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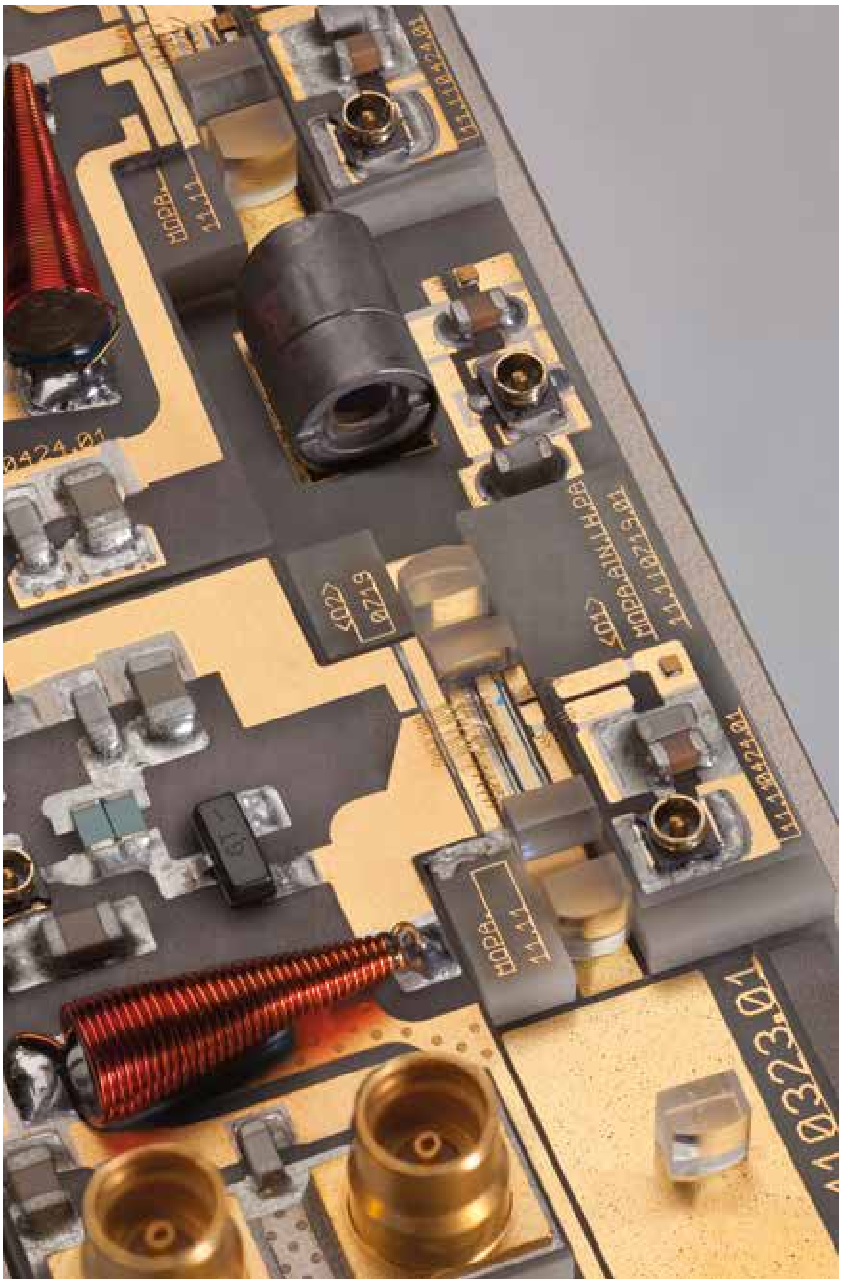
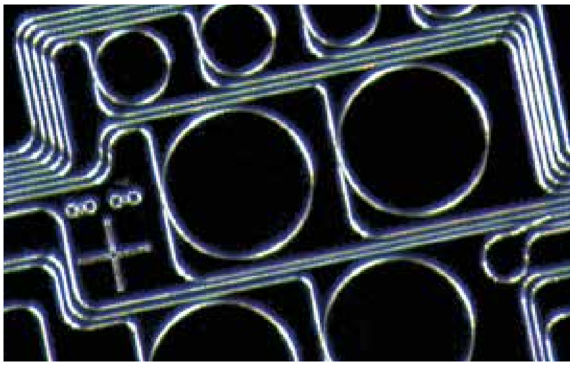
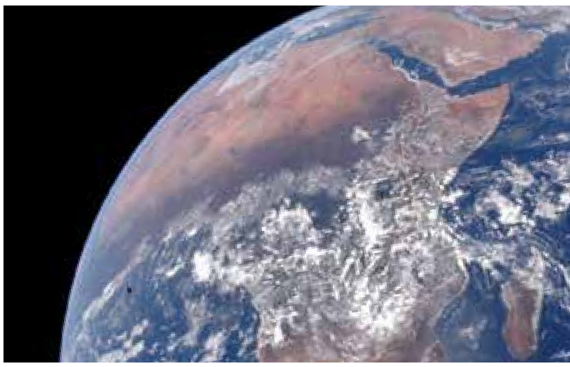
Ferdinand
Braun
Institut







