Leibniz
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frequent

Diode lasers for sensor & analytics applications

Customized developments

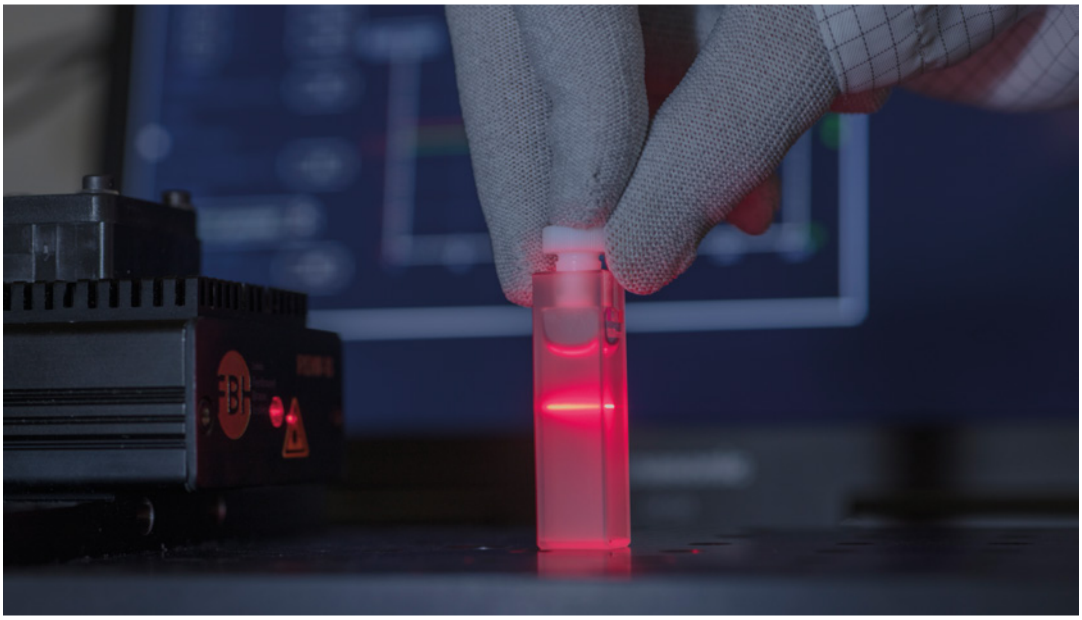
→ for rapid SERDS

→ for LiDAR applications

→ for nonlinear frequency conversion

FBH diode lasers for sensor applications – highly capable, flexible and easy-to-use

The FBH has long-term experience in developing diode laser based light sources tailored for sensor and analytic applications. These lasers can be utilized very flexibly in industry, health and well-being as well as in environmental and scientific applications. As different as these applications may be, what they have in common is their need for high-power, diffraction-limited and tunable narrow-linewidth laser sources – with adjusted properties, of course.



PPC-controllable prototype of an FBH diode laser source used for sensor applications.

In order to develop the optimum device for the respective application, FBH scientists coordinate closely with each customer before starting the design process. Developments are accompanied by comprehensive testing. Potential optimizations can be easily integrated in the next development steps, since the institute's competencies cover the full value chain, from design and processing of the laser diodes up to operational devices. Moreover, tailor-made demonstrators and prototypes are conceptualized and realized in house. As a result, industrial and scientific partners can easily test FBH's R&D results in their specific applications.

Diode lasers with advanced functionalities – meeting customer's demands

FBH developments include wavelength-stabilized, narrow-band-emitting diode lasers and diode laser modules, which are suitable for a great variety of demanding applications such as Raman, fluorescence, and absorption spectroscopy. Using Y-branch DBR diode lasers with electrically controlled micro-heaters, which are implemented above the gratings, provides dual-wavelength laser emission and wavelength tuning over several nanometers. These sources are ideally suited for shifted excitation Raman difference spectroscopy (SERDS), enabling to extract Raman signals efficiently and rapidly from disturbing backgrounds such as fluorescence and ambient light, thus improving Raman spectroscopy in real-world applications.

With sampled grating lasers, recently developed at FBH using GaAs based devices for the first time, wider wavelength tuning of several tens of nanometers is obtained. With these diode lasers, the FBH provides capable laser sources whose spectral distance can be adjusted flexibly to the desired bandwidth, matching the sample under investigation.

