Leibniz Gemeinschaft

Der Senat

SEN 0067/07
22.11.2007

Stellungnahme zum

Paul-Drude-Institut für Festkörperelektronik (PDI)

im Forschungsverbund Berlin e. V.

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Vorbemerkung

Der Senat der Wissenschaftsgemeinschaft Gottfried Wilhelm Leibniz – Leibniz-Gemeinschaft – evaluiert in Abständen von höchstens sieben Jahren die Forschungseinrichtungen und Einrichtungen mit Servicefunktion für die Forschung, die auf der Grundlage der Ausführungsvereinbarung „Forschungseinrichtungen“[1] von Bund und Ländern gemeinsam gefördert werden. Diese Einrichtungen haben sich in der Leibniz-Gemeinschaft zusammengeschlossen. Die wissenschaftspolitischen Stellungnahmen des Senats werden vom Senatsausschuss Evaluierung vorbereitet, der für die Begutachtung der Einrichtungen Bewertungsgruppen mit unabhängigen Sachverständigen[2] einsetzt. Die Stellungnahme des Senats sowie eine Stellungnahme der zuständigen Fachressorts des Sitzlandes und des Bundes bilden in der Regel die Grundlage, auf der der Ausschuss Forschungsförderung der Bund-Länder-Kommission für Bildungsplanung und Forschungsförderung (BLK) überprüft, ob die Einrichtung die Fördervoraussetzungen weiterhin erfüllt.

Auf der Grundlage der vom Paul-Drude-Institut für Festkörperelektronik (PDI) eingereichten Unterlagen wurde eine Darstellung der Einrichtung erstellt, die mit dem Institut sowie den zuständigen Ressorts des Sitzlandes und des Bundes abgestimmt wurde (Anlage A). Die vom Senatsausschuss Evaluierung eingesetzte Bewertungsgruppe hat das PDI am 13./14. November 2006 besucht und daraufhin einen Bewertungsbericht erstellt (Anlage B). Auf der Grundlage dieses Bewertungsberichts und der vom PDI eingereichten Stellungnahme zum Bewertungsbericht (Anlage C) erarbeitete der Senatsausschuss den Entwurf einer Senatsstellungnahme. Der Senat der Leibniz-Gemeinschaft hat die Stellungnahme am 22. November 2007 erörtert und verabschiedet. Er dankt den Mitgliedern der Bewertungsgruppe für ihre Arbeit.

1. Beurteilung und Empfehlungen

Der Senat schließt sich der Beurteilung und den Empfehlungen der Bewertungsgruppe an. Das PDI arbeitet als Forschungsinstitut an der Herstellung und Analyse von ultradünnen Materialschichten zur Verwendung in Halbleiter-Nanostrukturen und konzentriert sich bei seinen Arbeiten als eine der wenigen Einrichtungen in Deutschland auf neue Materialien bei III-V Halbleitern, welche durch Molekularstrahlepitaxie-Verfahren hergestellt werden können. Das Institut hat durch verschiedene innovative Arbeiten und Entwicklungen sowie durch den Aufbau mehrerer technologisch hervorragender Epitaxie-Anlagen zu wesentlichen Fortschritten auf diesem Forschungsgebiet beigetragen und erbringt insgesamt sehr gute bis exzellente wissenschaftliche Leistungen. Das PDI hat die Empfehlungen des Wissenschaftsrates aus dem Jahr 1999 zum größten Teil umgesetzt und sich seit der letzten Evaluierung exzellent entwickelt. Der Rang der Forschungsarbeiten des PDI, welche in einigen Bereichen weltweit führend sind, wird durch die bemerkenswerte Zahl und die sehr gute Qualität der Publikationen des Instituts belegt.

Die gegenwärtigen Arbeiten des PDI beschränken sich ausschließlich auf Fragestellungen aus dem Bereich der Grundlagenforschung. Zukünftig sollte das Institut innerhalb der durchgeführten Projekte verstärkt auch die mögliche Nutzung der neuen Materialien in Halbleiterbauelementen untersuchen, indem es beispielsweise entsprechende Bauelement-Prototypen selbst

[1] Ausführungsvereinbarung zur Rahmenvereinbarung Forschungsförderung über die gemeinsame Förderung von Einrichtungen der wissenschaftlichen Forschung (AV-FE)

[2] Status- und Funktionsbezeichnungen, die in diesem Dokument in der männlichen oder weiblichen Sprachform verwendet werden, schließen die jeweils andere Sprachform ein.

fertigt und analysiert. Des Weiteren wird dem Institut empfohlen, bei der Auswahl neuer Forschungsprojekte künftig jeweils das Potential der Arbeiten für mögliche Halbleiteranwendungen zu prüfen und seine Sichtbarkeit bei möglichen Anwendern seiner Forschungsergebnisse zu erhöhen. Das PDI sollte zudem eine Patentstrategie erarbeiten und die Zahl seiner Patentanmeldungen erhöhen.

Die theoretische Begleitung von am PDI durchgeführten Projekten zum besseren Verständnis der erzielten experimentellen Ergebnisse durch entsprechende Modellierungen und Simulationen sollte durch eine Kooperation mit externen Theoriegruppen deutlich verstärkt werden.

Die seit der letzten Evaluierung stark verbesserte Kohärenz des Forschungsprogramms ist ein Verdienst des ehemaligen Institutsdirektors, welcher zu den Pionieren bei der Anwendung der Molekularstrahlepitaxie zur Herstellung neuartiger Halbleitermaterialien zählt. Die Bemühungen der gegenwärtigen Interimsleitung, dieses Forschungsprogramm auf gleich hohem Niveau fortzusetzen, werden anerkannt. Das PDI sollte allerdings die Organisationsstruktur seiner Forschungsarbeiten überprüfen, da gegenwärtig eine klare Verantwortlichkeit für die Koordination der verschiedenen *Core Research Areas* des PDI fehlt. Das Forschungskonzept des designierten neuen Institutsdirektors, welcher im November 2007 seine Arbeit aufnimmt, ist hochaktuell und sehr relevant für die Erforschung neuer Halbleitermaterialien. Der Wissenschaftliche Beirat des PDI arbeitet gut, sollte aber in Zukunft seinen Sachverstand noch stärker nutzen, um das Institut bei der Auswahl neuer Forschungsprojekte kritisch zu beraten.

Das PDI sollte sich in den nächsten Jahren um eine deutliche Steigerung seiner Drittmittel von DFG und EU bemühen, die derzeit noch nicht zufrieden stellend sind. Die technische Ausstattung des PDI war bisher auf einem ausreichend hohen Niveau, um gute Leistungen zu erzielen. Um zukünftigen Anforderungen gerecht zu werden, müssen jedoch jetzt neue Investitionen vorgenommen werden. Deutliche Verbesserungen sind auch bei der Infrastruktur des Instituts erforderlich.

Die Kooperation mit den drei Berliner Universitäten im Rahmen dreier Sonderforschungsbereiche wird begrüßt und sollte in Zukunft noch weiter ausgebaut werden, insbesondere durch eine Erhöhung der Zahl gemeinsamer Berufungen. Auch die Kooperationen mit anderen Forschungsinstitutionen auf nationaler und europäischer Ebene und mit industriellen Partnern sollten verstärkt werden. Das PDI engagiert sich in der Nachwuchsförderung und verfügt über exzellente Nachwuchswissenschaftler. Es wird empfohlen, die Zahl der Doktoranden zu erhöhen und die Ausbildung der Nachwuchswissenschaftler durch ein strukturiertes Doktorandenprogramm zu verbessern.

Das PDI ist eine international gut positionierte und für Deutschland unverzichtbare Forschungseinrichtung für die Herstellung und Analyse von neuen Materialien für III-V Halbleiterbauelemente mittels der Molekularstrahlepitaxie. Es erfüllt nach Auffassung des Senats ohne Einschränkung die Anforderungen, die an Einrichtungen von überregionaler Bedeutung und gesamtstaatlichem wissenschaftspolitischen Interesse zu stellen sind. Eine Eingliederung des PDI in eine Hochschule wird nicht empfohlen. Aufgrund der notwendigen personellen und technischen Ausstattung und der Langfristigkeit einiger Projekte können die Aufgaben des PDI nicht von einer Hochschule erfüllt werden.

Der Wissenschaftliche Beirat des PDI wird gebeten, dem Senat nach drei Jahren über die Umsetzung der Empfehlungen, insbesondere im Hinblick auf die Verstärkung der Bemühungen zum Technologietransfer und die Verbesserung der Infrastruktur und der technischen Ausstattung des Instituts, zu berichten.

2. Zur Stellungnahme des PDI

Das PDI hat zum Bewertungsbericht Stellung genommen (Anlage C).

Das Institut bedankt sich für die konstruktiven Vorschläge zu einer weiteren Verbesserung seiner Leistungsfähigkeit. Der zukünftige Institutsdirektor, welcher im November 2007 seine Arbeit am PDI aufnimmt, wird sich aktiv dafür einsetzen, die Empfehlungen umzusetzen.

Der Senat begrüßt den konstruktiven Umgang mit den ausgesprochenen Empfehlungen.

3. Förderempfehlung

Der Senat der Leibniz-Gemeinschaft empfiehlt Bund und Ländern, das PDI als Forschungseinrichtung auf der Grundlage der Ausführungsvereinbarung „Forschungseinrichtungen“ weiter zu fördern.

Senate Evaluation Committee

SAE 0129/06
07.11.2006

Annex A: Presentation

Paul Drude Institute for Solid State Electronics (PDI)[1]
Berlin

Contents

Appendices

[1] This presentation, compiled by the Evaluation Office, has been approved by the Institute and by the relevant Federal and State departments.

List of Abbreviations

2H	Hexagonal crystal structure with AB stacking
6H	Hexagonal crystal structure with ABCACB stacking
Al	Aluminium
As	Arsenic
AvH	*Alexander von Humboldt-Stiftung* (Alexander von Humboldt Foundation)
BESSY	*Berliner Elektronenspeicherring-Gesellschaft für Synchrotronstrahlung m.b.H.*
Bi	Bismuth
BLK	*Bund-Länder-Kommission für Bildungsplanung und Forschungsförderung* (*Bund-Länder* Commission for Educational Planning and Research Promotion)
BMBF	*Bundesministerium für Bildung und Forschung* (German Federal Ministry of Education and Research*)*
C	Carbon
Co	Cobalt
Cu	Copper
C-plane	(0001) Lattice Plane of the Wurtzite Crystal Structure
DFG	*Deutsche Forschungsgemeinschaft* (German Research Foundation)
DVD	Digital Versatile Disc
EU	European Union
Fe	Iron
FU Berlin	*Freie Universität Berlin*
FVB	*Forschungsverbund Berlin e. V.*
Ga	Gallium
Ge	Germanium
GK	*Graduiertenkolleg* (Research Training Group)
HU Berlin	*Humboldt-Universität zu Berlin*
In	Indium
K	Kelvin
KLR	*Kosten-Leistungs-Rechnung* (cost accounting system)
Li	Lithium
MBE	Molecular-Beam Epitaxy
M-plane	(1-100) Lattice Plane of the Wurtzite Crystal Structure
MQW	Multiple Quantum Well
MRAM	Magnetoresistive Random Access Memory
N	Nitrogen
NEDO	New Energy and Industrial Technology Development Organization

Ni	Nickel
NICOP	Naval International Cooperative Opportunities in Science and Technology Program
NTT	Nippon Telegraph and Telephone Corporation
O	Oxygen
P	Phosphorus
PDI	Paul Drude Institute for Solid State Electronics
QCL	Quantum-Cascade Laser
RG	Research Group
RTN	Research Training Networks
SAB	Scientific Advisory Board
SAE	*Senatsausschuss Evaluierung* (Senate Evaluation Committee)
SAW	Surface Acoustic Wave
Sb	Antimony
SEM	Scanning Electron Microscopy
SenWFK-BE	*Senatsverwaltung für Wissenschaft, Forschung und Kultur Berlin*
SFB	*Sonderforschungsbereich* (Collaborative Research Centre)
Si	Silicon
TEM	Transmission Electron Microscopy
THz	Terahertz
TU Berlin	*Technische Universität Berlin*
TVöD	*Tarifvertrag für den öffentlichen Dienst* („Salary scale for public employees in Germany“)
WR	*Wissenschaftsrat* (German Science Council)

1. Development and Funding

The Paul Drude Institute (PDI) for Solid State Electronics was founded in 1992, based on a recommendation by the German Science Council (*Wissenschaftsrat,* WR) following the evaluation of the institutes of the former Academy of Sciences of the German Democratic Republic.

The PDI developed out of the *Zentralinstitut für Elektronenphysik* and, in 1992, was included in the so-called *“Blaue Liste”* in which associated institutes are jointly financed by the German Federal States (*Länder*) and the German Federal Government (*Bund*) according to the *Ausführungsvereinbarung “Forschungseinrichtungen”.*[2] The PDI became a part of the *Forschungsverbund Berlin e. V. (FVB)*, founded in 1992, which is the legal entity responsible for eight member institutes within the state of Berlin.

[2] Ausführungsvereinbarung zur Rahmenvereinbarung Forschungsförderung über die gemeinsame Förderung von Einrichtungen der wissenschaftlichen Forschung (AV-FE)

The previous evaluation of the PDI by the German Science Council took place in 1998. Based on the statement by the WR and a joint statement by the German Federal Ministry of Education and Research (BMBF) and the responsible Ministry of the State of Berlin (*Senatsverwaltung für Wissenschaft, Forschung und Kultur Berlin, SenWFK-BE*) in March 2000, the committee of the *Bund-Länder* Commission for Educational Planning and Research Promotion (BLK) decided to continue funding the PDI.

2. Mission, Tasks, Main Work Areas and Scientific Environment

The **mission** of the PDI is to conduct research in materials science and solid state physics with special emphasis on low-dimensional systems in nanostructured semiconductors. The unique properties of low-dimensional systems are strongly influenced by the structural and energetic peculiarities of interfaces. Therefore, by intentionally adjusting the nature and distribution of internal interfaces in a static and dynamic way, the mechanical, optical, electronic, and magnetic properties of nanostructured solids can be tuned over a wide range by means of materials engineering at the atomic level. The Institute thus tries to find answers to the challenge, as to whether, in the future, information and communication technology will rely on new principles, such as quantum computing, or on the realisation of new functionalities in new nanomaterial combinations.

The Institute is organised in three research groups (RG), as depicted in the organisational structure in Appendix 1 (top), and one project group (“PHARAO”) dedicated to in-situ x-ray diffraction during epitaxial growth at the Berlin synchrotron facility (BESSY). This structure represents the areas of competence of the PDI staff and the corresponding allocation of research equipment. Research is carried out in interdisciplinary research areas, in which scientists, engineers, and technicians from the research groups collaborate for a certain period of time. In the past three years, the members of the research groups have been involved in six **core research areas**, which are linked to each other as depicted in Appendix 1 (bottom).

