Abstract Book

Electron Beam Spectroscopy for Nanophotonics 2023

Antwerp, 11-13 Oct 2023

Day 1 - Oct 11 2023

8.30 - 9.00	Registration and welcome
	Session 1: Time-resolved and ultrafast electron optics
9:00 – 9:45	**Jom Luiten** - Exploring the temporal coherence limits of electron beams using microwave cavities (Invited talk)
9:45 – 10:30	**Armin Feist** - Coupling single electrons and photons using high-Q photonics (Invited talk)
10:30 - 11:00	*Coffee break*
11:00 – 11:15	**Stefanie Kraus** - Coherent nanophotonic electron acceleration
11:15 – 11:30	**Spencer Jolly** - Vacuum laser acceleration with arbitrary aberrated ultrafast vector beams
11:30 – 11:45	**Jan-Wilke Henke** - Dynamics of soliton formation in an optical microcavity traced by electron energy-gain spectroscopy
11:45 – 12:00	**Rudolf Haindl** - Coulomb correlated multielectron states in a transmission electron microscope beam
12.00 - 13.00	Walking lunch
	Session 2: Exploring the phase of electron beams
13:00 – 13:45	**Axel Lubk** - Micron-sized magnetic multipole devices for charge particle optics (Invited talk)
13:45 – 14:30	**Thomas Juffmann** - Information and imaging, electrons and light (Invited talk)
14:30 – 15:00	*Coffee break + Group photo*
15:00 – 15:15	**Hoel Laurent Robert** - Development of ptychography methods for the structural measurement of materials with low doses and high efficiency
15:15 – 15:30	**Malo Bézard** - Polarized EELS and CL in STEM
15:30 – 15:45	**Francisco Vega Ibáñez** - Quantum wavefront shaping with a 48-element programmable phase plate for electrons
15:45 – 16:00	**Zdenek Nekula** - Arbitrary shaping of electron pulses in scanning electron microscopes
16:00 - 16:15	**Noémie Bonnet** - Cathodoluminescence emission of a single-layer semiconductor material in the electron microscope
16:15 - 16:30	**Mauro Porcu** - Development of a high-performance time-resolved solution: the Thermo Scientific approach
16.30 - 18.00	Poster session 1

Day 2 - Oct 12 2023

	Session 3: Theory of electron-light interactions
9:00 – 9:45	**Javier Garcia de Abajo** - Challenges and opportunities enabled by the interaction between free electrons and optical fields (Invited talk)
9:45 – 10:30	**Hugo Lorenco Martins** - Mode-selective imaging and population of the polarized local density of states (Invited talk)
10:30 – 11:00	*Coffee break*
11:00 – 11:15	**Andre Goncalves** - Multi-plasmon effects in photoemission from nanostructures: Plasmon satellites
11:15 – 11:30	**Valerio Di Giulio** - Nonclassical generation of light by free electrons
11:30 – 11:45	**Leila Rocio Prelat** - Electron coupling to surface polaritons mediated by small scatterers
11:45 – 12:00	**Cruz I. Velasco** - Quantum decoherence of free electrons by interaction with distant objects
12.00 - 13.00	Walking lunch
	Session 4: Electron-beam spectroscopy of nanooptics
13:00 – 13:45	**Sophie Meuret** - Time resolved cathodoluminescence of InGaN/GaN quantum well in an ultrafast transmission electron microscope (Invited talk)
13:45 – 14:30	**Luiz Titzei** - Cathodoluminescence excitation spectroscopy (Invited talk)
14:30 – 15:00	*Coffee break*
15:00 - 15:30	**Stephan Reitzenstein** - High-performance deterministic in situ electron-beam lithography enabled by cathodoluminescence spectroscopy (Invited talk)
15:30 – 15:45	**Eduardo Dias** - Probing the ultrafast dynamics of charged plasmas with electron beams
15:45 – 16:00	**Jérôme Martin** - Probing Aluminum nanoantennas with electrons
16:00 – 16:15	**Fatemeh Davoodi** - Spin–orbit interactions in plasmonic crystals probed by site-selective cathodoluminescence spectroscopy
16.30 - 18.30	Poster session 2
19.30 - 22.00	Conference dinner - University Club

Day 3 - Oct 13 2023

Session 5: Advanced ultrafast techniques

9:00 – 9:45	**Olga Smirinova** - Ultrafast molecular chirality: a topological connection (Invited talk)
9:45 – 10:30	**Wong Liang Jie** - Free electron-driven nanomaterials for versatile X-ray generation and quantum optics (Invited talk)
10:30 – 11:00	*Coffee break*
11:00 – 11:15	**John H. Gaida** - Attosecond electron microscopy using Lorentz PINEM and free-electron homodyne detection
11:15 – 11:30	**Dennis Rätzel** - Controlling quantum systems with modulated electron beams
11:30 – 11:45	**Saskia Fiedler** - Pump-probe cathodoluminescence spectroscopy of silicon nanospheres
11:45 – 12:00	**Nahid Talebi** - Phase-locked photon–electron interaction without a laser
12.00 - 13.00	Walking lunch Departure

List of posters

Evelijn Akerboom	Electron-near-field coupling strength in plasmonic nanoparticles using electron energy dependent cathodoluminescence spectroscopy
Yves Auad	Time calibration studies for the Timepix3 hybrid pixel detector in electron microscopy
Jassem Baaboura	Nanometer and nanosecond resolved lifetime measurements through electron-photon coincidences
Gabriele Bongiovanni	Ultrafast pump-probe experiments in a TEM using a microwave cavity
Simona Borrelli	Direct observation of Sub-Poissonian Statistics of Free Electrons with Sub-picosecond Resolution
Florian Castioni	Perspectives in charge carriers recombination dynamic in TMDs at the nanometer scale
Paolo Cattaneo	µeV electron spectrometer calibration using a phase-modulated electron beam
Fatemeh Chahshouri	Phase-locked optical gating of free electrons
Alissa Freilinger	Atomically thin amorphous carbon and amorphous silicon – which structural information can be obtained?
Davy Gerard	EELS imaging and spectroscopy of fractal-like optical antennas
Giulio Guzzinati	CEFID: A flexible platform for advanced spectroscopic experiments
Luc Henrard	Examples of Classical and quantum methods for surface plasmon response simulation
Johannes Illmer	Sub-eV free electron spectrometer for ultrafast scanning electron microscopes
Shima Kadkhodazadeh	Electron Energy Loss Spectroscopy Mapping of Topology-Optimized Photonic Cavities With Extreme Dielectric Confinement
Stefan Kempers	Pulsed Laser Phase Plate in a Cavity-Based Ultrafast Electron Microscope
Matthias Liebtrau	Coupling free-electrons and light by an optical fibre-integrated metagrating
Stefano Marinoni	Cathodoluminescence investigation of nanostructured GaN tips
Hollie Marks	Controlling free-electron-light-matter interactions with nanophotonics
Nika van Nielen	Pump-probe cathodoluminescence microscopy for dynamic material analysis
Mark van Ninhuijs	Time-of-Flight EELS
Mark van Rijt	RF-pulsed TEM for EBEAM sensitive samples
Luca Serafini	Development of radio frequency electron beam devices
P. Elli Stamatopoulou	Electron beams traversing spherical nanoparticles: discontinuous Galerkin vs analytical approach
Jakub Urban	Adaptive strategies in PINEM coupling parameter measurement
Francisco Vega	Ultra-Fast Beam Shaping for Differential Imaging in HAADF STEM
Meng Zhao	Apply vortex beam to ptychography

