output power and the lateral beam parameter product M^2 depend on the geometry of the tapered

laser (width and length of ridge waveguide, length of taper amplifier). A heterostructure with a 5 nm compressively strained InGaP single quantum well (SQW) was the basis for this study. The tapered lasers were soldered p-side down on CVD-diamond heat spreaders for optimum heat transfer. Concerning the ridge width, a common trend of increase of M^2 with the RW width w_{RW} was observed. This can be explained by the propagation of multiple laser modes in case of a broader ridge waveguide deteriorating the beam quality. For further optimization a rather narrow ridge width $w_{RW} = 3 \mu\text{m}$ was chosen and the influence of the length ratio $L_{RW} : L_{TA}$ on the output power and the corresponding beam quality was investigated. The total length of the lasers was 2 mm. It was found that a long TA section is more suitable for reaching high power because thermal rollover occurs at higher current. This is a geometric effect associated with the different areas of the taper amplifier. The current density necessary for a certain output power is always lower for the longer TA section. This is especially crucial for red lasers because of the small electron barrier height. Concerning the beam quality, it was found that by increasing the TA length from 1000 μm to 1500 μm , the output power can be increased by a factor of two without compromising the beam quality. A further increase of the TA length requires longer chips. Since an increase of the total length is critical due to the CTE mismatch between GaAs and CVD diamond, for the improved design the RW section length was reduced to only 250 μm and the total device length was slightly increased to 2250 μm , allowing a TA length of 2000 μm .

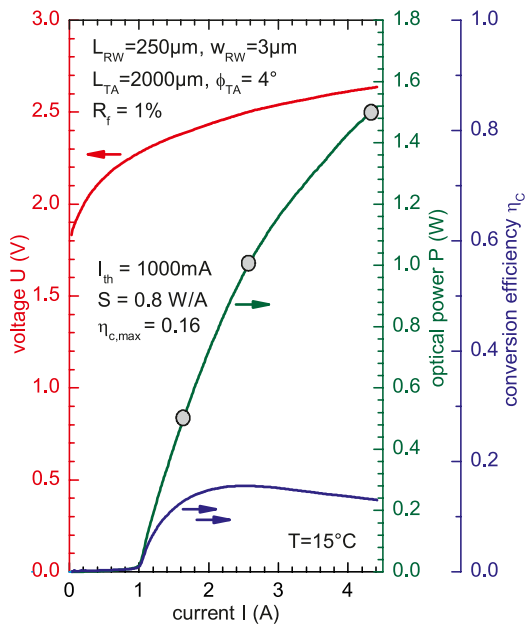


Fig. 2. Results of tapered laser with improved design ($L_{TA} = 2000 \mu\text{m}$): power-voltage-current characteristic and conversion efficiency. The dots on the output power curve mark the power levels for which the beam quality was determined.



High-power tapered diode laser at 660 nm mounted p-down on CVD-diamond heat spreader and c-mount.

The resulting power-voltage-current characteristics together with the conversion efficiency are given in Fig. 2. For three designated output power levels (0.5 W, 1.0 W and 1.5 W), the beam quality was determined. The device achieved a record output power of 1.5 W with a beam quality close to the diffraction limit. $M^2(1/e^2)$ is 1.5 for all three output powers while $M^2(\sigma)$ increases from 2.1 at 0.5 W to 2.5 at 1.0 W and 4.6 at 1.5 W. The power contained in the central lobe is 93% up to a power of 1.0 W and reduces to 85% at 1.5 W.

The excellent results obtained from the optimized layout with a longer taper amplifier can be understood in terms of a reduced phase-amplitude coupling which determines the susceptibility of the laser to filamentation. Further beneficial effects associated with a longer taper section (and thus a larger taper area) are a more effective cooling and a reduced current density. Reliability tests of this device showed excellent results. It was tested for 1300 h at a power of 0.5 W. After this time, the output power was increased to 0.75 W and the laser was operated for further 2000 h. Finally, the device was set to $P = 1.0 \text{ W}$ where it operated so far for more than 4700 h without failure. We have thus demonstrated reliable operation of a 660 nm tapered laser over 8000 h at power levels up to 1.0 W.

Publication

C. Kaspari, G. Blume, D. Feise, K. Paschke, G. Erbert, M. Weyers, "Optimisation of 660 nm high-power tapered diode lasers", IET Optoelectron., in print (2011).

➤ Hochleistungslaser im roten Spektralbereich eignen sich für medizinische Anwendungen wie die photodynamische Therapie, analytische Methoden wie etwa Fluoreszenz-Bildgebung und Laserprojektionssysteme. Bei allen Anwendungen, die eine Einkopplung in ein Strahlführungssystem (Lichtwellenleiter, Mikroskop, etc.) erfordern, ist ein nahezu beugungsbegrenzter Strahl für optimale Transmission notwendig.

Bezüglich der Strahlgüte erfüllen Rippenwellenleiter-Laser die Voraussetzungen, emittieren aber eine zu geringe Leistung (maximal 200 mW). Um nahezu beugungsbegrenzte Strahlung im Watt-Bereich zu erzeugen, können Trapezlaser genutzt werden. Die mit Trapezlasern im roten Spektralbereich bisher höchste erreichte Leistung wurde 2007 am FBH realisiert: 1,0 W bei einer Wellenlänge von 670 nm und einer Strahlqualität von $M^2(1/e^2) = 1,7$. Wir haben verschiedene Trapezlaser-Geometrien experimentell untersucht und konnten mit einem nochmals optimierten Design die Leistung auf 1,5 W bei einer Wellenlänge von 660 nm steigern. Bei dieser Leistung wurde eine Strahlqualität von $M^2(1/e^2) = 1,5$ gemessen. ■

A new generation of diode laser designs: high power and high efficiency at the same time

High-power broad area diode lasers provide the optical energy for high performance industrial laser systems. In such systems, the output of many single emitter diode lasers is combined to form a high-brightness source suitable for applications such as cutting or welding. The single emitters used ultimately limit the overall system performance, and both the highest possible output power and the highest possible power conversion efficiency are required. In recent years, broad area diode lasers have demonstrated peak power conversion efficiencies in excess of 70%. However, these peak efficiencies were achieved using lasers with short cavity lengths of ~ 1 mm. Short cavity devices are not efficiently cooled, which means that the peak efficiency occurs at low output power level of 2-5 W per laser (for diode lasers with 100 μm stripes) and rapidly falls at higher powers. Current industrial systems require single emitters with powers of at least 12-15 W per 100 μm , and high efficiencies must be sustained.

In the past year, FBH scientists have developed a new generation of laser designs that demonstrate increased absolute efficiency at high power levels (Fig.1). This development work built on a series of careful diagnostic studies. The efficiency at high power in broad area diode lasers is limited by two properties of the diode lasers: their electrical resistance and the tendency of the output power to saturate at high current levels. Our diagnostic studies showed the electrical resistance to largely be dominated by the

low-doped p-side waveguide. In traditional diode laser designs, power saturation typically occurred due to device over-heating. Efficiencies were low, heat-sinking was inefficient and the energy barriers preventing carrier leakage inside the devices were low and easily overcome at high temperature. In modern designs, these effects play a much smaller role, and three other factors were found to dominate the power saturation.

Firstly, for lasing to occur, high densities of electrons and holes must be brought together in the active region, where they provide optical gain. Passing photons induce the electrons and holes to recombine, forming stimulated lasing light. At high power levels, the optical density is so large that the electrons and holes are removed faster than they can be replaced and the overall gain falls, leading to power saturation—a process termed gain saturation. Secondly, modern high-power devices typically have a cavity length, of > 4 mm, increasing their surface area for efficient cooling. To direct light out of the front of the laser, a high reflection coating is used on the rear facet and a low reflectivity on the front facet. Longitudinal hole-burning is a side effect of long cavities and asymmetric coatings. A high optical power density accumulates inside the device at the output facet, which depletes the electrons and holes, reducing the local gain, which again leads to power saturation, as indicated in Fig. 2. Finally, in order to reach the highest powers, high currents must flow through the diode lasers.

The p-side waveguide has a high resistance (low mobility, low doping) meaning that a high voltage is dropped across this region at high current. The voltage is high enough



Fig. 1. A new generation of FBH diode laser designs offers very high conversion efficiency at high optical output power. These long cavity lasers are mounted on sub-mounts for use in industrial laser systems.

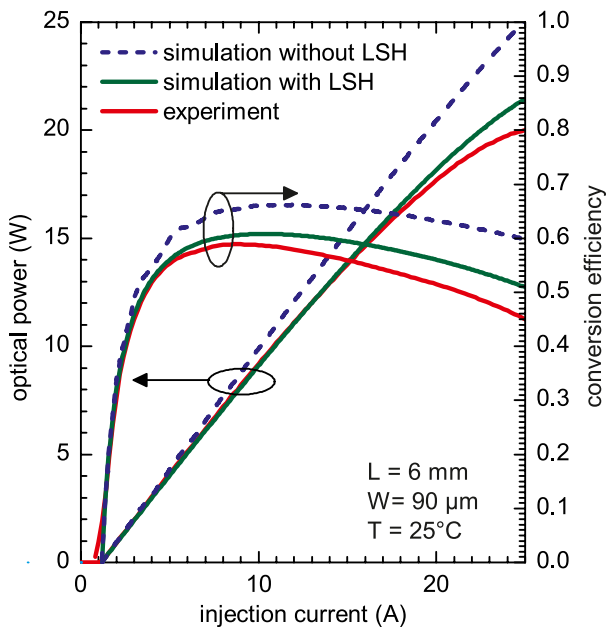


Fig. 2. In non-optimized designs, longitudinal spatial hole-burning (LSH) leads to power saturation (simulated efficiency is higher as it includes no package resistance).

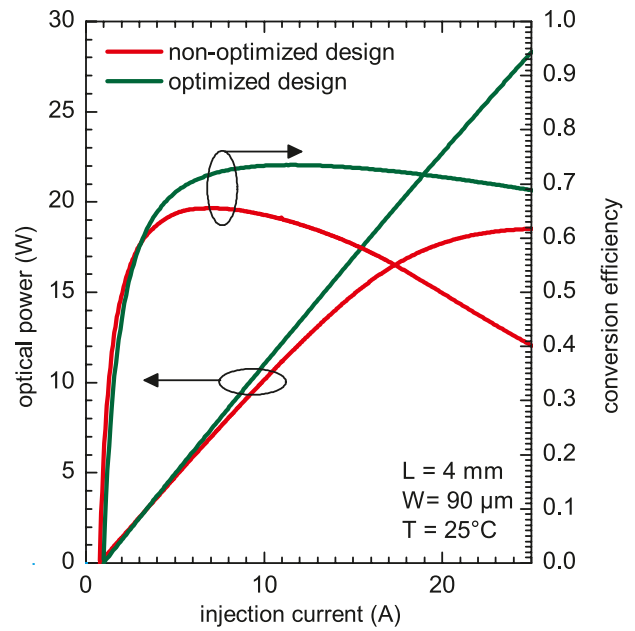


Fig. 3. In optimized designs, efficiencies of > 70% are predicted to be sustained to over 12 W per 90 μm stripe.

to bend the band edge, enabling carriers to escape from the active region and be lost, leading once more to power saturation.

In order to sustain high efficiency at high power, new designs had to be developed that were compatible with long cavity lengths, mitigated gain saturation, longitudinal hole burning and current driven leakage and simultaneously reduced the device resistance. In the new FBH designs, the thickness and doping of the p-type waveguide is carefully chosen to minimize both its resistance, and the impact of current-induced leakage. Gain saturation is addressed by minimizing the overlap of the optical field with the active region. Longitudinal hole-burning is also mitigated by this low overlap, together with careful selection of facet coatings.

The new designs rely on the use of a very asymmetric waveguide, where the active region is located close to the p-side cladding layers. One key challenge is to maintain

a stable, single vertical optical mode up to high power levels. Such stable high-efficiency operation is enabled in these designs by combining highly asymmetric waveguides with carefully chosen composition and doping level for the core and cladding layers. A summary of progress to date is shown in Fig. 2, which collects simulation results from two vertical designs. In recent experimental work on early variants of these new designs, very low optical losses figures of below 0.5 cm^{-1} have been demonstrated, together with power conversion efficiencies of > 65% at power levels of 12 W. Further design optimization offers the way to achieve, for the first time, power conversion efficiency of > 70% at power levels of over 15 W per 100 μm stripe (Fig. 3).

Publication

H. Wenzel, P. Crump, A. Pietrzak, X. Wang, G. Erbert, G. Tränkle, "Theoretical and experimental investigations of the limits to the maximum output power of laser diodes", *New J. Phys.*, vol. 12, no. 085007 (2010).



Der direkte Einsatz von Diodenlasern in der industriellen Fertigung ist bisher nur eingeschränkt möglich, weil die Leistung der eingesetzten Hochleistungs-Breitstreifenlaser für viele Anwendungen nicht ausreicht. Verbesserungen sind bislang daran gescheitert, dass bei Erhöhung der Ausgangsleistung der Laser der Wirkungsgrad der Umwandlung von elektrischer in optische Leistung (Konversionseffizienz) stark abnimmt.

Mithilfe theoretischer und experimenteller Untersuchungen konnten nun am FBH im letzten Jahr die Ursachen für dieses Verhalten identifiziert werden. Eine liegt in der

inhomogenen Leistungsverteilung in langen Laserresonatoren, welche die Verstärkung und damit auch die Leistung in der Nähe der Lichtaustrittsfläche reduziert. Eine andere besteht in Verbiegungen der Energiebänder, wodurch ein Teil der injizierten Ladungsträger durch stimulierte Rekombination kein Laserlicht mehr erzeugt.

Auf der Basis dieser Studien wurden neue Designs für Laserdioden entwickelt, die aus einem 100 μm breitem Streifen eine Konversionseffizienz von mehr als 70% bei einer Ausgangsleistung von mehr als 15 W erreichen. ■

940 nm lasers: building blocks for pump modules

Diode laser pumped ultra-short pulse lasers generating high peak power pulses in the pico- and femto-second range are essential tools for many applications in industry and research such as for micromachining and generation of coherent UV- and X-ray radiation. The latter are used, for example, in material analytics as well as in chemistry to analyze processes and properties of matter at atomic and molecular level. A novel compact ultra-short pulse laser with a pulse energy > 1 J and a high repetition rate of 200 Hz is currently developed within a cooperation between Max-Born-Institute and FBH. For this project, FBH has designed 937 nm high-power diode lasers (Fig. 1) which are assembled into efficient pump modules in collaboration with Jenoptik Laser GmbH.

The modules operate in quasi-continuous wave (QCW) mode, which is determined by the solid-state laser design. With a pulse width of 1 ms and a repetition rate up to 200 Hz one single module shall supply a pulse energy of 2 J and a peak power of 2 kW, respectively. The pump modules consist each of about 70 single diode lasers and are smaller than an A4 sheet. A compact beam shaping optical setup combines the laser beams of every laser chip and focuses them into a high-power optical fiber with a core diameter of 1 mm and a numerical aperture of 0.22. Target is a wall plug efficiency of at least 50%.

In order to reach the specifications, the semiconductor structure of the laser chips was optimized for high QCW peak power and electro-optical efficiency on the one hand and for efficient fiber coupling on the other hand. The lateral chip design bases upon a 400 μm wide stripe array with a resonator length of 4 mm which enables high laser power combined with low lateral far field angles resulting in low values for the beam parameter product. The latter is important for efficient and stable fiber coupling. Different stripe geometries have been investigated to achieve the best possible performance. The epitaxial design of the chip is optimized for high reliability and simple beam shaping by using a super-large optical cavity structure. Such a structure reduces facet load which leads to a higher catastrophic optical damage level and additionally decreases the vertical far field angle. The electro-optical characteristic and the lateral far field profile of the laser diode at 25°C heat sink temperature are shown in Fig. 2. Operating in QCW mode with a pulse width of 1 ms and duty cycle 1%, the laser reaches an optical peak power of 59 W ($I = 64.5$ A) and a maximum conversion efficiency of 61%. This is nearly twice the nominal power for 2 J of the pump module. The lateral far field angle with 95% power enclosed is 12° to 14°. Vertical far field divergence with 95% power enclosed is 45°. The achieved beam quality enables fiber coupling with an efficiency of more than 80%.