“Ferromagnet-Semiconductor Hybrid Structures”

This research area is devoted to investigations of ferromagnet-semiconductor and ferromagnetic semiconductor hetero- and nanostructures, which are expected to yield a highly spinpolarised current in the semiconductor and/or exhibit a high tunnelling magnetoresistance in magnetic-tunnelling-junction geometries. In particular, PDI aims at understanding the mechanisms involved in spin injection and spin alignment, the relation between the crystallographic order and the spin polarisation as well as the nature of the exchange interaction in magnetic compounds. An important criterion for the materials selection is a Curie temperature above room temperature.

Two types of ferromagnetic systems are investigated: dilute magnetic semiconductors and ferromagnetic metal films on semiconductors. In addition, spin-filtering effects upon tunnelling through symmetry-adapted insulating barriers are under investigation.

“Control of Elementary Excitations (Photons, Electrons, Spins, Magnetic Flux) by Acoustic Fields”

Acoustic fields are used in this research area to modulate the dimensions and physical properties of micro- and nanostructures. These tunable temporal and spatial modulations are employed for the control of elementary excitations in semiconductors and superconductors. The elastic vibrations are inserted as bulk or surface acoustic waves (SAW), which are temporally and spatially varying strain fields. The strain wave may be accompanied by an alternating electric field with the wavelength of the SAW, if the wave is travelling in piezoelectric III-V semiconductors or on a piezoelectric substrate.

The interaction of these acousto-electric fields with photons, electrons, spins, and magnetic fluxes is investigated. These studies give insight into fundamental processes with the perspective of developing new concepts for information storage and mechanisms for data processing. The research in this area is divided into the subtopics: (i) generation and control of high-frequency acousto-electric vibrations in thin films, (ii) dynamic photon control, and (iii) transport and manipulation of electronic and magnetic objects in thin films.

“Group-III Nitrides for Optoelectronics”

The research activities for wide-gap group-III nitrides such as (Ga,In,Al)N cover the investigation of GaN films with nonpolar surfaces such as the *M*-plane ((1-100) orientation of the wurtzite crystal structure), of group-III nitride heterostructures, and of GaN-based nanostructures. The research includes the role of interfaces, structural defects, and strain as well as optical properties. Nonpolar surfaces of the wurtzite crystal structure are important for light-emitting diodes without internal electric fields and for polarisation-sensitive photodetectors. Anisotropically strained *M*-plane GaN films on lithium aluminate ($LiAlO_2$) are investigated with regard to their very large in-plane polarisation anisotropy, which can be used for polarisation-sensitive photodetection without a macroscopic polarisation filter. For heterostructures, GaN/(Al,Ga)N and (In,Ga)N/GaN multiple quantum well (MQW) structures of both orientations, *C*-plane ((0001) orientation of the wurtzite crystal structure) on 6H-SiC and *M*-plane on $LiAlO_2$, are investigated. For nanostructures, GaN quantum dots embedded in AlN on *C*- and *M*-plane 6H-SiC are synthesised and characterised. The self-alignment and real structure of defect-free GaN nanocolumns and nanodisks on Si(111) are studied by transmission electron microscopy (TEM).

The research activities for dilute group-III nitrides focus on the correlation of the inherent defect structure of (Ga,In)(N,As) epilayers and QWs on GaAs(001) with their optical properties. (Ga,In)(N,As) QWs with a nitrogen content of 2 to 5% usually exhibit interface undulations and lateral nano-sized composition fluctuations, which reduce the luminescence efficiency. Their origin is investigated by spatially resolved electron energy-loss spectroscopy in combination with chemically sensitive dark-field TEM. The growth conditions are optimised to realise quantum wells emitting at about 1.5 μm and edge-emitting lasers at 1.44 μm.

“Intersubband Emitters: GaAs-based Quantum-Cascade Lasers”

The research comprises the detailed investigation of the conditions for the lasing process and the lasing properties of GaAs-based quantum-cascade lasers (QCLs). The GaAs-based materials system is used as a model system for mid-infrared QCLs, since the barrier height can be varied without introducing any significant strain into the system. On the one hand, QCL structures are designed, grown, processed, and characterised with a systematic parameter variation, for example of the doping density. On the other hand, a numerical model is developed to correlate the results calculated for a large number of parameters with experimental investigations of the transport, optical, and lasing properties. By varying the internal physical properties such as population inversion and field distribution, the threshold current density and the lasing energy are optimised as a function of device parameters (e. g. design, doping profile) and operation conditions (e. g. operating field strength). Recently, investigations on GaAs-based THz QCLs have started.

“Nanofabrication”

The research is based on the PDI’s long-standing expertise in the field of molecular-beam epitaxy (MBE) of III-V semiconductors, which permits growth control on the atomic scale. The growth mechanisms, self-organisation effects, morphological instabilities, and the kinetics of interface formation and interface ordering are studied to realise artificial low-dimensional semiconductor systems and nanostructured materials. The heteroepitaxy of dissimilar materials and the interface and defect engineering are utilised to generate new and distinct materials combinations and specific epitaxial orientations with tailored functionalities. Close collaboration with the Core Research Area “Nanoanalytics” is, according to the PDI, indispensable for the successful fabrication of nanostructures.

At present, the nanofabrication research covers a broad range of functional materials systems: low-dimensional GaAs-based heterostructures, metastable ternary and quaternary III-V compounds, and the combination of dissimilar materials by extreme heteroepitaxy.

Complementary to the nanofabrication by growth-controlled techniques, atom-by-atom manipulation by low-temperature scanning tunnelling microscopy is used to assemble individual nanostructures with strict control of size, geometry, and composition.

“Nanoanalytics”

The nanofabrication and nanoscience at the PDI require dedicated analytical in-situ and ex-situ characterisation techniques with high sensitivity and spatial resolution. In-situ reflection high-energy electron diffraction is utilised to monitor the growth process during MBE and to control the growth on the atomic scale. In addition, in-situ x-ray diffraction with synchrotron radiation (“PHARAO Project Group” at BESSY) is carried out to investigate surfaces and, in particular, interfaces of epitaxial layers during growth and in real time. Furthermore, local spectroscopy on individual atomic clusters and molecules is performed in-situ by low-temperature scanning tunnelling microscopy.

In addition, ex-situ high-resolution x-ray diffraction is routinely used to characterise the structure of as-grown materials. Transmission electron microscopy (TEM) methods including high-resolution imaging, electron diffraction, and electron energy-loss spectroscopy are applied to study the structural and chemical properties of individual units, ensembles of nanostructured materials, and their interfaces. In parallel, scanning electron microscopy (SEM) in combination with cathodoluminescence spectroscopy and imaging probe the local optical properties.

The **research groups** represent the areas of competence of the research staff and the allocation of research equipment, and they provide the platform of knowledge and expertise on which the interdisciplinary core research areas operate. Each research group is headed by one senior scientist with a *Habilitation* or an equivalent scientific qualification.

The **“Nanostructuring Research Group”** provides most of the custom-designed nanostructured materials needed for research in solid state physics devoted to information technology. MBE is used to realise artificial III-V semiconductor structures, ferromagnet-semiconductor heterostructures, and metastable heterostructures with a designed length scale in the growth direction down to the monolayer level. The epitaxial growth process and the structural properties of low-dimensional systems are investigated. To avoid cross-contamination and to ensure highest sample purity, the different materials must be grown in separate growth chambers (for instance, ferromagnetic metals and Heusler alloys cannot be grown in an As-containing growth chamber, Si cannot be grown in a previous III-V chamber). All MBE systems are equipped with reflection high-energy electron diffraction for in-situ growth monitoring and one system additionally with reflectance difference spectroscopy for special monitoring purposes. High-resolution x-ray diffraction and TEM are important integral parts of the “Nanostructuring Research Group” in order to characterise the structural and chemical perfection of the nanostructures with high sensitivity and high spatial resolution during or immediately after fabrication for rapid feedback. High-resolution TEM in combination with spatially resolved electron energy-loss spectroscopy are applied for extensive investigations.

The **“Semiconductor Spectroscopy Research Group”** investigates elementary excitations (photons, electrons, and spins) and their control by SAWs using dedicated spectroscopic techniques. The transport properties of ferromagnetic layers, in particular the planar and anomalous Hall effects, are studied in high magnetic fields at low temperatures. In order to determine the spin-injection efficiency of ferromagnet-semiconductor hybrid structures, their magneto-optical properties, in particular the degree of circular polarisation, is studied for light-emitting diodes with a ferromagnetic layer on top. The design and the transport properties of quantum-cascade lasers are explored, and their optical properties are investigated using intersubband (mid- and far-infrared) and interband (near-infrared) spectroscopy. The optical polarisation properties of wide-gap group-III nitride films with nonpolar surfaces are examined using polarised transmission, reflectance, photoreflectance, and photoluminescence spectroscopy. Defects and carrier diffusion in dilute (Ga,In)(N,As) films are studied using cathodoluminescence spectroscopy in a scanning electron microscope. The quantum transport of carriers and spins is investigated theoretically.

The **“Nanoacoustics Research Group”** studies structural, mechanical, magnetic, and electronic properties of laterally nanostructured solids. The stress evolution during growth of the nanostructures, e. g. of self-organised SiGe and InAs quantum dots, is measured in-situ by a custom-designed cantilever beam magnetometer and correlated with the involved growth processes. In the case of ferromagnetic nanostructures, their magnetisation and magnetic anisotropies are also determined. From direction-dependent magnetostriction measurements, the magnetoelastic coupling constants are derived, which provide direct insight into the mechanisms and nature of the exchange interaction. Magnetic force microscopy is employed to investigate the magnetic domain structure. As an ultimate bottom-up approach for the preparation of artificial nanostructures of predefined size and shape, a low-temperature scanning tunnelling microscope has been developed. Utilising atomic and molecular manipulation, nanostructures of fundamental interest are assembled atom-by-atom or molecule-by-molecule and investigated by elastic and inelastic tunnelling spectroscopy.

The **“PHARAO Project Group”** at BESSY studies the kinetics of epitaxial growth and the formation of (hetero) interfaces in real time by synchrotron x-ray diffraction and analyses the observed data quantitatively by kinematic theory. This project group, which is part of the “Nanostructuring Research Group”, is evaluated separately every three years according to the regulations of BESSY GmbH for the PDI beamline.

According to the PDI, the research in the field of information and communication technology is important on a **national level** for the development of competitive products and services in the future. Therefore, the BMBF provides extensive funding for research in information and communication technology in several programmes, among them the nanoQUIT programme, which directly supports projects in the Core Research Areas “Ferromagnet-Semiconductor Hybrid Structures” and “Control of Elementary Excitations by Acoustic Fields”. In addition, a magnetoresistive random access memory (MRAM) programme is pursued at Infineon Technologies

AG in collaboration with IBM Deutschland GmbH, which demonstrates the interest of national industry in spin- and magneto-electronics.

The exploration of light emitters for new wavelength ranges in the Core Research Areas “Group-III Nitrides for Optoelectronics” and “Intersubband Emitters” aims at the deep ultraviolet region on the one hand and at the THz region on the other. According to the PDI, the Institute’s concept to fabricate hexagonal group-III nitride heterostructures on nonpolar planes to avoid the internal electric fields has greatly improved the internal quantum efficiency of ultraviolet light emission and has attracted great interest from national and international laboratories working on solid state lighting and next-generation digital versatile discs (DVD). The national significance of the work on THz sources based on intersubband emitters is evidenced by a recent BMBF research action programme named Terahertz Systems in the framework of “IT-Research 2006” and “Optical Technology”.

In the view of the PDI, the Core Research Areas “Nanofabrication” and “Nanoanalytics” with the central growth method MBE combined with in-situ and ex-situ characterisation are the backbone of the research activities at the Institute. MBE allows the atomically controlled growth of low-dimensional heterostructures with high structural perfection. The feasibility of combining very dissimilar materials with different physical properties on the subnanometer scale is the most important requirement for exploring new physical phenomena and new device functionalities. The tailored epitaxial growth combined with the detailed understanding of the nanostructure and the direct correlation with the mechanical, electrical, optical, and magnetic properties forms the basis for the **unique research profile** of the PDI in Germany.

The PDI considers its collaboration with leading national establishments with an overall research profile not dissimilar to its own to be a criterion for the national significance of the Institute. The three leading national establishments with an overall research profile to a certain extent similar to the one of the PDI are the Walter Schottky Institute, *Technische Universität München*, the Max Planck Institute for Solid State Research, Stuttgart, and the Center of Nanoelectronic Systems for Information Technology (CNI) at the Research Centre Jülich. In addition, the PDI is actively involved in three Collaborative Research Centres (*Sonderforschungsbereiche*, SFBs) with universities and research institutes in Berlin and one Research Training Group (*Graduiertenkolleg*, GK): SFB 296, Growth-correlated properties of low-dimensional semiconductor structures; SFB 546, Structure, dynamics, and reactivity of transition-metal-oxide aggregates; SFB 658, Elementary processes in molecular switches at surfaces; GK 1025, Fundamentals and functionality of size- and interface-controlled materials: Spin- and optoelectronics.

The PDI defines its role as a **non-university institute** which combines cutting-edge nanostructure materials science with solid state physics embedded in the rapid development of information and communication technology. The strategy to fulfil this role is based on an interdisciplinary research approach. Intricate and flexible research strategies are combined with a comprehensive scientific infrastructure to become truly competitive at international level. In addition, this requires competence in different scientific disciplines, highly specialised experimental and technical skills, committed project management, and sustainable networking with national and international partners with respect to specific, long-term scientific goals.

The required scientific knowledge, the technological know-how, and the interdisciplinarity are preserved and developed by a continuous and flexible hiring policy, whereby individual scientists and technicians can be employed on contracts usually lasting longer than, e. g. the duration of a Ph. D. thesis or a postdoctoral fellowship. At the same time, the flexibility to attract non-permanent scientific staff at the postdoctoral and visiting scientist level allows for a rapid build-up of new competence in strategic key areas.

In addition to the interdisciplinary approach, according to the PDI, long-term and well focussed commitment and dedication on the part of the scientists involved are needed for the success of the research areas pursued at the PDI. This is considered to be most obvious in the “PHARAO” project at BESSY, which took seven years from the initial planning to produce the first scientific results worth publishing. The need to preserve and develop technological expertise and scientific knowledge over longer periods is reflected by the level of precision which the nanofabrication activities have reached. The continuous exploitation of new materials combinations, e. g. for spintronics, also requires close interaction between nanofabrication and dedicated nanoanalytics to avoid costly and time-consuming trial-and-error attempts.

Maintenance, development, and servicing of most of the equipment used in the experiments require well-trained and experienced technicians and technical engineers. The same holds true for the (small) device processing clean-room laboratory.

