Leibniz-Gemeinschaft

Der Senat

23. März 2015

Stellungnahme zum Ferdinand-Braun-Institut Leibniz-Institut für Höchstfrequenztechnik (FBH) im Forschungsverbund Berlin e. V.

Inhaltsverzeichnis

Vorbemerkung

Die Einrichtungen der Forschung und der wissenschaftlichen Infrastruktur, die sich in der Leibniz-Gemeinschaft zusammengeschlossen haben, werden von Bund und Ländern wegen ihrer überregionalen Bedeutung und eines gesamtstaatlichen wissenschaftspolitischen Interesses gemeinsam gefördert. Turnusmäßig, spätestens alle sieben Jahre, überprüfen Bund und Länder, ob die Voraussetzungen für die gemeinsame Förderung einer Leibniz-Einrichtung noch erfüllt sind.[1]

Die wesentliche Grundlage für die Überprüfung in der Gemeinsamen Wissenschaftskonferenz ist regelmäßig eine unabhängige Evaluierung durch den Senat der Leibniz-Gemeinschaft. Die Stellungnahmen des Senats bereitet der Senatsausschuss Evaluierung vor. Für die Bewertung einer Einrichtung setzt der Ausschuss Bewertungsgruppen mit unabhängigen, fachlich einschlägigen Sachverständigen ein.

Vor diesem Hintergrund besuchte eine Bewertungsgruppe am 24. und 25. Juni 2014 das Ferdinand-Braun-Institut (FBH) in Berlin. Ihr stand eine vom FBH erstellte Evaluierungsunterlage zur Verfügung. Die wesentlichen Aussagen dieser Unterlage sind in der Darstellung (Anlage A dieser Stellungnahme) zusammengefasst. Die Bewertungsgruppe erstellte im Anschluss an den Besuch den Bewertungsbericht (Anlage B). Das FBH nahm dazu Stellung (Anlage C). Der Senat der Leibniz-Gemeinschaft verabschiedete am 23. März 2015 auf dieser Grundlage die vorliegende Stellungnahme. Der Senat dankt den Mitgliedern der Bewertungsgruppe und des Senatsausschusses Evaluierung für ihre Arbeit.

1. Beurteilung und Empfehlungen

Der Senat schließt sich den Beurteilungen und Empfehlungen der Bewertungsgruppe an.

Das Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik (FBH) im Forschungsverbund Berlin e. V. widmet sich erfolgreich grundlagen- und anwendungsorientierten Forschungen im Bereich der Mikro- und Millimeterwellentechnik sowie der Opto- und Leistungselektronik. Im Mittelpunkt steht die Erforschung elektronischer und optischer Komponenten, Module und Systeme auf der Basis sogenannter III/V-Verbindungshalbleiter. Die Arbeiten umfassen die vollständige Wertschöpfungskette und reichen vom Entwurf über die Fertigung bis hin zur Charakterisierung von Bauelementen und deren Anwendung im Gesundheits-, Mobilitäts- und Kommunikationsbereich. International zählt das FBH zu den renommiertesten Kompetenzzentren im Bereich der III/V-Halbleitertechnologie.

Das Institut bearbeitet seine wissenschaftlichen Fragen auf der Grundlage einer Matrix-Struktur in drei langfristig angelegten, übergreifenden Forschungsprogrammen. Die **Arbeitsergebnisse** der sieben darin zusammengefassten Arbeitseinheiten werden in zwei Fällen als „sehr gut“, in einem Fall als „sehr gut bis exzellent“ und in vier Fällen als „exzellent“ bewertet. In den letzten Jahren gelang es dem Institut eindrucksvoll, das bereits sehr hohe Leistungsniveau weiter zu steigern. Dabei wurden zahlreiche, bereits 2007 positiv eingeschätzte Themenbereiche ausgebaut, aber auch Arbeiten zu einzelnen in der Vergan-

[1] Ausführungsvereinbarung zum GWK-Abkommen über die gemeinsame Förderung der Mitgliedseinrichtungen der Wissenschaftsgemeinschaft Gottfried Wilhelm Leibniz e. V.

genheit wichtigen Themen abgeschlossen. Allerdings sollte das FBH prüfen, wie es künftig noch schneller neue Forschungsansätze aufgreifen kann, um in seinem international hoch kompetitiven Umfeld konkurrenzfähig zu bleiben.

Es gelingt dem Institut überzeugend, neben der Bearbeitung wichtiger grundlegender Fragen der Halbleitertechnologie innovative optoelektronische Bauelemente zu entwickeln. Diese erfolgreiche Anwendungsorientierung hat insbesondere durch die Entwicklung höher-komplexer Systeme in den letzten Jahren weiter zugenommen. Beim sich daran anschließenden Wissens- und Technologietransfer in die Industrie sollte das Institut künftig häufiger selbst die Initiative ergreifen und mit innovativen Projektideen aktiv auf seine Partner zugehen. Es wird begrüßt, dass das FBH großen Wert auf die Balance zwischen Grundlagenforschung, Anwendungsorientierung und Transfer legt.

Das FBH arbeitet erfolgreich mit den Berliner Universitäten zusammen. Zwei Wissenschaftler sind gemeinsam mit der Technischen Universität Berlin (TU) auf Professuren berufen, darunter der Direktor. Positiv ist, dass 2015 auch mit der Humboldt-Universität zu Berlin (HU) ein gemeinsames Berufungsverfahren durchgeführt werden soll. Die **Kooperationen** im Rahmen der universitären Lehre, der Betreuung des wissenschaftlichen Nachwuchses sowie einer Vielzahl wissenschaftlicher Projekte und Verbünde sind beeindruckend. Die Zusammenarbeit im Rahmen von *Joint Labs* ist hervorragend und führte zu einer engen strategischen Verflechtung des FBH mit den Partner-Hochschulen TU und HU in Berlin sowie der Goethe-Universität Frankfurt am Main. Die Kooperationen des FBH mit einer Vielzahl wissenschaftlicher Einrichtungen der außeruniversitären Forschung sind ebenfalls bemerkenswert, insbesondere auch in der Leibniz-Gemeinschaft.

In der Vergangenheit konnte das FBH seine **Drittmittel**einwerbungen steigern und hat damit ein angemessenes Niveau erreicht. Das Institut wirbt seine Projektmittel bei einer beeindruckenden Vielzahl von Mittelgebern ein. DFG-Mittel sollten auch in Zukunft wenigstens die Höhe der geleisteten Abgabe erreichen.

Der Senat begrüßt, dass in der Vergangenheit substantielle Mittel zur Verbesserung der **Infrastruktur** aufgewendet wurden. Das FBH verfügt damit über eine äußerst leistungsfähige apparative und räumliche Ausstattung. Diese Infrastruktur sollte auch weiterhin auf dem neuesten Stand gehalten werden, um international wettbewerbsfähig bleiben zu können. Der mittlerweile fertiggestellte Institutsanbau wird die räumliche Situation nochmals verbessern. Es wird begrüßt, dass das FBH bereits jetzt die Möglichkeiten gemeinsamer Nutzungen von technischen Infrastrukturen auslotet. Der Senat empfiehlt, diesen Weg gemeinsam mit den in Berlin und Brandenburg vorhandenen universitären, außeruniversitären und industriellen Partnern weiterzuverfolgen.

Nach einer Wachstumsphase hat das FBH eine Größe erreicht, mit der es seine Aufgaben gut bewältigen kann. Im Jahr 2013 wurde die Verbindlichkeit des Stellenplans aufgehoben und stattdessen eine institutsspezifische Quote für unbefristete Beschäftigungsverhältnisse eingeführt. Die damit geschaffene Flexibilität im **Personalbereich** sollte das FBH insbesondere zur dauerhaften Absicherung seiner technischen Schlüsselfunktionen nutzen.

Die Anteile wissenschaftlicher Mitarbeiterinnen auf verschiedenen Qualifikationsstufen am FBH entsprechen den deutschlandweit geringen Prozentanteilen von Frauen in der Elek-

trotechnik und der Physik. Dennoch muss das FBH deutlich mehr **Wissenschaftlerinnen** gewinnen, um die nach dem Kaskadenmodell institutsspezifisch verbindlich festgelegten Zielquoten zu erreichen. Dies gilt vor allem für Positionen mit Leitungsaufgaben, die zum Zeitpunkt des Evaluierungsbesuchs ausschließlich von Männern besetzt waren.

Der Senat begrüßt, dass sich die Anzahl der am FBH betreuten **Promovierenden** in den vergangenen Jahren verdreifachte. Die Ausbildungsphase ist gut strukturiert und sollte durch eine stärkere Berücksichtigung der von der Leibniz-Gemeinschaft formulierten Richtlinien zur Betreuung Promovierender weiter verbessert werden.

Das FBH hat sich seit der letzten Evaluierung folgerichtig und kohärent weiterentwickelt. Seine exzellenten, international konkurrenzfähigen Arbeiten im Bereich der III/V-Halbleitertechnologie sind zeitgemäß, deren Anwendung und Transfer sind von hoher wissenschaftlicher, gesellschaftlicher und wirtschaftlicher Relevanz. An einer Hochschule ist die Erfüllung der Aufgaben des FBH in dieser Form nicht möglich. Eine Eingliederung des FBH in eine Hochschule wird daher nicht empfohlen. Das Institut erfüllt die Anforderungen, die an eine Einrichtung von überregionaler Bedeutung und gesamtstaatlichem wissenschaftspolitischem Interesse zu stellen sind.

2. Zur Stellungnahme des FBH

Der Senat begrüßt, dass das FBH beabsichtigt, die Empfehlungen und Hinweise aus dem Bewertungsbericht bei seiner weiteren Arbeit zu berücksichtigen.

3. Förderempfehlung

Der Senat der Leibniz-Gemeinschaft empfiehlt Bund und Ländern, das FBH als Einrichtung der Forschung und der wissenschaftlichen Infrastruktur auf der Grundlage der Ausführungsvereinbarung WGL weiter zu fördern.

16 June 2014

Annex A: Status Report

Ferdinand-Braun-Institut
Leibniz-Institut für Höchstfrequenztechnik (FBH)
im Forschungsverbund Berlin e. V.

Contents

1. Structure, Tasks and Institutional Environment

Development and funding

Ferdinand-Braun-Institut, *Leibniz-Institut für Höchstfrequenztechnik im Forschungsverbund Berlin e.V. (FBH)* was founded on January 1st, 1992 based on an evaluation of the German Council of Science and Humanities (*Wissenschaftsrat*). It emerged from two institutes of the former Academy of Sciences of the German Democratic Republic, the "*Zentralinstitut für Elektronenphysik* (ZIE)" and the "*Zentralinstitut für Optik und Spektroskopie* (ZOS)". In 2008, as a result of the last evaluation, the Leibniz-Association Senate recommended the continuation of FBH's joint funding. On the basis of the Senate's recommendations and a joint statement by the responsible departments at Federal and *Länder* level in April 2008, the Joint Science Conference determined that FBH still met the requirements for joint funding.

Responsible department at *Länder* level: Berlin Senate Department for Economics, Technology and Research

Responsible department at federal level: Federal Ministry of Education and Research (BMBF)

Legal form and organisation

FBH is member of *Forschungsverbund Berlin e.V*. (FVB), an association representing eight Leibniz-research institutes. Administrative tasks are collaboratively organised within the FVB by the Joint Administration and each institute's associated administrative unit. FBH is managed collaboratively by its Director (scientific head) and the Managing Director of FVB (administrative management).

Specific processes of the institute are handled directly by FBH, including management of human resources, finances, purchasing and sales, and controlling. Central administrative services, however, are allocated to the FVB Joint Administration with its head office in Berlin-Adlershof. Beyond the classical administrative sector, key issues like legal affairs, patent protection and administration, European affairs as well as press and public relations are provided centrally by FVB. Moreover, the member institutes share a corporate IT network.

