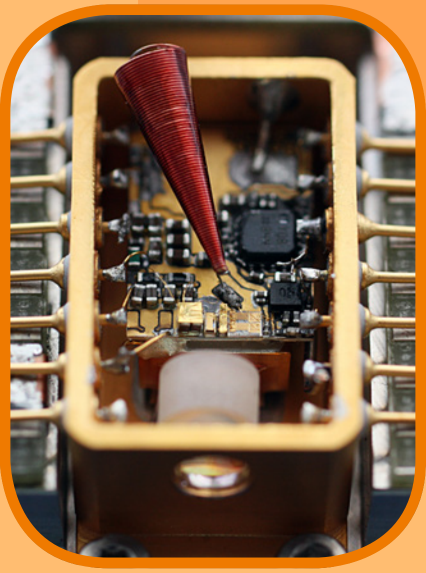
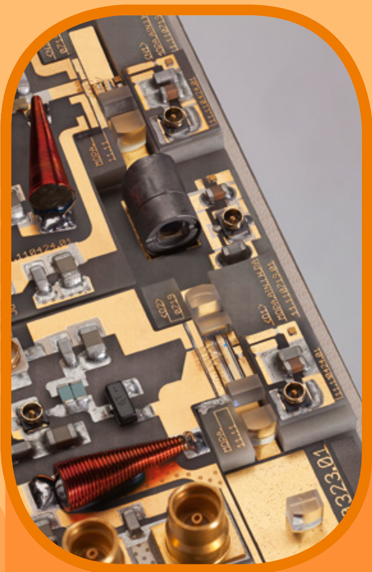
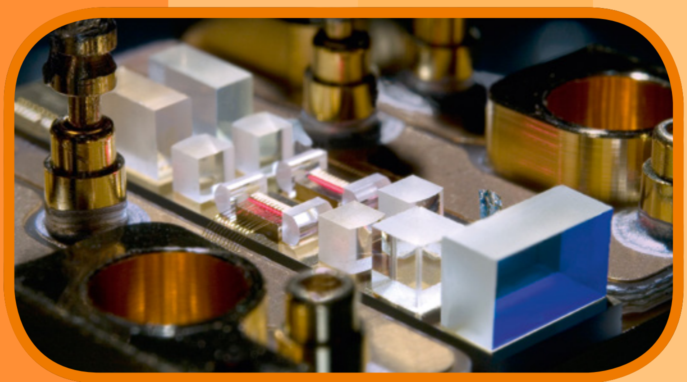




frequent

Research news from the Ferdinand-Braun-Institut



Hybrid diode laser modules

- compact & flexible light sources
- maximum robustness for space
- extraordinary sensitivity for sensors
- high brilliance for display technology

Hybrid-integrated compact diode laser modules

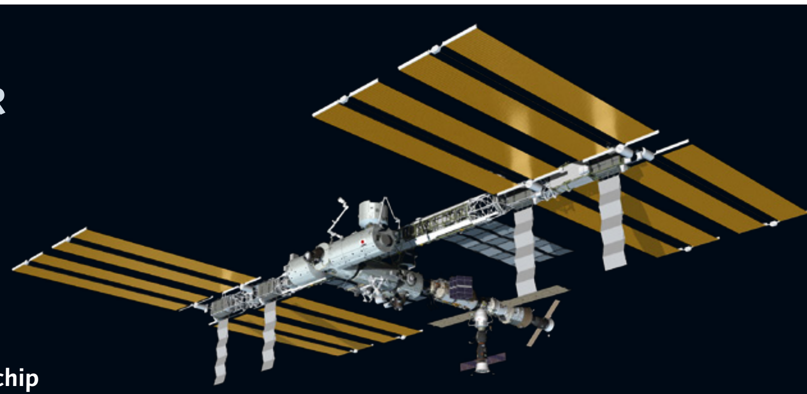
Smart laser sources for materials analysis, medicine, metrology, and displays