Finally, to be successful in new strategic key research areas at the international level, the Institute believes that it is necessary to be able to (re)act quickly with a critical mass of both experienced staff and sophisticated equipment.

The PDI considers that its **international visibility and reputation** have increased significantly since the last evaluation in 1998, as revealed by the large number of scientific publications in leading international journals, the number of invited talks given by PDI scientists at major international conferences, the great demand amongst international visiting scientists to carry out research at the PDI, and the interest of international research laboratories in collaboration. Leading international establishments with an overall research profile similar to that of the PDI are the University of California at Santa Barbara (USA), Naval Research Laboratory, Washington (USA), Nippon Telegraph and Telephone Corporation (NTT) Basic Research Laboratories, Atsugi (Japan), *École Polytechnique Fédérale de Lausanne* (Switzerland), and *Technische Universität Wien* (Austria). The exchange of visiting scientists with some of these and other establishments secures the continuation of networking activities at the international level. This helps to maintain the international competitiveness of the Institute in research and to sharpen the research profile, in particular due to the interplay between cooperation and competition. The PDI is actively involved in several international projects funded by the European Union (EU), and it provides leading international scientists with special custom-designed nanostructures.

The **medium-term objectives** of the six core research areas have been developed according to the Institute’s latest research programme, which has been approved by the Scientific Advisory Board. With the appointment of a new director, there may be changes in the objectives described below:

“Ferromagnet-Semiconductor Hybrid Structures”

Future research aims at decisively improving spin-injection efficiency to obtain a highly spin-polarised current in the semiconductor. For efficient spin injection, three different materials systems will be investigated: dilute magnetic wide-gap semiconductors, half-metallic ferromagnets, and appropriate tunnelling barriers for spin filtering. Main tasks will be the development of methods to improve long-range ordering without inducing interfacial reactions or surface segregation and to investigate the relation between the crystallographic order and the spin polarisation.

“Control of Elementary Excitations (Photons, Electrons, Spins, Magnetic Flux) by Acoustic Fields”

The fabrication of higher-frequency interdigital transducers will become an important part of the research activities on SAW. For dynamic photon control, the investigations of the interaction between acoustic waves and polarisations will be continued as the PDI recently demonstrated that excitons can be coherently controlled by acoustic waves. For transport and manipulation of electronic and magnetic objects in thin films, a new concept for a SAW-based single photon detector will be studied and single-carrier/single-spin/single-vortex transport will be investigated using high-frequency, high-power SAWs.

“Group-III Nitrides for Optoelectronics”

For wide-gap group-III nitrides, the development of polarisation-sensitive photodetectors based on GaN films will be completed. The main research in the future will be on GaN-based nanostructures. In the area of dilute group-III nitrides, the focus will be on basic electrical and elastic properties of quaternary (Ga,In)(N,As) alloys. Basic studies on the electrical and mechanical properties will be continued as a function of epitaxial orientation using a series of (Ga,In)(N,As) epilayers.

“Intersubband Emitters: GaAs-based Quantum-Cascade Lasers”

The research activities will focus on THz-QCLs based on the GaAs/(Al,Ga)As materials system. One aim is the growth of buried layers of intermetallic compounds for the bottom contact and bottom waveguide layer in THz QCLs. Furthermore, several techniques for single-mode tuning of the resonator in broad-band QCLs will be explored.

“Nanofabrication”

In this core research area, the growth of high-quality (Al,Ga)As/(In,Ga)As heterostructures on GaAs(110) will be extended to other substrate orientations with a higher index plane for creating quantum wells and self-assembled quantum wires. These low-dimensional structures are then incorporated into cavities for SAW applications. For metastable semiconductor compounds, the basic kinetics of the surfactant-mediated growth of metastable (Ga,In)(N,As) epilayers will be investigated to clarify the influence on morphological instabilities, interface structure, and composition inhomogeneities. In the area of heteroepitaxy of group-III nitrides, the possible field of application of ammonia-assisted MBE for the growth of nitride-based heterostructures and devices will be studied in detail. Further activities are directed toward the epitaxial growth of nitride-based nanostructures and toward the study of interface effects on the self-assembled or self-organised growth mechanism. For functional organic molecules linked to semiconductor surfaces, the aim is to combine the well-established functionality of conventional semiconductors with new functionalities based on molecular structures.

“Nanoanalytics”

The in-situ x-ray study of the growth kinetics during MBE at the PDI will investigate the incorporation of a number of atomic species in several binary semiconductors. For the ex-situ study of structure-property relations in nanostructured materials, the epitaxial orientation of nitride-based nanocolumns and -disks in dependence of the substrate material as well as the lateral strain variation along single nanodisks will be investigated by cathodoluminescence spectroscopy and imaging as well as TEM. The self-assembly of the nanostructures by lateral surface manipulation will be another objective. With regard to interfaces in heteroepitaxial systems, the atomic arrangement of interfaces will be studied by in-situ x-ray diffraction (“PHARAO” project) and by ex-situ advanced TEM techniques. In-situ microscopy techniques will be introduced to investigate the dynamic processes at interfaces and during the order-disorder transition.

The PDI's **long-term strategy** will be in line with the Institute's long-term research programme, where the research in nanostructure materials science and solid state physics explores new possibilities of storing and processing information and exploits new wavelength ranges for light emission, higher modulation frequencies, and higher power levels for information processing. In view of the appointment of a new director in the near future after the recent retirement of the PDI director, the PDI considers information on the long-term strategy highly speculative.

3. Structural Features and Organisation

The PDI is legally part of the ***Forschungsverbund Berlin e.V.*** (FVB), which acts as a service provider for joint administrative services and as a legal holding for eight research institutes in Berlin. Scientifically, the PDI, a member of the Leibniz Association, operates as an autonomous research institute headed by the director. Legally, the PDI is represented by the director together with the managing director of the FVB.

The PDI is organised in three research groups (see Appendix 1, top) and one project group. This organisational structure defines the areas of competence and the allocation of research equipment. To make the most efficient use of the resources available, the research is carried out in six interdisciplinary research areas which are linked to each other as shown in Appendix 1 (bottom).

The supervisory committee of the FVB is the **Board of Trustees** *(Kuratorium)*. This board consists of one representative of the state of Berlin and the Federal Government, an academic representative jointly appointed by the Berlin universities, four academic members from outside Berlin, and three members from the industrial sector. Institute- and subject-specific aspects are dealt with by the Institute's own subcommittees, preparing decisions for the Board of Trustees. The board decides on matters including

- the Institute's business plans and programme budgets and the FVB's financial plan
- the FVB's annual financial statement and the annual report of the FVB's Executive Board
- the acceptance and release of the FVB's research institutes
- the appointment of the members of the academic committees
- the appointment of the scientific directors, the administrative director, and the senior scientists in the case of W2/W3 appointments
- the principles for appeal procedures, success reviews, and strategies for implementing research findings.

The **Scientific Advisory Board** (SAB) is composed of at least six, but no more than twelve internationally recognised scientists (among them three Physics Nobel Prize Winners to date), who are closely linked to the working areas of the Institute. The members are appointed for a four-year term and only half of the members begin and end a term concurrently. One consecutive reappointment is possible. According to the PDI's statutes, the SAB advises the director and the Board of Trustees of the FVB on fundamental issues relating to the scientific work programme. It evaluates scientific performance at regular intervals, carries out a formal biannual assessment (**audit**), and advises the Board of Trustees on appointment procedures for the director and leading scientists.

The **quality of scientific research** is supported further by a number of obligatory standards, which have been established at the Institute:

- Guidelines for scientific conduct: All research activities at the PDI have to comply with the internal “guidelines for securing good scientific conduct”. These guidelines include mechanisms to deal rapidly and fairly with allegations of scientific misconduct or disputes related to authorship practices, sharing of data, mentoring and supervision, or comparable issues.
- Internal review system: All publications have to undergo a strict internal review process. Before submitting a manuscript to a journal, an internal form, summarising the results of the internal review and signed by the reviewer, has to be deposited at the office of the Institute’s secretary. The internal report, together with a copy of both the submitted and published manuscripts, has to be kept in the Institute’s files for ten years.
- Institute and research group seminars: In the research groups, regular seminars and meetings are held, in which actual research results and technical questions are presented, discussed, and evaluated. Discussion groups coordinate the research of the subtopics being actively investigated. Currently, nine discussion groups are active. Discussion groups can be discontinued and initiated according to the scientific needs. These discussion groups are headed by one or two staff scientists and usually meet twice a month to discuss problems and achievements in the group. The dissemination and discussion of information is supported by an intranet-discussion-site, where every member of the PDI can comment on and discuss topics of interest to the PDI.
- Cost accounting system (*Kosten-Leistungs-Rechnung,* KLR): KLR was recently introduced as a means of measuring research “efficiency” in an objective way. The KLR framework allows for a formal annual assessment of the results in the core research areas. Important criteria include: scientific publications, patents, talks and poster presentations at national and international conferences, as well as externally awarded funds. The potential, validity, and value of this approach are still being evaluated.
- Rehearsal of talks and previews of posters before going to conferences: All talks and posters to be presented at conferences have to be rehearsed and discussed publicly at the Institute.

Achieving **equally attractive working conditions and opportunities** for all employees is considered to be an important management task by the PDI. The PDI is implementing the essential features of the *Bundesgleichstellungsgesetz*, to which the Federal Government and the states have committed themselves in the agreement on the implementation of equal opportunities in their joint promotion of research (AV-Glei). These measures complement existing regulations, such as the agreement on the principles of equal opportunities (*Vereinbarung zur Chancengleichheit*), which was taken by the FVB board of directors in October 2004. The Institute has an equal opportunity commissioner and a deputy equal opportunity commissioner. On the reporting date (31.12.2005), the proportion of female employees at the Institute was 28.8%, whereby 5.1% of the scientific and higher management personnel were women (see Appendix 6). In the last 12 months, three female and five male employees have been hired. The PDI states that, when filling a vacant scientific or technical position, women are especially encouraged to apply. The Institute offers the possibility of flexible working hours, which helps to alleviate difficulties in combining family and work. Gender-specific promotion programmes include a special award for young female scientists, granted annually by the FVB for outstanding thesis work.

4. Resources and Personnel

The PDI is located in the centre of Berlin, which makes it especially attractive for visiting scientists and guests. It occupies three floors (3rd, 6th, and 7th) of an eight-floor building run by the *Humboldt-Universität zu Berlin* (HU Berlin) with additional rooms in the basement and on the 2nd floor. Although the building is very close to an underground line, vibrational disturbances are low because of a special rubber damping of the rails. However, instruments which are sensitive to electric and magnetic fields require shielding (e. g. TEM and SEM). Each of the three PDI research groups is mainly located on one of the three floors. The clean-room facilities and the PDI library are also on the 3rd floor, the mechanical workshop uses a room on the 2nd floor, the low-temperature scanning tunnelling microscope (LT-STM) and the x-ray diffractometers are installed in the basement.

The PDI has a small **in-house library** with a small selection of the journals and books that are used most frequently in daily work at the Institute. Most of these journals can be also accessed online. Articles and books that are not available at the PDI library are usually procured within two days, either from an institution in Berlin or via the ‘subito’ library service, by two half-time librarians.

IT services at the PDI are provided for the typical requirements of a research institute, such as experiment control, data acquisition, data processing, storage and visualisation, numerical computation, publishing, and communication. The IT infrastructure is organised on three levels, personal computers (PCs), local area network (LAN), and corporate network. The computer facilities at the PDI consist of about 120 PCs and seven laptops, which are used with a wide range of Windows- or Linux-based applications, a local network relying on a BNC-based LAN with a bandwidth of 10 Mbit/s per segment, which is connected to the FVB’s corporate network and internet by optical fibres allowing a bandwidth of 100 Mbit/s, and eight servers for general service as well as three servers for numerical calculations (among them a cluster machine). A permanently maintained and updated firewall protects the entire network infrastructure from outside attacks.

The **facilities** for nanostructuring include several MBE systems, each of them dedicated and optimised for producing and investigating the various specific materials systems and nanostructures, which present the basis for all core research areas. One MBE system that is characterised by highest purity and reproducibility is used for the fabrication of low-dimensional III-V semiconductor heterostructures with a complex layer sequence and structure design. Ferromagnet-semiconductor hybrid structures are realised in a specially arranged two-chamber MBE system combining the requirements for an As-free growth of metals with the preparation of tailored (Al,Ga,In)As epilayers. The group-III nitride layers and heterostructures with high-quality interfaces are grown in a plasma-assisted and As-free MBE. Dilute and metastable (In,Ga)(N,As) nitrides and dilute magnetic semiconductors are prepared in conventional MBE systems. All facilities are equipped with reflection high-energy electron diffraction for in-situ growth monitoring. The ex-situ structural characterisation is performed by x-ray diffractometry and transmission electron microscopy in close cooperation with the Core Research Area “Nanoanalytics”. The PDI's “PHARAO” experiment at BESSY consists of the beamline, a six-circle diffractometer, and three MBE chambers. All epitaxy chambers are continuously on site, a feature differing from most competing beamlines at other synchrotrons. The synchrotron light is shared with two neighbouring beamlines with 20% of the time being available for the measurements. The PDI is autonomous in administering the experiments at this beamline.

The facilities for optical spectroscopy include continuous-wave photoluminescence and photoluminescence excitation spectroscopy from the ultraviolet (325 nm) to the near-infrared spectral region (1.7 µm), Raman spectroscopy, transmission, reflectance, and photo-reflectance spectroscopy, time-resolved photoluminescence spectroscopy on a pico- to microsecond time scale from the ultraviolet (240 nm) to the near-infrared spectral region (1.3 µm), pump-and-probe spectroscopy with a subpicosecond time resolution, Fourier-transform spectroscopy for the mid- and far-infrared spectral regions, and cathodoluminescence spectroscopy and imaging in a scanning electron microscope. The spectroscopic techniques for the near-infrared to ultraviolet spectral regions can also be used with a spatial resolution down to about 1 µm and in magnetic fields up to 16 Tesla. At the same time, the incoming and detected light can be linearly or circularly polarised. Magnetotransport experiments can be performed up to magnetic fields of 16 Tesla and down to temperatures of 50 mK.

An ultrahigh-vacuum cantilever-beam magnetometer (CBM) is employed for in-situ measurements of the stress and the magnetic properties (magnetisation, magnetic anisotropy, magneto-elastic coupling) of ferromagnet-semiconductor hetero- and nanostructures. This magnetometer is attached to an MBE-system fully equipped with surface analytical instrumentation for in-situ structural investigations. For ex-situ investigations of the morphology and the magnetic domain configuration, an atomic force microscope is available. Furthermore, a low-temperature scanning tunneling microscope (LT-STM) with a minimum operating temperature of 7 K has been built. With the LT-STM, artificial nanostructures of predefined size and shape can be assembled by atomic and molecular manipulation and investigated with atomic resolution by elastic and inelastic tunneling spectroscopy.

