Technische Universität Braunschweig

PTB

Summer School on Metrology 2024

6 – 9 August

Optical Nanosystems – Light in Metrology




QuantumFrontiers
Light and Matter at the Quantum Frontier

B-IGSM Braunschweig International Graduate School of Metrology

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Dear PhD students, lecturers, colleagues,

On behalf of PTB and TU Braunschweig and as speaker of the Braunschweig International Graduate School of Metrology – B-IGSM and the Metrology Initiative Braunschweig, I would like to warmly welcome you to Kloster Drübeck!

This year we took optics in metrology in the focus of our B-IGSM summer school and the bright prospects of photonic applications in many areas of metrology will again be presented by very distinguished colleagues. I am looking forward to meet you in person in the wonderful venue close to the Harz mountain range and I am sure we will have many enlightening talks and fruitful discussions during this summer school.

Meinhard Schilling

Spin qubits based on color centers in diamond

In this talk we will discuss the basics of defect centers in diamond.

Spin qubits in diamond for nanoscale nuclear magnetic resonance

Nuclear magnetic resonance (NMR) is a powerful spectroscopy technique e.g. applied in chemistry, biology and medicine. The conventional method of NMR is limited in sensitivity and does not allow, e.g., the detection of single molecules. Single Nitrogen-vacancy (NV) centers in diamond, on the other hand, can detect nuclear spins on the nanometer scale. This enables single molecule imaging and spectroscopy with NMR and is promising for applications in biochemistry and in biomedicine. In this talk I will discuss several recent advances of NV based Nanoscale NMR.

Nabeel Aslam

Since 9/2023	Full (W3) Professor in Physics at the Felix-Bloch-Institute for Solid-state Physics, Leipzig University
2022 – 2023	Tenure Track W1 Juniorprofessor in Experimental Physics, Institute of Condensed Matter Physics, TU Braunschweig
2018 – 2022	Feodor Lynen Fellow, Department of Physics, Harvard University, Cambridge, MA, USA. Postdoc Advisor: Prof. Mikhail Lukin and Prof. Hongkun Park
2018	Dr. rer. nat. in Physics, University of Stuttgart. Thesis Advisor: Prof. Jörg Wrachtrup. Thesis: Nanoscale Nuclear magnetic resonance with chemical structure resolution
2012	Diplom (equivalent to M.A.) in Physics, Johannes Gutenberg University Mainz

Academic Recognition

2020	Bruker Thesis Prize awarded by the ESR group of the Royal Society of Chemistry and funded by Bruker Corporation
2019	Finalist Quantum Futur Award funded by the German Federal Ministry of Education and Research

Overview of AFM-based techniques for accurate and traceable nanometrology

The presentation will offer an overview on metrological Atomic Force Microscopy (AFM) for various nanometrology tasks. Following an introduction to the fundamental aspects, the talk will delve into two crucial metrology tasks. The first involves calibrating the geometrical properties of nanometrology systems, including magnification, nonlinearity, squareness, flatness, resolution, and noise. The second task focuses on true 3D metrology of complex nanostructures, including critical dimension (CD), line edge/width roughness (LER/LWR), sidewall angle (SWA), among others. Two approaches for realising traceability in nanometrology – a top-down approach and a bottom-up approach will be addressed. Application examples including an extreme ultraviolet (EUV) photomask standard, nanoscale standards calibration, and a novel material measure for optical areal surface topography tools will be demonstrated. As nanotechnologies rapidly evolve, the presentation will finally discuss future prospects, for instance, the application of hybrid metrology, data fusion, and artificial intelligence (AI) for nanometrology.

Gaoliang Dai

Dr. Gaoliang Dai is currently a research scientist and head of the working group "3D nanometrology" at the Physikalisch-Technische Bundesanstalt (PTB) – the national metrology institute of Germany. Gaoliang gained a BSc and a PhD in optical engineering from the Tsinghua University, P. R. China, in the year of 1994 and 1998, respectively. He was a R&D engineer in the Physik Instrument (PI) GmbH & Co till the year 2001 before he joined the PTB. His research interests including the dimensional nanometrology, surface metrology, interferometry, nanopositioning, AFM and TEM techniques. He has received research fundings from EMPIR, ECSEL JU, ENIAC JU, TransMeT and industry in over ten projects. He has authored more than 100 papers in peer reviewed highly ranked journals, received five "best paper" and "outstanding paper" awards, as well as offered a number of keynote and invited presentations in international conferences. Gaoliang serves as an editorial board member for the journals Nanomanufacturing and Metrology, Metrology and Measurement Technology. He is a council member of the International Committee on Measurements and Instrumentation (ICMI), a Fellow of the International Society of Nanomanufacturing (ISNM), and a member of the Metrology Focus Team of the IEEE-International Roadmap for Devices and Systems (IRDS). In addition, he is also a university guest professor.

