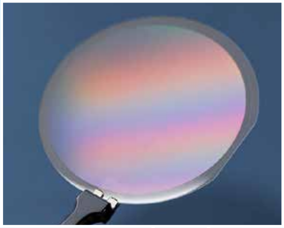
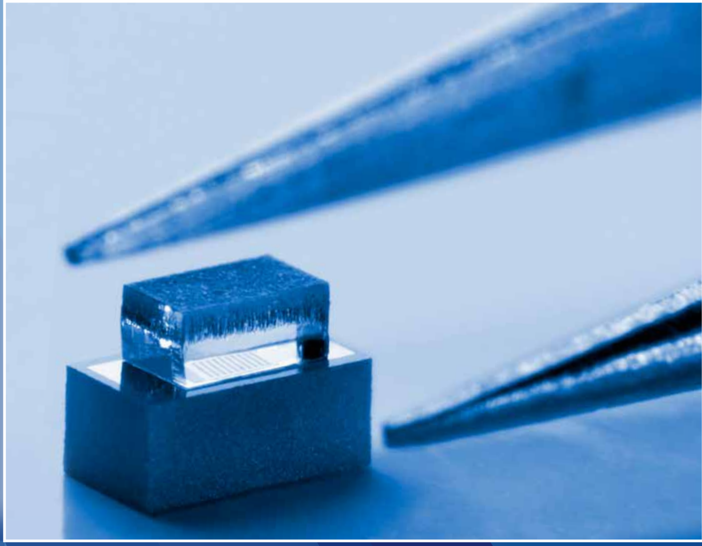
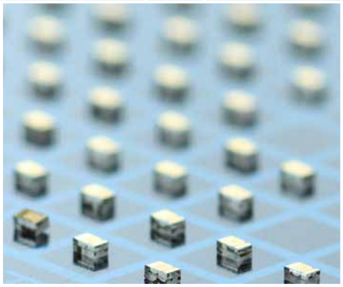
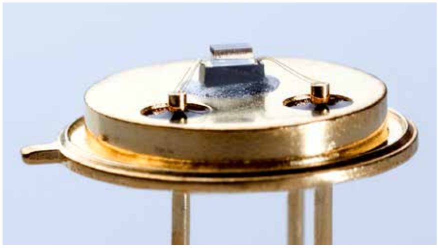
frequent

Research news from the Ferdinand-Braun-Institut





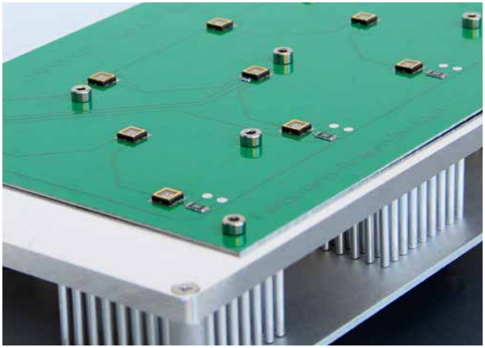




Ultraviolet light from LEDs

▶ technology with benefits
▶ novel approaches to disinfect water
▶ surface treatment

▷ product in focus
▷ research in focus



Technology with benefits— ultraviolet light from semiconductor LEDs

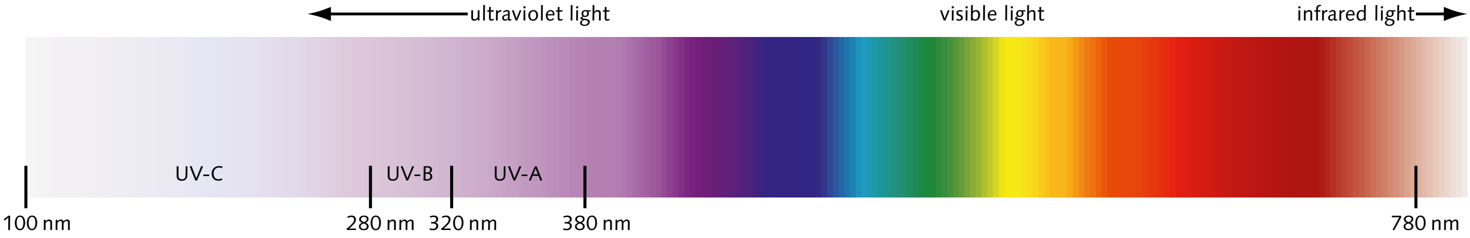
A great variety of applications, ranging from water disinfection to UV curing, make use of the advantageous properties of ultraviolet (UV) light. Until recently, the generation of ultraviolet light was limited to conventional sources such as mercury gas discharge lamps. However, modern semiconductor-based UV light emitting diodes (LEDs) can outperform these conventional sources in many respects: Rather than emitting a limited number of discrete wavelength lines given by the respective gas molecules, the spectrum of a UV LED can be freely adjusted by the semiconductor alloy composition. In addition, toxic substances like mercury are replaced by environmentally friendly group-III nitride semiconductors. Last but not least, UV LEDs can be turned on and off rapidly; they are fully dimmable, allow efficient heat extraction, and provide a compact form factor. In the long run, UV LEDs are expected to score with long operation lifetimes, a high efficiency, and an attractive pricing. Therefore, their market share is expected to take a leap from about 45 million $US in 2012 to 270 million $US in 2017—with an annual growth rate predicted to be around 43 % (cf. Yole Développement, March 2013).

