Leibniz-Gemeinschaft

Der Senat

27. November 2014

Stellungnahme zum Paul-Drude-Institut für Festkörperelektronik (PDI) Leibniz-Institut im Forschungsverbund Berlin e. V.

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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.

Vor diesem Hintergrund besuchte eine Bewertungsgruppe am 13. und 14. Februar 2014 das Paul-Drude-Institut für Festkörperelektronik in Berlin. Ihr stand eine vom PDI erstellte Evaluierungsunterlage zur Verfügung. Die wesentlichen Aussagen dieser Unterlage sind in der Darstellung (Anlage A dieser Stellungnahme) zusammengefasst. Die Bewertungsgruppe erstellte im Anschluss an den Besuch den Bewertungsbericht (Anlage B). Das PDI nahm dazu Stellung (Anlage C). Der Senat der Leibniz-Gemeinschaft verabschiedete am 27. November 2014 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 PDI betreibt Forschung an der Schnittstelle von Festkörperphysik und Materialwissenschaften. Die Arbeiten konzentrieren sich dabei auf die Herstellung und Untersuchung niedrig-dimensionaler Strukturen in Halbleitern. Im Mittelpunkt der Forschungen stehen international bestens wettbewerbsfähige Arbeiten zu den Grundlagen der Molekularstrahlepitaxie, zu neuartigen Materialien und nanoskaligen Heterostrukturen. Auf dieser Materialexpertise aufbauend, verfolgt das Institut weitere Forschungsfragen im Bereich Spintronik, akustische Oberflächenwellen, Nanodrähte und Quantenkaskadenlaser. Ferner strebt das PDI an, neue informationstechnologische Anwendungen anzustoßen.

Es ist ein überzeugender Ansatz, die methodische Stärke des PDI in der Molekularstrahlepitaxie als Grundlage für das **Institutskonzept** heranzuziehen, denn diese ausgezeichnete Expertise stellt ein Alleinstellungsmerkmal dar. Das PDI sollte die daran anschließenden physikalischen und materialwissenschaftlichen Fragen noch stringenter als bisher entwickeln und auswählen, nicht zuletzt mit Blick auf mögliche Anwendungen. Dazu müssen strategische Leitlinien klarer definiert und das Institutskonzept von 2009 präzisiert werden.

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

Die wissenschaftlichen Themen werden in sechs Core Research Areas (CReA) bearbeitet. Davon sind zwei CReA methodisch, die übrigen vier sind inhaltlich definiert. Die **Arbeitsergebnisse** der beiden methodisch orientierten CReA werden als “sehr gut bis exzellent” und “gut bis sehr gut” bewertet. Die vier inhaltlich definierten CReA werden mit “exzellent”, “sehr gut” und in zwei Fällen mit “gut bis sehr gut” bewertet. Die Gliederung des Instituts in Core Research Areas ist überzeugend und hat sich bewährt. Zusätzlich gibt es eine Gliederung des PDI in Abteilungen mit Personal- und Budgetverantwortung. Mit Blick auf die Größe des Instituts sollte überprüft werden, ob es weiterhin notwendig ist an der Organisation des Instituts in Abteilungen im Sinne einer Matrixstruktur festzuhalten.

Das PDI kooperiert in der Berliner Forschungslandschaft vor allem mit der Humboldt-Universität zu Berlin, unter anderem durch die gemeinsame Berufung des Direktors. Daneben gibt es weitere wichtige **Kooperationen** mit einigen Forschungseinrichtungen, zu nennen ist vor allem das Helmholtz-Zentrum Berlin, und mit der Industrie. Das Institut sollte seine Zusammenarbeit mit Berliner Hochschulen und auch mit anderen außeruniversitären Forschungseinrichtungen national und international weiter intensivieren. Mit seinen Materialproben ist es ein äußerst attraktiver Partner. Das PDI wird ermuntert, mit dieser starken Expertise aktiver als bisher auf andere Institutionen im In- und Ausland zuzugehen.

Wie empfohlen hat das PDI die Einwerbung von **Drittmitteln** bei der DFG deutlich erhöht. Demgegenüber sanken Einnahmen aus Förderungen des Bundes, auch EU-Mittel wurden in geringerem Umfang eingeworben. Die Veränderung im Drittmittel-Portfolio spiegelt die zunehmende Bedeutung grundlagenorientierter Arbeiten am PDI. Der Anteil der Drittmittel am Gesamtbudget des Instituts ist nach wie vor vergleichsweise niedrig. Er muss erhöht werden. Industriepartner sollten für eine auch finanzielle Beteiligung an Forschungsvorhaben gewonnen werden, z. B. über die (Ko-)Finanzierung von Promotionsstellen.

Das PDI rekrutiert **wissenschaftliches Personal** sehr erfolgreich international und es wechseln Beschäftigte des Instituts weltweit auf weiterführende Positionen. Allerdings arbeiten auf allen Qualifikationsstufen und Hierarchieebenen nur wenige **Wissenschaftlerinnen**. Auch wenn man berücksichtigt, dass immer noch mehr Männer als Frauen eine Promotion in der Physik anstreben, ist der Frauenanteil unter den Promovierenden am PDI gering. Dementsprechend sind die Zielquoten für weiterführende Positionen wenig ambitioniert. Unter den leitenden Wissenschaftlern ist keine Frau. Das PDI muss dringend Verbesserungen erreichen.

Die **Promovierenden** werden am PDI sehr gut ausgebildet und betreut. Wie empfohlen konnte das PDI gegenüber der letzten Evaluierung deren Anzahl erheblich erhöhen. Diese Entwicklung sollte das Institut fortsetzen. Gleichzeitig sollte auch eine strukturierte Förderung für alle Promovierenden angeboten werden. Dies könnte z. B. in Zusammenarbeit mit einer Berliner Hochschule und anderen Institutionen geschehen.

Das PDI betreibt international wettbewerbsfähige Forschung zu den Grundlagen der Molekularstrahlepitaxie, zu neuartigen Materialien und nanoskaligen Heterostrukturen. Die meist grundlagenorientierten Arbeiten zielen dabei langfristig auf neue Anwendungen in der Informationstechnologie. Die Forschungsansätze, die das PDI verfolgt und die Infrastrukturen, die dafür zur Verfügung stehen, ermöglichen eine große wissenschaftliche Bandbreite, die von der Herstellung und Untersuchung niedrig-dimensionaler Strukturen in Halbleitern bis zur Herstellung von Bauelementen reicht. Eine Eingliederung in eine Hochschule wird vor dem Hintergrund dieser spezifischen Aufgabenstellung nicht empfohlen. Das PDI erfüllt die Anforderungen, die an eine Einrichtung von überregionaler Bedeutung und gesamtstaatlichem wissenschaftspolitischem Interesse zu stellen sind.

2. Zur Stellungnahme des PDI

Der Senat begrüßt, dass das PDI 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 PDI als Einrichtung der Forschung und der wissenschaftlichen Infrastruktur auf der Grundlage der Ausführungsvereinbarung WGL weiter zu fördern.

29 January 2014

Annex A: Status Report

Paul-Drude-Institut für Festkörperelektronik (PDI)
Leibniz-Institut im Forschungsverbund Berlin e. V.

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1. Structure, Tasks and Institutional Environment

Development and Funding

The *Paul-Drude-Institut für Festkörperelektronik* (Paul-Drude Institute for Solid State Electronics, PDI) was founded in 1992. It is funded in equal parts by the federal government and by the states (*Länder*). Its initial founding idea was to establish expertise in the growth and analysis of two-dimensional III-V heterostructures. In previous external evaluations by the German Council of Science and Humanities (*Wissenschaftsrat*) in 1999 and by the Senate of the Leibniz Associations in 2006 it was confirmed that PDI is an institution of national importance.

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

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

Mission and tasks

The mission of PDI is to explore epitaxial materials and new functionalities, aiming at semiconductor devices for future information technologies. In a mutual connection of material sciences and solid state physics, the research at PDI deals with fundamentals of epitaxial growth, new materials and nanoscale heterostructures. Likewise the physics of such structures with regard to functionality and device concepts are addressed.

Legal form and organisation

As a member of the *Forschungsverbund Berlin e. V. (FVB),* PDI belongs to a registered non-profit organisation under private law. Its supervisory committee is the Board of Trustees of FVB, which consists of up to ten members. The chair is appointed by the responsible department at *Länder* level; the deputy chair is appointed by the responsible federal department. The Board of Trustees is responsible for endorsing the programme budget, confirming the annual accounts, and appointing the PDI director, the managing director of FVB (head of administration), leading scientists, and the members of the Scientific Advisory Board. Decisions affecting PDI are prepared by the Institute Committee, which consists of representatives of the responsible departments at federal and *Länder* level as well as the chair of the Scientific Advisory Board; the scientific director of PDI and the managing director of FVB have guest status.

The institute is led by the director (scientific head) and the managing director of FVB (head of administration). The scientific director is in charge of staffing matters and responsible for designing and implementing the research programme. The head of administration is responsible for the institute's budget.

The Scientific Advisory Board (SAB), which consists of six to twelve internationally renowned scientists representing the range of disciplines of relevance to PDI, meets once per year. Members are appointed for four years. One consecutive reappointment is possible.

An organizational chart of PDI is given in Appendix 1.

Research structure

The institute is organized in four departments in accordance with the areas of competence of the PDI staff and the corresponding research facilities. Research is carried out in six Core Research Areas (CReA) in order to address interdisciplinary tasks between material science and solid state physics (see Appendix 1). For each CReA responsibility has been assigned to one of the department heads or to a senior scientist, respectively. The six CReAs are described in detail in Section 3.

National and international scientific environment

PDI is part of a research environment that is actively pursued in all regions where semiconductor industry is located such as Europe, North America or Southeast Asia. Hence many countries operate laboratories in scientific fields that are also addressed by PDI.

On the national level institutes working on comparable topics are the Walter Schottky Institut of TU München and several research institutes at the Peter Grünberg Institut of the Forschungszentrum Jülich. The latter is in close proximity to the Ernst Ruska-Centre (ER-C) for Microscopy and Spectroscopy with Electrons. According to PDI however, on this level PDI is the only institute which combines efforts in epitaxial growth with structural and interface investigation, dedicated optical spectroscopy and the processing of demonstrator devices.

Activities on III-arsenide and III-nitride materials and devices are carried out at the Fraunhofer-Institut für angewandte Festkörperphysik (IAF), Freiburg and at the Ferdinand-Braun-Institut – Leibniz-Institut für Höchstfrequenztechnik (FBH), Berlin. Both perform research that is application-driven and geared towards optimized devices.

On the European level, comparable activities are carried out in France at CNRS-Centre de Recherche sur l'Hétéro-Epitaxie et ses Applications (CRHEA), Valbonne, and at the Institut Nanoscience et Cryogenie (INAC) within CEA Grenoble. INAC profits from its proximity to the European Synchrotron radiation Facility ESRF, in a similar way as PDI profits from its beamline facility at BESSY II, Helmholtz Zentrum Berlin. Regarding the materials integration with Silicon, IMEC in Belgium is leading in Europe.