Exploring the temporal coherence limits of electron beams using microwave cavities

Jom Luiten, Peter Mutsaers, Stefan Kempers, Simona Borrelli, Tim de Raadt
Eindhoven University of Technology, Netherlands

Abstract

Contrary to the spatial coherence, the temporal coherence of state-of-the-art electron beams is still orders of magnitude away from the Heisenberg limit: $\Delta E \Delta t \approx 1.8 eV fs$. We use miniaturised microwave cavities to create and manipulate electron pulses of ultrashort duration and low energy spread, approaching this limit. This will enable electron spectroscopy of fundamental excitations at the shortest possible time scales. We have developed a novel method employing the combination of a microwave-cavity-based 2D streak camera and a fast event-driven detector to measure the statistics of a continuous electron beam, revealing anti-bunching at femtosecond timescales.

Coupling single electrons and photons using high-Q photonics

Armin Feist

Max Planck Institute for Multidisciplinary Sciences, Göttingen, Germany,
Georg-August-Universität Göttingen, Germany

Abstract

Introducing concepts from quantum optics in electron microscopy promises novel avenues for nanoscale probing and excitations but requires the ability to induce and detect correlated multi-electron/photon states.

My talk will discuss recent progress in coupling free electrons and photons via inelastic scattering at high-Q photonic modes. Stimulated interaction at an integrated photonic microresonator enables continuous-wave optical phase modulation, while spontaneous scattering produces electron-photon pair states. In analogy to spontaneous parametric down-conversion, this mechanism allows for heralded single-electron or Fock-state photon sources. Furthermore, we employ femtosecond-pulsed photoemission to create Coulomb-correlated multi-electron states, enabling sub-Poissonian electron beam statistics.

References

1. J.-W. Henke et al., Nature. 600, 653–658 (2021).
2. A. Feist et al., Science. 377, 777–780 (2022).
3. R. Haindl et al., Nat. Phys. (2023, DOI: 10.1038/s41567-023-02067-7).

Coherent nanophotonic electron acceleration

Stefanie Kraus, Tomáš Chouba, Roy Shiloh, Leon Brückner, Julian Litzel, Peter Hommelhoff,

Friedrich-Alexander University, Germany

Abstract

Today's particle accelerators use radio-frequency waves together with metallic structures to accelerate particles by alternating electric fields. We can now demonstrate the very same principle, but this time in the optical domain, with advances in laser and nanofabrication technology having enabled miniaturization of such devices. We show acceleration of electrons from 28 to 40 keV in a 500μm long structure, where we guide the beam transversally with "alternating phase focusing". This may lead to a new type of accelerator fitting on a chip.

Vacuum laser acceleration with arbitrarily aberrated ultrashort vector beams

S. W. Jolly[1] , J. Powell[1], S. Vallières[1], S. Payeur[1], S. Fourmaux[1], F. Fillion-Gourdeau[1], S. MacLean[1], and F. Légaré[2]

[1]ULB, Brussels, Belgium,
[2]INRS-EMT, Varennes, Canada

Abstract

The acceleration of electrons to relativistic energies has recently been demonstrated by our team using the longitudinal fields of tightly-focused ultrashort vector beams ionizing a dilute gas. We extend this with a framework to simulate the acceleration process with tightly-focused radially-polarized light having arbitrary aberrations. Nontrivial aberrations and spatio-temporal effects will be shown to be important.

Dynamics of Soliton Formation in an Optical Microcavity Traced by Electron Energy-Gain Spectroscopy

Jasmin Kappert[1,2], Yujia Yang[3,4], **Jan-Wilke Henke**[1,2], Arslan S. Raja [3,4], Germaine Arend[1,2], Guanhao Huang[3,4], Armin Feist[1,2], Zheru Qiu[3,4], Rui Ning Wang[3,4], Aleksandr Tusnin[3,4], Alexey Tikan[3,4], Tobias J. Kippenberg[3,4], and Claus Ropers[1,2]

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[4]Center for Quantum Science and Engineering, Swiss Federal Institute of Technology Lausanne (EPFL), Switzerland

Abstract

Integrated photonics has boosted the interaction strength of light with free electrons, enabling nanoscale spectroscopy of optical states with a continuous electron beam. Here, we employ electron energy-gain spectroscopy (EEGS) to investigate nonlinear optical excitations inside a high-Q microresonator. Starting from a coherent optical state, increasing the input power leads to the formation of dissipative Kerr solitons via various nonlinear intracavity states, evident in characteristic optical and EEG spectra.This scheme may be extended to different quantum states of light, and the interaction with solitons facilitates high frequency electron beam modulation.

Coulomb-correlated multi-electron states in a transmission electron microscope beam

Rudolf Haindl, Armin Feist, Till Domröse, Marcel Möller, John H. Gaida, Sergey V. Yalunin, and Claus Ropers

Max Planck Institute for Multidisciplinary Sciences, Göttingen, Germany
4th Physical Institute, University of Göttingen, Göttingen, Germany

Abstract

In this work, we characterize Coulomb-correlations in laser-triggered electron number states generated at a Schottky emitter in a transmission electron microscope. Based on an event-based detection scheme, we classify electron pulses according to the number of electrons n=1-4 contained. We find that the spectra of the n-state components have a characteristic n-peak spectral shape and identify a characteristic pair-correlation energy of around 2 eV. The strong inter-particle energy exchange is caused by acceleration-enhanced inter-particle Coulomb interaction, as confirmed by trajectory simulations. The high fidelity of few-electron states enables the preparation of distinctive electron statistics for correlated probing and lithography.