Modules designed to fit specific requirements

The FBH has realized several compact UV LED modules, each customized for the specific demands of the application. In collaboration with its partners from universities, other research institutes, and companies, functionality and effectiveness of the modules have been successfully demonstrated. Continuous disinfection of a flow cytometric cell sorter in a medical environment, for example, has been demonstrated. Current development efforts aim at enhancing this approach to clinical applications, such as the therapy of humans suffering from autoimmune disorders. For this purpose, very specific rare cells shall be isolated from the human body; they can then be grown in vitro in large quantity and returned to the patient to treat the disease. In further experiments, the concentration of secondary metabolites in plants could be significantly enhanced by illumination with UV LEDs—an effect which may be used to grow vegetables enriched with specific human-protective secondary metabolites for functional foods and nutraceuticals.

Full technology chain

FBH has developed epitaxial growth processes and chip fabrication technologies to realize UV LEDs emitting in the spectral range between 380 nm and 235 nm. The technology involves the full process chain including metal organic vapor phase epitaxy (MOVPE), LED chip processing, and flip-chip mounting up to the assembly of complete UV LED modules. This also comprises modeling of heterostructure designs and simulation of the device characteristics at all process stages. FBH has developed, for example, focusable LEDs emitting in the spectral range around 365 nm with very small emitting areas. Due to the special chip design, closely resembling point sources, the UV light can be easily coupled into optical fibers—a key feature particularly for mobile applications such as battery-powered devices used for in situ blood gas sensing.



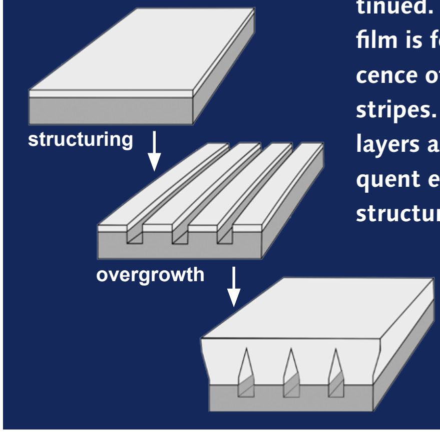
ABOUT ULTRAVIOLET LIGHT—AND ITS APPLICATIONS

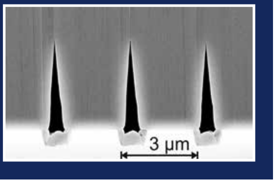
Visible light covers the wavelength range from about 780 nm in the red down to 380 nm in the violet. The invisible ultraviolet (UV) light, however, is electromagnetic radiation at shorter wavelengths, distinguished in near UV (UV-A, 380–320 nm), mid UV (UV-B, 320–280 nm), and deep UV (UV-C, 280–100 nm). The sun is a natural UV source, though hardly utilizable for commercial applications, since water vapor, ozone, and oxygen naturally occurring in the atmosphere absorb a significant portion of the UV-B and UV-C radiation.

However, UV light can be generated technically and used in many ways: Organic and inorganic compounds, for example, undergo various chemical reactions when subjected to UV light. Exposing polymers to ultraviolet light results in cross-linking of molecule chains which hardens and solidifies the material. UV light can break chemical bonds in the DNA strands and hence suppress the replication of micro-organisms—a key process in water disinfection. In addition, UV light can be used for the treatment of skin diseases, for the detection of fluorescence markers as well as for sensing of various gases and liquids.

ELO—BOOSTING UV LED EFFICIENCY

The efficiency of UV LEDs significantly depends on the crystal quality of the semiconductor heterostructures. These structures are epitaxially grown on sapphire substrates by metal organic vapor phase epitaxy. To improve the crystal quality as well as to reduce the stress in the growing layers, FBH has successfully implemented the method of epitaxial lateral overgrowth (ELO) in LEDs emitting in the UV-B and UV-C range. After the deposition of AlN layers and subsequent structuring into a stripe pattern, AlN growth is continued. As a result, a compact film is formed due to coalescence of the laterally growing stripes. These advanced AlN layers are the basis for subsequent epitaxy of the diode structures.