Progress achieved in diode laser design and technology during recent years is the prerequisite for new kinds of laser sources that are assembled as compact, hybrid diode laser modules. These advancements include improved efficiency, output power, and implementation of gratings as wavelength filters. The novel diode laser modules can be very flexibly designed according to specific requirements, thus making entirely new applications possible. For material analysis in medicine, food control, and environmental analytics, for example, bulky equipment has been used so far. With the sophisticated diode laser modules, they can now be replaced by significantly smaller, thus mobile devices. This also applies to display technology. In addition to the small size, superior brilliance is the key argument for the use of diode lasers in displays. Another example is space applications requiring very compact, "nearly weightless", and robust laser sources. They are used as transmitters in communication channels between satellites, in ultra-precise optical clocks, and in fundamental physics experiments. Such niche products, by the way, are important technology drivers accelerating developments in various further application fields. The smart and compact laser modules are, of course, also highly attractive for stationary devices making the overall system structure much simpler. This way, weight, energy consumption, and service efforts can be reduced.

The FBH has extensive experience and long-term know-how in diode laser chip technology. Core competencies in this field include design, epitaxy, and wafer processing. FBH successfully developed diode lasers with high wall-plug efficiency, very high output powers, and cutting edge brilliance by implementing gratings and other optical mode filters. Thus, diode laser technology provides the basis for tailored chips. To fully exploit the potential of these achievements and to go a step ahead into application, FBH developed its particularly flexible technology for hybrid integration of diode laser chips with further optical and electronic components. As a next step, the development of fiber coupling is now in progress. Chip technology and sophisticated assembly to smart modules under one umbrella turned out to be very successful, leading to effective and short development processes.

Within all these activities, FBH keeps the application in mind right from the start. Thus, working closely with industrial and research partners already during the R&D process enables the FBH to develop customized modules including the necessary adjustments in the course of all stages of module development.

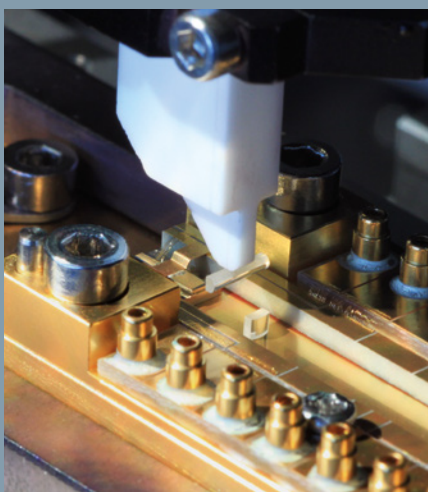
FLEXIBLE LIGHT SOURCES— CUSTOMIZED SOLUTIONS FOR SPECIFIC APPLICATIONS



High-end diode laser chips are the base for small and tailored light sources to be used in a great variety of applications. However, what makes FBH's compact diode laser sources effectively smart and custom-made, are further sophisticated steps implemented additionally to chip technology. To achieve the desired properties, diode laser chips are flexibly assembled together with appropriate micro-optics and electronic components onto a micro-bench. The overall hybrid-integrated diode laser module is only as small as a matchbox, enabling, for example, beam shaping, modulation, frequency transformation, building external microresonators, and fiber coupling. Thus, it can be flexibly adjusted to the requirements of the respective application. In its current research activities, FBH is dealing with the specific challenges of each module and application. For a Raman sensor used in material analytics, for example, an optode with optical elements will be integrated to enable direct probing of material. High-power RGB laser sources developed at the FBH require cutting-edge diode laser chips, but also high-end nonlinear crystals and thermal management. In space, extremely robust, vibration-proof, reliable, and stable light sources are needed for harsh environment operation. The small dimensions make these laser modules also ideally suited for portable systems.