Internationally, institutions with a similar scope exist in the USA, e. g. at National Renewable Energy Labs (NREL). Also universities like UC Berkeley or UC Santa Barbara have comprehensive activities similar to PDI’s through collaborations of respective research groups in the Departments of Materials, Electrical Engineering and Physics.

In Korea, the Korea Advanced Institute of Science and Technology (KAIST), a research university for science & technology, follows similar goals. In Japan, research with a scope similar to PDI’s is conducted in several of the autonomous subunits of the National Institute of Advanced Industrial Science and Technology (AIST).

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

PDI sees its supra-national significance linked to its scientific excellence, its active participation in collaborations at the national and international level, its commitment to the training of young students and its collaborations with industry.

To follow its mission PDI necessitates a close interplay between material science of nanostructured solids and solid state physics. Specifically, this means an interaction between material growth, structural investigation and the study of physical properties. The prerequisite for this thematic width are multiple collaborations of scientists with a wide range of competences in a research environment that is stable, predictable and based on a long term funding. According to PDI, such an environment cannot be provided by a university.

2. General concept and profile

Development of the institution since the last evaluation

At the time of the last evaluation PDI was organized in the three research departments “Nanostructuring”, “Nanoacoustics”, “Semiconductor spectroscopy” and the service department “Technology and Services”. In 2008, the department structure was reorganized. The department of Nanoacoustics was discontinued with its former head accepting a professorship at Johannes Kepler University Linz. The department “Epitaxy” was newly founded. It comprises all growth activities at PDI. All activities on structural investigations and on low-temperature STM were grouped into the department of „Microstructure“. The department of “Semiconductor Spectroscopy” remained unchanged. In 2012 the service department was renamed into “Technology and Transfer”, in order to reflect the increased efforts in knowledge and technology transfer.

Departments are defined by areas of competence of PDI staff and the corresponding research facilities and mainly lay out the organizational framework. Research, however, is carried out in six “Core Research Areas” (CReAs). Two CReA (“Nanofabrication” and “Nanoanalytics”) are methodologically oriented. The other four (“Ferromagnet-Semiconductor Hybrid Structures”, “Control of Elementary Excitations by Acoustic Fields”, “III-V Nanowires of Optoelectronics”, “Intersubband Emitters”) are topically defined and typically have emerged from projects which were started within Nanofabrication or Nanoanalytics. The six CReAs are described in detail in Section 3.

Since the appointment of a new director in 2007, activities on semiconductor nanowires have been strengthened. Subsequently, the new Core Research Area “III-V nanowires for optoelectronics” was initiated in 2008. It focuses on both, III-nitride and III-arsenide nanowires. Many goals have been taken over from the former Core Research Area “III-nitrides for optoelectronics” that was discontinued. Activities on planar III-nitrides are now part of the Core Research Area “Nanofabrication”.

Since the last evaluation, the following topics have been discontinued or scaled back

- Work on dilute nitrides, dilute magnetic semiconductors, manganese arsenide and on the epitaxy of intermetallic alloys on compound semiconductors

- In-situ probing of stress evolution during growth of nanostructures by an ultra-high vacuum cantilever beam technique
- Low-temperature STM work on individual Co-Cu atom chains on Cu(111) surfaces
- The use of acoustic fields for optical modulators is now mainly carried out through external collaborations.

On the other hand, the following new topics have been initiated or extended substantially:

- Studies on the growth of III-nitride and III-arsenide nanowires on silicon
- Atom manipulation on semiconductor surfaces
- Studies of acoustic charge transport have been extended to nanostructures
- Acoustic transport of indirect excitons (characterized by very long lifetimes) and modulation of microcavity polaritons and their Bose-Einstein condensates
- Fabrication of application specific quantum cascade lasers for terahertz emission

Results

In the period 2010-2012, a total of 219 scientific papers appeared in peer-reviewed international journals. Additionally, 64 articles in conference proceedings and 4 individual contributions to edited volumes were published. Highlights of PDI's research in the reporting period are described in more detail in Section 3, which is devoted to the six Core Research Areas that constitute the institute's research programme.

The competence of PDI in surface acoustic wave technology, including specific scientific know-how and modelling, has been made available as a service to external partners, e. g. the Leibniz Institute for Innovations for High Performance Microelectronics (IHP) and the Mesa+ Institute for Nanotechnology at University of Twente, Netherlands. These activities also form the basis for different scientific collaborations, e. g. in the framework of EU-funded projects. On a small scale PDI is supplying epitaxial wafers, masks or technological services.

PDI holds 18 granted patents. Additional 9 patents are registered (see Appendix 3). They include specific equipment for MBE, mechanisms for light emitting diodes, direct writing lithography or principles of magnetologic devices and spintronic circuits. All patents are screened and evaluated together with the patent marketing agency Ascenion. The administration is conducted by *Forschungsverbund Berlin e. V.* and external patent attorneys. The department of "Technology and Transfer" at PDI is responsible for technology transfer supervising all processes from intellectual property screening over invention disclosure, valuation, and patenting to marketing.

Academic events and public relations

In the period from 2010 to 2012 scientists from PDI have presented a total of 101 invited talks at conferences and at other institutions.

The most visible international conference organized by PDI was the "International Conference on Molecular Beam Epitaxy" in 2010. It was organized with support from a group of Humboldt-Universität zu Berlin. The conference was held in Berlin and drew an international attendance of about 450 participants.

Since 2008, PDI has been organizing "PDI topical workshops". The intention is to bring together all active players from emerging or dynamic research fields in which PDI is scientifically involved.

Since the last evaluation, the institute's website has been relaunched. The annual report underwent a complete redesign in order to be accessible to a broader audience. Local activities like "*Lange Nacht der Wissenschaften*" or "*Humboldt Unterwegs*" have been actively supported. Research highlights are regularly passed on to non-scientific media via the PR-team of *Forschungsverbund Berlin e. V.* In November 2012 the "science-facade" was opened. For this project the institute has teamed up with a group of media artists to develop a large-scale, artistic display which presents research results within a video-installation on five large shop-windows on the ground floor of the PDI building. The event received media coverage, e.g. in Berlin's TV news and local newspapers.

Strategic work planning for the next few years

The long-term strategy of PDI (*Institutskonzept*) was approved by the Scientific Advisory Board in 2009. It states two main objectives for PDI's research for the next years:

1. Materials research and physics oriented research on novel materials combinations, growth induced nanoscale heterostructures and their monolithic integration into silicon.
2. The development of new concepts for the encoding, transmission and processing of information, based on quantum properties of elementary excitations.

It is planned to continue the methodologically oriented approach of the Core Research Areas "Nanofabrication" and "Nanoanalytics" as the driving organizational form. Hence promising new activities will spawn from these two CReAs into sub-projects which may evolve into novel independent CReAs.

More detailed strategic goals for the individual Core Research Areas are given Section 3.

Appropriateness of facilities, equipment and staffing

The total revenue of PDI in 2012 was approximately 10.3 M€. Appendix 3 gives a detailed list of PDI's revenue and expenditures from 2010 to 2012.

Institutional funding

In 2012, PDI's institutional funding, 50 % of which is provided by the Federation and 50 % by the *Länder,* was 7.9 M€.

PDI considers its building infrastructure to be satisfactory in the near future when ongoing renovations and moves of office spaces will be completed in 2014. Between 2009 and 2012 a completely new, 500 m^2 clean room for the molecular beam epitaxy labs was installed on the ground floor of the building with funds from the institute's investment fund.

PDI sees a necessity for a renewal of scientific equipment for future strategic developments and to sustain its competitiveness. Within the next years, the institute plans to acquire the following equipment using its equipment investment funds:

- Electron spectroscopy: combined tool for X-ray, UV photoemission and angle resolved photoemission (XPS, UPS, APRES)
- Optical spectroscopy with high spatial resolution: integrated atomic force and confocal optical microscope
- Advanced electron microscopic methods: upgrade PDI's STEM by a retro-fitted system to correct aberrations

Furthermore, PDI states that additional equipment investment funds are necessary for the acquisition of the following systems:

- Small scale patterning: In-situ patterning for subsequent overgrowth by e. g. focused ion beam in UHV connection with MBE
- Advanced electron microscopy methods: Low energy electron microscopy (LEEM) for the investigation of growth
- MBE facilities: modern MBE for III-arsenides

In addition four scientific positions and one technical staff position are required, reasoned by PDI due to an increased range of competence:

- Scientist (TVöD E 13/E 14) to permanently direct the planned activity on photoemission spectroscopy
- Scientist (TVöD E 13/E 14) within CReA IV to concentrate on the physics of polaritons and their condensates
- Scientist (TVöD E 13/E 14) within CReA I for the epitaxy of novel materials
- Scientist (TVöD E 13/E 14) for a permanent position in knowledge- and technology transfer
- Technical staff (TVöD E 11/E 12) to permanently sustain the varied activities on small scale patterning

<u>Revenue from project funding grants</u>

The revenue from project funding grants was 1.6 M€ (18 % of the total budget) in 2010, 1.9 M€ (21 %) in 2011, and 1.3 M€ (14 %) in 2012. For the whole period from 2010 to 2012 this adds up to 4.8 M€. In the same period the share of expenditures from project funding grants from the German Science Foundation (DFG) amounted to 2 M€, while expenditures from grants from the Federal and *Länder* governments amounted to 1.6 M€, and expenditures from grants from the EU amounted to 426 k€.

3. Core Research Areas of PDI

Core Research Area I: Nanofabrication (18.86 FTE)

Work programme

The research of CReA I focuses on the fabrication of novel types of nanostructured crystals and the investigation of fundamental growth mechanisms. The perspective of such samples is to enable the investigation of physical phenomena or to offer novel tailored functionalities that may inspire electronic devices. The research is mainly based on molecular beam epitaxy (MBE). In the starting phase of this CReA MBE of planar III-As and III-N heterostructures as well as the fabrication of hybrid structures with ferromagnetic materials had been the main research activity. In the last years it has increasingly been extended to include other materials such as oxides, alloys along the GeTe-Sb_2Te_3 (GST) pseudo-binary line, and graphene. The growth of III-V nanowires had also been conducted in this CReA until a dedicated CReA "III-V Nanowires for Optoelectronis" was started in 2010. Also in 2010 a junior research group was established which focuses on the growth of graphene by MBE directly on semiconducting as well as insulating substrates and investigates the formation of graphene layers on SiC substrates.

Results

In the period 2010-2012 41 articles in peer-reviewed journals and 21 articles in conference proceedings were published. In the same period, expenditures from project grants from the German Science Foundation (DFG) totalled 185 k€ while 250 k€ were raised from the Federal or *Länder* governments. In addition, 205 k€ were spent from revenues from the competitive procedure of the Leibniz Association. Research highlights included the epitaxial growth of phase change materials and the demonstration of reversible phase switching, and the growth of mono- and few-layer nanocrystalline graphene on Al_2O_3 substrates by molecular beam epitaxy.

