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frequent

Compact atmospheric plasma sources

- all-rounders with huge market potential
- ultra-compact plasma source μPQ
- μPQ goes industry – surface activation in printing
- prototypes – making R&D results utilizable

Editorial

Our FBH microwave plasma sources are like a well-assorted toolbox. They offer a cost-efficient and flexible solution for a wide range of requirements and applications.

We have been developing such atmospheric-pressure plasma sources for many years. With our in-house Prototype Engineering Lab, we have advanced them for industrial use. Hence, it is not surprising that our cooperation partners and customers are increasingly using FBH's sources successfully in their applications.

In this *frequent* issue we present the broad spectrum and the efficiency of these plasma sources as the main topic. In addition, our short news keep you posted on further developments from the Ferdinand-Braun-Institut.

I wish you an inspiring reading, Günther Tränkle

Using plasmas

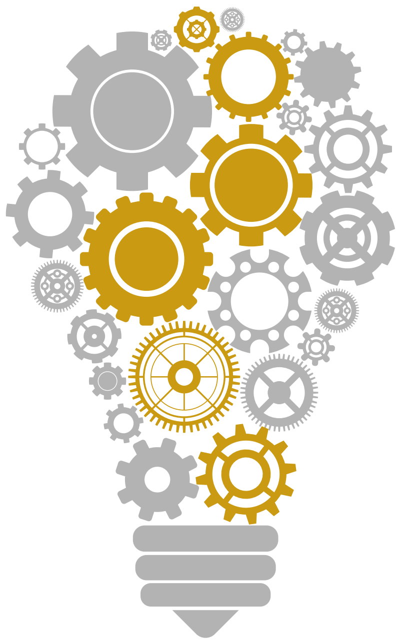
Technical gas discharge plasmas must be permanently supplied with energy, otherwise the plasma extinguishes. The positive and negative charge carriers then combine to form neutral atoms and molecules. The electrons released in plasmas give rise to new physical properties and affect their environment. Both electric and magnetic fields can control plasmas in such a way that they are directed towards a certain surface or kept away from another surface. This is used, among other things, for material coating or surface hardening. The application spectrum is broad and ranges from atomic layer deposition to material processing such as cutting or welding. In the medical sector, they are used for disinfection and wound healing.

Making R&D results utilizable – prototype engineering at FBH

FBH's Prototype Engineering Lab complements the institute's scientific competence. Based on the research results, it develops prototypes that can be tested in industrial applications. This way, the institute ensures rapid transfer into market-oriented products, processes, and services.

With its team of engineers and technicians, the Prototype Engineering Lab performs systematic device engineering of user-friendly prototypes for customized applications:

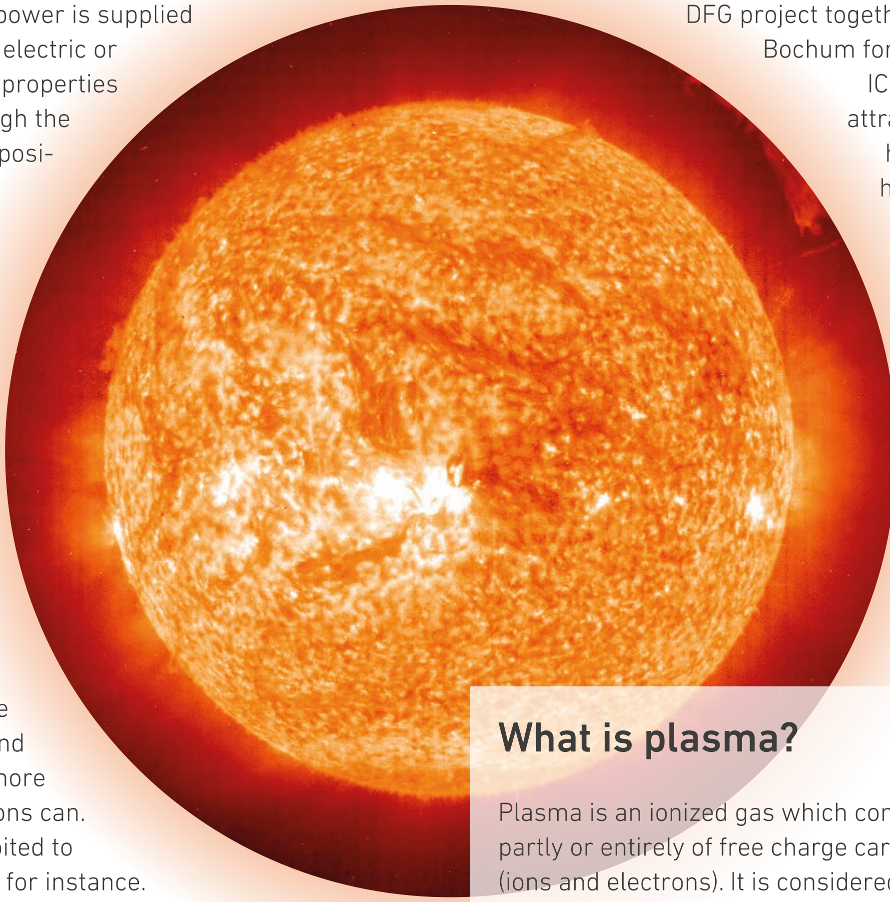
- Transforming research modules into stand-alone equipment that can be operated outside a lab environment
- Miniaturization of laboratory set-ups, utilizing dedicated electronics and optimized mechanical design
- Easy-to-use prototypes integrating power supply, sensors, and control unit



Microwave plasmas – all-rounders with huge market potential

Low-pressure plasmas have been used as a technical tool for quite some time, but only since plasmas can be generated also under atmospheric conditions new fields of application have opened up. Cold plasmas, for example, are highly attractive in industrial production when treating temperature-sensitive materials and activating surfaces. Recently, plasma processes have been established also in medicine and medical technology, to support wound healing and for sterilization of medical instruments, for instance.

To generate a plasma, power is supplied to a gas by applying an electric or magnetic field. Plasma properties can be controlled through the energy supply, the composition of the gas and the pressure. What makes microwave plasmas specific is their high excitation frequency, typically in the 2 GHz range. Basically, frequency influences plasma applications in three ways. First, plasma characteristics change with growing frequency because the ionized atoms cannot follow the electromagnetic field and thus do not move any more while the lighter electrons can. This effect can be exploited to generate cold plasmas, for instance. Second, the electrical resonators needed to couple the energy into the plasma shrink in size, which allows realizing very compact plasma sources not feasible at lower frequencies. Third, the electron density is quasi-constant during a microwave period, thus making the plasma very efficient and avoiding generation of harmonics.



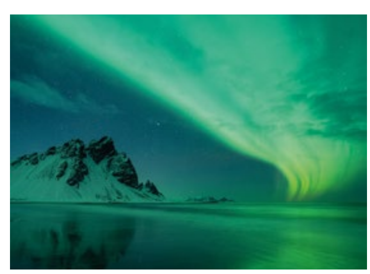
Compact microwave plasma generators for atmospheric and low-pressure conditions

FBH's atmospheric plasma sources require neither a vacuum chamber nor a high-voltage supply. They work under normal ambient air conditions. An oscillator integrated in the source generates a microwave signal in the 25-watt range, using an FBH high-performance gallium nitride transistor, which delivers high power at high efficiency. The oscillator feeds its 2.45 GHz signal through a resonant structure to the gas and thus ignites and maintains the plasma. Altogether, this results in a source with very small form factor. Electrically, only a DC supply is required. In a joint effort with the in-house Prototype Engineering Lab, this source was developed as a modular building block that can be tailored to the needs of the respective application.

The second topic of microwave plasma work at FBH is less mature, but very promising. It is about generating an inductively coupled plasma (ICP) within a small volume with an edge length of 10 cm, which was demonstrated in a DFG project together with Ruhr-Universität Bochum for the first time ever. Such ICP plasmas feature highly attractive properties such as high electron density and high plasma purity. Again, microwave excitation allows shrinking down bulky equipment to handy sizes.