COMPREHENSIVE KNOW-HOW IN HIGH PRECISION MOUNTING AND ASSEMBLING

Hybrid-integrated, matchbox-size laser modules are assembled on micro-benches consisting of AlN ceramics. This material offers a high thermal conductivity, a low thermal expansion coefficient, and an economic price at the same time. At FBH, various bonding technologies are available for mounting of laser components including beam forming optics. Different solder materials are used for active light-emitting components, which makes this technology very flexible. A flip-chip bonder allows careful sequencing with highest precision of ±1 µm and ±0.1 mrad to position the diode laser and amplifier chips. Passive components like micro lenses and components with low thermal load can be glued with FBH's high-precision mounting equipment. In conjunction with a precisely designed geometry, this enables accurateness in the range of ±0.3 µm and ±0.03 mrad using UV glue. For HF modulation and low-noise applications, electronic elements are additionally implemented on the micro-bench near the active semiconductor chips.



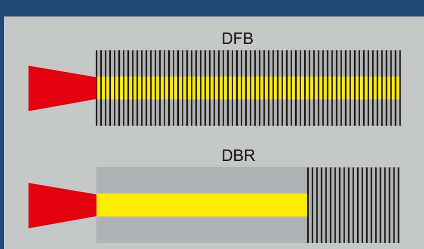
◀ *High-precision mounting of a micro lens into a compact diode laser module.*

ADVANCED GRATING TECHNOLOGY

Diode lasers are the most efficient source of optical energy. However, the emission lies within a wavelength range of several nanometers, which is too broad for many applications, for example in spectroscopy. When a periodic grating is built into the semiconductor, the wavelength range can be narrowed a million times to femtometers. In the past decade, FBH scientists have developed the advanced process techniques and laser designs required to deliver such grating-stabilized diode lasers with very high performance. Two technologies have been developed:

- **surface-etched gratings,**
- **gratings that are buried in the semiconductor using two-step epitaxial growth techniques.**

These allow the FBH team to produce wavelength-stabilized lasers that are tailored for each application.



▲ *Wavelength-stabilization by integrated Bragg gratings, schematic top view DFB and DBR laser.*

▲ *SEM image of surface Bragg grating, cross-section along resonator axis.*

EDITORIAL

High-performance light sources in matchbox-size

From the near-infrared to the visible spectral range, FBH diode laser modules score with excellent features: precise wavelength, direct modulation, output stability, small dimensions, low energy consumption, and high reliability. These properties make the compact light sources highly attractive for various applications, from display technology, sensor and medical technology to space applications. The small-dimensioned diode laser modules integrate beam-shaping optics, external resonators, and oscillator-amplifier configurations into one package.

We wish you an inspiring reading of this **frequent** issue presenting current FBH developments in this field,

Günther Tränkle

Günther Tränkle

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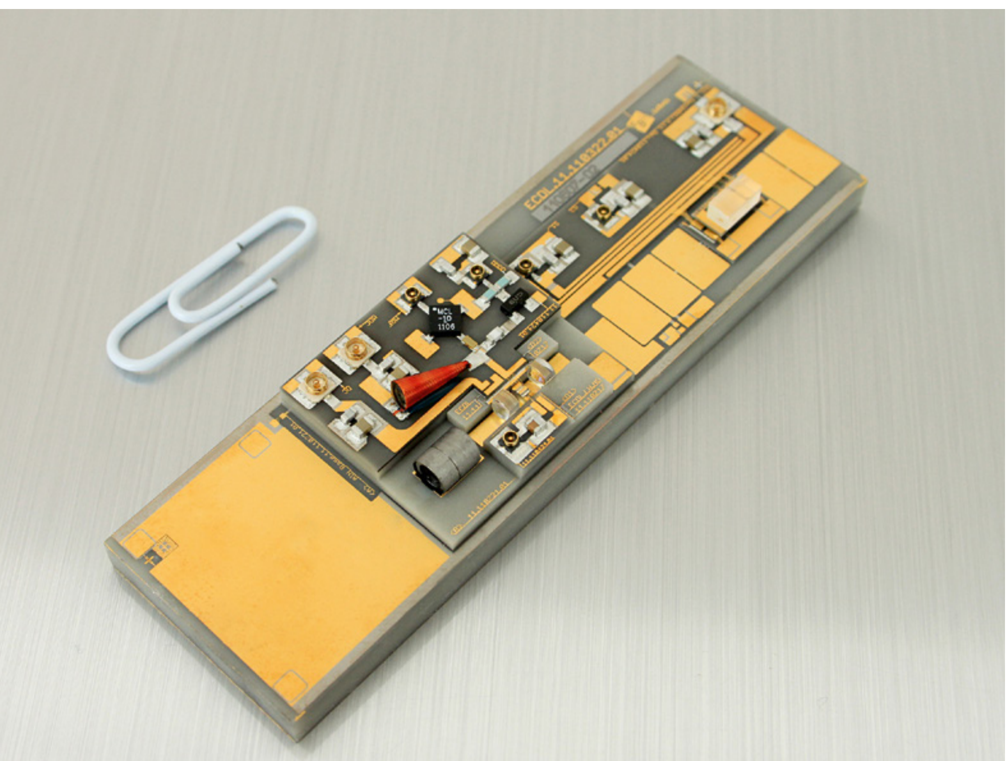
Compact and robust diode laser modules for space applications