The PDI's clean room is equipped with the standard facilities for optical and electron-beam lithography, including wet and dry chemical etching as well as a direct laser writer for rapid mask fabrication. Thermal and electron-beam evaporators as well as a sputtering system are available for the preparation of metallic and insulating films.

In addition to its mission of being an institute of basic research, the PDI offers **services** comprising the supply of custom-designed nanostructure samples, measurements of specific samples, and the transfer of knowledge (patents, licences, consulting) to external partners within projects as part of joint collaboration with public institutions (free of charge) and on a commercial basis. Services are mainly based on the Institute's research activities. This has not changed since the last evaluation.

The Institute's annual **budget** amounted to a total of 6.9 Mio. € in 2005 (see Appendix 2). The institutional support thereof was 5.6 Mio. € (81%) and has been at approximately this level for the last three years. Third-party funding in relation to total financial resources reached 19% in 2005, 17% in 2004, and 21% in 2003. The most important source of third-party funding is the Federal Government of Germany.

In 2005, 4.0 Mio. € were provided for personnel, 1.4 Mio. € for materials, supplies and equipment, and 1.3 Mio. € for investments. On the report date, 31.12.2005, the Institute had a total of 73 employees (66.2 full-time equivalents; see Appendix 4). Of these, 42% of the positions were for academic and senior management staff. Not including doctoral candidates, 16 % of the academic staff and senior management were paid at group E15 level according to the *Tarifvertrag für den öffentlichen Dienst* (TVöD) or higher, and were exclusively financed from institutional resources.

The seven doctoral candidates (4.2 full-time equivalents) were all employed on a temporary basis on the report date, 31.12.2005, and were 57% financed from institutional resources and 43% from third-party resources. Other staff (technicians, administration) were essentially (91%) financed from institutional resources. Among the academic and senior management staff, 32% were employed on temporary contracts. There were 26 employees paid according to group E14 TVöD, 20 (77%) of those were financed from institutional resources. Of these 20 persons, 90% were employed on permanent contracts. All employees funded by third-party resources were employed on temporary contracts.

Approximately 29% of the academic staff were aged 39 or younger, 39% were 40 to 49, and 32% were aged 50 or older. At the Institute, approximately 32% have worked at the establishment for less than five years, 19% for five to nine, and 48% for 10 to 14 years. A total of 21 (29%) women were employed at the PDI as of 31.12.2005. The only woman on the academic and senior management staff was on a temporary contract, whereas of the women listed as other staff, 63 % were on permanent contracts.

In their **assessment of resources**, the Institute points out that, by combining institutional and project funding, the PDI has established and maintained a competitive scientific basis for current research activities. The laboratory facilities and the equipment installed at the PDI are dedicated to basic research. Networking with national and international partners and hosting visiting scientists constitute an important mission of the PDI. In this way, the Institute establishes a continuous exchange of know-how and human resources, in particular graduate students and junior researchers, with leading groups worldwide. Many of the multilateral and international research projects, in which the PDI is now active, were initiated during prior networking with potential partners. In this early exploratory stage, the validity of new ideas and concepts can be tested, and possible collaboration can be exploited. In the view of the PDI, this not only leads to a more realistic estimate of the necessary experimental efforts and budget required, but also to a higher success rate in grant applications as well as in project goals. The cost accounting system (KLR) has been recently introduced as a means for measuring research "efficiency" in an objective way. Important criteria include: scientific publications, patents, talks and poster presentations at national and international conferences, as well as externally awarded funds. The potential, validity, and value of this approach are still being evaluated. However, for a realistic estimate of the planned budget for a third-party project, the use of the KLR is regarded as being very important.

The PDI foresees a number of funding-related problems affecting the future competitiveness of the Institute:

- Scientific equipment and infrastructure need renewing after 10 to 15 years' operation.
- The salary level for both scientists and engineers makes it extremely difficult to attract internationally renowned individuals.
- The new legal framework for the employment of scientists, engineers, and technicians (TVöD) hardly acknowledges previous work experience. The provisions for bonus payments in this new legal framework are insufficient and too bureaucratic.
- There are insufficient financial resources for a PDI visiting scientist programme for international collaboration.

All **academic (and non-academic) positions** open are regularly advertised, initially as an internal announcement within the FVB and then in nationally distributed print media and on the Internet, i. e., on the PDI website and on the Internet platform of the *Physik Journal* of the *Deutsche Physikalische Gesellschaft* (www.prophysik.de). Candidates are chosen on the basis of their previous scientific performance and their expertise and qualifications in the relevant scientific areas. Selected candidates are invited to a job interview including the presentation of a seminar talk.

According to the Institute's statutes, the regulations for appointing the heads of the research groups are similar to those at German universities, i. e., in addition to advertising internationally, the procedure includes selecting and inviting the best candidates for interview and requesting expert opinions from referees. This process leads to a short-list of three candidates. The appointment is made by the director in agreement with the Institute's Scientific Advisory Board.

In 2005, the majority of the postdoctoral researchers came from the following continents: Europe (26%), America (16%), and Asia (37%). Four permanent staff members are from Japan, Brazil, Austria, and Russia.

In the next few years, several of the PDI's scientific and technical staff members will retire. In view of the medium-term expectations, which are based on a stagnant overall budget at best, the Institute will have to consider reducing the total number of staff due to the continuous increase in salaries and other personnel-related costs. In this context, the PDI considers it important to examine the continuously increasing costs for administration critically.

With respect to the scientific staff, the most important change was the retirement of the last PDI director at the end of September, 2006. The candidates for the directorship were selected together with the *Humboldt-Universität zu Berlin* (HU Berlin), in line with the requirements of the PDI's research programme. An offer has been made for the directorship of the PDI and a chair at the HU Berlin. In the light of the number of staff scientist positions, which are currently filled on a temporary basis (5) and which will become available due to retirement in the next five years (3), the new director will have a great deal of flexibility to incorporate her/his ideas in human-resources development.

5. Promotion of Junior Academics and Cooperation

For the **promotion of students and professional training of young scientists**, the PDI generally collaborates with the Institute of Physics at the HU Berlin. In the period from 2003 to 2005, eight doctoral students received their degrees. One student received a Master degree at the *Fachhochschule für Technik und Wirtschaft Berlin*. Since the last evaluation, the fraction of non-German young scientists and students has increased substantially. In December 2005, approximately 75% of the doctoral students were non-German.

Students and postdoctoral researchers receive further training through seminars and colloquia with external guests as well as informal internal seminars given by PDI scientists. In addition, the students are called upon to participate actively in the "International Humboldt Graduate School on Structure, Function and Application of New Materials" and in the "Autumn School on Materials Science and Electron Microscopy" held annually at the HU Berlin. The seminar for doctoral students held regularly at the PDI serves as a forum to practice oral skills and for a general exchange of information. In the last three years, the PDI has been actively involved in

Research Training Networks (RTN) funded by the EU comprising the projects “Nanospectra” and “Quantum magnetic dots: Model structures for exciting new applications”.

Five members of staff were **offered chairs or professorships** at universities between 2000 and 2006, which were all accepted.

PDI staff are involved in **teaching** at all three Berlin universities and at the Berlin campus of Stanford University. The teaching obligations of the former director of the PDI, who had a professorship at the HU Berlin, were defined in the collaboration contract with the university, which was periodically reviewed by the internal university committee. The PDI also plays an active role in the “International Humboldt Graduate School on the Structure, Function and Application of New Materials”, which started in 2001. Due to the limited capacities for training non-scientific staff at the PDI, this type of professional training is conducted in cooperation with the *Ferdinand-Braun-Institut für Höchstfrequenztechnik* in Berlin. Currently, two trainees are working in the field of microtechnology.

The PDI considers its research to be embedded in a variety of **collaborations** on the regional, national, and international level. In addition to numerous bilateral projects between the PDI and university groups, the PDI participated or is still participating in three SFBs, one Research Unit (*Forschergruppe)*, and one Research Training Group (*Graduiertenkolleg*), funded by the German Research Foundation (*Deutsche Forschungsgemeinschaft,* DFG), (see p. 8). Several collaborative research programmes funded by the EU and the BMBF are conducted in close contact with the Max Planck Institute for Solid State Research (Stuttgart), the *Gesellschaft für Angewandte Mikro- und Optoelektronik mbH* (Aachen), the *Centre de Recherche sur l’Hétéro-Epitaxie et ses Applications, Centre National de la Recherche Scientifique* in Valbonne (France), the IMEC in Leuven (Belgium), and the University of Montpellier II (France).

The PDI has also been involved in an international project with institutions in Japan, Russia, and Germany entitled, “Nanoscale Elasticity and Quantum Effects in Artificial Semiconductor Structures”, funded by the New Energy and Industrial Technology Development Organization (NEDO) in Japan, which was coordinated by NTT Basic Research Laboratories in Atsugi, Kanagawa (Japan). In addition, the PDI was engaged in a joint research programme on p-type doping of GaN and (Al,Ga)N layers grown by MBE, funded by the Office of Naval Research in the USA within the Naval International Cooperative Opportunities in Science and Technology Program (NICOP). The cooperation partners were the West Virginia University in Morgantown, West Virginia (USA), and the Polytechnical University of Madrid (Spain).

Within Germany, the PDI has several **industrial partners**. Technical advice was provided for JPK Instruments (Berlin) in their phase of foundation and in the first two years of full operation. With *CreaTec Fischer & Co. GmbH* in Erligheim, the PDI develops MBE systems for the fabrication of heterostructure field-effect transistors on the basis of GaN and low-temperature scanning tunnelling microscopes for application in MBE systems. The PDI considerably assisted teleBIT-com GmbH in Teltow in improving their SAW-based sensor devices. In the last three years, the PDI’s international industrial partners were the Research Laboratories of Motorola Inc. in Tempe, Arizona (USA), and NTT in Atsugi, Kanagawa (Japan).

In order to maintain its international scientific standing, the PDI considers it essential to have access to sufficient and flexible funds to support **visiting scientists** from around the world. The PDI’s Scientific Advisory Board has repeatedly emphasised the importance of visiting scientists for the successful operation of the PDI and strongly supports the current policy on international scientific exchange. In the years 2003 to 2005, a total of 59 visiting scientists spent at least one week at the PDI, 29 of them more than three months. During the last years, four recipients of Humboldt Research Awards, granted by the Alexander von Humboldt Foundation (AvH), spent an extended period of time working at the PDI. Additionally, there were five visiting scientists who were Humboldt Research Fellows, supported by the AvH during their stay at the PDI. In the rankings including the institutes in the Leibniz Association, published in the AvH's Annual Report 2005[3], the PDI comes in third place in terms of the number of Humboldt Research Awards for the years 2000 to 2005. In 1999, the director of the PDI received the Max Planck Research Award, in recognition and furtherance of outstanding academic achievements, which is granted jointly by the Max Planck Society and the AvH. The award money has been used to intensify existing and initiate new international collaborations between the PDI and scientists around the world. PDI scientists are regular visitors at other research laboratories and universities. During the years 2003 to 2005, PDI scientists went on 33 visits to other establishments, lasting from at least one week to three months.

6. Results – Research, Development and Services

The PDI considers **publications** in international peer-reviewed journals as well as conference proceedings and contributions to books to be a major part of its scientific mission. Publications, together with invited talks and contributions at international conferences determine the Institute's visibility in the international scientific community. The PDI aims at publication in international high-impact journals with a peer-review system. For shorter (letter) papers: Applied Physics Letters, Europhysics Letters, Nature, the Rapid Communication section of Physical Review B, Physical Review Letters, etc., and for longer papers archival journals such as the Journal of Applied Physics, Journal of Crystal Growth, Physical Review B, physica status solidi, and others. Joint publications with external collaborators are also encouraged, particularly those based on research cooperation. During the present reference years 2003 to 2005, the PDI published 297 papers in peer-reviewed journals and 57 papers in conference proceedings and contributions to books (see Appendix 7).

Presentation of results at **conferences** represents an important aspect of the publication concept. Key results are submitted to the most important conferences in the relevant scientific areas. The PDI considers the organisation of scientific meetings and conferences to be an important service to the scientific community and, in addition, a mark of recognition of its own scientific performance. Among the most important were the 26th International Symposium on Compound Semiconductors (1999) in Berlin, the 3rd Japanese-German Workshop on Recent Progress in Advanced Materials Devices, Processing and Characterisation (2000) in Berlin, the 3rd International Symposium on Blue Laser and Light Emitting Diodes (2000) in Berlin, the 4th Japanese-Spanish-German Workshop on Recent Progress in Advanced Materials Devices, Processing and Characterisation (2002) in Cordoba (Spain), the 6th Japanese-German Workshop on Recent Progress in Advanced Materials Devices, Processing and Characterisation (2006) in Berlin, and the *Sonderkolloquium zum 100. Todestag von Paul Drude* (2006) in Berlin. Furthermore, members of the PDI's scientific staff are involved in the organisation and management of numerous external events as member of programme committees, advisory boards, and steering committees for national and international conferences and workshops.

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[3] http://www.humboldt-foundation.de/de/stiftung/jahresbericht/jahresbericht_2005.pdf (p. 117)

Although the PDI sees its main research focussed on basic science, it is interested in the **exploitation of results and technology transfer**. Therefore, technologically interesting results are always checked for potential patenting and application by an industrial partner. For example, two international patent applications have been filed referring to a new concept for magnetic reconfigurable computation which has been developed at the PDI. Since this concept is based on magnetoresistive elements very similar to the storage elements in MRAM, there are good prospects for a future technological application. One commercial success is the low-temperature scanning tunnelling microscope, built as a prototype by a former staff member at the PDI. Another recent example is the cooperation with the German company *CreaTec Fischer & Co. GmbH* to develop an ammonia-assisted MBE system for the fabrication of nitride-based vertical-cavity surface-emitting lasers. This activity is supported by the BMBF. A high-temperature diffusion cell has already been patented and commercialised by this company. The PDI holds four national and two international **patents**. Since the last evaluation, they have applied for eight patents. So far, no revenue has been generated by intellectual property rights.

Due to being an institute concentrating on basic research, **knowledge transfer** mainly occurs through publications and scientific cooperation, patents, and technology transfer. PDI scientists are involved in several cooperative research projects with universities, other research institutions, and industrial partners (see also Section 5). Cooperation with guest scientists pursuing the same scientific goals as the Institute is considered by the PDI to be a very efficient channel for mutual knowledge transfer and continues to be one of its central objectives. In addition, the Institute offers its facilities and its scientific know-how to **external users**, most of whom come from start-up companies with limited access to scientific equipment. The PDI has actively contributed to the European White Book on fundamental research in materials science (2002 and 2006) by providing articles. This White Book is regarded as guidance for European politicians, who are responsible for the future orientation of science and technology. These **consultations** are important input for the scientific content of the next Framework Programme for European research.