Micron-Sized Magnetic Multipole Devices for Charge Particle Optics

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Abstract

Tunable electromagnets and corresponding devices, such as magnetic lenses, deflectors or stigmators, are the backbone of medium- and high-energy charged particle optical instruments, such as electron microscopes. However, the built-in electromagnets are typically structurally bulky, require active (water) cooling, and cannot generate swiftly changing magnetic fields due to their large resistivity and inductance. These restrictions make them unsuitable for fast beam manipulation, multibeam instruments and miniaturized applications. To overcome these limitations miniaturization of tunable magnetic devices is required.

Recently developed microcoil technology[1] allows to fabricate miniaturized magnetic CPO devices based on micron-sized coils. These microcoils (diameter: several 10 μms) are fabricated via lithography-patterned microelectronic structures, which assemble into 3D tubular architectures due to strain engineering within the multilayered polymer structure. The current-carrying copper layer of more than 100 nm thickness sustains more than 100 mA current in vacuum that generates a field of several mT depending on the number of windings. That field is further increases by introducing a soft-ferromagnetic wire (radius 5μm, saturation magnetization 0.2T, relative permeability 1000) into the zero-pitch microcoils.

Employing and adapting the microcoil technology, we fabricate miniaturized magnetic CPO devices directly around an aperture plate (etched into the wave via Bosch process) in a multipolar arrangement (i.e., as monopole, dipole and quadrupole). The micron-sized devices were then introduced into dedicated high-frequency aperture holders facilitating fast switching of the

devices within aperture planes of a TEM. With that alternating magnetic fields of about ±100mT up to a hundred MHz, supplying sufficiently large optical power for many charged particle optics applications is feasible, notably including fast beam blanking and focusing for stroboscopic imaging. Notably, the quadrupole devices allow switchable line foci of a focal length of ca. 5 cm at 300 kV acceleration voltage, which is comparable to macroscopic bulk devices[2]. Possible applications of such micron-sized and fast optics are miniaturized electron microscopes or ultrafast imaging of magnetization dynamics such as the motion of domain walls.

References

1. D. Karnaushenko, T. Kang, V. K. Bandari, F. Zhu, and O. G. Schmidt. Advanced materials 32.15 (2020), p. 1902994.

2. R. Huber, F.L. Kern, D. Karnaushenko, E. Eisner, P. Lepucki, A. Thampi, A. Mirhajivarzaneh, C. Becker, T. Kang, S. Baunack, B. Büchner, D. Karnaushenko, O. Schmidt, A. Lubk, Nature Communications 13 (2022), 3220,

3. We acknowledge funding from the IMPRESS project under the HORIZON EUROPE framework program for research and innovation (grant agreement n. 101094299).

Information and Imaging, Electrons and Light

Thomas Juffmann

University of Vienna, Austria

Abstract

In electron microscopy, it is crucial to minimize dose in order to prevent electron-induced specimen damage. We will discuss an information theoretical approach to quantifying the information that can be obtained about certain parameters of interest in a given microscope. We will then present results on optical wave-front shaping and optical near-field electron microscopy and will discuss how these techniques can help to reduce damage in electron microscopy.

Development of ptychography methods for the structural measurement of materials with low doses and high efficiency

H. L. Robert, J. Verbeeck

EMAT, University of Antwerp, Belgium

Abstract

Recent progresses in detector technology have led to the introduction of several new applications in STEM. Among them is electron ptychography, which consists in the retrieval of the electrostatic potential of a specimen, by exploiting the elastically scattered intensity as a function of scan position. Here, we present newer developments of ptychography, aiming at achieving an improved speed of the process and a higher dose-efficiency, including with the use of event-driven detection. We also take an interest into three-dimensional reconstructions for the structural investigation of materials. Finally, the long-range shape sensitivity of simpler approaches will also be discussed.

Polarized EELS and CL in STEM

Malo Bézard[1], Y. Auad[1], D. Gérard[2], J. Béal[2], J. Martin[2], A. Tavabi[3], R. Dunin-Borkowski[3], M. Kociak[1]

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[2]Univ. Technologique de Troyes, CNRS, Light nanomaterials nanotechnologies (L2n), 10000 Troyes, France
[3]Enst-Ruska Center, Forschungszentrum Juelich, 52428 Juelich, Germany

Abstract

Compared to pure photon-based spectroscopies, Electron Energy Loss Spectroscopy (EELS) and Cathodoluminescence (CL) are the best candidates to access the polarisation at deep sub-wavelength scale. We will present our recent theoretical and experimental efforts towards mapping polarisation in a STEM using EELS and a vortex sorter and polarized CL.

Quantum Wavefront Shaping with a 48-element Programmable Phase Plate for Electrons

Francisco Vega Ibáñez[1], Chu-Ping Yu[1], Armand Béché[1,2], Johan Verbeeck[1],

[1]University of Antwerp, Belgium
[2] Adaptem EU, Belgium

Abstract

We present a 48-element programmable phase plate for coherent electron waves. The phase plate chip is controlled by a series of 16-bit digital-to-analog converters and is mounted on an aperture rod placed in the C2 plane of a state-of-the-art TEM. We give a comprehensive characterization of the device's response along with a test of its performance by creating a set of orthogonal quantum states. The phase plate allows hysteresis-free switching up to 100 kHz, making it highly attractive for adaptive optics. We survey other novel imaging schemes towards improving techniques like ptychography, tomography, and differential imaging.

Arbitrary shaping of electron pulses in scanning electron microscopes

Zdeněk Nekula, Andrea Konečná

Brno University of Technology,
Brno, Czech Republic

Abstract

We develop a module for the arbitrary shaping of electron pulses in scanning electron microscopes (SEM). The module consists of dynamic optical elements such as deflectors and compressors which create pulses in a range of ps with a high electron density and also keep a high spatial resolution. This approach is dedicated to the fast acquisition of time-resolved data. We present the theoretical possibilities and limitations of dynamic optics and also its applications.

Cathodoluminescence emission of a single-layer semiconductor material in the electron microscope

Noemie Bonnet[1], Jassem Baaboura[2], Steffi Y. Woo[2], Florian Castioni[2], Kenji Watanabe[3], Takashi Taniguchi[4], Luiz H.G. Tizei2, Toon Coenen[1]

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[4] International Center for Materials Nanoarchitectronics, National Institute for Material Science, Japan

Abstract

In this contribution, we will explore the interaction between the electron beam and Van der Waals heterostructures, made up of a transition metal dichalcogenide (TMDC) monolayer, here MoSe2, encapsulated in few layers of hexagonal boron nitride (hBN), a wide bandgap material (bandgap 5.95 eV). Using both electron energy-loos spectroscopy (EELS) and cathodoluminescence (CL) in a scanning (transmission) electron microscope (S(T)EM), we will highlight the possible mechanisms leading to CL emission in such heterostructures.