FBH diode lasers are also developed as pulsed light sources in LiDAR systems for autonomous driving and for 3D object detection. One quite specific pump laser source for a LiDAR system has only recently passed its practical test on board the Aeolus satellite, which now helps to measure Earth's winds. Aeolus is expected to play a key role in better understanding the workings of the atmosphere and thus will improve weather forecasting.

Diode lasers from the FBH also aim at nonlinear frequency conversion, which enables access to specific wavelengths that currently cannot be addressed by direct-emitting diode lasers. They target wavelengths, ranging from the ultraviolet to the visible spectral range.

In summary, FBH diode lasers enable very robust, small-sized laser sensors that offer stable measurements with highest accuracy – even under challenging conditions when the "wanted" signals are superimposed by disturbing background signals. They therefore allow for particularly compact systems that can be used very flexibly.

Editorial

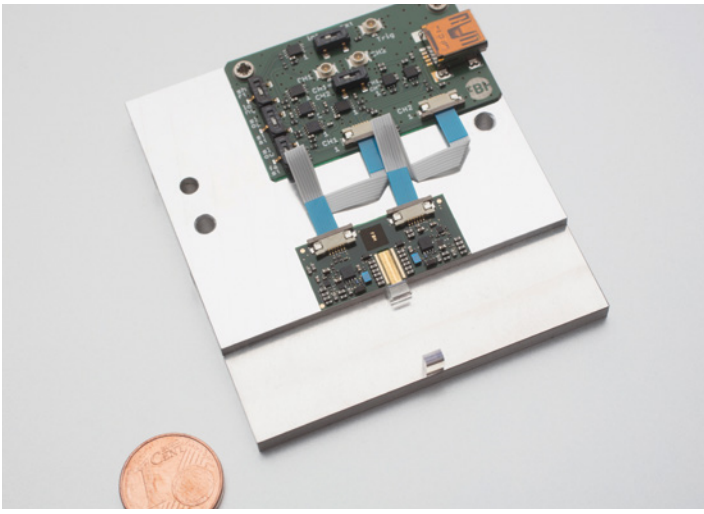
Diode lasers change the dimensions – also in sensor technology! They ensure that overall systems become increasingly compact and can therefore be used in mobile applications. For many years, FBH has been developing advanced diode lasers along the entire value chain, from novel dual-wavelength diode laser chips up to a SERDS Raman system, which has demonstrated its capability in on-site analysis in precision agriculture. Moreover, FBH is increasingly combining its expertise in optoelectronics and III-V electronics, which results in sophisticated electronic control systems for pulsed laser sources. They deliver fast pulses in the nanosecond range with freely selectable repetition rates and can be used very flexibly, from materials processing to LiDAR applications. In this way, FBH offers tailor-made solutions that are precisely designed to meet the requirements of its customers.

This frequent issue informs you about current FBH developments for sensor applications. I wish you an inspiring reading!

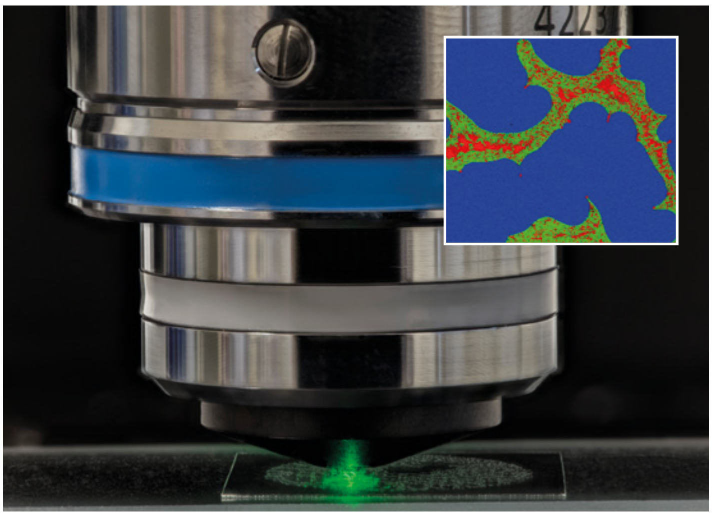
Günther Tränkle

High-power laser drivers for ultra-short pulse generation

The maximum range of a LiDAR system depends on the available optical pulse power, the range resolution is determined by the pulse width. Typical scenarios demand for power levels exceeding 100 watt at pulse widths from 3 to 10 ns. To generate such short and powerful laser pulses, pulse drivers with a peak current value of more than 100 A are needed. The unique challenge is providing the high-speed high-current switching circuit as well as handling the parasitic inductances due to the assembly of the laser diode and the driver board. FBH drivers use GaN devices in the final stage in order to allow for optimum high-current switching as well as for high efficiency and high repetition rates. They achieve record performance: 100 W optical pulse peak power are obtained in a pulse-width range between 3 ns and 10 ns, with pulse currents between 180 A and 250 A.