Superconductors as quantum particle sensors: From photon counting to single-molecule detection

Single photon technologies are crucial for quantum communication, quantum sensing, quantum metrology and quantum computation. This applies specifically to superconducting single photon (particle) detectors (SSPDs) which offer the currently best detection efficiency and the fastest response for quanta of light, from the ultraviolet to the mid-infrared. In this lecture, after an introduction to the basics of SSPDs, I will highlight the paradigm shift from the SSPDs based on meandering nanowires and relying upon the hot-spot model to the last-generation detectors made of a few-micrometer wide superconductor bridges based on a vortex-assisted mechanism of their voltage response [1]. As a an extension to particles of other types, I will also elaborate on the applications of SSPDs in mass spectrometry, including the recent demonstration of single-molecule detection of macromolecule ion beams [2].

[1] Different single photon response of wide and narrow superconducting MoSi strips, Yu. P. Korneeva et al., Phys. Rev. Appl. 13, 024011 (2020)

[2] Highly sensitive single-molecule detection of macromolecule ion beams, M. Strauss et al., Sci. Adv. 9, eadj2801 (2023)

Optical control of dynamic states in superconductors

The dynamics of magnetic flux quanta determines the magneto-resistive response of superconductors and it is crucial, e.g., for their single-photon counting capability. At the same time, exposure of superconductors in a vortex state to a focused laser beam or a microwave stimulus entails the rich physics of light-matter interaction, in which "matter" is represented by an ensamble of vortices and a high-frequency stimulus plays the role of microwave "light". In this lecture, we will begin with the visualization of vortices by scanning SQUID-on-tip microscopy [1] and the control of their arrangements by focused laser beams. We will follow the changes in the shape of the vortex cores with increase of the energy of the electrons in the core and the evolution of the vortex configurations in strongly non-equilibrium regimes. Two potential applications of fast-moving vortex ensembles will be discussed in the context of fluxon-based spin-wave metrology and vortex counting and velocimetry using slitted superconducting constrictions [2].

[1] Imaging of super-fast dynamics and flow instabilities of superconducting vortices, L. Embon et al., Nat. Comm. 8, 85 (2017)

[2] Vortex counting and velocimetry for slitted superconducting thin strips, V. M. Bevz et al., Phys. Rev. Appl. 19, 034098 (2023)

Oleksandr Dobrovolskiy

Oleksandr Dobrovolskiy received his Ph.D. degree from the B. Verkin ILTPE (Kharkiv, Ukraine) in 2009, studying vortices in superconductors. Afterward, he moved to the Physics Institute, Goethe University Frankfurt am Main, investigating magneto-transport phenomena in nanoscale hybrid systems and leading the Nano-Fluxonics laboratory (after habilitation in 2016). He received a D.Sci. degree in superconductivity (ILTPE, 2016) and promoted to Professor of Low Temperature Physics. From 2019 to 2024, he was with the Faculty of Physics, University of Vienna, leading the Superconductivity and Spintronics Laboratory at Nanomagnetism and Magnonics. He has authored more than 130 research works and has been Pincipal Investigator in more than 10 research projects. In July 2024 he has been appointed a professorship at the Technische Universität Braunschweig to lead the division on Cryogenic Quantum Electronics at the Institute for Electrical Measurement Science and Fundamental Electrical Engineering. His research interests encompass quantum electronics and hybrid systems, nanomagnetism, superconductivity, and 3D nanoarchitectures.

Multiplexing interferometers using range-resolved interferometry

Optical interferometry is widely used for non-contact, high-precision displacement measurements in many areas of science and technology. Multiplexing interferometers within a single beam to obtain interferometric phase measurements at multiple locations along the beam is, however, a relatively new idea. This is possible using laser wavelength-modulated interferometric signal processing approaches that can separately demodulate signals from multiple interferometers differing in their respective optical path lengths. Methods such as the range-resolved interferometry (RRI) technique, using sinusoidal laser wavelength modulation of cost-effective yet highly coherent diode lasers, can be employed to simultaneously demodulate signals originating at different ranges with sub-nanometer resolutions similar to regular interferometric techniques.

