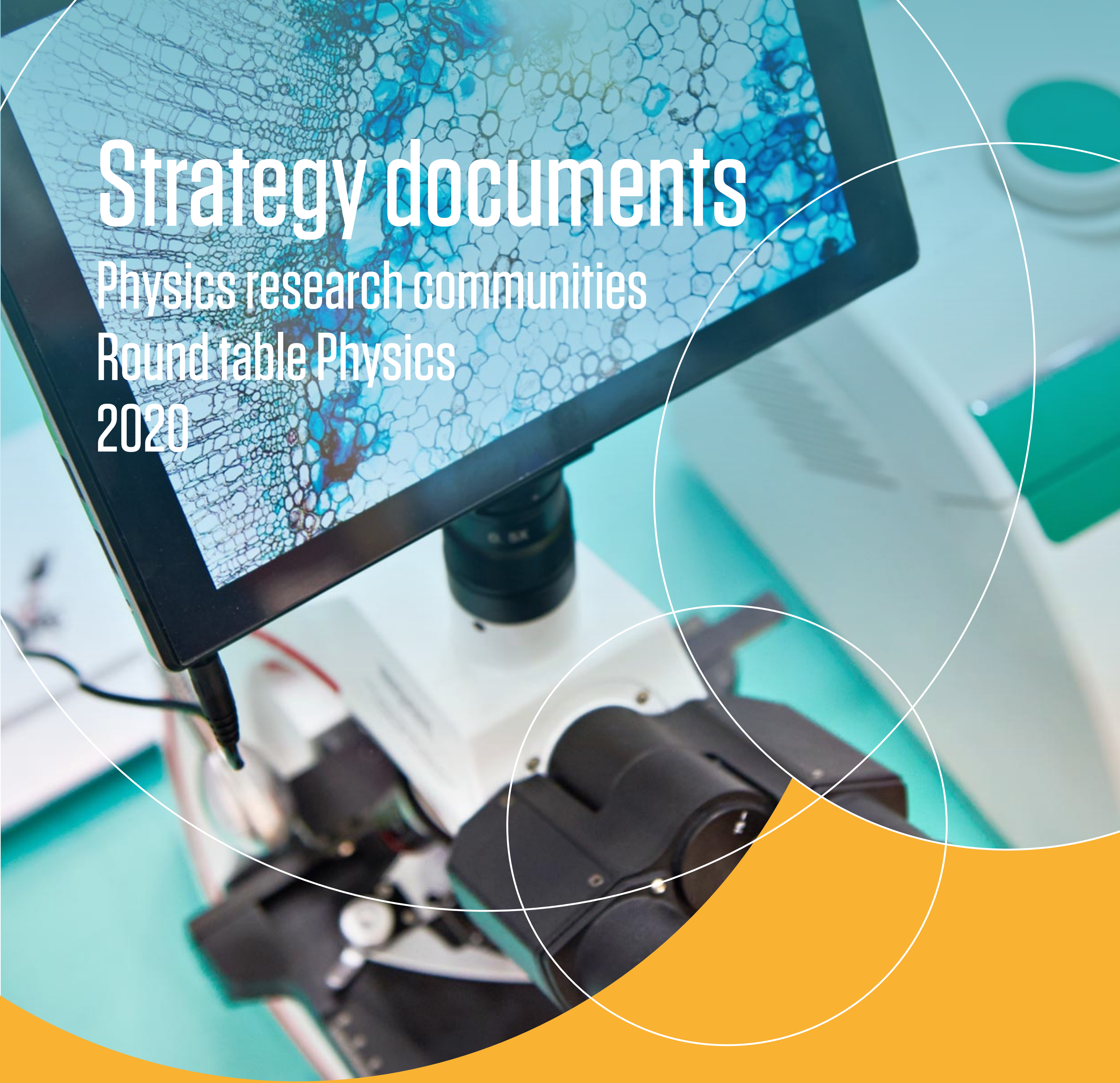

Strategy documents

Physics research communities
Round table Physics
2020

Physics for Technology and Instrumentation

1. Scope of research community advisory committee

'Physics for Technology and Instrumentation'
'Physics for Technology and Instrumentation' (PTI) covers the fundamental physical understanding and development of new technologies and engineering innovations, in e.g. acoustics, optical metrology, medical technology, microscopy, integrated photonics, nano-electronics, quantum information, magnet technology, advanced light sources and (charged) particle and X-ray beam techniques. The gained knowledge is used to advance the capabilities of new and existing technologies and instrumentation. The application of the technologies and instrumentation is primarily addressed by the other physics research community advisory committees of NWO. The PTI research community advisory committee divides her field up into four main themes: 'Physics for Fabrication', 'Sensing, Detecting and Probing', 'Sources', and 'Actuation and Manipulation' which are outlined in section 2.

2. Vision for the next ten years

New and improved materials, sources, sensors and actuators, and manufacturing methods are key ingredients for practically all 50 Key Enabling Technologies identified in the Elsevier report "Quantitative Analysis of Dutch Research and Innovation in Key Technologies" (June 2018). Therefore, PTI research is highly relevant for meeting the "Grand Societal Challenges of the 21st century".

In the coming decade, significant breakthroughs must be realized in the quest for "materials by design". To make this happen, we must develop novel methods and tools for reliable and accurate massively parallelized actuation and manipulation of particles, fields and materials, and for in situ and in operando characterization, monitoring and control of the fabrication of micro-, nano- and quantum materials, structures and devices with atomic or molecular precision on a large scale. Seamless integration and control of multiple physical processes, materials and components is essential for building high-performance devices like robust many-qubit quantum chips, ultra-sensitive hyphenated sensors, massively parallelized biosensors and biopolymer sequencers, advanced sources of both radiation and particles, and fusion reactors. Source development is a key technology driver to meet future needs in science, industry, health care and other areas such as agriculture. The Key Enabling Technologies rely for a large part on advanced source technology, either directly (e.g. photonics) or indirectly (e.g. advanced materials, nanotechnology, food and agriculture, health, etc.). Sources with improved brightness, efficiency and accuracy must be developed to enable novel applications. In addition, transitioning innovations from research laboratories to users requires increased attention to aspects such as compactness, robustness, cost and ease of use.

