Leibniz
Gemeinschaft
Der Senat

12. Juli 2022

Stellungnahme zum Ferdinand-Braun-Institut gGmbH Leibniz-Institut für Höchstfrequenztechnik (FBH)

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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. Der für das FBH zuständigen Gruppe stand eine von der Einrichtung erstellte Evaluierungsunterlage zur Verfügung. Die wesentlichen Aussagen dieser Unterlage sind in der Darstellung (Anlage A dieser Stellungnahme) zusammengefasst.

Wegen der Corona-Pandemie musste der für den 7. und 8. Dezember 2021 vorgesehene Evaluierungsbesuch am FBH in Berlin entfallen. Die Bewertung erfolgte im Rahmen eines Ersatzverfahrens, das der Senatsausschuss Evaluierung (SAE) in Umsetzung eines Grundsatzbeschlusses des Senats vom 31. März 2020 eingerichtet hat. Der Senat hält in diesem Grundsatzbeschluss fest, dass das Ersatzverfahren ein Notbehelf ist und ausschließlich auf Einrichtungen angewendet wird, die im Regelturnus von sieben Jahren evaluiert werden. Die Bewertungen, auf deren Grundlage der Senat Stellung nimmt, sind auf zentrale Kernfragen der Entwicklung und Perspektive einer Leibniz-Einrichtung fokussiert. Ausführliche Einschätzungen und Schlussvoten zu Teilbereichen und Planungen für „kleine strategische Sondertatbestände" müssen regelmäßig entfallen.

Die Bewertungsgruppe erstellte den Bewertungsbericht (Anlage B). Das FBH nahm dazu Stellung (Anlage C). Der Senat der Leibniz-Gemeinschaft verabschiedete am 12. Juli 2022 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 gGmbH, Leibniz-Institut für Höchstfrequenztechnik (FBH) betreibt anwendungsorientierte Forschung auf den Gebieten der Hochfrequenzelektronik, Photonik und Quantenphysik. Die Arbeiten umfassen die gesamte Wertschöpfungskette von der Grundlagenforschung bis hin zur Produktion von einsatzbereiten Modulen und Systemen auf Basis von III-V-Verbindungshalbleitertechnologien. Die Anwendungsfelder reichen dabei von der Kommunikationstechnik über die Sensorik und Medizin bis hin zur integrierten Quantentechnologie.

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

Das Institut erarbeitet sehr gute und vielfach hervorragende **Forschungsergebnisse**. Diese werden in den einschlägigen Zeitschriften veröffentlicht und von den jeweiligen Fachgemeinschaften stark wahrgenommen. Angesichts des Niveaus der geleisteten Arbeiten besitzt das FBH das Potential, noch häufiger in höherrangigen Zeitschriften zu publizieren, die sich auch an eine breitere, interdisziplinäre Leserschaft wenden.

Auf der Grundlage seiner Forschungsarbeiten erbringt das FBH im Bereich des **Technologietransfers** ausgezeichnete Leistungen. Neue Erkenntnisse führen regelmäßig zu Ausgründungen. Eine beeindruckend hohe Zahl von Patenten trägt erheblich dazu bei, dass die Arbeiten von Unternehmen wahrgenommen werden. Auch hohe Drittmitteleinwerbungen aus der Industrie (sowohl aus Projektfinanzierungen als auch aus Auftragsarbeiten) zeugen von der erfolgreichen Umsetzung der Anwendungsorientierung des Instituts.

Das FBH hat sich **seit der letzten Evaluierung** erfolgreich weiterentwickelt. Im Zusammenhang mit ruhestandsbedingten Wechseln unter den leitenden Wissenschaftlern wurden einzelne Themen beendet, die interne Organisationsstruktur angepasst und neue, vielversprechende Projekte begonnen. Insbesondere die Etablierung eines zusätzlichen Forschungsbereichs zu integrierten Quantentechnologien war eine sehr gute strategische Entscheidung. Hierfür hat das FBH ab 2019 eine dauerhafte Erhöhung der institutionellen Förderung von 4,1 Mio. € erhalten. Außerdem erhielt es als Verbundpartner der von 2017 bis 2021 vom BMBF-geförderten Forschungsfabrik Mikroelektronik Deutschland (FMD) insgesamt 40 Mio. € zur Modernisierung und zum weiteren Ausbau seiner ausgezeichneten Forschungsinfrastruktur. Durch diese Entwicklungen ist das Institut seit der letzten Evaluierung deutlich gewachsen.

Die **institutionelle Förderung** ist für die derzeitigen Aufgaben angemessen. Sie stieg von 12 Mio. € im Jahr 2013 auf 19 Mio. € im Jahr 2020. Gleichzeitig erhöhte das FBH die eingeworbenen **Drittmittel** von durchschnittlich ca. 10 Mio. € pro Jahr (2011-2013) auf ca. 25 Mio. € pro Jahr (2018-2020). Sie machen damit mittlerweile 55 % des Gesamtbudgets aus. Ein großer Anteil dieser außergewöhnlich hohen Mittel wurde bei Bund und Ländern eingeworben. Zur Diversifizierung des Drittmittelportfolios könnten verstärkt auch europäische Förderoptionen in den Blick genommen werden.

Das Institut steht nun vor einer Phase des **personellen Umbruchs**. Der langjährige und äußerst erfolgreiche Institutsdirektor geht in einigen Monaten in den Ruhestand. Es wird begrüßt, dass das FBH und die TU Berlin die Stelle erneut gemeinsam besetzen und das Berufungsverfahren bereits weit fortgeschritten ist. Eine zentrale Aufgabe der neuen wissenschaftlichen Institutsleitung wird sein, die Arbeiten am FBH nach dem Wachstum der letzten Jahre weiter zu konsolidieren. Dabei bleibt es eine Herausforderung, ein ausgewogenes Verhältnis zwischen Grundlagenforschung und anwendungsorientierter Arbeit in Zusammenarbeit mit der Industrie zu wahren. In den kommenden Jahren stehen zudem fünf weitere ruhestandsbedingte Wechsel auf der Leitungsebene an. Das Institut sollte rechtzeitig die notwendigen Schritte einleiten, damit keine Vakanzen auf diesen wichtigen Positionen entstehen. Die Besetzungsverfahren sollten mit geeigneten Maßnahmen (z. B. in Bezug auf die Breite der Stellenanforderungen in der internationalen Ausschreibung) verbunden werden mit dem Ziel, die Zahl der Wissenschaftlerinnen in leitenden Funktionen am FBH zu erhöhen. Der Senat bittet das Aufsichtsgremium, bis zum 31. Dezember

2024 über die bis dahin neu besetzten Positionen und die Strategie für weitere Besetzungen zu berichten.

Das FBH hat Pläne zum Aufbau eines **neuen Labors „III/V-Halbleiter für die Luft- und Raumfahrt"** vorgestellt. Dieses soll die Infrastruktur für die Entwicklung raumfahrtbezogener Technologielösungen am FBH bereitstellen und die Basis für gemeinsame Projekte mit Forschungs- und Industriepartnern bilden. Zur Finanzierung ist die Beantragung dauerhafter zusätzlicher Mittel der Bund-Länder-Förderung in Höhe von 3,45 Mio. € vorgesehen (zzgl. eines Eigenanteils von 0,65 Mio. €). Davon sollen 29 zusätzliche Stellen eingerichtet und regelmäßige Ausgaben für Infrastruktur/Sachkosten und Investitionen abgedeckt werden. Die Pläne sind im Grundsatz schlüssig, allerdings muss sichergestellt werden, dass der Ausbau langfristig tragfähig ist. Vor diesem Hintergrund sollte das FBH prüfen, inwieweit neben der Luft- und Raumfahrt weitere Anwendungsfelder der Quantentechnologie einbezogen werden können. Die Planungen sollten unter der neuen Institutsleitung unter Berücksichtigung ihrer Gesamtstrategie weiterentwickelt werden.

Für die **wissenschaftliche Qualifizierung** bietet das FBH ein hervorragendes Arbeitsumfeld mit ausgezeichneten Entwicklungsmöglichkeiten. Die Anzahl der Promovierenden ist zuletzt aber gesunken und sollte künftig wieder erhöht werden.

Der Frauenanteil am wissenschaftlichen Personal ist seit der letzten Evaluierung leicht gestiegen, bleibt mit nur rund einem Fünftel des wissenschaftlichen Personals aber nach wie vor erheblich zu niedrig. Das FBH muss Neubesetzungen auf allen Hierarchieebenen nutzen, um mehr **Wissenschaftlerinnen** zu gewinnen. Dies gilt insbesondere für die anstehenden Wechsel auf Leitungsebene, wo bislang kaum Frauen vertreten sind, und ebenso auf der Ebene der Promovierenden, denn der Anteil der Doktorandinnen ging gegenüber der Situation vor sieben Jahren zurück.

Das FBH pflegt enge **Kooperationen** mit der TU Berlin, mit der neben dem Direktor eine Abteilungsleitung gemeinsam berufen ist. In den letzten Jahren intensivierte sich auch die Zusammenarbeit mit der HU Berlin. An TU und HU Berlin, sowie an den Universitäten Cottbus-Senftenberg, Frankfurt am Main und Duisburg-Essen hat das Institut mit seinen sogenannten *Joint Labs* ein ausgesprochen erfolgreiches Instrument der Zusammenarbeit ins Leben gerufen. Hervorzuheben ist außerdem die Mitarbeit des FBH im Leibniz-WissenschaftsCampus “GraFOx” zur Erforschung von Oxiden, in dem unter anderem auch die HU Berlin beteiligt ist.

Bis Ende 2020 war das FBH eines von acht Leibniz-Instituten im Forschungsverbund Berlin e. V. (FVB). Seitdem ist es eine rechtlich selbständige **gemeinnützige Gesellschaft** mit beschränkter Haftung. Die erforderlichen Strukturen mit Geschäftsführung, Gesellschafterversammlung und Aufsichtsrat wurden zügig geschaffen. Es wird begrüßt, dass die derzeit noch übergangsweise wahrgenommene administrative Geschäftsführung ab September 2022 dauerhaft besetzt sein wird.

Das Institut erfüllt die Anforderungen, die an eine Einrichtung von überregionaler Bedeutung und gesamtstaatlichem wissenschaftspolitischem Interesse zu stellen sind. Mit seinem breiten, von der Grundlagenforschung bis in die industrielle Produktion reichenden

Portfolio verfolgt es ein sehr erfolgreiches, anwendungsorientiertes Konzept. Die Erfüllung der dabei wahrgenommenen Aufgaben ist an einer Hochschule in dieser Form nicht möglich. Eine Eingliederung des Instituts in eine Hochschule wird daher nicht empfohlen.

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 November 2021

Annex A: Status report

Ferdinand-Braun-Institut gGmbH
Leibniz-Institut für Höchstfrequenztechnik, Berlin (FBH)

Contents

1. Key data, structure and tasks

Key data

Year established:	1992
Admission to joint funding by Federal and *Länder* Governments:	1992
Admission to the Leibniz Association:	1997
Last statement by the Leibniz Senate:	2015

Legal form:	gGmbH
Responsible department at *Länder* level:	The Governing Mayor of Berlin Higher Education and Research
Responsible department at Federal level:	Federal Ministry of Education and Research (BMBF)

Total budget (revenue 2020)

€ 19m institutional funding

€ 27m revenue from project grants

€ 2m revenue from services

Number of staff (2020)

138 individuals in research and scientific services

85 individuals in service sector

26 individuals in administration

Mission and structure

According to its statutes, the *Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik* (FBH) is dedicated to conducting application-oriented research in the fields of high-frequency electronics, photonics and quantum physics. It aims to research and realise the entire value chain from design to ready-to-use systems for applications in communication, sensor technology, medicine and integrated quantum technology, among others. It works in a disciplinary and interdisciplinary manner in the fields of components, circuits and systems, materials and process technology, and computer-aided design methods. The FBH cooperates with universities in research and teaching. It promotes young scientists and participates in university courses. Its research and development work is carried out in close cooperation with industrial partners (cf. §2 of the statutes).

The FBH's research activities are conducted in four research areas (see below). Each research area comprises labs (dealing with specific device, model and system development) and departments (providing and further developing technical and scientific resources).

While the institute's research is pursued in a networked and interdisciplinary manner that also relies on cooperation between the various research areas, the following sub-programmes form the underlying structure (see appendix 1 for the organisational chart and chapter 7 for a detailed description of the sub-programmes):

Research Area "Electronics"

- Sub-programme "RF to THz electronics" (see 7.1)
- Sub-programme "Power electronics" (see 7.2)

Research Area "Photonics"

- Sub-programme "Monolithic high-power and high-brilliance lasers" (see 7.3)
- Sub-programme "Hybrid integrated laser sources" (see 7.4)
- Sub-programme "UV light sources" (see 7.5)

Research Area "Integrated Quantum Technology" (see 7.6)

Research Area "III-V Compound Semiconductor Technology"

- Sub-programme "Materials" (see 7.7)
- Sub-programme "Processes" (see 7.8)

Additionally, the FBH has created a Prototype Engineering Lab as an active interface between industry and science in order to transfer research results into market-oriented products, processes and services (see chapter 2).