RRI thus provides novel capabilities in precision interferometry, including, for example, position or angular encoders with multiple degrees-of-freedoms using only a single fiber-coupled access port. Furthermore, the tomographic view of all signal sources that are present in a given interferometric setup provided by RRI can be very useful for diagnostic or alignment purposes. Also, even if the measurement of only a single location is of interest, the ability to cleanly suppress parasitic signal contributions due to multiple reflections allows for highly linear displacement measurements, even using very simple and compact optical measurement heads. Therefore, range-resolved signal processing techniques open up interesting and novel solutions to existing measurement problems in precision engineering and advanced dimensional metrology.

Thomas Kissinger

Thomas Kissinger received his PhD from Cranfield University in the UK in 2016 on the topic of range-resolved interferometric signal processing. He carried on at Cranfield as Research Fellow, later Lecturer, applying interferometric sensing to areas as diverse as in-process 3D imaging for additive manufacturing or fibre optic shape measurements for helicopter blades and was awarded a Royal Academy of Engineering Research Fellowship in 2018. Since 2021, Thomas is Tenure-Track Junior Professor in Nanofabrication and Nanomeasurement Technology at TU Ilmenau in Germany, where he is researching interferometric techniques for precision metrology and positioning, fibre optic sensing and 3D imaging.

Bistatic wind lidar system for precise wind speed measurement

In the field of wind energy, there is a demand for an alternative to costly wind met masts for the precise determination of wind speed. Although so-called wind lidar systems are already used as optical wind speed remote sensing devices, they do not provide the necessary accuracy and traceability to the SI units. For this reason, a bisatic wind lidar system has been developed at the Physikalisch-Technische Bundeanstalt, which enables wind speed measurement with high temporal and spatial resolution. In the lecture, the basic features of optical flow velocity measurement, the bistatic wind lidar system and a differentiation from commercially available lidar systems will be presented.

Stefan Oertel

Stefan Oertel studied electrical engineering and physics at the Technical University of Dortmund. Afterwards he worked in the field of semiconductor laser spectroscopy in the Department Nanostructures at the University of Hanover and prepared his PhD thesis “Spin dynamics in GaAs and (110)-GaAs heterostructures”. Since 2014, he is working in the Group Fluid Flow Measuring Techniques at the Physikalisch-Technische Bundesanstalt with a focus on optical flow velocity measurement.

Timetable

	Tuesday	6 Aug 2024
12:00	Lunch	
13:15	Meinhard Schilling	**Welcome**
13:30	Getting to Know Each Other (Game)	
14:30	Olav Werhahn	**Community structures and general principle in international metrology**
15:30	Coffee Break / Group Picture	
16:15	Gaoliang Dai	**Overview of AFM-based techniques for accurate and traceable nanometrology (1)**
17:15	Bernhard Roth	**Integrated photonics for sensing, imaging and metrology – manufacturing and application**
18:15	Dinner	
19:30	Poster Session 1	

	Wednesday	7 Aug 2024
08:30	Anton Peshkov	**Twisted light (1)**
09:30	Ekkehard Peik	**Laser Excitation of the ^{229}Th nucleus – Towards a nuclear clock (1)**
10:30	Coffee Break	
11:00	Olav Werhahn	**Photons and metrology – making use of light-matter interactions for climate sciences**
12:00	Lunch	
13:30	Gaoliang Dai	**Overview of AFM-based techniques for accurate and traceable nanometrology (2)**
14:30	Nabeel Aslam	**Spin qubits based on color centers in diamond**
15:30	Coffee Break	
16:15	Guided Tour on the Premises of Kloster Drübeck	
18:15	Dinner	
19:30	Social Gathering at the Wine Tavern	

	Thursday	8 Aug 2024
08:30	Nabeel Aslam	**Spin qubits in diamond for nanoscale nuclear magnetic resonance**
09:30	Coffee Break	
10:00	Group Work	
12:00	Lunch	
13:30	Oleksandr Dobrovolskiy	**Superconductors as quantum particle sensors: From photon counting to single-molecule detection**
14:30	Ekkehard Peik	**Laser Excitation of the ^{229}Th nucleus – Towards a nuclear clock (2)**
15:30	Coffee Break	
16:15	Thomas Kissinger	**Multiplexing interferometers using range-resolved interferometry**
17:15	Poster Session 2 / Poster Review	
18:15	Dinner	
19:30	Action Bound "Klosterbrand"	