Work planning

A future work planning exists for every class of materials. The focus of the III-As growth activity will be the fabrication of three-dimensional heterostructures. In the field of III-nitrides the growth of InN, (In,Ga)N with high In-content, and of superlattices is planned, as well as the use of Si micropillars as starting surface. The activity with rare-earth oxides will be directed to the use of these oxides as buffer layers for the integration of other materials investigated at PDI. A new activity dealing with oxides will be the growth of transparent semiconducting oxides for power electronics and sensing applications. For the phase-change materials GST a future objective will be the fabrication of Sb_2Te_3/GeTe superlattices, aiming at the reduction of the power needed for switching - in cooperation with the industrial partner Micron. Work related to the synthesis of graphene will be extended to Si substrates and the formation of heterostructures with atomic layers of hexagonal boron nitride.

Core Research Area II: Nanoanalytics (15.25 FTE)

Work programme

The mission of this CReA is the development and combination of experimental and theoretical tools for the analysis of materials on a nanometer scale. Experimental methods comprise X-ray synchrotron diffraction to investigate surfaces and interfaces in epitaxial layers and three-dimensional nanostructures during growth at the PHARAO beamline operated by the CReA at Bessy II Helmholtz-Zentrum Berlin. After growth structural and optical properties are investigated by electron microscopy techniques including imaging, diffraction and spectroscopy. In addition, low-temperature scanning tunnelling microscopy (STM) is applied to create and analyze individual nanostructures. All these methods of analysis aim at the clarification of relations between structure and properties of materials. The research focus covers the following key aspects:

- Interfaces in epitaxial nanoscale heterostructures
- Order-disorder phenomena and phase transitions in semiconductors, metal and oxide alloys
- Structural, chemical and mechanical properties of low-dimensional and/or metastable material systems
- Manipulation and spectroscopy of materials at the single-atom scale

Results

In the reporting period 3 individual contributions to edited volumes, 73 articles in peer-reviewed journals and 17 articles in conference proceedings were published. In the same period, revenues from project grants from the German Science Foundation (DFG) totalled 1004 k€ while 400 k€ were spent from EU grants. In addition, 516 k€ were spent from revenues from the Federal or *Länder* governments and 205 k€ from the competitive procedure of the Leibniz Association. One of the research highlights was the experimental demonstration of a sigmoidal variation of the composition profile across semiconductor hetero-interfaces. By theoretical modeling it was further shown that this is a universal feature of III-V hetero-interfaces, which is not related to specific growth techniques, but results from specific growth dynamics that are caused by strong cooperative interactions during two-dimensional island formation. In nano-objects such as 3D nanowires, the chemical composition and crystal polarity were determined with highest spatial resolution by electron energy-loss spectroscopy in transmission electron microscopy (TEM). Furthermore, the technique of single atom manipulation by low-temperature STM was established to create ultimately small quantum structures on III-V semiconductor surfaces and to study their electronic properties.

Work planning

Medium-term directions and objectives are defined for every key aspect of the research focus. Among special aspects, PDI's general interfaces studies aim at a development of experimental research methods and their application to novel interface systems such as graphene layers on SiC substrates. Research in conjunction with the PHARAO experiment will focus on the understanding of growth kinetics and formation of buried interfaces and epilayers under the conditions of growth. With respect to STM-assembled nanostructures on InAs, it is planned to combine ingredients of atom manipulation and electronic confinement to engineer coupled quantum dot structures which are rigorously defined by the underlying surface lattice.

Core Research Area III: Ferromagnet/semiconductor hybrid structures (8.5 FTE)

Work programme

The integration of ferromagnetism into semiconductor devices focuses on the promising aspect of utilizing the electron spin for processing, communication, as well as storage of information in semiconductor spin- and magnetoelectronics (spintronics). Investigations of this CReA aim at an understanding of heteroepitaxial growth as well as structural and magnetic properties of ferromagnetic (FM) films grown on III-V semiconductors (SC). An additional goal is to identify and understand mechanisms involved in spin transport which are relevant for concepts for spintronic devices. A key issue with respect to the development of materials is the epitaxial growth of high-quality ferromagnetic films on semiconductors. Studies on SC/FM core/shell NWs, which have the potential to act as building blocks in spintronic applications, are conducted in cooperation with Core Research Area V.

CReA III participates in the DFG Priority Programme SPP 1538 "Spin Caloric Transport" and investigates how epitaxial Heusler alloy/semiconductor hybrid structures can be used in spin-caloric applications. Since the last evaluation, Heusler alloys have become the major focus of the ferromagnetic materials development, while activities on MnAs, (Ga,Mn)As and GaN:Gd ferromagnetic films had been reduced and eventually stopped.

Results

In the reporting period, 17 articles in peer-reviewed journals and 2 articles in other journals were published. In the same period, revenues from project grants from the German Science Foundation (DFG) totalled 118 k€ while 46 k€ were spent from grants from the Federal or *Länder* governments. The research activity covered the development of materials and thus the growth of high-quality ferromagnetic films on semiconductors. A ferromagnet-semiconductor hybrid structure studied at PDI consists typically of a Heusler alloy such as Co_2FeSi on a GaAs transport channel. Regarding spin injection and transport the spin generation and spin lifetime in semiconductor channels combined with ferromagnetic metals as spin-polarized sources were investigated. Further, concepts for spintronic devices were explored. For lateral transport structures consisting of Co_2FeSi stripes on an *n*-GaAs transport channel, a device concept, in which the basic building block consists of a local spin valve utilizing spin extraction instead of spin injection at the ferromagnetic stripes, was demonstrated.

Work planning

The combination of materials development and its implementation into concepts of spin injection, detection, and manipulation will be continued as the major focus of this Core Research Area. Also the investigation of concepts to optimize the efficiency of spin injection from a ferromagnet into a semiconductor at room temperature will remain a main research topic. Studies of spin transport phenomena will be conducted in close cooperation with the Core Research Area IV.

<u>Core Research Area IV: Control of Elementary Excitations by Acoustic Fields</u> (5.67 FTE)

Work programme

The subject of research of this CReA is the control of elementary excitations in semiconductors using spatially and time dependent fields. Mostly, these dynamic fields are generated by surface acoustic waves (SAWs). They are excited by transducers on the surface of semiconductor structures. Research activities include basic studies of the interaction between semiconductor excitations with dynamic fields as well as the development of new materials for acoustic modulation and their exploitation for novel device functionalities. The following topics have been addressed in the last years:

- SAW generation and propagation control in semiconductor structures
- Acoustic manipulation and transport of carriers and spins for quantum information applications
- Coherent control and transport of photonic excitations

While investigations during the previous reporting period aimed at the manipulation of photons by acoustic fields the emphasis is now placed on acoustic control of excitons and exciton-polaritons.

Results

In the reporting period 1 individual contribution to an edited volume, 23 articles in peer-reviewed journals and 14 articles in conference proceedings were published. In the same period, revenues from project grants from the German Science Foundation (DFG) totalled 388 k€. In addition, 295 k€ were spent from revenues from the Federal or *Länder* governments. Research includes works in an industrial collaboration with Telebitcom GmbH and the Leibniz Institute for Innovations for High Performance Microelectronics (IHP, Frankfurt/Oder), where piezoelectric ZnO and AlN films were used for the monolithic integration of SAW devices on silicon CMOS silicon chips. CReA IV was involved in the DFG Priority Program 1285 "Semiconductor Spintronics". Among scientific highlights one finds the electric control of spin lifetime in (111) GaAs quantum wells and the coherent modulation of polariton condensates by acoustic fields. Other projects demonstrated acoustically driven anti-bunched photon sources using the acoustic charge transport in GaAs nanowires with embedded (In,Ga)As quantum dots.

Work planning

Future work planning on SAW generation and propagation control will concentrate on materials and processes for the generation of intense, high-frequency acoustic modulation beams. Work planning for acoustic manipulation and transport of carriers and spin encompasses control and manipulation of single carriers and spins during transport, combination of acoustic spin transport with electrical spin injection and detection, integration of functionalities and acoustic carrier and spin transport in monolayer graphene on SiC. Future topics dealing with coherent control and transport of photonic excitation include polaritons and indirect excitons in the quantum limit and excitonic systems at higher temperatures.

Core Research Area V: III-V Nanowires for Optoelectronics (17.35 FTE)

Work programme

This CReA investigates how specific properties of nanowires can be employed to improve optoelectronic devices or to enable new functionalities and applications. An overall research vision is light emission on a Si platform. Both, group-III-nitride as well as group-III-arsenide nanowires are grown by MBE, typically on silicon substrates and without any external catalyst. By means of experimental characterization techniques, properties of nanowires that influence applications, in particular for light-emitting diodes (LEDs) are studied. The work also includes the fabrication of demonstrator devices.

Nanowire research at PDI started with optical and structural analysis of GaN-based nanowires. With the appointment of the new director in 2007 activities were extended to include own growth experiments. In addition to work on III-N nanowires also research on III-As nanowires was initiated. A focus was the understanding of nanowire nucleation and growth within the two CReAs Nanofabrication and Nanoanalytics. Also nanowire luminescence was investigated in the framework of the former CReA Group-III Nitrides for Optoelectronics. In 2008 the Core Research Area "III-V Nanowires for Optoelectronics" was newly installed. Since 2010, it comprises all former activities. Also additional research topics such as heterostructures, strain relaxation, doping, polytypism or light coupling have been pursued.

Results

In the reporting period 55 articles in peer-reviewed journals and 8 articles in conference proceedings were published. In the same period, revenues from project grants from the German Science Foundation (DFG) totalled 192 k€ while 311 k€ were spent from grants from the Federal or *Länder* governments. One research result is a model for the growth of gallium nitride nanowires, including nucleation, evolution of shape, and self-regulation of diameter and length. Other research highlights include the achievement and analysis of high minority carrier lifetimes in GaAs nanowires grown on silicon and a direct experimental determination of the spontaneous polarization of GaN. Regarding applications, LEDs based on ensembles of either III-N or III-As nanowires grown on Si substrates were fabricated, and prospects of (In,Ga)N nanowires for solar water splitting were explored.

Work planning

For the future it is planned to further develop LEDs based on nanowires. The planning includes LED fabrication combined with selective-area growth to obtain multi-colour LEDs in a single growth run. Also, in a hybrid approach the high internal quantum efficiency of organic materials for light emission will be exploited. Moreover, the monolithic integration with Si technology will be pursued. On the one hand, it is planned to achieve functional III-N nanowire LEDs controlled by transistors processed in the Si substrate on which the nanowires are grown. On the other hand, III-As nanowire heterostructures are intended to be employed as monolithic photodetectors for Si photonics. Finally, the direct growth of LED structures on metallic substrates is planned. Beyond these application-oriented topics more fundamental research directions will be the analysis of optical transitions in single nanowires with the help of polarization-resolved spectroscopy in external magnetic fields, the correlation between structure and emission for single nanowire heterostructures, and the band structure of III-As semiconductors in wurtzite structure.