Fig. 1. Diode lasers as pump sources for ultra-short pulse lasers.

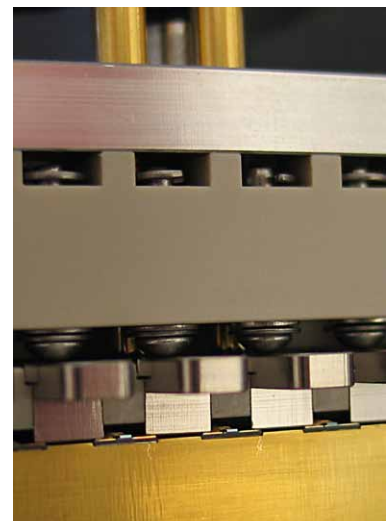


Fig. 3. Measurement device.

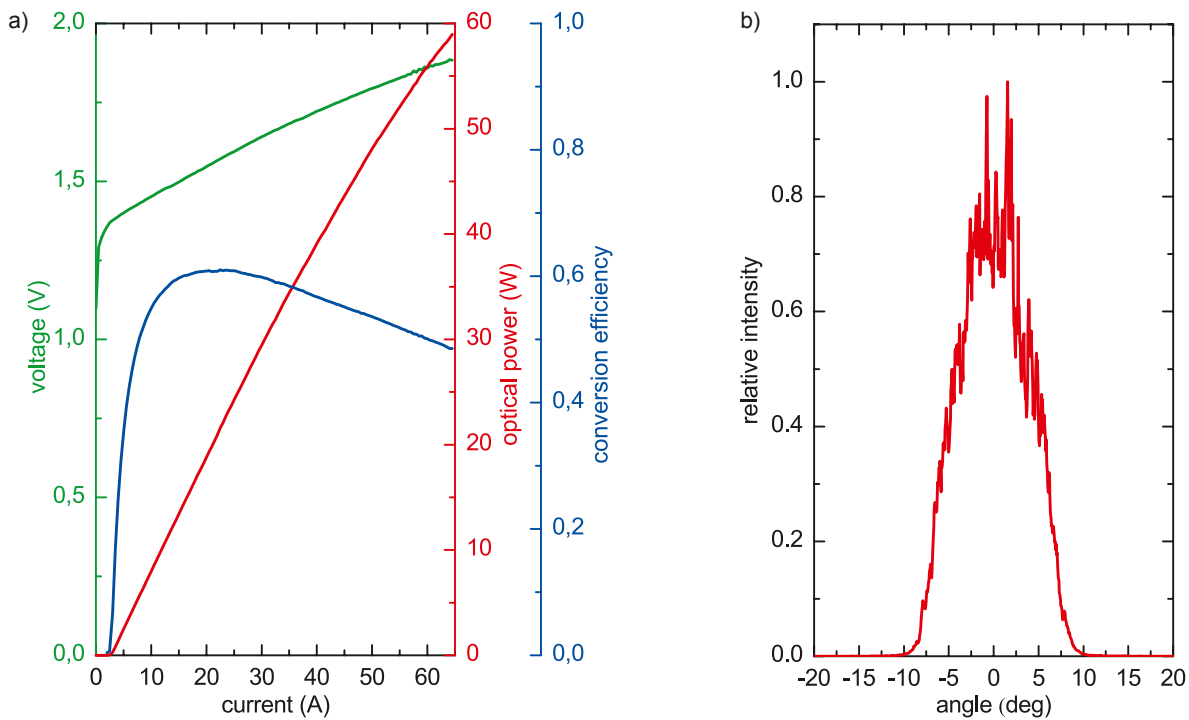


Fig. 2. Electro-optical characteristic a) and far-field profile b) of the laser chip, mounted onto AlN submount, at 25°C and QCW operation (1 ms pulse width, 1% d.c.).

The laser chip is mounted onto a compact conduction cooled 4.5 mm x 4 mm small aluminum nitride ceramic heat sink using AuSn solder. All materials are nearly expansion matched. FBH uses a fully automated high-performance soldering system designed for industrial production and high accuracy. Thus, placement accuracy is better than $\pm 5 \mu\text{m}$ in lateral direction of the chip which is necessary to fulfill the optical design requirements of the module. A facet inspection is integrated into the process to decrease the failure ratio. Wire bonding process is automated, too.

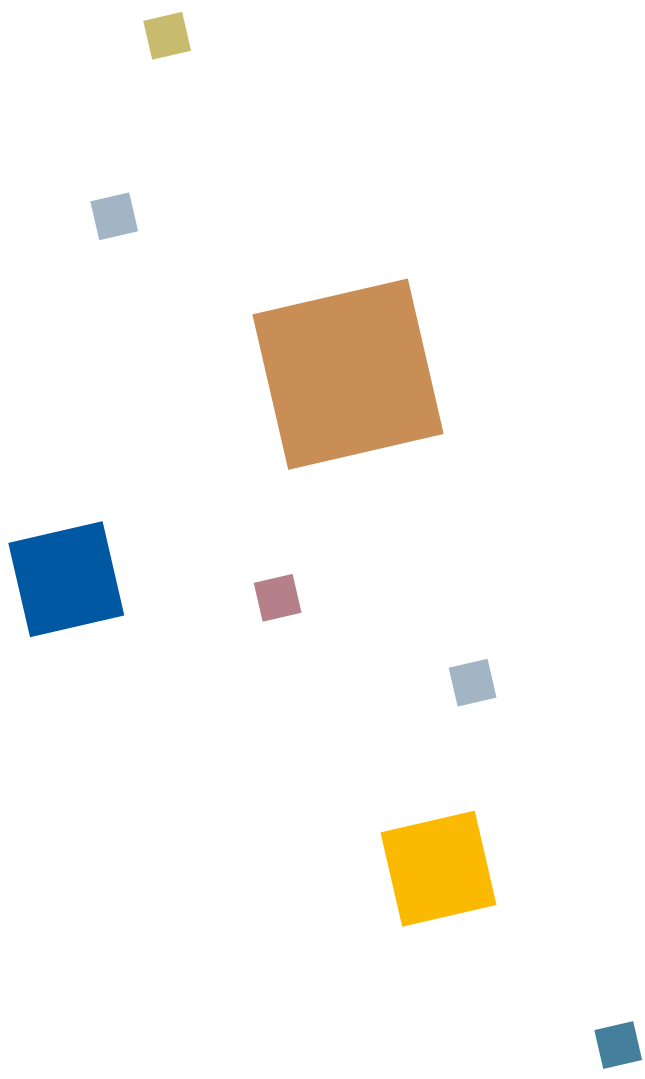
Before mounting the lasers into the module, each laser runs a 168 hours lasting burn-in test to ensure quality and reliability. First, a test measurement is done: at a current of 40 A and QCW operation, the optical power of each laser is measured. This process is automated to ensure an efficient work flow. Operating conditions are close to the specs of the final product: pulse width is 1 ms, repetition rate is 10 Hz to avoid heating of the chip since the submount is only clamped onto the measurement and burn-in holder (Fig. 3). If the optical power is below the set tolerance value, which is 38 W, the laser is rejected. The mean yield of this selection process is currently 87%. Only lasers passing the test are burned and then measured again; lasers that fail are also rejected. Lasers which passed the burn-in show no degradation. Their mean failure ratio is only 6%.

Hence, the FBH successfully developed a laser chip which is the basis for industrial manufactured and low-cost pump modules for high-power laser systems. First pump module

prototypes will be built up in the first quarter of 2011, directly followed by a small series production. Ongoing research activity aims at enhancing beam quality, power and conversion efficiency of the semiconductor structure.

Diodegepumpte Kurzpuls Laser mit extrem hohen Spitzenleistungen sind wichtige Werkzeuge für Industrie und Forschung. Sie werden z.B. in der Mikromaterialbearbeitung oder zur Erzeugung kohärenter UV- und Röntgenstrahlung eingesetzt. Ein neuartiger kompakter Ultrakurzpuls Laser höchster Leistung und hoher Pulsfolgefrequenz > 100 Hz entsteht derzeit am MBI in Kooperation mit dem FBH.

Das FBH entwickelt dafür gemeinsam mit Jenoptik ein neuartiges Pumpmodul auf der Basis hocheffizienter 937 nm Diodenlaser. Bei einer Pulsbreite von 1 ms und einer Repetitionsrate von 200 Hz soll ein einzelnes Modul eine Pulsenergie > 2 J in einer Faser bereitstellen. Ziel ist dabei, einen elektrooptischen Gesamtwirkungsgrad von mindestens 50% zu erreichen, um diese Pumpmodule auch für künftige diodegepumpte Festkörperlaser tauglich zu machen. Die Halbleiterstruktur der Diodenlaser wurde daher so optimiert, dass ein Laserchip eine optische Leistung von 35 W mit hoher Brillanz bei einem Konversionswirkungsgrad von 60% erreicht. Circa 70 solcher Halbleiterchips bilden ein Pumpmodul. Erste Prototypen sollen im 1. Quartal 2011 zur Verfügung stehen. Damit hat das FBH einen Laserchip als Basis für industriell gefertigte und kostengünstige Pumpmodule für Hochleistungslasersysteme entwickelt. ■



BUSINESS AREAS & RESEARCH

GaN Optoelectronics » GaN-Optoelektronik

GESCHÄFTSBEREICHE & FORSCHUNG



GaN-Optoelektronik



Im Geschäftsbereich GaN-Optoelektronik gilt das Hauptaugenmerk der Entwicklung innovativer Lichtquellen auf Basis des Halbleitermaterials GaN und seiner Legierungen AlGaIn und InGaIn. Diese Materialbasis eröffnet die Möglichkeit, hocheffiziente Lichtemitter in einem breiten Spektralbereich herzustellen, der den gesamten sichtbaren und große Teile des ultravioletten (UV) Spektrums abdeckt. Die Forschungs- und Entwicklungsarbeiten am FBH konzentrieren sich dabei auf Laserdioden mit einer Emissionswellenlänge im Bereich von 400 bis 450 nm, Leuchtdioden (LEDs) für den nahen (UV-A) und mittleren (UV-B) ultravioletten Spektralbereich und UV-Photodetektoren. Während die Laserdioden mit kundenspezifischen Wellenlängen z.B. auf den Einsatz in der Atom- und Molekülspektroskopie abzielen, sind die LEDs für Anwendungen wie Wasserdeseinfektion oder Phototherapie interessant.

Die Bauelemententwicklung umfasst die Modellierung der optischen und elektrischen Eigenschaften von GaN-basierten Schichtstrukturen, das Wachstum mittels Metallorganischer Gasphasen-Epitaxie (MOVPE), die Chipherstellung im Reinraum, die Chipmontage auf Wärmesenken bzw. in Gehäusen und die elektrooptische Charakterisierung der Bauelemente. Das FBH arbeitet dabei eng mit der Arbeitsgruppe „Experimentelle Nanophysik und Photonik“ der TU Berlin zusammen. Über den neu eingerichteten innovativen regionalen Wachstumskern „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 2010 war von Fortschritten bei der Materialentwicklung und der Bauelementherstellung geprägt. Über eine Optimierung der aktiven Zone und der Wellenleiterstruktur wurden erstmalig blaue Laserdioden mit einer Emissionswellenlänge im Bereich 430 - 440 nm realisiert. Ausgangspunkt für diese Entwicklung waren Breitstreifenlaserdioden im violetten Spektralbereich, deren maximale Ausgangsleistung im gepulsten Betrieb pro Facette bis zu 3 W beträgt. Die Chiptechnologie von Rippenwellenleiterlaserdioden wurde unter anderem durch einen neu etablierten, selbstjustierenden Prozess zur Herstellung schmaler Rippen weiter entwickelt. Diese Arbeiten an Schichtstrukturen auf der polaren c-Fläche des GaN wurden durch solche auf semipolaren Oberflächen ergänzt. LEDs mit violetter, blauer, grüner und gelber Emission wurden damit erfolgreich demonstriert. Im Bereich der UV-LEDs wurde insbesondere die Montagetechnologie der Chips ausgebaut, so dass nunmehr LEDs mit einer Emission bei 320 nm in Flip-Chip-Montage auf AlN-Submounts zur Verfügung stehen. Darüber hinaus wurde mit der Entwicklung von LEDs mit einer Emission bei 360 nm begonnen, die ihr UV-Licht gerichtet durch semi-transparente Vorderseitenkontakte abstrahlen. Solche LEDs sind insbesondere für Anwendungen in der Sensorik interessant.

GaN Optoelectronics

To develop innovative light sources based on the semiconductor material GaN and its alloys AlGaIn and InGaIn is the main objective of the Business Area GaN Optoelectronics. The material system opens up the possibility to fabricate highly efficient light emitters in a broad spectral region which covers the entire visible range and large parts of the ultraviolet (UV) spectrum. Research and development at FBH focus on laser diodes emitting in the 400 nm to 450 nm wavelength range, UV-A and UV-B light emitting diodes (LEDs) as well as deep UV photodetectors. Custom laser diodes with tailored wavelengths find application in e.g. atom and molecule spectroscopy, whereas UV LEDs are interesting for applications in water disinfection and phototherapy.

The device development includes modeling of optical and electrical properties of GaN-based layer heterostructures, growth by metalorganic vapor phase epitaxy (MOVPE), chip fabrication in a cleanroom environment, chip mounting on heat sinks as well as packaging, and electro-optical characterization of the devices. FBH collaborates closely with the group "Experimental Nanophysics and Photonics" at TU Berlin. Within the framework of "Berlin WideBaSe" as a regional center of economic growth, the Business Area GaN Optoelectronics at FBH closely cooperates with a number of companies in Berlin such as Osram, Jenoptik, OSA Opto Light and eagleyard Photonics.

The year 2010 was marked by progress achieved in material development and device fabrication. By optimizing their active region and waveguide structure, blue laser diodes with an emission wavelength in the range 430 - 440 nm were realized for the first time at FBH. Broad-area laser diodes in the violet spectral region with a maximum output power of 3 Watt per facet under pulsed operation were the starting point for this development. The chip processing technology of ridge waveguide laser diodes was improved by establishing a self-aligned process for the fabrication of narrow ridges. The work on light emitters on the polar c-plane of GaN was supplemented by activities on semipolar surfaces which resulted in demonstrating semipolar InGaIn quantum well LEDs with violet, blue, green and yellow emission. In the area of UV LEDs particularly the mounting technology of chips advanced such that LEDs with an emission at 320 nm are now available in flip-chip geometry on AlN submounts. Moreover, FBH has started to develop top-emitting UV LEDs at 360 nm with a focused beam through semitransparent contacts on the chip front side. Such LEDs are very interesting for applications in sensor systems.

True-blue laser diodes on bulk GaN substrates

Gallium nitride semiconductor materials and its alloys with AlN and InN exhibit a direct band gap that covers a wide spectral range from deep ultraviolet to near infrared. Still, (In,Ga)N laser diodes (LDs) are commercially available only for a limited number of distinct wavelengths and with properties that mainly fit the requirements of specific applications such as blue-ray disk drives, laser projectors and laser printers. Besides consumer electronic products, nitride-based LDs could also enable compact and efficient systems for a wide range of novel applications in the area of spectroscopy. However, these applications require a specific emission wavelength as well as unique optical properties like lateral and longitudinal single mode operation.