▼ *Micro-integrated diode laser module for Bose-Einstein condensation and atom interferometry experiments in space.*



Quantum sensors based on cold atoms are currently moving into the focus of various application fields like precision time keeping, geodesy, geo-physics and exploration, navigation, and fundamental physics. Up to now, the operation of these sensors requires an infrastructure that is, in principle, only provided by an optics laboratory. There is also the fact that no equipment existed so far which could survive and operate properly under the harsh conditions of a field deployment and much less in space. Consequently, the German Space Agency DLR, the European Space Agency ESA, and the European Commission through the EU-FP 7 program fund projects that aim at maturing all aspects of the technology relevant for quantum sensor applications.

FBH is contributing to these activities by developing a hybrid micro-integrated diode laser technology. The corresponding compact laser modules meet the electro-optic (EO) requirements and can, at the same time, cope with the operating conditions determined by the harsh environment. In terms of electro-optical performance, the main challenge common to all cold atom quantum sensor applications is the spectral stability and spectral purity of the laser system. While atom interferometry requires lasers with sub-100 kHz linewidth or a fractional frequency instability less than 1 part in 10^9, the laser linewidth eventually has to be reduced to the sub-1 Hz level (1 part in 10^{15}) for optical atomic clocks. These EO requirements are complemented by the request for minimum mass, minimum volume, maximum energy efficiency, and maximum resilience against mechanical and thermal stress.

Within a public-funded project, FBH has developed suitable compact laser modules for Bose-Einstein condensation and atom interferometry experiments on rubidium atoms. Tests shall be carried out on board a sounding rocket, with a launch in 2013. For that purpose, diode laser modules with external cavity (ECDL) have been micro-integrated onto $50 \times 25\ mm^2$ AlN ceramic micro-optical benches. The modules each comprise a semiconductor laser chip, micro lenses for beam collimation, and a volume holographic grating for frequency selection and spectral stabilization. Volume and mass of these laser systems are reduced by a factor of 100 or more as compared to commercially available systems. The laser system design omits any moveable parts in order to provide the mechanical stability and resilience against random vibration and mechanical shock—a relevant precondition for space applications. FBH laser systems have successfully passed random vibration tests up to 20 g (root-mean-square) and are also in operation at the ZARM drop tower in Bremen. Here, the laser system even undergoes accelerations up to 50 g.

Novel dual-wavelength diode laser modules as basis for portable SERDS sensor systems

Diode lasers are attractive excitation light sources for Raman spectroscopy to investigate and detect substances even at low concentrations. Current activities aim at portable measuring systems for different applications, such as food control and medical applications. FBH recently developed a compact diode laser module suitable for Shifted Excitation Raman Difference Spectroscopy (SERDS) allowing to detect weak Raman signals covered by fluorescence or background light. To excite the SERDS signals, FBH's 671 nm monolithic distributed Bragg reflector (DBR) diode laser uses two neighboring excitation wavelengths. The monolithic laser source together with hybrid-integrated micro-optical elements enables highly compact sensor systems.