Development of a high-performance time-resolved solution: the Thermo Scientific approach

Mauro Porcu

Thermo Fisher Scientifc, Netherlands

Abstract

Pulsed illumination has gained considerable traction in the last years. On one hand, it enables deep insights into rapid physical, chemical and biological dynamical processes and, on the other, it has shown to be effective in mitigating the damage to the sample caused by the electron beam. The presentation will give a technical overview of the recent hardware developments at Thermo Fisher Scientifc that transform the Spectra S/TEM into a powerful Ultra-fast electron microscope.

Challenges and opportunities enabled by the interaction between free electrons and optical fields

Javier Garcia de Abajo

ICFO - Institut de Ciencies Fotoniques, Barcelona, Spain

Abstract

Electron beams play a pivotal role in the quantum photonic toolkit, serving as both a means to uncover fundamental phenomena and a resource for manipulating nanoscale quantum optical modes. Recent advancements, driven by cutting-edge electron sources and ultrafast light pulses, have significantly enhanced our ability to control the longitudinal and transverse wave functions of free electrons. This presentation provides an overview of the interplay between free electrons, light, and photonic nanostructures, with a focus on quantum aspects and exploration of exciting challenges and opportunities. Topics include nanoscale nonlinear optical response sampling, density matrix manipulation, optical modulation for sub-nanometer/sub-femtosecond electron pulse generation, and sensing schemes enabled by the quantum nature of electron-light interactions.

Mode-selective imaging and population of the polarized local density of states

Hugo Lourenço-Martins

CNRS-CEMES, France

Abstract

In the first part of the conference, we will demonstrate that EELS with phase-shaped electron beams allows the direct measurement of the polarized electromagnetic local density of states (pLDOS). Particularly, we will show that the use of electron vortex beam enables a direct measurement of the local optical spin density. In a second part, we will demonstrate how EEGS can be used to probe the modal structure of the pLDOS. By combining a boundary element method and a compressed sensing approach, we demonstrate the reconstruction of the complex amplitude of plasmonic modes in individual nano-resonators directly at the nanoscale.

Multi-plasmon effects in photoemission from nanostructures: Plasmon satellites

P. André D. Gonçalves, F. Javier García de Abajo

ICFO - Institut de Ciencies Fotoniques, Barcelona Institute of Science and Technology, Spain

Abstract

Photoemission spectroscopies are renowned techniques for mapping bandstructures and resolving quasiparticle dynamics in condensed matter. Here, we investigate multi-plasmon effects imprinted in the photoemission spectrum from plasmonic nanostructures. Such effects, driven by electron–plasmon interactions, lead to the emergence of satellite peaks distanced from the main core-level peak by quanta of the plasmon energy. We derive universal scaling laws for the plasmon satellite probabilities and investigate the impact of the system's morphology and dimensionality. We further predict the appearance of energy-gain satellites in optically pumped nanostructures. Our work opens new directions for investigating ultrafast electron–plasmon interactions in nanophotonics.

Nonclassical generation of light by free electrons

Valerio Di Giulio, F. Javier García de Abajo

ICFO - Institut de Ciencies Fotoniques, Barcelona Institute of Science and Technology, Spain

Abstract

E-beams are typically used in electron microscopes to map optical excitations with nanometric precision. Recently, the ability of tailoring free electrons through PINEM stimulated a new line of research where e-beams are not further seen as probes but as active elements used to control the quantum state of a second specimen. Here, we show how, in order to generate quantum states of light with free electrons, a nonlinear element has to be included in the dynamics. We demonstrate how the fluctuating density of slow electrons can trigger multiphoton processes therefore creating quantum light states such as squeezed states.

Electron coupling to surface polaritons mediated by small scatterers

L. Prelat, E. J. C. Dias, F. Javier García de Abajo

ICFO - Institut de Ciencies Fotoniques, Barcelona Institute of Science and Technology, Spain

Abstract

Surface polaritons can concentrate optical energy down to deep-subwavelength regions in which the field intensity is strongly enhanced, providing a natural platform to apply ultrafast electron microscopy. Specifically, although the excitation of strongly confined polaritons is difficult to achieve by optical means due to wavelength mismatch, the combination of electrons and optical scatterers constitutes a natural approach to boost it. We explore electron–surface-polariton coupling mediated by small scatterers and find optimum conditions that strongly maximize such coupling. Furthermore, we show that an electron interacting with a periodic array of scatterers placed near a polariton-supporting surface can generate polariton Smith-Purcell emission.

Quantum decoherence of free electrons by interaction with distant objects

Cruz I. Velasco, F. Javier García de Abajo

ICFO - Institut de Ciencies Fotoniques, Barcelona Institute of Science and Technology, Spain

Abstract

We theoretically study electron-beam decoherence by analyzing the interaction between a single electron beam prepared in a two-path spatial superposition state and material structures. Inelastic scattering of the electron by the structure results in partial loss of quantum coherence between the two paths. Although an infinite probability of inelastic interactions is obtained for each path for an infinitely extended plate (e.g., a half-plane), the decoherence probability remains finite at finite interpath separation. Besides its fundamental interest, this result introduces an approach to measuring the vacuum temperature and nondestructively sensing the presence of distant objects.

Time resolved cathodoluminescence of InGaN/GaN quantum well in an ultrafast transmission electron microscope

C. Santini[1], N. van Nielen[5], L. Tizei[2], D. Lagarde[3], R. Cours[1], S. Weber[1], A.V. Sakharov[4] , A. F. Tsatsulnikov[4], A. E. Nikolaev[4], A. Arbouet[1], M. Kociak[2], A. Polman[5], A. Balocchi[3], N. Cherkashin[1], **S. Meuret**[1]

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[4] Ioffe Institute, St Petersburg, Russia
[5]AMOLF, Amsterdam, Netherlands

Abstract

The development of time-resolved Cathodoluminescence (TR-CL) in a scanning electron microscope has enabled the measurement of the lifetime of excited states in semiconductors with a sub-wavelength spatial resolution[1–3]. While TRCL is usually done in a scanning electron microscope, the improvement of the spatial resolution and the combination with other electron-based spectroscopies offered by transmission electron microscopes has been a step forward for TR-CL [4,5]. Our TRCL experiment are performed in a unique electron microscope, based on a cold-FEG electron gun [6]. This technology allows among other things to reach a spatial resolution of a few nanometers, essential for the study of III-V heterostructures.