The work at FBH focuses on the realization of external cavity InGaN LDs emitting at 435.9 nm. This wavelength corresponds to the $7_3S_1 - 6_3P_1$ line of atomic mercury in gas-discharge lamps, which is used for numerous biomedical and medical applications such as fluorescence microscopy for malaria or tuberculosis diagnosis, cell and neural research, food safety chemical analysis and environmental testing.

Research activities were building on our established 405 nm laser diode technology, for which we have already demonstrated continuous wave operation of ridge-waveguide laser devices. One of the major challenges regarding the realization of blue-emitting laser diodes is the higher indium mole fraction in the InGaN quantum wells (QW). Due to the large lattice mismatch between InN and GaN as well as the tendency to phase separation, InGaN alloy non-uniformities occur in the active region. In addition, InGaN/GaN heterostructures exhibit strong piezoelectric fields along the growth direction, which leads to a reduction in the oscillator strength and a shift in emission energies due to the quantum-confined Stark effect. Simulations of the

gain spectra and waveguide structure were used to optimize the design of the InGaN active region and the separate confinement heterostructure. The simulation efforts were complemented by gain measurements and investigations of the far-field pattern of optically pumped InGaN MQW structures. We found that InGaN QWs and barriers with reduced thickness were beneficial for low threshold lasers emitting around 440 nm. The optimum number of quantum wells was determined to be two. Design changes had a positive effect on both the material gain and the crystal perfection of the active region. Finally, by adjusting the InGaN growth conditions and by using low defect density bulk GaN substrates we were able to achieve peak material gain values that are comparable to our 405 nm LDs.

Another issue of increasing the lasing wavelength is that the optical mode is less confined in the waveguiding layer due to a smaller refractive index difference between the GaN waveguide core and the surrounding aluminum gallium nitride (AlGaN) cladding layer. Therefore, the waveguide design was optimized with the help of simulation tools and gain measurements of optically pumped laser structures. By increasing the width of the n-side GaN waveguiding layer we were able to significantly reduce the mode leakage towards the substrate, to increase the modal gain and to reduce the threshold power density for optically pumped lasing (see Fig.1). Employing the optimized active region growth scheme, optical threshold power densities around 200 kW/cm² were achieved at 440 nm in comparison to around 100 kW/cm² for 405 nm laser structures.

Device structures with such optimized InGaN MQW active region and separate confinement heterostructure were epitaxially grown and processed into broad area LDs. Lasing

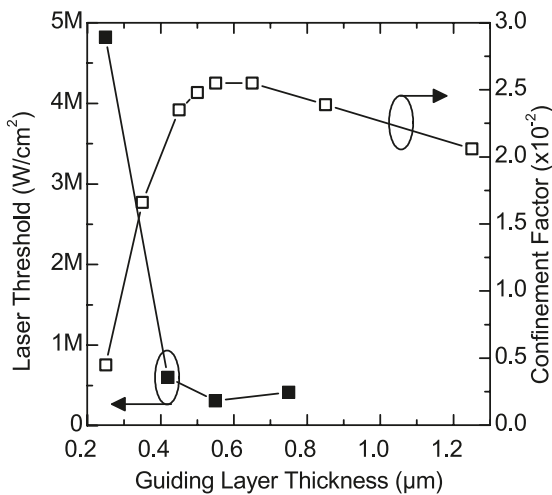


Fig. 1. Measured laser thresholds (solid squares) and calculated optical confinement factors (open squares) of optically pumped 450 nm lasers for different guiding layer thicknesses.

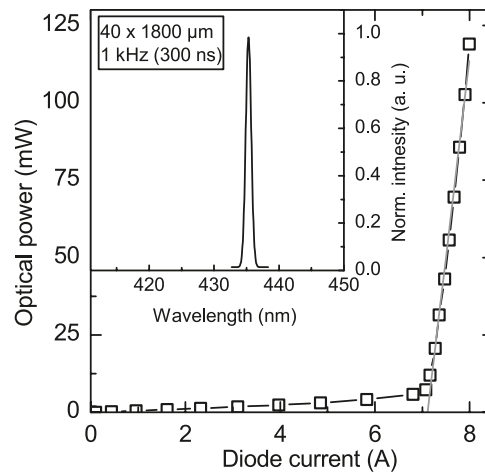


Fig. 2. Light output power versus current characteristics (L-I) of an uncoated broad area laser diode emitting at 436 nm. The inset shows the laser emission spectrum above threshold.

at 436 nm with threshold current densities of below 10 kA/cm² were achieved in pulsed mode (see Fig. 2). Based on these results, ridge waveguide laser structures will be developed in the next step.

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Die 435,9-nm-Linie von Quecksilberdampf-lampen wird u.a. in der Lebensmittel- und Umweltkontrolle genutzt; mittels Fluoreszenz-mikroskopie können auch Krankheitserreger wie Malaria oder Tuberkulose diagnostiziert werden. Kompakte Halbleiterlaserdioden dieser Wellenlänge könnten diese Lampen ersetzen und effiziente mobile Detektoren ermöglichen.

Das FBH hat nun seine Aktivitäten in der GaN-Lasertechnologie vom Dauerstrichbetrieb bei 405 nm auf größere Wellenlängen erweitert. Der dabei erhöhte Indiumanteil im InGaN der aktiven Zone reduziert die Materialverstärkung, da aufgrund der höheren Gitterfehlpassung verstärkt Zusammensetzungsfluktuationen und dreidimensionales Wachstum auftreten. Zudem nimmt die modale Verstärkung bei längeren Wellenlängen ab, da der Einschluss der Wellenleitermode sinkt. Mithilfe von Simulationen wurde zunächst die Wellenleitung optimiert und dann die aktive Zone so modifiziert, dass der höhere Indiumgehalt nicht zu Degradationen führt. So konnten Breitstreifenlaser mit einer Emissionswellenlänge von 436 nm und einer Schwellstromdichte von 10 kA/cm² im gepulsten Betrieb realisiert werden. ■

Flip-chip mounted light emitting diodes in the UV-A and UV-B spectral range

Nitride-based light-emitting diodes (LEDs) operating in UV-A and UV-B ranges are very promising for a number of applications, including UV curing, phototherapy, sensing, spectroscopy, and counterfeit detection. Although the performance of UV LEDs has been continuously improved over the years, their efficiency is still relatively low. High density of threading dislocations, which act as non-radiative recombination centers, poor carrier injection, and inefficient light extraction are some of the factors limiting the efficiency. FBH in collaboration with TU Berlin has undertaken a number of steps in the growth and fabrication of UV LEDs to improve the efficiency of these devices comprising optimization of the quantum well light emitting region, reduction of the defect density and development of advanced chip designs including nanopixel contacts and micro-LED arrays.

UV LED structures emitting near 320 nm and 380 nm were grown on sapphire substrates. The structures comprise a p-doped GaN contact layer, a p-doped AlGaN electron blocking layer, an InAlGaN multi-quantum well (MQW) active region, an n-doped AlGaN current spreading layer, and an undoped AlGaN buffer. UV light is extracted through the transparent sapphire substrate and AlGaN buffer as well as current spreading layers. UV LED chips

were fabricated using photolithography and dry-etching techniques. Palladium was used to form the p-electrode metal contact while a Ti/Al/Mo/Au layer system was developed to form a low resistance n-electrode metal contact. Silicon nitride was deposited to passivate the chip surface. The chip emitting area has different geometries: multi-finger as well as micro-LED arrays were used to increase light extraction and to improve thermal management. Fig. 1 shows a UV LED chip with a micro-LED array recently fabricated at FBH.

A laser scribing and cleaving process was developed to obtain individual 1.0 mm x 0.6 mm LED chips. The chips are mounted on a high thermal conductivity aluminum nitride (AlN) submount in a flip-chip configuration, such that light can be extracted through the UV transparent sapphire substrate (see Fig. 2). This configuration has several advantages:

- the thermal management is superior since heat is conducted directly to the AlN submount, the LED can therefore be operated at higher currents,
- depending on the selected metal system for the p-contact it can be used as optical reflector which increases the total light output,
- there is no need to develop a p-electrode contact which is transparent in the UV range.

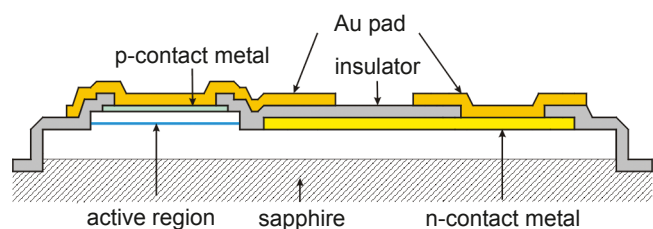
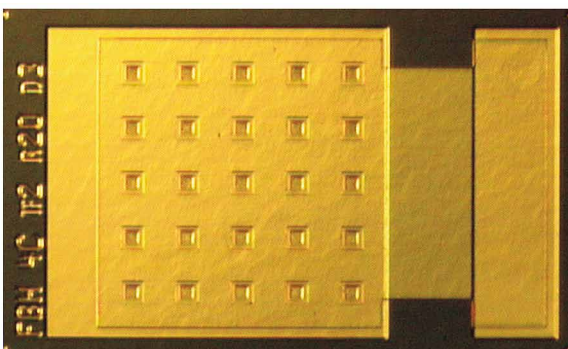


Fig. 1. Top-view of an LED chip with a 5 x 5 micro-LED array (left). Sketch of an LED chip in cross section (right).



Leuchtdioden (LEDs) auf der Basis von GaN, die im UV-A- und UV-B-Bereich emittieren, sind für zahlreiche Anwendungen von Interesse, beispielsweise für die Spektroskopie, zur Lichttherapie, zum Härten oder um gefälschte Banknoten zu identifizieren.

In Zusammenarbeit mit der TU Berlin hat das FBH Leuchtdioden mit einer Emissionswellenlänge von 380 bzw. 320 nm entwickelt. Für eine optimierte Lichtextraktion wurden verschiedene Chipdesigns wie Multifingerkontakte und Mikro-LED-Arrays verwendet. Mittels Laserstrahlen und Spalten wurden die Wafer in Einzelchips der

Größe 1,0 mm x 0,6 mm vereinzelt und anschließend für eine effiziente Wärmeextraktion in einer Flip-Chip-Konfiguration auf AlN-Submounts montiert. Das UV-Licht wird dann durch das transparente Saphir-Substrat und den AlGaIn-Puffer emittiert. Vergleicht man die Effizienzen der verschiedenen Chip-Designs bei hohen Strömen, so erweisen sich die Mikro-LED-Arrays als vorteilhaft. Erklären lässt sich dies durch die segmentierten Kontakte, die die laterale Strom einschnürung verringern und durch den erhöhten Umfang des Kontakts die Effizienz der lateralen Wärmeextraktion verbessern. ■

Fig. 3 shows emission spectra of UV-A and UV-B LED chips fabricated for on-wafer measurements and flip-chip mounting. The LEDs fabricated so far cover the wavelength range from 315 to 380 nm. Comparing the different chip designs at elevated currents the micro-LED arrays show higher efficiencies than LEDs with square-shaped or multifinger contacts. This effect can be attributed to a reduced lateral current crowding in strongly segmented contacts and a superior heat dissipation by an increased circumference of the contact.

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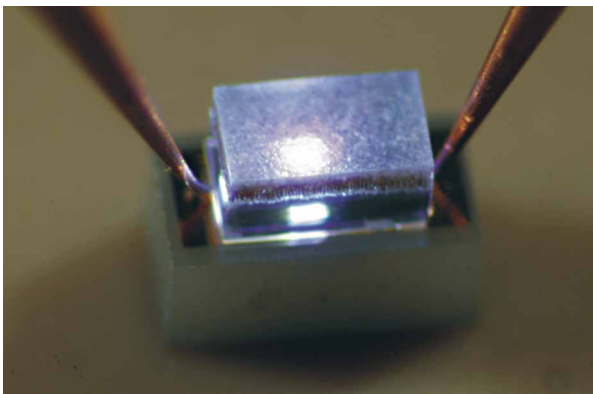


Fig. 2. LED chip mounted epi-side down onto an AlN submount and contacted by needles.

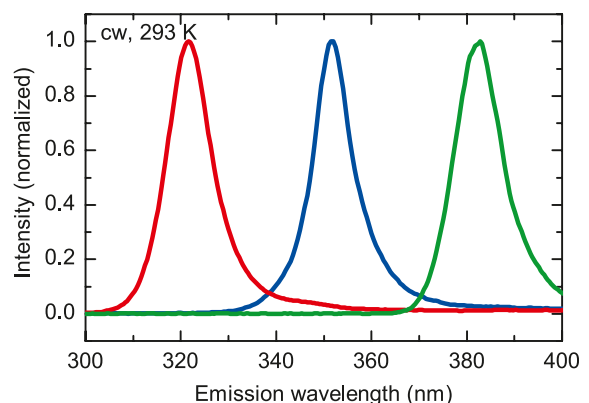


Fig. 3. Emission spectra of UV-A and UV-B LED chips.

Blue and green light emitting diodes on free-standing semipolar GaN

Light emitting diodes (LEDs) in the visible spectral range are of high importance for various applications like solid-state lighting, back illumination of LC displays and short-range data transfer in plastic optical fibers. In the past two decades, high-efficiency LEDs based on the InGaN material system with excellent device performance have been developed. Nevertheless, especially green and yellow emitters with high indium content in the InGaN active region suffer from poor external quantum efficiencies. One major culprit for these poor efficiencies is the presence of strong piezoelectric fields in the InGaN quantum well (QW) active region of light emitting diodes.

The polar *c*-plane (0001) is the standard crystal plane for epitaxial growth of GaN-based devices. Since the polarization fields are directed along the surface normal, they have maximum impact on the carrier recombination in the active region. By growing LED structures on other crystal planes than the *c*-plane, piezoelectric fields in the quantum wells can be reduced (semipolar planes) or even completely eliminated (nonpolar planes). This reduction of polarization fields increases the electron and hole wave function overlap in the active region and hence drastically enhances radiative recombination rates. Furthermore, the choice of the crystal plane also influences the indium incorporation efficiency during growth which allows to produce structures with high indium content for long wavelength

applications more easily. In order to limit spatial separation of the electron and hole wave function, InGaN quantum wells in the active region of light emitters on *c*-plane are normally less than 3 nm thick. In the case of nonpolar and semipolar devices, this constraint is relaxed and thicker wells are possible.

Within a collaboration of Ferdinand-Braun-Institut and Technische Universität Berlin, LED structures with 6.5 nm thick quantum wells have been grown by metal organic vapor phase epitaxy on semipolar (10 $\bar{1}$ 1) and (20 $\bar{2}$ 1) crystal orientations of bulk GaN substrates. The processing of LED chips from these samples (i.e., photo lithography, metallization and dry etching) poses various challenges due to the very small size of non-*c*-plane GaN substrates (typical 4 x 6 mm²). Therefore, special processing techniques like the mounting of samples on foreign carriers have been developed and LEDs with semitransparent top contacts have been fabricated.

The semipolar LEDs emit light from the near ultra violet (385 nm) through blue (435 nm) up to the green and even yellow region (480 - 580 nm) with emission powers in the milliwatt region as shown in Fig. 2. The spectra in Fig. 3 show that the emission peak broadens with increased indium content, which is attributed to non-optimized growth conditions for InGaN QWs on semipolar planes.