The advent of new capabilities in control and information technology (e.g. control of fields, dynamic models, machine learning) will change how we generate, process, and utilize scientific data, leading to new advances and greater complexity in materials design and instrumentation (e.g. stochastic and multivariate sensors). All these developments also enable high-precision intervention in complex matter and processes.

From an industrial perspective, identifying the lines of physical investigation with the highest potential for viable technologies with a broad application base remains an important challenge that requires explicit attention. For selected curiosity-driven pure scientific research, where the end justifies the means, exotic PTI concepts might be the way to go. However, in most fields, well thought out PTI concepts, consisting of a careful selection of technically and economically manufactural components are preferred, because of their higher potential to trigger new high-impact products that benefit the Dutch economy. Therefore, researchers are encouraged to explicitly apply these selection criteria when proposing new research proposals, and when making critical decisions during the execution of their research. A good connection between researchers and industry is crucial to make this a success.

3. Scientific themes

Theme 1: Physics for fabrication

Scientific challenge: Physics for fabrication is at the heart of being able to manipulate materials in two- and three-dimensions from the (sub)nano- to micro-scale regime.

Being able to precisely control materials at these length scales not only underpins many fundamental discoveries, but is also crucial to many technological advances. For example, the control and design of two-dimensional materials, correlated materials, and engineered lattices of thin films with atomic or molecular precision is still in its infancy and can lead to (r)evolutionary breakthroughs in fields such as energy, quantum information technology, data storage, national security, and health. Therefore, novel fabrication processes and techniques need to be developed to fabricate such nano-engineered materials and structures. Understanding the physics that govern the processes at play at these ultra-small dimensions is crucial to advance this field.