Advanced Raman analysis and imaging



FBH has recently expanded its measurement technology with a confocal Raman microscope. Thus, the institute possesses another powerful analytical tool to conduct spatially resolved investigations and chemical imaging of different samples such as solids, biological material, and polymers. Raman spectra are generated point by point over an area, rendering 2D and 3D spatial distributed chemical information of the sample under study. The Raman microscope alpha300 R offers two excitation wavelengths at 532 nm and 785 nm and can be flexibly used for both scientific projects and industrial services. The tool is additionally equipped with a TrueSurface option to measure the topography of the sample surface with an optical profilometer. This information helps to guide the focus of the excitation and collection spot for Raman imaging experiments of real-world samples.

FBH developments enable rapid shifted excitation Raman measurements

Raman spectroscopy is an established method to analyze organic and inorganic substances. The FBH bridges the gap between various life science applications and high-end diode laser technology. This enables the development of suitable light sources for high-precision Raman measurements that were already successfully performed on food, soil, plants, and human skin. For several years now, mobile devices like handheld sensors are commercially available and open up application fields including point-of-care diagnostics, on-site food inspection and detection of hazardous substances. Still, Raman signals are weak, and additional challenges have to be considered. Laser-induced fluorescence originating, for example, from biological samples or ambient light such as daylight could mask the Raman signals and hence complicate identification, especially for unknown substances.

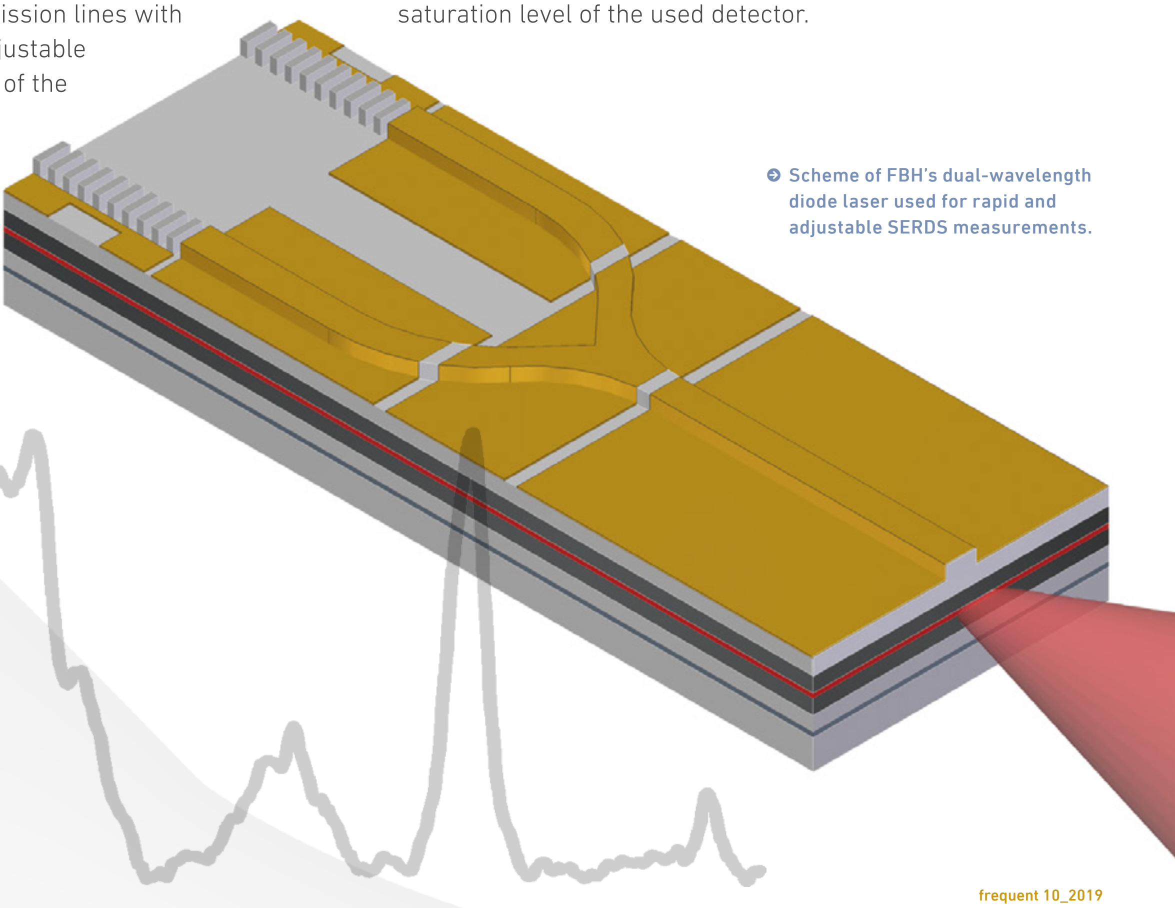
However, the shifted excitation Raman difference spectroscopy (SERDS) approach is a powerful and easy-to-use spectroscopic technique to overcome these drawbacks. SERDS requires an excitation light source with two individually controllable emission lines. As a result, Raman signals can be clearly separated from disturbing background interferences. The FBH has demonstrated suitable monolithic dual-wavelength diode lasers emitting at 785 nm and 671 nm, respectively. The spectral distance of the two excitation wavelengths was chosen in a way that they are close to the full width at half maximum (FWHM) of the Raman bands under study. However, for various substances the spectral width of the Raman signals can differ between a few to several tens of wavenumbers. To improve SERDS, the excitation source should provide two emission lines with a flexible spectral distance adjustable with respect to the bandwidth of the Raman signals under investigation.