What is plasma?

Plasma is an ionized gas which consists partly or entirely of free charge carriers (ions and electrons). It is considered to be the fourth state of matter and occurs when substances are heated up. More than 90 % of the visible universe is in plasma state, such as the sun and the stars. On Earth, thermal plasmas occur in fire, and electric plasmas in lightning or polar lights. Characteristic is their typical glow, which is caused by radiation emitted from excited gas atoms, ions or molecules.



µPQ – ultra-compact atmospheric-pressure microwave plasma source

Microwave plasmas are characterized by low plasma temperature, excellent intensity and good homogeneity. Furthermore, when generated under atmospheric pressure, they can be used efficiently and cost-effectively in a variety of applications, preferably for surface treatment such as activation, coating, and cleaning.

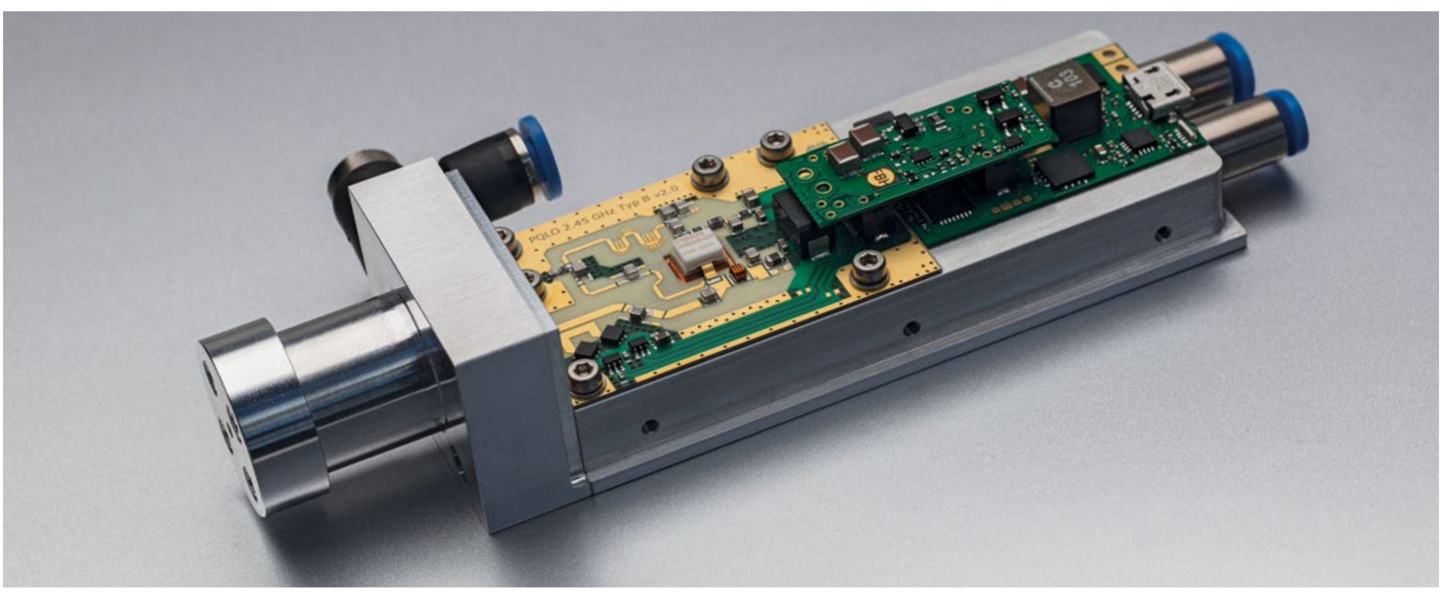
For this purpose, the FBH has developed an extremely compact plasma source that provides a microwave plasma with up to 20 W power, which is sufficient for many applications. With it, even temperature-sensitive materials like plastics can be treated without any problems. The source is also suitable for medical applications.