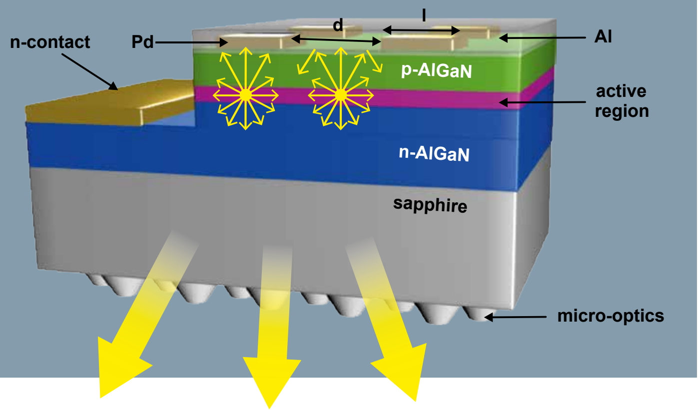




ADVANCED CONCEPTS FOR LIGHT EXTRACTION

Light extraction is crucial for the realization of high-efficiency UV LEDs. At the FBH, two novel concepts to enhance light extraction have been developed and successfully implemented into UV LEDs.

- **A general approach, applicable to all LEDs, uses microstructures etched into the backside of the sapphire substrate. Reflection at the additional facets increases the probability of photons to enter the escape cone of the chip and thus enhances the LED efficiency.**
- **The concept of nanopixel contacts addresses near-UV LEDs with a UV transparent p-side of the semiconductor. A two-dimensional array of palladium pads of submicrometer size serves as low resistance contact, while the space between the pads is filled with aluminum as a reflector for UV light.**



EDITORIAL

UV LEDs—capturing new markets

UV LEDs with short wavelengths increasingly yield efficiencies and output powers making these light sources utilizable for a rising number of applications—new as well as established ones. Thus, it is to be expected that conventional UV light sources are more and more replaced by environmentally friendly LED devices.

A whole series of novel developments at FBH are conducted within strategic networks, bringing major partners along the value chain together. This approach ensures a rapid transfer of technology, helping the institute and its associate partners to remain internationally competitive. In "Berlin WideBaSe", a network financed by the Federal Ministry of Education and Research (BMBF), for example, ten companies and three research institutions joined forces to develop, manufacture, and market optoelectronic and electronic devices based on wide bandgap semiconductors, including UV LEDs. Such joint efforts create confidence and therefore, quite often, lay the foundation for further collaboration. Only recently, the "Advanced UV for life" concept has been successful in the "Zwanzig20" competition. A consortium of currently 22 partners, among them many already affiliated within "Berlin WideBaSe", bundles competencies to bring tailored UV light sources for medicine, water treatment, and sensors into the market. Within the next five years up to 45 million Euros will be provided by the BMBF—a great success not only for the FBH itself, but also an acknowledgement for its collaborative, output-driven approach.

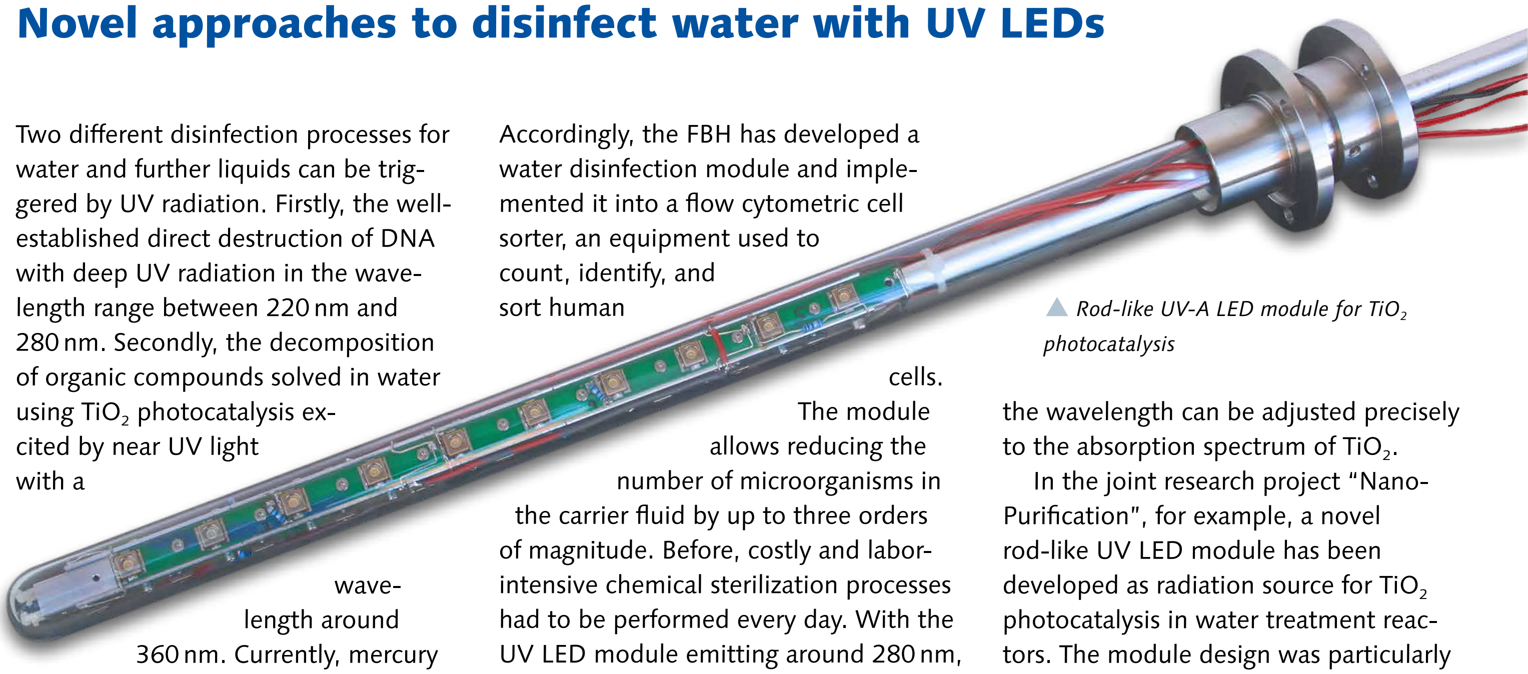
We wish you an inspiring reading of this frequent issue presenting current FBH developments in the field of UV LEDs,