	Friday	9 Aug 2024
08:30	Anton Peshkov	**Twisted light (2)**
09:30	Oleksandr Dobrovolskiy	**Optical control of dynamic states in superconductors**
10:30	Coffee Break	
11:00	Stefan Oertel	**Bistatic wind lidar system for precise wind speed measurement**
12:00	Lunch	
13:30	Group Work Results	
14:30	Poster Award Ceremony	
14:45	Meinhard Schilling	**Goodbye**
15:00	Farewell Coffee	

Laser Excitation of the ^{229}Th nucleus – Towards a nuclear clock

There is strong interest in ^{229}Th because of the unique low-energy (8.4 eV) isomer that exists in this nucleus. With a transition energy in the range that is typical for resonances of the valence electrons and that is accessible for laser excitation, this nuclear resonance is attractive as the reference of an optical clock that combines high accuracy with a strong sensitivity for hypothetical effects of new physics that may be sought in frequency comparisons with atomic clocks. We have recently achieved resonant laser excitation of ^{229}Th in Th-doped calcium fluoride crystals using a tabletop tunable laser system at 148 nm wavelength. I will discuss possible implications of this development on a nascent field of quantum nucleonics.

Ekkehard Peik

Head of Department Time and Frequency at PTB,
Director and Professor
Privatdozent at the Physics Department of Leibniz University Hannover

Since 2007	Head of Department Time and Frequency, PTB
2019	Head of Working Group Laser Nuclear Spectroscopy, PTB
2003 – 2019	Head of Working Group Optical Clocks with Trapped Ions, PTB
2001 – 2003	Staff Scientist in the Time Unit Laboratory, PTB
1999	Habilitation, Ludwig-Maximilians-Universität München
1994 – 1996	Marie-Curie-Fellow at Ecole normale supérieure, Paris
1993	PhD, Ludwig-Maximilians-Universität München
1988	Dipl. Phys., Ludwig-Maximilians-Universität München
1982 – 1988	Study of physics at the universities of Göttingen and München

Scientific interests: quantum optics and laser spectroscopy, atomic and nuclear physics, laser cooling and trapping, metrology of time and frequency with atomic clocks, tests of fundamental principles

Twisted light

Light beams with a helical wavefront are known in the literature as twisted (or structured) light. Unlike “ordinary” plane-wave radiation, twisted light carries a non-zero projection of the orbital angular momentum (OAM) onto its direction of propagation. Twisted light has proven to be a valuable tool in fields as diverse as super-resolution microscopy, optical tweezers and optical communication. During the lectures we will discuss the basic properties of twisted light and its application to problems in atomic physics.

Anton Peshkov

Anton A. Peshkov received a bachelor's degree in 2012 and a master's degree in 2014 at Saint Petersburg State University in the field of “Wave processes and methods of their investigation”, and then in 2018 received the degree of Dr. rer. nat. at the Friedrich Schiller University Jena for his thesis on “Interaction of atoms with twisted light”. Since then, he has worked as a researcher at the Technical University of Braunschweig and Physikalisch-Technische Bundesanstalt. Anton A. Peshkov's current area of scientific interest is the study of the application of structured light beams to problems of atomic physics and metrology.

Integrated photonics for sensing, imaging and metrology – manufacturing and application

Systems based on optical principles can provide new solutions for unmet needs in fields as versatile as medical diagnostics, point of care testing, environmental analytics or production monitoring. They are particularly suitable for applications requiring non-invasiveness, high spatial or spectral resolution, robustness or immunity against electric and magnetic fields. This comes along with a huge demand on miniaturization and compactness for their fabrication, in order to realize precise measurement devices at higher volume and affordable costs. These trends have driven the development of manufacturing technologies for high-resolution structuring at micro- and nanoscales in the last decade. In this presentation, I will report on our work on the fabrication and application of 2D and 3D optical structures with resolution beyond the diffraction limit reaching sub-100 nm feature size. For fabrication, we employ methods such as two-photon polymerization (2PP) or microscope projection photolithography (MPP). In the production chain, we also use UV nanoimprint lithography (UV-NIL) for replication at high throughput, especially for high-resolution and high-aspect-ratio features. Also, inline and offline metrology are required for monitoring and optimization of the process outcome. The structures produced are validated in applications such as distributed sensing, plasmonics or multiplexed analytics. Current work also revolves about the implementation of a digital model on board of the physical system for functionality analysis and performance estimate. Ultimately, we envision that artificial intelligence-based design and data analysis will further advance system capabilities, e.g. towards predictive measurement devices, and enable solutions for some of the global challenges of our time.