The small-sized plasma source contains a resonator for plasma excitation, a power oscillator operating in the 2.45 GHz ISM band as well as control and monitoring electronics – all integrated into a very handy housing of only 114 x 33 x 25 mm^3. Center piece of the efficient power oscillator is an FBH GaN transistor.

Design and development of the plasma source rely on FBH's comprehensive know-how in microwave technology. As a first step, a novel nonlinear plasma model was developed which predicts the electrical properties of the capacitively coupled microwave plasma (CCP) as a function of the absorbed power. Only with this knowledge it was possible to realize a microwave plasma source that both safely ignites the plasma and maintains it in a power-efficient way. Similarly, the resonator used for plasma excitation had to be carefully characterized, modelled and optimized. Among others, different electrode shapes were investigated to obtain the most suitable construction. Last but not least, the microwave power oscillator was optimized in terms of output power and efficiency as well as robustness against tolerances. One result of these comprehensive design efforts is that the plasma source can be easily adapted to different application scenarios, since it offers various tuning possibilities. For example, the power fed to the plasma can be adjusted over a wide range, also during operation.

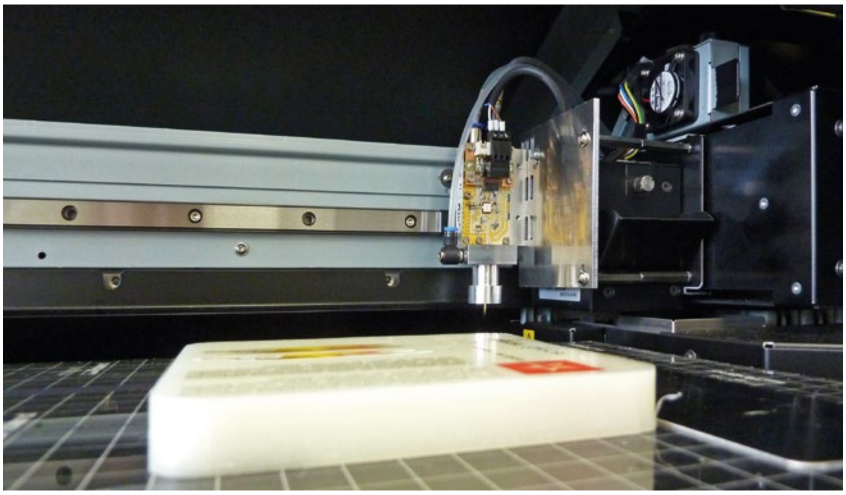
Ultra-compact atmospheric microwave plasma source µPQ

Beyond offering outstanding properties and versatile operation, this new generation of FBH plasma sources is very easy to put into operation. Basically, only a 48 V DC voltage, gas supply and water cooling are required. Due to the special microwave power oscillator design, the plasma source works with a variety of gases including argon, air, oxygen, and nitrogen. The standard water cooling can be replaced by air cooling, if required. Because the built-in control and monitoring electronics ensure safe operation in any case, the plasma source can either work completely independently or be controlled and monitored externally by the user. Therefore, the source can be used both as a stand-alone hand-held solution and as part of industrial equipment.

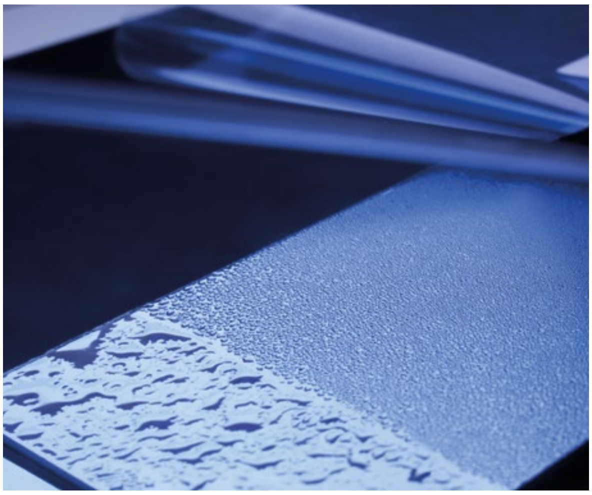


The compact microwave plasma source integrates resonator, power oscillator, control and monitoring electronics