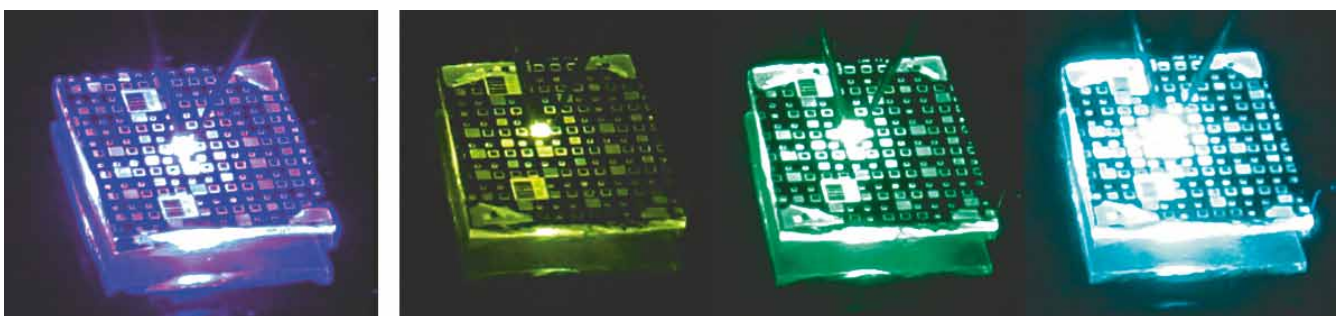


Fig. 1. LEDs on semipolar (20 $\bar{2}$ 1) substrates, left: 435 nm, 20 mA injection current, right: varying injection currents (5, 20 and 100 mA) result in strong blue shift, 490 - 580 nm.

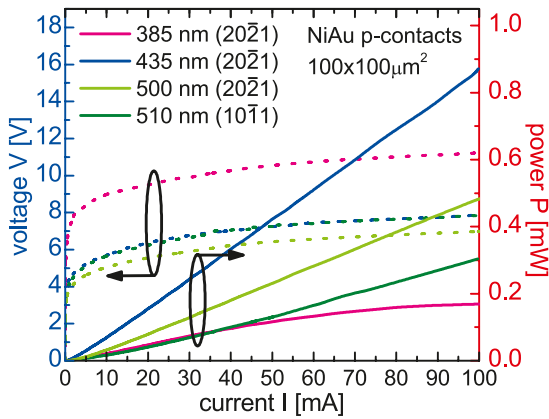


Fig. 2. Light output and voltage characteristics for semipolar LEDs.

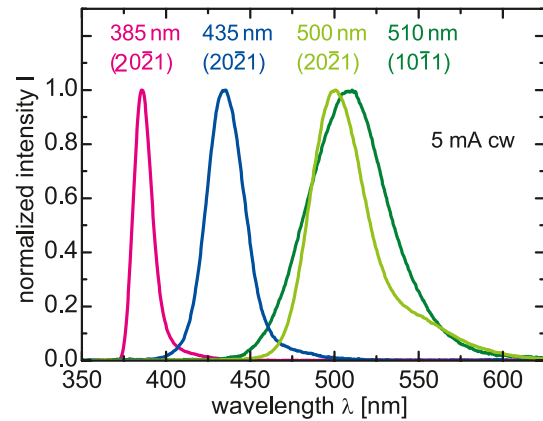


Fig. 3. Normalized emission spectra of semipolar LEDs at 5 mA.

When the current is raised, the peak wavelength shifts to shorter values (blue shift). In the case of green LEDs on the $(20\bar{2}1)$ plane, this leads to a change in the emission color from yellow to green (see Fig. 1). The blue shift for violet and blue LEDs is smaller which can be attributed to different origins: Polarization fields cause a shift to longer wavelengths (red shift) due to a triangular potential in the quantum wells which reduces the effective bandgap for carrier recombination. If carriers are injected, polarization charges are screened and polarization fields are reduced, resulting in a blue shift and an increase of radiative emission efficiency. However, in the case of semipolar substrates, this effect should be small. The second reason for the blue shift can be found in the non-uniformity of indium content and/or quantum well thickness: States in regions with high indium content are filled first with carriers. If the current is further increased, higher energy states in regions with lower indium content are populated and start to contribute to the light emission. Hence, the wavelength shifts to shorter values. Due to low fields in semipolar structures, it is expected that this band filling is the major cause for the wavelength shift.

In summary, semipolar LEDs with emission wavelengths from violet to blue and green-yellow have been produced and emission powers in the milliwatt region have been demonstrated. Although this is still lower than for comparable c-plane based structures, these initial experiments show that semipolar light emitters are viable candidates for high-efficiency LEDs and laser diodes, particularly in the blue and green spectral range.

Publications

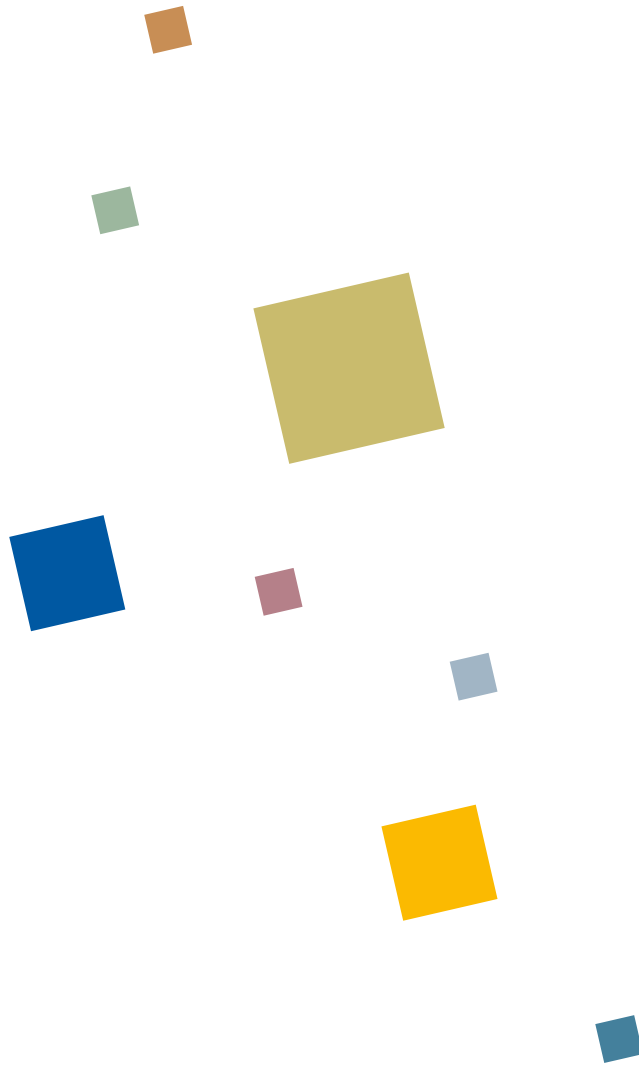
J. Raß, T. Wernicke, R. Kremzow, W. John, S. Einfeldt, P. Vogt, M. Weyers, M. Kneissl, "Facet formation for laser diodes on nonpolar and semipolar GaN", *phys. stat. sol. (a)* 207, 1361 (2010).

T. Wernicke, S. Ploch, V. Hoffmann, A. Knauer, M. Weyers, M. Kneissl, "Surface morphology of homoepitaxial GaN grown on non and semipolar GaN substrates", *phys. stat. sol. (b)* 248, 574 (2011).



Leuchtdioden im sichtbaren Spektralbereich werden unter anderem zur allgemeinen Beleuchtung, Hintergrundbeleuchtung von Flachbildschirmen und Datenübertragung in Kunststofffasern eingesetzt. Leistungsfähige LEDs sind zwar verfügbar, jedoch ist die Effizienz insbesondere von grün und gelb emittierenden Dioden auf der polaren c-Ebene durch interne elektrische Polarisationsfelder nach wie vor gering. Durch Wachstum der Halbleiterstruktur auf nichtpolaren und semipolaren Ebenen werden die Felder stark reduziert oder sogar eliminiert, wodurch die Effizienz steigt.

In Kooperation mit der Technischen Universität Berlin wurden LEDs mit Wellenlängen vom ultravioletten (385 nm) über blau (435 nm) bis zum grün-gelben Spektralbereich (480-580 nm) auf semipolaren $(10\bar{1}1)$ und $(20\bar{2}1)$ -Ebenen hergestellt. Diese zeigen optische Ausgangsleistungen im Milliwatt-Bereich und das grundsätzliche Potenzial semipolarer Emmitter für Hochleistungs-LEDs und Laserdioden, insbesondere für den blauen und grünen Spektralbereich. ■



BUSINESS AREAS & RESEARCH

Materials & Processes » Materialien & Prozesse

GESCHÄFTSBEREICHE & FORSCHUNG



Materialien & Prozesse



Der Schwerpunkt der Aktivitäten in Technologieentwicklung und Materialforschung am FBH liegt mittlerweile bei den Gruppe-III-Nitriden. Es wird jedoch weiter intensiv daran gearbeitet, die Effizienz und die spektralen Eigenschaften von Laserdioden auf dem etablierten und gut beherrschten Galliumarsenid (GaAs) zu verbessern. Bei den Galliumnitrid (GaN)-Bauelementen konzentrieren sich die Aktivitäten auf Leistungsbaulemente für Mikrowellen- und Leistungs-Schaltanwendungen, UV-LEDs, Laserdioden und jetzt auch UV-Photodetektoren. Die umfassenden Aktivitäten der Abteilungen Material- und Prozesstechnologie liefern dabei die technologischen Voraussetzungen für gezielte Entwicklungen von Bauelementen, die später in den jeweiligen Geschäftsbereichen realisiert werden.

Beispiele dafür sind die Schichtentwicklungen für GaN-basierte Hochvolt-Leistungstransistoren sowie die Epitaxie von Ga(In)N-Schichtstrukturen mit nichtpolarer Orientierung, die effizientere blaue und grüne Laserdioden ermöglichen. Ebenso wird an defektarmen AlN-Schichten als Grundlage für ultraviolette Leuchtdioden geforscht. Von zentraler Bedeutung, insbesondere für GaN-basierte Laserdioden, sind entsprechende Substrate mit geringer Defektdichte. Diese werden am FBH mittels Hydride Vapor Phase Epitaxy (HVPE) hergestellt. Neu begonnen wurden Arbeiten zu (Al)GaN-basierten Photodetektoren mit dem Ziel der Bauelemententwicklung sowie für den Einsatz als Werkzeug zur Materialcharakterisierung. Um diese Vielfalt an Aufgaben bei der Herstellung von nitridischen Epitaxieschichten effizient bearbeiten zu können, wurde eine weitere Mehrscheiben-Epitaxieanlage (AIX 2600 G3 HT) installiert. Damit können insbesondere Prozesse für bipolare Bauelemente mit p-Dotierung (LEDs, Laserdioden) von solchen für unipolare Bauelemente (GaN-HFETs, Photodetektoren) getrennt bearbeitet werden.

Im Bereich der Prozesstechnologie konzentrierten sich die Arbeiten auf die Entwicklung von robusten Prozessmodulen für die Fertigung von GaN-basierten Hochleistungstransistoren mit „Embedded“ oder „Recessed Gates“. Die Inbetriebnahme der neuen Elektronenstrahl-Belichtungsanlage und des neuen „Soak“ Lift-Off-Prozessors ermöglicht nun am FBH Gatestrukturen mit Abmessungen ≤ 250 nm mit hoher Reproduzierbarkeit. Die Installation eines neuen Belackungs- und Entwicklungsautomaten ergänzt die Anlagen-Modernisierung in der Lithographie. Bei UV-LEDs und Lasern auf GaN-Basis steht die Entwicklung von Trockenätzverfahren und geeigneten Ohm'schen Kontakten zu p-GaN und n-AlGaIn im Vordergrund. Außerdem wurden Ätzverfahren zur Herstellung von Gitterstrukturen für GaAs-basierte Laser weiterentwickelt.

Basierend auf dem existierenden Herstellungsprozess (vgl. Jahresbericht 2007) wurden im vergangenen Jahr neue Entwicklungen für InP-basierte HBTs in Transfer-Substrat-Technologie gestartet. Diese adressieren z. B. Anwendungen für bildgebende Verfahren bei 70 - 300 GHz. Im Rahmen eines Verbundprojektes begannen am FBH erstmals Arbeiten zur Prozessierung und zum thermischen Management von Terahertz-Quantenkaskadenlasern. Die Laser, die auf GaAs/AlGaAs-Heterostrukturen vom Paul-Drude-Institut basieren, sind für spektroskopische Anwendungen vorgesehen. Die F&E-Kooperation zur Herstellung von UV-Photodetektoren auf Basis von Siliziumkarbid (SiC) wurde erfolgreich fortgesetzt. Darüber hinaus laufen weiterhin externe Dienstleistungen wie Lieferung von Epitaxiewafern, Analytik von Schicht- und Bauelementstrukturen sowie Waferprozesse für Kunden aus Forschung und Industrie.

Materials & Processes

The FBH has continued to shift its focus from well established GaAs technologies to group-III nitrides. However, increasing efficiency and spectral properties of GaAs laser diodes are aims which are still intensely pursued. In the field of gallium nitride (GaN) devices, work is focused on power transistors for microwave and power switching applications as well as laser diodes and UV LEDs. The Materials Technology and Process Technology Departments provide the technological preconditions for the development of devices that are realized in the respective business areas.

Examples are the development of epitaxial layers for GaN power transistors for high operating voltages as well as growth of Ga(In)N heterostructures with nonpolar orientation paving the way for more efficient blue and green laser diodes. Also AlN layers with reduced defect density for UV LEDs are being developed. Especially for GaN-based laser diodes, substrates with low defect density are of pivotal importance. At FBH, such substrates are developed using hydride vapor phase epitaxy (HVPE). (Al)GaN photodetectors, both as device and as tool for the characterization of epitaxial layers, are a new research topic.

In device processing, activities were focused on the development of robust and reliable process modules for fabrication of GaN-based high-power transistors with “embedded” and “recessed” gates. The installation and commissioning of a new electron beam exposure system and a new “soak” lift-off processor enables FBH to reproducibly fabricate gates with ≤ 250 nm dimension. A new coater and developer tool has been set up, complementing and updating our lithography facilities. Regarding UV LEDs and GaN laser diodes, the development of dry etching processes and the ohmic contact formation to p-GaN and n-AlGaN were in focus. Efforts have been made to further optimize the fabrication of gratings in order to stabilize the wavelength of GaAs laser diodes.

Based on an existing transferred substrate technology (see annual report 2007), processing of InP-based HBTs has been re-established last year. These devices address e.g., imaging applications at 70-300 GHz. For the first time, FBH has started activities in processing and thermal management of terahertz quantum cascade lasers within a joint research project. These lasers, that are built on GaAs/AlGaAs heterostructures grown at Paul-Drude-Institute, are targeted for spectroscopic applications. The research cooperation on fabrication of UV photo detectors based on SiC has successfully been continued. 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 fields.

New electron beam lithography for direct writing applications with highest precision

Continuous upgrading of technical equipment is a vital precondition to process state-of-the-art semiconductor devices. To meet the ongoing challenges in device development and the needs of partners from research and industry, it is of strategic importance for FBH to keep its equipment up-to-date and compatible with industry standards. In this context, FBH purchased a new electron beam exposure system (e-beam) that allows a reliable and reproducible technology for sub-micron structures. The new tool is primarily dedicated to manufacture high-power GaN-based transistors, innovative microwave components, single-mode diode lasers, and photomasks. Besides, the e-beam will also be used to generate nanostructures for explorative research and common projects with research and industrial partners.