2. Overall concept and core results

Overall concept

The FBH sees its mission in pursuing application-oriented research in the fields of high-frequency electronics, photonics and quantum physics along the entire value chain from design to ready-to-use systems. On the one hand, this is carried out through the realisation of high-frequency components and circuits up to the Terahertz range (e.g. for communication technology, power electronics and sensor technology). On the other hand, the institute develops powerful and highly brilliant lasers and efficient light-emitting diodes from the infrared to the ultraviolet spectral range (e.g. for applications in materials processing, display technology and precision metrology, life sciences and medical technology). The institute 's current research work within its four research areas can be summed up as follows:

The overarching goal of the research area **III-V Electronics** is to develop electronic components for efficient power generation at high frequencies, high voltages and short switching times. Current topics are GaN-based RF (radio frequency) power modules for application in mobile communications base stations, digital power amplifiers, terahertz components & systems, InP Devices, the utilisation of plasmonic effects for terahertz detection, GaN-based switching transistors & Schottky diodes for high voltages and currents, and fast high-current drivers and transistors based on new wide bandgap materials such as aluminium nitride and gallium oxide (normally-off and vertical transistors).

In the research area **Photonics**, the FBH works on diode lasers and LEDs for dedicated purposes. The portfolio ranges from research concerning material science and laser physics to the development of ready-to-use diode laser modules and prototypes. A particular focus lies on high power diode lasers, laser modules, laser sensor technology and GaN optoelectronics.

The research area **Integrated Quantum Technology** was established in 2019 and is dedicated to transferring technology to industry through proof-of-concept demonstrators in the areas of quantum sensing, communication, simulation and computing. Current activities include work on quantum photonic components, integrated quantum sensors, diamond nanophotonics and photonic quantum technologies.

The research area **III-V Technology** bundles resources in materials and process technology as well as packaging and mounting technology. It forms a basis for the development of components in the other research areas and focuses on epitaxy nitrides, epitaxy arsenides, process technology, assembly and mounting technology as well as material analysis.

Results

<u>Research</u>

Scientists at the FBH regularly publish and present their scientific results to the academic community, resulting in an average of 105 peer-reviewed journal **publications** per year (see appendix 2). The FBH refers to the following most important results since the last evaluation:

1. demonstration of the potential of digitised GaN power-amplifier modules for the next-generation wireless infrastructure (presentation of the first Watt-class digital transmitter and world-leading results for wideband discrete supply modulation (class G))
2. obtaining record values for broadband circuits using InP-HBT MMICs, thereby advancing the state of the art with regard to ultra-high bandwidth circuits (A 150 GHz bandwidth TWA and a 200 GHz bandwidth SPDT switch)
3. realisation of hybrid integrated GaN high speed power cores consisting of either discrete or monolithically integrated half bridges and driver circuits on polycrystalline thermally highly conductive AlN substrates
4. development of Galliumoxid transistor technology to the international state of the art (by demonstrating power switching transistors on <100> oriented substrates with 1800 V breakdown voltage and drain current up to 2.5 A)
5. advancement of the flip-chip packaging approach, demonstrating an unprecedented bandwidth of 0…500 GHz with InP chips, with less than 1 dB insertion loss throughout the full band (achieved by using micro-bumps and a careful electromagnetic design of the interconnect and the transmission-line geometries)

6. development of high power diode laser bars with 9XX nm with a peak power per bar at over 2 kW, efficiency at 1 kW beyond 70 % and a lateral far field reduced to ~ 11° (95 % power)
7. realisation and successful testing in industrial set-ups of pulsed high power diode lasers having peak wavelength stabilised against temperature variations for LiDAR applications. Lasers emit 40 W (single emitter) to 600 W (10 mm bar) optical pulse power in 4 ns pulse operation based on in-house electrical drivers (showing record switching up to 1 kA for 4 ns pulse width and using a dedicated topology with GaN transistors in the final stage)
8. realisation of customised laser diodes for a wide range of applications, many unique in the world, by using monolithically integrated surface or buried Bragg gratings and active/passive sections realised by multistep growth
9. development of dual-wavelengths chips for shifted excitation Raman difference spectroscopy in real-world applications with portable sensors for point-of-care diagnostic, precision agriculture, and food quality control
10. development of epitaxial processes for the realisation of UVB and UVC LEDs with state-of-the-art or record efficiency and reliability (including numerous novel and advanced technical approaches such as sputtering of AlN start layers, high-temperature annealing, epitaxial lateral overgrowth, and the use of nano-patterned sapphire substrates to fabricate AlN/sapphire templates with dislocation densities in the mid 108 cm 2) with an increasing shift in focus to almost unique far-UVC LEDs emitting around 233 nm, for which maximum optical powers beyond 3 mW at 200 mA have been demonstrated
11. development of micro-integrated, narrow line-width diode laser modules and unique assembling techniques and their successful operation at the ZARM drop tower and during sounding rocket missions, facilitating a number of first demonstrations, e.g. proof-of-concept of an optical clock in space, realisation of a Bose-Einstein-Condensate in space, demonstration of an iodine-based frequency reference in space with a micro-integrated ECDL-MOPA laser module (> 500 mW ex single mode optical fiber at 1064 nm, 26 kHz technical linewidth @ 1 ms)
12. development of an ultra-compact narrow linewidth diode laser based on the monolithic integration of active and passive waveguides in a solitary opto-electronic device (achieving record-low linewidth for a monolithic diode laser at 25 kHz @ 1 ms, 1.6 kHz intrinsic, 1064 nm).

<u>Transfer</u>

The FBH sees technology transfer as a core factor in its research and development work. It cooperates with industrial partners, research institutes and universities to implement its research results. The FBH has created a total of 10 spin-offs and received, within the past seven years, €30,5m in direct industry revenues. Finally, it holds a patent portfolio of 80 patent families and filed a total of 203 applications giving rise to a right of priority between 2018 and 2020 (see appendix 2), with the main purpose of project acquisition.

The institute established two dedicated structures to promote engineering and technology transfer. The interdisciplinary **Science Management team** offers support in establishing and managing the networks involved in transfer and commercialisation.

The **Prototype Engineering Lab**, on the other hand, provides practical functional models and prototypes. The lab was established in 2014. With its seven engineers and precision mechanics, it aims at facilitating technology transfer, showcasing portable prototypes that function as miniature laboratory setups. In this way, the FBH's research components are to be more easily accessible for potential industrial partners. Thus, the institute hopes to enable possible research projects and cooperation while at the same time ensuring feedback on the operation properties of components and modules.

Research Infrastructure

While the extensive technological infrastructure of the FBH (including its clean rooms, equipment and specialised facilities for micro- and optoelectronics, see chapter 4) is used for processing orders from external partners, it is only made available to third parties to a very limited extent in the institute's collaborations.

3. Changes and planning

Development since the previous evaluation

Structural Changes

Since 2017, the FBH is part of the **Research Fab Microelectronics Germany (FMD)**, which was established in cross-location by eleven institutes of Fraunhofer's association Microelectronics, the Leibniz Institute for High Performance Microelectronics (IHP) and the FBH, and which was funded by BMBF and state ministries to strengthen the position of the European semiconductor and electronics industry in global competition. Until the end of 2021, BMBF will have supported this joint activity with € 350m. The FBH is integrated into the technology park "Compound semiconductors". The institute used the additional funding within the framework of the FMD to increase its equipment pool significantly. For more than € 40m, a second high-grade clean room was refurbished and is to be put into full operation at the end of 2021. It includes a new process line for III-V semiconductors, electronic characterisation equipment and 3D-printers for metals, ceramics and gold and copper microstructures.

In 2019, the former Joint Lab "Laser metrology" evolved into an additional research area, **Integrated Quantum Technology**. It was financed through a permanent increase of the FBH's basic funding by federal and *Länder* governments by € 4.1m starting that year. This new unit follows the goal of making quantum technology usable for science and industry in a variety of application areas (see chapter 7.6)

With the end of 2020, the FBH left the umbrella of Forschungsverbund Berlin e. V. and now acts independently as ***Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik***. An independent administration has been built up, a permanent administrative director is yet to be appointed.

Changes in research areas

In the past seven years, the FBH has not abandoned any of its fundamental topics in microwave and millimetre-wave engineering as well as optoelectronics based on III-V semiconductors. It has, however, continually adjusted them and has taken up new topics as well.

The three long-established research areas of **III-V Electronics, Photonics and III-V Technology** have been revised over the years: Since the last evaluation, the former business areas have been divided into smaller labs, some of them in cooperation with university groups as Joint Labs (see the organisational chart in appendix 1). This had the intention to grant even younger scientists more autonomy and influence.

Additionally, a restructuring took place in the research area Photonics upon the retirement of the head of the Optoelectronics Department. In a reorganisation of his rather large area of responsibilities, a number of previous group leaders were designated as heads of newly established labs. The former group leader for Special Optical Devices was appointed as the new head of the Optoelectronics Department. The restructuring process also led to some adjustments in the III-V Technology area where research activities on mounting and assembling were bundled in a separate mounting and assembly (AVT) department.

Within the newly established research area Integrated Quantum Technology, a former group leader was promoted to head of the Joint Lab Quantum Photonic Components. Further lab heads were chosen through the regular hiring procedure.

Overall, a development took place towards the research and realisation of complex modules and subsystems for electronic (microwave) and optical applications, along with the realisation of operational systems. Along these lines, the Prototype Engineering Lab was established as a new unit in the area of III-V Technology with the goal to cover the necessary competencies in electronics, mechanical engineering and computing (see chapter 2).

Strategic work planning for the coming years

Personnel Changes

The FBH expects significant changes on the leadership level in the upcoming years, following the imminent retirement of its scientific director. Procedures are under way to jointly appoint his successor together with TU Berlin once more, the position was advertised on 01.03.2021. In the next five years, the following additional executives will retire:

- 2022: Head of the Power Electronics Department
- 2023: Head of the Microwave Department
- 2024: Head of the Laser Sensors Lab
- 2025: Head of the Joint Lab THz Components and Systems
- 2026: Head of the Materials Technology Department

At the moment, the position of a permanent administrative director is also still to be filled after the FBH’s leaving the Forschungsverbund Berlin e. V. in the end of 2020.

<u>Changes in research areas</u>

The entire research and transfer programme of the FBH will, as a basic approach, continue along the lines that have been followed in recent years. A deepened understanding and improved technology are sought in the realisation and application of semiconductor "light emitters" from the MHz to the UV range. The FBH also intends to work increasingly in the following strategic focus areas: Digitisation of RF & THz front ends for 5+G, pump laser modules & systems, optical & RF sensing (LiDAR, Radar, Raman), Integrated Quantum Technology and III-V semiconductor modules & systems for space applications. Generally, the FBH is planning to maintain its strong focus on III-V semiconductor technology and components while at the same time investing in research on systems or applications where it sees feasible opportunities emerge, such as applications in specific areas like (Raman) spectroscopy for life sciences, medical applications and agriculture and THz sensing (in radar and spectroscopy).

In the research area of **III-V Electronics** digital architectures for energy-efficient ultra-wideband transceivers in the frequency range up to over 100 GHz are to be researched, aiming to digitalise the hardware for wireless communications. This digitalisation will require dedicated semiconductor components as well as new concepts in circuit design and high-frequency measurement technology. Radar systems are another field where digitalisation is judged to become increasingly important and where the FBH intends to get involved.

In the research area **Photonics,** high power diode lasers will continue to be an important aspect of the institute's work. The FBH states that they are already under way with the realisation of "pump engines" for a new generation of very high pulse ultra-high field laser systems and are preparing to research further into the coherent coupling of diode lasers. In the field of optical sensor systems, a new Joint Lab with the BTU Cottbus is to deepen application research into the development of novel spectroscopic methods for life and environmental sciences. A number of recently taken strategic options in the area of photonics are also still being expanded and anchored at the institute.

The recently established research area **Integrated Quantum Technology** will be closely coordinated with research work done at the Institute of Physics at Humboldt-Universität Berlin. The results from the former Joint Lab Laser Metrology are to be further expanded here, aiming to produce coherent beam sources, but also entire assemblies in a technology suitable for field and space applications. Technologies such as additive manufacturing and laser material processing with ultra-short pulse lasers are also to be further developed here, as well as (together with potential users) standardised and usable quantum systems. In terms of qualitatively expanding activities around the actual semiconductor device, the focus is on GaAs-based photonic integrated circuits. A last focus concerns passive components such as waveguides. In the past, the FBH has striven to qualify its semiconductor components for applications in space. In the future, this work is supposed to be continued and expanded systematically with the aim of becoming a supplier of III-V semiconductor components and modules for e.g. ESA/DLR and NASA.

The research area **III-V Technologies** will continue its work and expand its scope as needed. Coping with the further increase in technological complexity is seen as a challenge in the context of the exploration of further materials such as diamond and the broader use of nanostructures as well as the parallel management of industry-oriented work on large substrates on the one hand and explorative processes for new physical concepts on the other. The new equipment installed as part of the FMD and the MES system is to be transferred to routine operation. The technology portfolio is to be supplemented as required, for example in the area of atomic layer etching.

Planning for additional funds deriving from institutional funding

The FBH stresses its existing investment in the fields of future mobility, satellite navigation, communication and research in space. This forms the basis for outlining future plans: In order to use its competencies sustainably and resiliently for transports, aeronautics and space, the institute proposes to establish a dedicated lab **"III/V Semiconductors for Aerospace"** which would subsequently pursue the following goals:

- providing the personnel and technical infrastructure to make sustainable and resilient technical solutions available, especially for the national space industry (based on III-V semiconductor technology as well as packaging and interconnection technology for applications in the areas of transport, aerospace and space)
- considering the thematic orientation of the national space programme continuously in the definition of the FBH's research programme
- processing research and industrial projects jointly with partners in industry and research (especially with DLR institutes where cooperation is seen as feasible due to the distribution of competencies).

The FBH maintains that additional funds would be required for the institute to consolidate the existing personnel and technical infrastructure and to upgrade it in a way that meets the product safety requirements for aerospace. In particular, it intends to strengthen its research on the reliability of electronic and optoelectronic III-V semiconductor components and hybrid integrated models and to establish the relevant product assurance measures. This would require an expansion of the existing technical infrastructure as well as the establishment and safeguarding of dedicated staff that keeps the required technical and organisational expertise at the institute on a permanent basis. Even assembly and connection technologies must be adapted to the requirements of product safety.

