HL 11: Focus: Advanced TEM spectroscopy - low energy excitations and chemical composition at high resolution (joint session KFM/HL)

The recent progress in transmission electron microscope (TEM) based spectroscopies in terms of spatial, temporal and spectral resolution allows to address new regimes of electronic and vibrational excitations and therefore widened our understanding of condensed matter. This session focuses on recent developments and applications of spectroscopy techniques in the TEM, in particular electron energy loss spectroscopy in the low-loss regime for optical properties and core-loss regime for chemical analysis, at both atomic and medium resolution. Moreover, contributions on ultrafast techniques as well as energy dispersive X-ray spectroscopy, hardware and technique developments, theory and simulation and data processing will be discussed.

Organizer and Chair: Axel Lubk (IFW Dresden)

Time: Monday 15:00–18:40 Location: PHY 5.0.20

Invited Talk HL 11.1 Mon 15:00 PHY 5.0.20

Fifteen years of electron magnetic circular dichroism — •Ján Rusz — Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden

Electron magnetic circular dichroism (EMCD; [1]) has been proposed in 2003 and for the first time experimentally realized in 2006. Since then the method went through a rapid development at both fronts - experimental and theoretical. Dynamical diffraction effects severely complicate EMCD detection and often reduce the its strength. To circumvent this, numerous ways of acquiring EMCD have been proposed and many of them were experimentally tested. Recently, EMCD was detected using astigmatic electron beams on antiferromagnets, or with convergent probes, resolving magnetic signals from areas smaller than a square nanometer. In high-resolution TEM setting, EMCD signal from individual atomic planes was detected using the PICO instrument, where a crucial role was played by chromatic aberration corrector. Theory predicts that electron vortex beams should be efficient probes of EMCD at atomic resolution. Successful realization of this experiment could be extended further to probe the third dimension by means of magnetic depth sectioning. We will review the recent history of EMCD, its present state-of-art and discuss some of its challenges for the near future.

[1] P. Schattschneider et al., Nature **441**, 486 (2006).

HL 11.2 Mon 15:30 PHY 5.0.20

Spectral Field Mapping of Surface Plasmon Resonances using High Energy Electrons — •Jonas Krehl[1], Giulio Guzzinati[2], Johannes Schultz[1], Pavel Potapov[1], Jerome Martin[3], Jo Verbeeck[2], Bernd Büchner[1], and Axel Lubk[1] — [1]IFW Dresden, Dresden, Deutschland — [2]EMAT, Antwerpen, Belgien — [3]Institute Charles Delaunay, Troyes, Frankreich

Surface plasmons resonances (SPR) are discrete modes in the response of the electron gas near the surface of a metallic nanoparticle. They contain very strong and localized electric and magnetic fields which enables interesting nanophotonic applications. Conventional electron energy-loss spectroscopy (EELS) is readily used for mapping the loss probablity of these modes with high energy and high spatial resolution.

The energy-loss signal only entails the longitudinal inelastic momentum transfer (IMT), so for a more comprehensive study of the fields of plasmon modes the lateral IMT components are crucial. The associated beam deflection is only a few μrad so we needed to develop a especially low-angle TEM setup for energy-filtered diffraction. With the energy slit set to a particular mode, the full IMT corresponds to a spectral component of the projected (along the beam trajectory) fields.

We demonstrated this technique in mapping the electric field at the dipole mode of an aluminium nanorod and compared the results with boundary-element-method simulations where we reached reasonable quantitative agreement. We are developing several extensions to this technique which e.g. tackle methodic problems or enable the mapping of magnetic fields.

HL 11.3 Mon 15:50 PHY 5.0.20

Automatic Truncation of Principal Components in the PCA Analysis of EELS and EDX Spectrum-Images — •Pavel Potapov[1], Paolo Longo[2], and Axel Lubk[1] — [1]Leibniz Institute for Solid State and Materials Research (IFW), Dresden, Germany — [2]Gatan Inc, Pleasanton, CA, USA

The Principal Component Analysis (PCA) allows to denoise drastically STEM EELS and EDX spectrum-images by extracting the meaningful fraction of data while cutting off the irrelevant noise. The number of meaningful PCA components is usually estimated through the evaluation of a scree plot - a dependence of the log eigenvalues (variances) on the component index. This strategy however introduces some subjectivity in the treatment. A novel promising method for the truncation of principal components is the analysis of bivariate scatter plots. This method can be easily implemented in automatic algorithms promoting a smooth, unsupervised data treatment flow.