The production-type though versatile e-beam exposure system was delivered by Vistec Electron Beam GmbH in December 2009. Vistec's SB251 system (Fig. 1) features

a variable-shaped beam, vector scan and continuously moving stage ("write-on-the-fly") technology and allows direct write applications on up to 200 mm wafers. An advanced 50 kV electron optics provides a maximum current density of 20 A/cm². System specifications include a minimum feature size of ≤ 50 nm (isolated line in resist), direct write overlay accuracy of $(3 \sigma) \leq 30$ nm and stitching accuracy of 30 nm (maximum deviation). Especially the high overlay accuracy leads to a major enhancement of FBH's processing capabilities. A further essential advantage for our technology is the fast interchange between wafers with different diameters as well as wafer pieces (halves, quarters) and the electrostatic wafer chuck that flattens warped wafers.

Before move-in of the e-beam system, very demanding installation requirements concerning temperature stability, magnetic disturbances, and mechanical vibrations had to be ensured at the installation site in the cleanroom. To

prepare the environmental conditions, substantial reconstruction took place already in fall 2009, requiring a complete shut-down of the cleanroom to build a new foundation and to modernize the air-conditioning system.



Fig. 1. Electron Beam Exposure Tool SB251.

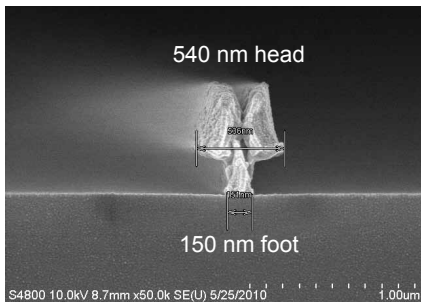


Fig. 2. T-gate with 150 nm foot width generated with direct write e-beam lithography.

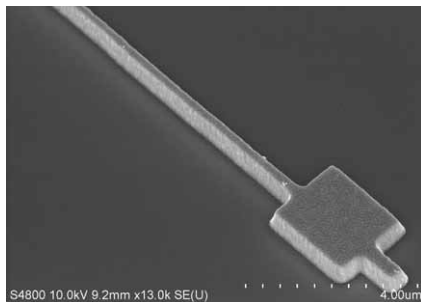


Fig. 3. Detail of a 250 nm box gate.

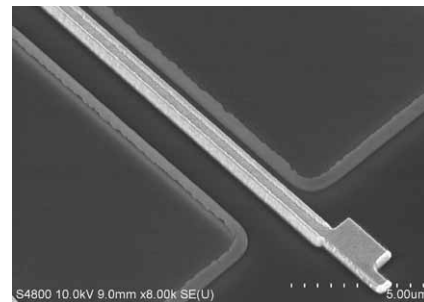


Fig. 4. Detail of an embedded gate with 250 nm foot width.

After passing all standard acceptance tests in April 2010, the new e-beam has already been used for photomask writing. In June 2010, the SB251 also passed all FBH-specific acceptance tests in due time. These tests demonstrated the capability of the system for gate technologies of high-power transistors and for grating technologies of semiconductor lasers. Based upon FBH's technology, 50 nm wide metal lines were generated by metal lift-off, and T-gates with a foot width of 150 nm were demonstrated (Fig. 2). Phase gratings with 70 nm line width (lines and spaces) were processed using one of FBH's standard resist processes. The new e-beam provides an essential pre-condition to realize sub-micron dimensions. However, in e-beam lithography further important process steps are involved such as resist processing, etching, metallization and metal lift-off.

Main functional elements of each microwave transistor are gates formed by long, narrow metal stripes at the surface of the semiconductor. They are among the most delicate structures being produced at FBH. A crucial step to finally form the structures is the metal lift-off process. During this step, the resist is removed by means of special solvents that also take off the additional metal. In today's standard lift-off processors a solvent is sprayed under constant pressure

on the surface of the wafer. Soaking and lifting are accomplished in one step. During such type of metal lift-off the delicate gate structures could easily be torn off or damaged by smallest metal pieces, leading to a malfunction of the device. Gate structures of 500 nm down to 250 nm have been sufficient so far. However, latest developments of innovative microwave components suitable for highest frequencies require metal stripe widths far below 250 nm at a length of 125 μm .

In order to increase reproducibility and throughput, we have recently taken a new automatic lift-off processor into operation that allows us to lift-off delicate structures very gently. This soak lift-off processor separates soaking from lifting. After soaking the wafer with the resist in a soak chamber, a lift-off step follows in a spray and rinse chamber. Compared to standard lift-off processors, the chamber has several nozzles with different spray characteristics, allowing us to tailor lift-off process conditions very precisely to the delicate structures. With this process, 250 nm gate structures were successfully lifted at a very high quality (see Fig. 3 and 4). We just recently started to transform and to qualify the new lift-off technique for our device processes and developments.



Ende 2009 wurde eine neue Elektronenstrahl-Belichtungsanlage (E-Beam) zur Herstellung von Sub-Mikrometerstrukturen für Hochleistungs-Transistoren und -Laser geliefert. Das VISTEC-Belichtungssystem SB251 erfüllte im April 2010 die Standard-Abnahmetests. Insbesondere die hohe Justier- und Positioniergenauigkeit verbunden mit einer hohen Prozessstabilität und Reproduzierbarkeit erweitern die Möglichkeiten am FBH deutlich. Der variable Formstrahler erlaubt die Direktbelichtung auf bis zu 200 mm Wafern. Eine moderne 50 kV Elektronenoptik liefert eine Maximalstromdichte von 20 A/cm². Die Systemspezifikationen sind u.a. eine Auflösung von ≤ 50 nm (isolierte Linie in Lack), eine

Überdeckungsgenauigkeit von ≤ 30 nm und ein Versatz zwischen den Bearbeitungsfeldern von max. 30 nm.

Im Juni 2010 wurde die Leistungsfähigkeit der Anlage in kundenspezifischen Abnahmetests nachgewiesen und Phasengitter mit 70 nm Linienbreite („lines and spaces“) mittels Standard-Lackprozessen des FBH hergestellt. Außerdem wurden 50 nm breite Metallstreifen sowie T-Gates mit Fußbreiten von 150 nm durch Metall-Lift-Off erzeugt. Die Beschaffung eines modernen Lift-Off-Prozessors, der eine besonders schonende und reproduzierbare Erzeugung der empfindlichen 250 nm Gates ermöglicht, vervollständigt die Modernisierung der E-Beam-Lithographie. ■

Boule-like growth of GaN by HVPE

Blue-violet laser diodes are increasingly utilized in data storage devices (“blue ray disc”) and new technologies like RGB-laser projection. Moreover, ultra-high brightness LEDs are used in solid-state lighting, and fast high-power switches, which are required, for example, in electrically powered (green) cars, are currently under development. These technologies all base on high-end group III-nitride devices, and their realization requires or can essentially profit from growth on native GaN substrates.

Hydride vapor phase epitaxy (HVPE) of GaN is an established method towards high-quality GaN substrates since they can not yet be produced by usual 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 (NH₃). The technique provides a sufficiently high growth rate and good scalability. From the device point of view, a very low threading dislocation density (TDD) and a high thermal conductivity of the substrate are strongly desired.

In order to take full economic and technical benefit from the HVPE method, leading manufacturers currently switch 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 machine. The most challenging part consisted in the development of growth procedures to prepare boule-like GaN crystals of about 50 mm in diameter and a length of several mm. This task included the investigation and development of starting GaN seed layers grown on sapphire by metal organic vapor phase epitaxy (MOVPE) as well as comprehensive parameter studies to optimize the growth conditions in HVPE to achieve boule-like GaN growth. Still, not all issues have been solved, but the current process provides already GaN-boules exceeding 6 mm using a growth rate of 450 μm/h (Fig. 1). Such a crystal thickness has been shown by some manufacturers of GaN substrates, but has been achieved at considerably lower and therefore less economical growth rates of only 100 μm/h. A further increase in crystal thickness requires improvements of the surface morphology and, simultaneously, avoidance of cracking. Parallel to such progress, it has to be assured that the structural properties

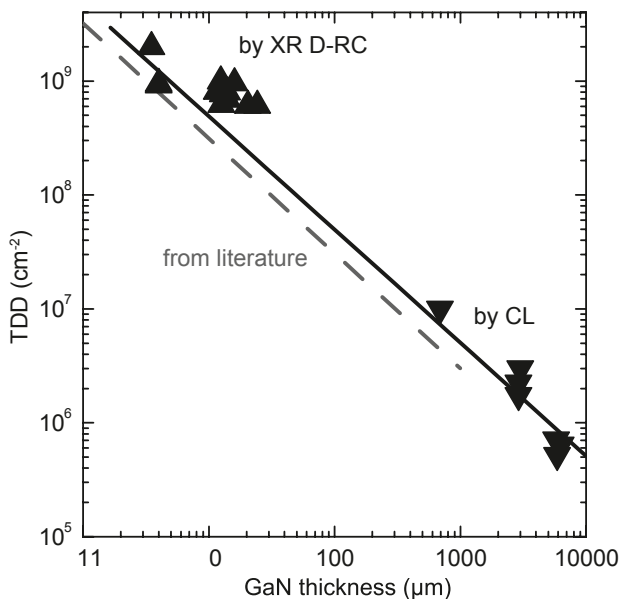


Fig. 2. Threading dislocation density vs. increasing thickness of the GaN layer as determined by x-ray diffraction (XRD) and cathodoluminescence (CL). The broken line corresponds to literature [Jasinski et al. J. Electr. Mat. 31, 429,(2002)].

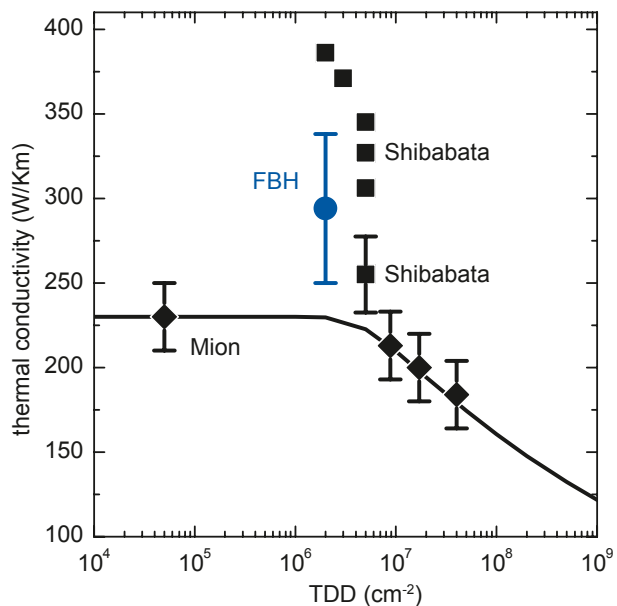


Fig. 3. Thermal conductivity of GaN vs. threading dislocation density. The measurement was performed at Fraunhofer IKTS Dresden. Other values correspond to [Mion et al., Appl. Phys. Lett. 89, 092123, (2006), Shibata et al., Mat. Transact. 48, 2782, (2007) and US 2009/0081110 A1 (2009)].



Fig. 1. GaN boule of 6.3 mm thickness grown within 14 hours at a growth rate of 450 $\mu\text{m}/\text{h}$.

do not degrade. TDD, i.e. the density of dislocations which terminate at the surface, and thermal conductivity are suitable figures of merit for the material quality. The TDD is shown (Fig. 2) to continuously decrease with the GaN layer thickness due to mutual dislocation annihilation. Values far below 10^6 cm^{-2} have been achieved. The thermal conductivity of the obtained GaN material is among the best ever reported results and about 70% of the theoretical upper limit (Fig. 3).

The FBH collaborates with the commercial substrate manufacturer Freiburger Compound Materials and supplies GaN boules for the development of substrate preparation processes. Parts of these research activities at FBH were funded by the Federal Ministry of Education and Research.

Publications

E. Richter, U. Zeimer, F. Brunner, S. Hagedorn, M. Weyers, G. Tränkle, "Boule-like growth of GaN by HVPE", Phys. Stat. Sol. C 7, 28-31 (2010).

E. Richter, U. Zeimer, S. Hagedorn, M. Wagner, F. Brunner, M. Weyers, G. Tränkle, "Hydride vapor phase epitaxy of GaN boules using high growth rates", J. Cryst. Growth 312, 2537-2541 (2010).



Blau-violette Diodenlaser werden in Datenspeichersystemen oder in der Laserprojektion verwendet, während superhelle LEDs und Leistungsschalter aktuelle Forschungsthemen für Beleuchtung und Elektroautos sind. Solche Bauteile erfordern GaN-Substrate, die mit gängigen Kristallzüchtungsmethoden bisher nicht herstellbar sind.

Die Hydridgasphasenepitaxie (HVPE) bietet hohe Wachstumsraten und wird für die Herstellung dicker GaN-Schichten eingesetzt, die dann jeweils ein Substrat darstellen. Da die Versetzungsdichte aber noch relativ hoch ist, wird weltweit an HVPE-Prozessen zur Erzeugung mehrerer mm dicker, schneidbarer Kristalle mit geringerer Versetzungsdichte gearbeitet.

Das FBH hat die Entwicklung eines dafür geeigneten vertikalen HVPE-Reaktors durch AIXTRON unterstützt und Prozesse für 6 mm dicke GaN Kristalle mit 50 mm Durchmesser entwickelt. Die Wachstumsrate liegt bei 450 $\mu\text{m}/\text{h}$, wobei niedrige Versetzungsdichten $< 10^6 \text{ cm}^{-2}$ und hohe thermische Leitfähigkeiten erzielt werden. ■

Bow engineering of AlGaIn-GaN HFETs using an award-winning in-situ metrology system

GaN-based heterostructure field effect transistors (HFETs) increasingly gain market share in microwave high-power applications. Despite significant progress in device performance, issues like reliability and price competitiveness remain to be solved. For the latter, scaling to larger substrate diameters is important in order to reduce cost per die. The growth of GaN device structures on SiC substrates introduces wafer bow which increases with substrate size. This degrades layer uniformity and manufacturing yield. Excessive substrate curvature may even result in rejection of the wafers by optical lithography tools. Wafer bowing has also a huge impact on wavelength homogeneity of InGaIn-based light emitters due to the strong temperature dependence of the indium incorporation during epitaxy.

In order to separate different stress components during metalorganic vapor phase epitaxy (MOVPE),

an in-situ curvature measurement system is indispensable. At Ferdinand-Braun-Institut, the wafer bow sensor EpiCurveTT from the Berlin company LayTec is used to monitor strain evolution during nitride epitaxy. The sensor is a combination of three different measurement techniques: multi-wavelength reflectometer, emissivity-corrected pyrometer and wafer bowing deflectometer. The latest generation of EpiCurve sensors (Fig. 2) features three 405 nm laser spots averaging curvature values in different directions enabling a resolution of $\pm 1 \text{ km}^{-1}$. Successive field testing of different EpiCurveTT prototypes at the FBH along with the sensor development at LayTec has now been awarded with the "Science Creates Jobs 2010" prize. Out of the 35 applicants for this technology transfer award (www.wissenschafttarbeit.de), LayTec's EpiCurveTT development project was recognized by the jury as the most relevant technological breakthrough and economic success.