Integrated Quantum Technology

Exploiting the Full Potential of Quantum Technology

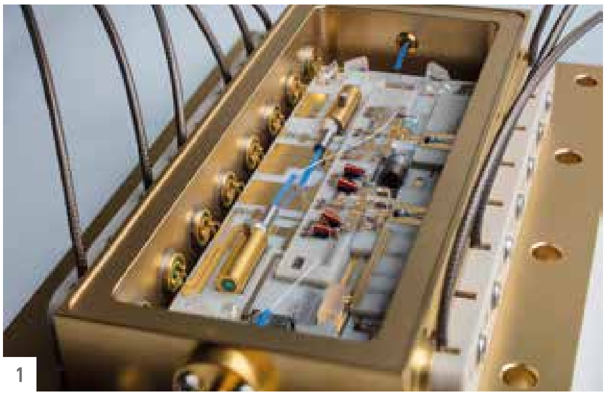
Over the last decades, fundamental research has demonstrated that quantum mechanics provides solutions to problems that cannot be solved by classical means, or that quantum mechanics can provide solutions at a level of performance unrivalled by classical approaches.

Concepts from quantum optics and atomic physics find application in the fields of quantum sensing, quantum communication, quantum simulation, and quantum computing. Within its research area Integrated Quantum Technology, FBH carries out R&D activities that 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 extends its portfolio where necessary. Since quantum technologies currently feature an early technology readiness level and related research – to a large extent – is still fundamental, FBH teams up with university and industrial partners to cover the full value chain, from concept and proof-of-concept demonstration through technology development all the way to the final components and subsystems. It comprises systems that enable field operation or even deployment in the harsh environment of outer space.

To ensure proper operation in the field and in space, FBH conducts extensive testing of its components, modules and systems. Various laser modules were successfully operated in space. This includes the first proof-of-concept demonstration of optical frequency references based on rubidium, potassium and iodine as well as the first realization of a sample of ultra-cold atoms (Bose-Einstein condensate) as a source for precision inertial sensing.



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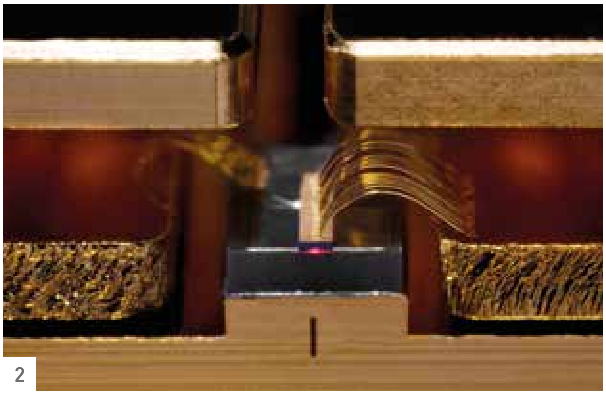

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The FBH has long-term experience of commercial delivery and collaboration on development projects with industrial partners, and uses an integrated management system (ISO 9001, 14001, and 45001).

Quantum photonic components

The FBH has comprehensive expertise in developing electro-optical components and hybrid micro-integrated modules that provide coherent radiation required, e.g., for the implementation of quantum optical sensors or quantum computers based on cold ions or neutral atoms. Emphasis lies on narrow and ultra-narrow linewidth lasers that are also relevant for coherent free-space communication, laser metrology and space applications. Development cycles comprise modeling, simulation, design and implementation of the necessary components. Activities include the development of:

- active and passive electro-optical semiconductor components
- hybrid micro-integration technologies for complex electro-optical modules, including smart automation of alignment and integration steps
- micro-integrated electro-optical modules, specifically for quantum technology applications and coherent (inter-satellite) communication
- techniques required for in-depth characterization of the electro-optical performance of lasers and of electro-optical components regarding user-relevant parameters

1 Micro-integrated extended cavity diode laser (master oscillator power amplifier) for precision iodine spectroscopy in space (© FBH/Schurian.com)

2 Red-emitting laser diode – the basis for compact, energy-efficient and robust diode laser modules emitting in a broad wavelength range (© FBH/Schurian.com)

3 JOKARUS payload used to demonstrate the first optical frequency standard based on molecular iodine in space (© HU Berlin/Franz Gutsch)

4 A direct optical spectroscopy setup probing the 6P manifold in rubidium 85 and 87 with a blue/violet 420.3 nm laser (© HU Berlin)