Günther Tränkle

Günther Tränkle

▸ www.fbh-berlin.de/frequent

Novel approaches to disinfect water with UV LEDs



Rod-like UV-A LED module for TiO_2 photocatalysis

Two different disinfection processes for water and further liquids can be triggered by UV radiation. Firstly, the well-established direct destruction of DNA with deep UV radiation in the wavelength range between 220 nm and 280 nm. Secondly, the decomposition of organic compounds solved in water using TiO_2 photocatalysis excited by near UV light with a wavelength around 360 nm. Currently, mercury gas discharge lamps are used for such processes. Since several years, UV LEDs have increasingly attracted interest as alternative UV radiation sources. Main advantages are their tailored wavelength, long lifetime, compact form factor, and low operation voltage. At the FBH, several modules and systems have been realized efficiently using the emitted UV radiation and thus bringing UV LED technology into new applications.

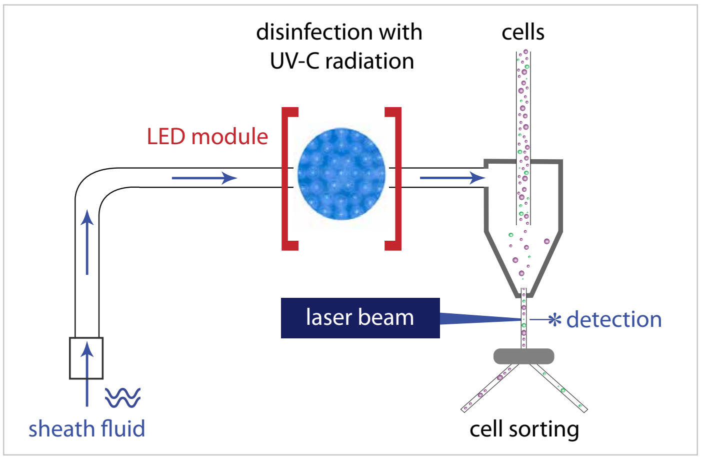
Clever disinfection—extending maintenance cycles of medical equipment

Irradiation in the deep UV range is an effective way to prevent microorganisms from reproduction. Since LED efficiency has been constantly improved in recent years, they can already be used for liquids with low flow rates in the order of a few liters per minute. Accordingly, the FBH has developed a water disinfection module and implemented it into a flow cytometric cell sorter, an equipment used to count, identify, and sort human cells. The module allows reducing the number of microorganisms in the carrier fluid by up to three orders of magnitude. Before, costly and labor-intensive chemical sterilization processes had to be performed every day. With the UV LED module emitting around 280 nm, the cell sorter remains sterile for at least seven days after system sterilization without any chemical cleaning. The module has been developed in close collaboration with Technische Universität Berlin and is currently being tested in flow cytometers at German Rheumatism Research Centre Berlin.