FBH's supervisory committee is the Board of Trustees of FVB, which consists of ten members. The chair is appointed by the responsible department at Länder level; the deputy chair is appointed by the responsible federal department. The Board of Trustees is responsible for endorsing the programme budget and business plans, confirming the annual accounts, and appointing the FBH director, the managing director of FVB (head of administration), leading scientists, and members of the Scientific Advisory Board. Subject-specific matters concerning FBH are prepared by a dedicated subcommittee (Institutsausschuss).

The Scientific Advisory Board (SAB) advises the institute's management on fundamental aspects of the scientific work programme, on national and international cooperations, and on appointment procedures for the director and leading scientists. It evaluates the institute's scientific performance at regular intervals.

Mission and tasks

According to its statutes, FBH explores semiconductor technologies for applications in the fields of microwaves and optoelectronics. Its multidisciplinary research addresses components, modules and systems based on semiconductor materials and processes, on numerical modelling, and on simulation.

FBH's research has a strong focus on emitters of microwaves and light. Research in the GHz range and at NIR & VIS wavelengths is mostly application-oriented. FBH integrates these devices in complex modules for applications in communications, life sciences, sensing, production technologies, precision measurements and more. Research activities at frequencies towards the THz range and at UV wavelengths explore the basics and the feasibility of new device and module concepts as well as of advanced manufacturing processes.

Furthermore, FBH focuses on power devices. This holds not only for microwave and light emitters aiming to extend the limits of present technology, but also for FBH's research activities towards highly efficient gallium nitride (GaN) devices for applications in power electronics.

Research structure

Research and development is organised in four departments (Microwaves, Optoelectronics, Materials Technology, and Process Technology) as well as in four business areas (Microwave Components and Systems, GaN Electronics, Diode Lasers, and GaN Optoelectronics), which cover the main research programmes comprising basic research topics as well as development and transfer towards the industrial application (see appendix 1). FBH's business areas mainly interact with partners in research and industry.

Scientific work at FBH is realised in three major research programmes that are divided in sub-programmes representing the units of evaluation:

Electronics

1. RF electronics
2. Power electronics

Photonics

3. Monolithic brilliant laser diodes
4. Hybrid integrated laser sources
5. Monolithic UV and VIS light sources

III/V Compound Semiconductor Technologies

6. Materials
7. Processes

National and international academic environment

According to FBH, III-V compound semiconductors are employed ubiquitously in all consumer applications used in the domains of communication, transportation, industrial production, health, and nutrition. Despite the impressive advances of silicon technology in the field of high-frequency electronics, III-V components still represent key enablers of power generation and highest frequencies. On the optoelectronic side, they are indispensable due to the material-related spectral properties. By its own statement, only a few institutions are comparable to FBH as the combination of component design and characterisation with semiconductor technology represents a unique selling point.

With its concentration on the emitter side in both microwaves and optoelectronics, FBH considers itself as one of the largest III-V compound semiconductor technology research institutes in Europe. As such, it is comparable to the Fraunhofer Institute for Applied Solid State Physics (IAF) in Freiburg. However, while there are clear similarities between these two institutes with regard to their general fields of expertise, both differ significantly in terms of research topics, as FBH claims.

The Fraunhofer Institute for Telecommunications “Heinrich-Hertz-Institute” in Berlin is running a III-V technology as well, but specialises in indium phosphide (InP) components for optical telecommunications, which differs significantly from the FBH fields of expertise.

On the European level, comparable institutions mentioned by FBH are IMEC Belgium with its branch on high-power gallium nitride (GaN) electronics and the Alcatel-Thales III-V Lab in France. With IMEC, there is marginal overlap with the FBH business area GaN electronics, which is exploited in project cooperation. Alcatel-Thales III-V Lab is an industrial research centre working in microwave and optoelectronics areas and running GaN and InP technology, as FBH does. European Universities with semiconductor processing capabilities are widespread, but seldom compare to FBH’s specific profile, as the institute claims.

In the USA, according to FBH, the University of California, Santa Barbara (UCSB) and the Massachusetts Institute of Technology (MIT) run similar programmes. FBH rates UCSB with its activities in the THz field on transistor development and circuit design as probably most comparable to itself.

National interest and justification for funding as a non-university institution

Through its research programme, especially by focusing on photonics and microsystems engineering, FBH contributes on its own account to the twelve key technologies that have been identified in the High-Tech Strategy of the German government in order to act as drivers of innovation in application fields and other fields of technology. According to the institute, another important feature of FBH is its rapid and sustained transfer of research results to the marketplace. Based on III-V compound semiconductors, FBH is offering solutions for key components. In this context, diode lasers and UV LEDs are of particular importance.

The institute pursues an interdisciplinary approach of complex methods in simulation, technology, and metrology. This requires an industrial-level epitaxy, comprehensive process lines, and the matching mounting and assembling technologies, closely linked to simulation, design and characterisation techniques. Consequently, permanent staff and comprehensive infrastructures are necessary and must continually be improved. According to FBH, these prerequisites cannot be provided by a university.

2. General concept and profile

Development of the institution since the last evaluation

According to its mission, FBH pursues applications-oriented research in microwave and millimetre-wave engineering, and in optoelectronics focused on III-V compound semiconductors. As said by the institute, the necessity of conducting research on these high power and efficient emitters has increased since the last evaluation in 2007.

At the component level, the development of the III-V semiconductor technology has been systematically pursued. In addition, FBH has extended its research towards electronic and optoelectronic modules and subsystems with greater complexity. Furthermore, FBH has begun to integrate its components and modules into specific systems, especially in optoelectronics. Consequently, FBH fabricates pulsed laser radiation sources and diode laser systems with output powers in the kW range. To achieve this, the institute integrates its semiconductor components with mechanical and optical components and employs control circuitry supplied by external partners.

During the reporting period (2011–2013), FBH also started research in the field of applications. It is using its laser radiation sources in laser sensor technology for specific applications in the life sciences. These specific projects involve detection and verification of medications in human skin, determining the maturity of meat products, and measurements of anti-oxidant concentrations in the skins of fruits. Through this applied research, FBH is acquiring and verifying the current specifications of its laser radiation sources.

Results

The institute's results of the last years resulted from research and development in the domains of microwaves, photonics and III-V semiconductor technology. They include the following achievements:

- Microwave high-power amplifier modules using binary modulation and GaN MMIC (Monolithic Microwave Integrated Circuit) power switches for digital transmitters
- Wafer-level integration of InP-DHBTs (double-hetero bipolar transistor) on BiCMOS for circuits in the THz frequency range from 100… 300 GHz
- Technological development and fabrication of normally-off transistors characterised by high breakdown voltage and low on-resistance
- Development of high-performance NIR (near-infrared) diode lasers

- Development of GaN optoelectronics for LEDs in the UVB spectral region around 310 nm, and LEDs and laser diodes in the UVC region significantly below 300 nm
- Establishment of a technological platform for complex miniaturised diode laser modules suitable for applications in the field of laser metrology, free-space optical communications, Raman spectroscopy, and 3D holographic displays
- Development of customer-specific III-V technology modules and epitaxial layer structures growth processes by MOVPE (metalorganic vapouur phase epitaxy) for an international client base.

In the reporting period, FBH has published 65 (2011), 61 (2012) and 103 (2013) articles in peer-reviewed journals. For the number of articles published in other journals and for the number of industrial property rights, please refer to appendix 2.

FBH is also committed in knowledge and technology transfer. According to the institute, its research results are leading to novel electronic and optoelectronic components and modules for applications in the fields of communication, health, energy, and security as well as in industry production and aerospace. FBH has been continuously cooperating with over fifty industrial firms on the base of research and development contracts and services. In specific cases, FBH goes beyond its delivery programme of prototypes to beta-testing the components and modules (cf. chapter 5).

Since the last evaluation, commercialisation and technology transfer activities at FBH have led to four spin-offs. Furthermore, FBH has opened its laboratories for universities, institutes, and companies. Teams of scientists and engineers supplement the research know-how, from application development through to prototypes.

Academic events and public relations

FBH regularly organises symposia, workshops and conferences in the fields of its research and development interests. Vice versa, staff members are regularly invited as speakers in events in Germany and abroad. Within the reporting period (2011–2013), 72 invited talks have been held.

Public relations activities of FBH include presentations at trade fairs and related events, the institute's website, press releases, the brochure "frequent" (addressing stakeholders from industry, science, funding bodies and politics), presence in social media, and events attracting the interested public (Long Night of Science, Girls Day etc.).

Strategic work planning for the next few years

In the future, according to FBH, its overall research and transfer programme will continue to be the basic guideline. The institute intends to advance further by deepening the understanding of FBH's technology in realising and applying semiconductor emitters from the MHz to the UV range.

Besides the focus on III-V semiconductor technology, on devices and on components, FBH intends to intensify research on modules, subsystems and system-related work (tool building). This includes research on applications in specific fields. Currently, FBH discusses several long-term options with partners in research and industry which might

generate additional research (sub-) programmes at the institute. These options include pump laser modules and systems, digital microwave PAs (power amplifier) for the future wireless infrastructure, and integrated quantum technologies.

Appropriateness of facilities, equipment and staffing

FBH states that, in general, its equipment and staffing is appropriate to fulfil its mission. The institute runs clean-room laboratories with the necessary equipment and employs dedicated staff to run III-V semiconductor epitaxy, processes and packaging on an industry-like level. In the framework of its collaboration with universities (Joint Labs, cf. chapter 4), FBH provides access also to external experts complementing its expertise.

According to the institute, there are experienced senior scientists and senior technicians in all research areas securing newly generated know-how. As said by FBH, it tries to hire this staff mainly on permanent positions. The basic management principles of the institute's "programme budget", however, state that only 40 % of FBH's budget can be allocated to permanent staff positions (cf. chapter 6). FBH's mid-term staff development plan provides for keeping the present size of the institute. Nevertheless, FBH anticipates need for additional competence in some fields.

In 2015, the retirement of the head of the department "Optoelectronics" might open up the opportunity to add another professorship based on a joint appointment with Humboldt University Berlin.

3. Subdivisions of FBH

3.1. Electronics – RF electronics (40.2 FTE altogether; 17.2 FTE research; 12 PhDs)

Work programme development

The main research target of this sub-programme is to push the limits of microwave analogue devices and circuits with regard to output power and efficiency versus frequency. This is achieved following three different directions: Highest power, using GaN-HEMT (high-electron-mobility transistor) technology, highest frequencies, using InP-HBT (heterojunction bipolar transistor) technology, and exploration of new amplifier and device concepts.

Since the last evaluation in 2007, two major changes were implemented in order to keep the focus described before: First, GaAs (gallium arsenide) based work was discontinued in order to strengthen GaN activities. Accordingly, activities on the digital PA concept were intensified. Second, the THz electronics group was newly established together with the measurement facilities and an extended process portfolio.

Results

- Stabilisation of 4" GaN processes for 0.5 µm HEMTs and establishment of a 0.25 µm MMIC process
- Discrete GaN power transistors with output powers up to 100 W at 2 GHz

- Development of frequency-agile GaN power transistors with tuneable matching networks in package
- Demonstration of Coplanar X-band GaN MMIC power amplifiers
- class-S/class-D PA modules using digital/binary modulation
- Development of a 3" InP-on-BiCMOS wafer-scale process for mm-wave and sub-mm-wave circuits
- Demonstration of InP-on-BiCMOS circuits up to the 250 GHz band
- Improvement of understanding of calibration procedures for on-wafer measurements in W-band and beyond
- Development of microwave plasma generators with integrated GaN power oscillator and small form-factor
- Development of high-speed drivers for lasers and electro-optical modulators

Work planning

In the next few years, the sub-programme “RF-electronics” intends to increase activities in the field of GaN high-power amplifiers on concepts targeting the digital microwave PA. The topic of THz circuits is expected to remain a broad research theme for at least the next five years, with an increasing potential as to applications. This includes exploration of plasmonic detection and emission. Two new topics are envisaged: GaN-on-BiCMOS and wide-bandgap-PAs on new material systems such as AlN.