Current examples of such processes and techniques that are being developed in the Netherlands are plasma-enhanced atomic layer deposition of designer nanolayers to improve the lifetime of solar cells, techniques to grow 3D nanowire hashtags to prove the existence of Majorana fermions, and molecular beam deposition to realize organic/inorganic nanolayered hybrids for optoelectronics.

Theme 2: Sensing, detecting and probing

Scientific challenge: Exploring new territory in experimental physics, both fundamental and applied, depends strongly on the development of new sensors. Furthermore, there is an ongoing demand for increasingly smaller and smarter sensing devices with better performances. Their development requires a detailed understanding of matter-matter and radiation-matter interactions, synthesis of advanced materials, and novel sensing and probing techniques. For example, metamaterials can bridge the THz detection gap in the electromagnetic spectrum, complex (bio)physical systems and instrumentation need novel signal transduction techniques, and novel approaches like machine learning and Bayesian inference are needed for processing of non-trivial high-dimensional signals.

The first challenges in this field are related to the development of instruments with unprecedented performance. New research directions will focus on developing devices capable of measuring in multiple space and time dimensions, and with supreme sensitivity (down to single particles, molecules, or atoms), low noise, wide dynamic range, high specificity, high (space, time, and energy) resolution, and (ultra)fast and parallelized acquisition. Future instruments will have to take into account fabrication and operational constraints, such as the requirements of low power, low cost, high durability and a sustainable life cycle. In addition, new challenges will arise in the handling and processing of large amounts of annotated data, and in the design of the device architecture, in particular concerning miniaturisation, effective cooling, and the integration of multiple components. Finally, more and more measuring devices will be designed by taking into account their application environment and the associated safety and durability challenges, such as for biocompatible and non-invasive sensors, and instruments that operate in in situ and in operando conditions.

Theme 3: Sources

Scientific challenge: Sources of radiation and particles are at the heart of almost all areas of physics. Many advances in physics are made possible by the availability of improved sources, and therefore there is continuous drive towards better sources for better physics. A distinction can be made between sources of radiation (including but not limited to lasers, LEDs, acoustics, synchrotrons, plasma-based light sources and free-electron lasers) and sources of (charged) particles such as electron and ion beams, but also including plasmas themselves. In both cases, source development entails both the improvement of source parameters, but also improvements in the ability to accurately characterize sources.

Radiation sources are widely used for probing and manipulating matter. In such sources, wavelength and intensity are important parameters, but also the ability to control the spatial and temporal properties of radiation sources is essential. Source improvements directly impact the achievable resolution in microscopy and lithography, time-resolved measurements of ultrafast phenomena, and spectroscopy, but also opens new possibilities for e.g. element-resolved detection, studying matter in extreme fields, and quantitative 3D imaging. Major source challenges include the ability to make bright sources at extreme wavelengths (EUV, X-ray, but also infrared and THz) and increasing stability, efficiency, compactness and lifetime.

Also the ability to control the spatial and temporal profiles of radiation sources, including aspects such as polarisation and e.g. orbital angular momentum, is of crucial importance in many applications. Another particularly important property of radiation sources is their coherence: the phase of light fields is of crucial importance for focus ability and wavefront control, diffractive imaging and metrology, and access to the quantum nature of light. Single-photon sources and attosecond EUV sources based on high-harmonic generation are important examples of compact coherent sources based on quantum phenomena. Furthermore, metrology of the source itself is a challenge by its own right, as knowledge of the source parameters is often the limiting factor in the accuracy of an experiment.