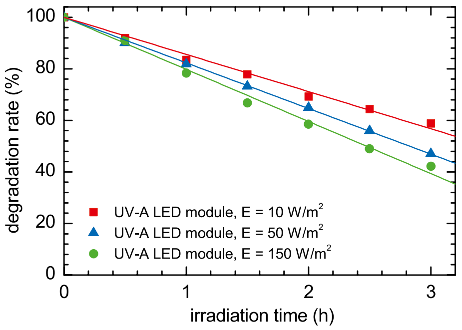
Photocatalysis—efficient activation of surfaces

Substances that are difficult to degrade, including medication, chemicals, and organic compounds, can be efficiently decomposed by TiO_2 photocatalysis. Applications for the process range from house paints to medical surfaces. To benefit from the self-cleaning and antimicrobial effect even in small and geometrically complex constructions, compact UV LEDs are an attractive option. They additionally promise to be particularly efficient since the wavelength can be adjusted precisely to the absorption spectrum of TiO_2.

In the joint research project "NanoPurification", for example, a novel rod-like UV LED module has been developed as radiation source for TiO_2 photocatalysis in water treatment reactors. The module design was particularly optimized in terms of high density packaging of the UV LEDs, effective thermal management, and modular expandability. This design enables sufficiently high UV irradiance at a wavelength of 360 nm and flexible adaption to different reactor geometries. Efficient heat dissipation of the thermal power loss from the UV LEDs is particularly important, because low temperatures is one key to long operation lifetimes as well as constant emission wavelength and optical power. The photocatalytic efficiency of the system has been demonstrated by determining the degradation rate of methylene blue, a stain to highlight structures in biological tissues. For this purpose, a TiO_2 layer, activated by the emission from the UV LED module, was used resulting in a degradation rate of ≥ 20 %/h at an irradiance of 150 W/m^2. ■



Principle of flow cytometric cell sorter with integrated UV-C LED module



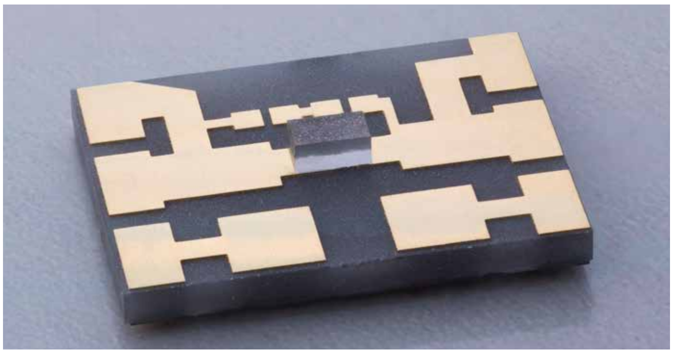
Degradation rate of methylene blue by a TiO_2 layer activated with UV-A LEDs

Surface treatment by UV light—high-power LEDs on the rise

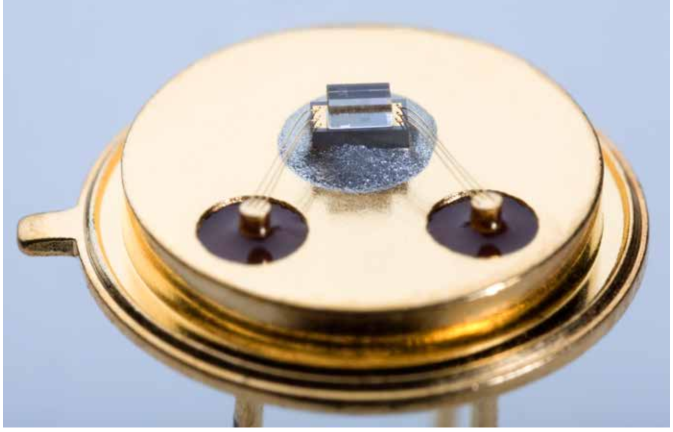
UV-B LEDs emitting in the wavelength range from 280 to 320 nm are ideally suited for surface treatment of polymers, resist curing, hardening of paints, plant growth lighting, and phototherapy. However, the usage of these devices is hampered by the large optical power required for many of these applications. Within the "Berlin WideBaSe" network, the FBH and its partners have developed flip-chip mounted bottom-emitting UV-B LEDs that deliver a high optical output power of more than 13 mW at high currents. Moreover, the devices show long operation lifetimes—more than 1,000 hours under continuous-wave operation at room temperature. A loss in optical power occurs mainly during the first 50 hours; further degradation is slow even for operation currents as large as 300 mA. These results significantly exceed commercially available UV-B LEDs which are typically specified for operation at a low current of 20 mA.