3.2. Electronics – Power Electronics (5 FTE altogether; 3 FTE research; 2 PhDs)

Work programme development

FBH’s research work on “GaN power electronics” started in 2006 with a long term goal to realise radiation hard GaN FETs (field-effect transistors) for power switching up to 1000 V in space. This work has been intensified with the inauguration of the business unit “GaN electronics” in 2007. Since then, research on normally-off transistors for high blocking voltages, with low on-state resistivity and optimised dynamic properties dominates. Based on the pre-existing processes for discrete and monolithically integrated circuits, systematic optimisations of epitaxial designs, technological modules, and lateral structure designs have allowed for a breakdown of voltage increase from initially 60 V to 1200 V, the development of normally-off transistors (p-GaN based with epitaxial overgrowth), and the optimisation of high voltage switching capabilities.

For all research work, the whole processing sequence from epitaxy to device processing and packaging has been taken into account. All design and processing modules in the fabrication chain have been modified and are still being further adapted. Reliability characterisations combined with the identification of degradation mechanisms have increasingly gained importance and are fed back into technological development cycles. Research on quasi-vertical transistor technology is conducted since three years. These devices will enable standard chip mounting techniques and additionally offer the potential of dissipating heat from both chip sides. Currently, the process modules towards this type of devices are under development.

Results

- Elaboration of full understanding of lateral and vertical breakdown mechanisms of GaN transistors
- Demonstration of normally-off FETs
- Elaboration of full understanding of mechanisms limiting switching efficiency
- Close cooperation with industry (Infineon, Bosch, IXYS, Kaco, UMS, etc.)
- Development of quasi-vertical GaN high voltage transistors
- Foundation of Joint Lab “Power electronics” in collaboration with TU Berlin

Work planning

In the next few years, the sub-programme “Power Electronics” will concentrate on GaN power transistors with regard to the optimisation of epitaxial layer stack and lateral device geometry for high voltage normally-off GaN devices, and technology transfer to industry.

FBH anticipates that industry will take over GaN power electronics for the mass market in the next few years and intends to support this deployment. Furthermore, research on the following topics will be strengthened: true vertical GaN switching transistors and transistor modules, GaN electronics for harsh environment, and system applications.

3.3. Photonics – Monolithic Brilliant NIR Laser Diodes (36.1 FTE altogether; 15 FTE research; 5.2 PhDs)

Work programme development

This sub-programme focuses on research on semiconductor chips based on GaAs heterostructures. Since 1992, work has been advanced mainly by deepening the understanding of laser diodes especially with regard to output power, efficiency and spatial beam quality as well as with regard to reliability. Furthermore, intense research is done for frequency stabilisation and line width control. All valuable parameters in vertical and lateral chip structure are explored by simulation and realisation in operation conditions as well as in various mounting schemes.

Laser diodes are used in basic investigations as well as in basic and applied research and in industrial applications. For many of these applications, laser diodes with beam forming optics on a common carrier plate are integrated. Since the last evaluation, FBH has included pulsed laser diodes and amplifiers in its research programme. Wavelength range has been extended. Furthermore, there is a focus on the frequency stabilisation, on the improvement of spatial beam parameters, and on research towards the long-term reliability of high power laser diodes.

The sub-programme is focusing on quantum well lasers. To obtain kW-pulses for application in laser ignition systems for gas engines, FBH had run projects on nano-stack laser diodes with integrated tunnel junctions, but they were skipped. FBH stopped any work on VCSELs (vertical-cavity surface-emitting laser) so as to focus on edge-emitting lasers. Concerning NIR and red laser diodes, FBH pursues international transfer activities with its spin-off companies and with other customers.

Results

- Improved understanding of high power and high brilliant lasers as well as laser bars
- Development, optimisation and continuous fabrication of highly reliable pump laser benches for inter-satellite free space communication.
- Highly coherent laser diodes for interferometry and sensors
- High power, high brilliant ridge waveguide laser and tapered laser diodes
- Extension of the long-wave and the short-wave edges of the wavelength range
- Short pulse light sources for seed laser in materials processing

Work planning

In the next few years, the sub-programme "Monolithic Brilliant NIR Laser Diodes" will concentrate on deepening the understanding of laser diodes based on the GaAs materials system. The need of pump light for terawatt- and petawatt-laser systems to be used in accelerator physics, X-ray generation and power generation in laser fusion machines will be addressed. Due to retirements of the department head "Optoelectronics" in 2015 and the group leader "Mounting technologies" in the second half of 2014, the successions have to be prepared. FBH intends to announce the optoelectronics position as a joint professorship with Humboldt University Berlin.

3.4. Photonics – Hybrid Integrated Laser Sources (23 FTE altogether; 7 FTE research; 15 PhDs)

Work programme development

This sub-programme focuses on the realisation and application of compact laser diodes modules with high complexity customised for specific applications. Wavelengths are in the NIR and red spectral range based on the wavelengths of the semiconductor chips. The visible and UV spectral range is addressed by second harmonic generation in periodically poled non linear crystals. In addition to the technology for the realisation of the laser diodes, the sub-programme explores and operates the technology for module mounting and assembling; appropriate simulation and design is included.

Research on hybrid integrated laser sources is conducted in three areas "Hybrid Laser Sources for NIR and VIS" (with focus on output power, efficiency and brilliance), "Laser Sensors" (with focus on compact laser sources for Raman, absorption and fluorescence spectroscopy), and "Laser metrology" (with focus on complex laser diode modules providing narrow line width and high frequency stability). Since 2008, FBH is running a Joint Lab with Humboldt University Berlin led by the university chair of "Optical Metrology" (cf. chapter 5).

Results

- Development and optimisation of compact hybrid integrated light sources in visible spectral range (red to blue)
- Development and optimisation of laser diode modules for highly sensitive Raman spectroscopy and shifted excitation Raman difference spectroscopy (SERDS)

- Development of laser diode modules for LIDAR
- Availability of space compatible or qualified designs and technology for complex laser diode modules
- Development of building blocks for photonic integrated circuits based on passive, double hetero-structure GaAs/AlGaAs-chips
- Development of SiO2-based microresonators for ultra-narrow line-width lasers and for sensing applications
- Development of measurement techniques to characterise the spectral stability and modulation capability of single mode laser modules

Work planning

In the next few years, the sub-programme "Hybrid Integrated Laser Sources" will focus on micro-module designs with respect to optical, electrical, mechanical and thermal aspects and push the limits of the sub µm-integration technology. Transfer of know-how to industrial partner is anticipated. Specific topics will be hybrid laser sources for NIR and VIS, laser sensors, and laser metrology (joint lab with Humboldt University Berlin).

3.5. Photonics – Monolithic UV and VIS Light Sources (7.2 FTE altogether; 4.2 FTE research; 1 PhDs)

Work programme development

In this sub-programme, the activities of the leader's university group and those of FBH have been integrated in a Joint Lab (business unit "GaN Optoelectronics"). Here, the entire value chain for GaN optoelectronic devices has been established. Currently, there is a large focus on UV emitters. Progress has been made in AlGaN materials quality and UV emitter performance. Meanwhile, the LED devices cover the entire UVA, UVB, and large parts of the UVC spectral range. Progress has been made in the areas of semiconductor laser epitaxy and ridge waveguide technology. Moreover, stable technologies for the fabrication of single-mode ridge-waveguide laser diodes are established.

Results

<u>Research</u>

- Epitaxial growth of Al(Ga)N on sapphire with reduced dislocation densities
- Homoepitaxy of InGaN quantum well laser diodes on GaN bulk substrates
- AlGaN, InGaN and InAlGaN quantum well heterostructures with high internal quantum efficiencies for UVC, UVB, UVA and violet emitters
- Low resistance n-AlGaN over the entire composition range for lateral current injection
- Control of p-doping over the entire composition range
- Advanced chip designs for high performance UV LEDs
- Understanding of polarisation effects in (Al,In,Ga)N UV LEDs

Scientific collaboration and technology transfer

- Transfer of know-how within projects, e. g. epitaxy and chip processing of UVC-LEDs to Osram
- Launch of a spin-off company “UV-Berlin” to commercialise UVB & UVC LEDs
- Epitaxy and chip processing of AlGaN wafers for solar blind Schottky photo-detectors, of top-emitter UVA LEDs, and of RW laser diodes
- Design & fabrication of UVB- and UVC LED modules for water purification, medical disinfection and plant growth lighting

Work planning

In the next few years, the sub-programme “Monolithic UV and VIS Laser Sources” intends to put particular emphasis on UV LEDs (high power, high efficiency, long-lifetime UVB & UVC LEDs, improving yield and throughput, pushing wavelength range, better understand degradation mechanisms, improving light extraction efficiency, concepts for dislocation reduction), and on laser diodes (InGaN DFB lasers with high brilliance, high power lasers with high beam quality, high power narrow linewidth violet and near UV laser diodes, development of AlGaN-based deep UV laser diodes).

3.6. III/V Compound Semiconductor Technologies – Materials (26.7 FTE altogether; 10.2 FTE research; 8.5 PhDs)

Work programme development

This sub-programme mainly focuses on the vapour phase epitaxy of two-dimensional hetero-structures composed of group III-arsenides and group III-phosphides as well as on group III-nitrides. Hydride vapour phase epitaxy is explored for the growth of thick (AlGa)N layers, targeting on the use of these layers as substrates or templates for the epitaxial growth of functional hetero-structures in the group III-nitride material system.

Due to the maturity of the group III-arsenides and group III-phosphides, the epitaxy of sophisticated and tailor-made hetero-structures for advanced edge-emitting lasers in the wavelength range between 1.2 -0.6 µm diodes was in focus over the last years and still is.

Know-how obtained with the growth of perfect distributed GaAs/AlAs-Bragg reflectors is used for the epitaxy of highly stable saturable absorbing mirrors. Materials based on GaN are utilised for transistors for microwave and power switching applications as well as for UV LEDs and UV photo-detectors. These activities have been intensified over the last years.

Results

- Stable supply of optimised and customised GaAs heterostructures
- Support of Spin-off TESAG (now JENOPTIK; GaAs LDs)
- Commercial supply of SAM chips for short pulse laser systems
- Supply of optimised and customised GaN hetero-structures for RF and power electronics.
- Development of GaN laser diode epi (polar, non-polar in Joint lab with TUB)

- Development and supply of AlN templates for UVB and UVC LEDs
- Development of HVPE growth process for GaN boules and AlGaN templates
- Development of AlGaN photodetector

Work planning

In the next few years, the sub-programme "Materials" will concentrate on the growth and the properties of optimised and customised hetero-structures of GaAs and GaN based materials. Special emphasis will be placed on stable delivery of GaAs-based laser hetero-structures and on the supply of GaN-based laser diode hetero-structures. Further planning includes the development of growth processes for UVB and UVC LEDs, the supply of GaN-HFETs for RF-devices and MMICs, and the development of hetero-structures and growth processes for GaN power electronics at higher voltages. Based on the experience in AlGaN LEDs high-performance applications, high Al-content or p-n-diodes will be realised. Moreover, improvement of HVPE growth processes for GaN-boules for thicker crack-free boules are planned as well as the development of HVPE growth processes for thick Al(Ga)N templates with high transparency for UV LEDs.

3.7. III/V Compound Semiconductor Technologies – Processes (22.6 FTE altogether; 9.6 FTE research; no PhDs)

Work programme development

Semiconductor processing has been concentrating on the advancement of III/V compound semiconductor technology as the basis of research on RF-components and power electronic devices as well as on laser diodes and LEDs. III-V semiconductors which are in focus are based on GaAs and GaN mainly. There is research on the processing of InP based materials for HBTs that are realised in a proprietary transferred-substrate technology. Furthermore, there is research on the processing of SiC, Si and diamond.

Chip processing comprises all technologies necessary and typical for III-V semiconductors. They are operated under industry-like conditions and regulations. It is intended to achieve and to guarantee long-term reproducibility and homogeneity at any step of the fabrication chain. Special emphasis is placed on basic developments for the programmes on electronics and optoelectronics, process development and device fabrication on request of external partners as well as on process services for external partners.