According to the FBH, the following new positions are to be created:

<u>**9 positions** for the development of the new Competence Centre</u>

- 1 management position (EG 15)
- 2 positions (EG 14) for project management
- 2 positions (EG 14) for project-related product assurance,
- 4 positions (EG 14) for the supervision of product assurance (1x clean room technology & mounting/assembly, 1x opto-electronics, 1x microwave technology, 1x integrated quantum technology)

8 positions for scientific work

- 4 positions (EG 14) for scientific staff members in materials technology, process technology, optoelectronics and mounting/assembly
- 4 positions (EG 6-8) for technical staff members (materials technology, process technology, optoelectronics and mounting/assembly)

4 positions for investigations on the reliability of quantum sensor systems and photonic modules:

- 2 positions (EG 14) for scientific staff members
- 2 positions (EG 6-8) for technical staff members

2 positions for studies on the reliability of electronic components and modules:

- 1 position (EG 14) for a scientific staff member
- 1 position (EG 6-8) for a technical staff member

6 positions in administration, services and non-research work:

- 3 positions (EG 8-10) in administration (organisation, purchasing, accounting)
- 1 position (EG 8) in technical services
- 1 position (EG 8) for a technical staff member in the precision mechanics workshop
- 1 position (EG 10) for a technical staff member in the electronics workshop/Prototype Engineering Lab

Overall, 29 additional staff members are to be financed, amounting to personnel costs of € 2,42m in 2029. In addition, the institute plans approximately € 1,06m p.a. for infrastructure/consumables and € 600k for investment costs. In total, the FBH calculates an additional institutional funding of about € 4,1m to be needed for financing personnel, infrastructure/consumables and investments.

Both the institute's Scientific Advisory Board and Supervisory board recommend the FBH's application for a small extraordinary item of expenditure.

„Extraordinary item of expenditure“: summary of funds planning

	2025	2026	2027	2028	Permanently
Own funds + additional funds = „extraordinary item of expenditure“	*€3,79m*	*€3,86m*	*€3,94m*	*€4,01m*	*€4,10m*
Own funds from existing funding by institution (at least 3 % of core budget)	*€0,60m*	*€0,62m*	*€0,63m*	*€0,64m*	*€0,65m*
Additional funds of institutional funding	*€3,19m*	*€3,24m*	*€3,31m*	*€3,37m*	*€3,45m*

4. Controlling and quality management

Facilities, equipment and funding

Funding (see appendix 3)

Out of the FBH's overall budget of around € 48,1m in 2020, € 19,1m (40 %) were **institutional funding** according to the administrative agreement between the Federal and *Länder* Governments with regard to the joint funding of member institutions of the Leibniz Association (AV-WGL).

Between 2018 and 2020, **revenue from project grants** totalled approximately € 70,2m (Ø € 23,4m p.a.), corresponding to 55 % of the overall budget. Thereof, € 51,7m were raised from Federal and *Länder* Governments (Ø € 17,2m p.a.), € 13,4m from industry (Ø € 4,5m p.a.), € 2,1m from the EU (Ø € 712k p.a.), € 1,7m from DFG (Ø € 551k p.a.) and € 1,3m from the Leibniz Association (Ø € 424k p.a.).

Services generated a revenue of €5,3m over the three-year period (Ø € 1,8m p.a.).

Facilities and equipment

The FBH's **facilities** are located at the Adlershof Technology Park in Berlin. The institute relies heavily on its clean room laboratory environment which it uses to conduct III-V semiconductor epitaxy, processes and packaging. The available technological infrastructure (semiconductor technology, device metrology and microintegration technology) is deemed to be appropriate for the objectives of the institute at this point. Among the major basic equipment, the institute lists e-beam lithography systems, I-line wafer steppers, a high voltage implanter, six epitaxy reactors for GaAs and GaN based materials and facet passivation technology. A second clean room is currently being worked on in the context of FMD with funding from BMBF and the State of Berlin (see chapter 2). On the longer run, the FBH is planning to cover the increased costs from operating its second clean room full-scale (at least €3m) through third party funding, especially in industrial collaborations.

The institute's **IT infrastructure** is operated by a dedicated team of 5 employees. It includes the office environment with 340 PCs as well as 240 dedicated computers for equipment operation and 20 terminal servers. High-performance computing capabilities and secure data storage are ensured through clusters of predominately virtualised servers that are linked to a central data storage unit. According to the FBH, the systems meet both external and internal data security and integrity requirements.

Organisational and operational structure

The FBH is headed by a **Scientific Director** on the one hand and an **Administrative Director** on the other.

The institute's major commitments in research are organised in four **research areas** (see chapter 2). As stated above, each consists of two types of organisational units: **labs** dealing with specific device developments and **departments** providing and advancing the technical and scientific resources. Focus and scientific topics are determined by the management and carried out under the operational responsibility of the labs or departments.

The heads of all departments and labs report directly to the scientific director, as do a number of further **Central Service** groups, namely the units for (i) technical support, (ii) communications, (iii) quality management, occupational safety and environment protection as well as (iv) internal revision, patent and legal affairs.

The **Science Management** department deals with strategic issues, technology transfer and networking, as well as with vocational education and training, all aspects of administration and IT support. In the future, these groups are to report to the administrative director.

The scientific director, the coordinators of the four research areas and the department heads form the **Internal Steering Committee**. Here, important strategic decisions as well as major investments are discussed on a monthly basis.

The **Institute Council / Scientific Council** meets on a monthly basis as well to circulate organisational information and scientific results and to discuss potential issues. It comprises all department and lab heads, the equal opportunity representative, one representative each of the work council, the technical service, IT, quality management and PR, and 3 elected staff participants.

Quality Management

For its scientific work, the FBH applies a policy based on the rules of **good scientific practise** as recommended by DFG. An elected ombudsperson and deputy serve as independent contacts, mediating conflicts and reporting cases to the director if necessary. Key figures are used as a basis for the monitoring of business processes in research, development and technology transfer.

The institute commits to **Open Access** in making all its publications available as citable metadata on the institute's website. The portal *Leibniz Open* is used for the publication of university theses and research reports. Additionally, the FBH participates in DEAL to publish research results under a free license.

Process data is centrally recorded and linked to its metadata in line with the Lab 4.0 model through a uniform software system (MES). This is to allow for **digital process control** and data assignment, filtering and evaluation.

The institute states that a **technology transfer strategy** is followed on several levels: Commercialisation objectives are achieved by aiming to offer well-matched products and services to customers from a single source, considering the individual specifications of the customer. Strategic partnerships with industrial firms are to ensure the conversion of research results into practical applications, and the FBH additionally transfers some of its product ideas into spin-offs (including eagleyard Photonics GmbH and JENOPTIK Diode Lab GmbH). Finally, the training of scientific and technical staff and staff mobility while working on joint projects are also integrated into the transfer strategy in the shape of transfer via heads.

The **Science Management Department** (see above) monitors collaboration with partners from research and industry as well as technology transfer, expansion of commercialisation and cooperation in research and technology networks. The recently established Prototype Engineering Lab goes beyond that, applying measures of commercialisation in developing portable stand-alone devices to make research results accessible through standard interfaces.

Quality management by advisory boards and supervisory board

The FBH's **Scientific Advisory Board** (SAB) is responsible for assessing the work accomplished at the institute and for evaluating the programme budgets. It consists of international external experts from universities and research facilities as well as from industry. The SAB is appointed by the Supervisory Board (see below) and meets annually. Half-way between two Leibniz evaluations, the SAB conducts a two-day audit in order to obtain a comprehensive overview of the status of the institute and to assess the general course of work. The last audit took place in 2018.

The institute's **Supervisory Board** monitors the legality, appropriateness and economic efficiency of the FBH's management and determines the basic principles of business policy. It is usually made up of two members each from the federal and state government, two scientific members and two representatives from the industry. Beyond appointing of the SAB members, the Board's functions include passing resolutions on the institute's programme budget, on appointments of institute directors and leading scientific staff, on basic policy principles and success evaluation as well as on the FBH's annual financial statements and the annual report of the FBH's directors.

5. Human Resources

As of 31 December 2020, the FBH employed 293 people (240 in 2013), and an additional 45 individuals regularly worked at the institute through collaborations like Joint Labs without being employed there. 140 of the employees were occupied in research and scientific services, 85 in science-supporting service positions, and 26 in science-supporting administrative positions (see appendix 4).

There has been a considerable amount of fluctuation due to young researchers leaving the institute upon the completion of their degrees or research stays, but also due to senior staff members going into retirement. Between 2018 and 2020, the institute welcomed a total of 114 new staff members, and further changes lie ahead with the imminent retirement of several leading scientists in coming years (see chapter 3).

Leading scientific and administrative positions

With the retirement of the scientific director as well as several department heads, the FBH is headed for significant changes on its leadership level (see chapter 3). An administrative director is currently being appointed as well. According to the FBH, a general recruiting and staff development strategy is in place, ensuring smooth transitions in this situation.

Staff with a doctoral degree

Post-doctoral researchers are supported through special career-building measures, including the Leibniz Mentoring Programme for Female Scholars. The FBH supports development opportunities in the areas of further academic studies, improving and updating technical skills through seminars and courses and general / soft-skill development.

The institute aims to keep staff fluctuation at a minimum in order to guarantee skilled employees in the specialised areas of expertise required. Currently, 51 % of the staff is employed on temporary contracts, but the FBH intends to decrease this percentage in the future.

Doctoral Candidates

As of 31 December 2020, the FBH employed 33 doctoral candidates (additionally, one doctoral student was a scholarship recipient). The institute advertises for doctoral candidates nationally and internationally. Most doctorates take about 5 years, and the PhD is awarded by one of the universities the FBH is cooperating with. Candidates are employed as full-time staff members on temporary contracts of usually 2 years with later extension. Each candidate has one academic supervisor (commonly a department head or the scientific director). The second supervisor is a senior scientist within the respective group.

Beyond the supervision, routine meetings with the doctoral candidates are held by the scientific director in order to monitor progress and results from a higher-level perspective. PhD candidates give presentations in the weekly institute seminars, participate in academic education and are encouraged to attend in-house courses for improving various general and soft skills.

The institute's PR department stays in touch with its former doctoral students as alumni contacts.

Science supporting staff

The FBH claims to put significant effort into education and training. Up to six apprenticeships for microtechnologists are offered every year, and one additional apprenticeship each for an IT specialist and a precision mechanic is offered every third year. Trainees are supervised by three coordinators and each trainee has an individual mentor. The institute offers courses for them and runs a lecture series held by the apprentices themselves. In the past three years, one precision mechanic and 10 microtechnologists successfully completed their trainings, one of whom received several awards for their excellent result.

The institute highlights its involvement in career orientation and in strategies for attracting young people for a potential career in MINT. It regularly employs project-funded education managers that are at the core of ANH Berlin (a network for high technology education and training that supports the recruitment of trainees and staff). Ongoing funding projects aim at improving processes for attracting target groups to dual vocational training, integrating them into career paths and promoting specific professional development programmes. The institute also approaches schools with various activities to interest pupils in natural and technical sciences.

Equal opportunities and work-life balance

The FBH implements the DFG's standards for **gender equality** through various measures from promoting woman in management, executive levels and the skilled trades to committing to providing a family-friendly workplace. An equal opportunity commissioner is installed as a contact person for all FBH staff.

18 % of the 1st and 2nd level executives (0 % in 2013), 27 % of the group leaders (19 % in 2013) and 12 % of the doctoral candidates (26 % in 2013) are woman. In total, 19 % of the employees in research and scientific services are female, as compared to 17 % in 2013 (see appendix 4). According to the institute, this proves a smooth transition in the career path to the higher levels. They highlight that a special emphasis in their engagement for technical education is on gender aspects, trying to gain a better overall balance between males and females in the MINT sector (for example through a regular Girls' Day and a regional girls' technology congress). At a later stage, female students and PhD candidates are supported through networks and assistance with career-building.

The FBH's strategy for supporting a healthy **work-life balance** includes flexible working hours, HR development through re-entry agreements and advanced vocational training during or after maternity / parental leave, a playroom for employees' children in case of a lack of child care vacancies and an advisory service for families as well as help with finding suitable day-care options. Furthermore, the FBH provides five places in day-care for its employees' children. In July 2021, the institute was re-awarded the TOTAL E-QUALITY certificate which it has been holding since 2009. It has also received prizes for being a family-friendly workplace in its district (Köpenick, Berlin) several times.

6. Cooperation and environment

Cooperation with universities

Collaboration with universities is pursued through joint appointments, Joint Labs and other cooperation models.

The following cooperation with universities exists on the staff level:

Technische Universität Berlin (TUB)

- Joint appointment of the scientific director of the FBH (C4)
- Joint appointment of the head of the Microwave Department (W3)
- 20 % co-financing of the head of the Joint Lab GaN Optoelectronics (W3)
- 2 additional Joint Lab: GaN Optoelectronics and Power Electronics

Humboldt-Universität zu Berlin (HUB)

- 50 % co-financing of the head of the Joint Lab Quantum Photonic Components (W3)
- 3 additional Joint Labs: Integrated Quantum Sensors, Diamond Nano Photonics and Photonic Quantum Technologies
- Additionally, the FBH co-finances HUB's Transmission Electron Microscopy Lab with € 30k annually as part of a cooperation.

One further Joint Lab each connect the FBH to **Goethe Universität Frankfurt/Main** (THz Components & Systems; 50 % co-financing of the head of the Joint Lab), **Brandenburgische Technische Universität Cottbus-Senftenberg** (BTU-CS – FBH Microwave) and **Universität Duisburg-Essen** (InP Devices) respectively.