Flexible and rapid measurements using monolithic dual-wavelength diode lasers

Recently, the FBH has realized dual-wavelength diode lasers at 785 nm with electrically adjustable spectral distance. These monolithic devices have a footprint of only 3 mm x 0.5 mm and provide two excitation lines with an optical power up to 170 mW. Two separate heater elements are implemented close to each distributed Bragg reflector (DBR) grating at the rear side of the semiconductor chip. These on-chip resistor heater elements allow to flexibly adjust the spectral distances between 0 and 2.3 nm (0 and 36 cm^{-1}) simply by changing the heater current. Moreover, these dual-wavelength diode lasers enable a fast alternating operation between both laser lines for rapid SERDS and thus investigations with exposure times down to the millisecond range.

At FBH, Raman and SERDS experiments with Irish cream as test sample were successfully carried out using SERDS distances between 1 cm^{-1} and 30 cm^{-1}. The liquor was excited using an alternating operation between both laser lines with exposure times down to 50 ms. Separation and identification of closely neighboring Raman bands of different components of the Irish cream could be improved with a 15-fold increased signal-to-background noise using the selected SERDS distance of 15 cm^{-1}.

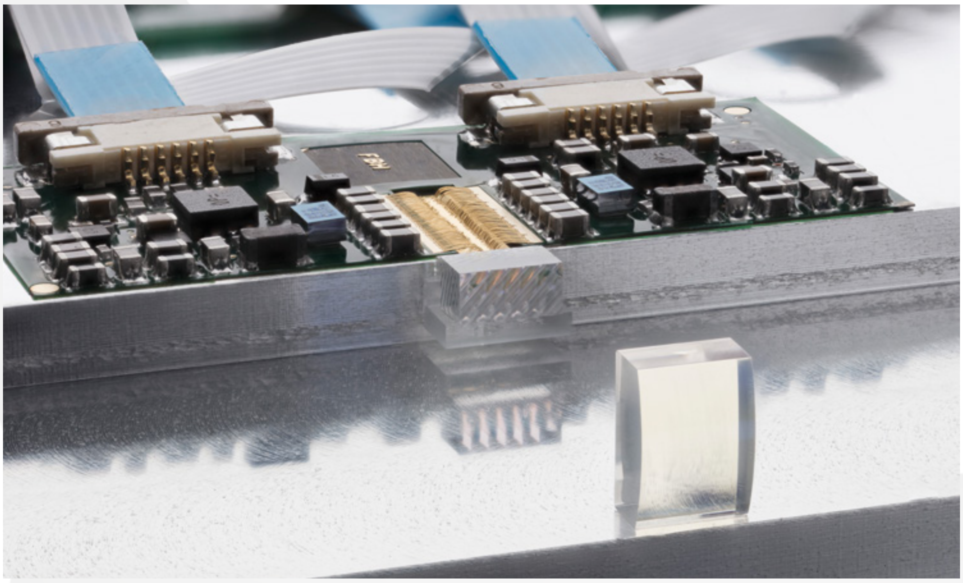
These FBH innovations make Raman spectroscopy accessible for rapid measurements which show huge disturbing background signals, and whose intensities are often close to the saturation level of the used detector.