The dual-wavelength diode laser (Fig. 1) is the key component with a footprint of 0.5 x 3 mm², delivering an output power up to 110 mW. The spectral width is smaller than 0.5 cm^{-1}, the spectral distance between both emission lines 10 cm^{-1}. SERDS capabilities were successfully demonstrated by measurements of an analyte (polystyrene) using a broad-band light source simulating a disturbing background (Fig. 2). The Raman lines were covered by the disturbing light. SERDS allows recovering these weak lines from the sample spectrum and shows a 25-fold improvement of signal-to-background noise.

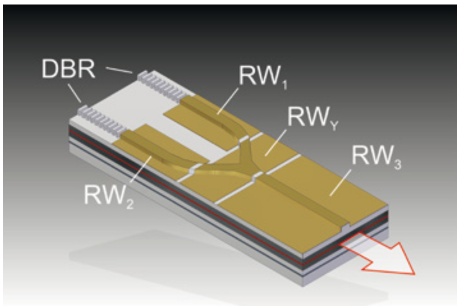


Fig. 1: Scheme of dual-wavelength DBR diode laser.

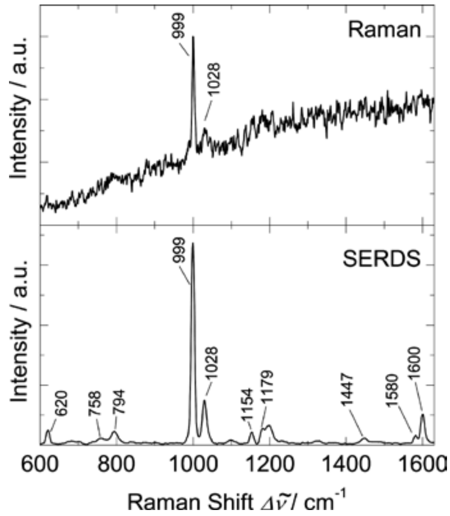


Fig. 2: Raman and SERDS spectrum of polystyrene excited with dual wavelength diode laser in disturbing background. While Raman lines are covered by background noise showing only two distinct lines, SERDS delivers a characteristic fingerprint spectrum.

High brilliance for display technology

Pico-projectors based on diode lasers are already commercially available. However, projectors requiring a higher light output of 500 lumens and above are still based on lamps. FBH is currently developing hybrid-integrated diode laser modules in the basic colors with the following desired properties: > 1 W output power and radiance > 100 MW/cm²/sr. These compact laser modules integrate customized diode laser chips and beam forming optics. While red light can be generated directly from the chip, for green and blue light, nonlinear frequency conversion by single-pass second harmonic generation (SHG) from near-infrared to visible light is used. Key element for the infrared light source is an internal wavelength-stabilized tapered diode laser providing high output power of up to 8 W—measured after beam forming optics—and good beam quality to deliver 1 W in the visible range. Separate contacts on chip additionally enable modulation. Careful design and precise positioning of the micro lenses, which form the beam by focusing it into the optical nonlinear crystal, is needed. For chip mounting, submounts with highest possible thermal conductivity are used. FBH successfully integrated the laser and the SHG crystal into a small module package, featuring high precision and minimal thermal crosstalk between laser chip and crystal. Prototype modules with more than 1 W output power and a nearly diffraction-limited beam were demonstrated. Integration of multiple emitters is planned and should enable even higher light fluxes and reduced speckles.

Hybrid-integrated diode laser module for display applications.