Cooperation with non-university partners

A dedicated group within the FBH's Science Management Department targets the initialisation and coordination of networking activities. Some core academic collaborative projects are listed below:

- Since 2017, the FBH is part of BMBF's initiative Research Fab Microelectronics Germany (FMD, see chapter 3).
- The institute coordinates the Germany-wide consortium Advanced UV for Life (AUVL) that was launched in 2013 and aims to open up innovative applications for ultraviolet light. The consortium was funded with up to € 45m until 2021. Having grown from 23 to now 50 partners over the years and increasingly attracting members from industry, it has intensified its focus on applications and industry. AUVL is continuing cooperation as an association with its legal office at the FBH since 2021.
- The FBH partakes in the BMBF project iCampus through its involvement in the Innovation Campus Electronics and Microsensor Technology Cottbus at BTU Cottbus-Senftenberg which aims to establish innovative and sustainable technology clusters. Cooperation between research institutions and companies is to promote application-specific sensor developments.
- The FBH's Prototype Engineering Lab that was founded within the framework of Leibniz Application Laboratories in 2013 and received BMBF funding of approximately € 1,9m. It aims to act as an interface between industry and science (see chapter 2).
- Until recently, the FBH has partaken in two different collaborative research activities: The DFG-funded Semiconductor Nanophotonics Collaborative Research Center (CRC 787), which ended in 2020, and the Helmholtz Research School on Security Technologies (HRSST) that ran until 2019.
- The FBH is a member of the "Leibniz Research Alliance for Medical Engineering" which focuses on translating research into marketable products in the biophotonic sector.
- The institute has evolved from associated partner to full member in the Leibniz ScienceCampus Berlin "Growth and Fundamentals of Oxides for electronic applications (GraFOx)" in 2020. The partner institutions (including two more Leibniz institutes with PDI and IKZ as well as the universities of Magdeburg, Leipzig and HUB, the Fritz-Haber-institute of the Max Planck Society and the Helmholtz-Zentrum Berlin) aim to explore ways to optimally utilise the application potential of oxides.
- The FBH is also part of the Leibniz Research Network "Mathematical Modelling and Simulation (MMS)", aiming to systematically exploit the potential of mathematical

modelling and simulation methods for effective use and synergies in scientific and technological progress.

Beyond academia, the FBH stresses its extensive collaboration and networks with **industrial partners** and points to having established a number of strategic partnerships with industry (for example in research areas dealing with high power laser diodes, optoelectronic modules, high brilliance pump modules and GaN transistors and templates).

The institute supplies industrial partners in the Berlin region and in Europe with key components, and a total of 10 **spin-offs** have been created so far.

International cooperation

Internationally, the FBH's most important research cooperation involves, among others, the Fitzpatrick Institute for Photonics and the Department of Biomedical Engineering at Duke University, USA, the National Chiao Tung University, Taiwan, Risø DTU, Denmark and the University of Surrey, UK.

Institution's status in the specialist environment

According to its own assessment, the FBH is one of the largest III-V research institutes in Europe. In Germany, only the **Fraunhofer Institute for Applied Solid State Physics (IAF)** in Freiburg operates on a similar scale, but while there are clear similarities between these two institutes with regard to their general fields of expertise, they differ in terms of the more detailed research topics. **The Fraunhofer Institute for Telecommunications / Heinrich-Hertz-Institute (HHI)** in Berlin runs a III-V Technology as well, but with a different focus.

On the European level, the FBH names the **Interuniversity Microelectronics Centre (IMEC)** in Belgium and the **Alcatel-Thales III-V Lab** in France as facilities with which there are overlaps and occasional common activities. Among European Universities, **Chalmers** in Sweden has the most similarities with the FBH's areas of interest. Worldwide, the **University of California, Santa Barbara (UCSB)** and the **Massachusetts Institute of Technology (MIT)** in the US run similar programmes.

The UK **Quantum Technology Hub Quantum Sensors & Timing** which consists of more than 80 university and industrial partners pursues projects with different size and focus than the FBH, but the FBH states that its technology plays a minor role there.

7. Sub-programmes of the FBH

Research area 1 – Electronics

7.1 Sub-programme RF to THz electronics

[33,7 FTE, thereof 21,8 FTE Research and scientific services, 7,9 FTE Doctoral candidates, and 4,0 FTE Service staff]

As can be seen in the overview in chapter 1, the sub-programme RF to THz electronics comprises the following departments and labs:

- *Microwave Department*
- *RF Power Lab*
- *Digital PA Lab*
- *Joint Lab BTU-CS - FBH Microwave*
- *Joint Lab THz Components & Systems*
- *Joint Lab InP Devices*
- *GaN Microwave Devices Lab*

The main research target in this sub-programme is to optimize electronic components in the GHz to THz range in two aspects:

(i) develop novel transceiver circuit and device concepts, with special focus on digitisation, exploiting the high-speed high-power switching potential of III-V devices

(ii) improve circuit performance for frequencies above 100 GHz, particularly in terms of output power and efficiency.

Utilising access to the full III-V semiconductor fabrication chain at the FBH with GaN-HEMT (high-electron-mobility transistor) and InP-HBT (heterojunction bipolar transistor) processes, the approach extends from devices and circuits through modules up to the system level. The unit aims at offering new solutions for wireless communications (5G, 6G, …), radar sensing and imaging, including the requirements of green ICT.

Along these lines, work comprises the following topics:

- microwave and mm-wave high-power intelligent transmitters and receivers with high dynamic range, addressing the requirements of the wireless communications infrastructure including space and other applications
- THz and broadband components and modules for the frequency range between 100 GHz and 2 THz, as a key enabler for 6G as well as for radar sensing and imaging
- high-speed high-current drivers for pulsed laser sources, e.g. for LiDAR applications
- dedicated III-V processes (GaN-HEMT, InP-HBT, and AlN as a new wide-bandgap material) to realise the above-mentioned components
- hetero-integration of III-V-on-BiCMOS (bipolar complementary metal-oxide-semiconductor), primarily InP-on-BiCMOS and, in the future, GaN-on-BiCMOS, to facilitate embedding of III-V circuit functions in Si-based systems
- advanced RF competence in simulation, modelling, circuit design, characterisation, and chip packaging.

Between 2018 and 2020, the sub-programme published 77 articles in peer-reviewed journals. The revenue from project grants totalled approx. € 33,4m (Ø € 11,1m p.a.). € 31,9m (Ø € 10,6m p.a.) thereof were obtained from federal and *Länder* governments, € 950k (Ø € 317k p.a.) from DFG, € 383k (Ø € 128k p.a.) from EU funding, € 93k (Ø € 31k p.a.)

from industry and € 70k (Ø € 23k p.a.) from the Leibniz Association (competitive procedure). Another € 33k (Ø € 11k p.a.) were acquired as revenue from commissioned work. As of 31 December 2020, 56 patents were held and 85 applications giving rise to a right of priority were filed between 2018 and 2020. In the three-year period, 6 doctoral degrees were completed.

7.2 Sub-programme Power electronics

[7,7 FTE, thereof 5,8 FTE Research and scientific services, 1,0 FTE Doctoral candidates, and 0,9 FTE Service staff]

The sub-programme Power electronics comprises the following departments and labs:

- *Power Electronics Department*
- *GaN Power Electronic Devices Lab*
- *Joint Lab Power Electronics*

In order to efficiently exploit the institute's wide band gap power electronics technology for power electronic systems and for developing system relevant characterisation schemes, the Joint Lab power electronics was initiated in 2014 as a cooperation between the FBH and TU Berlin. This led to a focused iterative improvement of GaN power devices for power system applications including hybrid integration schemes based on polycrystalline AlN submounts ("High speed power cores") and monolithic integration schemes. In the meanwhile, the activities on wide band gap power devices have been extended to vertical GaN transistors based on native GaN substrates, initially for direct laser driving applications by chip-on-chip integration with GaAs based diode lasers and now, in the new European projects YESvGaN and GaN4AP, for high voltage power switching systems running at more 1200 V drain bias.

Furthermore, the FBH scientists started exploiting new ultra-wide bandgap materials such as AlN and Ga_2O_3. The former started in a project within the frame of Leibniz project funding (AlPower) and is now the baseline for active BMBF and DFG projects. The latter is based on an intensive cooperation with IKZ Ga_2O_3 crystals and epitaxy and now topic of ongoing projects on lateral and vertical Ga_2O_3 devices.

Between 2018 and 2020, the sub-programme published 13 articles in peer-reviewed journals. The revenue from project grants totalled approx. € 2,6m (Ø € 864k p.a.). € 1,2m (Ø € 388k p.a.) thereof were obtained from federal and *Länder* governments, € 1m (Ø € 337k p.a.) from the Leibniz Association (competitive procedure), € 254k (Ø € 85k p.a.) from DFG, € 163k (Ø € 54k p.a.) from EU funding and € 1,2k (Ø € 0,4k p.a.) from industry. Another € 269k (Ø € 90k p.a.) were acquired as revenue from commissioned work. As of 31 December 2020, 29 patents were held and 3 applications giving rise to a right of priority were filed between 2018 and 2020. In the three-year period, 1 doctoral degree was completed.

Research area 2 – Photonics

7.3 Sub-programme Monolithic high-power and high-brilliance lasers

[34,5 FTE, thereof 16,5 FTE Research and scientific services, 6,3 FTE Doctoral candidates, and 11,7 FTE Service staff]

The sub-programme Monolithic high-power and high-brilliance lasers comprises the following departments and labs:

- *Optoelectronics Department*
- *High-Power Diode Lasers Lab*

The main research target of this sub-programme is the design, fabrication, characterisation and continuous improvement of a wide variety of diodes lasers, which are tailor-made for the intended area of application, regarding

(i) highest optical power, efficiency or brilliance

(ii) excellent reliability

(iii) fixed wavelength or small spectral linewidth or tunability

(iv) pulsed operation

(v) special application

Wavelengths span from 600 to 1200 nm (GaAs-based), operated from ps-pulses to continuous wave, from mW to a few W in a spectrally and spatially single mode to many kW in highly multimode units.

The FBH targets the full value chain from device design (using self-developed sophisticated 3D modelling tools), through epitaxial growth (also advanced highly vertically asymmetric designs, AlGaAs regrowth) and wafer process technology (including monolithic frequency stabilisation, facet passivation, buried blocking), into high power packaging (short pulse, multi-contact, low thermal resistance) and beam combining techniques (dense wavelength, coherent), and are used for the development and delivery of application-ready modules (High power narrow-spectrum LiDAR, kW-class high duty cycle QCW pumps). Characterisation techniques including life time testing are available at the FBH.

In addition to the deeper understanding of the physics and the progress in the technology of diode lasers, the development of lasers is focused on their use in research and in industrial applications, where individually customised and unique laser diodes are provided by FBH for partners and customers in science and industry. Partners vary from large industry (Trumpf, Jenoptik) to emerging space (TESAT, Airbus), automotive LiDAR (Bosch) and high energy class laser research (EuPRAXIA).

Between 2018 and 2020, the sub-programme published 67 articles in peer-reviewed journals. The revenue from project grants totalled approx. € 4,4m (Ø € 1,5m p.a.). € 2,9m (Ø € 963k p.a.) thereof were obtained from industry, € 1,5m (Ø € 500k p.a.) from federal and *Länder* governments, € 5,6k (Ø € 1,9k p.a.) from DFG and € 5,4k (Ø € 1,8k p.a.) from foundations. Another € 1,7m (Ø € 581k p.a.) were acquired as revenue from commissioned work. As of 31 December 2020, 84 patents were held and 53 applications giving rise to a right of priority were filed between 2018 and 2020. In the three-year period, 5 doctoral degrees were completed.

7.4 Sub-programme Hybrid integrated laser sources

[13,9 FTE, thereof 8,9 FTE Research and scientific services, 5,0 FTE Doctoral candidates]

The sub-programme Hybrid integrated laser sources comprises two labs:

- *Laser Modules Lab*
- *Laser Sensors Lab*

FBH's research here dates back until 2007. Since then, a technology platform has been built up for the micro-integration of laser diodes or amplifiers together with other optical components, such as micro-optics, nonlinear crystals, micro-isolators, beam deflectors and filters, which are assembled with high precision on a single optical micro-bank with a footprint of a few cm^2.

Activities have been systematically and significantly expanded. This sub-programme now focuses on research for the realisation and application of compact laser diode modules with (very) high complexity, tailored for specific applications in the field of sensor technology, as well as the medical and biological field. The wavelengths are in the NIR and red spectral range, based on the wavelengths of GaAs-based semiconductor chips. The visible, UV or mid-IR spectral range is addressed by frequency conversion in periodically poled nonlinear crystals.

The Lasers Sensor Lab und the Laser Modules Lab are responsible for projects and research goals in this sub-programme. Several other sub-programmes are involved: In addition to the complete technology for realising the laser diodes, FBH researches and operates technology for module assembly and mounting; corresponding simulations and design are included. The two main labs integrate passive components such as micro-lenses, optical microisolators or nonlinear crystals, which are sourced from external suppliers or research partners.

Between 2018 and 2020, the sub-programme published 47 articles in peer-reviewed journals. The revenue from project grants totalled approx. € 2,5m (Ø € 848k p.a.). € 1m (Ø € 339k p.a.) thereof were obtained from EU funding, € 1m (Ø € 337k p.a.) from federal and *Länder* governments, € 324k (Ø € 108k p.a.) from industry and € 193k (Ø € 64k p.a.) from the Leibniz Association (competitive procedure). Another € 363k (Ø € 121k p.a.) were acquired as revenue from commissioned work. As of 31 December 2020, 41 patents were held and 28 applications giving rise to a right of priority were filed between 2018 and 2020. In the three-year period, 3 doctoral degrees were completed.

