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frequent

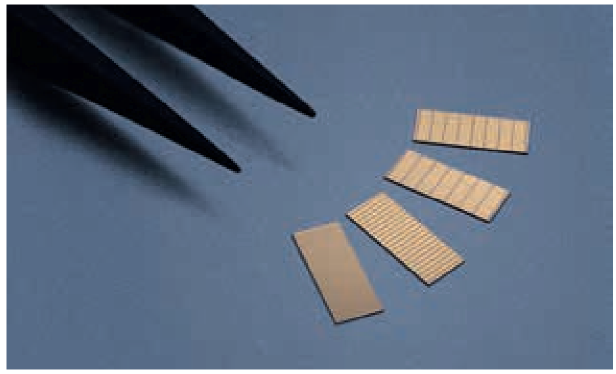
FBH developments in high-power diode lasers

... used in established & future industrial applications

- full value chain in-house
- customized & flexible: from chip development to systems
- high performance & continuous improvement

High-power diode lasers: key technology & enabler for future industrial applications

High-power diode lasers are compact, versatile and highly efficient light sources, generating output powers from single emitters with many tens of watts to bars yielding up to 2 kilowatts to multi-kilowatt modules. Semiconductor technology also allows manufacturing at high volumes and low costs in €/W. Their customizable properties and output powers, delivered in a narrow beam to a single spot with excellent efficiency, make them key components for a wide range of applications. In mechanical engineering, the automotive industry and medical technology, semiconductor-based lasers are indispensable tools. They are used as pump sources and, thanks to ever-improving output powers, increasingly directly. Especially in material processing, the world's largest laser market (reaching a record volume of $21 billion in 2021, with rapid ~10 % year-on-year growth predicted to follow*), diode lasers are essential components. In this field, we cooperate with the leading laser systems manufacturers as a reliable supplier – from chip development to laser modules, ready for integration into our customer's systems. Moreover, our light sources are an enabling technology for emerging applications. We develop laser diodes in the wavelength range from 620 nm to 1200 nm in our own cleanroom facilities, relying on our long-standing and comprehensive know-how from design and chip development, through III-V processing to the final modules and systems.



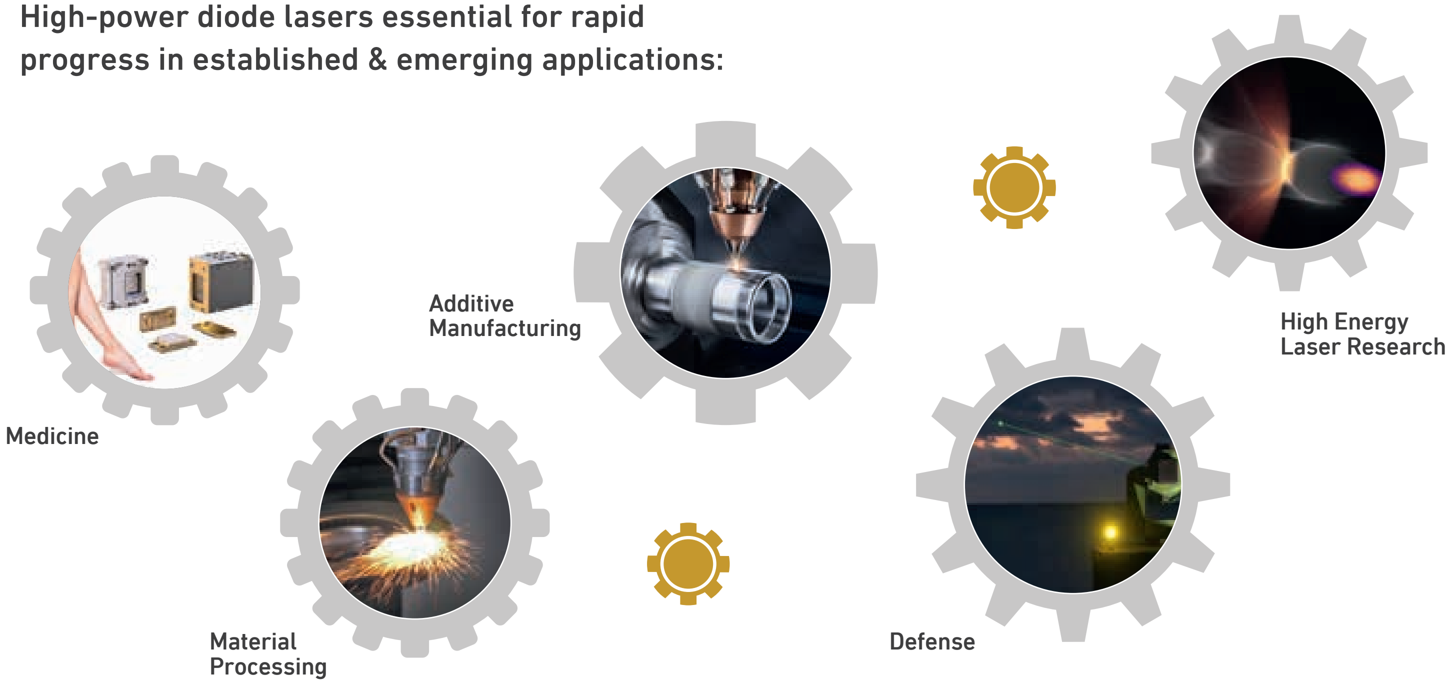
Full value chain in-house: from device design to laser chips to high-performance laser modules and systems.