µPQ goes industry – efficient and cost-effective surface activation



µPQ integrated into an industrial printer system to prepare plastic material for printing



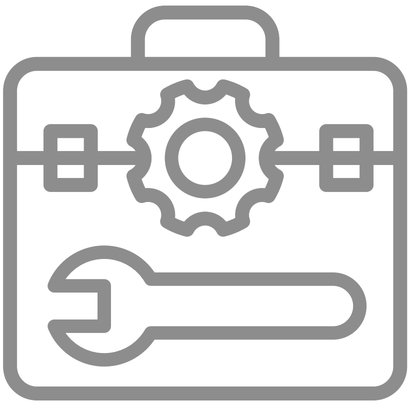
Better adhesion thanks to plasma treatment: left activated, right untreated surface

Due to their low surface tension, plastic surfaces can hardly be glued, coated or printed satisfactorily without pre-treatment. In order to increase adhesion, the surface is either treated with a primer, a chemically active adhesion promoter, or activated with a low-pressure plasma. In both cases, adhesion points are created by changing the surface bonds. With the ultra-compact atmospheric microwave plasma source µPQ developed by FBH, a cost-effective alternative to increase surface tension and improve adhesion has become available.

The new plasma source has already been successfully integrated and tested in several digital printer models in cooperation with TECHNOPLOT CAD Vertriebs GmbH, a digital printing specialist. Due to its extremely compact dimensions and the resulting low weight, the plasma source can be mounted directly in front of the print head. Therefore, activation of the material surface and subsequent printing are performed in a single step.

Improved printability of the plastics polyethylene (PE), polypropylene (PP), Teflon® (PTFE), and acrylic glass (PMMA) was successfully demonstrated. Also, printability of glass could be significantly increased. Since ambient air is used as process gas, operating costs are kept low. During the tests, the plasma source proved to operate stable at any time with either air or water cooling.

µPQ – adaptable for versatile applications



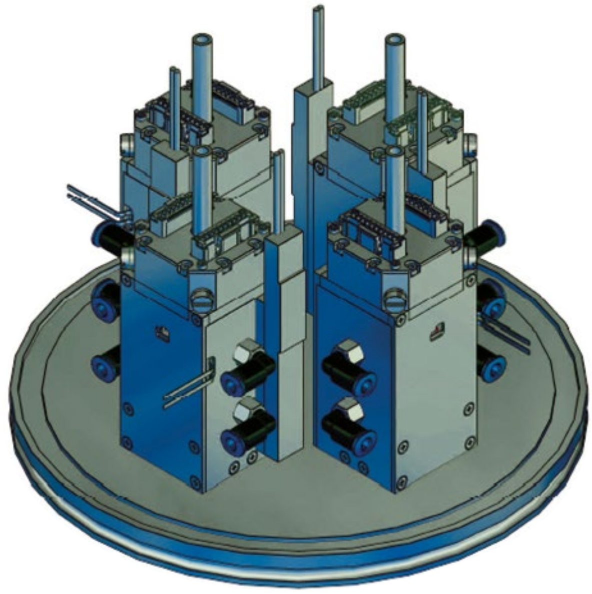
FBH's µPQ has been optimized by integrating all components into one compact housing. Therefore, it can be used very flexibly with different gases and tailored to customer-specific requirements. It is ideal for challenging applications in the fields of surface treatment, cleaning and disinfection. µPQ is particularly suited for

- applications where a precise localization of the treatment area is necessary
- treatment of thermally sensitive materials
- complex geometries with hard-to-reach details
- attachment on moving machine parts
- flexible usage by hand during manual assembly or medical treatment

The Prototype Engineering Lab is specialized in developing the most suitable set-up according to customer's needs. For example, the plasma technology can be arranged as an array to treat larger areas or special geometries. Also, combinations with UV LEDs are an option in order to improve printing or coating of highly sensitive materials.