7.5 Sub-programme UV light sources

[9 FTE, thereof 6,8 FTE Research and scientific services, 2,0 FTE Doctoral candidates, and 0,2 FTE Service staff]

The sub-programme UV light sources comprises one joint lab:

- *Joint Lab GaN Optoelectronics*

Research on monolithic UV and VIS light sources is an integral part of the Joint Lab GaN Optoelectronics with a group at the TU Berlin. The Joint Lab covers the entire value chain for GaN optoelectronic devices, with a focus on ultraviolet light-emitting diodes (UV LEDs) and diode lasers. This includes the epitaxial growth of InAlGaN-based heterostructures by metal-organic vapor phase epitaxy (MOVPE), chip processing technologies, mounting and packaging of chips as well as device characterisation including lifetime and reliability testing. In collaboration with the Prototype Engineering Lab the development of turn-key ready UV LED modules that can be delivered to application partners has picked up markedly.

The start of the BMBF-funded consortium “Advanced UV for Life” in 2014 has led to significant advances in AlInGaN materials development and a strong focus on UV LEDs. Today, UV LED devices of this sub-programme cover an emission wave-length range from 330 nm (UVB) to 230 nm (UVC). So far, the UV LED development has been focused on three key wavelength bands: high power and long-lifetime UVB LEDs (~310 nm) and their application e.g. in plant growth lighting and photo-therapy, high-power and long-lifetime near-UVC LEDs (~265 nm) and their application e.g. for water purification and surface disinfection as well as far-UVC LEDs (~230 nm) and their application e.g. for skin-tolerant inactivation of pathogens and gas sensing. The Joint Lab is currently working on further improving the electro-optical characteristics of UV LEDs, especially in far-UVC, and applying them to enable new areas of applications in cooperation with partners from industry and research.

In 2015 the start-up company UVphotonics NT GmbH was established which aims at commercialising UV LEDs based on the technologies developed at FBH and TU Berlin.

In addition to UV LEDs, another focus is on diode lasers with emission in the blue and violet spectral range. Such components are utilized in the fields of spectroscopy, quantum technologies, and metrology. FBH has developed technology for laterally single-mode ridge waveguide diode lasers as well as longitudinally single-mode DFB and DBR diode lasers in the wavelength range 400 nm to 430 nm. The current focus is to extend the lifetime of these lasers to enable applications in the integrated quantum technology such as atomic clocks.

Between 2018 and 2020, the sub-programme published 35 articles in peer-reviewed journals. The revenue from project grants totalled approx. €2m (Ø € 656k p.a.). € 1,6m (Ø € 545k p.a.) thereof were obtained from federal and *Länder* governments, € 232k (Ø € 77k p.a.) from DFG, € 89k (Ø € 30k p.a.) from industry and € 11k (Ø € 3,7k p.a.) from foundations. Another € 0,9k (Ø € 0,3k p.a.) were acquired as revenue from commissioned work. As of 31 December 2020, 23 patents were held and 10 applications giving rise to a right of priority were filed between 2018 and 2020. In the three-year period, 1 doctoral degree was completed.

Research Area 3 – Integrated Quantum Technology

7.6 Sub-programme Integrated Quantum Technology

[26,5 FTE, thereof 18,0 FTE Research and scientific services, 5,5 FTE Doctoral candidates, and 3,0 FTE Service staff]

The research area Integrated Quantum Technology (IQT) comprises four Joint Labs:

- *Joint Lab Quantum Photonic Components*
- *Joint Lab Integrated Quantum Sensors*
- *Joint Lab Diamond Nanophotonics*
- *Joint Lab Photonic Quantum Technologies*

It was established in 2019 and financed through a permanent increase of FBH's basic funding by € 4.1m, with the Joint Lab Quantum Photonic Components (formerly Joint Lab Laser Metrology) serving as the nucleus. Since then, three more Joint Labs have been established in cooperation with HU Berlin. The mission of the research area is to pursue the technology development necessary to pave the way for the second quantum revolution and to allow for an industrialisation of quantum technology.

The Joint Lab Quantum Photonic Components (QPC) focuses on R&D of complex, compact, and robust photonic modules for QT-applications, currently based on monolithic and hybrid integration concepts. A significant part of its activities aims at developments for space applications including proper product assurance activities.

The Joint Lab Integrated Quantum Sensors (IQS) focuses on the development of compact and robust quantum sensors for field and space applications. The long-term vision of IQS is the development of a "system-on-a-chip" platform quantum sensing.

The Joint Lab Diamond Nanophotonics (DNP) is researching novel concepts for guiding, capturing and manipulating light on the nano- and microscale. The aim is to achieve controllable light-matter interaction to efficiently couple quantum memories in diamond to individual light particles (photons).

The Joint Lab Photonic Quantum Technologies develops optical chip-based quantum devices that can be directly interfaced with optical fibres. Chip-integrated optical components constitute the technological platform for the required low-loss, nonlinear optical quantum devices. The Joint Lab is jointly operated by FBH and the Fundamentals of Optics and Photonics group at HU Berlin.

Between 2018 and 2020, the sub-programme published 24 articles in peer-reviewed journals. The revenue from project grants totalled approx. € 8,2m (Ø € 2,7m p.a.). € 6m (Ø € 2m p.a.) thereof were obtained from federal and *Länder* governments, € 1,9m (Ø € 617k p.a.) from industry, € 304k (Ø € 101k p.a.) from EU funding and € 30k (Ø € 10k p.a.) from DFG. Another € 22k (Ø € 7k p.a.) were acquired as revenue from commissioned work. As of 31 December 2020, 2 patents were held and 10 applications giving rise to a right of priority were filed between 2018 and 2020. In the three-year period, 2 doctoral degrees were completed.

Research Area 4 – III/V compound semiconductor technology

7.7 Sub-programme Materials

[19,8 FTE, thereof 11,1 FTE Research and scientific services, 1,0 FTE Doctoral candidates, and 7,6 FTE Service staff]

The sub-programme Materials comprises one department:

- *Materials Technology Department*

It mainly focuses on the vapor phase epitaxy of heterostructures of group III-arsenides and -phosphides on the one hand and group III-nitrides on the other hand. These heterostructures form the basis for device development at FBH and for partners and customers. Since the quality of the layer structures and conformance to the target specifications of the devices can only be judged by making devices, work is based on intensive cooperation between heterostructure growth/analysis and device processing/characterisation performed by the internal and external customers and development partners.

Group-III arsenides and phosphides are grown for edge-emitting laser diodes for internal development in the research areas Photonics and Integrated Quantum Technology, and customer-specific heterostructures are also provided to external partners and customers.

The sub-programme also supports the development of heterostructures by analysing heterostructures with respect to crystalline, optical and electrical properties. Analysis of device failures by methods like cathodo-luminescence is performed to optimise device processing and mounting. These services are also offered to external customers, especially for failure analysis on laser diodes.

Between 2018 and 2020, the sub-programme published 50 articles in peer-reviewed journals. The revenue from project grants totalled approx. € 3,8m (Ø € 1,3m p.a.). € 3m (Ø € 1m p.a.) thereof were obtained from federal and *Länder* governments, € 561k (Ø € 187k p.a.) from industry and € 181k (Ø € 60k p.a.) from DFG. Another € 727k (Ø € 242k p.a.) were acquired as revenue from commissioned work. As of 31 December 2020, 15 patents were held and 8 applications giving rise to a right of priority were filed between 2018 and 2020. In the three-year period, 3 doctoral degrees were completed.

7.8 Sub-programme Processes

[53,8 FTE, thereof 15,0 FTE Research and scientific services, 2,8 FTE Doctoral candidates, and 36,0 FTE Service staff]

The sub-programme Processes comprises the following two departments:

- *Process Technology Department*
- *Mounting & Assembly Department*

This sub-programme conducts the advancement of its III/V compound semiconductor technology in four directions:

- basic developments for FBH's main areas in electronics, photonics and quantum technologies
- process development of passive optical elements such as, e.g., waveguides and resonator structures on chip
- process development and device fabrication on request of external partners
- process services for external partners from academia and industry

Semiconductor processing at FBH has been concentrating on the advancement of its III/V compound semiconductor technology for a long time – both frontend and backend, as well as mounting and assembly – notably as the basis for its research on RF-components and power electronic devices as well as on laser diodes and LEDs.

In the Process Technology Department, the focus on III/V semiconductors is based on GaAs and GaN mainly; research work is done 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 AlN, Ga_2O_3, SiC, Si, sapphire and diamond for quite specific applications mostly in connection with FBH's programmes in electronics, optoelectronics, and integrated quantum technology. Processing is mostly done on full wafers ranging from 2" -4"; wafer quarters and pieces down to <10 mm edge length are processed as well.

The Mounting and Assembly Department is a packaging laboratory specialised in the requirements of photonics, integrated quantum technology and III-V Electronics. Semiconductor chips are separated, electrically contacted and assembled on suitable heat sinks in order to exploit the technological potential of the devices and to be able to supply the devices to customers and partners. Stable mounting processes with low process fluctuations ensure valid results in the characterisation of the components in measurement technology and, at the same time, mounting process developments are carried out to expand the range of mounting products, driven by the requirements of component development.

FBH runs its semiconductor technology in clean room environments (best class is IOS 5). The process line is operated under industry-like conditions and regulations by dedicated staff. In line with the combination of working according to industrial standards and throughput on the one hand and with very high flexibility on the other hand is, according to the institute, a bigger part of the research work is spent to achieve and to guarantee long-term reproducibility and homogeneity at all steps in the fabrication chain.

Between 2018 and 2020, the sub-programme published 3 articles in peer-reviewed journals. The revenue from project grants totalled approx. €6,8m (Ø € 2,3m p.a.). € 6,6m (Ø € 2,2m p.a.) thereof were obtained from industry, € 247k (Ø € 82k p.a.) from EU funding and € 19k (Ø € 6,2k p.a.) from federal and *Länder* governments. Another € 2,1m (Ø € 691k p.a.) were acquired as revenue from commissioned work. As of 31 December 2020, 14 patents were held and 6 applications giving rise to a right of priority were filed between 2018 and 2020.

8. Handling of recommendations from the previous evaluation

FBH responded as follows to the 11 recommendations of the last external evaluation (highlighted in italics, see also statement of the Senate of the Leibniz Association issued on 10 November 2014, pages B-2/B-4):

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."*

FBH states to have continued basic research in its long-lasting research fields as well as in newly established topics, as demonstrated by its publications. According to the institute, the number of DFG-projects increased from 4 projects in 2014 to 14 projects in 2020.

Technology transfer is claimed to have been facilitated by developing more complex modules and systems for specific applications.

The institute points to its dedication to application and industry-oriented research and development. In specific cases, they go beyond the demonstration of components and modules in the context of pilot series and aim to create an active interface between science and industry in order to be able to translate research results into marketable products, processes and services even faster with their Prototype Engineering Lab.

With the additional scientific-technical infrastructure available through the federal funding for Research Fab Microelectronics German (FMD, see chapter 3), FBH is expecting opportunities from new types of research cooperation, but also a need for increased cooperation with industrial companies in order to maintain the necessary financial resources long-term.

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."*

FBH points at having started several new research topics and cooperations in recent years and firstly highlights FMD once more (see above), adding that the institute also pursued its research in Raman spectroscopy in life sciences, medical application and agriculture, partaking in the research cooperation iCampus at BTU Cottbus-Senftenberg in the field of microsensors technology (see chapter 6).

The newly established research area of Integrated Quantum Technology is also deemed to open up new future-oriented research topics in cooperation with university partners (see chapter 7.6).

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."*

To address these recommendations FBH initiated an internal discussion about future topics leading to an extraordinary meeting of the scientific advisory board in 2017. According to the institute, the leading scientific staff continuously discusses new areas of research and application. In 2018, an internal research conference was held to discuss the most important topics for the next 5-10 years, leading to a strategy concept which forms the basis for organising the upcoming generation change at management level.

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."*

According to FBH, the institute has achieved a steady expansion and renewal of infrastructure in recent years (see chapter 3). With the strategic expansion through FAB, numerous new facilities are added to its technological base in semiconductor technology and device metrology. (see chapter 3). In public/private partnership programmes, JENOPTIK Diode Lab, eagleyard Photonics, Lumics, and SENTECH make use of infrastructure at the FBH, generating fees.

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."*

FBH claims to widely contribute to conferences and workshops, not only by papers and presentations, but also by organising these or being committee/programme member or chair. Also, they point to 22 current international joint projects (compared to 8 in 2014). For specifics on cooperation, see chapter 6.

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."*

FBH points out that the number of networks and the intensity of collaboration within these has increased significantly since the last evaluation. Especially the FMD network and AUVL are highlighted to include regular application field specific workshops as well as technology platform discussions where potential research and application is discussed.

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."*

The institute points to framework cooperation contracts with the spin-offs, as well as further agreements regarding licenses, R&D projects and the use of infrastructures. In addition, the FBH gGmbH holds small shares in the spin-offs eagleyard Photonics and UVphotonics NT. Thus, they see their cooperation with the spin-offs as transparently defined.

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****."*

The quota for permanent staff is quoted as 50 % of the operating budget since 2017. FBH claims to have used this instrument to reduce temporary employment of long-serving technical staff in particular, and to secure their skills for the operation of technical facilities. The permanent employment rate was 32 % at the end of 2020. According to the institute, it would be useful and appropriate that the personnel quota should not include technical and administrative staff as the structure of the institute requires a high percentage of employees in the operational area.