The Institute uses a wide range of resources to impart its scientific results and findings to the **general public**. These include public events, general articles in more popular scientific journals, such as Scientific American, *Humboldt-Spektrum,* and *Spektrum der Wissenschaften*, or presentations on the PDI website. The Internet is used as a forum for information about present work. Another important example is the annual *Lange Nacht der Wissenschaften* (Science Night) in Berlin, in which the PDI has participated, presenting the “PHARAO” project at BESSY in Adlershof. The PDI’s intention is to gain the interest of young people and potential students in modern science by presenting up-to-date research topics in a popular and understandable manner.

According to the PDI, members of the staff hold **important offices** in scientific organisations and committees. This is viewed as both an indicator of the Institute’s significance on the national and international level and as a necessary service to the scientific community. In addition, PDI scientists have received a number of **prizes, awards and honorary titles** since the last evaluation, which also indicates the degree of national and international recognition that the PDI enjoys. These included the Max Planck Research Award and four Visiting Professorships in Japan and Spain.

7. Implementation of German Science Council's Recommendations

The recommendation of the German Science Council (*Wissenschaftsrat*) to continue funding in January 1999 included the recommendations listed below (in *italics*). According to the Institute, the measures introduced in response to the recommendations have also been developed further in cooperation with the Scientific Advisory Board and are briefly described below each paragraph.

a) *The existing competence in the area of molecular-beam epitaxy should be further extended and utilised as the basis for further development.*

The existing expertise in molecular-beam epitaxy (MBE) has been utilised to grow ferromagnetic semiconductors and to fabricate heterostructures of dissimilar materials, for example ferromagnetic layers on semiconductors and hexagonal nitrides on tetragonal lithium aluminate. The competence in MBE has been further extended by using x-ray diffraction based on synchrotron radiation to study the growth mechanisms in-situ and in real time.

b) *The Forschungsverbund Berlin should negotiate for all associated institutes reduced prices for energy and other consumables.*

Currently, contracts for discounts exist between the *Forschungsverbund Berlin* (FVB) and, for example, Vattenfall (energy), Air Liquide (gases, liquid nitrogen and helium), VWR International (chemicals), and several vendors of laboratory supplies.

c) *The Institute should develop a long-term research programme in close cooperation with the Scientific Advisory Board.*

In close cooperation with the Scientific Advisory Board, a long-term research programme for the Institute has been developed, which is embedded in the rapid development of information and communication technology. The research in nanostructure materials science and solid state physics explores new possibilities to store and process information and exploits new wavelength ranges for light emission, higher modulation frequencies, and higher power levels for information processing. In addition, the Institute tries to find answers to the question of whether in the future information and communication technology can rely on new principles, such as quantum computing, or on the realisation of new functionalities in new combinations of nanomaterials. The PDI research programme is evaluated every year in close cooperation with the Scientific Advisory Board.

d) *The search for the new head of the "Nanoacoustics Research Group" should look for an established scientist, who is capable to execute scientifically and technologically relevant research concepts.*

The new head of the "Nanoacoustics Research Group" implemented two new research concepts, i. e., atom-by-atom manufacturing and nanomagnetism, which have developed into world-leading research activities in the last three years. The existing activities using scanning probe microscopy combined with surface acoustic waves were exploited to the ultimate limit of probing elastic properties on the nanoscale and then terminated. Surface acoustic waves are now widely used in the Institute to modulate the electronic, magnetic, and superconducting properties dynamically and to promote spin transport in semiconductor nanostructures for quantum information processing.

e) *Interdisciplinarity in mode of operation and interrelation of research topics should be strengthened.*

The six core research areas, depicted in Appendix 1, are strongly interdisciplinary and interrelated as indicated. The staff scientists active in each core research area come from at least two research groups. The regular meetings of the nine discussion groups, based on these core research areas, promote the dissemination of results and problems as well as the interdisciplinary exchange of knowledge. Furthermore, these meetings integrate efficiently new members into the Institute, in particular visiting scientists.

f) The theory group should be incorporated more actively in the overall research programme.

Following the strong recommendations of the German Science Council in 1991, a theory group was never established at the Institute. Two staff members with a background in theoretical physics are strongly tied to the core research areas. If needed, close cooperation with theory groups both in Berlin and elsewhere is carried out.

g) The number of doctoral students appears to be too small and should be increased.

In 1997, the PDI had six Ph. D. students. In the last three years, the average number of doctoral students varied between 11 and 12.

h) The external funding through projects, in particular from the DFG, should be increased.

The amount of external funding has been significantly increased. The Institute is now actively involved in three SFBs with the three universities in Berlin.

i) The number of publications from the Research Groups “Nanoacoustics” and “Semiconductor Spectroscopy” in renowned international journals should be increased.

The improvement of interdisciplinarity in the ongoing research activities has greatly enhanced the number of publications by authors from these research groups in renowned international journals.

j) The cooperation with all three universities in Berlin should be intensified, and the PDI scientists should be involved in teaching.

In addition to the cooperation with the *Humboldt-Universität zu Berlin* (HU Berlin), based on the joint appointment of the director, and the *Freie Universität Berlin* (FU Berlin) in the field of nanomanipulation, the research cooperation with all three universities in Berlin has also been significantly intensified through the active involvement of the PDI in three SFBs with the FU Berlin, the HU Berlin, and the *Technische Universität Berlin* (TU Berlin). Prof. Dr. H. T. Grahn is actively involved in teaching at the TU Berlin, as is PD Dr. R. Koch at the FU Berlin. Dr. T. Hesjedal taught at Stanford University in Berlin. Since January 2006, he has been replaced by Dr. D. Schaadt. Prof. Dr. K. H. Ploog has been very actively involved in establishing the International Humboldt Graduate School funded by the DFG, in addition to his teaching at the HU Berlin.

k) The PDI research programme should be coordinated with the non-university institutions Ferdinand Braun Institute (FBH), Heinrich Hertz Institute (HHI), and Fraunhofer Institute for Applied Solid-State Physics (IAF).

From the very beginning, the PDI research programme was compatible with both university and non-university research laboratories to avoid a duplication of research activities. In the last five years, the above mentioned institutions have strongly devoted their activities to applied research and development for industry with large wafer sizes, dedicated clean-room facilities, and production-type equipment. Therefore, the gap between these activities and those at the PDI, which are research-oriented as recommended by the German Science Council in 1991, has increased. Nevertheless, collaborations are going on in several areas. In addition, collaboration with the Institute for Semiconductor Physics (IHP) in Frankfurt/Oder, which has undergone two reverse changes in the R&D direction in the last ten years, has started again.

In addition, there are a number of recommendations of the German Science Council the PDI has commented on.

l) The heterostructures grown by MBE for external users should be sold at market prices.

Since the PDI focuses on fundamental research, selling MBE-grown structures at market prices has turned out to be unrealistic.

m) It is recommended that the Institute should develop marketable products.

The PDI focuses on fundamental research. With the present scientific and nonscientific staff and equipment, it is not possible to develop marketable products.

n) The research on quantum wires and dots should be continued.

Since the researcher, who was in charge of this research field, left the Institute in 2000, the activities in this area were strongly reduced. During the last two years, the PDI has started to investigate GaN nanocolumns and quantum dots as well as Sb-based lowdimensional systems to reactivate this research direction.

o) The emphasis of the future tasks in the "Semiconductor Spectroscopy Research Group" should be reduced with regard to service for the other research groups, but increased with regard to the concentration of independently chosen research topics.

The current structure of the Institute relies on close cooperation between the three research groups as evidenced by the six core research areas. The topics investigated in the "Semiconductor Spectroscopy Research Group" are embedded in these six core research areas and therefore cannot be considered as being service. The selection of research topics is carried out for the Institute as a whole.

p) Research cooperation, which leads to further developments for application-related products, should be strengthened.

The PDI focuses on fundamental research. Therefore, it has not strengthened research cooperation with regard to application-related products.

q) The leading researchers should be more strongly involved in the formulation of the research programme.

The nine discussion groups promote the dissemination of results and problems as well as the interdisciplinary exchange of knowledge. At the same time, both leading researchers and staff scientists have become more involved in the process of defining new goals and new directions in the research programme

r) The Scientific Advisory Board should have more long-term members and a long-term chairman.

Between 1999 and 2005, Prof. J. Wolter was chairman of the Scientific Advisory Board. Since Prof. Wolter served a total of nine years on the Scientific Advisory Board, he had to leave the Board at the end of 2005 and a new chairman had to be elected at the last meeting in early 2006. Since 1999, only one member has left the Scientific Advisory Board before his term ended.

s) The consumables of the institutional support should be kept at a sufficiently high level to ensure an appropriate use of the equipment and MBE facilities.

Over the last years, the consumables financed from institutional funding have been effectively reduced due to the increasing cost of personnel, increasing fees for the administration in the FVB, additional fees for the FVB's corporate network, and the membership fees for the Leibniz Association. Currently, a considerable fraction of the consumables is covered by external funding.

t) The laboratory space is in part not appropriate and could be improved.

A substantial improvement of the laboratory space is only possible by substantial financial investments. For example, after 14 years of operation, the clean-room facilities for the MBE laboratories need to be completely renewed.

u) For the registration and preservation of patent rights, funds have to be made available in the budget.

Given the current size of the Institute's budget, it is not even possible to register and preserve the rights for a smaller number of patents.

v) The PDI should give scientists more often the possibility to obtain a Ph. D. degree or Habilitation.

In 2005, six students received their Ph. D. degrees. Since the last evaluation, one scientist has completed his *Habilitation* and a second *Habilitation* was discontinued because the scientist obtained a university professorship outside Germany.

w) A closer collaboration with industry is desirable.

Since the PDI focuses on fundamental research, closer collaboration with industry in Germany is rather difficult to achieve.

x) The theory group should aim at a closer cooperation with the Weierstrass Institute for Applied Analysis and Stochastics as well as the theorists of the Berlin universities.

There has never been a theory group at the PDI. The two staff members with a background in theoretical physics work together closely with colleagues at the PDI and, when necessary, carry out their research work with other theory groups in Berlin and elsewhere.

y) The PDI should increase their ties with regard to application-oriented research areas with other institutions, for example with the Institute for Semiconductor Physics (IHP) in Frankfurt/Oder.

The PDI has recently started a new collaboration with the IHP in Frankfurt/Oder on heteroepitaxy of metal oxides on silicon and metals research for microelectronics. In the previous years, collaboration was not possible because the orientation of the IHP research had changed significantly.

Response to the recommendations of the German Science Council with regard to the evaluation of the four "*Blaue Liste*" physics institutes in Berlin

The following measures have been introduced by the Institute in response to the German Science Council's recommendations of January 1999 regarding the four *"Blaue Liste"* physics institutes in Berlin, (*Stellungnahme zu den Physik-Instituten der Blauen Liste in Berlin – Über-*

greifende Gesichtspunkte) and have been developed further since then in close cooperation with the Scientific Advisory Board.

a) The work of the Ferdinand Braun Institute (FBH) and the PDI on GaN should be combined in view of a continuous supply chain.

The FBH did not perform any work on GaN for many years. More recently, the FBH has been working on electronic devices based on group-III nitrides with polar orientations, while the PDI focuses on light-emitting emitters and photodetectors based on group-III nitrides with nonpolar orientations.

b) For investigations on electron transport and point defects in devices, the FBH and PDI should increase their complementary collaboration.

The PDI has investigated electron transport and point defects in samples and devices produced at the FBH, which has resulted in several joint publications by P. Krispin (PDI) and A. Knauer (FBH) over the last few years.

c) Patent activities and their utilisation should be increased.

The PDI responded to a similar statement in the previous section (see p. 23, recommendation u).

d) The integration of the scientific staff in the realisation of the research programme should be improved.

The PDI responded to a similar statement in the previous section (see p. 22, recommendation q).

e) The laboratory space of the PDI needs in parts to be improved.

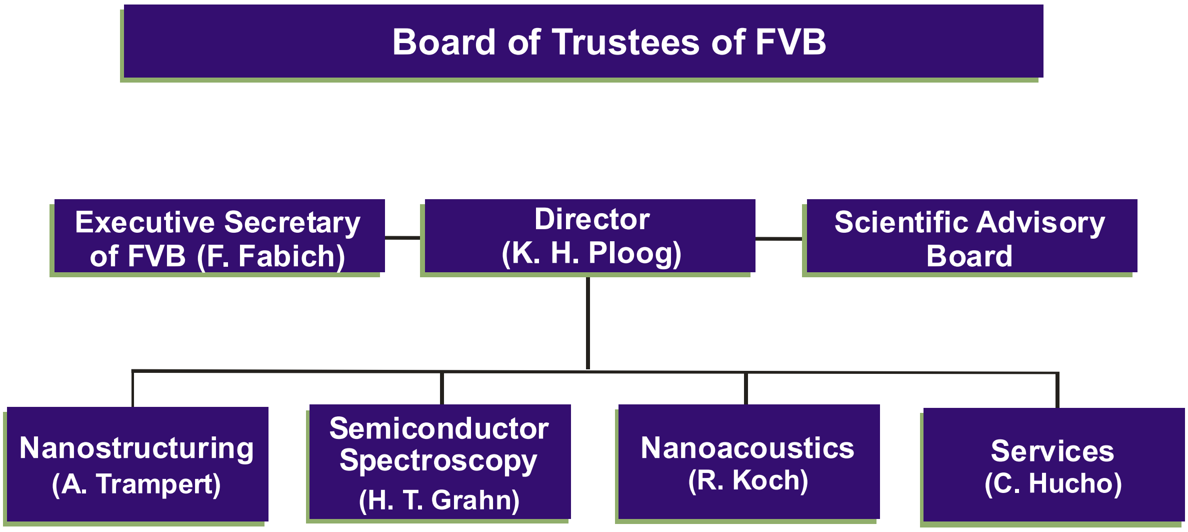
The PDI responded to a similar statement in the previous section (see p. 23, recommendation t).

f) The external funding, in particular by industry, is still too small.

For an institute with the research profile and size of the PDI, it is very difficult to obtain significant external funding directly from industrial partners.