Core Research Area VI: Intersubband Emitters: GaAs-based Quantum-Cascade Lasers (6.17 FTE)

Work programme

Activities on terahertz (THz) quantum-cascade lasers (QCL) at PDI started in 2006, while previous research on mid-infrared QCLs was terminated in 2007. This CReA focuses on modeling, design, fabrication, and experimental investigation of unipolar lasers emitting in the THz spectral regime as well as on the development of customized THz QCLs. All investigated structures are based on GaAs/(Al,Ga)As heterostructures. Currently, THz QCLs can be operated in pulsed mode only below 200 K and in continuous-wave mode below 130 K. One of the main research objectives is the development of THz lasers operating at higher temperatures. The research strategy comprises three main topics:

- Development and investigation of THz quantum-cascade lasers for different frequencies and applications.
- Development of customized THz quantum-cascade lasers for specific applications.
- Development and investigation of THz lasers based on gain without inversion.

Results

In the period 2010-2012, 12 articles in peer-reviewed journals and 2 articles in conference proceedings were published. In the same period, revenues from project grants from the German Science Foundation (DFG) totalled 103 k€, while 156 k€ were spent from grants from the Federal or *Länder* governments. Research highlights cover all three main topics that are pursued. For example, in order to achieve single-mode emission, distributed-feedback QCLs were fabricated based on single-plasmon wavequides with first-order gratings. In cooperation with the *Deutsches Zentrum für Luft- und Raumfahrt* (DLR) in Berlin, a local oscillator for 4.745 THz, which meets a complete set of requirements such as wall plug efficiency, precise frequency, beam profile, and operation in a Stirling cooler, was developed for GREAT (German Receiver for Astronomy at Terahertz Frequencies) with SOFIA (Stratospheric Observatory for Infrared Astronomy). In addition, several THz QCLs used for spectroscopic applications, for THz wavefront analysis and for THz imaging were supplied to DLR in Berlin. In cooperation with the *Ferdinand-Braun-Institut – Leibniz-*

Institut für Höchstfrequenztechnik, in Berlin, an epi-down mounting scheme for stressless assembly was realized, which provides enhanced heat dissipation at the corresponding operating temperature and high stability against thermal cycling.

Work planning

Future planning includes an extension of the underlying model for a previously developed simulation tool in order to allow for studies of physical processes as well as for the development of design principles and customized lasers. In addition the density-matrix model using a generalized Fermi's golden rule will be implemented, which will allow for a more realistic description of the transport and optical properties of THz QCLs and lasers based on gain without inversion. Furthermore, possibilities for an improvement of growth stability by implementing additional in-situ control mechanisms into the molecular beam epitaxy system will be explored. It is planned to use the epi-side-down mounting of THz QCLs, which has been developed, as a basis for the exploration of novel functionalities by on-chip integration. Medium-term perspectives include the exploration of nitride-based heterostructures for THz QCLs that may increase the frequency range and operating temperature. A long-term goal is to reach room temperature operation of intersubband lasers for the THz regime based on gain without inversion.

4. Collaboration and networking

Collaboration with universities

PDI is linked with Humboldt-Universität zu Berlin (HU Berlin) through a joint appointment (*S-Professor*) of the director and to Technische Universität Berlin (TU Berlin) through an extraordinary professorship of one of the department heads. This facilitates collaborative research and training of students. A special collaboration is established with the group for theoretical solid state physics of HU Berlin through one joint postdoctoral researcher, financed by PDI, who works on topics of common interest. To strengthen theoretical research in collaboration with external groups has been recommended in the last evaluation. The academic staff at PDI is involved in teaching at HU and TU Berlin.

Further collaborations of PDI with university research groups include a membership in the Humboldt Center for Modern Optics at HU Berlin, a Pro FIT project of *Investitionsbank Berlin* coordinated by eagleyard Photonics GmbH with HU Berlin and a joint DFG project with *Universität Siegen.*

PDI participates in the following Collaborative Research Centers (*Sonderforschungsbereiche*, CRC) of the German Science Foundation (DFG):

- CRC 546, HU Berlin: Structure, Dynamics, and Reactivity of Aggregates of Transition Metal Oxides, project C4. (ended in 2011)
- CRC 658, FU Berlin: Elementary Processes in Molecular Switches at Surfaces, project A2.
- CRC 951, HU Berlin: Hybrid Inorganic/Organic Systems for Opto-Electronics, project B8.

Additionally, PDI is involved in two DFG Priority Programs (*Schwerpunktprogramme*).

Collaboration with other domestic and international institutions

PDI collaborates in national and international projects funded by BMBF and EU with other research institutions. During the reporting period 2010-2012 PDI has participated in the following EU projects:

- SMASH: Smart Nanostructured Semiconductors for Energy-Saving Light Solutions (ended 2012).
- SINOPLE: Surface-Engineered (In,Ga)N Heterostructures on N-Polar and Nonpolar GaN Substrates for Green Light Emitters.
- PASTRY: Phase Change Memory Advanced Universal Switches Through Thin Alternating Layers.

Additionally, during the reporting period PDI participated in five BMBF projects, was engaged in three bilateral projects co-financed by DFG and the Japan Science and Technology Agency as well as other international bilateral projects.

Other collaborations and networks

PDI cooperates with industrial partners on a bilateral basis and through participation in research networks funded through BMBF, EU, and other funding organizations. Examples are Osram Opto Semiconductors in Regensburg, Micron Semiconductors Italia, and CreaTec Fischer & Co. GmbH in Erligheim. There also exist cooperation agreements with small and medium-size companies in the Berlin-Brandenburg area. Examples are teleBITcom GmbH in Teltow, eagleyard Photonics GmbH in Berlin, and OpTecBB, a regional network on optical technologies.

During 2010-2012 a total of 50 scientists visited PDI for at least one week, 26 of them for longer than three month.

5. Staff development and promotion of junior researchers

Staff development and personnel structure

At the end of 2012 PDI had 62 employees in research and scientific services, corresponding to 52.7 full-time equivalents (FTE). Additionally the staff consisted of 24 persons (23 FTE) with service positions, mostly laboratory personnel, and 7 (4.9 FTE) administrative employees (see Appendix 4).

In general, staff positions are temporary with a period of two years, unless the candidate has had a permanent position before. The heads of research groups are hired following similar rules as for appointments at German universities, including an international advertisement, an interview process and an evaluation of references eventually leading to a ranking of candidates.

Recent newly filled staff positions were the position of the director in November 2007, the appointment of the head of the new department Epitaxy in May 2008 and the hiring of the leader of the junior research group “Graphene” in 2010. Seven scientists were hired on permanent contracts, four retired. The head of the former department Nanoacoustics accepted a full professorship at Johannes Kepler University Linz in 2007. A senior scientist became CTO at Createc GmbH, a manufacturer of MBE and STM equipment, in 2010.

Promotion of gender equality

PDI promotes gender equality on the basis of recommendations by DFG and the Leibniz Association and is implementing the essential features of the Implementation Agreement on equal opportunities for the Leibniz Association (*Ausführungsvereinbarung Gleichstellung).* The institute has an equal opportunity commissioner and a corresponding deputy. An additional measure is the decision on principles of equal opportunities (*Vereinbarung zur Chancengleichheit*), which was taken by the board of directors of FVB in 2004. PDI states, that is has implemented a system to track and monitor the development of quota of female staff members, the so-called *Kaskadenmodell,* which is obligatory for all Leibniz institutions.

PDI supports flexible solutions that facilitate a life-work balance. Individual agreements on working hours are possible. Important institute meetings and seminars are terminated before 4 pm to enable parents to pick up children from child care or to assist other family members.

In 2012 PDI was certified by *berufundfamilie* gGmbH.

Promotion of junior researchers

In comparison to the last evaluation PDI has approximately tripled the number of PhD students to about 20 and accepted students preparing their master thesis. Student-seminars require young researchers to present and discuss their results internally. In the reporting period nine persons finished their PhD successfully.

Usually, a doctoral thesis is expected to be finished after 3 years. An extension for a fourth year is possible. The average time for a doctoral thesis was 3.7 years in the reporting period. About 25 % of the PhD students are third party funded.

In the reporting period six former postdocs of PDI received professorships when returning to their home countries in China, India, Spain, Taiwan and the USA, and also Germany.

Vocational training for non-academic staff

As a member of the *Forschungsverbund Berlin e. V.* PDI finances two vocational training positions at the administration at FVB and Ferdinand-Braun-Institut (FBH).

6. Quality assurance

Internal quality management

PDI has established internal "Guidelines for the Implementation of the Rules to Ensure Good Scientific Conduct" with which all internal research activities have to comply. The guidelines are in accordance with the recommendations of the German Research Foundation (*Deutsche Forschungsgemeinschaft*, DFG).

All publications of PDI staff members have to undergo an internal review system overseen by the department heads, which is similar to the review process of scientific journals.

On the level of the Core Research Areas at least twice a month meetings are held, in which research results, interpretations, technical questions and concepts are presented and discussed.

A system of cost-performance-assessment (*Kosten-Leistungs-Rechnung*, KLR) was introduced.

Quality management by the Scientific Advisory Board

The Scientific Advisory Board (SAB) advises the director, the representatives of the State of Berlin and of the Federal Government and the Board of Trustees of FVB in fundamental questions of the scientific work programme and the national and international cooperation of the institute. SAB also conducts regular audits within the evaluation-periods according to the guidelines issued by the Leibniz Association. Furthermore, it advises the Board of Trustees on appointment procedures for the director and leading scientists.

Report of SAB from August 2010 and implementation of recommendations

PDI was last evaluated in 2007. Subsequently the Senate of the Leibniz Association requested a report of the SAB on the implementation of recommendations, especially regarding the issues:

- Improvement of PDI's technical equipment and infrastructure
- Enhancement of PDI's efforts in technology transfer

SAB reported in August 2010 that PDI has implemented essential recommendations. Further, SAB stated that scientific topics are chosen in such a way that collaborations with industrial partners can be increased.

The Senate of the Leibniz Association noted that SAB has ascertained the implementation of the essential recommendations. The Senate further reminded that a coherent general concept, which links the different fields of research including criteria for novel research topics with regard to industrial relevance, is expected for the next evaluation.

Implementation of recommendations from the last external evaluation

PDI responded to the 16 recommendations summarised on page B-12 of the 2007 evaluation report (highlighted here in italics) as follows:

<u>Mission, Tasks, Main Work Areas</u>

1. *PDI should demonstrate to a larger extent the potential applicability of its research results for use in semiconductor devices:* PDI argues that this is done wherever possible, e. g. with fully processed QCLs beyond prototype status. Activities on nanowire LEDs or phase change materials are conducted in collaboration with industrial partners who process test devices.