Results

- Basic developments for FBH's programmes on electronics and optoelectronics, e. g.
  - electron beam lithography and dry etching
  - development of wafer level transferred substrate technology
  - wafer level integration of diamond heat sinks on InP MMICs
  - patterning of SiC and sapphire-templates for UV-LEDs and GaN-HVPE
  - development of high-Q toroidal SiO2 resonators and resonator arrays
- Process development and device fabrication on request of external partners
- Process services for external partners from academia and industry

Work planning

In the next few years, the sub-programme “Processes” will concentrate on stabilisation, improvement and enhancement of III-V semiconductors. Special emphasis will be placed on quality assurance, on application-oriented development of novel processes, on device-oriented technology development for the realisation of THz transistors and MMICs, on process development and device fabrication on request of external partners, and on services for external partners from academia and industry.

4. Collaboration and networking

Collaboration with universities

FBH maintains close links with several regional universities and beyond which are cultivated through joint appointments, Joint Labs and other cooperation models. FBH staff members also contribute to academic education through various university teaching positions, which amounted to approx. 260 hours per week and semester between 2011 and 2013.

Currently, FBH has two joint appointments with Technische Universität Berlin (TUB). In addition, two Joint Labs on GaN Optoelectronics and Power electronics exist with TUB. By this arrangement, scientists are appointed as full professors at university with FBH covering part of the salary so that the respective person partially works at FBH. Furthermore, there is a close collaboration with the professorship for Microwaves at TUB.

FBH participates in the German Research Foundation (DFG)-funded Semiconductor Nanophotonics Collaborative Research Center (CRC 787) as well as the Helmholtz Research School on Security Technologies (HRSST) run at TUB.

In addition, FBH closely collaborates with Humboldt University Berlin (HUB). Currently, there exist two formal links, one within a Joint Lab with the professorship for Optical Metrology, who is also head of the Laser Metrology group at FBH (with FBH covering part of the salary), and a second within the Transmission Electron Microscopy Lab at HUB, with FBH providing one scientist to the team and covering running costs of 30k€ annually.

In 2015, FBH intends to announce the succession of the current head of the Optoelectronics Department as a joint professorship with HUB.

A forth Joint Lab exists with Goethe University Frankfurt/Main (GUF) with the Chair for Terahertz Technology also heading the THz Electronics group at FBH.

Since 2012, FBH collaborates with Brandenburg University of Technology Cottbus – Senftenberg with the Chair of Microwave Technologies leading a group on low-noise components at the institute.

Collaboration with other domestic and international institutions

FBH collaborates with institutions and companies worldwide. According to the institute, this is part of FBH’s general strategy as well as its internationalisation strategy. The

Science Management Department of FBH is assisting in initialising and coordinating the networking activities of the institute.

Major collaborative networks with FBH participation are

- "Advanced UV for Life" with the goal to develop novel components, systems, and treatments based on UV light-emitting diode (LED) technology; 23 partner institutions coordinated by FBH, funded until 2019 with up to 45 million Euro
- "Berlin WideBaSe", funding period 2010-2013, combines know-how and technical resources from ten enterprises and three research institutions in the field of wide band-gap semiconductors; funding level of 6.5 million Euro, 2.7 of which have been allocated to FBH
- "Leibniz Technology Transfer Association Microelectronics" bundles research and development of currently ten Leibniz institutes in micro- and optoelectronics and Microsystems technology.
- "Leibniz Application Laboratories" – MiTOS (Leibniz Microwave Technology, Optoelectronics and Solid State Electronics Application Laboratory, funded 2009–2011 by the Federal Ministry of the Interior) and Veriplan (continuation of MiTOS founded in 2013, funded by the Federal Ministry of Education and Research). The Application Laboratories aim at creating an interface between industry and science to transfer research results into demand-oriented experimental models and beta-prototypes.
- "Leibniz-Research Alliance for Medical Engineering". The mission of this alliance is to provide a platform for national scientific communication, exchange, and collaboration in the field of medical engineering; its major focus is on the translation of ideas in the biophotonic sector.

Between 2011 and 2013, the institute collaborated in nine major EU projects, from which one project is coordinated by FBH.

As part of its internationalisation strategy, FBH encourages the exchange of personnel. In the period 2011–2013, 13 guest scientists worked at FBH. In the same period, six FBH staff stayed at host institutions in non-European countries.

Other collaborations and networks

FBH has established strategic partnerships with industry for some of its focus areas of research, e. g. Tesat Spacecom, Jenoptik, Trumpf, Toptica (all Germany), NEC (Japan), and QSI (Korea). Beyond this, the institute has many industrial partners in the Berlin region and in Europe.

5. Staff development and promotion of junior researchers

Staff development and personnel structure

As of 31 December 2013, FBH employed 237 people (212 FTE including scholarship holders, students assistants and trainees). Among them, 127 (121 FTE) were scientists,

including eleven scholarship recipients. Among scientific staff, approx. 20 % were women, 90 % of which were employed on temporary contracts (cf. appendix 4).

Overall, 64 % of FBH's regular staff is employed on temporary contracts. As the FBH further elucidates, this percentage might, however, decrease in future in order to accomplish the institute's research goals.

Since 2007, total staff grew from about 180 to approx. 270 by the end of 2013 including about 30 further people working at FBH joint labs, even though it is hard for the institute to find candidates with sufficient experience and prior knowledge for many position within FBH. In order to counteract a considerable fluctuation of staff in the past – 56 new co-workers joined FBH in the period 2011–2013 while 32 regular employees of the institute left during the same time – FBH made use of a recruiting and staff development strategy comprising career building measures, a Junior Professional Programme, campus based training at Adlershof and teaching activities at the Berlin universities to attract students. In addition, FBH offers academic studies, seminars and courses as well as soft-skills development for its employees to further develop their potential and their skills.

Promotion of gender equality

At the end of 2013, approx. 13 % of scientific staff and approx. 26 % of doctoral candidates were female (17 % of all scientific staff). Currently, there are no female researchers at the highest executive levels of the institute (Departments, Business Areas). However, 19 % of the group leaders at FBH are female. As FBH elucidates, the percentage of women among scientific staff is closely related to the situation with regard to graduates in the fields of electrical engineering and physics. Following the binding cascade model, FBH intends to raise the percentage of its female employment rate to 25 % and 28 % for scientific staff and doctoral candidates, respectively, by 2017.

FBH's policy follows the DFG's "Research-oriented standards on gender equality". They are implemented by various measures, i.e. the provision of a family-friendly workplace, flexible work options, stay-in-touch programmes, parental leave and human resources programmes. In order to further raise interest of girls in technical and scientific issues, FBH supports special events such as the Engineering Day for Girls.

In 2009, and again in 2013, FBH was awarded the TOTAL-E-QUALITY certificate for its involvement and measures to implement equal opportunity. FBH also received several times a certificate as family-friendly workplace of the Berlin district Treptow-Köpenick.

Promotion of junior researchers

By the end of 2013, FBH staff included 46 doctoral candidates (representing almost 20 % of total staff, including seven scholarship recipients) up from 20 at the time of the last evaluation in 2007.

Between 2011 and 2013, 21 academic degrees qualifying for doctoral work (diploma, Master) were completed under the supervision of FBH staff.

During the same period, 14 doctoral dissertations were completed at FBH. Depending on field, different curricula for PhD students are common at the collaborating universities.

In physics, a curriculum is set up with a mixture of structured course works and independent scientific work, sometimes also with mandatory course requirements. In the field of engineering, the PhD period is designed as the first phase of professional practice. Accordingly, students are trained in a more industry-type environment without any dedicated educational contents. In accommodating these two traditions, FBH has developed guidelines for its PhD students, in order to qualify doctoral candidates for both a scientific and an industrial career. In doing so, FBH closely collaborates with TUB and HUB, e. g. most doctoral students who are working in the Optoelectronics and III-V Semiconductor Technology Programmes at FBH are engaged in the School of Nanophotonics at TUB.

FBH offers special career-building measures and opportunities to post-doctoral researchers in order to develop their scientific profile and reputation.

Vocational training for non-academic staff

According to FBH, the institute invests a good deal of effort in education and training for non-academic staff. Between 2011 and 2013, altogether ten apprentices completed their training at FBH: nine microtechnologists and one industrial mechanic. In order to support its education scheme, FBH has established a mentoring programme allocating each apprentice a senior scientist as a mentor.

6. Quality assurance

Internal quality management

FBH has been certified to the ISO 9001 quality standard (2004), the ISO 14001 environmental management standard (2006) as well as the BS OHSAS 18001 occupational health and safety assessment series (2007). Annual audits are monitoring conformance to the three standards, upon which FBH's Integrated Management System (IMS) is based.

As ISO-based quality management is focused on fabrication, administration processes, and management structure, it is complemented by a separate policy based on the rules of good scientific practice recommended by the German Research Foundation (DFG). Within the process of publication, FBH set up an in-house quality management procedure involving authors, leading scientists of relevant Departments and Business Areas as well as the director of the institute. In order to deal with critical issues, an Ombudsperson and a deputy are elected by the scientific staff for a 3-year term (one-time re-election permitted).

Quality management by the Scientific Advisory Board and Board of Trustees

The Scientific Advisory Board (SAB) consists of six to twelve scientists. They are appointed by the Board of Trustees of FVB for a period of four years, with the possibility of extension for a second period. The SAB meets annually, each meeting comprising scientific presentations on results and progress of work at FBH as well as a detailed report from the Director of the institute. SAB advises director and Board of Trustees on scientific issues, ongoing development, and future plans.

The recommendations of the SAB are dealt with in the monthly meetings of Departments and Business Area heads with the scientific director. They are also communicated to FBH's staff.

Between the external evaluations of FBH, the SAB conducts a two-day audit obtaining a comprehensive overview; the last audit took place in 2010.

Implementation of recommendations from the last external evaluation

In order to meet the Senate's key recommendations of the last evaluation (below in *italics*; cf. *Senatsstellungnahme zum Ferdinand-Braun-Institut für Höchstfrequenztechnik (FBH) im Forschungsverbund Berlin e. V.;* 5 March 2008; pp. B-13/14), FBH has reacted as described on the following pages. However, FBH did not comment on more detailed recommendations mentioned in the evaluation report, relating to

- the strengthening of fundamental research (pp. 3, B-3, B-4, B-10)
- suggested collaborations with industrial as well as scientific partners in the fields of GaN electronics and optoelectronics (pp. B-6, B-7)
- the strengthening of the institute's involvement in its spin-offs (p. B-11)
- the allocation of investment funds (p. B-10)
- increased flexibility in the compensation of staff (B-10)

<u>General concept and profile</u>

1) *"Besides its mid-term research goals, FBH should develop a long-term concept for treating basic research topics that may lead to technologies relevant for the future. This concept should also include alternatives that take into account the case of a falling demand of applications based upon current materials systems and technologies FBH is presently working on."*

   According to FBH, the institute has developed a comprehensive long-term concept (cf. section 2). Part of this strategy was to establish the Indium Phosphide (InP)-based technology for THz applications providing alternatives for the GaN electronic path.

2) *"The review of opportunities to merge the activities of FBH, IAF in Freiburg, and HHI in Berlin should be continued."*

   "FBH should work towards increased collaboration with the Fraunhofer Institutes IAF in Freiburg and HHI in Berlin on the technologies employed in the program area Basic Technologies."

   As the FBH points out, this recommendation was the outcome of discussions with IAF and HHI ongoing at the time of the previous evaluation procedure. Contacts on merging process technologies went on for some time but had no results. According to FBH, none of the various options turned out to be viable.

3) *"It is recommended to develop more advanced systems expertise at FBH based on collaborations with scientific institutions, in particular in the fields of optical systems engineering in the Optoelectronic program area as well as in communication systems exper-*

tise for the Microwave engineering program area. For the latter, possible employment of microsystem elements should be considered."