In this presentation we will discuss the advantage and inconvenient of TRCL in a UTEM and present our results on the study of charge carrier dynamics in a 4 nm In0.3Ga0.7N/GaN quantum well. We studied the QW emission dynamic both along and across the quantum well and correlate the results with strain map and high resolution HADF images.

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6. F. Houdellier et al, Ultramicroscopy, vol. 186, pp. 128–138, 2018.

Cathodoluminescence excitation spectroscopy

Luiz H. G. Tizei

U. Paris-Saclay, CNRS, Laboratoire de Physique des Solides, Orsay, France

Abstract

The energy lost by electrons leading to photon emission can be tracked using time coincidence EELS-CL experiments. The spectrum of electrons that generate photons, which we name cathodoluminescence excitation (CLE) spectrum, is analogous to that of photoluminescence excitation spectroscopy (PLE). It measures materials relative quantum efficiency as a function of energy loss in a far wider range than that easily accessible with photons. We have used this technique to measure defects' lifetimes, map defects' absorption with nanometer resolution and follow the evolution of GaN quantum disks emission energy and lifetime as a function of internal electric field screening (quantum confined Stark effect).

High-performance deterministic in situ electron-beam lithography enabled by cathodoluminescence spectroscopy

Stephan Reitzenstein

Institut für Festkörperphysik, Technische Universität Berlin, Berlin, Germany

Abstract

Self-assembled semiconductor quantum dots with excellent emission properties have proven to be among the best candidates to meet the needs of emerging photonic quantum technologies. However, their spatial and spectral positions vary statistically on a scale that is far too large for their system integration via fixed lithography and inflexible processing schemes. To overcome these issues, we developed in-situ electron-beam lithography (EBL), in which we first select suitable quantum dots by high-resolution cathodoluminescence directly followed by EBL to integrate the selected emitters into photonic nanostructures in a scalable manner with nm alignment accuracy to fabricate high-performance photonic quantum devices.

Probing the ultrafast dynamics of charged plasmas with electron beams

E. J. C. Dias and F. J. García de Abajo

ICFO - Institut de Ciencies Fotoniques, Barcelona Institute of Science and Technology, Spain

Abstract

Dense micron-sized electron plasmas, such as those generated upon irradiation of metallic surfaces by intense laser pulses, constitute a rich playground to study light-matter interactions, many-body phenomena, and out-of-equilibrium charge dynamics. Here, we demonstrate that femtosecond electron beams are ideal probes to investigate the ultrafast spatiotemporal dynamics of such plasmas. We develop a comprehensive microscopic theory to predictably describe the evolution of laser-pulse-induced plasmas and their interaction with electron beams, and use this theory to explain recent ultrafast electron microscopy experiments, whereby the position and temporal dependence of the observed electron acceleration permits the characterisation of the plasma-generated terahertz fields.

Probing Aluminum nanoantennas with electrons

Jérôme Martin[1], Davy Gérard[1] and Thomas Simon[1] ,Mathieu Kociak[2], Gabriel Arditi[2], Xiaoyan Li[2] and Odile Stéphan[2]

[1]University of Technology of Troyes, France
[2]LPS, Université Paris-Saclay, Orsay, France

Abstract

Aluminum is an appealing plasmonic material, combining a broadband metallic behavior, a wide availability and CMOS compatibility. We analyze the plasmonic response of aluminum nanorods using both optical and electronic spectroscopies. We experimentally evidence a strong coupling phenomenon between the multiple orders of the nanorod's plasmonic resonance and the interband transition of aluminum. The resulting hybrid modes are analyzed using a model for strong coupling to extract the Rabi energies.

Spin–orbit interactions in plasmonic crystalsprobed by site-selective cathodoluminescence spectroscopy

Fatemeh Davoodi[1], Masoud Taleb[1], Mohsen Samadi[1], Maximilian Black[1], Janek Buhl[2], Hannes Lüder[2], Martina Gerken[2], and Nahid Talebi[1,3]*

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Abstract

This study explores spin-orbit coupling in a plasmonic crystal using theoretical and experimental methods. Through cathodoluminescence (CL) spectroscopy and numerical calculations, we observe energy band splitting resulting from the unique spin-orbit interaction within the crystal. Angle-resolved CL and dark-field polarimetry experiments confirm circular-polarization dependent scattering of surface plasmon waves, revealing the connection between scattering direction and transverse spin angular momentum. Additionally, we propose an interaction Hamiltonian based on axion electrodynamics to explain the breaking of surface plasmon degeneracy caused by spin-orbit coupling. These findings highlight the potential applications of spin-orbit interactions in plasmonics.

Ultrafast molecular chirality: a topological connection

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Abstract

I will describe our very recent results on marrying chiral and topological properties in ultrafast electronic response of chiral molecules in gas phase and show that it brings such benefits as new highly efficient and robust chiral observables not relying on interaction with magnetic field, in contrast to standard chiroptical methods. I will present two vignettes where topological connection appears in optical or electronic chiral response:

(i) Chiral topological light and topological properties of high harmonic emission, generated by such light in chiral molecular gases

(ii) Topological properties (Geometric magnetism) of ultrafast currents in chiral molecules and new classes of highly efficient enantio-sensitive observables

Free electron-driven nanomaterials for versatile X-ray generation and quantum optics

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Abstract

Free electrons are a mainstay in X-ray generation due to the relative ease of accelerating electrons up to 10s or 100s of keV, corresponding to X-ray photon energies. I present our study of nanomaterial-based free-electron-driven X-ray generation processes that surpass the conventional X-ray tube in versatility. I show that in our regime of operation, significant quantum back-action of the electron recoil on the emitted X-ray photon ("quantum recoil") can manifest strongly even at room temperature and in the presence of noise. Our results should pave the way to compact, hyperspectral X-ray imaging and new prospects for X-ray quantum optics.

Attosecond electron microscopy using Lorentz PINEM and free-electron homodyne detection

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Abstract

The aim of time-resolved electron microscopy is to follow the excitations and dynamic states of matter at the nanoscale with a temporal resolution ultimately reaching the attosecond regime. Periodically time-varying fields in an illuminated sample give rise to inelastic scattering of free electrons, which allows the spectroscopic imaging of near-field intensities using PINEM. However, sensitivity to the optical phase is required to access the evolution of nanoscale fields and structures within the light cycle.
In this contribution, we present two phase contrast techniques for imaging optical near fields at nanostructures. Specifically, we implement Lorentz-mode PINEM and free-electron homodyne detection (FREHD). Using these techniques, we image optical fields at nanostructures with few-nanometers spatial and sub-cycle temporal resolutions.