2. *A long-term strategy for the selection of potentially applicable new research topics is needed in order to help the Institute move more toward application-oriented research:* Following PDI, this has been done by aligning projects along large trends of information technology, both with regard to materials and nanostructures, as well as for device and systems concepts.

3. *The existing research approaches should be extended to include more theoretical research work in collaboration with external groups:* PDI supports the group for theoretical solid state physics of HU Berlin by financing one postdoc position, where work is performed towards topics with large overlap of interests. Other collaborations include theorists from the Naval Research Lab, Washington D.C. and the Fritz-Haber-Institut Berlin.

<u>Structural Features and Organisation</u>

4. *The organisational structure of PDI is not optimum, as no explicit responsibilities have been assigned for the coordination of the work within and between the different core research areas:* Responsibilities for CReAs have been assigned. In addition, also scientific coordination of some CReAs has been organised.

5. *Within the new discussion groups, the selection process for new scientific topics should be more structured:* Discussions for the selection and evaluation of scientific topics are held within brainstorming-sessions, meetings within and between CReAs and retreats. Final decision is taken by the department-heads and the director taking into account advice from the Scientific Advisory Board.

6. *The Scientific Advisory Board should offer external advice of selecting new research topics to a greater extent:* See 5.

7. *PDI has a backlog in the implementation of an efficiency-related cost calculation system at the Institute. This needs to be improved:* Complete KLR procedures are implemented in cooperation with FVB e. V.

8. *The programme budget must be further improved, as the current version contains one programme area only:* The program budget now contains the two program areas "Innovative Semiconductor Systems" and "Technology and Services".

<u>Resources, Expenditures and Personnel</u>

9. *The infrastructure of the cleanrooms should be upgraded and renewed:* All four (non-cleanroom) MBE laboratories and the central MBE cleanroom have been combined into one large cleanroom which was newly built between 2009 and 2011. Renewal of the cleanroom for semiconductor technology is in progress and is scheduled to be completed in the first half of 2014.

10. *The IT services should be made state-of-the-art:* All hardware was renewed in 2008. The newly hired head of IT services provides extensive user support.

11. *The online access to important scientific literature is strongly limited for PDI staff and should be improved:* The most frequently consulted scientific journals held by the institute in printed form are now also accessible electronically. The publication management system Mendeley is available for all staff members.

12. *The Institute's third-party funding, particularly from the DFG and the EU, should be substantially increased:* PDI has increased the percentage of third party funding from 12 % in 2007 to 21 % and 14 % in 2011 and 2012, respectively.

Promotion of Junior Academics and Cooperation

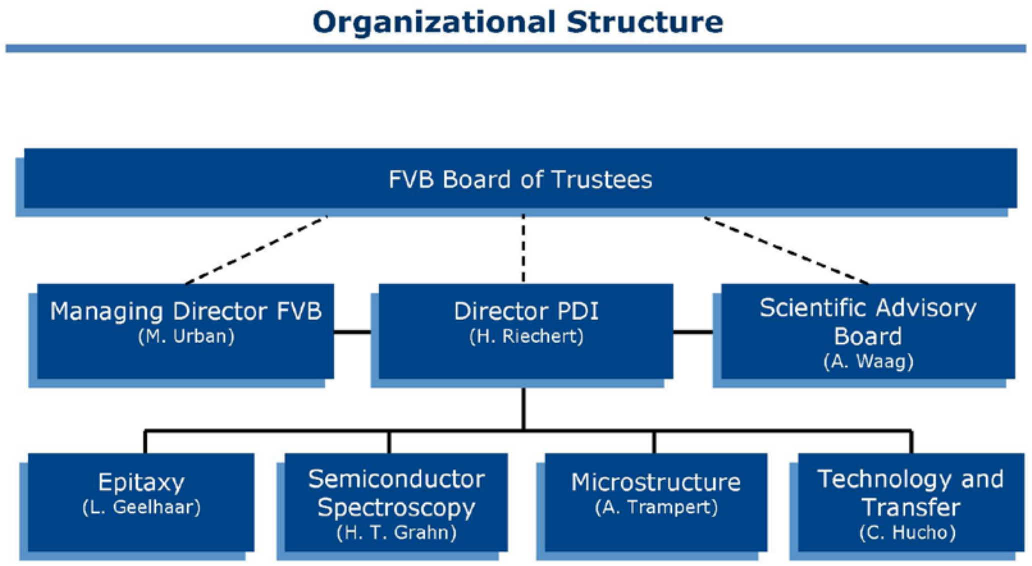
13. *The education of junior academics should be improved by way of a structured Ph.D. programme:* The number of PhD students has been increased from previously about 7 to 20. In weekly seminars students give talks and invite experienced scientist from PDI to present scientific topics or for coaching.
14. *Cooperation with the three universities of Berlin and within the national scientific community should be further strengthened:* PDI explains that collaboration with HU Berlin has been strengthened. The institute has also collaborations with groups from FU and TU Berlin and is involved in three Collaborative Research Centers in Berlin (two of them ongoing). An intense collaboration exists with the Helmholtz Zentrum Berlin. On the national level, PDI participates in two priority programs of DFG.

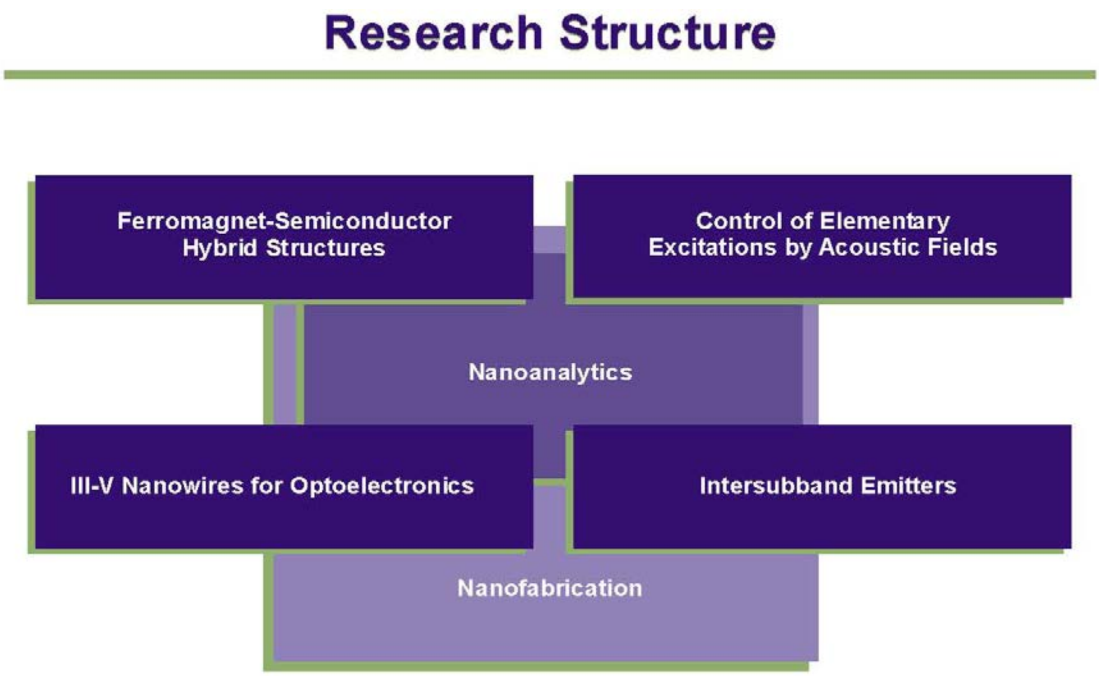
Results and Scientific Resonance

15. *PDI should develop a patent strategy, increase its number of patent applications and become more actively involved in the technological transfer of its results:* PDI has developed a patent strategy that is specifically tailored to the institute's research culture. These activities were financially enabled by support from BMBF and involve a professional technology transfer company. A strategy was generated by a newly hired scientist and the department head of Technology and Transfer. A patent office was set up within PDI.
16. *The public relations activities of the Institute could be improved:* Since the last evaluation, the institute's website has been relaunched, the annual report has been overhauled to be accessible by a broader audience, and interface-activities like the "*Lange Nacht der Wissenschaften*" or "*Humboldt Unterwegs*" have been actively supported. Research highlights are regularly passed on to non-scientific media via the PR-team of *Forschungsverbund Berlin e. V*. The institute has teamed up with a group of media artists to develop a large-scale, artistic display which presents research results on five large shop-windows in the basement of the building. This "science-facade" was opened in November 2012 and received good media coverage, e. g. in Berlin's TV news.

Appendix 1

Organisational Chart





Appendix 2

Publications and patents

	Period		
	2010	2011	2012
Total number of publications	**91**	**95**	**101**
Monographs	0	0	0
Individual contributions to edited volumes	2	1	1
Articles in peer-reviewed journals (conference proceedings)	61	64	94
Articles in other journals	28	30	6
Working and discussion papers	0	0	0
Editorship of edited volumes	0	0	0
Number of publications per full-time equivalent (FTE) in 'research and scientific services' (not including doctoral candidates)	2.02	2.11	2.24

Industrial property rights (2010–2012) [1]	Granted	Registered
Patents	18	9
Other industrial property rights	0	0
Exploitation rights/licences (number)	1	

[1] Concerning financial expenditures for revenues from patents, other industrial property rights and licences see Appendix 3.