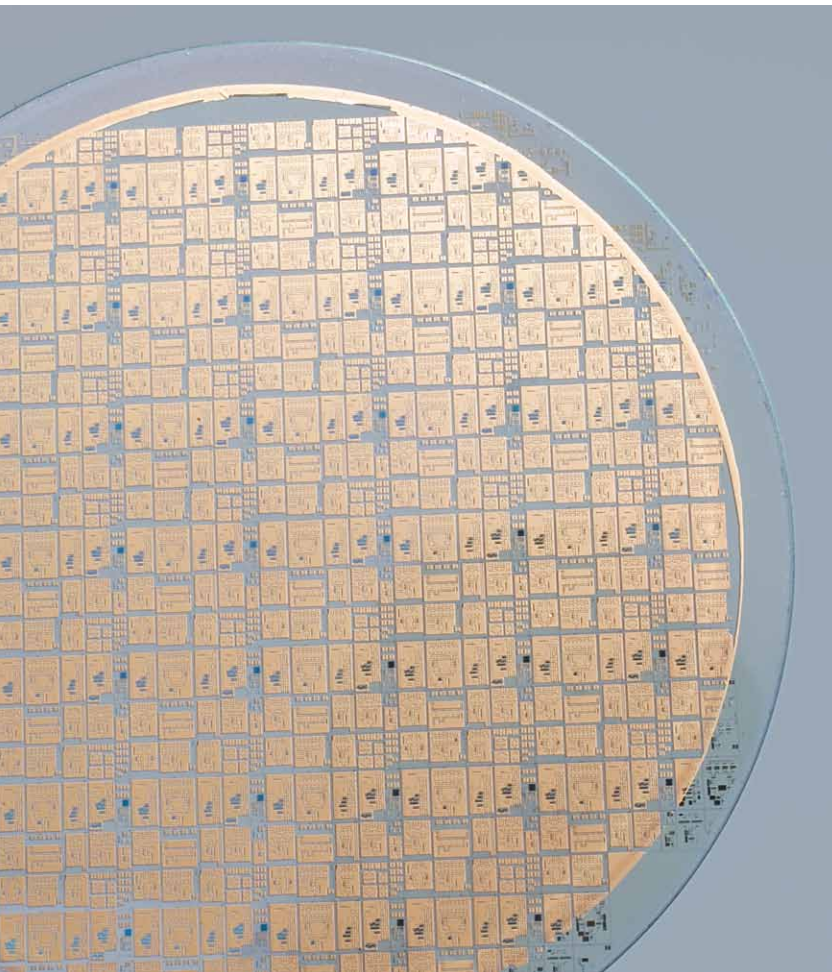


Fig. 1. Processed 3 inch SiC wafer with AlGaIn-GaN HFET device structure.

Fig. 3 shows an example of bow optimization for the growth of an AlGaIn-GaN HFET structure on 3 inch SiC. Keeping the layer structure the same, only the growth of the AlN wetting layer on the SiC substrate has been changed. Fig. 3 (lower part) shows the development of wafer bow during the growth. The obvious difference in curvature slope starts with the GaN buffer growth on top of the differently grown AlN wetting layer. The initial growth of the GaN(0001) layer on AlN(0001) occurs via coalescence of three-dimensional islands, which affects strain and density of threading dislocation in the GaN buffer. A fast coalescence of small strained islands preserves a higher compressive strain during GaN-on-AlN growth. In contrast, a slow coalescence of larger and more relaxed islands is followed by a low-strain growth mode resulting in an overall lower bow after growth of the complete structure. During cooling, the convex wafer bow is reversed due to the higher thermal expansion coefficient of GaN compared to SiC. While this yields a remaining convex bow of more than $40 \mu\text{m}$ in case of the non-optimized recipe, the wafer curvature of the low-strain GaN buffer is nearly compensated after cooling down.

These differences in the coalescence process are visible in the 405 nm reflectance signal (Fig. 3 upper part). While the surface-sensitive reflectance

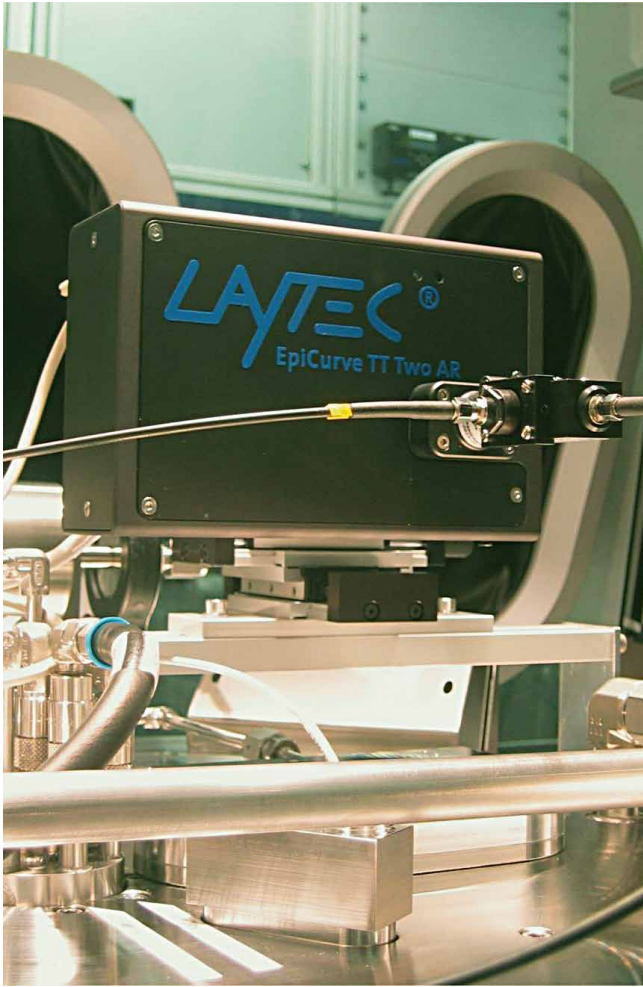


Fig. 2. EpiCurveTT-Blue sensor head installed on the lid of the MOVPE reactor.

shows clear Fabry-Perot oscillations from the very beginning of growth in the case of the high-bow recipe, it is largely damped at the GaN growth start during the low-bow run. This indicates a higher initial GaN surface roughness as a result of a prolonged three-dimensional island growth mode in case of the low-bow recipe which is confirmed by atomic force microscopy (AFM) measurements.

Using in-situ monitoring, an optimization of the growth process for a given layer sequence was possible resulting in wafers that can be processed by stepper lithography with high yield.

Publications

F. Brunner, O. Reentilä, J. Würfl, M. Weyers, "Strain engineering of AlGaIn-GaN HFETs grown on 3 inch 4H-SiC", Phys. Status Solidi C 6, No. 5 2, 1065 - 1068 (2009).

V. Hoffmann, A. Knauer, F. Brunner, S. Einfeldt, M. Weyers, G. Tränkle, K. Haberland, J.-T. Zettler, M. Kneissl, "Uniformity of the wafer surface temperature during MOVPE growth of GaN-based laser diode structures on GaN and sapphire substrate", J. Cryst. Growth, in press (2011).



GaN-basierte Heterostruktur-Feldeffekttransistoren sind wichtige Komponenten für die wachsenden Märkte mikrowellenbasierter Hochleistungs-Anwendungen. Beim Wachstum der HFET-Schichtstrukturen auf SiC-Substraten kommt es jedoch zu einer Verbiegung, die mit dem Durchmesser zunimmt. Dies führt zu Inhomogenitäten von Schichtparametern aber auch zu Problemen bei der Weiterverarbeitung wie etwa der optischen Lithografie. Eine Reduktion der Verbiegung ist daher unverzichtbar für die kostengünstige Fertigung auf großen Durchmessern.

Zur Trennung verschiedener Verspannungsanteile bei der metallorganischen Gasphasenepitaxie nutzt das FBH den Krümmungssensor EpiCurveTT der Firma LayTec. Der in-situ Sensor kombiniert die Waferkrümmungsmessung mit Reflexionsmessungen und emissivitätskorrigierter Pyrometrie. Für seinen Beitrag bei der Sensorentwicklung wurde das FBH anteilig mit dem Technologie-Transferpreis „wissen schafft.arbeit 2010“ ausgezeichnet.

Anhand von zwei nominell gleichen HFET-Strukturen auf 3 Zoll SiC wird die Waferkrümmung beispielhaft gezeigt. Unterschiede werden mit Einsetzen des GaN-Wachstums auf der optimierten AlN-Startschicht sichtbar. Die verringerte Waferkrümmung wird durch das anfänglich stärker ausgeprägte Inselwachstum der GaN-Schicht befördert. Die mit dem verlängerten Inselwachstum einhergehende verzögerte Schichtkoaleszenz führt zu einer Verspannungsreduktion und damit einem nahezu flachen Wafer nach der Abkühlung, der problemlos prozessiert werden kann. ■

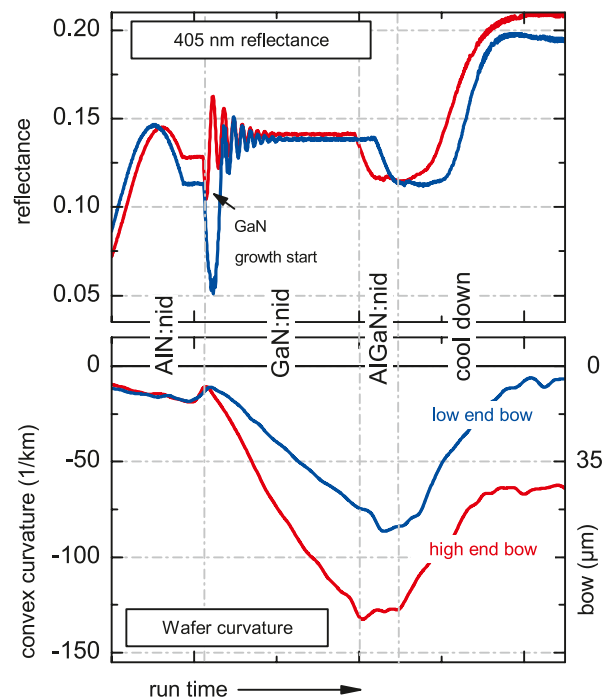


Fig. 3. Transients of reflectance at 405 nm (upper part) and curvature (lower part) during growth of an AlGaIn/GaN transistor heterostructure.

GaN-based UV photodetectors for monitoring applications

Photodetectors for the UV spectral region are required to control high-power UV lamps, UV LEDs and excimer lasers. Such detectors are used in UV lithography, for disinfection (sterilization of air and water) and medical applications like treatment of psoriasis. Due to their direct bandgap, nitride-based devices are highly promising for wavelength-specific detectors that are blind in the visible region. They can be tuned by composition and offer the possibility to incorporate heterojunctions. Based on FBH's expertise in nitride-based devices, the institute has extended its activities beyond transistors, LEDs and laser diodes to UV photodetectors. These devices are developed in cooperation with JENOPTIK Polymer Systems GmbH (JOPS) and TU Berlin.

GaN-based UV photodetectors can be designed with lateral current path as MSM (metal-semiconductor-metal) detectors. These straightforward devices with only two back-to-back Schottky contacts on an either non-intentionally doped (nid) or lowly-doped absorber layer (see Fig. 1a) promise tailored spectral responsivity and short switching times. An additional AlGaN cap layer can provide a further

barrier to reduce the dark current and allows to use ohmic contacts. Schottky detectors with a thin semi-transparent Schottky contact feature a vertical current path. Here, n-doped layers are necessary (see Fig. 1b) to realize the ohmic backside contact. These devices offer low dark current, high responsivity and the advantage of bias-free operation.

MSM photodetectors with different absorber compositions were realized at the FBH on sapphire substrates. Fig. 2 shows a light microscope image of GaN MSM photodetectors with various designs. The responsivity spectra of detectors with different absorber layers are presented in Fig. 3. For GaN the responsivity has its maximum at 364 nm. The cut-off wavelength is 366 nm. Due to internal gain, the GaN MSM detectors show a very high responsivity of 16 A/mW. Transient effects are observed when switching the illumination on and off (persistent photo conductivity – PPC). Such transients result from charging/ decharging of traps in the material and offer a means for the study of material properties. Beyond photodetectors, these traps are also relevant in devices such as GaN-based transistors, where they yield the desired high-resistivity buffers but can also cause unwanted dispersion.

The addition of aluminum into the absorber shifts the responsivity spectrum to the blue. Adding 20% aluminum results in a cut-off wavelength of 316 nm. The UV/VIS contrast is higher than 10^3 for AlGaN. When indium is added the cut-off wavelength shifts to the red. The InGaN absorber with 11% indium shows a cut-off wavelength of 445 nm. For the InGaN absorber the UV/VIS contrast is lower than for GaN and AlGaN due to the material's

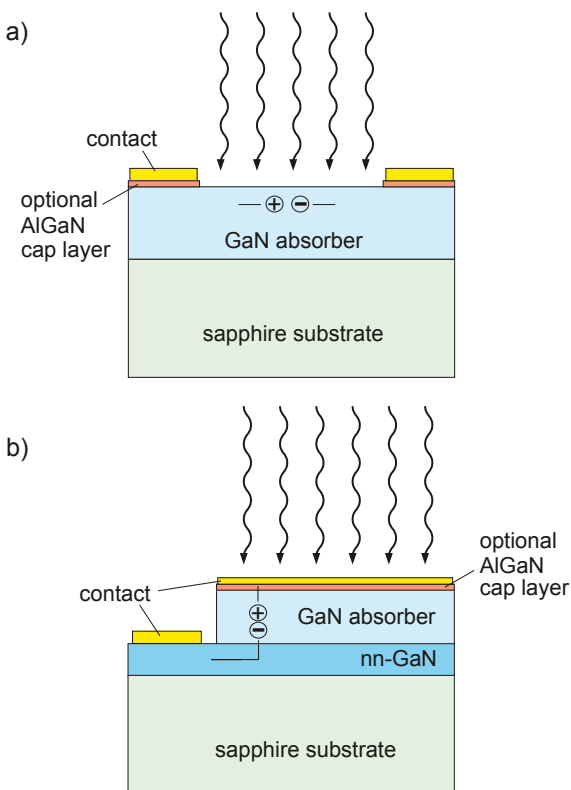


Fig. 1. Sketch of a) MSM and b) Schottky photodetector with GaN absorber.

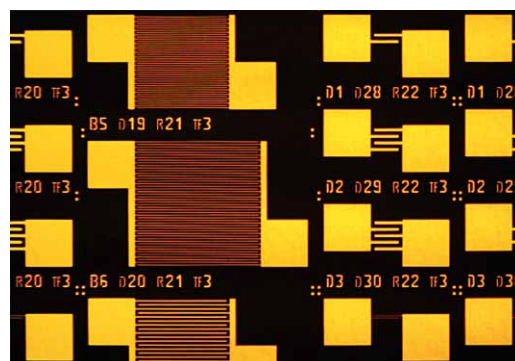


Fig. 2. Light microscope image of GaN MSM photodetector with various designs.

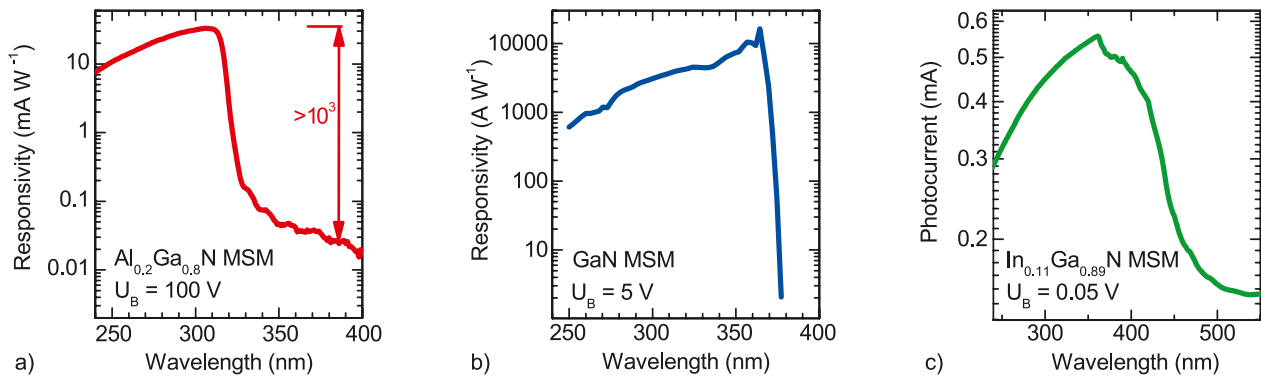


Fig. 3. Responsivity spectra of a) MSM photodetectors with $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ and b) GaN absorbers and c) photocurrent spectrum of a photodetector with $\text{In}_{0.11}\text{Ga}_{0.89}\text{N}$ absorber (@0.1 μW incident power).