In the past, FBH extended its systems expertise in several regards, e. g. with an epidermis scanning project for medical diagnosis of human skin (in collaboration with Charité University Hospital Berlin) or in a joint project with Max-Born-Institute on short-pulse kW laser systems. In the microwave field, digital power amplifier modules for the wireless infrastructure are being developed in cooperation with NEC (Japan).

As recommended, FBH considered links to microsystem technology but this option did not open up new opportunities. Instead, FBH enhanced collaboration with Goethe University Frankfurt/Main on THz radar system components and broadened the microplasma field.

4) *"FBH should consider whether it would be wise to focus its work in the Explorative Technologies program area on a few selected wavelength regions in the field of GaN optoelectronics."*

This refers to activities now performed within the GaN Optoelectronics Business Area. In contrast to 2007, work is now more focused, mainly on research on UV LEDs, as FBH states. Research on emitters towards the green spectral range has been omitted.

5) *"On the organisational side, the subdivision of the programme areas into smaller organisational units by establishing project departments should be continued."*

Following this recommendation, the organisational structure of the institute was developed accordingly: GaN Optoelectronics, which was previously a "*Projektabteilung*" (project department), is now a Business Area with two groups. Moreover, the application-related activities in the Microwave and the Optoelectronics Departments were outsourced into two new Business Areas named Microwave Components & Systems, and Diode Lasers (cf. chapter 2). These Business Areas are further subdivided presently into four and five groups, respectively.

<u>Collaboration and networking</u>

6) *"FBH should adopt a leading role in international research consortia."*

As FBH points out, it has a coordinating role in several European projects (cf. chapter 4). Also, FBH has initiated large BMBF-consortia, *e. g.* "Berlin WideBaSe (wide band gap semiconductors)" and "Advanced UV for life".

7) *"The number of guest scientists at FBH as well as the number of guest stays of FBH staff at other institutions should be increased significantly."*

According to FBH, the number of guest stays at the institute increased from 11 in 2003–2005 to 13 in 2011–2013; at the same time the number of FBH staff members on leave at external institutions grew from 1 to 6.

Appropriateness of facilities, equipment and staffing

8) *"FBH should intensify its efforts to obtain DFG project funding for the recommended future basic research topics."*

In the past, FBH intensified its efforts to obtain DFG project funding. The number of DFG projects has increased from four (2011) and six (2012/13) to eight in 2014 while the amount of DFG funding increased from 220k€ (2011) to 390k€ (2013).

Promotion of junior researchers

9) *"The PhD programme at FBH should be more structured. In addition to working with Technical University Berlin on training junior scientists and technicians, FBH should also enhance its collaboration with Humboldt University Berlin."*

In order to qualify doctoral candidates for both a scientific and an industrial career, FBH has developed guidelines for its PhD education (cf. chapter 5). Collaboration with Humboldt University in training PhD students has become closer.

Results and scientific impact

10) *"For the recommended future work on basic research topics, FBH should work towards achieving a higher proportion of publications."*

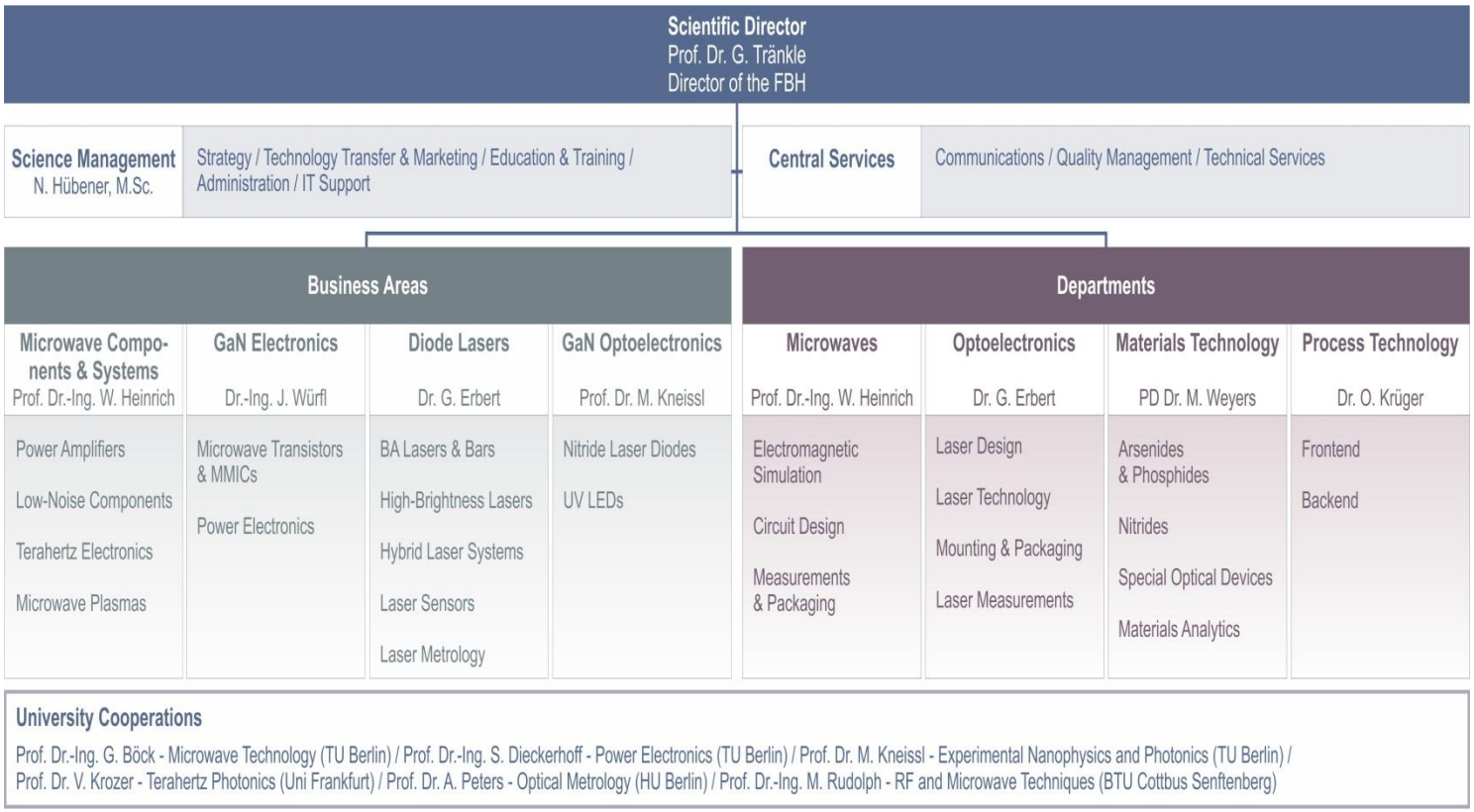
With 103 peer-reviewed publications in 2013, situation has been improved compared to the previous external evaluation when ca. 50 refereed publications were reported.

11) *"In about 3 years, the institute should reassess its present patent strategy."*

A patent office at the *Forschungsverbund* was established and FBH went through a sector-oriented valuation process with an external advisor.

Appendix 1

Organisational Chart



Appendix 2

Publications and patents

	Period		
	2011	**2012**	**2013**
Type of publications			
Monographs	0	0	2
Individual contributions to edited volumes	0	0	0
Articles in peer-reviewed journals	65	61	103
Articles in other journals	22	21	37
Working and discussion papers	0	0	0
Editorship of edited volumes	0	0	0
Number of publications per full-time equivalent (FTE) in 'research and scientific services' (not including doctoral candidates and science management)	1.3	1.2	2.1

	2011		**2012**		**2013**	
Industrial property rights	Granted	Registered	Granted	Registered	Granted	Registered
Patents	68	75	69	102	78	114
Other industrial property rights	5	0	5	0	4	0
Exploitation rights/licences (number)	9		9		9	

Appendix 3

Revenue and Expenditure

Revenue		2011			2012			2013 [1]		
		K€	% [2]	% [3]	K€	% [2]	% [3]	K€	% [2]	% [3]
Total revenue (sum of I., II. and III.; excluding DFG fees)		21.913,3			24.026,4			22.287,8		
I.	**Revenue (sum of I.1.; I.2. and I.3)**	21.402,2	100 %		23.673,7	100 %		21.812,3	100 %	
1.	Institutional funding (excluding construction projects and acquisition of property)	11.860,5	55 %		11.725,7	50 %		12.025,5	55 %	
1.1	Institutional funding (excluding construction projects and acquisition of property) by Federal and *Länder* Governments according to AV-WGL	11.860,5			11.725,7			12.025,5		
1.1.1	*Proportion of these funds received through the Leibniz competitive procedure (SAW procedure)* [4]	*520,0*			*856,7*			*559,2*		
1.2	Institutional funding (excluding construction projects and acquisition of property) not received in accordance with AV-WGL	0,0			0,0			0,0		
2.	Revenue from project grants	9.045,2	42 %	100 %	11.354,9	48 %	100 %	9.149,8	42 %	100 %
2.1	DFG	220,4		2 %	252,8		2 %	387,0		4 %
2.2	Leibniz Association (competitive procedure) [4]	520,0		6 %	856,7		8 %	559,2		6 %
2.3	Federal, *Länder* Governments	6.399,2		71 %	6.728,1		59 %	5.066,4		55 %
2.4	EU	522,0		6 %	715,1		6 %	1.173,0		13 %
2.5	Industry	1.383,6		15 %	2.782,2		25 %	1.905,4		21 %
2.6	Foundations	0,0		0 %	20,0		0 %	58,8		1 %
2.7	*If applicable: other sponsor*	0,0		0 %	0,0		0 %	0,0		0 %
3.	Revenue from services	496,5	2 %		593,1	3 %		637,0	3 %	
3.1	Revenue from commissioned work	487,6			425,8			592,5		
3.2	Revenue from publications	0,0			0,0			0,0		
3.3	Revenue from exploitation of intellectual property for which the institution holds industrial property rights (patents, utility models etc.)	8,9			6,6			44,5		
3.4	Revenue from exploitation of intellectual property without industrial property rights	0,0			0,0			0,0		
3.5	*Revenue from other services*	0,0			160,7			0,0		
II.	**Miscellaneous revenue** (e.g. membership fees, donations, rental income, funds drawn from	511,1			352,7			475,5		
III.	**Revenue for construction projects** (institutional funding by Federal and *Länder* Governments, EU structural funds, etc.)	0,0			0,0			0,0		

Expenditures		K€	K€	K€
Expenditures (excluding DFG fees)		23.701,1	23.934,8	22.614,8
1.	Personnel	11.123,5	11.559,2	12.392,2
2.	Material resources	6.964,2	6.482,1	6.632,0
2.1	*Proportion of these expenditures used for registering industrial property rights (patents, utility models etc.)*	122,0	251,4	264,8
3.	Equipment investments and acquisitions	4.360,1	4.123,6	3.222,7
4.	Construction projects, acquisitions of property	0	0	420,0
5.	"Reserves" (e.g. cash assets, unused funds)	1.131,3	1.518,5	-316,9
6.	Miscellaneous items	0	0	0

DFG fess (if paid for the institution - 2,5% of revenue from institutional funding)	288,0	285,8	281,0

Appendix 4

Staff

Basic financing and third-party funding / proportion of women (as of: 31 December 2013)

	Full time equivalents		Employees		Female employees	
	Total	on third-party funding	Total	on temporary contracts	Total	on temporary contracts
	Number	Percent	Number	Percent	Number	Percent
Research and scientific services	**109,77**	67,3	**116**	66,4	**20**	90,0
Professors / Directors (C4, W3, or equivalent)	2	0	2	0	0	0
Professors / Directors (C3, W2, A16, or equivalent)	0	0	0	0	0	0
Academic staff in executive positions (A15, A16, E15, or equivalent)	16,7	18	18	16,7	1	100
Scientists in executive positions (A13, A14, E13, E14, or equivalent)	4,67	42,8	5	20	2	0
Scientists in non-executive positions (A13, A14, E13, E14, or equivalent)	43	64	44	63,6	4	100
Science management (from E13, senior service)	6,4	68,8	8	75	3	100
Doctoral candidates (A13, E13, E13/2, or equivalent)	37	100	39	100	10	100
Service positions	**63,9**	43,8	**64**			
Laboratory (E9 to E12, upper-mid-level service)	19,9	30,2	20			
Laboratory (E5 to E8, mid-level service)	26	69,2	26			
Laboratory (E3 to E4, mid-level service)	2	100	2			
Technical services (from E13, senior service)	1	0	1			
Technical services (E9 to E12, upper-mid-level service)	4	0	4			
Technical services (E4 to E8, mid-level service)	7	28,6	7			
Information technology - IT (from E13, senior service)	1	0	1			
Information technology - IT (E9 to E12, upper-mid-level service)	3	0	3			
Administration	**12,2**	20,5	**13**			
Head of administration	**0**	0	0			
Staff positions (from E13, senior service)	2,5	100	3			
Secretary (E5 to E8, mid-level service)	2,9	0	3			
Administration (financial administration, personnel, etc.) (E9 to E12, upper-mid-level service)	3	0	3			
Administration (financial administration, personnel, etc.) (E5 to E8, mid-level service)	3,8	0	4			
Student assistants	**4,7**	100	**22**			
Trainees	**11**	0	**11**			
Scholarship recipients at the institution	**11**	100,0	**11**		**5**	
Doctoral candidates	7	100	7		2	
Post-doctoral researchers	4	100	4		3	

10 November 2014

Annex B: Evaluation Report

Ferdinand-Braun-Institut
Leibniz-Institut für Höchstfrequenztechnik (FBH)
im Forschungsverbund Berlin e. V.