Scheme of FBH's dual-wavelength diode laser used for rapid and adjustable SERDS measurements.

High-performance light sources for LiDAR applications – from autonomous driving to weather monitoring

Light Detection and Ranging (LiDAR) is a well-established method for remote sensing. Various parameters can be measured by detecting backscattered light. These include distances and velocity of objects, aerosols, and dust as well as concentrations of gases, particles, and droplets over larger distances. The FBH has developed suitable diode laser based light sources that allow replacing commonly used pulsed high-power solid-state lasers with ps or ns diode lasers.



Pulsed laser source for automotive LiDAR applications. The emission of its three emitters is optically combined into one spot.

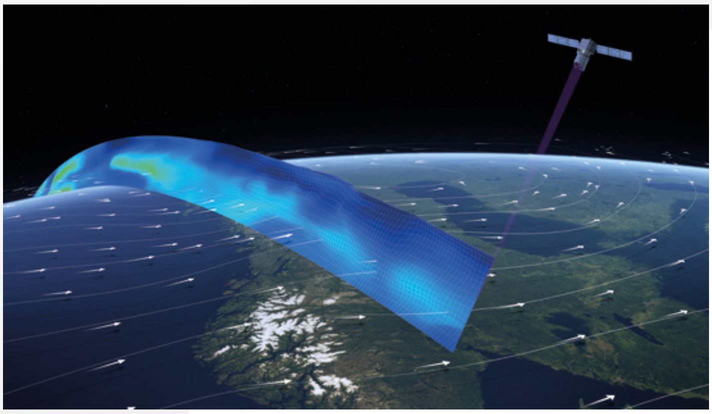
Ultra-precise distance measurements

Key components for distance measurements, which are required for autonomous driving and 3D object detection, are diode lasers generating short optical pulses in the range from 200 ps to 20 ns. FBH has developed the appropriate laser sources for this purpose, which use a tailored diode laser design for pulse generation and optimized RF components as electronic drivers. Both fields are core competencies of the institute. The design of the output circuit is optimized for high peak current up to 250 A, short optical pulse widths between 3 ns and 20 ns, high repetition rates, and high power efficiency. For automotive driving, 905 nm wavelength-stabilized diode lasers with a pulse peak power per emitter of up to 40 W are being developed. 3-emitter laser chips, whose emission can easily be optically combined into one single spot, yield up to 100 W. Further wavelengths between 650 nm and 1200 nm are possible.