Particle sources are equally important tools for probing matter, in particular high-brightness electron sources for electron microscopy and spectroscopy. For a range of other applications, the development of ion sources is crucial. One example is focused ion beams for milling and drilling at the nanoscale, where ion beam induced deposition and secondary ion mass spectroscopy are very active fields. Improved sources for focused ion beam and ion-beam-induced deposition are in fact essential for the semiconductor industry. Also for particle sources, developments towards increasing source brightness, efficiency, accuracy and lifetime are crucial for further advances and application potential.

Plasma sources are relevant for an array of applications, which roughly can be divided in (i) an array of applications in surface modification; (ii) as a source of primary particles or a mixture of particles and electromagnetic fields for triggering subsequent production of chemically active (molecular) species or other particles such as nanoparticles; (iii) a combination of both. Plasma sources operate in a wide range of pressures, gas mixtures, dissipated power, types of excitation etc. The major challenges for all of them include, but are not limited to, (i) extending the current energy range of the produced particles; (ii) precise control of the energy distribution of particles; (iii) reliable controllability and reproducibility; (iv) the ability to scale up from the laboratory size towards sources that enable beyond-state-of-the-art experiments and/or economic added value in terms of efficiency or higher throughput; (v) the ability to control the spatial distribution and uniformity; (vi) the ability to precisely tune and control the composition of the resulting chemically active (molecular) species or other particles such as nanoparticles; (vii) improving the lifetime of the sources. Diagnostics is of utmost importance in the development of the new sources. This includes the development and implementation of new diagnostics, as well as properly determining the properties of the new sources using both new and already existing diagnostics.

Theme 4: Actuation & Manipulation

Scientific challenge: The subfield of actuation and manipulation (A&M) addresses a heterogeneous set of exciting challenges, relevant for future instrumentation and associated physics. Novel A&M concepts for biomolecules, fluids, and plasmas in (micro-)reactors/detectors, e.g. based on scanning probes, ultrasound, electrowetting, micro- or nanomotors, and electric, magnetic or optical fields and waves, are required. Selective concentration of target biomolecules might speed up their reaction or detection from hours to minutes or seconds timescales, and eliminate interference from non-target molecules. Improved isolation concepts are needed, e.g. to shield micro- or nanodevices (or their content) from thermal, vibrational, and electromagnetic perturbations. Novel control concepts like model predictive control are needed to avoid limits and constraints in controlling complex dynamic system. Novel sample preparation methods, e.g. through STM or AFM, multi-beam, or guided nano-assembly are essential for many groundbreaking experiments and applications. The same holds true for A&M of fields and particle beams, optical wave fronts, and remote or non-invasive A&M under extreme conditions (e.g. in high vacuum or high pressure, or in complex biological systems like the brain). Novel massively parallelized A&M concepts must be developed for high-throughput assembly, reaction and detection (e.g. for discovering or detecting rare species in large ensembles, nano-pore based sequencing, multi-beam SEM/FIB). Calibration of such systems is a big challenge in itself.

4. Application perspective

Development of new and improved materials, detectors, sources and actuators, and manufacturing methods are expected to have an extremely wide application perspective and a large societal relevance. New developments in ‘Physics for Technology and Instrumentation’ are essential for driving advances in all Topsectors, especially in Agri & Food, Energy, Life Sciences & Health, Chemistry, HighTech Systems & Materials, as well as the Holland

High Tech innovations as described in the associated Roadmaps. Potential applications may include (non-exhaustive list):

Theme 1: Physics for Fabrication
- Better photovoltaic, optoelectronic and quantum devices
- Materials and devices to aid the transition to sustainable energy and circular economy (solar cells, batteries, fuel cells, gas storage, etc.)
- Novel and secure information processing/storage systems

Theme 2: Sources
- Better/brighter sources for improved microscopes, lithography, metrology, spectroscopy, diagnostics, lighting, process monitoring
- Plasma and particle sources for surface modification, wound healing (medicine) and disinfection (food and agriculture), fabrication, actuation and manipulation