Contents

1. Summary and main recommendations

Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik (FBH), a member of the *Forschungsverbund Berlin e. V.,* works in the field of high-frequency and photonic engineering. It pursues application-oriented research in microwave technology, millimetre-wave technology and optoelectronics concentrating on III/V-compound semiconductors with a particular focus on emitters with high power and high frequencies.

FBH was last evaluated by the Leibniz Association Senate in 2007/08. In its report it described the institute as one of the most competent centres of excellence for III/V-compound semiconductors in Europe. According to the Senate, FBH played an important and exemplary role in developing new technologies in advance of industrial production.

Since then, FBH has continued to develop consistently and coherently in this vein. It has managed to embrace new, sustainable themes, whilst cutting back or even abandoning less relevant themes. In general, the objects of research are ideally chosen and topical, which has enabled FBH to maintain its performance record at a very high level and even enhance it with regard to publications, the acquisition of third-party funding and the number of doctoral candidates supervised. The institute's work covers an impressive spectrum from fundamental research via integrating individual technical components to applications. As such, FBH manages to have a remarkable impact on science and technology. It truly conducts knowledge-driven and applied basic research. On this basis, FBH collaborates fruitfully with many partners in academia, science and industry, a policy it should drive even more in future. In order to ensure that its outstanding expertise in III/V-compound semiconductors continues to shine at this level, FBH should exploit its remarkable scientific potential to yet greater effect and upgrade the preconditions for responding even more quickly to promising themes and integrating them in its programme of work and research.

Overall, FBH's performance in the last seven years has meant that it continues to be recognised internationally as a centre of excellence for III/V-compound semiconductor technology. It has an excellent reputation both for fundamental research and for applications and transfer. All these areas which, in their entirety, constitute one of FBH's main strengths should be carefully balanced in future to ensure that the institute can fulfil its mission as a Leibniz institution. This is particularly relevant against the backdrop of FBH's strategic planning, which envisages driving forward the integration of individual components developed at the institute in systems of greater complexity and thus seeking to strengthen the transfer to applications.

Special consideration should be given to the following main recommendations in the evaluation report (highlighted in **bold face** in the text):

<u>General concept and profile (Chapter 2)</u>

1. By strengthening the integration of individual components developed at FBH into systems of greater complexity, the institute is directing its activities more towards the field of applications. This is consistent, but runs the risk of causing an imbalance. Thus the major challenge will be to achieve a balance between fundamental

research, applications and knowledge transfer in order to maintain the clear profile of a Leibniz institution.

2. Although FBH manages to pick up new themes quickly, due to the sometimes protracted procedures for acquiring third-party funding, valuable time is too-often lost in implementing innovative project ideas. It is, therefore, recommended that the procedures involved in embracing new research themes at FBH should be further accelerated. In order to remain competitive in its internationally highly-contested environment, the institute should also investigate which procedures and processes could be expedited.
3. By structuring and steering the process of identifying topics more efficiently, FBH could showcase its vast scientific expertise to even greater effect. Internal competitive funding mechanisms should, for example, be introduced to initiate projects in order to create greater scope for implementing high-risk project ideas.
4. It is welcomed that the funders of the institute plan to invest further financial resources from the European Regional Development Fund (EFRE) in the institute. This is important for guaranteeing FBH's remarkably high level of performance. In the long term, the institute will find it incumbent upon itself to operate and use technical infrastructure in the framework of resource sharing with other partners; the relevant strategies presented are convincing.

Collaboration and networking (Chapter 4)

5. By comparison with the last evaluation, both the number of visitors hosted by the institute as well as visits of FBH staff at other institutions, particularly abroad, has only increased slightly; as recommended at the time, the institute should significantly increase its efforts in this respect, not least in the interests of its own internationalisation.
6. In order to continue exploiting the full potential of collaborations, in future the institute should be more proactive in approaching its partners with its ideas for projects. Furthermore, the Review Board reiterates the recommendation made at the last evaluation to coordinate potential research fields and areas of interest with science and business in the framework of themed joint workshops and seminars.
7. The institute should take greater care to ensure that its role with regard to and its relationship with spin-offs are explicitly and transparently laid down in the relevant contracts. As already addressed in the context of the last evaluation, FBH must elaborate explicit terms of reference for this.

Staff development and promotion of junior academics (Chapter 5)

8. Regarding the portion of permanent employment contracts the funders should allow for equal treatment of FBH compared to other institutions in the *Forschungsverbund Berlin e. V.* FBH must use any additional flexibility it gains to maintain, in particular, its key technical functions in the laboratories and technical service.

9. Notwithstanding the institute's commendable success in recruiting women researchers, it must continue to drive its efforts to meet its self-imposed goal of target quotas set out in the cascade model. The share of women in executive-level positions must be increased significantly. In order to achieve this, FBH should continue to reinforce its proactive recruitment policy.
10. Despite significantly improved collaboration in the context of university programmes, the majority of doctorates taken at FBH are still based on one-to-one supervision. FBH should ensure that the standards formulated by the DFG as well as the guidelines adopted by the Leibniz Association on the promotion of doctoral candidates are observed.

Quality assurance (Chapter 6)

11. It is recommended to increase the proportion of foreign members in the institute's Scientific Advisory Board.

2. General concept and profile

Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik (FBH), a member of the *Forschungsverbund Berlin e. V.,* works in the field of high-frequency and photonic engineering. It pursues application-oriented research in microwave technology, millimetre-wave technology and optoelectronics concentrating on III/V-compound semiconductors with a particular focus on emitters with high power and high frequencies. The work conducted covers the whole value-added chain from technology and materials research via processing and mounting to the production of components and modules as well as the application of microwave and optoelectronic devices in sectors such as health, mobility and communications.

Development of the institution since the last evaluation

FBH is divided into four Departments and four Business Areas for the purpose of organising research themes and the transfer of results to industrial applications. Scientific questions are addressed in three cross-cutting, long-term research programmes (see Chapter 3). This matrix structure has proven its worth in the past and been very effective. On the basis of its research programmes, FBH manages to be highly innovative and, whilst addressing fundamental issues in semiconductor technology, to drive the development and improvement of components, modules, and devices. This has allowed the institute to maintain its performance record at a very high level since the last evaluation in 2007 and even enhance it with regard to publications and the acquisition of third-party funding.

FBH laid the foundations for its success by continuously developing its programmes of research and work: many topic areas, which were already rated positively in 2007, were extended by specifically embracing and integrating new developments such as those in Indium Phosphide (InP)-based technology for THz applications or Gallium Nitride (GaN) power devices. Building on its long-term core activities in III/V-compound semiconductors, the institute advanced its work on components, modules and subsystems at ever

higher degrees of complexity. In direct connection with this, FBH also intensified its work on integrating such modules and systems into applications, including pulsed radar sources. It is convincing that, in parallel, certain research themes that were important in the past, like Indium Gallium Phosphide (InGaP) heterojunction bipolar transistor (HBT) technology, have been cut back or abandoned altogether because they are being addressed far more by commercial providers.

Generally, FBH has chosen a very good path; since the last evaluation, it has developed consistently and coherently. Current research topics are very good and relevant and are responsible for the institute being recognised internationally as a centre of excellence for III/V-compound semiconductor technology to a greater extent than ever before. Indeed, some of the research conducted in the groups is on a par with the world leaders in the field (see Chapter 3). FBH's work has a sustained impact on the newest developments in science and technology and often provides the basis for developing industrial prototypes. It covers an impressive spectrum from fundamental research via integrating individual technical components in more complex (sub-)systems to applications, for example in the life sciences: FBH truly conducts knowledge-driven and applied basic research.

Results

In accordance with the recommendations, FBH doubled the volume of publications in the period following the last evaluation. Whilst in 2005 FBH staff (55.8 FTE[1]) produced a total of 60 publications, of which 53 were peer-reviewed articles, in 2013, this figure had increased to 142 publications, of which 103 were peer-reviewed articles (corresponding to 72.77 FTE[2]).

The number of published conference papers also increased; the individual groups attracted, in some cases, a great deal of attention at national and international conferences, which were also organised by FBH itself. The increase in the number of invited talks is a positive development.

In 2013, FBH held a total of 78 patents, a further 114 were registered. This is indicative of FBH's excellence and scientific performance, and makes the institute an attractive partner for collaborations. It is plausible that FBH continues to pursue these activities for strategic reasons although the costs of registering industrial property rights significantly outstrip the resulting income.

For years, FBH has very successfully engaged in transferring the results of its work and research to society; these efforts in the context of Girls' Day or the Long Night of Science are welcomed and should be continued. The tasks linked to this are carried out excellently by the Science Management Department, which was established in 2010.

FBH uses the standard tools of public outreach. In addition, it has a large portfolio of different publication formats and brochures with which it can present the results of its work and research focus areas to various target groups in academia, politics and industry.

[1] Academic and higher management staff, excluding doctoral candidates.
[2] Research and scientific service, excluding doctoral candidates.

Strategic work planning for the next few years

Plans for future projects and long-term options for cooperation with scientific and industrial partners build effectively on previous work. In this context, it is both obvious and logical to continue driving, in particular, the work on applying modules and subsystems developed at FBH, to enhance the degree of their performance and complexity as well as the integration of these units in systems. The institute has already made significant progress in this direction as a result of its involvement in the Berlin WideBaSe Project and by acquiring the Advanced UV for Life Project, which is financed by the BMBF. There is a great deal of potential for further innovations in the strong application bias of the consortia, some of which are headed by FBH, and there is every indication that it will develop successfully.

At the same time, by strengthening the integration of individual components developed at FBH into systems of greater complexity, the institute is directing its activities more towards the field of applications. This is consistent, but runs the risk of causing an imbalance. Thus the major challenge will be to achieve a balance between fundamental research, applications and knowledge transfer in order to maintain the clear profile of a Leibniz institution.

Although FBH manages to pick up new themes quickly, due to the sometimes protracted procedures for acquiring third-party funding, valuable time is too often lost in implementing innovative project ideas. It is, therefore, recommended that the procedures involved in embracing new research themes at FBH should be further accelerated. In order to remain competitive in its internationally highly-contested environment, the institute should also investigate which procedures and processes could be expedited.

By structuring and steering the process of identifying topics more efficiently, FBH could showcase its vast scientific expertise to even greater effect. Internal competitive funding mechanisms should, for example, be introduced to initiate projects in order to create greater scope for implementing high-risk project ideas.