Mastering technological challenges

To achieve these performances, many technological obstacles had to be overcome. With respect to material growth, the epitaxial layer structures were optimized in terms of optimum current injection into the active region of the heterostructure. For instance, an optimized electron blocking layer was developed minimizing the overflow of electrons beyond the active region. Moreover, the density of extended crystal defects was reduced by utilizing sophisticated concepts of AlGaN buffer layers deposited on sapphire substrates and applying the concept of epitaxial lateral overgrowth (ELO), respectively. This way, the internal quantum efficiency of radiative carrier recombination has been significantly enhanced. A large effort was also devoted to optimizing the chip design and fabrication process in order to achieve uniform light emission, to increase light extraction efficiency, and to obtain efficient heat dissipation. For instance, special micro-LED arrays with segmented electrical contacts were developed both to reduce current crowding and to increase heat extraction. Moreover, the metallization schemes for ohmic electrical contacts on n-type AlGaN were optimized by using, for example, novel elements like vanadium, resulting in a significantly reduced operation voltage of the LED. Finally, two concepts to increase the efficiency of extracting UV light from the LED chip have been developed: nanopixel p-contacts combined with an aluminum UV reflector and sapphire substrates textured with micro-optics. After laser scribing the LED wafers are diced into LED chips and then hard-soldered onto AlN ceramic submounts, ensuring a low thermal resistivity of the package. ■



▲▼ *UV LEDs from the FBH on different submounts*

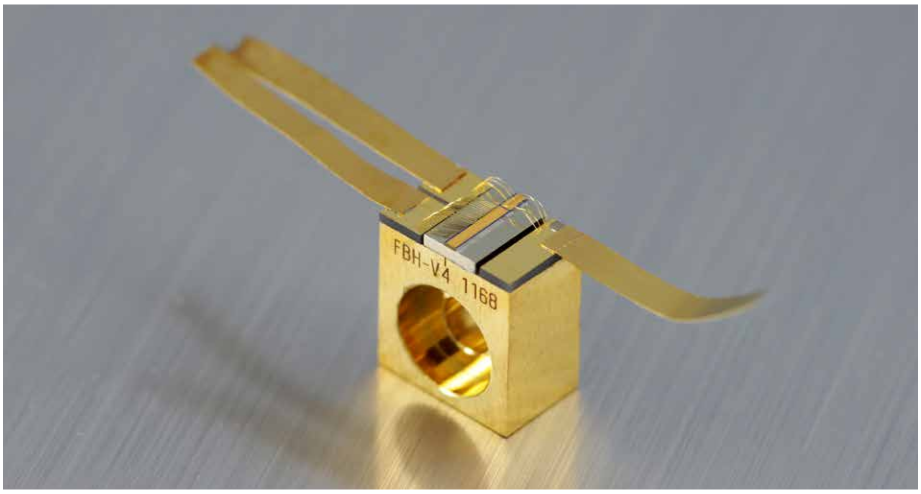


◀ *Multi-wafer reactor at FBH for metal organic vapor phase epitaxy of GaN*

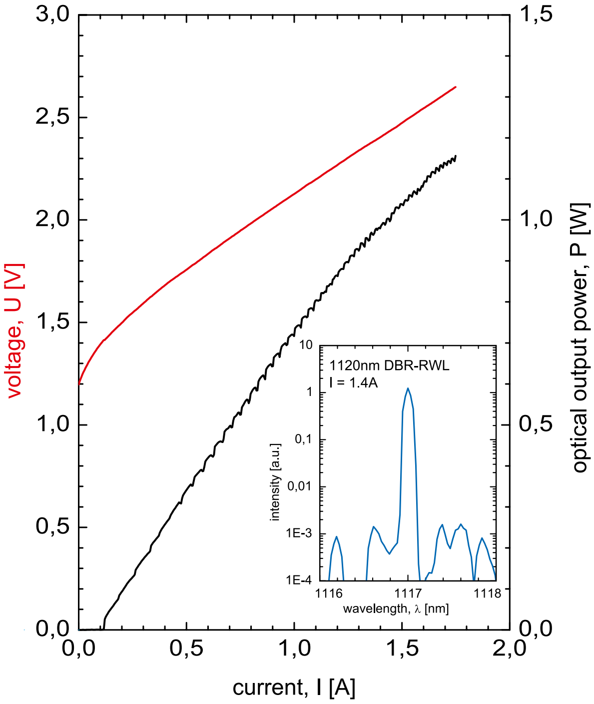
PRODUCT IN FOCUS

High brilliance 1120 nm diode lasers for compact 560 nm light sources

The FBH has developed a compact source at 1120 nm which is ideally suited for frequency doubling to 560 nm, a wavelength used for time-resolved fluorescence and atomic spectroscopy, photocoagulation in ophthalmology, medical skin treatments, and high-resolution refractometry. Unlike currently available laser sources, the FBH laser offers direct modulation capability, high efficiency, and flexible wavelengths. The laser bases on a monolithic distributed Bragg-reflector ridge-waveguide diode laser (DBR-RWL) featuring high optical output power, nearly diffraction limited beam, and narrow spectral linewidth. Furthermore, the new laser chip comprises electrical heaters next to the DBR, which enables a flexible tuning of the emission wavelength. The DBR-RWLs achieved output powers up to 1 W and a maximum conversion efficiency of ~ 34 % with spatial and spectral single-mode emission. They are the basis for future matchbox-sized laser modules enabling mobile applications and handheld devices. Thus, results of in situ measurements are instantly available.