Controlling quantum systems with modulated electron beams

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Abstract

Coherent control of quantum transitions—indispensable in quantum technology—generally relies on the interaction of quantum systems with electromagnetic radiation. Here, we theoretically demonstrate that the nonradiative electromagnetic near field of a temporally modulated free-space electron beam can be utilized for coherent control of quantum systems. We show that such manipulation can be performed with only classical control over the electron beam itself and is readily realizable with current technology. This approach may provide a pathway toward spectrally selective quantum control with nanoscale spatial resolution, harnessing the small de Broglie wavelength of electrons.

Pump-probe cathodoluminescence spectroscopy of silicon nanospheres

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Abstract

We study optical Mie resonances in single Si nanospheres (NPs) with sizes from 100 to 400 nm using novel pump-probe cathodoluminescence (CL) spectroscopy. We couple laser light into the SEM-CL system to locally heat individual NPs and observe a spectral shifts of Mie modes in CL, thanks to the thermo-optical effect in Si. Next, we create ns-short electron pulses using an electrostatic beam blanker allowing us to probe those spectral shifts in Mie modes upon laser heating. Ultimately, the systematic delay between the synchronized laser and electron pulse will enable us to study the time evolution of Mie modes in-situ.

Phase-locked photon–electron interaction without a laser

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Abstract

We present a new approach to simplify ultrafast photon-electron spectroscopy techniques in electron microscopes, which typically rely on complex and costly laser systems. Our method involves using cathodoluminescence spectroscopy, where an electron beam continually interacts with a precisely designed electron-driven photon source and the sample. By this configuration, we achieve phase-locked photons that exhibit mutual coherence with the near-field distribution of the swift electron. Our experimental results demonstrate the frequency and momentum-dependent correlation between the electron-driven photon source and sample radiation, attaining a remarkable degree of mutual coherence that enables us to perform spectral interferometry using an electron microscope.

Electron-near-field coupling strength in plasmonic nanoparticles using electron energy dependent cathodoluminescence spectroscopy

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Abstract

The control over near field distributions in nanostructures is important in many technological fields. Here, we use cathodoluminescence spectroscopy to study the interaction between 6-30 keV electrons and the induced dipolar field in 20-100 nm diameter gold nanospheres. To maximize the coupling strength, the electron must be phase-matched with the induced field. The highest CL in experiments is found to be 0.06%. It is possible to increase the interaction between electron and plasmon by slowing down the electrons (¡1keV) and strongly confine the electric field (¡5 nm). Our results provide insight in controlling and optimizing the mode excitation in nanostructures.

Time calibration studies for the Timepix3 hybrid pixel detector in electron microscopy

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Abstract

Electron microscopy (EM) has been profoundly transformed in recent years with the advent of direct electron detectors. In particular, Timepix3 is an event-based detector capable of outputting temporal information of individual electrons. The detector's nominal temporal resolution is 1.5625 ns, but reaching these values requires a good understanding of both the sensor (silicon) layer and the application-specific integrated circuit (ASIC). In this work, we discuss already well-established calibration procedures in the context of electron microscopy. Additionally, we show how the recently developed cathodoluminescence excitation spectroscopy (CLE) can be used to improve further and diagnose the calibration procedure.

Nanometer and nanosecond resolved lifetime measurements through electron-photon coincidences

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Abstract

III-nitride semiconductors are of immense interest due to their applications in lighting technologies. For light emitters, two important quantities are excitations' lifetime and their quantum efficiency. A combination of electron energy loss spectroscopy (EELS), cathodoluminescence (CL) and light bunching mapping has been used in scanning transmission electron microscope. In this contribution, we will consider still another route to map lifetimes and relative quantum efficiency in quantum disks GaN using temporal coincidences between EELS and CL. Lifetime measurements of excitations in GaN quantum disks in AlN nanowires using light bunching and CL-EELS coincidences will be described.

Ultrafast pump-probe experiments in a TEM using a microwave cavity

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Abstract

Pulsed electron beams are a promising tool for several applications in transmission electron microscopy. They can be used, for example, to reveal structural dynamics with up to sub-picoseconds temporal resolution. In this work, we explore the development of an ultrafast electron microscope based on a resonant radio frequency cavity. Pulses produced by such cavity are characterized by a high degree of coherency and can benefit from the continuous improvements of ultrabright electron sources. We investigate synchronization schemes to match the arrival time of cavity-generated electron pulses and laser pulses in order to perform ultrafast pump-probe experiments. In addition, we show preliminary results regarding the feasibility of photon-induced near-field electron microscopy (PINEM) experiments in our setup.

Direct observation of Sub-Poissonian Statistics of Free Electrons with Sub-picosecond Resolution

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Abstract

Measuring the fermion statistics of free electrons has long posed a significant scientific challenge due to the limited temporal resolution of available detectors. Fermion statistics is experimentally observed as electron anti-bunching, which corresponds to a lower coincidence rate on the detector compared to the classical Poisson distribution. Additionally, anti-bunching can also occur due to Coulomb scattering between electrons. Directly measuring electron anti-bunching requires precise determination of particle arrival times within extremely short time windows.

We propose here a method to accurately determine the arrival time statistics of electrons in a continuous beam with a sub-ps resolution. We present measurements covering time windows ranging from 100 ns to a few-100 fs at beam currents of 6 nA and 48 nA. We demonstrate a Poissonian-like behavior on the ns time scale, while pronounced sub-Poissonian statistics are observed on time windows ranging from a few-fs to a few-hundred fs.

Perspectives in charge carriers recombination dynamic in TMDs at the nanometer scale

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Abstract

Transition metal dichalcogenide (TMDs) became highly attractive photonic materials, particularly thanks to their bright and localized excitonic recombination processes. Using the electron microscope, the possibility to spatially probe their optical properties at the nanometer scale based on excitation (electron energy-loss spectroscopy, EELS) and emission (cathodoluminescence, CL) processes was shown (1). The present contribution aims to prospect the future approaches to characterize the dynamic of charge carriers recombination processes taking place in these 2D materials. The review will include time-resolved spectroscopic approach using the recently developed CL excitation (CLE) technique (2), phase shaped electron beam (3), or gain spectroscopy (4).