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."*

The institute states that the proportion of women at management level was 19 % at the end of 2020, a significant improvement to 2014 when there were no female department heads at all. The proportion of female group leaders has risen from 19 % to 27 %. The proportion of female scientists is currently 15 %. FBH points to having implemented several measures for securing equal opportunities.

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."*

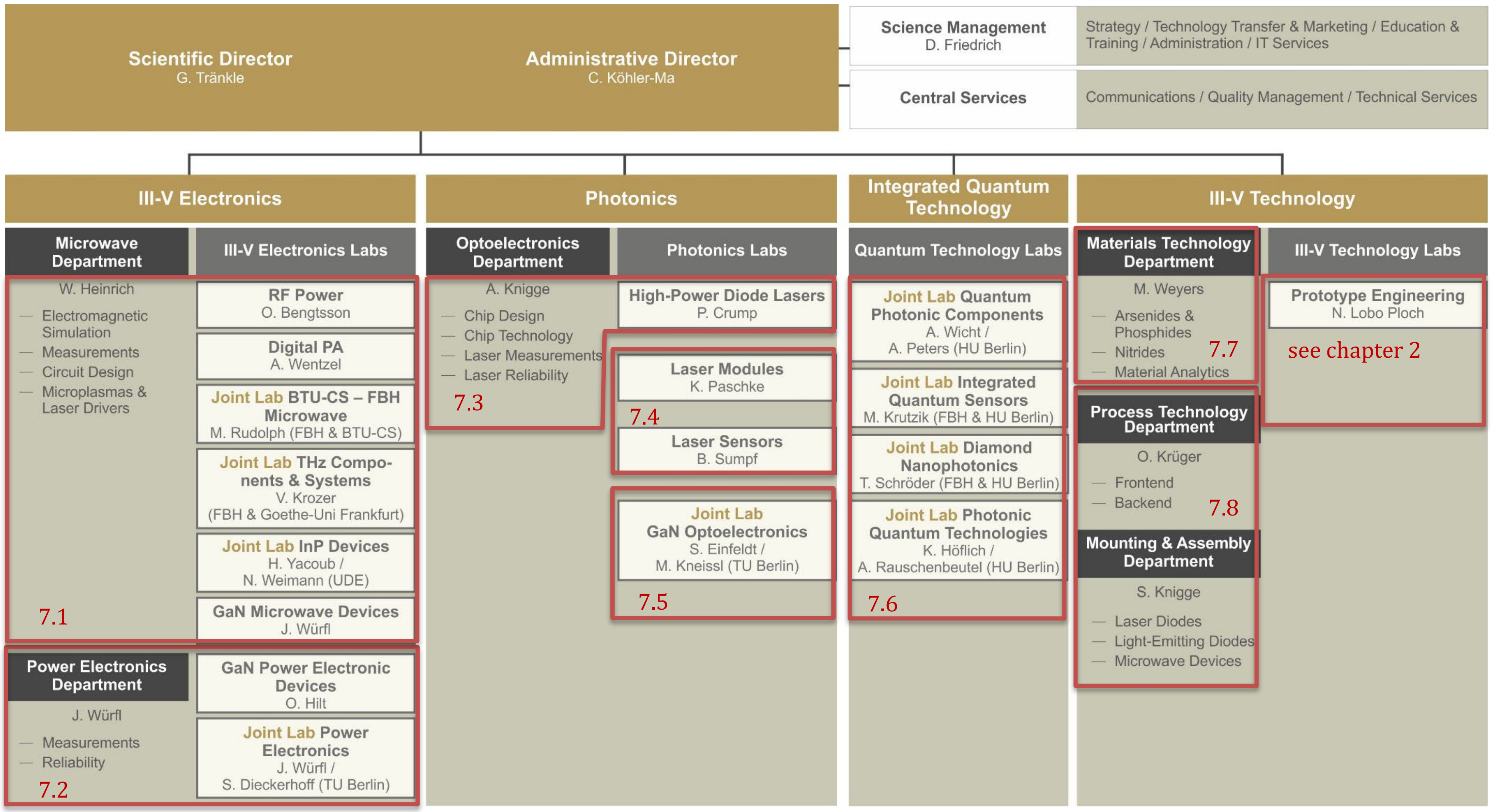
According to the institute, the training of its doctoral students is subject to an agreement based on the position paper of the German Council of Science and Humanities "Requirements for the Quality Assurance of Doctoral Studies" as well as the recommendations of the German Rectors' Conference "On Quality Assurance in Doctoral Studies" (cee chapter 3).

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

FBH states that the current Scientific Advisory Board has five foreign members (45 %) compared to 20 % at the time of the last evaluation.

Appendix 1

Organisational Chart



(red boxes marking sub-programmes in this evaluation)

Appendix 2

Publications, patents, and expert reviews

	Period		
	2018	**2019**	**2020**
Total number of publications			
Monographs	2	3	2
Individual contributions to edited volumes			
Articles in peer-reviewed journals	105	108	103
Articles in other journals	24	24	16
Working and discussion papers			
Editorship of edited volumes			

Patents	**2018**	**2019**	**2020**
Applications giving rise to a right of priority (in the calendar year)	77	65	61
Patents (number held as of 31.12. of the year)	246	246	264
Patent families (number held as of 31.12. of the year)	72	77	80

Other industrial property rights	**2018**	**2019**	**2020**
Applications giving rise to a right of priority (in the calendar year)			
Property rights (number held as of 31.12. of the year)	7	7	7
Property right families (number held as of 31.12. of the year)	7	7	7

Appendix 3 Revenue and Expenditure

	Revenue	2018			2019			2020[1]		
		k€	%	%	k€	%	%	k€	%	%
Total revenue (sum of I., II. and III.; excluding DFG fees)		**38.507,7**			**41.146,3**			**48.109,9**		
I.	**Revenue (sum of I.1.; I.2., and I.3.)**	**38.447,8**	100		**41.065,4**	100		**48.046,0**	100	
1.	Institutional Funding (excluding construction projects and acquisition of property)	14.951,5	39		18.094,7	44		19.093,1	40	
1.1	Institutional funding (excluding construction projects and acquisition of property) by Federal and *Länder* governments according to AV-WGL	14.951,5			18.094,7			19.093,1		
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	22.350,8	58	100	20.831,5	51	100	26.979,8	56	100
2.1	DFG	536,8		2	625,4		3	489,9		2
2.2	Leibniz Association (competitive procedure)	699,5		3	573,8		3	0,0		0
2.3	Federal, *Länder* governments	16.929,4		76	16.214,9		78	18.547,0		69
2.4	EU	1.010,9		5	858,4		4	266,2		1
2.5	Industry	3.172,7		14	2.542,4		12	7.676,6		28
2.6	Foundations	0,0		0	16,6		0	0,0		0
2.7	*Other sponsors*	1,4		0	0,0		0	0,0		0
3.	Revenue from services	1.145,5	3		2.139,2	5		1.973,2	4	
3.1	Revenue from commissioned work	1.126,1			2.120,3			1.950,3		
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.)	19,5			18,9			22,8		
3.4	Revenue from exploitation of intellectual property without industrial property rights	0,0			0,0			0,0		
II.	**Miscellaneous revenue** (e. g. membership fees, donations, rental income, funds drawn from reserves)	**60,0**			**80,8**			**63,9**		
III.	**Revenue for construction projects** (institutional funding by Federal and *Länder* governments, EU structural funds, etc.)	**0,0**			**0,0**			**0,0**		

	Expenditures	2018 k€	2019 k€	2020[1] k€
Expenditures (excluding DFG fees)		**38.248,1**	**40.318,3**	**39.627,0**
1.	Personnel	15.375,1	16.780,6	18.351,7
2.	Material expenses	7.668,9	8.244,8	8.825,8
2.1	*Proportion of these expenditures used for registering industrial property rights (patents, utility models, etc.)*	*253,3*	*284,4*	*273,8*
3.	Equipment investments	15.172,7	15.134,7	12.365,7
4.	Construction projects, acquisition of property	0,0	152,2	58,8
5.	Other operating expenses	31,3	6,0	24,9

	2018	2019	2020[1]
DFG fees (if paid for the institution - 2.5 % of revenue from institutional funding)	360,2	440,2	447,0

[1] Preliminary data

Appendix 4

Staff

(Basic financing and third-party funding / proportion of women (as of: 31 December 2020)

	Full time equivalents		Employees		Female employees		Foreigners
	Total	on third-party funding	Total	on temporary contracts	Total	on temporary contracts	Total
	Number	Percent	Number	Percent	Number	Percent	Number
Research and scientific services	**134,9**	57,4	**140**	55,5	**26**	58,5	**29**
1st level (scientific director)	1,0	0,0	1	0,0	0	0,0	0
2nd level (head of departments/labs)	15,8	12,6	16	12,5	3	33,3	2
3rd level (group leaders)	11,0	29,5	11	9,1	3	25,0	2
Scientists in non-executive positions (A13, A14, E13, E14 or equivalent)	75,6	68,0	79	68,4	16	71,7	16
Doctoral candidates (A13, E13, E13/2 or equivalent)	31,4	65,8	33	62,7	4	50,0	9
Service positions	**82,9**	49,5	**85**				
Laboratory (E9 to E12, upper-mid-level service)	33,6	48,7	34				
Laboratory (E5 to E8, mid-level service)	30,6	76,3	32				
Information technology - IT (E9 to E14, upper-mid-level service)	4,8	5,2	5				
Technical (large equipment, service) (E4 to E13, mid-level service)	13,8	7,2	14				
Administration	**23,5**	23,3	**26**				
Head of administration	**1,0**	0,0	1				
Staff positions (from E13, senior service)	9,2	48,6	11				
Staff positions (E6 to E8, upper-mid-level service)	2,9	0,0	3				
Internal administration (financial administration, personnel, etc.) (E8 to E12, upper-mid-level service)	10,5	9,6	11				
Student assistants	**8,1**	25,0	**33**				
Trainees	**10,0**	0,0	**10**				
Scholarship recipients at the institution	**1,0**	100,0	**1**		**0**		**1**
Doctoral candidates	1,0	100,0	1		0		1
Post-doctoral researchers							

17 May 2022

Annex B: Evaluation Report

Ferdinand-Braun-Institut gGmbH
Leibniz-Institut für Höchstfrequenztechnik, Berlin (FBH)

Contents

1. Summary and main recommendations

The Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik (FBH) conducts application-oriented research in the fields of high-frequency electronics, photonics and quantum physics. Its work encompasses the entire value chain, from basic research via processing and mounting to the production of ready-to-use modules and systems based on III-V compound semiconductor technology. The fields of application range from communication to sensor technology, medicine and integrated quantum technology.

The FBH's research results are very good, at times even excellent. It showcases them in an appropriate number of publications, some of them in top-tier journals. On the basis of its research activities, the institute achieves outstanding results in the field of technology transfer. It holds an impressive number of patents and has regularly enabled spin-offs over the past few decades. Technology transfer is also promoted through very close collaboration with industrial enterprises. This is reflected in very high levels of third-party funding from industry (project funding and commissioned work).

The FBH has made very good progress since the previous evaluation. In connection with the retirement of some leading scientists, a few topics have been terminated, the internal organisational structure has been adapted and new, promising projects have been started. In particular, the venture into quantum technologies in a new research area was a very good strategic decision. The FBH has been awarded a permanent increase in institutional funding of € 4.1m per year since 2019 (*Sondertatbestand*) for this purpose. It has also received considerable funds in the context of the Research Fab Microelectronics Germany (FMD). Between 2017 and 2021, the German Federal Ministry of Education and Research (BMBF) provided a total of € 350m to establish this network of 13 institutes from the Fraunhofer Gesellschaft and the Leibniz Association. The FBH received € 40m to modernise and expand its research infrastructure. Among other things, a second clean room was established at the FBH. As a result of the above-mentioned developments, the institute has grown considerably since the previous evaluation. Institutional funding rose from € 12m in 2013 to € 19m in 2020. At the same time, third-party funding increased from approx. € 10m per year on average (2011–2013) to approx. € 25m per year (2018–2020).

The FBH is now approaching a period of staffing transition. First, the director, who has been leading the institute since 1996, will retire in 2022. He has led the institute extremely well and has developed it into one of the top institutions in the field of semiconductor technology. Five other very successful leading scientists will also retire in the next few years.

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

<u>Overall concept, activities and results</u> (chapter 2)

1. The institute's research results are regularly published in the relevant **peer-reviewed journals** and are highly visible in the corresponding scientific communities. Given the high scientific quality of its research, the FBH has the potential to publish its results even more frequently in higher-ranking journals seen by an even broader readership, including those with a multidisciplinary reach.

<u>Changes and planning</u> (chapter 3)

2. It is good to see that the appointment process for the **new scientific director** is well under way. The position was jointly advertised with TU Berlin in April 2021. Ensuring the post is filled in a timely manner is of great importance because further personnel changes are due at leadership level in the next few years: three department heads and two lab heads are about to retire. The institute needs to ensure a smooth transition by initiating the appropriate processes in good time in order to find suitable high-profile scientists to fill these positions too.

   A key task for the new director will be to further consolidate the work at the FBH following the growth of the past few years. A continuing challenge will be to maintain a good balance between basic research and more application-oriented work that is often carried out in collaboration with industry.

3. The FBH is planning to apply for a **small extraordinary item of expenditure** (*Sondertatbestand*) to support its intensified activities connected to technology for aerospace. Additional annual funding of € 4.1m (of which € 0.65m is being provided from own funds) is to be used to establish a dedicated "III/V Semiconductors for Aerospace" lab. The aim is for it to provide infrastructure for the development of space-related technological solutions at the FBH and to form the basis for joint projects with research and industrial partners in this field, especially the German Aerospace Center (DLR).

