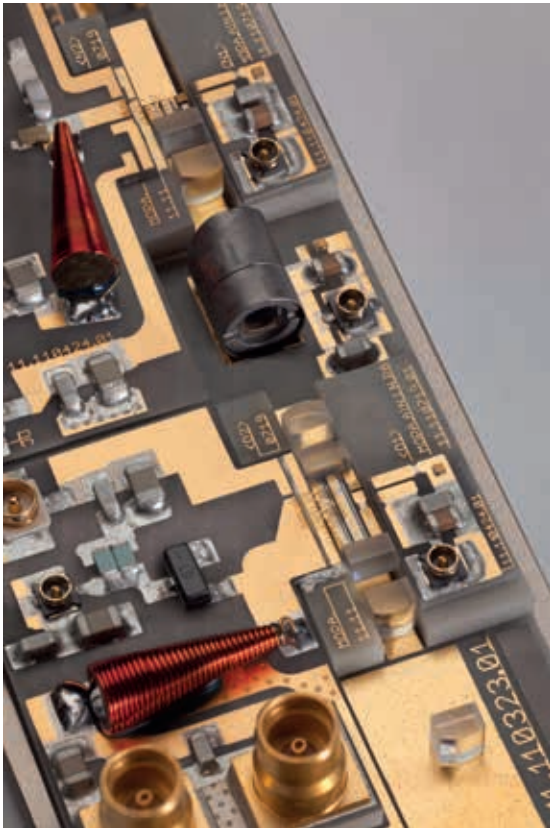




Leibniz  
Ferdinand  
Braun  
Institut



Integrated Quantum

Technology

# Exploiting the Full Potential of Quantum Technology

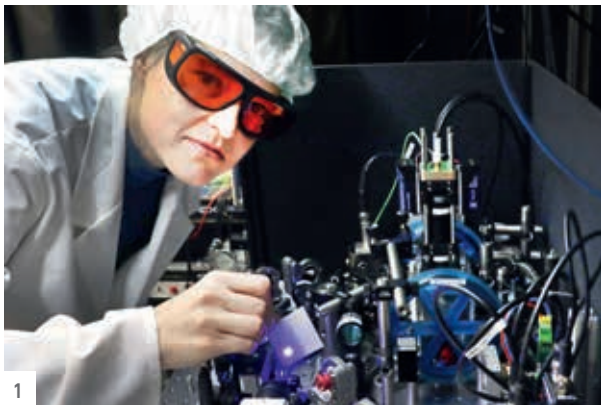
Fundamental research has demonstrated that quantum physics provides solutions to problems which cannot be solved by classical means and that quantum physical solutions may significantly outperform classical solutions. Thus, concepts from quantum optics and atomic physics are applied in quantum sensing, quantum communica-

tion, quantum simulation, and quantum computing. FBH's R&D activities in its research area Integrated Quantum Technology aim at advancing quantum technology so as to pave the way for the second quantum revolution to unfold its potential for tomorrow's society.

## FBH Activities in Quantum Technology

FBH builds on its core competencies in III-V semiconductor, microwave and diode laser technology and has teamed up with university (Joint Labs) and industrial partners to cover the full value chain. Accordingly, the expertise ranges from concept development and proof-of-concept demonstration through technology development all the way to realization and qualification of the final components, subsystems and systems.

FBH components, modules and systems are developed for operation outside of optical laboratories, in a real-world environment. This includes operation on board sounding rockets or satellites for geodesy, earth observation, inertial and future generation GNSS-based navigation or fundamental physics research. The first successful generation of a Bose-Einstein condensate and atom interferometric studies in space, for example, utilized laser modules that were developed and assembled by FBH.



The FBH has long-term experience of commercial delivery and collaboration on development projects with industrial partners, and uses an integrated management system (based on ISO 9001, 14001, and 45001).