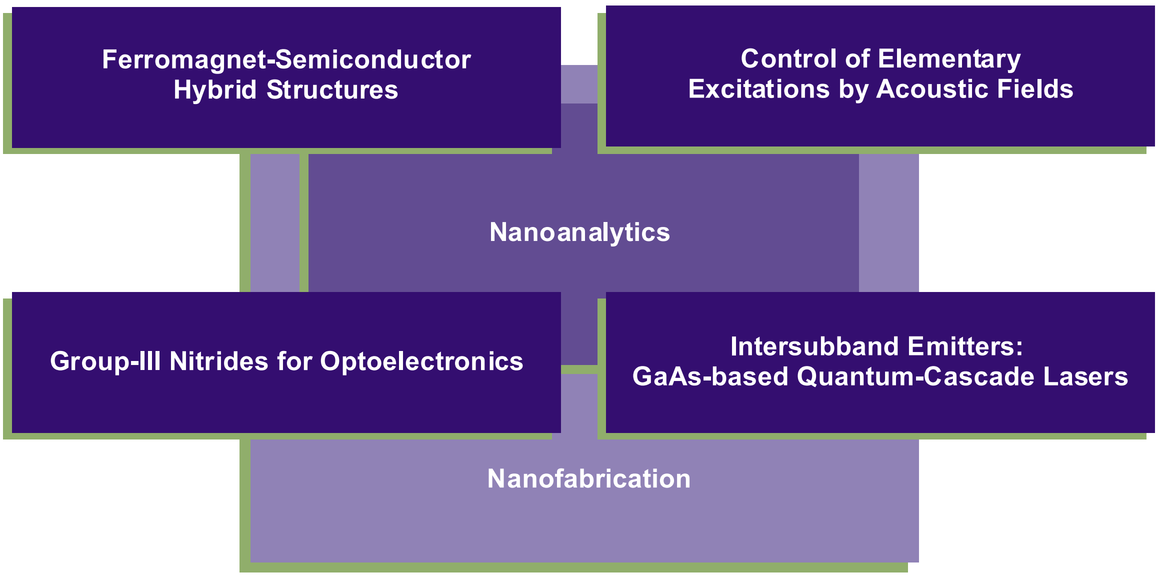
Appendix 1

Organizational Structure



Organisational structure of the PDI including the three research groups (as of August 11th, 2006).

Research Structure



Research structure of the PDI showing the six core research areas and their interrelation.

Appendix 2

Financial Resources and Allocation of Resources

(Figures in € 1,000)

		2005	2004	2003
I. Financial Resources (income)[1]		**6,882**	**7,050**	**7,164**
1.1	**Institutional Funding**	**5,560**	**5,860**	**5,672**
	-Federal States[2]	2,780	2,930	2836
	-Federal Government[2]	2,780	2,930	2836
	-Other institutional funding	0	0	0
	Institutional funding as a proportion of total financial resources	*81%*	*83%*	*79%*
1.2	**Research Support**	**1,281**	**1,155**	**1,461**
	As a proportion of total financial resources	*19%*	*16%*	*20%*
1.3	**Services, Contracts, Licences, Publications**	**0**	**0**	**0**
	As a proportion of total financial resources	*0%*	*0%*	*0%*
1.4	**Other Third-party Resources**	**31**	**20**	**25**
	As a proportion of total financial resources	*< 1%*	*< 1%*	*< 1%*
1.5	**Balance from Previous Year**	**10**	**15**	**6**
II. Expenditures		**6,882**	**7,005**	**7,130**
2.1	Personnel[3]	4,022	3,977	3,922
2.2	Materials, supplies, equipment[4]	1,425	1,473	1,318
2.3	Investments (not including building investments)	1,262	1,545	1,875
2.4	Building investments	0	0	0
2.5	Special positions (where applicable)	0	0	0
2.6	Allocation to reserves	173	10	15
2.7	*For information only: DFG charges[5]*	*143*	*150*	*145*

[1] Actual revenues in each year classified by financial resource; not incl. money in transit
[2] Support according to BLK decision
[3] Thereof personnel costs FVB/WGL: 208 T€/18 T€ (2005), 203 T€/18 T€ (2004) and 187 T€/17 T€ (2003)
[4] Thereof materials FVB: 45 T€ (2005), 79 T€ (2004), 34 T€ (2003)
[5] Not included in revenues and expenditures

Appendix 3

Third-party Resources Classified by Organisational / Scientific Unit[1]

(Figures in € 1,000)

	2005	2004	2003
I. Total	**1,312**	**1,175**	**1,486**
- DFG (German Research Foundation)	153	155	259
- Federal Government	955	759	963
- Federal States (German *Länder*)	0	0	0
- EU project funding	161	218	210
- Foundations, other research support	12	23	29
- R&D ass., industry, services, licences	0	0	0
- Other third-party resources[2]	31	20	25
II. By organisational unit[3]			

[1] Actual expenditure in each year classified by financial resource; not incl. money in transit unless explicitly specified

[2] Donations, membership fees etc.

[3] According to the Institute, it is not possible to assign a larger number of projects to a single research group or even a single core research area.

Appendix 4

Staffing acc. to Sources of Funding and Pay Scale[1]

- Personnel (financed by institutional and third-party resources) in terms of full-time equivalents [reporting date 31.12.2005] -

	Total Number	Number Financed by	
		Institutional Resources	Third-party Resources
Total	**66.20**	**55.40**	**10.80**
1. Academic Staff and Senior Management	**30.50**	**24.50**	**6.00**
- S (B4 and above)	0.00	0.00	0.00
- S (B2. B3) C4	1.00	1.00	0.00
- E15Ü	1.50	1.50	0.00
- E15	2.00	2.00	0.00
- E14	26.00	20.00	6.00
- E13	0.00	0.00	0.00
2. Doctoral Candidates	**4.20**	**2.40**	**1.80**
3. Other Staff	**31.50**	**28.50**	**3.00**
- E12, E11, E10	9.50	6.50	3.00
- E9, E8, E7	17.00	17.00	0.00
- E6	1.00	1.00	0.00
- E5, E4, E3	2.00	2.00	0.00
- E2, E1, other staff	0.00	0.00	0.00
- Trainees	2.00	2.00	0.00

[1] Employment positions acc. to *Tarifvertrag für den öffentlichen Dienst* (TVöD) or other collective pay agreements for staff financed by institutional or third-party resources (incl. trainees and guest scientists, but excluding diploma students, student assistants and contracts for work and services)

Appendix 5

Staffing acc. to Organisational / Scientific Unit

- Personnel (financed by institutional and third-party resources) in terms of full-time equivalents [reporting date 31.12.2005] -

	Total	Academic Staff and Senior Management [1]	Doctoral Candidates[2]	Other Staff, Trainees
Entire Establishment	**66.20**	**30.5**	**4.20**	**31.50**
Management	4.00	2.00	0.00	2.00
RG “Nanostructuring”	19.90	9.50	2.40	8.00
RG “Semiconductor Spectroscopy”	17.10	14.00	0.60	2.50
RG “Nanoacoustics”	7.20	4.00	1.20	2.00
Services	18.00	1.00	0.00	17.00

[1] Employment positions acc. to TVöD E14 and above (not incl. doctoral candidates)
[2] Doctoral candidates financed by institutional or third-party resources

Appendix 6

Personnel

- In persons (financed by institutional and third-party resources) acc. to pay scale [reporting date 31.12.2005] -

	Total number	Financed by third-party resources		Temporary contracts		Women		Women on temporary contracts	
		Number	%	Number	%	Number	%	Number	%[1]
I. Total	**73**	**12**	16.4	**27**	37.0	**21**	28.8	**9**	42.9
1. Academic staff and senior management	**31**	**6**	19.4	**10**	32.3	**1**	3.2	**1**	100.0
- S (B4 and above)	0	0	0.0	0	0.0	0	0.0	0	0.0
- S (B2, B3)	1	0	0.0	1	100.0	0	0.0	0	0.0
- E15Ü	2	0	0.0	1	50.0	0	0.0	0	0.0
- E15	2	0	0.0	0	0.0	0	0.0	0	0.0
- E14	26	6	23.1	8	30.8	1	3.8	1	100.0
- E13	0	0	0.0	0	0.0	0	0.0	0	0.0
2. Doctoral candidates	**7**	**3**	42.9	**7**	100.0	**1**	14.3	**1**	100.0
3. Other staff	**35**	**3**	8.6	**10**	28.6	**19**	54.3	**7**	36.8
- E12, E11, E10	11	3	-	3	-	6	-	2	-
- E9, E8, E7	18	-	-	3	-	10	-	3	-
- E6	2	-	-	1	-	2	-	1	-
- E5, E4, E3	2	-	-	1	-	1	-	1	-
- Wage groups, other staff	0	-	-	-	-	-	-	-	-
- Trainees	2	-	-	2	-	-	-	-	-

[1] Related to number of women in each wage group

Appendix 7

Publications

- Total number and grouped by core research areas[1] -

	2005	2004	2003
I. Total	**121**	**115**	**118**
- Monographs (authorship)	0	0	0
- Monographs (editorship)	0	0	0
- Papers in peer-reviewed journals	98	106	93
- Papers in conference proceedings and contributions to books	23	9	25
II. By research areas			
1. "Ferromagnet-Semiconductor Hybrid Structures"	**27**	**21**	**21**
- Monographs (authorship)	0	0	0
- Monographs (editorship)	0	0	0
- Papers in peer-reviewed journals	24	20	18
- Papers in conference proceedings and contributions to books	3	1	3
2. "Control of Elementary Excitations by Acoustic Fields"	**19**	**12**	**21**
- Monographs (authorship)	0	0	0
- Monographs (editorship)	0	0	0
- Papers in peer-reviewed journals	13	11	12
- Papers in conference proceedings and contributions to books	6	1	9
3. "Group-III Nitrides for Optoelectronics"	**24**	**18**	**19**
- Monographs (authorship)	0	0	0
- Monographs (editorship)	0	0	0
- Papers in peer-reviewed journals	17	16	16
- Papers in conference proceedings and contributions to books	7	2	3
4. "Intersubband Emitters: GaAs-based Quantum-Cascade Lasers"	**7**	**12**	**8**
- Monographs (authorship)	0	0	0
- Monographs (editorship)	0	0	0
- Papers in peer-reviewed journals	5	11	7
- Papers in conference proceedings and contributions to books	2	1	1

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[1] Each publication is counted only once and has been assigned to one core research area.

	2005	2004	2003
5. “Nanofabrication”	**18**	**24**	**26**
- Monographs (authorship)	0	0	0
- Monographs (editorship)	0	0	0
- Papers in peer-reviewed journals	17	24	23
- Papers in conference proceedings and contributions to books	1	0	3
6. “Nanoanalytics”	**26**	**28**	**23**
- Monographs (authorship)	0	0	0
- Monographs (editorship)	0	0	0
- Papers in peer-reviewed journals	22	24	17
- Papers in conference proceedings and contributions to books	4	4	6

Appendix 8

Documents submitted by the PDI

- Evaluation report according to the Evaluation Questionnaire for the Leibniz Association Research and Service Facilities (including tables)
- Organisation Charts of the PDI and the FVB
- Programme Budget 2007
- *Satzung des Forschungsverbundes Berlin e. V. mit Übersicht und Satzung des Instituts* (FVB Statutes, including an Institute overview and statutes)
- List of the members of the Board of Trustees of the *Forschungsverbund Berlin e.V.*
- List of the members of the Scientific Advisory Board (SAB) of the PDI for the years 2003 - 2005
- Minutes of the Meetings of the Scientific Advisory Board for the annual reports 2003, 2004, and 2005
- Audit of the SAB (2004)
- Report from the review panel on the performance of the PDI-CRG beamline U125/2-KMC
- Binding guidelines for the implementation of the rules to ensure good scientific practice at the PDI (in German and English)
- *Vereinbarung zur Förderung der Chancengleichheit* (Equal opportunities agreement)
- Lists: Discussion groups at PDI; Invited Lectures at Conferences; Employees who have been offered a chair or professorship; Projects funded by third-parties; Visiting scientists 2003 - 2005; Research cooperation 2000 - 2005; List of lectures and courses; Visits by PDI scientists to other establishments 2003 - 2005; Selected samples provided for external users; Publications 2003 - 2005; Most significant publications 2003 - 2005; Publications with external collaborators 2003 - 2005; Scientific meetings organised by members of the PDI

Senate Evaluation Committee

SAE 0164/07
29.08.2007

Annex B: Evaluation Report

Paul Drude Institute for Solid State Electronics (PDI)
Berlin

Contents

List of Abbreviations

BESSY	*Berliner Elektronenspeicherring-Gesellschaft für Synchrotronstrahlung m.b.H.*
BLK	*Bund-Länder-Kommission für Bildungsplanung und Forschungsförderung* (*Bund-Länder* Commission for Educational Planning and Research Promotion)
BMBF	*Bundesministerium für Bildung und Forschung* (German Federal Ministry of Education and Research)
CVD	Chemical Vapour Deposition
DFG	*Deutsche Forschungsgemeinschaft* (German Research Foundation)
EU	European Union
FBH	*Ferdinand-Braun-Institut für Höchstfrequenztechnik,* Berlin
FVB	*Forschungsverbund Berlin e. V.*
GaAs	Gallium Arsenide
GaN	Gallium Nitride
IAF	Fraunhofer Institute for Applied Solid-State Physics, Freiburg
In	Indium
MBE	Molecular-Beam Epitaxy
MnAs	Manganese Arsenide
M-plane	(1-100) Lattice Plane of the Wurtzite Crystal Structure
PDI	Paul Drude Institute for Solid State Electronics
PHARAO	*PDI-HU-Berlin-Aktivität zur Röntgenbeugung an atomaren Oberflächen*
QCL	Quantum-Cascade Laser
RHEED	Reflection High Energy Electron Diffraction
SAW	Surface Acoustic Wave
SFB	*Sonderforschungsbereich* (Collaborative Research Centre)
STM	Scanning Tunnelling Microscopy
VCSEL	Vertical-Cavity Surface-Emitting Laser
WR	*Wissenschaftsrat* (German Science Council)

1. Summarised Evaluation and Relevance of the Institute

The Paul Drude Institute for Solid State Electronics (PDI) conducts research in the fields of materials science and solid state physics with special emphasis on the growth and analysis of ultra-thin layers for use in nanostructured semiconductors. Like no other national research institute, it focusses its various projects on fundamental research topics dealing with new materials for III-V semiconductors grown by conventional molecular-beam epitaxy techniques. With its innovative and unconventional ideas and solutions and the use of several existing sophisticated molecular-beam epitaxy systems, PDI has been instrumental in advancing different areas of solid state physics and has developed new methods of semiconductor research.

Since the last evaluation, the Institute has developed excellently. The research programme has become far more coherent, and PDI has successfully strengthened the cooperation amongst its different research groups to become a homogeneous research institution.

The scientific work carried out by PDI is very good to excellent to a great extent, with a number of the Institute's projects being world-leading. The quality of publications is very high and the publication rate outstanding. The technical equipment at PDI is in excellent condition, and the infrastructure is well suited for the research activities performed. Several aspects relating to the infrastructure, however, will have to be improved over the next few years. Third-party funding, particularly from the DFG and the EU, should be substantially increased in the future.