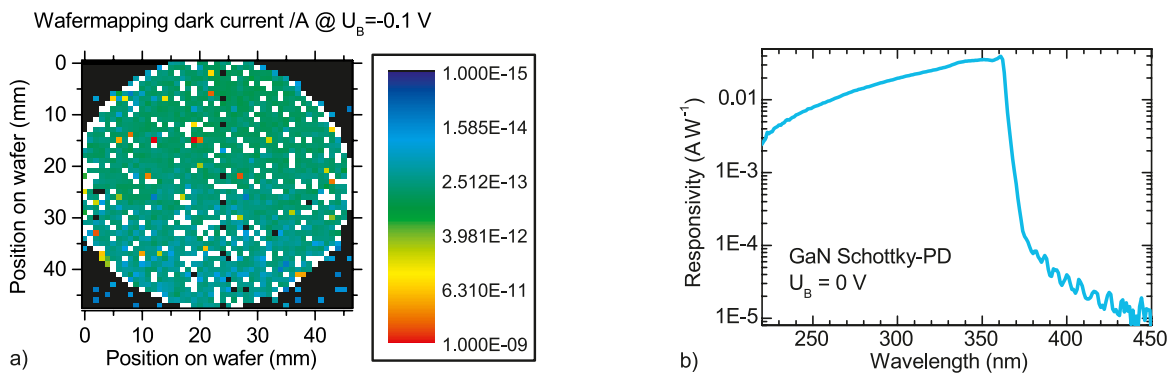


Fig. 4. GaN Schottky detector: a) dark current (map provided by JOPS) and b) spectral responsivity (measured at TU Berlin).

susceptibility for defect formation. This leads to higher dark current levels. However, a maximum responsivity of about 0.6 mA/W was still achieved for this detector. This value was determined from the corrected photocurrent, from which the dark current was subtracted.

Schottky detectors with GaN absorbers were realized together with the project partner JOPS based on epitaxial layers from FBH. First photodetectors with n-doped GaN absorbers showed average dark currents of about 30 pA at -0.1 V bias for devices with an effective detector area of about 0.45 mm^2 . Without bias voltage the maximum responsivity was about 28 mA/W for wavelengths between 335 nm and 356 nm. By optimizing the growth of the

absorber layer in order to reduce the density of midgap traps, the dark current decreased to about 4 pA and the responsivity increased to 40 mA/W (see Fig. 4). Therefore, the GaN Schottky detectors show state-of-the-art dark current while the responsivity needs further improvement. The GaN-based photodetector activities are funded by the State of Berlin within a PROFIT project and the BMBF within the Berlin WideBaSe initiative.

Publication

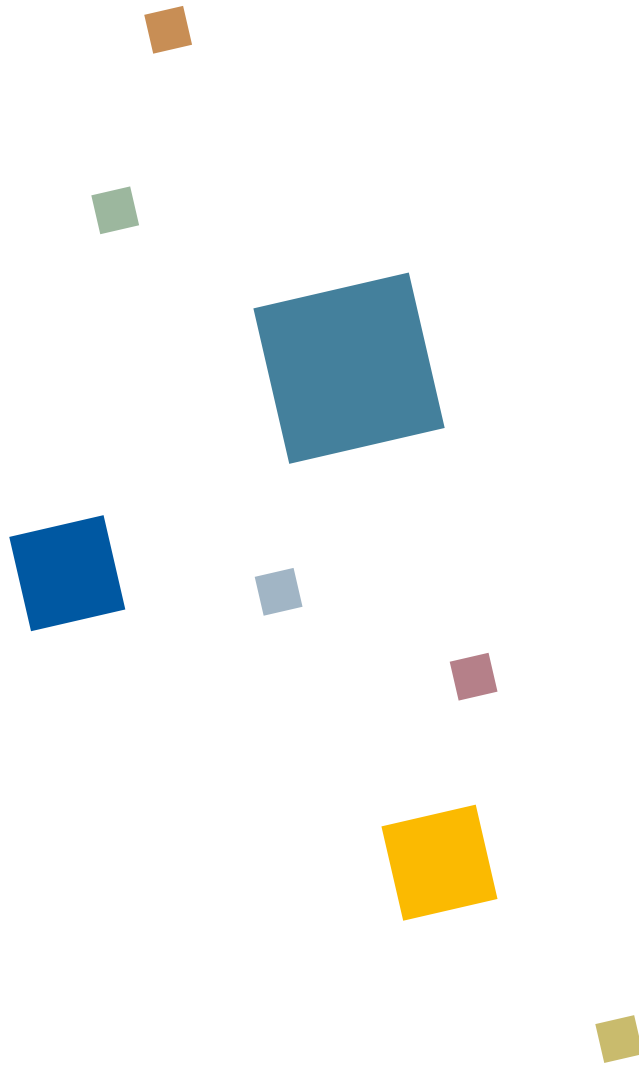
M. Martens, J. Schlegel, P. Vogt, F. Brunner, R. Lossy, J. Würfl, M. Weyers, M. Kneissl, "High gain UV photodetector based on AlGaN/GaN heterostructure for optical switching", to be published (2011).

UV-Photodetektoren auf der Basis von GaN sollen zur Überwachung von Hochleistungs-UV-Lampen, -LEDs und Excimerlasern eingesetzt werden. Das Materialsystem AlInGaN hat eine direkte Bandlücke, welche sich zudem über die Komposition anpassen lässt. Es zeichnet sich durch Unempfindlichkeit im sichtbaren Bereich und eine hohe Strahlungsfestigkeit aus. In Zusammenarbeit mit JENOPTIK Polymer Systems GmbH (JOPS) und der TU Berlin entwickelt das FBH MSM- und Schottky-Detektoren.

Mit am FBH hergestellten MSM-Detektoren auf Saphirsubstraten wurde eine maximale Empfindlichkeit bei

314 nm (AlGaIn-Absorber) und 365 nm (GaN-Absorber) demonstriert, wobei die Empfindlichkeit der GaN-Detektoren wegen der internen Verstärkung besonders hoch ist. Detektoren mit InGaIn-Absorberschichten weisen sogar Licht bis über 400 nm nach.

Schichtstrukturen mit GaN-Absorbern wurden am FBH hergestellt und zusammen mit JOPS zu Schottky-Detektoren prozessiert. Sie zeichnen sich durch Dunkelströme von wenigen Pikoampere aus, was durch die gezielte Optimierung der Kristallqualität der Absorberschicht erreicht wurde. ■



BUSINESS AREAS & RESEARCH

Science Management » Wissenschaftsmanagement

GESCHÄFTSBEREICHE & FORSCHUNG



Wissenschaftsmanagement: Management von Forschung, Bildung und Technologietransfer



Die Ende 2009 begonnene Umstrukturierung des Geschäftsbereichs Netzwerke in die Abteilung Wissenschaftsmanagement wurde 2010 erfolgreich fortgeführt und durch entsprechende Aktivitäten verstetigt. Die Arbeitsschwerpunkte wurden dabei dynamisch an aktuelle Entwicklungen und sich verändernde Rahmenbedingungen angepasst.

Thematisch gliedert sich die Abteilung in drei Säulen:

- › Strategie
- › Technologietransfer & Marketing
- › Bildung

Im Mittelpunkt der Aktivitäten stehen die Positionierung des Instituts in lokalen, regionalen, nationalen und internationalen Netzwerken sowie die Unterstützung der Abteilungen und Geschäftsbereiche bei Industrieprojekten, Fördervorhaben und beim Aufbau von F&E-Kooperationen.

Netzwerkaktivitäten und größere Verbundvorhaben erfordern koordinierende Strukturen. Die Abteilung Wissenschaftsmanagement bietet langjährige Erfahrungen beim Aufbau und der Führung entsprechender Geschäftsstellen. Dadurch werden Partneereinrichtungen, insbesondere die

kleinen und mittelständischen Unternehmen, von organisatorischen Aufgaben innerhalb von Fördervorhaben entlastet und können zudem die Geschäftsstellen für die interne und externe Kommunikation nutzen. Das Institut profitiert vor allem von der engen Vernetzung mit den Partnern und der verstärkten Sichtbarkeit innerhalb des jeweiligen Themenfeldes. Mittlerweile existieren Geschäftsstellen von vier Initiativen am FBH.

Auch die internen Dienstleistungen konnten ausgebaut werden. Insbesondere im Bereich Technologietransfer profitierten die wissenschaftlichen Kolleginnen und Kollegen von der Unterstützung beim Aufbau von Kooperationen sowie beim Transfer von Forschungsergebnissen in verschiedenen Themenfeldern. Das Verbundvorhaben Berlin WideBaSe ist hierfür ein gutes Beispiel.

Im Bereich Bildung nehmen die Aktivitäten rund um die Nachwuchswerbung und -förderung eine immer wichtigere Rolle ein. Die Bewerberzahlen für Ausbildungsplätze sinken im gesamten Technologiesektor stark. Dementsprechend verlagern sich die Aktivitäten des Ausbildungsnetzwerks Hochtechnologien Berlin zunehmend von der Schaffung von Ausbildungsplätzen hin zu deren adäquater Besetzung.



**Leibniz
Mikroelektronik**



**Leibniz
Applikationslabore**

ANH BERLIN
AUSBILDUNGSNETZWERK
HOCHTECHNOLOGIE BERLIN

Science Management: Management of research, education and technology transfer

Restructuring of the former Business Area Networks into the Science Management Department started in 2009 and was successfully continued in 2010. In this process, key activities were dynamically adjusted to current developments and changing conditions.

Thematically, the department is organized in three pillars:

- › Strategy
- › Technology Transfer & Marketing
- › Education & Training

The main focus of activities is to position the institute in local, regional, national and international networks and to support the departments and business areas in industrial cooperation, funding projects, and in the development of R&D cooperation.

Networking activities and joint projects often require coordinative structures. The Science Management Department thus offers its long-time experience in establishing and managing coordination offices. Partner institutions, particularly small and medium-sized business partners,

take advantage from that within funding projects and can access the know-how and infrastructure provided for internal and external communication. The institute, in turn, benefits from the coordination role especially by close linkage with partners and increasing visibility within the respective research areas. Meanwhile, offices of four initiatives are located at the FBH.

Internal services could also be expanded. Particularly in technology transfer, the scientific colleagues benefit from the development of collaborations and the transfer of research results. A good practice example is the joint project Berlin WideBaSe.

In the field of education and training, activities addressing youth advertising and promotion for technical education gain in importance. The number of applicants for training positions in the entire technology sector is decreasing. Accordingly, the focus of the high technology training network Berlin (ANH Berlin) has shifted more and more from creating new training positions to adequately fill the vacancies.



Strategic cooperation & networks

In 2010, FBH succeeded to start several activities in strategically important areas including Berlin WideBaSe as a highlight. The regional growth core with eight joint research projects was launched in July 2010 after more than two years of concept development. Several of FBH's departments and business areas and altogether 13 research and business partners are involved and benefit from the support provided by the Science Management Department. With the start of the project, a coordination office was set up there to manage the overall project as well as internal and external communication.

Since many years, the institute is engaged in the regional competence networks ZEMI—Centre for Microsystems Technology Berlin, whose office has been established at the Science Management Department, and OptecBB—Optical Technologies in Berlin Brandenburg. In addition, Günther Tränkle as CEO of OptecBB is speaker of the Berlin-Brandenburg future field optical technologies and microsystems technology. In 2010, the department again supported updating of the Berlin-Brandenburg future strategy for optical technologies and microsystems technology as well as the identification of the main activity areas.

Additionally, FBH is actively involved in the branding of the Leibniz Association. With the Leibniz Application Laboratory MITOS as well as with the Leibniz Technology Transfer Association Microelectronics, which have been built up since 2009, the public perception for the Leibniz Association itself and FBH as a Leibniz research institution could be strengthened. In particular, networking with other thematically related Leibniz institutes enhances the visibility on a national and an international level. By complementary R&D offers of the participating institutions, especially medium-sized and large companies can be addressed more specifically and comprehensively.

The function of Günther Tränkle as authorized representative for Knowledge and Technology Transfer (KTT) within the Leibniz Association, supported by the Science Management Department, further strengthened KTT structures in the branch office of the Leibniz Association and lead to new funding programs for Leibniz institutes to market their research results.

Thus, the Science Management Department could further establish FBH as a main contact point and lobby for

- › microsystems technology in the Berlin Brandenburg area,
- › microelectronics within the Leibniz Association,
- › wide bandgap semiconductors in Berlin.



2010 konnte das Ferdinand-Braun-Institut in mehreren strategisch wichtigen Feldern Erfolge verbuchen. Hervorzuheben ist der Start des regionalen Wachstumskerns Berlin WideBaSe, der im Juli 2010 nach über zweijähriger Konzeptentwicklung und Antragstellung mit acht Verbundprojekten im Bereich der Halbleiter großer Bandlücke gestartet ist. Durch sein langfristiges Engagement in verschiedenen Kompetenznetzwerken hat sich das FBH zudem als zentrale Anlaufstelle

und Interessensvertretung für die Mikrosystemtechnik-Branche und die Optischen Technologien in der Region weiter etabliert. Darüber hinaus beteiligt sich das FBH aktiv an der Markenbildung der Leibniz-Gemeinschaft: Die in 2010 ausgebaute Kooperation von Leibniz-Instituten in serviceorientierten Verbänden, wie dem Leibniz-Transferverbund Mikroelektronik hat die Sichtbarkeit der Gemeinschaft und des FBH als Leibniz-Forschungseinrichtung gestärkt. ■

Research profits from technology transfer



Zusätzliche Einnahmen bedeuten neben der Sicherung von hochkompetentem Personal auch zusätzliche Mittel für Material und Investitionen. Ein erfolgreicher Technologietransfer trägt somit wesentlich zur exzellenten Forschung des FBH bei. Die Abteilung Wissenschaftsmanagement hat 2010 den Transfer weiter ausgebaut: von Projektentwicklung über Unternehmensansprache, Kundenbetreuung, Projektmanagement bis zur Fördermittelrecherche und -akquise.

Mehrere strategische Verbünde und Vorhaben wurden von der Abteilung initiiert, die den Technologietransfer und die Verwertung von Forschungsergebnissen umfassen:

- › Der **Leibniz-Transferverbund Mikroelektronik** vernetzt FuE mehrerer Leibniz-Institute zur Mikroelektronik und initiiert verwertungsorientierte Kooperationen mit Unternehmen.
- › Das **Leibniz-Applikationslabor** am FBH ist eine Anlaufstelle für Unternehmen, Hochschulen und Institute und bietet vor dem Hintergrund einmaliger Forschungs- und Technologiekompetenz sowie modernster Laborausstattung umfangreiche Unterstützung für Produkt- und Verfahrensentwicklungen.
- › Das im November 2010 beendete Vorhaben **VALORES** – Valorization of Research Strategic Cooperation of Institutes – unterstützte die Zusammenarbeit des FBH und des Greifswalder Leibniz-Instituts für Plasmaforschung und Technologie bei der Verwertung ihrer Forschung.
- › Mit zwei Vorhaben zum **Ambient Assisted Living** ist die Geschäftsstelle des ZEMI an Entwicklungen und dem Einsatz von Mikrosystemtechnik für ein selbständiges Leben in einer alternden Gesellschaft beteiligt. ■

Bundling competencies in microelectronics

The Leibniz Technology Transfer Association Microelectronics coordinates the activities of several institutes of the Leibniz Association in the field of micro- and optoelectronics. At present, seven Leibniz institutes and Technische Universität Berlin join forces in the association; four new members of Leibniz Association are about to affiliate.