Improving weather forecasts – on earth and in space

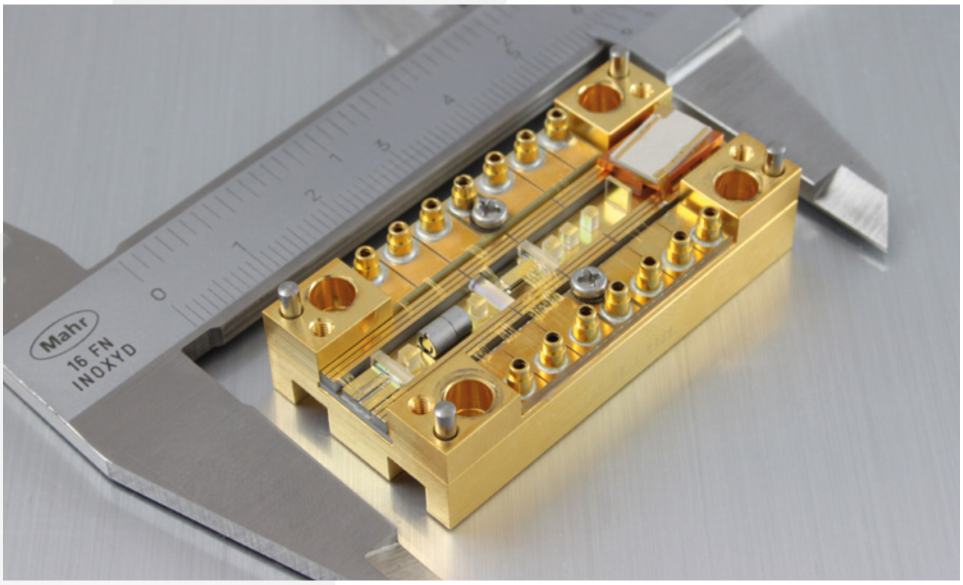
For weather monitoring applications, micro-pulse LiDAR (MPL) is using a short laser pulse with moderate peak power transmitted from earth to the atmosphere. As this pulse travels along, part of it is scattered by molecules, water droplets and other objects in the atmosphere. This effect can be used to detect aerosols as well as to determine water vapor concentrations, e.g., for weather forecasts – which makes a high output power along with a narrow spectral linewidth essential. In the case of determining gas concentrations, a dual wavelength operation is required to measure within (λ_{on}) and outside (λ_{off}) the absorption. The institute has been developing suitable monolithic and hybrid master oscillator power amplifier systems, which are refined with FBH's RF electronics components. When using a dual wavelength Y-branch laser at 960 nm, similar to the devices used for SERDS at 785 nm, the systems reach peak powers up to 16 W with a narrow spectral linewidth below 10 pm, which enables gas measurements under atmospheric conditions.

With the launch of ESA's Aeolus satellite, spaceborne measurements of wind speed have attracted a great deal of public attention. This can be attributed to the satellite's importance for accurate weather forecasts and climate modelling – especially in view of extreme weather phenomena due to climate change. Aeolus utilizes a 3D imaging system based on the ultraviolet (UV) LiDAR instrument ALADIN. FBH delivered the space-qualified diode lasers as pump sources for solid-state resonators. Their third harmonic is 355 nm UV light, which is well suited for the scattering of droplets in the atmosphere. FBH pump lasers exhibit outstanding reliability with mean-time-to-failure of over 10 million hours and proven resilience against environmental stress and space irradiation.



Profiling the world's winds with Aeolus (©ESA/ATG medialab).

Diode lasers for nonlinear frequency conversion



Diode laser module emitting in the yellow spectral range, e.g., for treatment of eye diseases by laser coagulation.

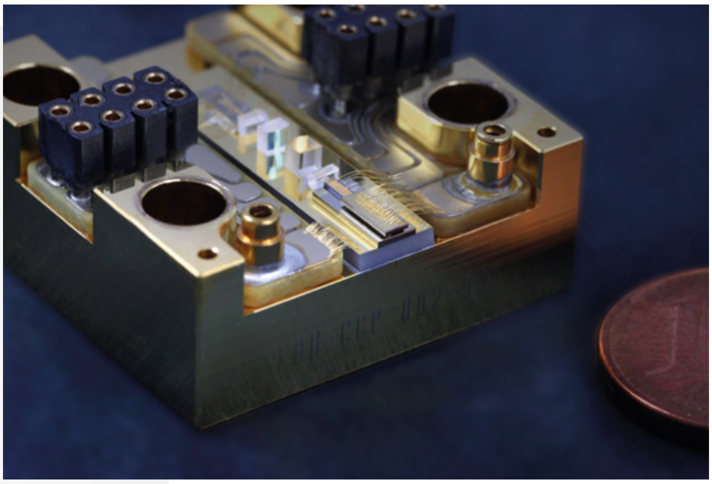
Diode lasers cover a broad range of emission wavelengths. A straightforward and efficient approach to compact devices with an increased number of usable wavelengths is nonlinear frequency conversion. Amongst others, it allows generating laser emission from the ultraviolet to the visible spectral range by second harmonic generation as well as up-converting infrared emission to detectable near-infrared wavelengths.