The improved coherence and quality of PDI's current research programme is due to the former director, who is one of the pioneers in the field of molecular-beam epitaxy applications for the growth of new materials for semiconductor research. The Scientific Advisory Board of the Institute fulfils its tasks well, but should offer external advice of selecting new research topics to a greater extent. The Institute's staff is highly motivated and highly qualified. PDI is actively engaged in educating and training junior academics, although there is still room for improvement in the current Ph.D. programme.

At present, PDI's activities are focussed on fundamental research topics with no knowledge transfer to more applied research institutions or partners from industry. In the future, PDI should demonstrate to a larger extent the potential applicability of its research results to the development of semiconductor devices by performing further research into the new materials created and building prototypes. A long-term strategy for the selection of potentially applicable new research topics should look to move the Institute more in the direction of application-based research. In addition, competing work by other institutions nationwide should be given more consideration. Further, PDI should endeavour to increase its cooperation within the national and European scientific community.

2. Mission, Tasks, Main Work Areas

The mission of PDI is to conduct research in materials science and solid state physics with special emphasis on low-dimensional systems in nanostructured semiconductors. Its special field of activity is the growth of ultra-thin layers by molecular-beam epitaxy (MBE), mainly for III-V semiconductors, as well as the analysis of the materials grown. All of the Institute's chosen research topics, which are pooled in six core research areas, are of great contemporary importance. Most of the research projects undertaken are unique on the national level, and some of the projects are even unique on the international level. The projects are carried out on a very high scientific level, and new, unconventional ideas and solutions are often investigated and applied. The scientific results are suitably documented in numerous publications in high-ranking international journals, and the value of PDI's work is manifested in numerous presentations of the Institute's results at international meetings and congresses. Several offers for professorships to young PDI scientists are further testimony of the quality and relevance of the Institute's current research.

Compared to the results of the last evaluation, the development of the Institute is excellent. PDI's research programme has become far more coherent, and this effort should be further continued. In addition, PDI has successfully strengthened the cooperation between its different research groups to become a homogeneous research institution.

At present, the results from PDI's fundamental research activities are not being adequately transferred to more applied research and product development in the field of III-V semiconductors, as conducted by other national research institutions. In a similar vein, no transfer of the Institute's results to industry exists. In the future, PDI should demonstrate to a larger extent the potential applicability of its research results to semiconductor devices by performing further analyses of the new materials created. Electrical transport and magnetotransport measurements, as well as capacitive characterisation techniques should be used more extensively. In addition, PDI should enhance its work by building prototype devices and by fortifying its cooperation with applied-oriented research institutions in the Berlin area and throughout Germany. A long-term strategy for the selection of potentially applicable new research topics should look to move the Institute more in the direction of application-based research and improve the Institute's visibility amongst potential users of its research work.

In some of the Institute's core research areas, competing work from across Germany has not been taken into due account over the last years. Latest trends observed by other groups have occasionally been ignored by PDI scientists, and the Institute's staff has not always participated in relevant nationwide research symposia. In the future, PDI should endeavour to increase its cooperation within the national scientific community.

PDI concentrates its different research efforts on the growth of new materials for III-V semiconductors on conventional MBE techniques. Alternative methods for the growth of complex layer systems, such as gas source MBE, chemical vapour deposition (CVD) and metal organic CVD, are neglected at the Institute. For many applications, however, the comparison between conventional MBE techniques and alternative deposition techniques is highly important for evaluating the potential of real device production. As a long-term strategy, these alternative techniques should also be considered by PDI in order to guarantee the future success of its research work.

Only two scientists of the Institute work on theoretical research aspects, a number that is not sufficient to meet the demand for theoretical investigations at the Institute. It is not recommended setting up a theoretical group parallel to the existing experimental groups. It would be helpful, however, to establish more intensive contact to external groups of theoretical physicists from universities or other institutions. This would help to broaden the existing research approaches and lead to a better understanding of the experimental results obtained at PDI.

PDI's research work cannot be conducted at a university as the personnel and technical resources required as well as the long duration of some research projects go beyond the capabilities of national university institutes in their present form.

The overall quality of the research work performed by PDI is very good to excellent, with some of the research projects being world-leading. Specifically, the projects of the six different core research areas of the Institute are rated as follows:

Core Research Area "Ferromagnet-Semiconductor Hybrid Structures"

The efforts within this core research area are devoted to investigations into ferromagnetic semiconductors, which are expected to yield a highly spin-polarised current and/or exhibit a high tunnelling magnetoresistance in magnetic-tunnelling-junction geometries. In particular, an improved understanding of the mechanisms involved in spin injection and spin alignment is sought.

The overall rating of this core research area is very good to excellent. The investigations performed are of excellent quality and great interest to the scientific community. They should definitely be continued in the future. To verify the various concepts, however, it will be necessary to go beyond the material and structural investigations performed. PDI should strive to measure spin transport electrically using device structures with ferromagnetic electrodes as well as build simple prototype devices. Such activities will help to further improve the reputation of this core research area and could be instrumental in stimulating continual attempts worldwide to demonstrate high spin injection efficiencies at room temperature.

Among the various projects, excellent results are obtained with manganese arsenide (MnAs) hetero- and nanostructures. High-quality epitaxial growth of these layers on gallium arsenide (GaAs) demonstrates the Institute's great competence in this difficult field of heteroepitaxy, and these results constitute an international breakthrough. Another highlight of this core research area is the subject of spin injection from ferromagnetic layers into semiconductors. These investigations are well recognised internationally and should definitely be intensified with respect to material and device properties. The characterisation of Heusler alloys performed is also of great interest owing to their high spin polarisation, high Curie temperature, and high thermal stability. These activities are at the fore of international developments in this field. In particular, the high level of structural characterisation using the possibilities of BESSY is unique worldwide. The investigations into dilute magnetic semiconductors have led to numerous interesting results and these efforts should be continued, too. The novel concept of a magnetic reconfigurable logic based on magnetoresistive elements would be an excellent application for the material investigations of this core research area. As, however, the leading scientist in this area has recently left the Institute, it is not clear whether these activities can be continued.

The infrastructure of this core research area is excellent. All members of staff appear to be highly motivated, and the interaction with the other core research areas is well organised. There is also a good ratio of internal research activities within this area to service activities for other research areas of the Institute. The team has published numerous papers in renowned international journals and made unique contributions to various conferences. The large number of guest scientists from abroad show the attraction this area has earned internationally.

Core Research Area "Control of Elementary Excitations by Acoustic Fields"

In this core research area, surface acoustic waves (SAW) are used to modulate the dimensions and physical properties of micro- and nanostructures. The tuneable temporal and spatial modulations are employed to control elementary excitations in semiconductors and superconductors.

The scientific work of this area is very good to excellent. The chosen topics are pursued with a remarkably high level of quality, originality and creativity. Thanks to its investigation of the interaction between elementary excitations, e.g. charge carriers, magnetic excitations or light, this core research area has advanced this field of research considerably and developed new techniques for semiconductor research.

In particular, the experiments on spin transport using SAWs are very interesting. The acoustic lattices and interference structures produced with SAW are also impressive. Their use as optical modulators looks particularly promising. The phase modulations using SAWs in Mach-Zehnder interferometers made from waveguides or for the transport of flux quanta in high Curie temperature superconductors are remarkable, too.

The experimental equipment in this research area is up-to-date, and the experiments have been set up very accurately. The SAW methods used by the members of this core research area demonstrate the staff's great skill in the design of devices that work at very high frequencies in the GHz range, with focussed and guided ultrasonic beams. The scientific results have been suitably published in renowned journals. It is hoped that this core research area will be able to continue this interesting work after the departure of this area's head scientist and the change of the Institute director. If the work does continue, nationwide and international cooperation should be intensified, in particular with theoreticians working in this research field.

Core Research Area "Group-III Nitrides for Optoelectronics"

The projects implemented in this core research area relate to two different research topics: wide band-gap nitrides and dilute nitrides for the 1.3 to 1.55 µm wavelength emission. The research activities for wide band-gap nitrides include the investigation of gallium nitride (GaN) films with nonpolar surfaces with group-III nitride heterostructures, as well as those with GaN-based nanostructures. The research activities for dilute group-III nitrides focus on the correlation between the inherent defect structure of (Ga,In)(N,As) epilayers on GaAs and their optical properties.

The research work on wide band-gap nitrides is outstanding worldwide. It includes the role of interfaces, structural defects and strain, as well as optical properties. The growth of *M*-plane GaN yields electric-field-free heterostructures for light-emitting diodes and for laser diodes. One very good and promising activity in the development of vertical-cavity surface-emitting lasers (VCSELs) using this material system is the doping of the aluminium nitride used in the Bragg reflectors. This activity is a huge step forward in the development of such a device. These studies clearly demonstrate the high level of expertise at the Institute with regard to the growth of extremely complex semiconductor layer systems. The studies on dichroism observed in the *M*-plane GaN and *M*-plane distributed Bragg reflectors are interesting, but could also be performed at a university institute.

The results of the research projects dealing with dilute nitrides are very interesting, but not outstanding. The scientists working on these topics meet international standards and have succeeded in constructing VCSELs. Within these research topics, PDI could make better use of its outstanding variety of analytical tools in order to obtain an even stronger relationship between the structure and properties of the dilute nitrides investigated. In addition, more devices need to be fabricated to obtain a better correlation between microscopic structure and device performance. The decision by PDI to leave the topic of n- and p-type doping of the *M*-plane GaN films to other research institutions is much regretted. Even if other institutions have more personnel and financial funding at their disposal for this area, it might be still worthwhile conducting further research at PDI.

Core Research Area “Intersubband Emitters: GaAs-based Quantum-Cascade Lasers”

The different projects within this core research area encompass detailed investigations into the conditions for the lasing process and the lasing properties of GaAs-based quantum-cascade lasers (QCLs).

Overall, the work of this core research area is good, and the results presented are interesting. Very detailed work is performed on the optimisation of the many available parameters, such as quantum well width and doping profile. To this end, comprehensive theoretical modelling has also been performed. The different activities of this research area are certainly very helpful in providing a detailed understanding of the influence of doping, layer thicknesses, and band-offsets on the lasing properties.

In the various projects, many devices with different design and doping level were grown and characterised using the many different characterisation methods available in the Institute. The team has chosen to focus its efforts on the GaAs system, since this material class is not investigated by other national institutions. However, this material system is the least promising for building semiconductor devices, with the exception of operation in the 2 to 5 terahertz regime.

This core research area is fitted with very good laboratories and equipment. Members of the research area have produced a number of publications in well-known journals.

Core Research Area “Nanofabrication”

The objective of all research activities within this core research area is the fabrication and investigation of nanostructures with novel functionalities. Most of the projects are based on the Institute’s long-standing expertise in the field of molecular-beam epitaxy of III-V semiconductors, which permits growth control on the atomic scale. In addition, the heteroepitaxy of dissimilar materials and defect engineering methods are utilised to generate new and distinct material combinations and specific epitaxial orientations with tailored functionalities. In addition to nanofabrication using growth-controlled techniques, atom-by-atom assembly by low-temperature scanning tunnelling microscopy (STM) is used to assemble individual nanostructures with strict size, geometry and composition control.

The work of this core research area has a very good to excellent quality. The combination of MBE as a top-down approach with low temperature STM as a bottom-up approach to grow structures is an important strategic activity that will extend the Institute’s area of competence. As several sophisticated MBE systems are available, it is possible to dedicate one process chamber to each particular material system. Thus, cross-contamination can be entirely avoided, which is a considerable advantage because it allows for the growth optimisation of a whole range of material systems.

Among the projects that focus on the use of MBE for the creation of binary, ternary, and quaternary III-V semiconductor structures, the development of a quantised electron system on a cylindrical surface, achieved by strain induced microstructuring, led to interesting electrical properties thanks to ballistic transport. The work on quantum cascade structures for mid-infrared and terahertz emitters will play an important role in the future. In attempts to combine dissimilar materials through the oriented growth of single crystalline films, interface formation, nucleation kinetics, and the growth parameters of several systems were analysed with support of the Institute's excellent nanoanalytical capabilities. The most valuable results are obtained for metastable III-V compounds such as dilute nitrides and dilute magnetic semiconductors. The understanding of these structures is essential for optoelectronics, magnetic switching and possibly for future spintronic systems, too. The studies of configurational changes to organic molecules such as cyclooctadiene on silicon by means of a low-temperature STM are also remarkable. Likewise, the STM results presented on copper atom chains and molecules interacting with metal nanostructures and silicon surfaces are impressive. It might be worthwhile intensifying these activities in the future, as they could be relevant for building nanoswitches and nanomachines. So far, however, these activities have not been related to the other material combinations studied at PDI. Furthermore, this project lacks a clear focus.

The infrastructure of this core research area is excellent with regard to the MBE activities. For the STM investigations, there is a certain need for better locations in order to avoid interference signals. The personnel consist of a good mixture between older experienced scientists and new young researchers with innovative ideas. The reputation that the work on MBE grown structures enjoys worldwide can be seen in the various publications in refereed journals and contributions at international conferences.

Core Research Area "Nanoanalytics"

In this core research area, dedicated analytical *in situ* and *ex situ* characterisation techniques with high sensitivity and spatial resolution are used to study newly fabricated semiconductor materials at the Institute. The available *in situ* X-ray diffraction with synchrotron radiation is used to investigate the surfaces, interfaces and film properties of epitaxial layers during growth and in real time. In combination with *ex situ* transmission electron microscopy methods, including high-resolution imaging, electron diffraction and electron energy-loss spectroscopy, it allows for the study of the structural and chemical properties of nanomaterials and their interfaces. Parallel to this, scanning electron microscopy (SEM) imaging in combination with cathodoluminescence spectroscopy allows for the probing of local optical properties.

The scientific quality of the work of this core research area is very good to excellent, even on an international level. The unique combination of the various techniques provides an insight into the growth of clusters and epitaxial layers, which could not be achieved by a more limited number of analytical techniques. This research area fulfils an important service function with intensive and immediate interaction with the other areas of the Institute. This area, therefore, cannot be separated from the others. For the requested long-term research strategy in nano-structure materials science and solid state physics at PDI, this core research area, which has highly sophisticated and advanced equipment, is of vast importance as it can be a nucleus for many important investigations.

Among the various projects in this area, *in situ* X-ray diffraction with synchrotron radiation, which is performed by the **"PHARAO Project Group"**, is an outstanding scientific highlight and unique worldwide. Throughout the last few years, this project has continuously delivered exceptional scientific results and is expected to continue to do so over the next few years. Three MBE machines for different material combinations are located at a beam line at BESSY and allow for the investigation of the growing samples *in situ*, including surfaces and buried interfaces. The information on the atomic structure of growing semiconductor surfaces, which was obtained by this PDI group, is impressive. In particular, as the data can be evaluated by applying kinetic theory approaches, relevant atomistic conclusions can be easily drawn. In addition, the set-up allows for the comparison of the results with standard reflection high energy electron diffraction (RHEED) data. This provides a better understanding of growth processes in the other MBE machines at PDI.