Theme 3: Sensing, Detecting and Probing
- Autonomous monitoring for automotive, health, environment, agriculture, industrial, etc.
- Self-contained multi-modal sensors, advanced data processing and self-calibration for better, smaller, smarter and cheaper devices
- Biocompatible, non-invasive, in-situ/operando sensors/detectors for safer, faster and more comfortable monitoring
- Inspection of photonic and semiconductor materials and devices

Theme 4: Actuation and Manipulation
- Accurate manipulation and/or concentration of (bio)molecules, fluids, fields/waves, particles, etc. for improved micro-reactors/detectors
- Low-power, small form factor massively parallelized A&M for high-throughput devices/reactors/detectors

5. Strengths and infrastructure in the Netherlands & international perspective

The landscape

The research landscape related to the newly formed 'Physics for Technology and Instrumentation' is vast, and no specific (recognized) niches within the Netherlands exist (yet). The associated infrastructure is very diverse and ranges from international facilities and national initiatives, represented on the "National Roadmap for Large-scale Research Facilities (LSRI)", to the basic infrastructure at universities and institutes, which have activities on optimization of techniques and instrumentation. In addition, many companies have related research embedded in their R&D departments. Several TO2 institutes, such as TNO, regularly work on PTI projects. Below is a non-exhaustive list of examples of facilities and infrastructure that have connections with 'Physics for Technology and Instrumentation'.

Infrastructure in the Netherlands

International facilities:
Examples of large international facilities are the "High Field Magnet Laboratory" (HFML) and the "Free Electron Lasers for Infrared eXperiments" (FELIX) laboratory. NWO and Radboud University Nijmegen jointly operate HFML and FELIX, which develop and exploit the world's highest continuous magnetic fields and intense radiation with unequalled tunability in the infrared/THz range. HFML-FELIX is one of the few Dutch, open-access, international user facilities and the only facility worldwide that couples continuous high field magnets to free electron lasers.

National facilities:
A key example of a national initiative is NanoLabNL, which hosts a broad spectrum of nanotechnology tools and tailor-made infrastructure at different locations such as UTwente, Groningen, TU/Eindhoven, TU Delft and AMOLF. It is an example of creating some alignment and coordination within the PTI domain. NanolabNL has enabled new instrumentation and high-end fabrication facilities that helped define scientific roadmaps on nanotechnology, photonics, quantum technology and advanced materials. Exponents include applied research initiatives such as Photon Delta, QuTech and ARCNL,

reiterating Netherlands strategic roles in these domains. As many of the high-tech developments in physics and instrumentation take place at the nanoscale, the National Roadmap initiative NEMI (Netherlands Electron Microscopy Infrastructure), with participation of nearly all universities and many academic hospitals, is also of high importance to PTI. This national infrastructure provides access to advanced scanning and transmission electron microscopes (SEMs and TEMs) allowing nanoscale and even atomic-resolution imaging of nanostructures and devices, as well as advanced analytical spectrometric methods providing mapping of chemical and physical properties.

Dutch universities:

At many Dutch universities and institutes we find groups working on subjects within the PTI scope. Some examples are listed here (non-exhaustive list): At Delft University of Technology (TU Delft) the Department of Imaging Physics focuses on developing novel instruments and imaging technologies. TU Delft also houses the Van Leeuwenhoek Laboratory for Advanced Imaging Research (VLLAIR) and the Dutch Optics Centre (a TNO and TU Delft joint innovation for next-generation optical instruments), Medical Delta (technological solutions for sustainable healthcare), and Delphi (geo-imaging) consortia. At Eindhoven University of Technology (TU/e) the department of applied physics is divided in three disciplines: ‘Fluids, Bio and Soft matter’, ‘Plasma and Beams’, and ‘Nano, Quantum and Photonics’ where the themes ‘Smart materials and Processes’, ‘Renewable Energy’, ‘High Tech Systems’ and ‘Engineering Health’ are tackled. They also house the following two centres: Centre for quantum materials and technology (QT/e) and Institute for photonic integration (IPI, also part of PhotonDelta). The University of Twente houses the MESA+ Institute, focusing on key enabling technologies (KETs) - photonics, fluidics, hard materials, soft materials and devices. Their main contributions are in the Health, ICT and Sustainability areas. Within the department of Applied Physics the groups ‘Applied nanophotonics’ and ‘Imaging and diagnostics’ readily fall within the scope of the advisory committee. Apart from HFML-FELIX, Radboud University also houses the Institute for Molecules and Materials (IMM). Utrecht University hosts the Debye Institute for nanomaterials. At University of Groningen, the Zernike Institute for Advanced Materials has particular expertise in technologies enabled by quantum electronic materials, spintronics, multiferroics, and optoelectronics. While Leiden has its well-known “Instrumentmakers school”. VU houses the LaserLab Amsterdam, where ground-breaking scientific research based on the interaction of light with matter is performed, spanning from the research on atoms and molecules to the investigation of living cells and tissue and sustainable energy sources. Knowledge on innovative diagnostic and therapeutic techniques is effectively translated into the clinic via clinical partners such as the Amsterdam University Medical Centres. These activities have generated best practice examples of entrepreneurial physics-to-market cases, like academic start-ups Optics11, Lumicks, and OPNT. Pushed by this series of successes, the VU and the UvA have launched the Demonstrator Lab, which aims at supporting entrepreneurial academics to become academic entrepreneurs. Maastricht houses the Maastricht Multi-Modal Molecular Imaging Institute (M4i Institute). It's goal is to perform fundamental, instrumentation and applied studies in molecular imaging.

University medical centres:

Next to the universities, many university medical centres (UMC’s) collaborate with physicists on optimization of techniques for medical purposes such as at the UMC Utrecht Center for Image Sciences and the Groningen Photon therapy centre at the University Medical Centre, Groningen that partners with KVI Centre for Advanced Radiation Technology, providing advanced technology for treatment of cancer. Other initiatives of collaborations are that of the Medical Delta, and the collaboration of Reaction Institute Delft with the department of Radiation Science & Technology (TU Delft).

NWO-institutes:

The NWO institutes are also home to research that falls within the scope of the research community. A clear example is the Advanced Research Centre for Nanolithography (ARCNL), a public-private partnership between the University of Amsterdam, the VU University Amsterdam, NWO, and ASML. NIKHEF has the department ‘Detector R&D’ where cutting-edge new instrumentation ideas are developed that can be used for research in accelerator-based particle physics and astroparticle physics. At DIFFER scientists work on new and improved energy technology for the future. AMOLF has a long history in the development of novel instrumentation, including ion accelerators, mass spectrometry, scanning probe microscopy and ultrafast cathodoluminescence microscopy. Finally also the Solliance institute (Eindhoven) has to be mentioned, where work on new instrumentation (e.g. atomic-layer deposition) is done for the solar (instrumentation) industry.

Partnerships with industry:
Many groups have formed partnerships with industry. This is seen as an important and positive trend as this helps new ideas to achieve actually implementation in instruments. Conversely, contact with industry may also spur new activities in academia. The advisory committee aims to stimulate this contact, what she sees as cross-fertilization between academia and companies (be they small or established industrial players). Many companies fall within the scope of the research community such as (but not limited to): ASML, Philips, ThermoFisher, ASMI, NXP, Smart Photonics, Fuji, Zeiss. The research community advisory committee will consider ways to foster a creative climate in which instrumentation challenges aimed at pushing new limits and/or new directions coming from industry, might be subject to proposals/funding. Also supported projects may lead to spin offs from academia, where students will continue with the ideas they have worked on. Examples are Delmic, Leiden Probe Microscopy, Lumicks and Optics11.