Wavelengths on demand by second harmonic generation

Recent developments at FBH have enabled access to new wavelengths, which currently cannot be addressed by direct-emitting diode lasers. Compact single-pass second harmonic generation of diode lasers and modules has opened the door to the ultraviolet and gaps in the visible spectral range. For the first time, external wavelength-stabilized GaN diode lasers have been frequency converted to 225 nm with up to 160 µW optical output power. This UV-C wavelength range is highly attractive for applications such as absorption and Raman spectroscopy. By using the developed FBH devices Raman signals can be spectrally separated from disturbing fluorescence contributions. To address the visible spectral range, 920 - 1180 nm ridge waveguide and tapered diode lasers with superior beam quality and internal Bragg gratings have been developed. Compact assemblies on CS mount or as miniaturized modules provide frequency conversion to 460 - 590 nm with watt-class output powers. These lasers are applied in Raman spectroscopy applications like food quality control and medical point-of-care detection as well as for direct pumping of laser systems such as titanium sapphire lasers. Operating these devices in pulsed mode opens up further demanding applications such as STED microscopy and fluorescence spectroscopy.

Widely tunable diode lasers for up-conversion and imaging

Based on achievements regarding wavelength-stabilized diode lasers, FBH has recently developed widely tunable ridge-waveguide diode lasers. Multi-branch diode lasers with micro-heaters above the internal Bragg gratings enable multi-wavelength laser emission with close to 10 nm thermal tuning. In a second approach, wavelength tuning of 23 nm was obtained using sampled-grating lasers. Necessary watt-class power scaling of these devices for nonlinear frequency conversion was demonstrated in master oscillator power amplifier configurations on compact 25 x 25 mm^2 CS mounts. Sum-frequency generation using devices emitting at 976 nm enables to up-convert infrared (IR) light at 2 - 25 µm to wavelengths < 1 µm, thus a spectral range that can be detected with standard Si-based detectors. The applicable wavelength tuning allows for multiple phase matching conditions and enables hyperspectral imaging in the IR using CCD cameras. These features open up a multitude of industrial and biomedical sensor applications such as combustion analysis, absorption or differential absorption, LIDAR spectroscopy, and cancer diagnostics.



Hybrid Y-branch dual-wavelength master oscillator power amplifier suited, e.g., for nonlinear up-conversion and hyperspectral imaging.

Product in focus

Compact microwave plasma source – a versatile tool for various applications

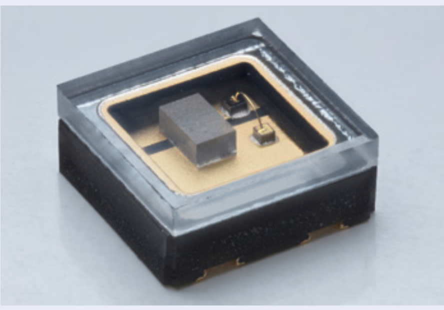
Atmospheric plasmas offer a wide range of applications in the field of surface treatment and activation, including temperature-sensitive materials. The FBH has developed a very compact plasma source, sized only 114 x 33 x 25 mm^3, that offers a 2.45 GHz microwave plasma in the 10…20 W range. The source only needs single 48 V DC supply, plus gas feeding and water cooling, which can also be replaced by air ventilation. Supply of the plasma medium, like air, argon, nitrogen, and oxygen, and the cooling medium is designed in such a way that the source can be used in a very flexible way. Applications range from the activation of surfaces (plastics, metals) in industrial production through cleaning and coating to medical applications.

The source comprises a microwave power oscillator, a resonator with plasma excitation and the control circuit, integrated in a single, miniaturized package. An FBH gallium-nitride transistor is used for most efficient microwave power generation. The source is easy to handle, either as a stand-alone plasma tool or as part of equipment.