Inductively coupled plasma sources, opening up new applications in plasma chemistry

The standard way of generating a plasma, using the discharge between two electrodes, creates a large space-charge region that limits the density of free electrons. Inducing currents in the plasma by magnetic coupling eliminates this disadvantage. This approach is known as Inductively Coupled Plasma (ICP). Moreover, plasma excitation with high frequency fields such as microwaves keeps the ions almost unmoved, while the electrons are strongly accelerated. Thus, they can create a high number of ions despite their short mean free path. This feature allows generating a cold and stable plasma even at atmospheric pressure.



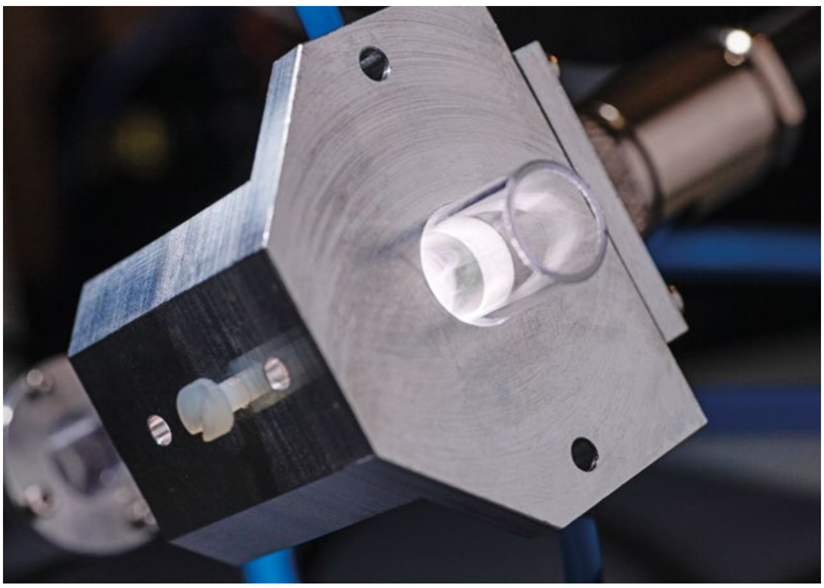
Quadruple sources, consisting of a 2 x 2 array of plasma jets as tested by SENTECH Instruments GmbH

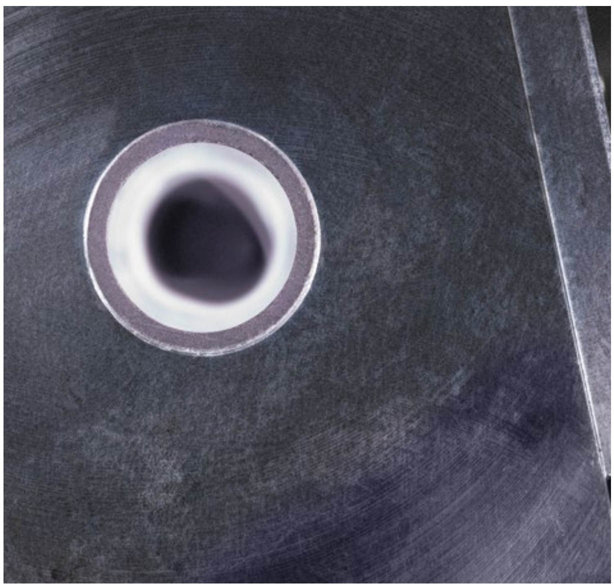
The FBH has developed a new miniature source based on a microwave ICP which combines these advantages. In the course of a project with Ruhr-Universität Bochum, FBH has proven for the first time worldwide the existence of a high-confinement ICP mode in a compact microwave source. This new type of source opens up a broad field of applications in plasma chemistry. In addition, it exhibits a record efficiency: More than 60 % of the incident microwave power is absorbed in the plasma.

The source also allows to create an inductively coupled plasma at atmospheric pressure, which has been successfully demonstrated with argon. Jointly with Ruhr-Universität Bochum, such sources have been characterized extensively in the pressure range 100 – 1000 Pa.