Emerging applications

As diode lasers improve, they enable an ever-wider scope of applications. These range from laser-based surgery to metal cutting and welding, from the assembly of complex shapes in additive manufacturing to target identification and destruction in defense applications, up to the generation of petawatts of pulsed power in high-energy laser research for particle acceleration, material research, and laser fusion. The FBH develops the technology needed for these ultra-high energy systems, from kilowatt-class laser bars, in cooperation with Trumpf, to ultra-high-repetition rate stacks for emerging multi-joule thulium lasers in cooperation with IOQ Jena, to the development of large laser facilities, as part of the EuPRAXIA project (www.eupraxia-facility.org). We continue to actively support and enable these developments, together with a wide range of partners from research and industry.

*Source: Optech Consulting, in Laser Focus World, 2022 Summary Report.

High-power diode lasers essential for rapid progress in established & emerging applications:



Interested?
Then please do get in touch with us!

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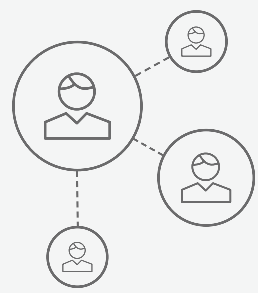
Benefits of a high-power cooperation with the FBH

+ **Complete value-chain** in-house, world-leading III-V technology
+ **Track record of successful cooperation** – from fundamental research to industrial applications
+ **Broadly skilled** scientific team with decades of experience
+ **High performance** – with international record values
+ **Continuous improvement** in brilliance, efficiency, performance, …
+ **Flexible realization** customized wavelengths, frequency-stabilized, …

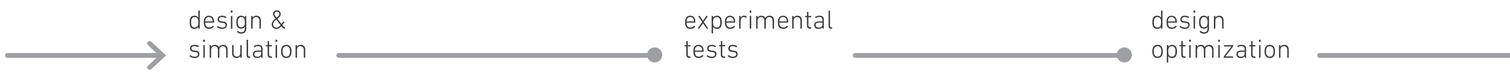
Ways of cooperating with us

- **Joint research project**
- **Industrial contract**
- **Direct sales or licensing**



From custom chips to leading-edge systems

- Pulsed diode lasers with leading-edge powers for pump applications
  - 350 W at 665 nm, 1000 W at 780 nm, 2000 W at 930 nm, from 1 cm bars
  - 70 W with 70 % efficiency from a single emitter with 1200 µm aperture, at 915 nm
- Continuous wave single emitters with leading-edge brightness for direct use
  - 20 W from 100 µm apertures at 915...980 nm, efficiency > 50 %
  - 20 W in a narrow (< 1 nm) spectrum from 200 µm apertures, efficiency > 50 %
- High duty cycle fiber-coupled kW-class modules for pump application
  - 1000 W in 1 mm core fiber from a single 780 nm stack at 10 ms 50 Hz
  - 6000 W in 1.9 mm core fiber from two 940 nm stacks at 1 ms 200 Hz
- Continuous wave free-space modules for direct use in additive manufacturing
  - 1000 W in a 1 mm spot at 780 nm



Reaching the highest powers by systematically optimizing material quality and device design

The FBH fabricates high-performance III-V diode lasers and modules, reaching ever larger optical output powers by combining excellent semiconductor materials with highly developed device designs. Specifically, to advance the high-power laser field and to enable continuous improvement in performance for industry, our scientists pursue systematic device studies to identify losses and to design innovative ways to bypass them.