   The proposed plan for a *Sondertatbestand* seems sound in principle. It is important though, to make sure that the envisioned expansion is sustainable in the long term. Against this background, the FBH should check to what extent other fields of application besides aerospace can be included. This would also offer additional possibilities to generate the third-party revenue as planned by the FBH. The plans should be further refined and assessed under the new director, taking into account his or her overall strategy for the institute.

<u>Controlling and quality management</u> (chapter 4)

4. The FBH has once again increased its **revenues for project funding**, which were already very high at the time of the last evaluation, from an average of around € 10m per year (2011–2013) to around € 25m per year (2018–2020). Accounting for 55 % of the overall budget, these revenues are remarkably high for a Leibniz Association institution.

   The majority of the funding portfolio comes from the federal and *Länder* governments and from industry. To further diversify its portfolio, the FBH could keep an eye out for international funding options within European project frameworks and even beyond.

5. Until the end of 2020, the FBH was a member of the Forschungsverbund Berlin (FVB), which provided a joint supervisory board and joint administration for eight Leibniz institutions in Berlin. Since 2021, the FBH has been acting independently as Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik. Since then, a dedicated FBH supervisory body has been established and a new administration has been set up. Currently the administration is still being managed on an interim basis, with a **permanent administrative director** due to be appointed in 2022. It is important to finalise this process as quickly as possible.

6. The FBH provides **junior researchers** with excellent working conditions. Doctoral students and post-doctoral researchers are well supported, with tailored career-building measures and development opportunities. While the number of completed degrees has gone up since the last evaluation from 14 (2011–2013) to 21 (2018–2020), the number of doctoral candidates has declined from 46 to 34. The number of doctoral students should be raised again.
7. In recent years, the percentage of **female researchers** in research and scientific services has increased slightly from 17 % in 2013 to 19 % in 2020. However, the overall number of female scientists at the FBH is still too low. The institute must use the upcoming vacancies to achieve improvements at the executive level, but improvements are also needed at the level of non-executive scientists and doctoral researchers.

2. Overall concept, activities and results

Overall concept

The FBH conducts application-oriented research in the fields of high-frequency electronics, photonics and quantum physics. Its work encompasses the entire value chain from basic research via processing and mounting to the production of ready-to-use modules and systems based on III-V compound semiconductor technology. The fields of application range from communication to sensor technology, medicine and integrated quantum technology.

Research is carried out in four research areas that are divided into eight sub-programmes (see chapter 7 for details). These sub-programmes comprise a total of six departments and 17 labs. Nine of these are operated as joint labs in cooperation with university partners.

Activities and results

Research

The research results of the FBH are very good, at times even excellent. They range over numerous areas where III-V semiconductor technology is relevant. Highlights include work on UV-LED technology, in mmWave and sub-THz electronics, and space applications. **The institute's research results are regularly published in the relevant peer-reviewed journals and are highly visible in the corresponding scientific communities. Given the high scientific quality of its research, the FBH has the potential to publish its results even more frequently in higher-ranking journals seen by an even broader readership, including those with a multidisciplinary reach.**

Transfer

On the basis of its research activities, the institute achieves outstanding results in the field of technology transfer. As of 2020, it holds a total of 264 patents, grouped into 80 patent families, and between 2018 and 2020 filed an annual average of 68 applications giving rise to a right of priority. The institute's work regularly leads to spin-offs, some of which are now important players in their own right and stand as further proof of the successful transfer of the institute's developments into commercial use. It also regularly generates high revenues through project funding from industry or commissioned work (see chapter 4).

Two units at the FBH work to further enhance its very successful transfer activities: an interdisciplinary Science Management team is dedicated to establishing and managing transfer and commercialisation networks, while a Prototype Engineering Lab provides functional models and prototypes for demonstrator purposes.

Research infrastructure

The FBH commands excellent infrastructure with up-to-date technology and equipment for micro- and optoelectronics, including two clean rooms, e-beam lithography systems, I-line wafer steppers, a high-voltage implanter, epitaxy reactors and facet passivation technology. This top-end laboratory environment fulfils the high demands of the institute's research and development activities in terms of advanced equipment. While commissioned work for external partners is processed here, the facilities are only made available to third parties within the institute's collaborations to a very limited extent.

3. Changes and planning

Development since the previous evaluation

Since the last evaluation, the FBH has developed its portfolio convincingly, building on its established strengths and strategically taking on new, promising topics. The three existing research areas (III-V Electronics, Photonics and III-V Technology) have been updated and restructured. In the Photonics research area in particular, new labs were established after the retirement of a department head. The introduction of relatively small labs now allows for more flexible adjustments.

The additional venture into quantum technologies was an excellent strategic decision. A new fourth research area, "Integrated Quantum Technologies", was established in 2019 with a permanent increase in institutional funding of € 4.1m per year (*Sondertatbestand*). It now comprises a total of four joint labs with HU Berlin, and is already showing great results (see chapter 7.6).

Since 2017, the FBH has been participating in Research Fab Microelectronics Germany (FMD), a network funded by the federal and *Länder* governments to support the German semiconductor and electronics industry. Profiting from additional funding of over € 40m, the FBH has established a second clean room at its facilities at Adlershof. As a result of the above-mentioned developments, the institute has grown considerably since the previous evaluation.

Strategic work planning for the coming years

The FBH is now approaching a period of staffing transition. Its long-serving and extremely successful director will retire in 2022. **It is good to see that the appointment process for the new scientific director is well under way. The position was jointly advertised with TU Berlin in April 2021. Ensuring the post is filled in a timely manner is of great importance because further personnel changes are due at leadership level in the next few years: three department heads and two lab heads are about to retire. The institute needs to ensure a smooth transition by initiating the appropriate processes in good time in order to find suitable high-profile scientists to fill these positions too.**

A key task for the new director will be to further consolidate the work at the FBH following the growth of the past few years. A continuing challenge will be to maintain a good balance between basic research and more application-oriented work that is often carried out in collaboration with industry.

Planning for additional funds deriving from institutional funding

The FBH is planning to apply for a small extraordinary item of expenditure (*Sondertatbestand*) to support its intensified activities connected to technology for aerospace. Additional annual funding of € 4.1m (of which € 0.65m is being provided from own funds) is to be used to establish a dedicated "III/V Semiconductors for Aerospace" lab. The aim is for it to provide infrastructure for the development of space-related technological solutions at the FBH and to form the basis for joint projects with research and industrial partners in this field, especially the German Aerospace Center (DLR).

The proposed plan for a *Sondertatbestand* seems sound in principle. It is important though, to make sure that the envisioned expansion is sustainable in the long term. Against this background, the FBH should check to what extent other fields of application besides aerospace can be included. This would also offer additional possibilities to generate the third-party revenue as planned by the FBH. The plans should be further refined and assessed under the new director, taking into account his or her overall strategy for the institute.

4. Controlling and quality management

Facilities, equipment and funding

Funding

The institutional funding of the FBH is deemed sufficient for its current activities. It rose from € 12m in 2013 to € 19m in 2020.

The FBH has once again increased its revenues for project funding, which were already very high at the time of the last evaluation, from an average of around € 10m per year (2011–2013) to around € 25m per year (2018–2020). Accounting for 55 % of the overall budget, these revenues are remarkably high for a Leibniz Association institution.

On average, € 17.2m p.a. was secured from the federal and *Länder* governments (a large share of this stems from BMBF-financed activities like FMD and Advanced UV for Life) and € 4.5m p.a. from industry. A further € 0.7m was obtained from the DFG and € 0.4m from the Leibniz Association (competitive procedure). **The majority of the funding portfolio comes from the federal and *Länder* governments and from industry. To further diversify its portfolio, the FBH could keep an eye out for international funding options within European project frameworks and even beyond.**

In addition, between 2018 and 2020, an average of € 1.6m p.a. was acquired from commissioned work.

Facilities and equipment

The FBH commands cutting-edge technological infrastructure that is very well suited to its work and goals. The existing infrastructure has recently been significantly expanded through the addition of a second clean room. The FBH's infrastructure is used extensively for commissioned work for companies and in projects financed by industry partners. The FBH should keep a close eye on capacity utilisation to ensure that it remains high in the long term. The increased importance of various aspects of sustainability is another factor to bear in mind.

Organisational and operational structure

The overall structural development of the institute and its research areas since the last evaluation makes good sense. Each research area is still divided into departments, but the business units have been replaced by smaller labs that allow for quick reactions to new developments and emerging topics. Organisational and administrative structures function transparently and smoothly.

Quality management

The FBH has suitable measures in place to ensure good scientific practice and appropriate data management. It also maintains comprehensive strategies for publication and technology transfer. It is good to hear that the renewal of the expired ISO certification for quality standards is under way, according to the institute.

Quality management by advisory boards and supervisory board

The Scientific Advisory Board (SAB) performs its tasks appropriately. In between evaluation periods, it conducted an audit of the institute, as is usual for Leibniz institutes.

The Supervisory Board also functions according to expectations. **Until the end of 2020, the FBH was a member of the Forschungsverbund Berlin (FVB), which provided a joint supervisory board and joint administration for eight Leibniz institutions in Berlin. Since 2021, the FBH has been acting independently as Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik. Since then, a dedicated FBH supervisory body has been established and a new administration has been set up. Currently the administration is still being managed on an interim basis, with a permanent administrative director due to be appointed in 2022. It is important to finalise this process as quickly as possible.**

5. Human Resources

Leading scientific and administrative positions

The FBH's scientific director, who has been in post since 1996, has led the institute extremely well and has developed it into one of the leading institutions in the field of semiconductor technology. He is now retiring. It is good to see that the next scientific director of the FBH will once again be jointly appointed with TU Berlin. The other leading scientists at the FBH are also doing outstanding work. Here too, a number of new appointments will be necessary in the next few years as a result of upcoming retirements (see chapter 3). With regard to the administrative director, see chapter 4.

Staff with a doctoral degree and doctoral candidates

The FBH provides junior researchers with excellent working conditions. Doctoral students and post-doctoral researchers are well supported, with tailored career-building measures and development opportunities. While the number of completed degrees has gone up since the last evaluation from 14 (2011–2013) to 21 (2018–2020), the number of doctoral candidates has declined from 46 to 34. The number of doctoral students should be raised again.

The high quality of the FBH's support for junior researchers is visible in the fact that several former doctoral students and post-doctoral researchers have moved up to higher positions in academia and industry (including within the institute's spin-offs).

Science supporting staff

The FBH's commitment to kindling an interest in a career path in STEM subjects among young adults is laudable. Several apprenticeships are offered every year, which also helps to ensure qualified staff for the operation of the institute's complex technologies. Between 2018 and 2020, ten microtechnologists and one precision mechanic completed their training.

Equal opportunities and work-life balance

In recent years, the percentage of female researchers in research and scientific services has increased slightly from 17 % in 2013 to 19 % in 2020. However, the overall number of female scientists at the FBH is still too low. It is noteworthy that there are now three female scientists among the 16 department and lab heads at the FBH (19 % as compared to none in 2013). Three of the eleven group leaders (27 % as compared to 19 % in 2013) and 16 of the scientists in non-executive positions (20 % as compared to 9 % in 2013) are women. There are currently only four women among the 34 doctoral candidates (12 % as opposed to 26 % in 2013). **The institute must use the upcoming vacancies to achieve improvements at the executive level, but improvements are also needed at the level of non-executive scientists and doctoral researchers.**

The FBH commits to supporting a healthy work-life balance for its employees, as documented by the TOTAL E-QUALITY certificate since 2009.

6. Cooperation and environment

Cooperation with universities

The FBH is deeply embedded in the local academic landscape in Berlin. Two joint appointments exist with TU Berlin, which also co-finances the head of a joint lab together with the institute. Another increasingly important partner is HU Berlin, with which the head of another joint lab is co-financed. The partnership was recently strengthened through three additional joint labs in quantum technologies. Upcoming new appointments could provide opportunities for further joint appointments.

There are strong links to universities outside the region as well, especially through the institute's joint labs. Beyond TU and HU Berlin, such labs exist in cooperation with Goethe University Frankfurt, where the FBH shares the financing of the lab head with the university, Brandenburg University of Technology Cottbus-Senftenberg and the University of Duisburg-Essen.

Another very welcome development is the FBH's involvement in the Leibniz ScienceCampus Growth and Fundamentals of Oxides for electronic applications (GraFOx). Partners are HU Berlin and the universities of Leipzig and Magdeburg, as well as the Paul Drude Institute for Solid State Electronics (PDI), the Leibniz Institute for Crystal Growth (IKZ), the Fritz Haber Institute of the Max Planck Society, and the Helmholtz-Zentrum Berlin für Materialien und Energie.

Cooperation with non-university partners

The institute participates in a number of research collaborations with non-university partners. It is part of Research Fab Microelectronics Germany (FMD, see chapter 3) a collaboration with 11 Fraunhofer institutes and the Leibniz-Institute for High Performance Microelectronics (IHP). The network received at total of € 350m between 2017 and 2021 to modernise and extend the equipment at the participating institutes. Within the Leibniz community, the FBH is also a member of the Leibniz Research Alliance Health Technologies as well as the Leibniz Research Network Mathematical Modelling and Simulation.

The FBH is very well connected with industry, for example in the BMBF-funded consortium Advanced UV for Life, which involves both businesses and research institutions. The institute is highly appreciated by its industrial partners, among which there are some major well-known companies. In the Berlin region in particular, the FBH also cooperates actively with small and medium-sized businesses, acting as a veritable enabler.

International cooperation

The FBH's reputation in the international scientific community is strong. It could make sense for the institute to look beyond its successful networks within the German-speaking countries and increasingly seek collaboration with academia and industry on a broader international level as well.