Bernhard Roth

Since 2014	Professor in Physics, Faculty of Mathematics and Physics, Leibniz University of Hannover
2012	Habilitation and Venia legendi in Physics, Faculty of Mathematics and Physics, Leibniz University of Hannover
2007	Habilitation and Venia legendi (Dr. habil.) in Experimental Physics, Quantum Optics, Ultracold Molecules, High-Precision Spectroscopy, Heinrich-Heine University Duesseldorf

2001 Dr. rer. nat. in Physics, University of Bielefeld, Atomic and Particle Physics, Topic: Spin-dependent asymmetry functions in the elastic and inelastic electron-cesium-scattering at intermediate energies

1997 Diplома in Physics, University of Bielefeld, Atomic and Particle Physics, Topic: Investigation of spin-dependent effects and differential cross sections in the elastic electron-cesium scattering

1992 – 1997 Study of Physics, University of Bielefeld

My research interests and main motivation lie in the area of optics and photonics as well as their applications in medicine, life sciences, sensing or monitoring.

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Community structures and general principle in international metrology

The Physikalisch-Technische Bundesanstalt (PTB), is the first national metrology institute on the planet, founded (as PTR at that time) in 1887. Since its beginning, PTB has set out to formulate the core of what nowadays is called metrology and the metrology community. Followed by many other countries worldwide, PTB has ever since contributed its leading role to the removal of trade barriers on one hand side and to push scientific accuracy ahead on the other hand side.
This presentation introduces to the community structures and general principles in metrology. It highlights international networking on the system of units and the relevance of metrology to all of our every-day lifes.

Photons and metrology – making use of light-matter interactions for climate sciences

Photons and their interaction with matter, in all phases, can be used to infer relevant information about climate change, the planet's health and our every-day environment. When it comes to establishing metrological traceability to spectroscopically deduced measurement results, up to now only a limited number of national metrology institutes (NMIs) reach out to scientists in the field working on climate actions. The Physikalisch-Technische Bundesanstalt is among the leading NMIs worldwide devoted to change that. This contribution showcases examples where metrology met spectroscopy using photons and providing metrological traceability to greenhouse gas species, emission monitoring and air quality measurement results.

Olav Werhahn

Since 8/2023	Executive Secretary Innovation Cluster for Environment and Climate (metrology), PTB
6/2021 – 7/2023	Executive Secretary of the JCRB, Bureau International des Poids et Mesures, Sèvres, France
1/2015 – 5/2021	Head of working group "Spectrometric Gas Analysis", PTB
Since 2010	Senior Scientist "Metrology in Molecular Spectroscopy", PTB
Since 2002	Scientist "Metrology in Chemistry", PTB
Since 2000	Post Doc "Ultrashort Pulse Laser Safety", PTB
1999	Dr. rer. nat in Physics, Georgia-Augusta-Universität, Göttingen
1996 – 1999	PhD project on "IR-Laser Spectroscopy on Hydrogen-bonded molecular clusters", MPI für Strömungsforschung, Göttingen
1995	Graduated as Diplom Physiker, Leibniz Universität, Hannover

Interests:
Spectroscopy, gases, metrology, international metrology and science diplomacy

Notes:

Site Plan of Kloster Drübeck

1 **Große Scheune** – lectures, summer school headquarters, group work, poster session
2 **Eva-Heßler-Haus** – meals and guestrooms
3 **Stall** – guestrooms
4 **Äbtissinnenhaus** – guestrooms
5 **Kleine Scheune** – guestrooms
6 **Alte Mühle** – reception of the Kloster
7 **Haus der Stille** – guestrooms
8 **Gärtnerhaus** – Weinstube (wine tavern)

Posters

Anderson	**Noise investigations in frequency combs and quantum-optical coherence tomography**
Bej	**Integrated Photonics Based on Gallium Nitride**
Gläßner	**Textile, Capacitive Brain Computer Interface for Controlling an Assistant Robot**
Mumme	**Low-Noise Readout Electronics for Josephson Junctions**
Nouri	**Investigations on Diamond-NV-Centers as Alternative Labels in STED Microscopy**
Schepergerdes	**From Cellulose to Current – Using Microbial Electrolysis Cells (MECs) for Energy Production**
Skubski	**Reference methods for road vehicle speed**
Wolgast	**Using adjustable DC offset fields in Magnetic Particle Spectroscopy towards sensitive immunoassays**