Based on our highly capable technology, from epitaxial re-growth to facet passivation, from innovative wafer-level device structuring to advanced assembly techniques, we are able to deliver rapid performance progress in high-power diode lasers and their modules.

Red laser bars with world-record QCW output power of over 350 W at 665 nm.

Pushing the boundaries

We use a portfolio of proprietary and commercial simulation tools to develop our device designs. These tools allow us to re-engineer the devices to bypass known performance limits or adapt the structures for new applications, by manipulating the optical field and current path. When necessary, we fabricate and test customized diode lasers to guide design and technological development efforts. In this way, we can test predictions and find further opportunities for performance scaling.

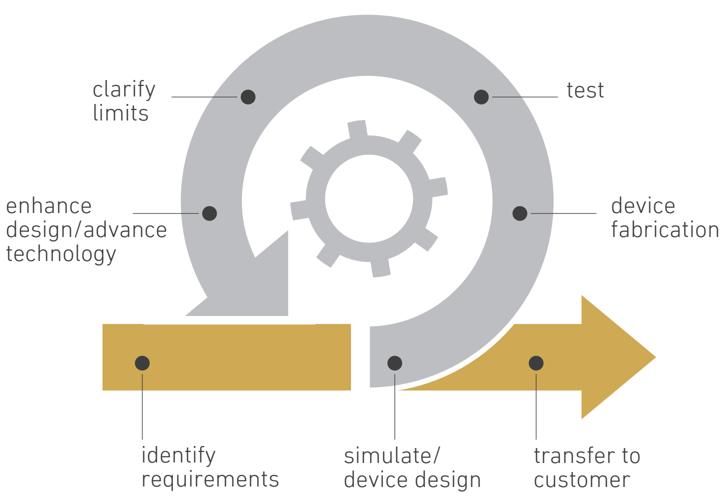
When new effects arise as a limit, we join forces with research partners in industry (e.g. Trumpf, Jenoptik) and academia (e.g. Uni Glasgow, Uni Kyoto, Lawrence Livermore National Labs) to develop the required capabilities. New, beneficial designs and technologies are typically patented to protect the interests of our commercial partners.

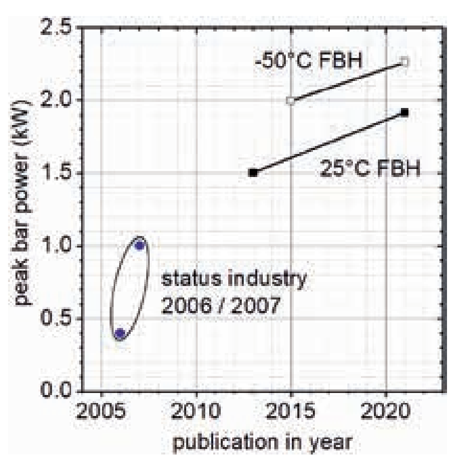
Examples

- Locating where the losses occur: studies of local spontaneous emission and current flow in specially structured lasers reveal regions in the device where electrons and holes collect at high bias and are lost.

- Understand what factors control performance: precise measurements of the diode laser properties over a wide range of temperatures and pulse widths (-50 ….150 °C, few ns to CW), separate the impact of current and temperature.

- Eliminate losses for rapid performance progress: innovative GaAs-based extremely (triple) asymmetric ETAS epitaxial layer structures were developed to cut leakage losses at high bias and subsequently realized with high quality, thus rapidly increased the optical output power to over 2 kW from a single laser bar at 930 nm.





Design improvements increased the emitted power of 1 cm diode laser bars at 930 nm from 400 W to around 2000 W.

Innovation in device technology for higher performance

MBE facet passivation tool: excellent reliability at high power and rapid throughput.

FBH's state-of-the-art implanter, for sophisticated lateral current control.

We rely on our modern cleanroom environment equipped with state-of-the-art processing tools and high-performance facilities, which provide the basis for our development of advanced diode lasers. Our epitaxial growth and processing technology capabilities allow us to fabricate extremely high-power diode lasers at conventional and customized wavelengths. Also, fast in-house mask fabrication is possible, to rapidly adapt chip designs to new requirements.