International perspective

The PTI community in the Netherlands competes at a global scale in, for example but not limited to, the following fields:

- Lithography, (ASML, ARCNL)
- Electron microscopy (NEMI)
- Health Tech Systems (diagnostic imaging, intervention medical systems)
- Light and scanning probe microscopy and spectroscopy
- Plasma sources, plasma-matter interactions, plasma control, plasma science
- Research in high magnetic fields and intense infrared/THz radiation (HFML-FELIX)
- NanolabNL
- Quantum information technology
- In situ/in operando cryogenics
- Photonics
- Microfluidics
- Nano-electronics
- Scanning Probe Techniques

In all the areas mentioned above the PTI community in the Netherlands collaborates as well as competes with the corresponding communities abroad, within Europe and beyond. The Dutch PTI community participates in a number of international partnerships. HFML is part of the European Magnetic Field Laboratory (EMFL), which has obtained Landmark Status of the European Strategy Forum on Research Infrastructures (ESFRI). FELIX is part of FELs of Europe and is strongly involved in the League of European Accelerator–based Photon Sources (LEAPS) whose primary goal is to promote and ensure the quality and impact of fundamental, applied and industrial research carried out at the European synchrotron and free electron laser user facilities. LaserLaB Amsterdam is part of LASERLAB-Europe, an Integrated Infrastructure Initiative of the European Union, forming a consortium of the 33 major laser centers in Europe.

6. Specific challenges for the community

PTI is a newly introduced research community advisory committee for physics. Its members stem from the former advisory committees ‘Phenomenological physics’, ‘Nano-physics and –technology’ and ’Condensed matter and optical physics’. Building and connecting this new community is therefore a specific challenge for the coming few to represent the community properly. A first effort to stimulate community building is to attain high visibility at Physics@Veldhoven through parallel session(s) covering topics that are specific to PTI, such as ‘Sources’ and ’Physics for fabrication’.

Another challenge is funding for globally competitive facilities. It is essential that the research infrastructure in the Netherlands remains up-to-date to be able to offer the Dutch research facilities, such as HFML-FELIX, NanolabNL and NEMI. Investment programmes for new equipment exist, such as NWO Groot and the National Roadmap for LSRI. However, it is difficult to structurally finance operational, maintenance and upgrade costs once a facility has been realized. The PTI community thus faces the challenge how to finance the Dutch research facilities in a sustainable and structural way to ensure that the Dutch research community maximally benefits from the investments made and that infrastructures remain state-of-the-art. PTI advices NWO to take strategic actions on this issue by consulting the Round Table Physics and the corresponding research communities. Another challenge is to connect the community with potential industrial partners. Many subjects within PTI have potential for industrial use. To leverage this, strong connections with industry need to be built. To stimulate this process, a PTI Industry day will be organised where researchers and representatives from industry can meet. The annual Physics with Industry event provides another route to strengthen connections.

7. Research portfolio

Organization	# PTI members
AMOLF	6
ARCNL	5
Cosine Research BV	1
DIFFER	8
Nikhef	9
NXP	1
Overig	1
Philips Lighting BV	1
Radboud Universiteit Nijmegen	10
Rijksuniversiteit Groningen	10
SRON	2
Technische Universiteit Delft	18
Technische Universiteit Eindhoven	16
TNO	1
Universiteit Leiden	9
Universiteit Twente	10
Universiteit Utrecht	5
Universiteit van Amsterdam	5
Vrije Universiteit Amsterdam	5
Total	**123**

Composition advisory committee Physics for Technology and Instrumentation

Ageeth Bol	TU/e
Serge Lemay	UT
Frans Widdershoven	NXP
Marloes Groot	VU
Stefan Witte	ARCNL
Tamalika Banerjee	RUG
Jacob Hoogenboom	TUD
Pieter Jan van der Zaag	Philips
Peter Christianen	RU
Andrea Baldi	DIFFER
Anna Sobota	TU/e
Niels van Bakel	NIKHEF