▲ *Enabling mobile applications: Distributed Bragg-reflector ridge-waveguide diode laser for future compact 560 nm light sources*



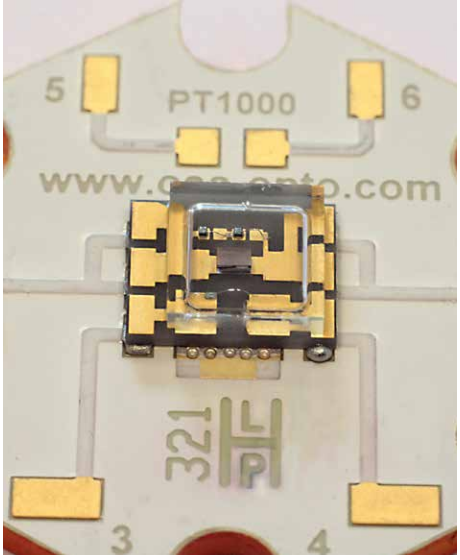
▶ *High brilliance: optical output characteristics up to 1.8 A and spectrum at 1 W of a 1120 nm laser diode*

RESEARCH IN FOCUS

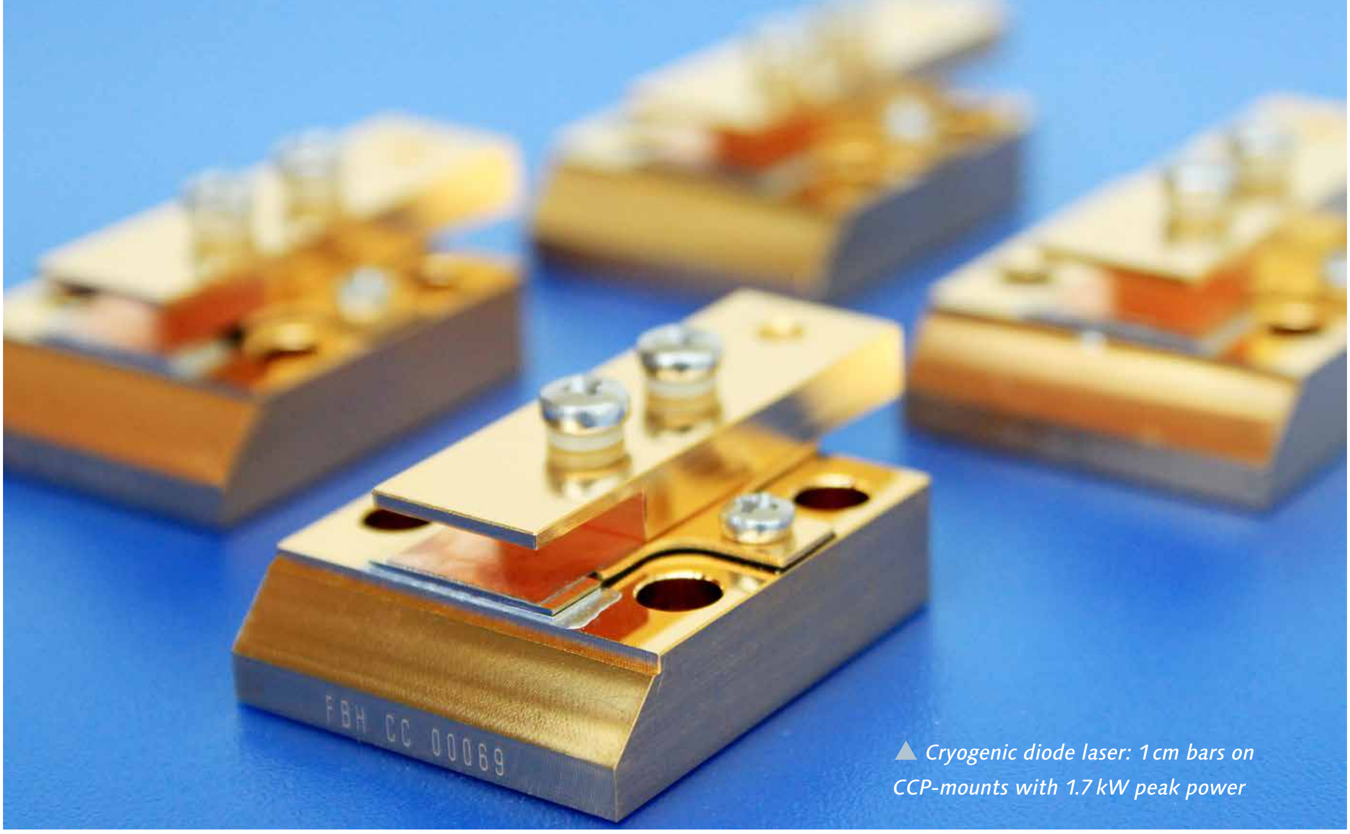
Advanced UV for life – novel ultraviolet light sources to the market