Highly developed AlGaAs buried regrown implantation techniques

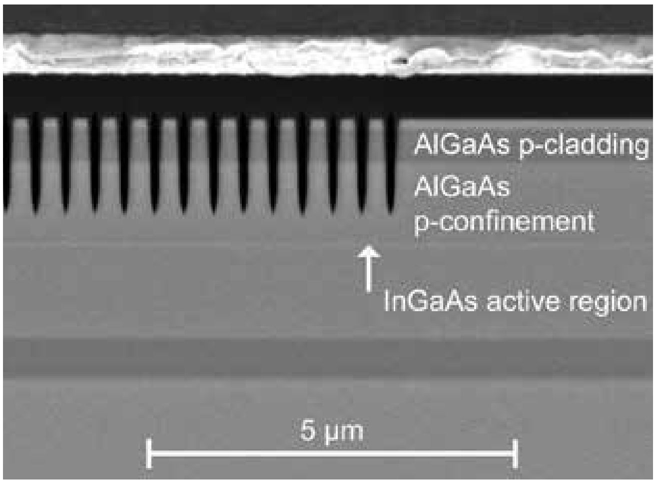
For example, we successfully suppressed current losses by combining highly developed AlGaAs regrowth techniques with innovative buried oxygen layers. These buried regrown implant structures (BRIS) were implemented with FBH's new cutting-edge ion implanter. The new devices deliver over 20 W of output power from a 100 µm aperture in a very narrow beam, for 915 nm diode lasers with best-in-class brightness.

Laser facet passivation – high power & reliability

To protect laser facets from failure we have further advanced our standard facet technology, thus expanding throughput and quality in a dedicated molecular beam-based passivation process. In parallel, for high-power applications, e.g., in space with the very highest demands on facet stability, we have introduced cleaving and passivation of laser bars in a vacuum, to fully suppress any oxidation of this critical surface. This eliminates facet failure as lifetime limit in 760 nm ridge waveguide lasers and allows 940 nm broad area lasers to operate at peak (saturation) power for more than 8,000 hours, without failure.

Grating technology – narrow linewidth & high brilliance

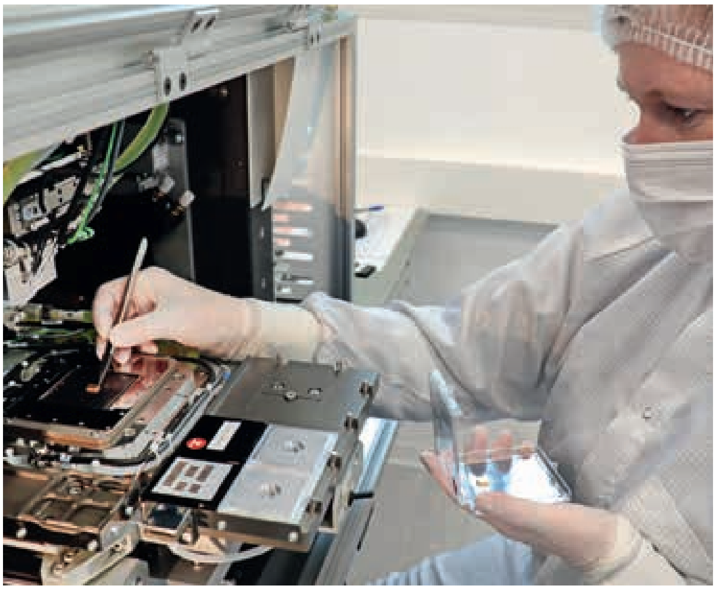
Novel functions can be introduced, such as implementing gratings inside the diode lasers to narrow the optical spectrum. Recently, we combined advanced highly asymmetric epitaxial layer designs with precisely etched surface gratings, using e-beam lithography and dry chemical etching techniques. As a result, new best-in-class grating-stabilized 970 nm laser bars were produced that deliver over 800 W output power within a 1 nm spectral line, with a conversion efficiency above 50 %, as needed to pump Yb:YAG.



Surface grating with 1.3 µm deep V-shaped grooves (vertical section).

Innovation in assembly to enable emerging applications

Diode lasers can only find application when assembled in a module, for proper cooling and beam delivery into the application. Advances in assembly and optical design techniques and the needed materials are essential for progress in existing applications and allow us to support the development of emerging fields. In addition, new functions and capabilities can be enabled by combining flexibility in device, assembly, and optics.