Two further distinct features need to be emphasized: First, the sources can be arranged in parallel as an array in order to obtain a plasma which is uniform over a large area. While classical sources have a limited processing surface due to the inhomogeneity of the generated plasma, such an array can extend this area significantly. Second, certain chemical processes require plasma generation and reaction of components at different places for optimum control. For this purpose, FBH has realized already a double ICP source, which offers the possibility to generate two plasma jets with two different gases and the chemical reaction occurring far away from the sources.

Such parallelization has been developed further in cooperation with the Berlin-based company SENTECH. Quadruple sources were built together with an FBH GaN-based oscillator and tested with oxygen for atomic layer deposition processes.





Inductively coupled plasma source driven at 2.45 GHz, working with argon at atmospheric pressure

Product in focus

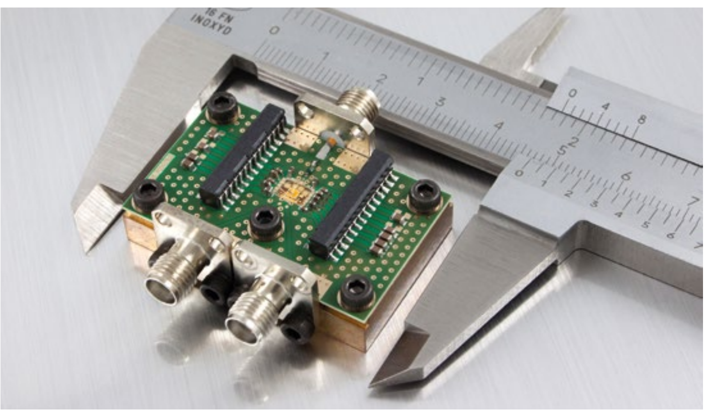
Micro-integrated laser sources with watt-level output power in the yellow-green spectral range

The FBH has developed very compact laser modules emitting at 561 nm and 576 nm with power levels in the watt range. They additionally provide a polarization-maintaining single-mode fiber output option. The diode-based laser systems, measuring only 76 x 54 x 15 mm^3, use a novel butterfly housing and are aimed at biomedical and spectroscopic applications. They are used, for example, in ophthalmology and high-resolution confocal microscopy and enable a significantly higher degree of miniaturization of the corresponding systems. In cw mode, they achieve output powers of more than 2 W at 561 nm and 1.5 W at 576 nm in free-space configuration.

The FBH uses second harmonic generation to generate high-brightness visible light, combining a full semiconductor master oscillator power amplifier (MOPA) with nonlinear crystals. An integrated micro-optical isolator shields the laser structure against back reflections, thereby retaining the spectral properties of the emission. The MOPA approach also allows for direct modulation without affecting the emission wavelength.

Research in focus

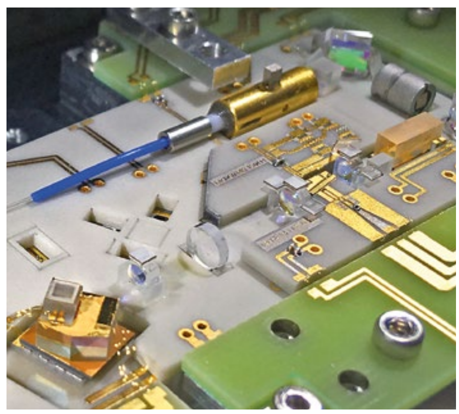
Fully GaN-based all-digital transmitter chain for massive MIMO



The FBH has developed a fully digital GaN-based transmitter module aiming to replace the analog transmitter chain. It extends the boundary of the digital domain behind the power amplifier (PA), yielding several benefits including compactness, low energy consumption and flexibility. It is therefore predestined for any (massive) MIMO application, utilizing beam forming techniques to multiple receivers. The module can be mounted right underneath each antenna element.