Bringing tailored ultraviolet (UV) light sources for medicine, water treatment, and sensors into the market is the objective of the “Advanced UV for Life“ consortium, coordinated by FBH.
This concept convinced the jury of the “Zwanzig20” competition funded by the Federal Ministry of Education and Research with up to 45 million Euros for the next five years. Today, 22 partner from research and industry crosslink their expertise from materials to components to systems. Thus, major partners in the field of UV light sources joined forces to develop the required UV technology for new applications.

For example, 310 nm UV-B LEDs developed by the FBH shall be further advanced within the cooperation. The LEDs, which can be used for production technologies like UV curing, deliver a large output power of 10 mW from a single chip due to optimized processing and mounting technology. The chips were then packaged by the industrial partner OSA Opto Light. Within “Advanced UV for Life”, the research and industrial partners aim to further develop such LEDs regarding additional wavelengths for further application fields.



▲ *Productive co-operation: prototype of a 310 nm UV LED with an optical power of 10 mW*



▲ *Cryogenic diode laser: 1 cm bars on CCP-mounts with 1.7 kW peak power*

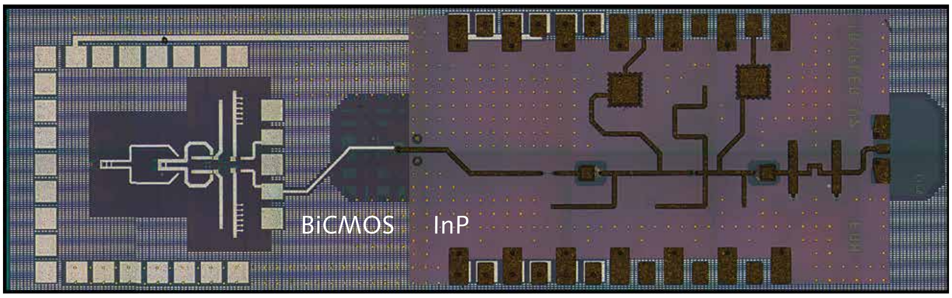
Ultra-high energy laser bars— record performance in frosty environment

Laser-induced fusion is a promising technology for future energy generation that would lead to a growing demand for large quantities of inexpensive ultra-high energy lasers. Corresponding laser facilities are being planned worldwide. In order to reduce production costs, which mainly arise from the amount of semiconductor material used, high power densities are requested. FBH recently gained particular attention for its research on cryogenic diode lasers: these deliver high optical power densities and at the same time minimize excess heat. The lasers are designed to operate best at low temperatures around 220 K. In this range, the semiconductor properties improve, with the output power and the electro-optical conversion efficiency η_E increasing, meaning that the heat generation can be reduced. Further improvements were achieved by a new mounting technology. The 1 cm wide diode laser bars were soldered p-down onto a CCP-mount, and the n-side contact was established by a thick copper foil rather than wire-bonds. At 220 K the laser emitted a peak power of 1.7 kW with a conversion efficiency η_E (1.5 kW) = 54 %. This is the highest power ever achieved from a 1 cm bar.

Signal sources up to 250 GHz in InP-on-BiCMOS technology

FBH and IHP in Frankfurt/Oder have further advanced their wafer-level InP-on-BiCMOS technology for broadband operation up to terahertz frequencies. This process combines the advantages of both InP-DHBT and SiGe-BiCMOS technologies. As a result, the first hetero-integrated signal source beyond 200 GHz has been successfully developed. It demonstrates the capability of the new process to realize essential mm-wave functions in the 250 GHz frequency range on the same chip. The circuit consists of a Voltage Controlled Oscillator (VCO) in BiCMOS technology and a frequency tripler in InP-HBT technology. With the VCO operating at 82 GHz with an output power of approximately 6 dBm, the tripler delivers –10 dBm at 246 GHz. Phase noise of the combined circuit is –87 dBc/Hz at 2 MHz offset.

▶ *Chip photograph of the InP-on-BiCMOS circuit*



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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 ultraviolet 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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