Appendix 3

Revenue and Expenditure

Revenue		2010			2011			2012 [1]		
		k€	%	%	k€	%	%	k€	%	%
Total revenue (sum of I., II. and III.; excluding DFG fees)		**9.462,3**			**10.782,6**			**10.253,0**		
I.	**Revenue (sum of I.1., I.2. and I.3)**	**8.818,0**	**100%**		**8.812,5**	**100 %**		**9.164,6**	**100 %**	
1.	Institutional funding (excluding construction projects and acquisition of property)	7.219,2	82 %		6.957,2	79 %		7.882,6	86 %	
1.1	Institutional funding (excluding construction projects and acquisition of property) by Federal and *Länder* governments according to AV-WGL	7.219,2			6.957,2			7.882.8		
1.1.1	*Institutional funding received through the Leibniz competitive procedure (SAW-Verfahren)* [4]	*0*			*0*			*0*		
1.2	Institutional funding (excluding construction projects and acquisition of property) not received in accordance with AV-WGL	0			0			0		
2.	Revenue from project grants	1.598,8	18 %	100 %	1.855,3	21 %	100 %	1.281,8	14 %	100,0
2.1	DFG	650,6		43 %	748,3		40 %	632,5		49 %
2.2	Leibniz competitive procedure (*SAW-Verfahren*) [2]	0,0		0 %	173,5		9 %	236,6		18 %
2.3	Federal, *Länder* governments	596,7		37 %	747,4		40 %	222,5		17 %
2.4	EU	122,6		8 %	133,6		7 %	170,3		13 %
2.5	Industry	0,2		0 %	0,0		0 %	0,0		0 %
2.6	Foundations	0,0		0 %	0,0		0 %	5,2		0 %
2.7	Other sponsors (if applicable, break down by source) [3]	228,7		14 %	52,5		3 %	14,7		1 %
3.	Revenue from services	0,0	0 %		0,0	0 %		0,0	0 %	
3.1	Revenue from commissioned work	0,0			0,0			0,0		
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.)	0,0			0,0			0,0		
3.4	Revenue from exploitation of intellectual property without industrial property rights	0,0			0,0			0,0		
3.5	*Revenue from other services, if applicable; please specify*	0,0			0,0			0,0		
II.	**Miscellaneous revenue** (e. g. membership fees, donations, rental income, funds drawn from reserves)	**344,3**			**690,1**			**512,4**		
III.	**Revenue for construction projects** (institutional funding by Federal and *Länder* governments, EU structural funds, etc.)	**300,0**			**1.280,0**			**576,0**		

Expenditures		k€	k€	k€
Expenditures (excluding DFG fees)		**9.462,3**	**10.782,7**	**10.252,9**
1.	Personnel	5.207,4	5.670,3	5.560,5
2.	Material resources	2.059,3	2.568,6	2.825,6
2.1	*Expenditures used for registering industrial property rights (patents, utility models, etc.)*	*33,6*	*26,9*	*34,5*
3.	Equipment investments and acquisitions	1.530,5	847,4	856,8
4.	Construction projects, acquisition of property	0,0	1.274,6	871,0
5.	"Reserves" (e. g. cash assets, unused funds)	665,1	481,8	139,0
6.	Miscellaneous items	0,0	0,0	0,0

DFG fees (if paid for the institution – 2.5 % of revenue from institutional funding)	192,8	191,9	199,2

1 Preliminary data: no

2 Competitive procedure of the Leibniz Association: until 31 December 2010, funds allocated through this procedure were designated as institutional funding. Since 1 January 2011, the Leibniz Association has granted these funds as project grants.

3 Funding by other sponsors includes for the most part conference funds. These conference expenses are usually provided by a number of sponsors and are accounted together as one project. Therefore these funds (normally small sums) are not allocated separately to each sponsor. In 2010 the unusually high expenditure of 228,7 k€ resulted due to the organization of a large conference (MBE 2010) with overall expenditure of 180,9 k€.

Appendix 4

Staff

(Basic financing and third-party funding / proportion of women (as of: 31/12/2012)

	Full time equivalents		Employees		Female employees	
	Total	on third-party funding	Total	on temporary contracts	Total	on temporary contracts
	Number	Percent	Number	Percent	Number	Percent
Research and scientific services	***52,65***	26 %	***62***	61 %	***6***	67 %
Professors / Direct. (C4, W3 or equivalent)	1	0 %	1	0 %	0	0 %
Professors / Direct. (C3, W2, A16 or eq.)	0	0 %	0	0 %	0	0 %
Academic staff in executive positions (A15, A16, E15 or equivalent)	4	0 %	4	0 %	0	0 %
Junior research group leaders / junior professors/ post-doctoral fellows (C1, W1, A14, E14 or equivalent)	0	0 %	0	0 %	0	0 %
Scientists in non-executive positions (A13, A14, E13, E14 or equivalent)	37,90	29 %	41	54 %	4	50 %
Doctoral candidates (A13, E13, E13/2 or eq.)	9,75	26 %	16	100 %	2	100 %
Service positions	***23***	4 %	***24***			
Scientific-technical staff (E9 to E12,upper-mid-level service)	14	7 %	14			
Scientific-technical staff (E5 to E8, mid-level service)	2	0 %	2			
Workshops (E9 to E12,upper-mid-level service)	1	0 %	1			
Workshops (E5 to E8, mid-level service)	3	0 %	3			
Library (E9 to E12, upper-mid-level service)	1	0 %	2			
Photo laboratory (E9 to E12, upper-mid-level service)	1	0 %	1			
Information technology - IT (E9 to E12, upper-mid-level service)	1	0 %	1			
Administration[1]	***4,87***	0 %	***7***			
Internal administration (financial administration, personnel etc.) (E9 to E12,upper-mid-level service)	1	0 %	2			
Internal administration (financial administration, personnel etc.) (E5 to E8, mid-level service)	1,87	0 %	3			
Building service (E5 to E8, mid-level service)	2	0 %	2			
Student assistants	0,2	0 %	1			
Trainees	**2**	0 %	2			
Scholarship recipients at the institution	***4,8***	100 %	***6***		***1***	
Doctoral candidates	1,8	0 %	3		1	
Post-doctoral researchers	3	0 %	3		0	

[1] In addition, PDI provides the salary for 4 employees in the central administration of the *Forschungsverbund Berlin e. V.*

16 July 2014

Annex B: Evaluation Report

Paul-Drude-Institut für Festkörperelektronik (PDI)
Leibniz-Institut im Forschungsverbund Berlin e. V.

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6. Quality Assurance B-11

Appendix:
Members of review board and guests; representatives of collaborative partners

1. Summary and main recommendations

PDI has set itself the challenging mission to explore epitaxial materials and new functionalities, aiming at semiconductor devices for future information technologies. For this purpose, the institute amalgamates material sciences and solid state physics.

The fundamentals of epitaxial growth, new materials and nanoscale heterostructures are the focus of research conducted at PDI and lead to internationally-competitive and excellent results. Building on this, the new material structures produced at the institute form the basis for further scientific investigation. Here, too, PDI can pride itself on some very good achievements and publications. Partly with regard to the recommendations of the last evaluation, PDI seeks to create the scientific foundation for new functionalities and device concepts. In individual cases, this ambitious goal has already been achieved.

The scientific themes are addressed in six Core Research Areas (CReAs). Two of these have an emphasis on methods; the other four are defined by content. The two method-related CReAs are rated as “very good to excellent” and “good to very good.” The four content-related CReAs are rated as “very good”, “excellent” and, in two cases, “good to very good.” Thus the overall performance is very good, although in the coming years the institute will have to align the formulation of its strategic guidelines even more closely to its 2009 long-term strategy.

PDI’s third-party funding portfolio has changed since the last evaluation. The proportion of DFG-funding has grown very satisfactorily in line with recommendations. On the downside, income from Federal Government funding dropped, and less EU funding was acquired. These changes reflect the increasing importance of fundamental research at PDI. Nevertheless, the proportion of third-party funding in the budget is still too low.

One positive development following on from the evaluation seven years ago is the increase in the number of Master and PhD students being supervised at PDI. There are now 20 doctoral candidates, almost twice as many as in 2007, but this number should be increased further. Currently, there is still no structured doctoral training programme in place.

On the Berlin research landscape, PDI cooperates above all with HU Berlin, particularly as a result of the joint appointment of the Director and a collaboration in theoretical physics. In addition, important collaborations also exist with some research institutions as well as with industry. There is, however, still considerable potential for further collaboration which is not being exploited appropriately.

In 2007, subsequent to the last evaluation, a new Director was appointed, and in 2008, one of the four Head of Department positions was re-filled. PDI has also been very successful in recruiting international researchers at the post-doctoral level whilst scientists, who have worked at PDI, relocate to more senior positions across the world.

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

General concept and profile (Chapter 2)

1. Based on PDI's excellent material samples, many innovative ideas are generated for further research topics in the various Core Research Areas. However, the strategic guidelines should be more stringently defined as a reference for determining the development of research topics at PDI. The institute's strategy 2009 (*Institutskonzept* 2009) leaves too many open questions. The approach of using the institute's strengths in methodology as the basis for the long-term strategy is convincing. However, PDI must exploit its excellent methodological expertise and material samples to develop and select scientifically productive physical and methodological questions more systematically than it has so far.
2. PDI should have an eye to industrially relevant applications when making decisions on selecting scientifically productive questions. In order to determine strategic goals it would, therefore, be recommendable to consult with partners in industry. An attempt should be made to involve them in research projects to a greater extent than has been the case so far, both as active and, for example, as financially active participants in (co-)financing doctoral positions. At the same time, PDI should not shy away from stating clearly that its research can often only aim to develop new devices in the long term. Given the institute's emphasis on fundamental research and its comparatively small size, this is quite plausible.
3. PDI should continue to increase the proportion of third-party funding in the budget.
4. PDI must develop an IT strategy.

Collaboration and networking (Chapter 4)

5. The institute should intensify its cooperation with Berlin universities as well as with other non-university research institutions at home and abroad. Its material samples make it an extremely attractive partner. PDI is encouraged to use this notable expertise to approach other institutions more proactively than it has done in the past.
6. The institute should specifically analyse which projects would be promising for involving companies – for example by financing doctoral positions. At present, this kind of collaboration with industry is not being utilised.

Staff Development and promotion of junior researchers (Chapter 5)

7. Even if the relatively low overall figures for women in physics in Germany are taken into account, very few women work at PDI, irrespective of the level of academic qualification or hierarchy. The situation is unsatisfactory. The target quotas set by PDI when introducing the cascade model are not ambitious enough and must be increased.
8. It should be possible to attract more doctoral candidates in working at PDI. As only a few scientists at PDI are entitled to supervise doctorates, cooperation should be sought with university teachers.

9. PDI's doctoral candidates should be part of a structured doctoral programme. PDI does not necessarily have to create such a programme on its own but could do so in cooperation with a university and possibly other institutions.

QUALITY ASSURANCE (CHAPTER 6)

10. It is recommended to establish discussion and decision-making structures to extend the existing informal mechanisms. In this context the following issues should be defined: how long-term strategies are declared to be binding, who is responsible for implementation and at which level (entire institute, Core Research Area), and at which intervals decisions and results should be evaluated.
11. Given the size of the institute the process of determining long-term strategies is made potentially more difficult at present by the almost overly-complex matrix structure. The establishment of Core Research Areas at PDI is convincing and has proved its worth. It should be examined whether it is still necessary to perpetuate the department structure with responsibility for staff and budgeting that exist beside the CReAs.

2. General concept and profile

Development of the institution since the last evaluation

PDI has set itself the challenging mission to explore epitaxial materials and new functionalities, aiming at semiconductor devices for future information technologies. For this purpose, the institute amalgamates material sciences and solid state physics.

The fundamentals of epitaxial growth, new materials and nanoscale heterostructures are the focus of research conducted at PDI and lead to internationally-competitive and excellent results. Building on this, the new material structures produced at the institute form the basis for further scientific investigation. Here, too, PDI can pride itself on some very good achievements and publications. With regard to the recommendations of the last evaluation, PDI seeks to create the scientific foundation for new functionalities and device concepts. In individual cases, this ambitious goal has already been achieved, such as collaboration with a company on nanostructures for solid-state lighting on silicon.

Following the appointment of the current Director in November 2007, work on semiconductor nanowires was extended and in 2008, the new Core Research Area "III-V nanowires for optoelectronics" was established. Consequently, work in CReA "III-nitrides for optoelectronics" was terminated. This development is welcomed.