### Atom-based quantum technology: photonic components & quantum sensors

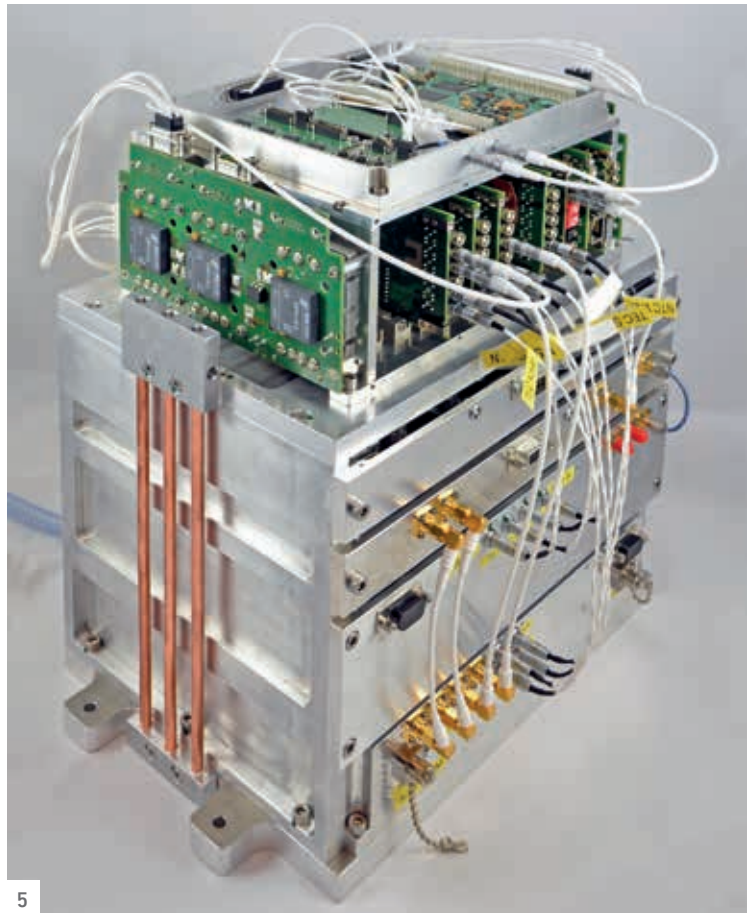
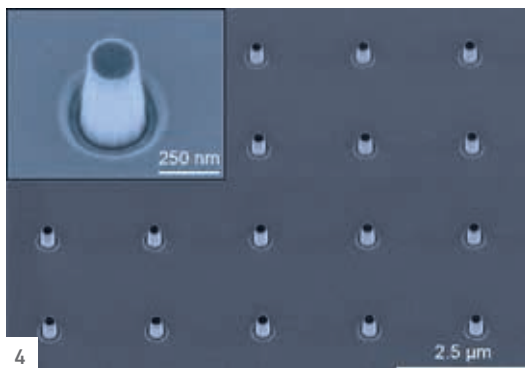
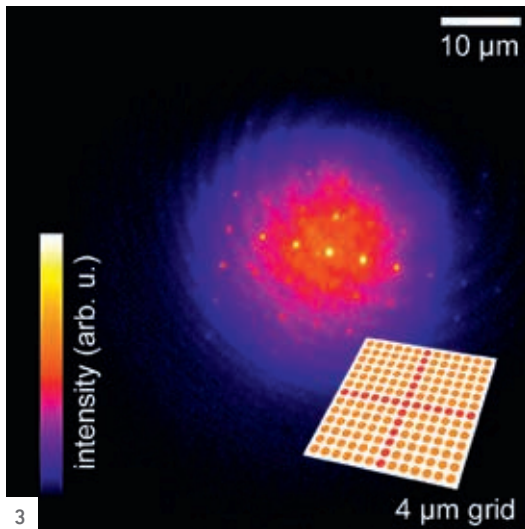
FBH has comprehensive expertise in developing electro-optical components and unique hybrid micro-integrated modules that generate and/or control coherent radiation. Realizations include miniaturized DFB, DBR and extended cavity diode laser (ECDL) modules with integrated optical amplifier at a wide range of wavelengths and with targeted properties (output power/linewidth) or switching and distribution modules used to control the optical fields as required. These lasers are then implemented into quantum optical sensors or quantum computers based on cold ions or neutral atoms.