Tailored picosecond laser pulse source PLS 1000

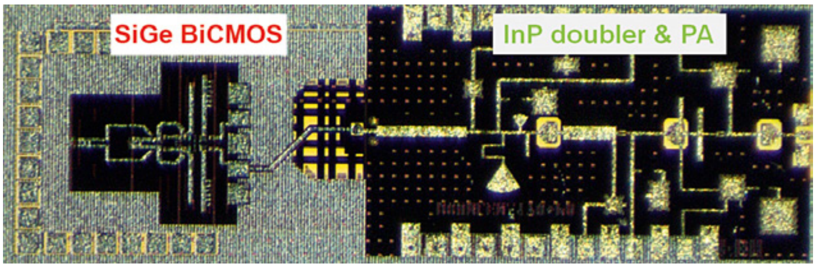
A compact diode laser pulse system PLS 1000 has been designed and manufactured at FBH combining in-house developed optical and electronic semiconductor components. PLS 1000 delivers ultra-short light pulses < 10 ps and provides any desired repetition rate from the Hertz to the 10 MHz range; pulse peak performance reaches > 10 W output power. With these properties, the efficient and compact laser system is ideally suited for materials processing in combination with fiber amplifiers, biomedical examinations based on fluorescence spectroscopy, and mobile short-range LIDAR systems.

The innovative system consists of a mode-locked laser with 4 GHz repetition rate, a novel pulse picker concept that enables picking single pulses, and an amplifier. All components are tailored high-end semiconductor diode laser chips. To enhance system speed, electronic drivers using FBH-made GaN transistors were developed. Thus, stable and user-friendly operation could be achieved. PLS 1000 can be operated either manually or computer-controlled and selects single pulses (single mode) as well as several consecutive pulses (burst mode).

Enhanced properties from combined SiGe and InP circuits

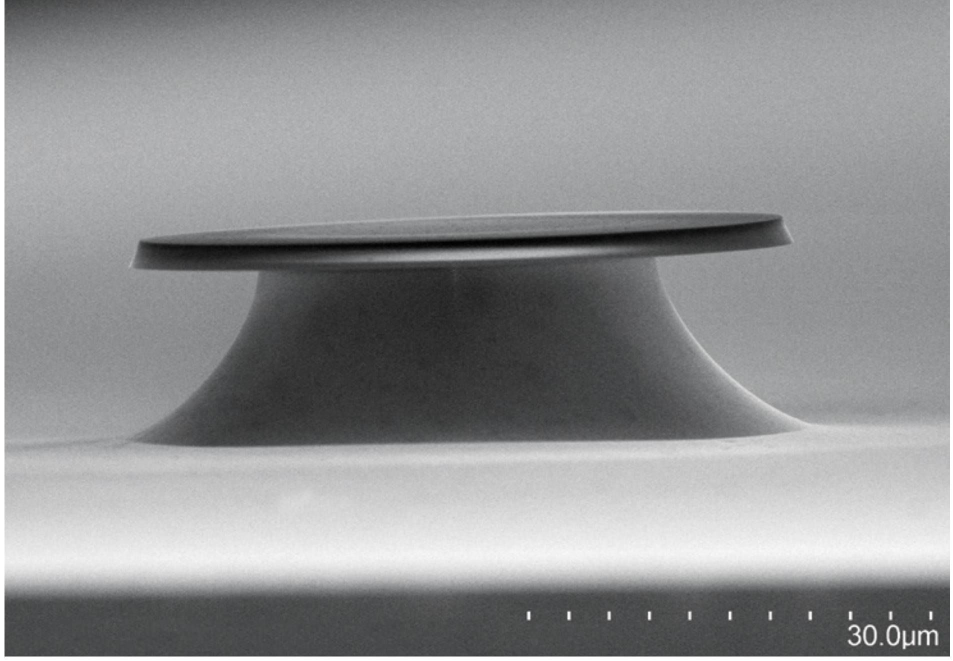
FBH and IHP from Frankfurt/Oder successfully combined SiGe-based BiCMOS and InP-based circuits by integrating them on one chip. Thus, new ambitious applications in the THz range are within reach including high-resolution imaging systems for medical and security technology as well as ultra-broadband mobile communication applications. At the frequency range around 100 GHz and beyond the breakdown voltage in CMOS circuits decreases, and accordingly the available output power degrades.