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μeV electron spectrometer calibration using a phase-modulated electron beam

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Abstract

We demonstrate a new method that requires a single acquisition for obtaining an absolute energy calibration and correcting the dispersion nonlinearities in the entire range of the spectrometer with ueV/pixel precision. The approach relies on the phase-matched interaction of 120 keV electrons with the evanescent fields of resonant modes circulating in a high-Q photonic integrated Si3N4 microresonator in a TEM. The inelastic interaction leads to a broad electron spectrum consisting in equally-spaced sub-bands that can be used as energy-ruler. Furthermore, the drifts of the spectrometer are studied by acquiring several spectra with several temporal delays.

Phase-locked optical gating of free electrons

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Abstract

Recent progress in coherent quantum interactions between free-electron pulses and laser-induced light have revolutionized electron wavepacket manipulation. By exploring sequential interactions in a phase-locked system between slow electrons and dipolar plasmons, we gain insights into the impact of plasmonic fields on the electron modulation. Our results demonstrate that the initial phase of the optical cycle together with phase offset between dipolar plasmons enable a precise control over the electron recoil in different light polarization states, resulting in selective acceleration or deceleration of electron energy and influencing the diffraction angle. These findings pave the way towards advancing ultrafast electron-light interferometry and electron pulse shaping scenarios.

Atomically thin amorphous carbon and amorphous silicon – which structural information can be obtained?

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Abstract

Structure determination for amorphous materials is not as straightforward as for crystalline materials. In this study, we explore which information can be obtained about the structure of few-angstrom-thick layers of amorphous carbon and amorphous silicon using different electron microscopy and data analysis techniques. 4D STEM datasets are acquired with a Nion Ultra STEM 100 at 60kV. Those will be analyzed via fluctuation electron microscopy (FEM) as well as via ptychographic reconstruction. FEM gives statistical information on the medium range order, whereas ptychographic reconstruction enables imaging of challenging samples at atomic resolution.

EELS imaging and spectroscopy of fractal-like optical antennas

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Abstract

Optical antennas perform the same functions for light that aerials do for radio waves, they can extract energy from a propagating electromagnetic field, and they can convert localized energy into propagating radiation. Here, we use aluminum self-similar, fractal-like structures as broadband optical antennas. Using electron energy loss spectroscopy (EELS), we experimentally evidence that a single aluminum Cayley tree, a simple self-similar structure, sustains multiple plasmonic resonances, and their spatial distribution is directly imaged. The spectral position of these resonances is scalable over a broad spectral range spanning two decades, from ultraviolet to mid-infrared.

CEFID: A flexible platform for advanced spectroscopic experiments

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Abstract

The CEOS Energy Filtering and Imaging Device (CEFID) is an energy filter and spectrometer offering the flexibility to implement groundbreaking experiments. Its design comprises highly optimised and stable optics up to the energy-selecting slit and a flexible projective stage, allowing to switch modes at will without compromising its stability. Panta Rhei, the filter's control software, implements interactive procedures for alignments, acquisition workflows and on-the-fly analysis. The platform is compatible with a wide range of detectors and scan generators from different manufacturers and can be easily extended to integrate with new hardware (e.g. lasers) and software (e.g. liberTEM, serialEM).

Examples of Classical and quantum methods for surface plasmon response simulation

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Abstract

Classical approach, based on electrodynamics, have proven their efficiency to simulate EELS of metallic nanoparticles. In this contribution we first analyze the selective tuning of the plasmonic wave-guide modes of a gold nanowire under laser-induced tip modifications with a DDA approximation (1). For other systems (chemical modification, small size) a quantum approach is necessary. In the second part of this contribution, we applied the decomposition of the dielectric function in a RPA-DFT method to interpret plasmon contribution to the SERS experiment on corrugated graphene (2).

References

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Sub-eV free electron spectrometer for ultrafast scanning electron microscopes

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Abstract

Photon-induced near field electron microscopy (PINEM) is a still nascent but already hot field of ultrafast electron microscopy and coherent electron-light coupling. Requirements towards energy resolution and coherence so far limited PINEM to transmission electron microscopes. The development of a compact sub-eV spectrometer allowed us to demonstrate PINEM with a scanning electron microscope (SEM) (1), benefiting from a large sample chamber and wide optical access inherent to SEMs. With beam energies of down to 0.5 keV this may enable new forms of free electron quantum experiments.
(1) R. Shiloh, T. Chlouba, and P. Hommelhoff Phys. Rev. Lett. 128, 235301 (2022)

Electron Energy Loss Spectroscopy Mapping of Topology-Optimized Photonic Cavities With Extreme Dielectric Confinement

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Abstract

Topology-optimized (TO) dielectric photonic crystal cavities enable light confinement below the diffraction limit, and are therefore promising building blocks for integrating photonics and electronics. Scattering-type scanning near-field optical microscopy has previously been used to characterize such cavities but suffers from a limited spatial resolution and the ability to measure the mode's evolution in space. Here, we have applied electron energy loss spectroscopy to map and visualize the fundamental mode of TO Si bow-tie cavities occurring at 0.8 eV in three dimensions.

Pulsed Laser Phase Plate in a Cavity-Based Ultrafast Electron Microscope

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Abstract

In electron microscopy, phase plates allow for imaging biological samples with atomic resolution by including the otherwise invisible phase information stored in the electron beam. We developed a theoretical model and auxiliary simulations demonstrating that femtosecond laser pulses can be used as a non-material phase plate. We will use the high repetition rate of our 75 MHz fiber laser together with the 100 fs pulses generated by a microwave streaking cavity to create a tunable, pulsed laser phase plate, that omits the limitations of a material-based device.

Coupling free-electrons and light by an optical fibre-integrated metagrating

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Abstract

Here, we embed a circular metagrating with the end facet of an optical fibre to demonstrate the coupling of free electrons and guided optical modes via the Smith-Purcell (SP) effect. Using hyperspectral angle-resolved light detection inside a scanning electron microscope, we probe the angular dispersion of SP radiation (SPR) orders that is emitted into both free space and the fibre core for electron energies in the range of 5 keV to 30 keV. SPR detected by a fibre-coupled spectrometer is spectrally filtered according to the finite numerical aperture of the fibre, revealing the coherent excitation of guided optical modes.