Appropriateness of facilities, equipment and staffing

In order to fulfil its current tasks, the institutional funding at FBH's disposal is adequate.

In the past, FBH reached a remarkably high level of third-party funding. In the period 2011-2013, the institute raised an average of approx. ten million EUR per year; third-party funding accounted for well over 40% of the entire budget. The increase the institute has achieved by comparison with the high level already noted at the last evaluation (approx. 36%) is very positive. FBH has now reached an appropriate level in terms of the mission set down in its statutes.

The institute raised significant funding from the Federation and the *Länder*. It was also successful in acquiring funding from industry, which accounted for an average of 20% of the third-party portfolio in the last few years. The Review Board, like the institute itself, sees potential for further increases in the share of third-party funding from industry

thanks to the particular focus on applications (see Chapter 3). It is welcomed that the volume of EU funding has also grown.

In the last few years, the institute acquired comparatively little funding from the DFG; 2013 was the first year in which funding from this source overtook DFG fees. It is positive that FBH has stepped up its efforts to acquire funding from the DFG in accordance with recommendations. At the same time, given the institute's thematic and strongly application-related emphasis, it is understandable that it prioritises other sources of third-party funding. The Review Board recommends maintaining the level achieved in 2013 and, in future, to raise funding at least equalling the fees paid to the DFG.

In the past, FBH made considerable investments in its technical infrastructure. It thus currently has very good and extremely efficient facilities that meet the highest standards. The clean rooms are excellent.

However, the generally outstanding level of technical equipment also results in requirements with regard to maintaining and, in some cases, renewing apparatus which cannot be completely met by FBH at present because the appropriations for investment are insufficient and a great deal of investment is currently earmarked for the construction work taking place in the period 2013 to 2015. **It is welcomed that the funders of the institute plan to invest further financial resources from the European Regional Development Fund (EFRE) in the institute. This is important for guaranteeing FBH's remarkably high level of performance. In the long term, the institute will find it incumbent upon itself to operate and use technical infrastructure in the framework of resource sharing with other partners; the relevant strategies presented are convincing.**

As has already occurred in the last few years in the context of Joint Labs, FBH should aim to open up its facilities even more to universities and other external partners.

3. Subdivisions of FBH

3.1. Electronics – RF Electronics (40.2 FTE in total; 17.2 FTE research; 12 PhDs)

The main research target of the group is to further extend the limits of microwave analogue devices and circuits. Overall, the work, which connects excellently with current themes pursued by RF Electronics, is convincing. It was a wise decision to enhance activities in the field of GaN and to establish a group on THz technology with the relevant measurement facilities in the context of a Joint Lab. In both these promising areas the group achieves very good results that are of great benefit to the other groups at FBH. All in all, the RF group is active at the forefront of the international field.

Staff produced convincing publications in the last few years which have gained the group visibility both nationally and internationally; recently, there has also been a noticeable increase in the number of articles appearing in peer-reviewed journals. The group also makes its mark at specialist conferences. Amongst the plethora of collaborations, special mention should be made of those with NEC (Japan).

Thanks to its excellent technical facilities the group has very great achievement potential which it should exploit to even greater effect. Yet more could be achieved, in particular, by implementing a more sophisticated GaN technology and exploiting the innovative INP-HBT technology. In both areas, long-term opportunities exist to intensify collaboration, particularly with partners in industry, and to further drive relevant third-party fund raising. In summary, the unit is rated as "very good".

3.2. Electronics – Power Electronics (5 FTE in total; 3 FTE research; 2 PhDs)

Essentially, the group addresses the fundamentals of developing GaN power transistors: the particular aim is to improve material knowledge on the basis of the electrical parameters of testing devices.

Work is appropriately focussed and produces convincing results which have recently been very well published in peer-reviewed journals. The group manages impressively to cover the entire process chain from design via epitaxy to the manufacture of components. Compared to its size, the group has an enormous impact which will increase as a result of the Joint Lab with TU Berlin, which was established in 2014.

Highly fruitful cooperation is conducted with other groups within the institute. The level of know-how is impressive and serves as the basis, amongst others, for the work conducted in the Department of Materials Technology on optimising epitaxial designs and technological modules. The themes are, however, also of major interest to industry and have the potential to raise an even larger volume of third-party funding from this source.

The group is encouraged to drive forward its fundamental research in the coming years. In order to remain competitive in future, projects in the field of AlN and integrated AlN, for example, should be completed even more quickly, a development the group could achieve by enhancing systems expertise. In summary, the unit is rated as "very good to excellent".

3.3. Photonics – Monolithic Brilliant NIR Laser Diodes (36.1 FTE in total; 15 FTE research; 5.2 PhDs)

This group has been conducting excellent application-related research for more than 20 years and has become a world leader in laser diode technology. Current projects have an impressive number of unique features and are of great importance, particularly for communications technologies. The broad spectrum of activities, which covers the entire value-added chain from design via epitaxy and chip processing through to characterisation techniques, is also impressive. Excellent devices for other groups at FBH as well as for companies are produced.

The excellent publications of this exceptionally well third-party funded group frequently involved collaborative partners. This is seen as proof of intensive, fruitful collaboration. In summary, the unit is rated as "excellent".

3.4. Photonics – Hybrid Integrated Laser Sources (23 FTE in total; 7 FTE research; 15 PhDs)

Using an integrated approach, this unit pursues an exceptionally interesting and successful idea that has generated outstanding basic research. In addition to excellent device technology, the work on characterisation is particularly impressive. Demonstration and application are excellent. The group raises an exceptionally large volume of third-party funding from industry and showcases its results internationally by publishing at the highest scientific level. The unit's cooperation with Humboldt-Universität zu Berlin in the Optical Metrology Joint Lab is particularly successful and fruitful. The holder of the relevant chair is also the head of one of FBH's working groups. It is recommended to consider how the use of resources for producing small series could be optimised so that, for example, doctoral candidates were not required to spend too much time constantly manufacturing the same modules. In summary, the unit is rated as "excellent".

3.5. Photonics – Monolithic UV and VIS Light Sources (7.2 FTE in total; 4.2 FTE research; 1 PhD)

In this group, which is considerably smaller than the other two Photonics units, remarkable progress has been made in the last few years. In such a strongly competitive field, it was the right decision to concentrate on UV lasers and LEDs. This highly sophisticated and efficiently organised work also distinguishes itself by excellent quality management. Systematic benchmarking has led to a whole series of research results that have been excellently published and can be considered world-leading.

The head of the unit also holds a chair at Technische Universität Berlin. Cooperation between FBH and TU Berlin in the context of the Experimental Nanophysics and Photonics Joint Lab, which was set up in 2006, has been very productive in the last few years. It allowed FBH to generate significant added value in its scientific portfolio. In summary, the unit is rated as "excellent".

3.6. III/V Compound Semiconductor Technologies – Materials (26.7 FTE in total; 10.2 FTE research; 8.5 PhDs)

The group works on the vapour phase epitaxy of two-dimensional hetero-structures. The aim is to develop tailor-made hetero-structures for advanced edge-emitting laser diodes. In addition, GaN-based materials are used as the basis for transistors for microwave and power switching applications, UV-LEDs and photo detectors.

The group's work is very good, particularly in the area of vapour phase epitaxy, not least due to the availability of excellent technical infrastructure. By international standards the group is very competitive, especially thanks to its striking knowledge and know-how in the fabrication of devices and applications, e.g. microwave and power switching applications. The support provided for other groups at FBH is impressive. The group forms a true backbone of FBH and also cooperates very effectively with external scientific partners such as the Paul-Drude-Institut für Festkörperelektronik (PDI).

Future plans focus on the growth and the properties of optimised and customised hetero-structures in order, amongst other things, to lay the material foundations for the

work of other groups at FBH. These plans are convincing. At the same time, the group is supposed to add weight to the area of fundamental research where both its record of acquiring third-party funding from the DFG and the BMBF as well as its impressive publication performance in the last few years indicate that it has great potential. It will fall to the group to find a more balanced approach towards basic material research und application-driven in-house transfer. This would also benefit the group's visibility internationally. The plans being considered to work with new-type wafer materials in future should definitely be implemented. In summary, the unit is rated as "very good".

3.7. III/V Compound Semiconductor Technologies – Processes (22.6 FTE in total; 9.6 FTE research; no PhDs)

This group deals with complex processes on the advancement of III/V-compound semiconductor technology. It has managed to produce outstanding, innovative work at industrial standard. On the whole, the entire group demonstrates an extremely high level of sophistication and performance, particularly with regard to collaborative activities. The very good cooperation with the Material Process group is particularly significant. In-house, the group feeds into the development of RF-components, power electric devices as well as laser diodes taking place in other groups. It is one of the institute's core groups.

In future, the group will concentrate on the stabilisation, improvement and enhancement of III/V-semiconductors. Plans to further strengthen device-oriented technology development, e.g. for the realisation of THz transistors, are persuasive and should generate even more funding from industry. In addition, the group should continue extending its already impressive collaborative efforts. It could also profit from being more proactive in the elaboration of collaborative research programmes. In summary, the unit is rated as "excellent".

Science Management

In 2010, FBH established its own Science Management Department, a major aim of which was to bundle the institute's strategic matters. The group now plays a central coordinating role in initiating and managing third-party projects, for example, as well as in the strategic positioning of the institute in large-scale networks. The group carries out its work in the areas of technology transfer and marketing, project management, and education and training development very efficiently and convincingly.

IT Service / Technical Service

IT Service is efficient and employs great specialised expertise in conducting the necessary tasks at the institute, including, amongst others, programming various laboratory experiments. It has a pronounced service focus and carries out its work with an impressive degree of commitment.

Technical Service is responsible for the institute's infrastructure, including the clean rooms and the ventilation of technical laboratories. The section is appropriately equipped and also does very good work.

4. Collaboration and networking

Collaboration with universities

FBH collaborates closely and successfully with Technische Universität Berlin (TU) and Humboldt-Universität zu Berlin (HU). This collaboration involves two joint professorial appointments, university teaching and training junior researchers as well as a large number of scientific projects and alliances. Collaborations are convincingly structured and have produced remarkable results in the past. FBH should extend its collaborations, particularly with regard to the joint use of technical infrastructure.

Furthermore, special mention should be made of the so-called Joint Labs, which are headed by university professors whose positions are partly financed by FBH. In the past, this has produced fruitful cooperation and close strategic/scientific cohesion between FBH and the respective university. From a scientific point of view, Joint Labs have proved their worth both for FBH and for the universities involved (TU Berlin, HU Berlin and Goethe University Frankfurt am Main) because they allow the institute to acquire additional expertise to complement its existing competence. It is welcomed that FBH has established three further Joint Labs since the last evaluation in 2007, making a total of four, including the Joint Lab for power electronics with TU Berlin, which was launched in 2014.

It is further welcomed that FBH plans to make a third joint appointment (with HU Berlin) in 2015 when the position of head of optoelectronics will become vacant due to retirement. It is good that FBH has already taken the initial steps in this process; it should now bring them to a speedy conclusion.

Collaboration with other domestic and international institutions

FBH maintains close relations with a large number of university and non-university scientific institutions. Collaboration is organised very convincingly. Similarly, the institute cooperates closely and profitably with many institutions in the Leibniz Association, particularly in the Berlin area.

It is welcomed that the institute is considering extending its collaboration with institutions in the *Forschungsverbund Berlin e. V.*, particularly with reference to the operation and use of joint technical infrastructure. This is of special relevance with regard to the plans to procure an epitaxy facility.

In the past, FBH has been very successful in raising funding through the Leibniz Association's competitive system (SAW): in the period 2011–2013, it averaged approx. 650 K EUR per year. Other activities, such as its involvement in the Leibniz Technology Transfer Association Microelectronics or in the application labs, with which FBH creates promising interfaces between industry and research, are very positive. This will be ideally complemented by the Pump Laser Center, which the institute wants to operate as a platform for future collaborations.