Results

The average overall performance of the six Core Research Areas is rated as "very good." The two method-related CReAs are rated as "very good to excellent" and "good to very good." The four content-related CReAs are rated as "very good", "excellent" and, in two cases, "good to very good."

PDI publishes a convincing number of peer-reviewed articles in high-impact international journals. One of the institute's particular unique features is its long-term expertise in molecular beam epitaxy. The quality of the samples grown is outstanding by international comparison.

At present, PDI holds 19 patents. As recommended seven years ago, this is a significant increase in comparison with the last evaluation. The patents have not, however, generated any income so far. PDI does not yet appear to have a coherent patent strategy. In the light of the continuing development of the long-term strategy, greater consideration should be urgently given to the future handling of patent applications and patents.

As recommended, the institute has intensified its public outreach. It is now both convincing and innovative. Special mention should be made of the Science Façade Project which presents scientific results to the public in the form of artistic installations in five shop windows on the ground floor of the institute.

Strategic work planning for the next few years

Based on PDI's excellent material samples, many innovative ideas are generated for further research topics in the various Core Research Areas. However, the strategic guidelines should be more stringently defined as a reference for determining the development of research topics at PDI. The institute's strategy 2009 (*Institutskonzept 2009*) leaves too many open questions. The approach of using the institute's strengths in methodology as the basis for the long-term strategy is convincing. However, PDI must exploit its excellent methodological expertise and material samples to develop and select scientifically productive physical and methodological questions more systematically than it has so far.

PDI is also encouraged to cooperate more intensively with other institutions on the development of new questions, especially as its excellent samples make it a decidedly attractive collaboration partner that has both much to offer and can benefit greatly from cooperation. It is a positive step that PDI, as recommended, has already built up formal institutional cooperation with HU Berlin. It should continue along this path and increase cooperation with theory and experimental groups.

PDI should have an eye to industrially relevant applications when making decisions on selecting scientifically productive questions. In order to determine strategic goals it would, therefore, be recommendable to consult with partners in industry. An attempt should be made to involve them in research projects to a greater extent than has been the case so far, both as active and, for example, as financially active participants in (co-)financing doctoral positions. At the same time, PDI should not shy away from stating clearly that its research can often only aim to develop new devices in the long term. Given the institute's emphasis on fundamental research and its comparatively small size, this is quite plausible.

Furthermore, PDI should examine any developments that promise this kind of potential to ascertain whether they might lead to spin-offs and how these could be promoted by the institute.

Appropriateness of facilities, equipment and staffing

The existing volume of institutional funding is sufficient to allow PDI to fulfil its mission. In order to purchase new equipment or employ staff for new tasks the institute should redeploy existing funds. Additional funding over and above the planned budget increase are, however, not necessary.

In the years 2010 to 2012, the proportion of third-party funding was 18%, 21% and 14% of the respective total income. The percentage of third-party funding in the years 2003 to 2005, for which PDI submitted figures for the last evaluation, was in the same range. However, the composition of third-party funding has changed in the interim: in the period 2003 to 2005, DFG funding only accounted for between 150K EUR and 260K EUR; in accordance with recommendations, these figures had increased significantly by the period 2010 to 2012 to 651K EUR, 748K EUR and 633K EUR, respectively. By contrast, income from Federal Government funding dropped and less EU funding was raised. The changes in the third-party funding portfolio reflect the increasing importance of fundamental research at PDI. **However, PDI should continue to increase the proportion of third-party funding in the budget**.

As recommended, the infrastructure in the clean rooms has been improved considerably since the last evaluation. To achieve this, the four MBE laboratories and the central MBE clean room were merged. Furthermore, extensive building work has been carried out to maintain the building structure which is due to be completed by the end of 2014.

PDI must develop an IT strategy. Although in 2009 a common archive was set up in line with a recommendation of the last evaluation, the securing of experimental data and other central information should be updated to comply with current technical standards.

3. Core Research Areas of PDI

Core Research Area I: Nanofabrication (18.86 FTE)

CReA I very successfully focusses on the fabrication of novel nanostructured crystals and fundamental growth mechanisms. PDI's expertise in this field stands out internationally. The work on a solid state version of the Lithium-ion battery is also impressive. Furthermore, the investigations on large band-gap oxides for high-voltage electronics are extremely innovative. Scientific work has been convincingly published in very well selected journals. It is pleasing that the work on fabricating materials has generated five patents.

In the field of phase-change materials (GST) very promising, application-related results have been achieved together with a partner in industry. Application-related achievements of this kind demonstrate that this CReA has a very firm basis for intensifying cooperation with industry. Yet greater use should be made of such opportunities, including joint, industry-funded projects.

In 2010, a junior research group for graphene was established in this CReA. The group has already produced and published top results, such as its investigations on the formation of graphene layers on SiC substrates.

Plans to expand work on graphene are well-justified and should be pursued, whereby the application potential of the topic should be exploited more thoroughly than it has so far. In view of the fact that, at present, other diverse themes are also being investigated in the CReA, it is important for the continuation of the Area's work to agree on prioritising and concentrating on central topics aligned to PDI's long-term strategy.

The overall performance of CReA I is rated as "very good to excellent".

<u>Core Research Area II: Nanoanalytics</u> (15.25 FTE)

The methodology-related area "Nanoanalytics" plays an important role in analytical services. The main focus is the characterisation and analysis of materials on a nanometer scale as well as research directed at characterisation methods designed to elucidate the mechanisms of epitaxial growth.

Particular mention should be made of the PHARAO Experiment that PDI is conducting at Helmholtz-Zentrum Berlin. It is unique as it allows for in-situ time resolved X-ray diffraction investigations during growth. There are only a few comparable experimental setups worldwide. In order to generate research questions for this experiment the measurements should, however, be evaluated with greater reference to theoretical studies.

Because of its important services, the CReA is cross-linked with most groups at the institute. The work on transmission electron microscopy (TEM), for example, is necessary for many research topics. Thus PDI should ensure that equipment remains state-of-the-art.

Scientific work in the CReA has been enhanced by convincing third-party funded projects. Achievements are published appropriately. Because of its services, the Area contributes, in particular, to the publications of other groups at PDI.

This CReA also conducts research on single atom manipulation. Individual nanostructures of a few atoms in dimension are produced by means of scanning tunneling microscopy. Whilst the findings are convincing, they hardly connect with other research at PDI. It is recommended to concentrate on investigations that lead to an improved scientific understanding of growth mechanisms.

The overall performance of CReA II is rated as "good to very good".

<u>Core Research Area III: Ferromagnet/semiconductor hybrid structures</u> (8.5 FTE)

The research in this CReA is concerned with the understanding of heteroepitaxial growth as well as structural and magnetic properties of ferromagnetic films grown on semiconductors for spintronics. The samples grown in this CReA are of the highest quality. It was a justified decision to terminate work on spin injection in planar MnAs/GaAs and concentrate on material combinations with higher spin polarisation instead. The resulting focus on so-called "Heusler alloys" has produced convincing results but publication performance should be improved.

Essentially, these studies target applications in spintronics. This is a highly ambitious goal which can only be achieved over a long-term period. Thus it is necessary to define interim goals and align the choice of topics accordingly. This will make it possible to make better use of the enormous potential of the excellent samples and acquire more targeted third-party funded projects. Intensified collaboration with external partners could also prove beneficial.

The overall performance of CReA III is rated as “good to very good”.

Core Research Area IV: Control of Elementary Excitations by Acoustic Fields (5.67 FTE)

The focus of this CReA is the control of elementary excitations in semiconductors using surface acoustic waves. The relevant scientific themes cover the whole spectrum of excitations. Particular mention should be made of the work on polaritons and their coherent modulation by acoustic fields which enjoy high visibility in the international scientific community.

The group has earned itself a place at the international forefront, as evidenced by many publications in high-impact international journals. Research is excellently complemented by third-party funded projects.

In addition to outstanding fundamental research, collaboration takes place with partners in industry. This is pleasing. Due to its small size, the group should, however, continue to focus essentially on fundamental research.

The overall performance of CReA IV is rated as “excellent”.

Core Research Area V: III-V Nanowires for Optoelectronics (17.35 FTE)

The focus of work in CReA V is the use of the specific properties of nanowires to improve optoelectronic devices and open up new functionalities and applications. The publication record of this CReA is very convincing.

The long-term research goal is to produce high-quality light-emitting diodes (LEDs) on the basis of nanowires. The group’s strategy to achieve this by growing nanowires on silicon substrates has not yet led to the intended results. However, the approach is very well chosen and this highly promising topic should therefore be continued. Innovative work has been conducted on solar water splitting using nanowires. Apart from this, it would make sense to pursue further work on developing optoelectronic devices in the infrared regime. The CReA would also benefit from involving more theoretical expertise.

One of the group’s core competencies is material growth, which has produced samples of outstanding quality. These samples should be made more available to other scientists in the context of collaborations.

The overall performance of CReA V is rated as “very good”.

Core Research Area VI: Intersubband Emitters: GaAs-based Quantum-Cascade Lasers (6.17 FTE)

This CReA concentrates on the modelling, design, fabrication and experimental investigation of terahertz quantum-cascade-lasers (QCL). The group controls the epitaxial growth of its QCL material samples outstandingly.

On the basis of specially-developed simulation software, combined with its own expertise in epitaxial growth, the CReA is able to fabricate tailored QCL which operate at precisely specified frequencies. In the context of a collaboration with the German Aerospace Center (*Deutsches Zentrum für Luft- und Raumfahrt*, DLR), for example, QCL are produced for detection in the terahertz regime. There is a demand for high-end products of this kind in the scientific community. Consideration should be given to launching a spin-off based on QCL activities.

The fundamental research questions, such as operation at high temperatures and the tunability of QCL, have been chosen purposefully. It is, however, not always clear how these ambitious goals can be achieved. Innovative approaches for new device concepts like new active regions or materials for light emission should be sought in order to maintain the international competitiveness of the research.

The overall performance of CReA VI is rated as “good to very good”.

4. Collaboration and networking

Collaboration with universities in Berlin

The Director of PDI holds a joint appointment with Humboldt-Universität zu Berlin (HU). A Head of Department, who is responsible for two Core Research Areas, is also an adjunct professor at Technische Universität Berlin (TU). In the recent past, a further seven members of PDI’s scientific staff have given individual lectures or seminars, mostly at HU, but also at Beuth University of Applied Sciences (Berlin) and Johannes Kepler University Linz (Austria). In the research sector, PDI is currently involved with two projects in two Collaborative Research Centres (*Sonderforschungsbereiche,* SFB) funded by the DFG at universities in Berlin. PDI also participates in two DFG priority programmes.