Automated assembly of diode lasers for use in high-power laser stacks.

Excellently equipped packaging technology & comprehensive optical design simulation

Strong investment in our assembly infrastructure has also enabled advances in packaging technology. Acquisitions include precision automated die- and wire-bonding tools and large volume hydrogen furnaces (for the low-defect soldering of complex multi-component modules). This is supported by a well-equipped workshop and highly skilled team for fabrication of customized assembly tools and module components.

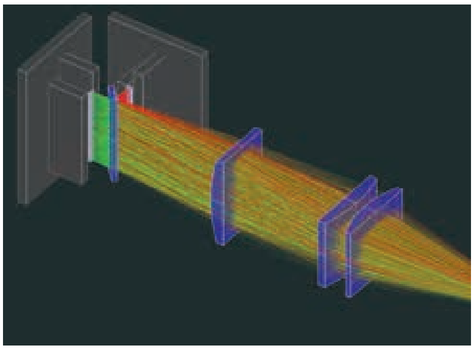
Our scientists and collaborators also deploy advanced techniques in optical design to collect and deliver the light of many devices into application, with the design tools made available to our industrial partners commercially via the spin-off BeamXpert. These designs are then assembled in-house, for example to produce efficient, advanced kW-class direct diode modules. They use collimating micro-optics and beam-combining elements, with the resulting optical output either delivered directly or from an optical fiber.

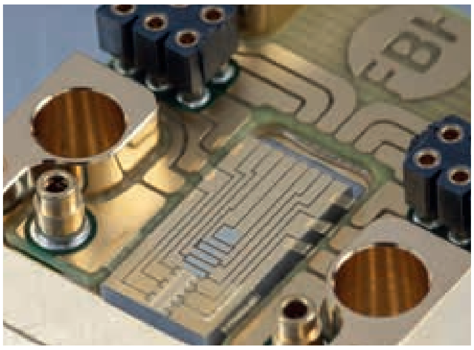
Exemplary realizations

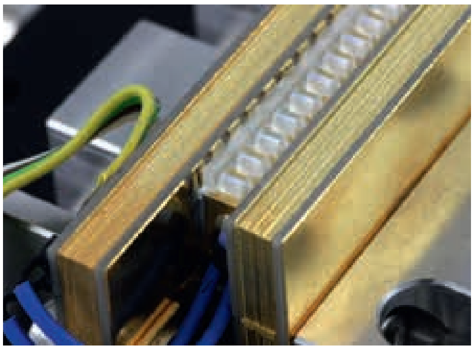
Miniaturized (8 x 3 mm) double-sided "stack element" packages effectively cool innovative wide-aperture diode lasers. They allow 70 W of QCW output power to be delivered from a single 915 nm diode laser with 70 % conversion efficiency, suitable for miniaturized solid-state and fiber laser systems.

By combining many stack elements, we have developed edge-cooled high-power stacks delivering kilowatts of power, used, for example, in direct material processing or high duty cycle pumping of solid-state lasers.

In a further example, customized packages with structured submounts allow the current to be regulated along the length of high-power diode lasers. This enables the temperature profile to be controlled, leading to a narrower lateral far field and hence delivering a more intense beam. These properties are needed for high-brightness direct material processing as well as for coupling into a narrow core fiber to pump fiber lasers.







Left: Optical design for customized industrial lasers. Center: Advanced single emitter packaging for highest brightness.
Right: Innovation in stack assembly for highest duty cycle and brightness.