By comparison with the last evaluation, both the number of visitors hosted by the institute as well as visits of FBH staff at other institutions, particularly abroad, has only increased slightly; as recommended at the time, the institute should signifi-

cantly increase its efforts in this respect, not least in the interests of its own internationalisation. This might be achieved by introducing exchange programmes or comparable actions. Doctoral candidates should also participate in these programmes, allowing them to complete certain phases of their training at other institutions at home and abroad.

Other collaborations and networks

FBH cooperates with many different partners in industry. In this context, the institute is highly successful in transferring the processes and prototypes developed at FBH to industrial applications. The institute's partners particularly value FBH's unique practice-related approaches and ways of thinking. **In order to continue exploiting the full potential of these collaborations, in future the institute should be more proactive in approaching its partners with its ideas for projects. Furthermore, the Review Board reiterates the recommendation made at the last evaluation to coordinate potential research fields and areas of interest with science and business in the framework of themed joint workshops and seminars.**

In the past, FBH initiated cooperation with Japanese partner institutions which proved very useful in fields such as RF Electronics. It is recommended to seek further cooperation with internationally leading institutions working on lasers both in academia and industry. With regard to other collaborations with external partners, as already recommended by the Scientific Advisory Board, the institute should define core competencies and key technologies, which can be classed as FBH's intellectual property and which should not be shared in the context of collaborations.

Since 2007, commercialisation and technology transfer activities at FBH have led to four spin-offs. It is positive that the institute has introduced and successfully implemented the requisite procedures. **The institute should take greater care to ensure that its role with regard to and its relationship with spin-offs are explicitly and transparently laid down in the relevant contracts. As already addressed in the context of the last evaluation, FBH must elaborate explicit terms of reference for this.**

Since the last evaluation, FBH has been involved in many alliances, networks and consortia. The resulting collaboration with partners in industry, science and research, which enables FBH to tap additional specialist and human resources expertise, is unique and generates high added-value for the institute. FBH takes on the role of lead partner ever more frequently, for example in the BMBF-financed consortium, Advanced UV for Life, which was acquired in 2014 and deals with UV-LED-based components, systems and processes.

5. Staff development and promotion of junior researchers

Staff development and personnel structure

Since the last evaluation, the number of staff at FBH has risen noticeably to approx. 240 (see enclosure A, appendix 4). Including the staff working in the four Joint Labs, at the end of 2013, 270 individuals were employed at FBH, that is, approx. 90 more than in

2007. FBH has dealt with the requisite management processes very efficiently. The staff are highly committed and the existing scientific and technical expertise is impressive. It is welcomed that, according to its own assessment, FBH has now reached a size commensurate with its tasks, which it plans to maintain.

At the end of 2013, some two-thirds of the people employed in research and scientific services had fixed-term contracts. In relation to the total number of staff at FBH, the figure for fixed-term contracts was approx. 64 percent. In the laboratories and technical services the percentage of fixed-term contracts was also high which means there is a danger of losing fundamental technical knowledge that is essential to the institute's future innovative potential. The institute should take appropriate measures to reduce this risk.

It is welcomed that, in 2013, the funders suspended the obligatory staff appointment plan (*Stellenplan*), thus allowing FBH much greater autonomy and flexibility in human resources planning. Since then, an institute-specific portion has been assigned to permanent employment contracts. This share should be fully utilised. According to the institute, the share was not exploited at the time of the evaluation visit. **On top of this, the funders should allow for equal treatment of FBH compared to other institutions in the *Forschungsverbund Berlin e. V.* FBH must use any additional flexibility it gains to maintain, in particular, its key technical functions in the laboratories and technical service.**

Promotion of gender equality

At the end of 2013, 20 female scientists were employed in research and scientific services (out of a total of 116 individuals employed in these fields): the proportion of women was approx. 17 percent. On the reporting date, the proportion of female staff on fixed-term contracts (90%) was well above the proportion for scientific staff as a whole (66.4%). Currently, there are no female researchers at the highest executive levels of FBH.

At the various levels of qualification, the proportion of women researchers corresponds closely with the figures for female graduates of electrical engineering and physics. **Notwithstanding the institute's commendable success in recruiting women researchers, it must continue to drive its efforts to meet its self-imposed goal of target quotas set out in the cascade model. The share of women in executive-level positions must be increased significantly. In order to achieve this, FBH should continue to reinforce its proactive recruitment policy.**

It is welcomed that, in 2013, FBH was awarded the TOTAL-E-QUALITY certificate for the second time. Together with other awards from the Berlin Borough of Treptow-Köpenick, this indicates how seriously the institute handles issues like family-friendliness and equal opportunities.

Promotion of junior researchers

It is pleasing that – in accordance with a recommendation from the last evaluation – FBH further increased the number of doctoral candidates: at the end of 2013, a total of 46

doctoral students were being supervised by FBH staff. It can be seen as a huge success that the number of doctoral candidates has thus almost tripled since the end of 2005.

The relatively recently-introduced guidelines for doctoral candidates have proved their merit and help to ensure that this phase of training is well structured. **Despite significantly improved collaboration in the context of university programmes, the majority of doctorates taken at FBH are still based on one-to-one supervision. FBH should ensure that the standards formulated by the DFG as well as the guidelines adopted by the Leibniz Association on the promotion of doctoral candidates are observed.**

FBH uses various tools for promoting junior researchers, such as a Junior Professional Management Programme. These tools are, however, usually only employed in the context of individual agreements; there are as yet no transparent, corresponding guidelines. The institute is recommended to bundle its existing measures, put them into writing in the form of a postdoctoral mentoring programme and make them available within the institute.

Vocational training for non-academic staff

FBH's commitment to further training and education for non-academic staff is very positive. The institute not only helps to train apprentices in technical fields but is also able to train highly-qualified staff in micro- and semiconductor technologies. From 2011 to 2013, two to three apprentices per year completed their training, including a total of four women.

6. Quality Assurance

Internal quality management

FBH has implemented sophisticated quality management for its technical and scientific processes which generate great innovative power and robust competitiveness. The ISO quality standards that have been introduced at the institute are remarkable. The systematic use of benchmarking is particularly impressive.

It is regrettable that FBH did not employ the same admirably high standards of quality assurance in preparing the written evaluation package. The deadlines for submitting the evaluation package, for example, were not met at this or the last evaluation by a considerable margin. This reduced the amount of time available to the members of the Review Board to study the documents. In connection with the next evaluation, FBH is expected to respect all deadlines.

Quality management by the Scientific Advisory Board, User Advisory Board and Supervisory Board

FBH's Scientific Advisory Board (SAB), which is composed of distinguished scientists, fulfils its tasks diligently and fairly. **It is recommended to increase the proportion of foreign SAB members.**

Together with seven other Leibniz institutions, FBH is a member of the *Forschungsverbund Berlin e. V.* (FVB). FVB's Board of Trustees carries out its tasks as FBH's supervisory body on the basis of its statutes. According to the AV-WGL[3], decisions made by the institutions' supervisory bodies on important research and science-policy matters, having significant financial implications, or referring to the institutions' managerial staff require the agreement of the representatives of the Federal Government and the *Land*. It is welcomed that FVB is currently revising its statutes so that they will comply with these requirements.

In order to prepare the Board of Trustees' decisions, committees have been established at the institutes composed not only of representatives of the Federal Government and the *Land*, but also of the chairs of the member institutes' advisory boards. This provision should be changed so that the chairs of the advisory boards only participate in institutes' committee meetings as non-voting members, as do the directors of the institutes and the managing director of FVB. This would guarantee a clear division between monitoring and advisory functions.

Implementation of recommendations from the last external evaluation

FBH has largely implemented the 11 recommendations made by the Leibniz Association Senate after the last evaluation (see Status Report, p. A-19 f.). The following are still valid:

(1) FBH should acquire DFG funding that at least equals the amount it pays in DFG fees (see Chapter 2).

(2) The number of visiting scientists should be increased significantly (see Chapter 4).

(3) FBH should ensure that its role with regard to and its relationship with spin-offs are explicitly and transparently laid down in the relevant contracts (see Chapter 4).

[3] Administrative agreement between the Federal and *Länder* Governments with regard to the joint funding of member institutions of the Leibniz Association.

Appendix

List of Participants

1. Review Board

Chair (Member of the Leibniz Senate Evaluation Committee)

Manfred **Bayer**	Experimental Physics II, TU Dortmund University

Deputy Chair (Member of the Leibniz Senate Evaluation Committee)

Jürgen **Troe**	Physical Chemistry Institute, Göttingen University

Reviewers

Colombo **Bolognesi**	Millimeter-Wave Electronics Group, Swiss Federal Institute of Technology / ETH Zurich
Lothar **Frey**	Fraunhofer Institute for Integrated Systems and Device Technology, Erlangen
Nicolas **Grandjean**	Institute of Condensed Matter Physics, École Polytechnique Fédérale de Lausanne
Kei May **Lau**	Department of Electronic & Computer Engineering, Hong Kong University of Science and Technology
Norbert **Lichtenstein**	Research & Development, II-VI Laser Enterprise GmbH, Zurich
Wolfgang **Menzel**	Microwave Techniques, University of Ulm
Thomas **Mikolajick**	Institute of Semiconductors and Microsystems, TU Dresden
Tomas **Palacios**	Electrical Engineering & Computer Science, MIT Boston
Alwyn **Seeds**	Department of Electronic & Electrical Engineering, University College London
Peter **Unger**	Optoelectronics, University of Ulm
Werner **Wegscheider**	Solid State Laboratory, Advanced Semiconductor Quantum Materials, Swiss Federal Institute of Technology / ETH Zurich

Representative of the Federal Government

Ingo **Höllein**	Federal Ministry of Education and Research, Bonn

Representative of the Länder *Governments (Member of the Leibniz Senate Evaluation Committee)*

Thomas **Grünewald**	Ministry of Innovation, Education and Research North Rhine-Westphalia, Düsseldorf

2. Guests

Representative of the relevant Federal government department

absent with apologies

Representative of the relevant Land *government department*

Bernd **Lietzau**	Berlin Senate Department for Economy, Technology and Research, Berlin

Representative of the Scientific Advisory Board

Robert **Weigel**	Chair in Technical Electronics, Friedrich-Alexander-University Erlangen-Nürnberg

Representative of the Leibniz Association

Brigitte **Voit**	Leibniz Institute of Polymer Research, Dresden

3. Representatives of partner institutions (for talks of one hour with review board and guests)

Christian **Thomsen**	Technical University Berlin, President
Peter **Leibinger**	TRUMPF GmbH, Management Board
Thomas **Zettler**	LayTec AG, CEO
Rolf **Jakoby**	Microwave Engineering, Technical University Darmstadt

2 December 2014

Annex C: Statement of the Institution on the Evaluation Report

Ferdinand-Braun-Institut
Leibniz-Institut für Höchstfrequenztechnik (FBH)
im Forschungsverbund Berlin e. V.

Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik im Forschungsverbund Berlin e. V. (FBH) highly appreciates the positive evaluation report given by the review board after its visit of the institute. It perceives the report as a fair description of its current status. The report confirms FBH's supranational significance, its excellence in its research and transfer activities compared to international standards and the high value of its application-oriented research programs performed in close collaboration with universities and industry.

FBH feels encouraged to continue the path taken and to follow the recommendations made by the review board. Especially it will

- work intensely on balancing fundamental research, applications and knowledge transfer,
- improve procedures to identify and implement high risk project ideas more quickly,
- strengthen efforts to increase number of visitors hosted by the institute and of visits of FBH's staff at other institutions, especially abroad,
- approach its partner in universities, research institutes and industry even more proactively with new ideas for collaborations and projects,
- increase significantly the share of women in executive-level positions,
- improve further the supervision of doctoral candidates.

Finally, FBH wishes to express its gratitude to the members of the review board and to the staff of the Division SAE of the Leibniz Association for their efforts and their great support during the evaluation. FBH thanks the members of its Scientific Advisory Committee for their continuous and excellent advice and the Senate of Berlin and the Federal Government for the sustainable financial support.