The upconverter is replaced by a modulator (FBH patent) that translates complex baseband signals into a purely binary data stream. The transition from the digital signal into the analog domain takes place in the band-pass filter only. The FBH module applies for the first time a novel robust and compact digital GaN PA chip with greatly reduced complexity compared to earlier designs. Full-scale output power at 30 V supply voltage was measured to exceed 3 W at 80 % drain efficiency. The realized module represents an ideal candidate for software-defined radio.

Ultra-narrow linewidth diode laser for LISA satellite mission



The upcoming Laser Interferometer Space Antenna (LISA) mission aims at detecting and characterizing gravitational waves. For this purpose, changes of the distance between test masses on board three satellites that are spaced 2.5 million km apart need to be measured with a sensitivity corresponding to a few pm. To accomplish this, three laser interferometers will be used that require very low-noise seed lasers like Nd:YAG NPRO.

As part of an ESA project, FBH has developed a micro-integrated ultra-narrow linewidth diode laser module (footprint 80 x 30 mm^2) as potential alternative to the NPRO seed laser. The module emitting at 1064 nm consists of an external cavity, a semiconductor gain chip with an anti-reflective coating on both facets, and a volume holographic Bragg grating. Here, the external cavity acts as a mirror and the resonant feedback is re-injected into the gain chip. As the light travels back and forth inside the external cavity before feeding back to the gain chip, this setup effectively implements a very long cavity, but at the same time avoids problems related to very long conventional ECDL setups. The module achieves a Lorentzian linewidth of 13 Hz and is at the same time capable of fast frequency tuning. It is suited for a variety of further applications like coherent optical communications.

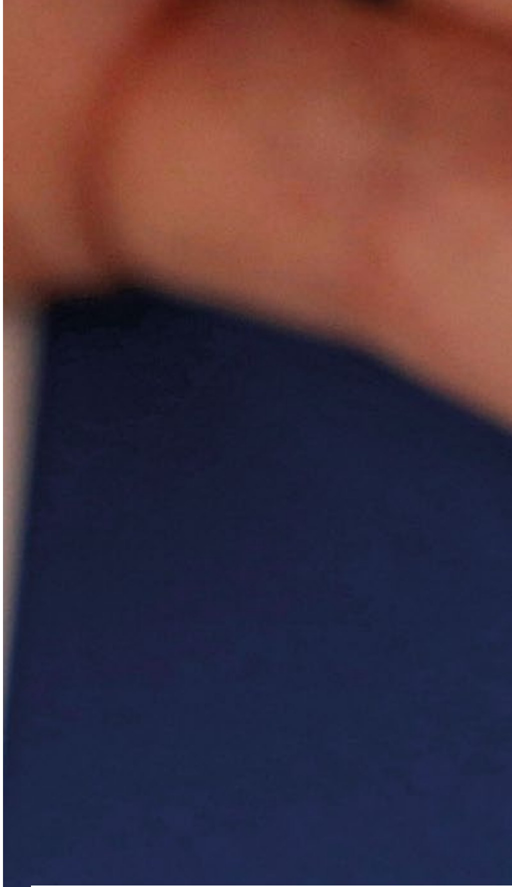
The Ferdinand-Braun-Institut, Leibniz-Institut fuer Hoechstfrequenztechnik (FBH) researches electronic and optical components, modules and systems based on compound semiconductors.

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 energy-efficient low-voltage drivers for use in a variety of applications.

The FBH is a center of competence 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. Within Research Fab Microelectronics Germany (Forschungsfabrik Mikroelektronik Deutschland), it joins forces with 12 other German research institutes, thus offering the complete micro and nanoelectronics value chain as a one-stop-shop.

In close cooperation with industry, FBH's research results lead to cutting-edge products. The institute also successfully turns innovative product ideas into spin-off companies. With its Prototype Engineering Lab, the institute strengthens its cooperation with customers in industry by turning excellent research results into market-oriented products, processes, and services.

The institute offers its international customer base complete solutions and know-how as a one-stop agency – from design to ready-to-use modules and prototypes. Overall, working in strategic partnerships with industry, FBH ensures Germany's technological excellence in microwave and optoelectronic research.



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