Emerging high-power applications: enabled by FBH competence

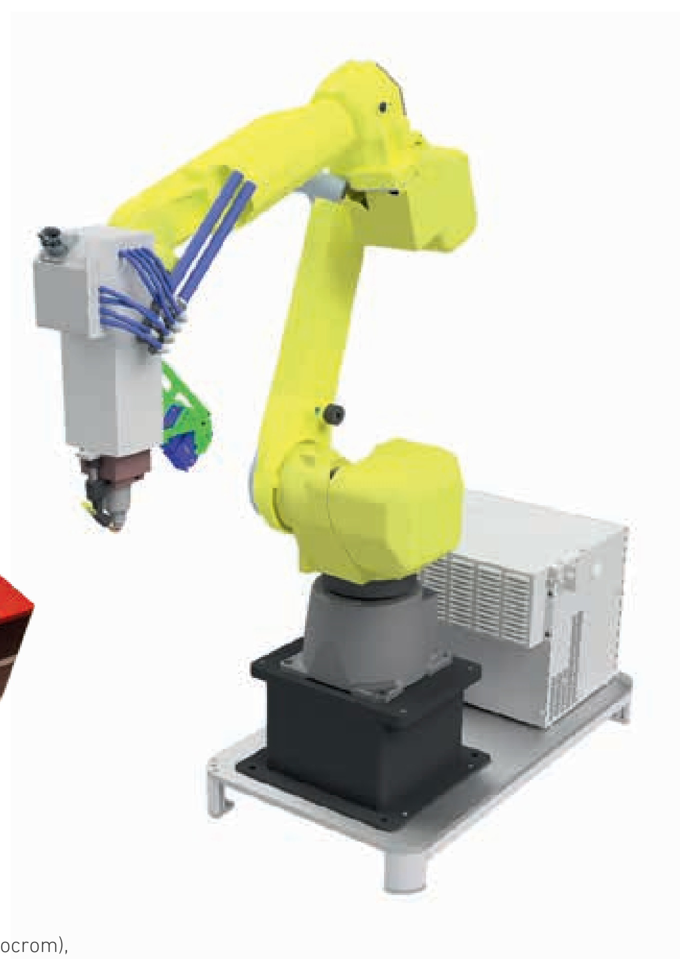
The FBH offers an unrivaled competence in high-power diode lasers and their modules, used to make many new applications possible. We combine deep understanding of diode laser physics, world-leading capabilities in design, simulation and diagnostic measurement with advanced skills in epitaxial growth and III-V processing technology. Innovative assembly and beam-forming techniques (optics) allow us to realize high-performance modules in support of a wide range of emerging applications. The high quality of our semiconductor technology ensures long lifetime and high power.

Recent examples include

- High-power 6xx nm diode laser bars (FBH innovation: highly efficient epitaxy, high fill factor bars) → compact, intense lasers for a wide range of medical applications, including dental and vein therapy, hair and tattoo removal (Jenoptik).
- Efficient, high-power CW modules at 780 nm (FBH innovation: efficient ultra-large single emitters, side-cooled single emitter stacks, compact, simple beam combination) → kW-class direct diode laser modules needed to flexibly create metal shapes in additive manufacturing applications (Photon Laser Manufacturing (PLM) & SKDK).
- Ultra-powerful kW-class CW and pulsed diode laser bars around 930 nm (FBH innovation: tailored thermal profiles for high power, extreme triple-asymmetric epitaxial designs) → cost-efficient, highly powerful disk lasers for metal cutting and generation of secondary radiation (Trumpf).
- Ultra-high brightness CW single emitters around 915 nm (FBH innovation: highly efficient epitaxy, buried regrown implant to prevent current spreading losses) → rapid metal cutting is achieved directly with diode laser modules (Monocrom).
- Ultra-high-duty cycle kW-class pulsed diode laser modules around 940 nm (FBH innovation: side-cooled stacks, highly asymmetric epitaxy, high facet quality) → prototype high repetition rate (100 Hz) multi-kilowatt pumps for a large-scale high-energy-class pulsed solid-state laser facility (EuPRAXIA).

Supported by successful transfer to industry

The FBH continuously works with more than 50 industrial companies in the frame of R&D assignments and services. We maintain long-term strategic partnerships with corporations including Bosch, Infineon, Jenoptik, TESAT Spacecom, and Trumpf. Additionally, our institute is an essential part in the value chain of many national and regional companies and thus promotes their market success. With our Prototype Engineering Lab, we additionally offer our partners easy access to state-of-the art research results – by means of functionally-efficient models and prototypes.



From left to right: diode-pumped disk laser system (Trumpf), direct diode module (Monocrom), robot-mounted direct diode laser system for application in additive manufacturing (PLM & SKDK).

The Ferdinand-Braun-Institut (FBH) is an application-oriented research institute in the fields of high-frequency electronics, photonics and quantum physics. It 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 such as communications, energy, health, and mobility. Specifically, FBH develops light sources from the near-infrared 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 and integrated quantum technology. 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 covering the full range of capabilities, from design through fabrication to device characterization. Within the Research Fab Microelectronics Germany (Forschungsfabrik Mikroelektronik Deutschland – FMD), FBH 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 and strategic partnership 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 thereby 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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