The association focuses on cooperation in research and development with regional SMEs. As the association bundles its fields of expertise in a wide-ranging portfolio, industry partners benefit from the central contact office bringing together corresponding researchers and technologies in joint projects. Common public relation activities increase the visibility of the Leibniz Association in general and the subject matters of each research institute in particular.

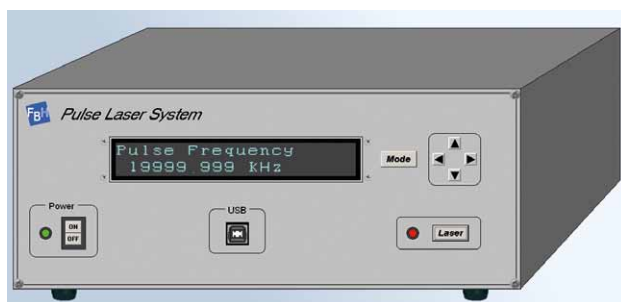


Fields of expertise within Leibniz Technology Transfer Association Microelectronics.

Application laboratory: transforming research results into innovative products

By establishing FBH's application laboratory in 2009, the institute broadens its range of R&D services and complements its expertise in specific technologies and components with competencies in systems. FBH's 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 development.

At FBH, a small team of engineers and scientists helps to advance research know-how and practice-oriented applications including feasibility and practicability of the components. The application team relies on unique research and technology competencies in optoelectronics and microwaves as well as state-of-the-art laboratory equipment. The laboratory offers support and advice, in particular, for FBH's departments, business areas and research groups and for small and medium-sized enterprises during product development.



Design study of the main control unit of the pulse laser system.



UV-LED disinfection device for liquids.

The FBH application laboratory further develops laboratory models into functional models. Examples for current projects are:

- › stand-alone pulse laser system as picosecond light source with integrated pulse picker for selecting pulse durations and amplifying laser pulses,
- › UV-LED disinfection device for liquids in flow cytometers at Deutsches Rheuma-Forschungszentrum,
- › probe for oscilloscopes with high insulation of electrical potential and with low feedback to the measurement signal.

An additional initiative within FBH's overall application laboratory activities is the "Microwave Technology Optoelectronics and Solid State Electronics" (MiTOS) application laboratory. This laboratory has been jointly established by Paul Drude Institute for Solid State Electronics (PDI) and FBH. Both institutes thus extend their competencies in III-V semiconductor technologies and bundle their unique technology potential. The PDI, for example, has developed semiconductor structures ensuring more efficient light generation of light-emitting diodes. These structures shall now be used in FBH's laser technology to create innovative light sources. Another cooperation field is the development of compact THz quantum-cascade lasers with high output power.



"magic board"—collaborative project SELBST (graphic courtesy of pme Familienservice GmbH).

VALORES: Valorization of Research—Strategic Cooperation of Institutes

The VALORES project, which had started two years ago, was successfully terminated in 2010. VALORES' aim was to improve the utilization of research results within the cooperating Leibniz institutes FBH and Leibniz Institute for Plasma Science and Technology (INP) in Greifswald. The results were incorporated into marketing concepts and utilization guidelines for scientists. Now, a framework agreement between both institutes allows them to initiate new research projects faster and facilitates corresponding valorization activities.

In a pilot project, transfer activities had been accompanied and evaluated on a model basis. For this purpose, VALORES developed instruments for further strategic alignment of research valorization and systematic expansion of cooperative research projects, industrial contract research and start-ups. The project thus helps to ensure that inter-institutional cooperation result in system solutions more quickly; these can then be marketed by industrial partners. To provide support for other Leibniz institutes, the VALORES results were compiled as guidelines for the Leibniz Association.

ZEMI: strong in Ambient Assisted Living (AAL)

The ZEMI office cooperates as a technology partner within two AAL collaborative projects which are funded by the BMBF. In the project MIDIS (service innovations for elderly people with microsystems technology), the partners develop the substantial basics and methodical approaches that enable cooperative development and successful marketing of new services. Aim is 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. In collaboration with transfer business partners, test pilot solutions for innovative services for seniors shall be developed.

In the collaborative project SELBST (self-determined life in the age with microsystems technology), ZEMI supports the network partner Fraunhofer IZM by developing an individual support and communication solution within a modular system. For that purpose, available products should be used as far as possible so that an individual customer solution can be easily adjusted and subsequently installed at home. The modular system shall be additionally completed by new available solutions based on microsystems technology to realize an adapted ambient assistance system.

Training & education: to ensure skilled personnel

Due to structural changes in economy and society, current demographic developments, and globalization, the vocational education and training (VET) system needs to be adapted to new requirements. The current training situation in microsystems, optical and nanotechnologies can be described as a bottle neck: transfer and implementation of new technologies into industrial applications are delayed by the lack of skilled personnel on all educational levels. With its well-established knowledge in this field, FBH helps to improve educational structures and to match requirements of companies and future staff.



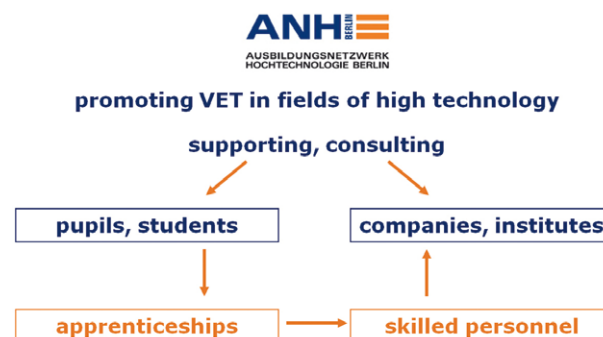
Seit einigen Jahren engagiert sich das FBH gemeinsam mit der ZEMI-Geschäftsstelle in der Nachwuchswerbung und vernetzt Akteure der beruflichen Ausbildung im Hochtechnologiebereich. Mit dem Ausbildungsnetzwerk Hochtechnologie Berlin (ANH Berlin) unterstützt das Institut in enger Zusammenarbeit mit der Lise-Meitner-Schule sowohl Unternehmen als auch Schüler/innen in allen Fragen der beruflichen Ausbildung. Von 2007 bis 2010 konnten so über 60 zusätzliche Ausbildungsplätze geschaffen werden. Um die Ausbildung attraktiver zu gestalten, entwickelt das Netzwerk Zusatzmodule und ein Modell zur besseren Anschlussfähigkeit der dualen Berufsausbildung an den Bachelorstudiengang Mikrosystemtechnik und optische Technologien.

Die Möglichkeit des grenzüberschreitenden Austauschs von Know-how und Good-Practice-Beispielen zur Verbesserung der beruflichen Aus- und Weiterbildung nutzt das FBH in der Leonardo da Vinci Partnerschaft „bottle neck“ mit Partnern aus fünf Ländern. Im Juni 2010 organisierte das FBH zudem im Rahmen des bundesweiten Netzwerks mst|femNet meets Nano and Optics einen Mädchen-Technik-Kongress, bei dem sich 125 Mädchen über Karrierechancen im MINT-Bereich informierten. ■

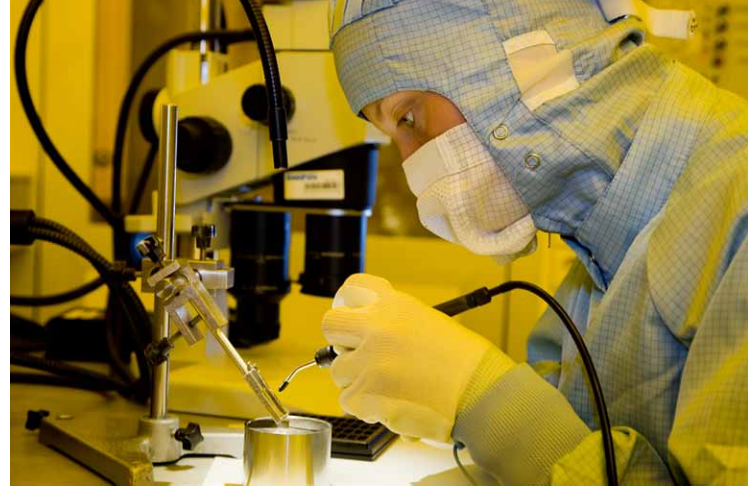
The training network ANH Berlin

By initiating the training network ANH Berlin (Ausbildungsnetzwerk Hochtechnologie), the FBH has been promoting vocational education and training for many years. In 2010, FBH and the vocational school Lise-Meitner-Schule continued their close cooperation within the network. Since ANH's foundation in 2007, more than 60 additional apprenticeships have been initiated by supporting research institutes and companies in all needs and questions concerning education potential in the rapidly changing high technology area. The network offers a wide and practice-oriented range of services for vocational education and encourages young people to opt for a career in natural and technical sciences.

In order to increase the attractiveness of VET, innovative content and training infrastructure, especially in the field of micro technology, are currently established. New flexible training modules, for example, will be developed for VET as well as for further training to meet changing skills needs in research and industry. In cooperation with the Brandenburg University of Applied Sciences, ANH Berlin intends to open new pathways for young people by acknowledging qualifications attained within vocational education and training at university level to promote permeability between academic and non-academic training.



Today's innovative training is essential to meet tomorrow's skills needs.



Bottle neck: European dimension in education and training in micro technology

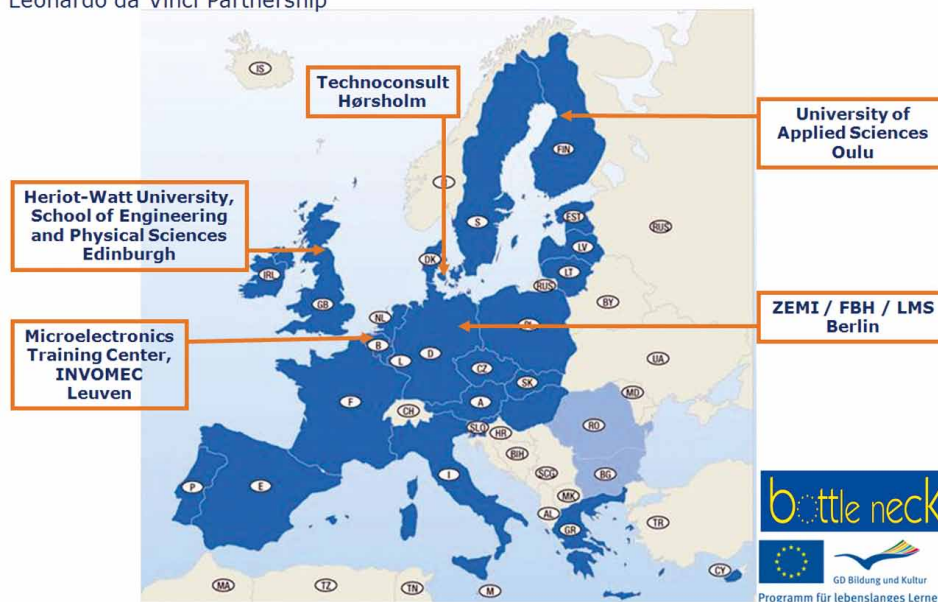
Tackling high-level skills challenges in science, technology, engineering and mathematics is the shared responsibility of professional institutions, employers and universities as well as governments all over Europe. With the partnership project "bottle neck", FBH together with ZEMI intends to initiate a transnational dialog in order to exchange know-how and experiences and to stimulate transfer of good practice. Thus, vocational education and training in the high technology field shall be improved to guarantee skilled personnel for the future. Bottle neck plans not only to initiate an exchange of information and know-how but also to promote the mobility of staff as well as students and trainees. Activities initially aim at involving trainers, teachers, research staff and multipliers. A positive influence on the training situation of apprentices, students and trainees is expected in the long run. The partnership project started in August 2010 and brings together partners from Denmark, Finland, UK, and Germany. The project is funded for two years within the EU program Leonardo da Vinci.

mst|femNet meets Nano and Optics

The proportion of girls and young women in high technology professions such as engineering, physics and chemistry is still low. FBH has been involved in this issue for many years by starting the former regional MST Education and Training Network AWNET. Currently, the new nationwide network mst|femNet meets Nano and Optics brings representatives from public administration, politics, industry, research and education together. 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 the Berlin-Brandenburg region in 2010, 125 girls from 7th to 12th grade had the chance to taste MINT and to test own technical talents. The girls received comprehensive information about training opportunities in VET and at universities. Staff from FBH supported the congress by presenting role models who explained career opportunities. Over the past few months, ZEMI succeeded in building a sustainable network with regional partners and also prepares the second girl's congress which will be held in June 2011.

bottle neck (2010-2012)

Leonardo da Vinci Partnership



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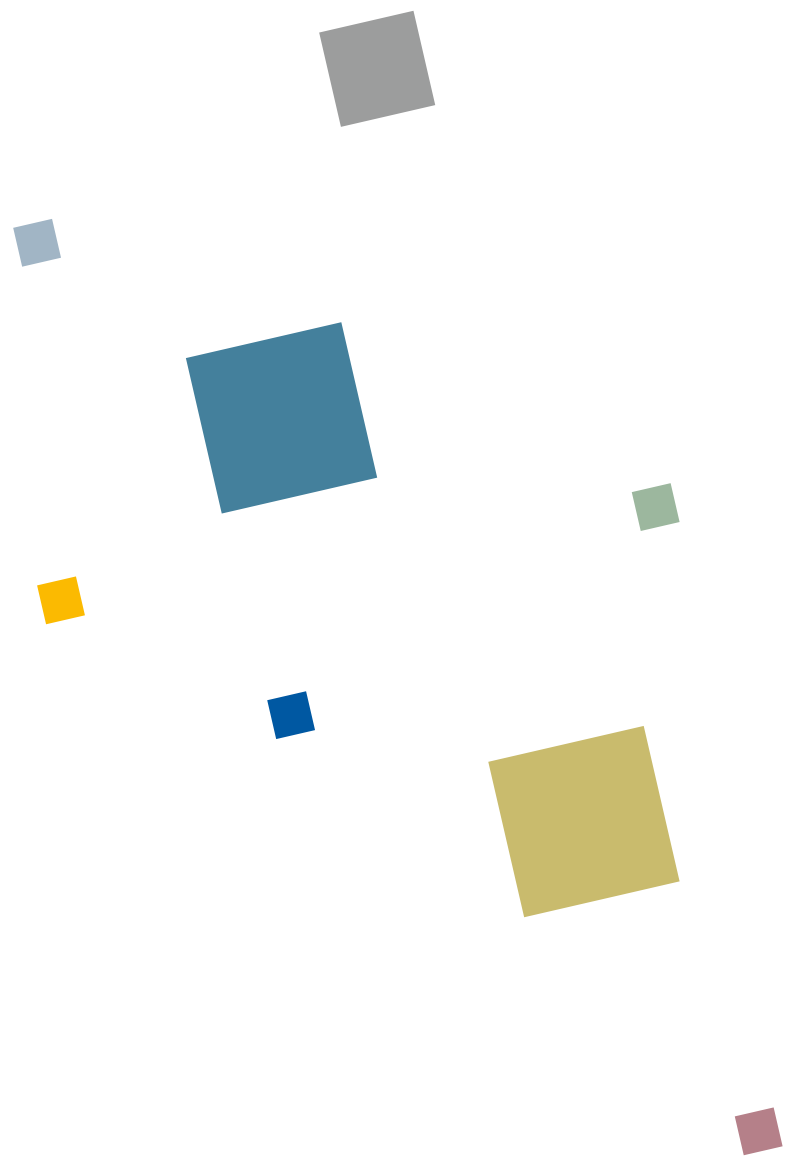
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