5 Advanced hybrid micro-integration technology at FBH for complex electro-optical modules (© FBH/Schurian.com)

6 Scanning electron microscopy image of an AlGaAs/GaAs-based multimode interference coupler with S-bends (© FBH)

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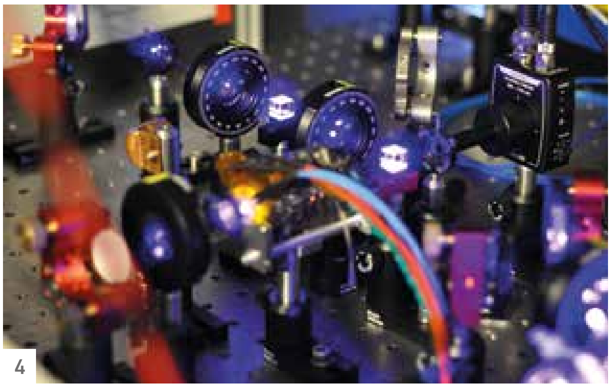

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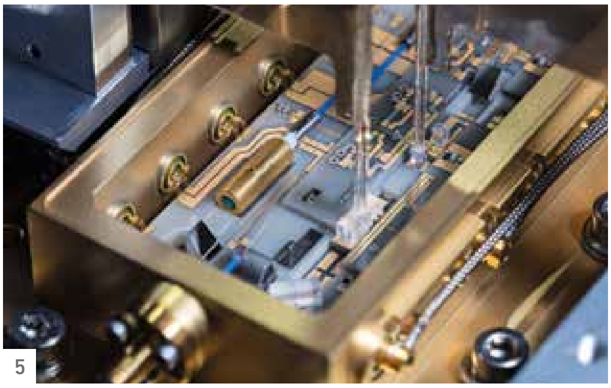

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Integrated quantum sensors

R&D is carried out towards developing the next generation of chip-scale quantum sensors for real-world applications. These sensors utilize high-precision spectroscopy techniques applied to atomic or molecular ensembles, either at room temperature or near absolute zero using laser cooling. Here, the intrinsic properties of quantum states and their precise manipulation with laser light are exploited. For this purpose, instruments for highly accurate measurements of physical quantities are to be realized, such as frequency, time, inertial forces as well as electrical and magnetic fields. Together with the activities located at HU Berlin, R&D efforts include the development of:

- atomic systems on-a-chip for frequency and timing applications, including development of micro-fabricated vapor cells and integrated sensor heads
- enabling technologies for atomic sensors including modeling, simulation and assembly of miniaturized electro-optical systems and compact vacuum concepts
- simplified and robust concepts for matter-wave sensors (e.g., beam optical references) and simulation of atom-optical tools
- laser systems and related technologies for space operation

Developments targeting the precise control of light

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 gallium phosphide, 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.

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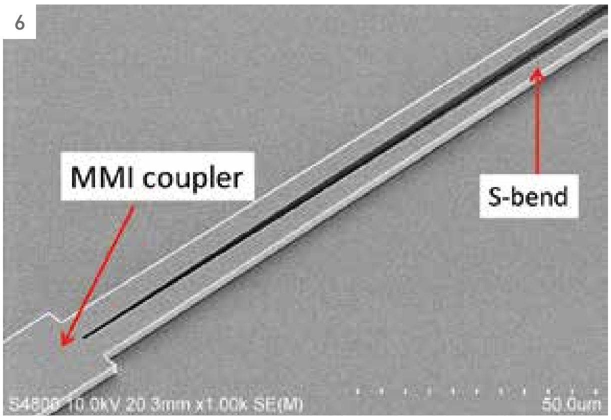

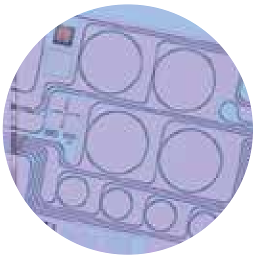

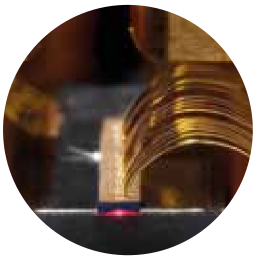

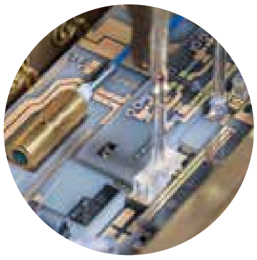

translating ideas into innovation

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

The FBH is an internationally recognized center of competence for III-V compound semiconductors. It operates industry-compatible and flexible cleanroom laboratories with vapor phase epitaxy units and a III-V semiconductor process line. The work relies on comprehensive materials and process analysis equipment, a state-of-the-art device measurement environment, and excellent tools for simulation and CAD.

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 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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