In cooperation with HU Berlin, FBH develops the next generation of compact quantum sensors and clocks for real-world applications. These sensors utilize high-precision spectroscopy techniques applied to atomic ensembles, both at room temperature and near absolute zero using laser cooling. This approach exploits the intrinsic properties of quantum states and their precise manipulation with laser light. For this purpose, instruments for highly sensitive and accurate measurements of physical quantities are to be realized, such as frequency, time, inertial forces as well as electrical and magnetic fields. Based on its expertise and heritage, FBH specifically develops components, modules and systems for spaceborne applications.

Activities include the development of:

- active and passive electro-optical as well as MEMS components, including laser chips, wafer-level gas cells, etc.
- micro-integrated electro-optical modules and physics packages, specifically for atom-based quantum technology applications and coherent (inter-satellite) communication
- simplified and robust concepts for quantum sensors and clocks
- enabling technologies, including hybrid microintegration, in-depth performance characterization, additive manufacturing, and advanced design methods
- hardware specifically for space applications





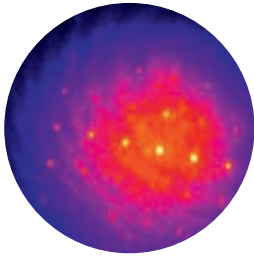
## Integrated photonic devices for quantum security

The FBH comprehensively investigates nanostructured diamond systems and materials. Developments aim at novel concepts for guiding, catching, and manipulating light on the nano- and microscale, and enabling strong light-matter interaction in diamond. The aim is to achieve a controllable light-matter interaction in order to efficiently couple quantum memories in diamond to individual light particles. These photons will then be efficiently coupled into optical fibers. Quantum memory-photon entanglement as well as quantum gates will then form the basis for the implementation of future quantum communication platforms that are more secure and versatile than present classical schemes. In the long term, compact on-chip modules for quantum communication and computing are to be developed. Such photonic modules are a decisive step towards quantum information processing based on optically active solid-state materials.

FBH research also aims at chip-integrated optical components based on lithographic processing of dielectric materials like silica on silicon and aluminum gallium nitride (AlGaN), combined with direct write techniques using focused beams of laser light, electrons, and ions. To achieve this, two breakthroughs are combined: ultra-strong quantum optical nonlinearities based on trapped atoms and nanofabricated optical waveguide chips that permit high-level control of light confinement and propagation. The on-chip components that will be fabricated with these techniques then constitute the technological platform for low-loss, quantum nonlinear optical devices.

- 1 Optical clock based on Ramsey-Bordé interferometry of thermal strontium atoms using a red 689 nm spectroscopy and a blue 461 nm read-out laser.
- 2 Red-emitting laser diode – the basis for compact, energy-efficient and robust diode laser modules emitting in a broad wavelength range.
- 3 Widefield image of silicon carbide with an array of fluorescent spots that correspond to ensembles of quantum emitters patterned with a focused helium ion beam. Inset: blow-up of the pattern, red marker dots of higher dose separate the target dose regions.
- 4 Scanning electron micrograph showing a tilted view of fabricated diamond nanopillars, each with a diameter of about 200 nm and about 500 nm height. Inset: close-up view of a single nanopillar.
- 5 JOKARUS payload used to demonstrate the first optical frequency standard based on molecular iodine in space. (© HU Berlin/Franz Gutsch)
- 6 Micro-integrated extended cavity diode laser (master oscillator power amplifier) for precision iodine spectroscopy in space.





# translating ideas into innovation

The Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik (FBH) is an application-oriented research institute in the fields of high-frequency electronics, photonics and quantum physics. It researches and realizes 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 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 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 partnerships 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—from design to ready-to-use modules and prototypes.

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