Other impressive projects of this core research area include the evaluation of the surface morphology as well as the surface reconstruction of the GaAs system. Concerning heteroepitaxy, the interface properties of GaAs with respect to MnAs have been characterised in detail. These topics lead to very interesting results that verify their importance in combination with fabrication techniques. An example of the combination of scanning electron microscopy and cathodoluminescence spectroscopy investigations is the characterisation of dislocations and local strain in GaN. These are important results regarding the optoelectronic properties of the material.

The infrastructure of this core research area is not ideal because the BESSY activities are separated from the rest of the equipment spatially. The staff consists of excellent individuals, all of whom are highly motivated. The research team is well organised and very efficient in its efforts to combine basic research with a service function for successful nanofabrication. The scientific results obtained are published in a variety of reviewed journals, and the number of original contributions at international conferences is a clear indication of the high-level research being carried out. The leading scientists are well reputed internationally, and numerous guest scientists from many countries are testimony to the international networks built up within this research area.

3. Structural Features and Organisation

The main research activities of PDI are carried out in six interdisciplinary core research areas, while the personnel are organised into three research groups and one project group. This **organisational structure** is not optimum, as no explicit responsibilities have been assigned to the Institute's senior researchers to coordinate the work within and between the different core research areas. The central role of the director within the Institute's structure is unclear and should be revised. The selection process for new scientific topics should be more structured within the given discussion groups.

The improved coherence and quality of PDI's current research programme is due to the **former director**, who is one of the pioneers in the field of MBE-grown materials and enjoys an excellent international reputation. The present **interim leading team** is working well and is striving to continue the research work on a persistently high level and to maintain the steady interaction with the administrative and technical staff. As of November 2007, a **new director** will take over at the Institute. The concept he has presented seems to be profound, and he undoubtedly has the competence required to lead PDI over the next few years and into a successful future. His suggestions as to the Institute's future research activities are of high contemporary relevance, well chosen and ambitious.

The communication between the management and the personnel functions well but the decisions taken by the Institute's management could be made even more transparent.

The **Scientific Advisory Board** works well, but its activities should be revised. In general, the Board should be more critical in the future. It should question in more detail the scientific topics selected for the PDI research programme and offer external advice to a greater extent. The Board should also continuously track the implementation of its recommendations. The minutes of the yearly Board meetings are too formal and could be more informative. In addition, the number of national scientists functioning as Board members should be increased.

The **administration** personnel at PDI are split between the internal administration of the Institute and those working in the administration offices of the *Forschungsverbund Berlin* (FVB). The cooperation works well. It must be ensured, however, that this split of administrative tasks between the Institute and the FVB does not result in the same work being done twice. In the future, PDI should consider fostering the employment of specifically trained personnel for the fulfilment of its internal administrative tasks.

An **efficiency-related cost calculation system** (*Kosten-Leistungs-Rechnung)* has not yet been implemented in an effective operation *(Wirkbetrieb)* at PDI. Compared to other Leibniz institutions, PDI has a backlog here, which needs to be improved. The programme budget must be further improved, too, as the current version contains one programme area only.

A transparent system of **performance-oriented funding** *(Leistungsbezogene Mittelvergabe)* is missing at the Institute.

The current **female quota** is rather low in compliance with the average quota of research institutions in the area of solid state physics. An increase in this quota among the scientific staff of PDI is desirable.

4. Resources, Expenditures and Personnel

The **infrastructure** at PDI is well suited for the chosen research activities, and all installations are maintained in an excellent condition. Several aspects of the infrastructure at PDI, however, need to be improved. The ventilating and air-conditioning systems in the laboratories have become obsolete. The infrastructure of the cleanrooms has not been renewed in fourteen years. It can barely meet the actual requirements for experiments performed at PDI and should undergo upgrading and renewal soon. The Institute's anticipated funding requirements for these tasks seem appropriate. The available lithography instruments are not state-of-the-art but still sufficient for the Institute's needs. PDI should also aim to remedy its need for more space by acquiring another storey in the present building, preferably one of the adjunct floors. On a longer timescale, the Institute might consider moving to the science and technology park at Berlin-Adlershof to profit from synergetic effects with the many other research institutions located there.

The **IT services** of PDI have not been renewed sufficiently for several years and should be made state-of-the-art as soon as possible. In particular, the data protection and backup systems should be substantially improved and centrally organised.

The Institute possesses a small **in-house library**, and the funding available for this library is rather large. By way of contrast, online access to important scientific literature is strongly limited for PDI staff and should be improved.

Over the past few years, the Institute obtained **third-party funding** mainly in the area of fundamental research from the German Federal Ministry of Education and Research (BMBF) and the German Research Foundation (DFG); by contrast, it has not yet been possible to obtain third-party funding from industry. Revenue from services was not obtained either. Some funding from the European Union (EU) was received. In general, an explicit interest on the part of the PDI's management to enhance the Institute's activities by third-party funding is lacking, and such funding, particularly from the DFG and the EU, should be substantially increased in the future. These efforts should be accompanied by attempts to build up connections to suitable European scientific partners and industrial companies.

The PDI staff is highly motivated and highly qualified, ranging from the upper management to the technical employees. While the internal cooperation and exchange of knowledge between the scientists and the technical personnel works well at PDI, education and training for technical staff could be further improved through additional cooperation with other institutions. PDI does not offer any **apprenticeship training** for junior technical staff at present.

5. Promotion of Junior Academics and Cooperation

Between 2003 and 2005, eight doctoral theses and one master thesis were successfully completed at PDI. In addition, one habilitation (postdoctoral teaching qualification) has been completed since the last evaluation.

The Institute is actively engaged in educating **junior academics** and boasts a number of excellent young researchers. However, the present number of seven Ph.D. students working at PDI should be increased, and the education of junior academics could be improved considerably through a structured Ph.D. programme. In December 2005, approximately three quarters of the Ph.D. students were non-German. The quota of international academics at PDI is excellent in general and demonstrates the Institute's outstanding international reputation for Ph.D. and post-doc positions in the field of solid state electronics. All foreign junior scientists are well integrated within the Institute.

The cooperation between PDI and the three universities of Berlin in the framework of three DFG collaborative research centres (SFBs) is much welcomed. This **cooperation with universities** should be further strengthened by increasing the number of joint appointments *(gemeinsame Berufungen)* with the different universities of Berlin. In particular, the possibility of offering jointly appointed junior professorships at the Institute should be looked into.

On a national level, **cooperation with other research institutes** is rare. PDI should foster such cooperation, both with other institutions in Berlin, e.g. *Ferdinand-Braun-Institut für Höchstfrequenztechnik* (FBH), and nationwide, e. g. the Fraunhofer Institute for Applied Solid-State Physics (IAF) in Freiburg. Likewise, the institutional cooperation on a European level should be improved, and PDI should strive to occupy a central function in **international networks**. In general, PDI should be more aware of competing work done by other groups. Regarding the selection of new research topics, the Institute should also evaluate the advantages of a tighter reconciliation of interests with potential cooperation **partners from industry**.

6. Results and Scientific Resonance

During the reference years 2003 to 2005, the average number of 73 employees and 8 doctoral candidates at PDI published an average of 118 articles per year. The quality of the **publications** is very high and the publication rate outstanding. PDI publishes a large number of peer-reviewed papers in high-quality international journals.

At present, a great number of very original research ideas and findings by PDI are being published. Unfortunately, these are not being further evaluated with respect to their transferability to demonstrators or even application products. Consequently, a lack of **patent assessment** exists at the Institute. PDI should develop a patent strategy, increase its number of patent applications, and become much more actively involved in the **technological transfer** of its results to industrial partners. As patent application can be quite costly, PDI should explore the financial feasibility of such proposed efforts and should endeavour to make use of the available administrative support of the FVB.

The very good reputation that PDI enjoys is manifest in the high acceptance rate of many of the Institute's staff at international meetings and congresses. PDI's participation in important national and international organisations, networks and committees is in most cases linked to the efforts of the former Institute director. The future executives of PDI should try to sustain these **board presences,** although it is accepted that this might be a difficult task, given the fact that the majority of panels have their own rules for the replacement of board members.

As PDI offers no services to external users to exploit the infrastructure at PDI, no related advertising for the Institute's facilities exists. Furthermore, the **public relations** activities of PDI are rather low. The Institute should strengthen its links with the media consultants of the FVB to improve the latter issue. The PDI's website should be modernised.

7. Implementation of the German Science Council's Recommendations

PDI has followed key recommendations given at the last evaluation by the German Science Council *(Wissenschaftsrat)* in 1999. For example, the Institute's competence in MBE-related research fields was further extended and utilised. Interdisciplinarity in mode of operation and interrelation between research topics has been strengthened. The number of publications from several research groups has also been increased.

In the statement of the Council, PDI was also required to conduct more application-oriented research. This call has not yet been followed by the Institute. Another recommendation of the Council has not been implemented effectively, as the decision-making process for the selection of new scientific topics is still unclear. The scientific discussions that have taken place within the newly established discussion groups are not yet regarded as fulfilling this recommendation. In the future, the selection process should be better structured.

8. Summary of the Evaluation Committee's Recommendations

PDI is one of the leading national and international research institutions in the growth of new materials for III-V semiconductors using classical molecular-beam epitaxy techniques. Since the last evaluation, the Institute has developed excellently. To sustain and further improve its scientific standard, the following measures are recommended:

Mission, Tasks, Main Work Areas

- PDI should demonstrate to a larger extent the potential applicability of its research results for use in semiconductor devices.
- 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.
- The existing research approaches should be extended to include more theoretical research work in collaboration with external groups.

Structural Features and Organisation

- 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.
- Within the new discussion groups, the selection process for new scientific topics should be more structured.
- The Scientific Advisory Board should offer external advice of selecting new research topics to a greater extent.
- PDI has a backlog in the implementation of an efficiency-related cost calculation system at the Institute. This needs to be improved.
- The programme budget must be further improved, as the current version contains one programme area only.

Resources, Expenditures and Personnel

- The infrastructure of the cleanrooms should be upgraded and renewed.
- The IT services should be made state-of-the-art.
- The online access to important scientific literature is strongly limited for PDI staff and should be improved.
- The Institute's third-party funding, particularly from the DFG and the EU, should be substantially increased.

Promotion of Junior Academics and Cooperation

- The education of junior academics should be improved by way of a structured Ph.D. programme.
- Cooperation with the three universities of Berlin and within the national scientific community should be further strengthened.

Results and Scientific Resonance

- 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 public relations activities of the Institute could be improved.

Appendix

Participants

1. Evaluation Team

Chairman (Member of the Senate Evaluation Committee, SAE)

Prof. Dr. Dr. Prof. h.c. mult. Thomas **Geßner**	Center for Microtechnologies, Chemnitz University of Technology; Fraunhofer Institute for Reliability and Microintegration, Berlin

Vice Chairman (Member of the Senate Evaluation Committee, SAE)

Prof. Dr. Richard **Wagner**	Institut Laue-Langevin, Grenoble (France)

External Experts

Prof. Dr. Ignaz **Eisele**	Faculty of Electrical Engineering and Information Technology, Bundeswehr University, Munich
Prof. Dr. Detlef **Heitmann**	Institute for Applied Physics and Microstructure Research Center, University of Hamburg
Prof. Dr. Ralf Thomas **Kersten**	neuroConn GmbH, Ilmenau
Prof. Dr. Wolfgang **Kleemann**	Department of Physics – Applied Physics, University of Duisburg-Essen
Prof. Dr. Claus **Klingshirn**	Institute for Applied Physics, Universität Karlsruhe (TH)
Prof. Dr. Hans **Lüth**	Institute of Thin Films and Interfaces, Research Centre Jülich
Prof. Dr. Wolfgang **Rühle**	Faculty of Physics, Philipps-Universität Marburg
Prof. Dr.-Ing. Heiner **Ryssel**	Chair of Electronic Devices, Friedrich-Alexander University of Erlangen-Nuremberg
Dr. Manfred **von Schickfus**	Kirchhoff Institute for Physics, University of Heidelberg
Dr. Joachim **Wecker**	Corporate Technology, Siemens AG, Erlangen

Federal Representative

RegDir Frank **Reifers**	Federal Ministry of Education and Research, Bonn

Representative of the States

MinDirig Dr. Frank **Speier**	Ministry of Innovation, Science, Research and Technology of the State of North Rhine-Westphalia, Düsseldorf

2. Guests

Representative of the relevant Federal Department

RegDir Dr. Werner **Salz**	Federal Ministry of Education and Research, Bonn

Representative of the relevant State Department

Dr. Rainer **Schuchardt**	Senate Administration for Education, Science and Research, Berlin

Representative of the Bund-Länder Commission for Educational Planning and Research Promotion, Bonn

– excused –

Representative of the Leibniz Association

Prof. Dr. Helmut **Eschrig**	Leibniz Institute for Solid State and Materials Research (IFW), Dresden

Chairman of the Scientific Advisory Board

Prof. Dr. Gerhard **Abstreiter**	Walter Schottky Institute, Technische Universität München

Representatives of Cooperating Institutions

The following representatives of cooperating institutions took part in a one-hour interview:

Prof. Dr. Helmut **Keupp**	Vice President, Freie Universität Berlin
Prof. Dr. Christian **Limberg**	Dean, Faculty of Mathematics and Natural Sciences I, Humboldt-Universität zu Berlin
Dr. Henning **Riechert**	Qimonda AG, Munich
Prof. Dr. Christian **Thomsen**	Dean, Faculty II - Mathematics and Natural Sciences, Technische Universität Berlin

26.09.2007

Anlage C: Stellungnahme der Einrichtung zum Bewertungsbericht

Paul-Drude-Institut für Festkörperelektronik (PDI)

im Forschungsverbund Berlin e.V.

The Paul Drude Institute for Solid State Electronics (PDI) would like to express its sincere gratitude to the Senate Evaluation Committee and the Department for Evaluation of the Leibniz Association for their very dedicated efforts during the whole evaluation process. We are extremely pleased with the very positive assessment of the Institute's development since the last evaluation. After a careful analysis of the report, the Institute is encouraged by the very positive evaluation of the research programme, scientific work and quality of the publications as well as publication rate, and the very positive rating of the core research areas. We feel that the recommendations for the further improvement of the scientific and administrative structure are very constructive and helpful. The new director (Prof. Dr. Henning Riechert, who will take up the directorship on November 1st, 2007) will discuss the evaluation report with the Scientific Advisory Board to introduce the measures necessary to implement the recommendations. This statement has been written by the current scientific management of the PDI in agreement with the new director.