7. Sub-programmes of the FBH

Research area 1 – Electronics

7.1 Sub-programme: RF to THz electronics

[33.7 FTE, of whom 21.8 FTE research and scientific services staff, 7.9 FTE doctoral candidates, and 4.0 FTE service staff]

The sub-programme is one of the largest at the FBH, with one department, three labs and three additional joint labs. It works very successfully on long-standing areas of expertise at the institute, dealing with the optimisation of electronic components in the GHz to THz range. The focus is on the development of transceiver circuit and device concepts by exploiting the potential of III-V devices, and on the improvement of circuit performance for frequencies above 100 GHz.

Since the last evaluation, the sub-programme has evolved very well. Its engagement in joint labs to further develop existing fields and explore new ones appears to be an excellent strategy. The involvement in the emerging field of InP electronics and the establishment of a Joint Lab for InP Devices in cooperation with the University of Duisburg-Essen is particularly promising. Research highlights include work on sub-mm-wave high-power transmitters and receivers and the hetero-integration of III-V-on-BiCMOS (bipolar complementary metal-oxide semiconductors), primarily focusing on InP and GaN. With regard to GaN, it is important to keep in mind that other institutions are already conducting intensive research in this area as well. The publication portfolio appears well-balanced and of high quality. In view of its innovative work, the sub-programme has the potential to increase its publication output even further. The application-oriented nature of the sub-programme's work is also reflected in a high number of patents. In order to further strengthen technology transfer, cooperation with companies should be expanded, e.g. through increased external use of the III-V processing line or the establishment of a joint lab with an industrial partner. Third-party funding is very high. It originates predominately from the federal and *Länder* governments through the Research Fab Microelectronics Germany (FMD). Using these funds, the excellent infrastructure has been partly upgraded and further expanded. In addition, the sub-programme successfully attracts funding from the DFG. Opportunities for further third-party funding could be found in competitive procedures at European level or through projects with industrial partners.

The future plans of the programme are well chosen and are aligned with the institute's core competences. The expansion of work in the field of microwaves for quantum technologies in cooperation with the "Integrated Quantum Technology" sub-programme, for instance, seems very promising. The plan to work on energy consumption and sustainability (green ICT) within the FMD also makes sense. When the current head of the Microwave department, who also coordinates the entire Electronics research area, retires in 2023, finding a suitable successor will be of vital importance for the future profile of the sub-programme.

7.2 Sub-programme: Power electronics

[7.7 FTE, of whom 5.8 FTE research and scientific services staff, 1.0 FTE doctoral candidates, and 0.9 FTE service staff]

This sub-programme is one of the smaller units at the FBH, with one department, one lab and one joint lab. It focuses on wide bandgap power electronics and, in particular, on the development of new wide bandgap power devices.

The sub-programme has consistently been producing very good research and development results for years. The impressive recent work on Ga_2O_3, for instance, which started after the last evaluation, has already become internationally visible. Publications are of good quality overall. However, the unit should aim to publish more frequently in higher-impact journals in the future. It holds a number of patents as well. Third-party funding is very good and has increased significantly since the last evaluation, including a recently acquired DFG project.

The sub-programme's future planning is promising: its venture into substrate transfer technology has great potential, as does the planned work with wide and ultra-wide bandgap materials. There are highly relevant findings on the radiation hardness of GaN technology for space applications, which the sub-programme intends to explore further in the future – collaborating with industry on such activities appears to be a sound strategy. In view of the application-oriented work that is conducted here, it is important to ensure that the devices reach the technology readiness levels required for successful industrial transfer.

Research area 2 – Photonics

7.3 Sub-programme: Monolithic high-power and high-brilliance lasers

[34.5 FTE, of whom 16.5 FTE research and scientific services staff, 6.3 FTE doctoral candidates, and 11.7 FTE service staff]

This sub-programme, which includes one department and one lab, specializes in III-V high-power and high-energy lasers. It designs, fabricates, characterises and improves tailor-made diode lasers for a wide range of applications, such as lidar for autonomous vehicles, drones and planes.

The sub-programme's work has remained consistently excellent for many years. The high quality of the research is reflected in an excellent publication record and a high number of patents. Its results are also well suited to addressing the needs of modern industries, forming the basis for very good transfer capability to SMEs as well as large-scale industry. Consequently, revenues from industry form a large share of the substantial third-party funding.

A very successful research programme in its own right, this sub-programme also ties in well with the institute's recent activities in the field of quantum technologies. In the future, the potential of high-pulse energy, short-pulse-width semiconductor lasers and their integration in fiber lasers might be worth further exploration. The general outlook for this unit is very positive. As some aspects of its work will be ready to be taken over by industry over time, adjustments to its focus will need to be considered in the medium to long term.

7.4 Sub-programme: Hybrid integrated laser sources

[13.9 FTE, of whom 8.9 FTE research and scientific services staff, 5.0 FTE doctoral candidates]

This sub-programme is made up of two labs. They work on compact laser diode modules tailored for specific applications in the fields of sensor technology, medicine and biology.

It has delivered numerous, sometimes excellent, results on a broad range of subjects, from wavelength conversion to short pulse generation, narrow linewidth and power scaling. The sub-programme has a high output in terms of publications. Besides its application-oriented proceedings, the sub-programme should also publish more in regular journals in the future. The number of patents is very high. All in all, it has been successful in securing third-party funding. Income from commissioned work shows a particularly impressive increase in recent years.

The way in which work is organized in this unit has been restructured since the last evaluation, along with the creation of two smaller labs instead of one big group. This appears reasonable, including in terms of staff development. Now, each of the labs needs to develop a clearly recognisable distinct profile. The sub-programme's general outlook is positive: the focus on applications in medicine, health, food and agriculture holds much promise, as does sub-µm integration technology. The establishment of a solid platform for optical trains is commendable. Some work has reached a stage where it might be worth considering a transfer to industry, e. g. via spin-offs.

7.5 Sub-programme: UV light sources

[9 FTE, of whom 6.8 FTE research and scientific services staff, 2.0 FTE doctoral candidates, and 0.2 FTE service staff]

This sub-programme comprises the Joint Lab GaN Optoelectronics with TU Berlin. Here, work on GaN optoelectronic devices is conducted, with a particular focus on UV LEDs and diode lasers. Current developments address highly relevant challenges like disinfection and medical application. Some of the results, for example with DFB/DBR diode lasers and far-UVC LEDs, are unique.

Over the past seven years, the joint lab has established a sound infrastructure, and its research results have been excellent. It has reached outstanding visibility with its state-of-the-art devices. Publications have been very good and appear in highly ranked journals. The number of patents is commendable. In 2015, a spin-off was established to commercialise achievements in the field of UV-LEDs. Third-party funding has increased since the last evaluation. This positive trend should be continued. A challenge will be to acquire other externally funded projects, especially when the funding from the Federal Ministry of Education and Research (BMBF) within the consortium "Advanced UV for Life" (2014–2022) runs out.

Since the last evaluation, significant progress has been made in this sub-programme concerning performance and process development, and additional new areas were addressed as well. Activities in the area of blue and UV laser diodes are highly relevant for the FBH's intensified engagement in quantum technologies. The sub-programme is also strongly involved in cooperation with both academia and industry.

Research area 3 – Integrated Quantum Technology

7.6 Sub-programme: Integrated quantum technology

[26.5 FTE, of whom 18.0 FTE research and scientific services staff, 5.5 FTE doctoral candidates, and 3.0 FTE service staff]

The new sub-programme was initially established in 2019 with additional federal and *Länder* funding (see chapter 3), based on the former "Laser Metrology" joint lab. It now consists of four joint labs. The quick and effective setup of this unit is noteworthy, and it has reached both critical mass and highly visible results in a short time. It pursues technology development to allow for industrialisation of quantum technology, with a particular focus on applications for space.

Among recent results, the outstanding achievements with laser modules, for example for quantum gases in space missions, are particularly impressive, and so is the excellent performance of a frequency reference prototype for nanosatellites. Even beyond space applications, this might be of interest for commercialisation in other industries that rely on precise and resilient timing. Publications are already impressive in both number and quality. Patent applications are picking up as well. External funding is excellent, largely stemming (directly or indirectly) from DLR funding for space activities.

Numerous interesting paths are opening up into the commercial exploitation of quantum technologies in the future. In order for these to become viable, it is important to build up technology transfer activities and use the opportunity to reach other parts of the industrial landscape besides aerospace. In this respect, the sub-programme is commended for its active engagement with companies within InnoQT, a regional network of science and business institutions with a focus on photonics for quantum technologies. Robotic hybrid integration of complex photonic modules is another strategic area that holds a lot of promise. This would also broaden the basis for potential third-party funding. Other players, like Fraunhofer and DLR, generally need to be kept in mind when strategically positioning the sub-programme for the future.

Research area 4 – III-V compound semiconductor technology

7.7 Sub-programme: Materials

[19.8 FTE, of whom 11.1 FTE research and scientific services staff, 1.0 FTE doctoral candidates, and 7.6 FTE service staff]

The sub-programme consists of the Materials Technology Department and mainly works on the vapor phase epitaxy of compound semiconductors. As such, it provides the key basic source of materials for the FBH's device development and thus forms – together with the Processes sub-programme – the technological basis for the work at the FBH.

On top of its vital importance for research in other units at the FBH, this sub-programme's consistently excellent work and results over many years have gained it high recognition in the scientific community as well. It publishes these results very successfully, but could profit from a stronger focus on high-impact journals. While its track record in third-party funding is already very good as well, and shows significant improvements since the last evaluation, an increased share of DFG projects might open up options for trying out even more innovative approaches.

Since the last evaluation, a very convincing development has taken place with the discontinuation of HVPE boule growth (in line with the overall focus of the institute) and a stronger focus on AlN. Also, for example, the sub-programme installed two new multiwafer reactors, clearly improved regrowth processes and worked on stacks for vertical power devices. The sub-programme has evolved very well and should continue on its successful path.

7.8 Sub-programme: Processes

[53.8 FTE, of whom 15.0 FTE research and scientific services staff, 2.8 FTE doctoral candidates, and 36.0 FTE service staff]

This is the biggest sub-programme of the FBH. It comprises two departments and is essentially responsible for the advancement of the institute's III-V compound semiconductor technology. It successfully develops and delivers processes and solutions that are vital for various devices fabricated at the institute, and it also provides significant services for external partners.

The sub-programme regularly obtains very high levels of project funding from industry and there are also stable revenues from commissioned work. Having profited from funding through the FMD, the process capabilities were widened in recent years. On the other hand, in this service-oriented area, publications of research results and patent applications play only a subordinate role.

The sub-programme has progressed well over the years and its performance is convincing. However, beyond its supporting functions, which it fulfils excellently, it also has the potential to increasingly pursue research questions of its own. In particular, it could develop its own scientific highlights in the very topical field of mounting and assembly.

8. Handling of recommendations of the last external evaluation

The FBH has addressed most of the recommendations made by the Leibniz Association Senate in 2014 (see status report, p. A-26f). The recommendation on gender balance (recommendation 9) still applies. The recommendations on maintaining a balanced profile between fundamental and application-oriented research (recommendation 1) and on internationalisation (recommendation 5) still apply in parts.

Appendix

1. Review Board

Chair (Member of the Leibniz Senate Evaluation Committee)

Roland **Sauerbrey**	Helmholtz-Zentrum Dresden-Rossendorf

Deputy Chair (Member of the Leibniz Senate Evaluation Committee)

Andreas **Fahrmeir**	Goethe University Frankfurt

Reviewers

Kai **Bongs**	School of Physics and Astronomy, University of Birmingham, UK
Joachim **Knoch**	Institute of Semiconductor Electronics, RWTH Aachen University
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Heike **Riel**	IBM Research, Zurich, CH
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Wolfgang **Stolz**	Department of Physics, Structure and Technology Research Laboratory, Universität Marburg
Andreas **Waag**	Institute of Semiconductor Technology, Technische Universität Braunschweig

Representative of the Federal Government

Volker **Wiesenthal**	Federal Ministry of Education and Research, Berlin

Representative of the Länder *governments*

absent with apologies

24 May 2022

Annex C: Statement of the Institution on the Evaluation Report

Ferdinand-Braun-Institut gGmbH
Leibniz-Institut für Höchstfrequenztechnik, Berlin (FBH)

The Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik (FBH) highly appreciates the positive evaluation report given by the Review Board. 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.

The FBH welcomes the support of the Review Board for the planned Sondertatbestand. It takes seriously the need to ensure that the envisioned expansion is also sustainable in the long term and will check the extent to which other fields of application can be included in addition to aerospace.

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 transfer.
- publish its results even more frequently in higher-ranking journals.
- keep an eye out for international funding options within the European project frameworks.
- further strengthen technology transfer and cooperation with companies, e.g. through increased external use of the III-V processing line. Efforts are underway to make particularly the InP MMIC process available to external partners and customers. EUROPRACTICE membership has been applied for.
- develop its own scientific highlights in the very topical field of mounting and assembly. The technological challenge of converging wafer, chip, assembly and mounting technologies has already been addressed in current project proposals (e.g. flip-chip-integration GaN-on-Si) and will be an important subject of future research activities.
- keep a close eye on the capacity utilization of its infrastructure to ensure that it remains high over the long term and to address the increasing importance of various aspects of sustainability.
- increase the number of doctoral candidates again, in particular when the transition in leading positions has taken place.
- further increase the number of women at the institute and use the upcoming vacancies to achieve improvements at all levels as well as of the doctoral candidates. Already in 2021, FBH could increase the number of female doctoral candidates from 12 % to 15 %. Among female group leaders, there was an increase from 27 % to 29 % in 2021. In September 2022, the position of the Administrative Director will be filled by a woman.

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 Board and the Supervisory Board for their continuous and excellent advice and the Senate of Berlin and the Federal Government for the sustainable financial support.