The institute should intensify its cooperation with Berlin universities as well as with other non-university research institutions at home and abroad. Its material samples make it an extremely attractive partner. PDI is encouraged to use this notable expertise to approach other institutions more proactively than it has done in the past. During the evaluation visit, the representative of HU Berlin proved to be very open to this; there are, however, manifold opportunities in Berlin in addition to HU. Not only research but also teaching should strive for more intense cooperation with Berlin universities, which would give PDI the chance to recruit more doctoral candidates. On top of this, it would allow junior postdoctoral researchers to gain the teaching experience required for their continued careers in academia. In addition to cooperation in teaching, PDI should use the opportunity to participate in structured doctoral training programmes in Berlin.

Given that PDI quite rightly considers itself to have a strong anchorage in fundamental research, the number of joint appointments should be increased in the long term. Due to the fact that the leading scientists have tenure, this objective cannot be achieved in the short term. It should be examined whether other institutional options exist to link this group with a university as has already happened in one case with the appointment of an adjunct professor. Furthermore, opportunities for joint appointments of junior professors should be examined.

Collaboration with other domestic and international institutions

An intensive and very successful cooperation exists with the Helmholtz-Zentrum Berlin. Since the end of the 1990s, PDI has operated the complex experimental facility PHARAO (see also Ch. 3, CReA II) at the photon source BESSY II in Berlin-Adlershof. As explained above, scientific collaboration with other non-university institutions should be intensified significantly.

In addition to this, PDI provides extremely good scientific services in the field of quantum-cascade lasers, amongst others for the German Aerospace Center. This work could lead to the launch of a spin-off (see Ch. 3, CReA VI).

Other collaborations and networks

In the framework of very good individual research projects, PDI also cooperates with industry. In the context of a project funded by the BMBF and one funded by the EU, for example, it has conducted successful research on light-emitting diodes in collaboration with a company.

PDI addresses further topics that would be suitable for collaboration with industry. **The institute should, therefore, specifically analyse which projects would be promising for involving companies – for example by financing doctoral positions. At present, this kind of collaboration with industry is not being utilised.**

5. Staff development and promotion of junior researchers

Staff development and personnel structure

In 2007, subsequent to the last evaluation, a new Director was appointed, and in 2008, one of the four Head of Department positions was re-filled. The Director and Heads of Department have a very good, trusting working relationship. They make excellent use of the opportunities offered by a relatively small institute. On an informal basis they share views on new ideas and potential projects.

PDI has also been very successful in recruiting international researchers at the postdoctoral level. They are initially employed on fixed-term contracts but, on principle, can be granted tenure in recognition of successful work. This notwithstanding, it makes good sense that 54% of the scientific staff are employed on fixed-term contracts, allowing a certain fluctuation amongst scientific staff. It is positive that, in the last few years, seven scientists working at PDI have moved on to more senior positions in Germany, the US, Spain, France, China, Taiwan and India.

Promotion of gender equality

There are no women amongst the leading scientists at PDI. Of the scientific staff, just under 10% of postdoctoral employees are female, whilst the figure for doctoral candidates is approx. 16%. In Germany in 2011 and 2012, approx. 20% of doctorates in physics were awarded to women; the proportion of female physics professors in the same period was roughly 9% (Source: *Deutsche Physikalische Gesellschaft*).

Even if the relatively low overall figures for women in physics in Germany are taken into account, very few women work at PDI, irrespective of the level of academic qualification or hierarchy. The situation is unsatisfactory. The target quotas set by PDI when introducing the cascade model are not ambitious enough and must be increased.

Promotion of junior researchers

One positive development following on from the evaluation seven years ago is the increase in the number of Master and PhD students being supervised at PDI. There are now 20 doctoral candidates, almost twice as many as in 2007. Between 2010 and 2012, nine doctorates were completed, the theses having been supervised at PDI. The average duration of 3.7 years for a doctorate is appropriate. **It should be possible to attract more doctoral candidates in working at PDI. As only a few scientists at PDI are entitled to supervise doctorates, cooperation should be sought with university teachers.**

PDI's doctoral candidates should be part of a structured doctoral programme. PDI does not necessarily have to create such a programme on its own but could do so in cooperation with a university and possibly other institutions.

Postdoctoral scientific staff enjoy a very good working environment at PDI and have good prospects for follow-up employment (see above). It is also pleasing that PDI has established its first internal junior research group within a CReA. Measures of this kind, such as acquiring third-party funding for a junior research group or introducing junior professorships together with neighbouring universities (see above), should be intensified. It is recommended to consider the introduction of mentoring for postdoctoral junior researchers with a view to their continued academic careers outside of PDI.

Vocational training for non-academic staff

It is welcomed that PDI has used its membership of the *Forschungsverbund Berlin e. V.* (FVB) to create opportunities for collaborative vocational training. This was not the case at the last evaluation. Two vocational positions are now financed, one in administration at FVB and one at FBH (*Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik*) being also a member of FVB.

6. Quality Assurance

Internal quality management

The Director heads the institute very competently and has a good and close working relationship with the Heads of Department/Heads of Core Research Areas. **It is recommended to establish discussion and decision-making structures to extend the existing informal mechanisms. In this context the following issues should be defined: how long-term strategies are declared to be binding, who is responsible for im-**

plementation and at which level (entire institute, Core Research Area), and at which intervals decisions and results should be evaluated.

Given the size of the institute the process of determining long-term strategies is made potentially more difficult at present by the almost overly-complex matrix structure. The establishment of Core Research Areas at PDI is convincing and has proved its worth. It should be examined whether it is still necessary to perpetuate the department structure with responsibility for staff and budgeting that exist beside the CReAs.

Quality management of the Scientific Advisory Board

The Scientific Advisory Board supports PDI very convincingly. It usually meets once a year. Between the evaluations conducted by the Leibniz Association Senate, the Board holds an audit of the entire institute. It should continue to be closely involved, especially in the ongoing development of the long-term strategy.

Implementation of recommendations from the last external evaluation

PDI has convincingly implemented a number of the 16 recommendations made at the last evaluation (see Status Report, p. A-17 ff.). However, attention must still be paid to the following recommendations from the last evaluation, which have either not or only partially, been implemented:

Recommendation 2: long-term strategy for the selection of potentially applicable new research topics / Recommendation 5: selection process for new scientific topics should be more structured: PDI has convincingly justified its anchorage in fundamental research. It must, however, develop its long-term strategy to a much greater extent and introduce a structured process for the selection of research topics (see Ch. 2 and Ch. 6).

Recommendation 3: The existing research approaches should be extended to include more theoretical research work in collaboration with external groups: The collaboration between PDI and the research group on theoretical solid state physics at HU Berlin is welcomed. Within special projects conducted by individual CReAs, PDI should also place more emphasis on theoretical input in order to be able to better identify comprehensive scientific questions at an early stage (See Ch. 3 et al.).

Recommendation 10: The IT services should be made state-of-the art: Improvements were made in 2009, but they are still not adequate (See Ch. 2).

Recommendation 12: The Institute's third-party funding, particularly from the DFG and the EU, should be substantially increased. Third-party funding income from the DFG has increased substantially. This is not the case with respect to EU funding. Given the national and international visibility and importance of PDI, third-party funding income should continue to be considerably increased overall (See Ch. 2).

Recommendation 13: The education of junior academics should be improved by way of a structured Ph.D. programme. This recommendation can also be implemented in collaboration with universities in Berlin and other research institutions (See Ch. 5).

Recommendation 14: *Cooperation with the three universities of Berlin and within the national scientific community should be further strengthened.* PDI's collaborations should still be intensified (See Ch. 4).

Recommendation 15: *PDI should develop a patent strategy, increase its number of patent applications and become more actively involved in the technological transfer of its results.* The number of patent applications has increased significantly. So far, no income could be generated from patents, but considerable costs occurred. In the light of the recommendations on long-term strategy in this report, PDI is, however, still called upon to continue improving its patents strategy (See Ch. 2).

Appendix

1. Review Board

Chair (Member of the Leibniz Senate Evaluation Committee)

Dagmar **Gerthsen**	Laboratory for Electron Microscopy, Karlsruhe Institute of Technology, Germany

Deputy Chair (Member of the Leibniz Senate Evaluation Committee)

Wolfgang E. **Nagel**	Center for Information Services and High Performance Computing, TU Dresden, Germany

Reviewers

Gernot **Güntherodt**	II. Institute of Physics A, RWTH Aachen University, Germany
Heinz **Kalt**	Institute of Applied Physics, Karlsruhe Institute of Technology, Germany
Michael **Oestreich**	Institute for Solid State Physics - Nanostructures Group, Leibniz Universität Hannover, Germany
Jörg **Osten**	Institute of Electronic Materials and Devices, Leibniz Universität Hannover, Germany
Lars **Samuelson**	The Nanometer Structure Consortium, Lund University, Sweden
Brian **Tanner**	Department of Physics, Durham University, UK
Alessandro **Tredicucci**	National Enterprise for nanoScience and nanotechnology, Pisa, Italy
Ralf B. **Wehrspohn**	Fraunhofer Institute for Mechanics of Materials IWM, Halle, Germany
Achim **Wixforth**	Institute of Physics, University of Augsburg, Germany
Josef **Zweck**	Department of Physics, University of Regensburg, Germany

Representative of the Federal Government

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

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

Susanne **Eickemeier**	Hessen State Ministry of Higher Education, Research and the Arts, Wiesbaden

2. Guests

Representative of the relevant Federal government department

absent with apologies

Representative of the relevant Land *government department*

Björn **Maul** Marie **Trappiel**	Berlin Senate Department for Economy, Technology and Research

Representative of the Scientific Board

Andreas **Waag**	Institute of Semiconductor Technology, Technische Universität Braunschweig

Representative of the Leibniz Association

Albert **Sickmann**	Leibniz-Institut für Analytische Wissenschaften – ISAS – e.V., Berlin

3. Representatives of partner institutions

Peter A. **Frensch**	Vice President for Research, Humboldt-Universität zu Berlin
Anke **Kaysser-Pyzalla**	Scientific Director Helmholtz-Zentrum Berlin
Matthias **Sabathil**	OSRAM Opto Semiconductors GmbH, Regensburg

24 September 2014

Annex C: Statement of the Institution on the Evaluation Report

Paul-Drude-Institut für Festkörperelektronik (PDI)
Leibniz-Institut im Forschungsverbund Berlin e. V.

First and foremost, PDI expresses its gratitude to the members of the evaluation commission for their efforts, in particular for the lively discussions concerning our research. We are pleased that the overall rating of our work is “very good” with parts being rated as “excellent”. We are delighted that our core competence on the fundamentals of epitaxy, new materials and nanostructures is viewed as “internationally competitive” and showing “excellent results”, with the prepared material being “outstanding by international comparison”. We are particularly pleased with the positive assessment in view of our efforts on the renewal of infrastructure, which consumed a significant fraction of our budget and imposed many experimental downtimes over the past years.

We are grateful for the report of the evaluation commission. It provides us with fresh motivation for our work and the recommendations given by the commission will form the basis for our discussions and decisions about PDI’s future strategy.