Cathodoluminescence investigation of nanostructured GaN tips

Stefano Marinoni (EPFL), Nicolas Tappy (Attolight AG), Christian Monachon (Attolight AG), Anna Fontcuberta i Morral (EPFL)

Abstract

This study investigates the impact of the manufacturing process on the properties of nanostructured GaN tips. Truncated hexagonal micro-pyramids with a 20μm wide base and 60μm height are fabricated with a top-down process based on Deep Reactive Ion Etching on epitaxially grown GaN on free-standing GaN stack. The study of the optical properties is conducted using both regular and time-resolved cathodoluminescence spectroscopy. By comparison with a pristine and flat GaN stack, we assess the impact of the plasma exposure on exciton energies and lifetimes, and we examine the effects of the nanostructures geometry on the collection of the cathodoluminescence signal.

Controlling free-electron-light-matter interactions with nanophotonics

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Abstract

Merging metasurface concepts with free electron radiation phenomena presents a powerful approach to investigate and shape the interaction between light and electrons. In this work, we design and fabricate a metagrating which generates tunable Smith-Purcell (SP) radiation under grazing electron incidence. We perform finite-difference-time-domain simulations and hyperspectral angle-resolved cathodoluminescence measurements, demonstrating control over the polarisation of SP emission by exploiting electric and magnetic resonances within elliptical nanocylinders. Further, we investigate the potential of optical-fibre-integrated metasurfaces for enhancing electron-light coupling, exploring prospects for the generation and manipulation of radiation, as well as the inverse process of controlling free-electrons with designed optical near-fields.

Pump-probe cathodoluminescence microscopy for dynamic material analysis

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Abstract

We implement ultrafast pump-probe cathodoluminescence (PP-CL) microscopy to study of dynamic processes in materials at the spatial resolution of the electron beam. Using synchronized fs-light pulses and ps-electron pulses with energies up to 30 keV generated through pulsed laser induced photoemission in a scanning electron microscope, we can study of carrier recombination dynamics in Cu2ZnSnS4, a promising semiconductor for photovoltaic applications, and the insulator-to-metal phase transition in resonant VO2 nanocylinders. Additionally, the set up can also be used for photon-induced near-field electron microscopy (PINEM), whereby swift electrons interact with a laser-driven near-field to coherently exchange light quanta.

Time-of-Flight EELS

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Abstract

The strange metal phase in diverse strongly correlated systems, most notably the high-Tc superconducting cuprates, and the recent observation of electronic fluid-like behavior in graphene present the pinnacle of challenges in modern fundamental condensed matter physics. A new theoretical framework suggests the presence of low energy excitations and predicts a dispersion, which can be seen as a fingerprint of dynamic collective processes driven by the heavy correlations. A radically new approach to electron energy loss spectroscopy (EELS) in the form of a time-of-flight (ToF) technique combines a high time resolution with high momentum and energy resolution and allows the investigation of the low energy excitations and hydrodynamic processes in strongly correlated materials. The cornerstone of ToF-EELS is a set of phase-synchronized radiofrequency cavities which are used to manipulate an electron beam in momentum-time phase space. Combined with a commercial field emission electron gun, the energy resolution of a four cavity setup ultimately can be reduced to 25 meV, whereas the temporal resolution can be pushed to a few ps, consequently rapidly advancing the field of ultrafast electron microscopy.

RF-pulsed TEM for EBEAM sensitive samples

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Abstract

The exposure of materials to a high-energy electron beam in TEM is known to generate electron beam damage. Especially for organic materials that are sensitive to inelastic scattering induced damage, this can result in significant loss of the original material information. In this work we test the hypothesis that a pulsed electron beam with a controlled waiting time between electron exposures can reduce the influence of inelastic scattering induced damage. To verify this the time spacing between electron exposure events is controlled on a variety of samples to gain better understanding on the underlying mechanism.

Development of radio frequency electron beam devices

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Abstract

We present developments in radio frequency electron beam devices for SEM. A low-voltage (¡ 5V RMS), electrostatic deflector was created. It is broadband (0Hz-1.37GHz) and can be used as a streak camera when combined with a pixelated detector. Additionally, it serves as a blanker by incorporating an aperture, enabling applications like radiation damage mitigation and probing resonant properties. For the last application a complementing fast photodiode detector was created to monitor the transmitted pulses. Simulations of the deflector were done with in-house code and showed good agreement with reality. Furthermore the code was used to design a single frequency beam intensity modulator.

Electron beams traversing spherical nanoparticles: discontinuous Galerkin vs analytical approach

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Abstract

We study the interaction of swift electron beams passing nearby, or traversing spherical nanoparticles, with electron energy-loss (EEL) or cathodoluminescence (CL) spectroscopies. We present a detailed (semi)analytic solution based on Mie calculations in the case of traversing electron trajectories and apply it to study a lossy and dispersive metallic sphere. We subsequently use these solutions to benchmark the implementation of electron-beam sources in a state-of-the-art numerical method, namely the discontinuous Galerkin time-domain (DGTD) method, showcasing excellent agreement. As a relevant application, we study EELS and CL of a metallic spherical particle with considerable surface roughness.

Adaptive strategies in PINEM coupling parameter measurement

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Abstract

Photon-induced near-field electron microscopy (PINEM) can provide information on nanoscale optical fields. By introducing an additional well-defined reference PINEM interaction, amplitude and phase of the sought electron-sample coupling can be retrieved upon analysis of a sufficient number of electron scattering events. We study the advantages of an adaptive approach consisting in modifying the reference interaction following each electron detection as a route towards the minimization of shot noise. This is an instance of adaptive PINEM electron modulation that we extend to the retrieval of more complex sample parameters with a reduced level of electron damage.

Ultra-Fast Beam Shaping for Differential Imaging in HAADF STEM

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Abstract

We demonstrate a novel technique for HAADF STEM based on the wavefront shaping capabilities of an electrostatic phase plate. Previous studies showed that a high fill factor is one key aspect when designing an electrostatic phase plate suited for STEM (1). We circumvent the problem by proposing an alternative sampling scheme inspired by other optical techniques, such as stimulated emission depletion microscopy (STED) (2) and switching laser modes microscopy SLAM (3). The simulated images show an improved resolution and removal of the background generated by the lower frequency tails originating from the scattering of the electron beam by the aperture.

Apply vortex beam to ptychography

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Abstract

Ptychography, an inline-holographic imaging technique in TEM, offers 3D object reconstruction without tilting and overcoming the information limit of the microscope. Experiments combining ptychography with diverse beam characteristics are rare. We will report on the advantages of Vortex beams for ptychography. Their singularity at the origin and broken symmetry in phase provides for higher phase diversity in comparison to Gaussian beam while it's donut-shaped intensity profile allows for efficient electron utilization, at limited dose. We will present simulations and reconstructions of vortex beam 4D-STEM data in coherent and partially coherent scenarios, exploring the advantages of beam shaping for ptychography.