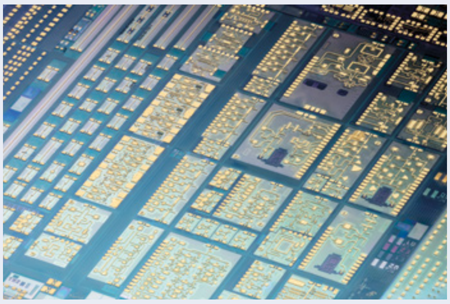
Research in focus

Deep UV LEDs with enhanced optical power

Within their Joint Lab GaN Optoelectronics, FBH and TU Berlin have considerably improved the performance of their deep-UV LEDs. LEDs emitting at wavelengths below 240 nm are of great interest for various applications including automotive (e.g. NO_x and NH_3 gas sensing), medical diagnostics, and space (e.g. photoionization of test masses). However, due to the very large bandgap energies of the $Al_xGa_{1-x}N$ layers of up to 6 eV in the deep-UV LED heterostructures, the performance of these devices degrades rapidly with shorter UV wavelength. After optimizing the n-type AlGaN current spreading layer, the quantum wells, the electron blocking layer and the step-graded p-type AlGaN superlattice, the LED efficiency could be significantly improved. AlGaN heterostructures grown by epitaxial lateral overgrowth on (0001) AlN/sapphire substrates using metalorganic vapor phase epitaxy were processed to single chips, flip-chip mounted in 3.5 mm x 3.5 mm ceramic packages and capped by quartz glass lids. The LEDs emit at 233 nm with a total power of 0.3 mW when operated at 100 mA. This power is more than one order of magnitude higher than previously obtained values, and it opens the door to new applications of deep-UV LEDs.



Towards terahertz transistors – transferred substrate InP/GaAsSb heterojunction bipolar transistor technology



FBH's InP MMICs heterointegrated on IHP's SiGe BiCMOS technology.

InP-based semiconductor devices offer the highest cut-off frequencies and largest breakdown voltages. FBH has developed an InP MMIC transferred substrate process, offering better scaling capabilities towards THz frequencies. This process also allows for heterointegration with SiGe BiCMOS or CMOS process technology. Consequently, the power generation capability of InP DHBT technology can be combined with the circuit complexity of silicon technology on a single microchip, thus avoiding coupling losses and reducing integration costs. Full RF front ends for THz applications can be manufactured. Unnecessary InP material is replaced by a polymer with excellent high-frequency properties, thus reducing parasitic capacitances as compared to the standard triple mesa process. Therefore, high cut-off frequencies can be achieved even with relatively large transistor dimensions. FBH has applied epitaxial structures with a GaAsSb base grown at ETH Zurich to its unique transfer substrate process for the first time, reaching cut-off frequencies beyond 530 GHz. Further scaled transistors with projected values of 900 GHz are in production.

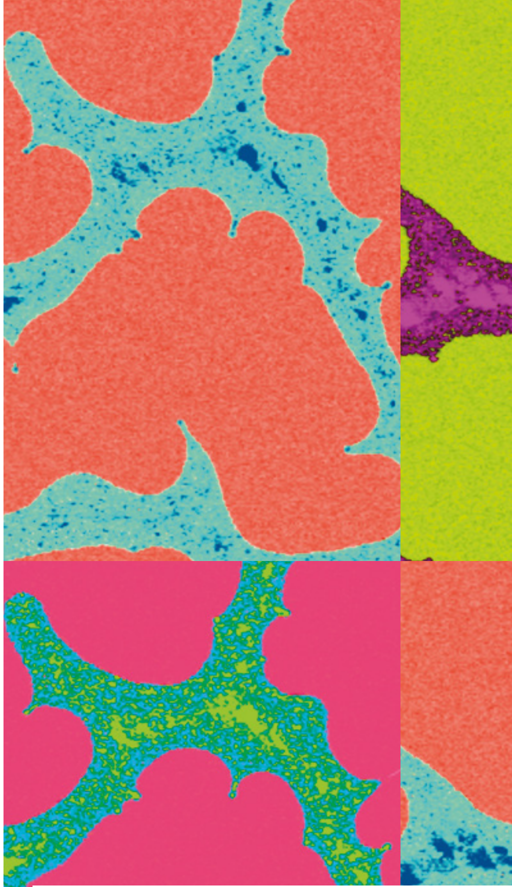
The Ferdinand-Braun-Institut, Leibniz-Institut fuer Hoechstfrequenztechnik (FBH) researches electronic and optical components, modules and systems based on compound semiconductors.

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 modules. 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, industrial sensing and imaging as well as car safety systems. In addition, the institute fabricates laser drivers and compact atmospheric microwave plasma sources operating with economic low-voltage drivers for use in a variety of applications.

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 through 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. Overall, working in strategic partnerships with industry, FBH ensures German 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. With its Prototype Engineering Lab, the institute additionally created an active interface between science and industry. By means of prototypes it turns excellent research results into market-oriented products, processes, and services. The institute thus offers its international customer base complete solutions and know-how as a one-stop agency – from design to ready-to-use modules and prototypes.



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