However, the novel material combination delivers the desired properties: high output power at high frequency. The independently preprocessed BiCMOS and InP wafers are arranged sandwich-like and bonded with few-micrometer precision on top of each other. This approach keeps all benefits both from the high level of production routine and integration of BiCMOS circuits and from the excellent InP material properties. InP double heterojunction bipolar transistors on top of BiCMOS demonstrate record high-frequency characteristics with transit frequencies f_t and f_{max} of 400 and 350 GHz delivering an output power of more than 26 mW at 96 GHz. Next steps aim at further stabilizing the process and optimizing the circuits. This way, the synergy potential created by combining both complementary semiconductor technologies shall be exploited to reach a performance level beyond the individual limits.



Integrated circuit consisting of a 85 GHz circuit in SiGe BiCMOS and a 170 GHz frequency doubler and power amplifier in InP.

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



Microresonator with excellent optical properties.

Microresonators of utmost quality for high-precision applications

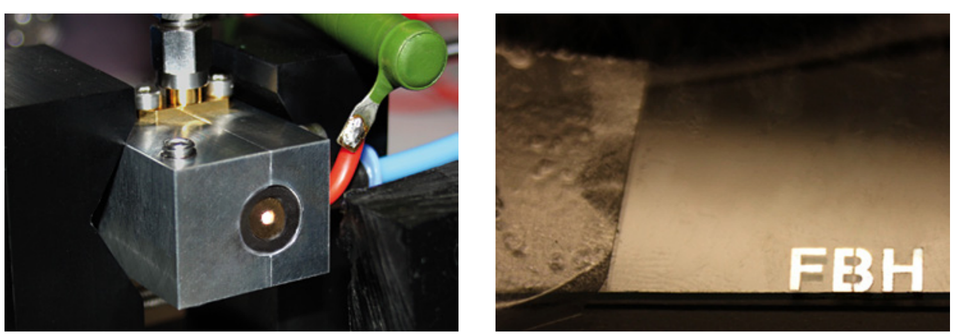
FBH and HU Berlin joined forces to advance high-quality optical micro-resonators. The tiny structures range from 50 µm - 500 µm in diameter with a thickness of about 1 - 2 µm. They can be assembled as compact and robust optical systems that may be tailored precisely and flexibly according to the requirements of the respective application.

The optical resonators investigated are silica disks that guide and store light in so-called "whispering gallery modes". Due to the excellent optical properties of the material and an elaborated process technology, light can be stored long enough to enable optical resonators with a linewidth of only a few 100 MHz. This feature is attractive for various applications, such as short-pulse light sources, spectrometers, and optical sensors. The laser metrology group has developed a test stand for optical characterization of such microresonators in the wavelength range of 765 - 781 nm. In the setup, the distance between a tapered fiber and the optical resonator can be controlled with a precision better than 10 nm; resonance frequencies and Q-factors can be measured automatically with high precision and reproducibility.

Thin film coating at atmospheric pressure

Many surfaces require surface treatment including flat-panel displays, mobile phones, and eye glasses. FBH developed a novel patented atmospheric source allowing sputter deposition of thin films at atmospheric pressure. So far, for this process bulky and costly vacuum coaters were used. The treatment has now been successfully transferred to ambient air thus enabling substantial cost reduction by eliminating expensive vacuum technology. It additionally opens up entirely new coating applications. Combining the microwave plasma with a dc current for ion extraction leads to stable operation and thus enables the desired thin film deposition. Up to now, even experts considered this process impossible. Due to the great market opportunities of this invention, a spin-off to commercialize the technology is currently being prepared.

The FBH prototype operates with a microwave resonator at 2.45 GHz driven by a solid-state transistor oscillator. Inert gases at flow rates of 25 - 100 l/h are ionized by microwave energy. An additionally applied dc voltage of > 100 V, delivering a current of approximately 100 mA, extracts ions from the plasma and accelerates them towards the target. Thus, a sputter process takes place at atmospheric pressure. Au films can be deposited with a sputtering rate of 30 nm/min. on an area of 5 mm².



Prototype plasma source (left) and the FBH logo sputtered with Au on glass (right).

Leibniz Ferdinand-Braun-Institut

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

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

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

The Ferdinand-Braun-Institut 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.

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