HL 11.4 Mon 16:10 PHY 5.0.20

Synthesis and high-resolution structural and chemical analysis of iron-manganese-oxide core-shell nanoparticles — •Aladin Ullrich, Mohammad Mostafizar Rahman, and Siegfried Horn — Universität Augsburg, Universitätsstr. 1, 86159 Augsburg

Nanoparticles were synthesized by thermal decomposition of a mixture of iron oleate and manganese oleate precursors in high-boiling solvents in the presence of Na-oleate and oleic acid as surfactants. The structural and chemical composition of the nanoparticles was investigated by high-resolution analytical transmission electron microscopy (TEM). The particles appear core-shell like in bright field TEM images. High-resolution TEM (HRTEM) analysis reveals a FeO/MnO like structure in the core and a spinel like structure in the shell. With high-resolution analytical methods like energy dispersive x-ray spectroscopy and electron energy loss spectroscopy, the distribution of the metals Mn and Fe, respectively, was investigated. Furthermore, differences in the oxidation state of these metals were found between the core and the shell region. The presence of sodium from the used surfactant (Na-oleate) on the surface of the particles has been proved.

HL 11.5 Mon 16:30 PHY 5.0.20

How sharp are atomically sharp interfaces in complex functional oxide heterostructures? — •Peter A. van Aken — Max Planck Institute for Solid State Research, Stuttgart Center for Electron Microscopy, Stuttgart, Germany

Complex functional oxide heterostructures have been serving as a multi-directional platform for engineering novel interface functionalities. Recent technical improvements of the epitaxial growth techniques enable fabricating high-quality thin films and heterostructures. The phenomena occurring at their interfaces can be tailored depending on the choice of the constituents. The key factor dominating the interface functionalities is the control of interface sharpness. Therefore, examining the interfacial structure and chemistry is vital for correlating with the underlying physical properties.

High-resolution analytical STEM investigations on various complex functional oxide heterostructures exhibiting different interface sharpness and different functionalities will be presented yielding that i) the growth technique has a direct impact on the structural and chemical sharpness of the interfaces, ii) two-dimensional doping of La2CuO4-based multilayers results in different dopant distribution at both sides of the interfaces which induces different superconducting mechanisms, iii) the choice of the dopant directly affects the interface sharpness. The effect of dopant distribution at interfaces on physical properties will be discussed.

Break 20 min

Invited Talk HL 11.6 Mon 17:10 PHY 5.0.20

Advanced Imaging and Spectroscopy in an Ultrafast Transmission Electron Microscope — •Armin Feist — IV. Physical Institute, University of Göttingen, 37077 Göttingen, Germany

Electron microscopy is tremendously successful in studying complex nanostructured systems, with a temporal resolution governed by typical detector response times. Overcoming these time-domain limitations, ultrafast transmission electron microscopy (UTEM) combines the versatile imaging, diffraction and spectroscopy capabilities of state-of-the-art TEM with femtosecond temporal resolution achieved by a laser pump/electron probe scheme [1,2].

Here, I will briefly introduce the UTEM methodology and show recent results of the Göttingen UTEM instrument, which features high coherence electron pulses generated from nanoscale field emitter tips [2]. The novel applications of UTEM include the study of coherent inelastic electron-light scattering (IELS) at laser-excited nanostructures [3,4]. Besides nanometer mapping of optical near-fields and plasmonic modes, IELS enables the transverse and longitudinal phase control of the free-electron wavefunction [4,5], as evident from characteristic multiphoton gain and loss spectra. In particular, this new concept now allows us to generate attosecond electron pulse trains with applications for optically phase-resolved electron microscopy [5].

[1] A. H. Zewail, Science **328**, 187 (2010). [2] A. Feist *et al.*, Ultramicroscopy **176**, 63 (2017). [3] Barwick *et al.*, Nature **462**, 902 (2009). [4] A. Feist *et al.*, Nature **521**, 200 (2015). [5] K. E. Priebe *et al.*, Nat. Photonics **11**, 793 (2017).

HL 11.7 Mon 17:40 PHY 5.0.20

Spectroscopic coincidence experiments in Transmission Electron Microscopy — •Daen Jannis[1], Knut Müller-Caspary[1], Armand Béché[1], Andreas Oelsner[2], and Jo Verbeeck[1] — [1]EMAT, University of Antwerp, Groenenborgerlaan 171, 2020 Antwerpen, Belgium — [2]Surface Concept GmbH, Am Sägewerk 23a, 55124 Mainz, Germany

Modern transmission electron microscopes are often equipped with EELS and EDX spectrometers. Both measurement techniques share the fact that excitations of atomic states are involved. Indeed, there is for every emitted X-ray photon at least one electron that transfers a part of its energy to excite the atom in the first place, and therefore one could imagine that they convey very similar information. Since the two signals originate from the same process, the temporal correlation between these signals can be measured. Our current setup consists of a novel delay line detector setup for EELS and a Super-X EDX detector. These allow to detect the energy and arrival time (time resolution 270 ns) of every incoming electron and X-ray. This setup keeps all detected events and allows for extensive post processing. By the measurement of every event, it is possible to disentangle the background from the coincidence signal opening up the possibility of background free EELS and EDX with EELS resolution.

[1] D. Jannis, K. Müller-Caspary, A. Béché A. Oelsner and J. Verbeeck. Unpublished Paper, 2018.

[2] D.J., A.B. and J.V. acknowledge funding from the Flemish Research Fund FWO under projectno. G093417N

HL 11.8 Mon 18:00 PHY 5.0.20

High-resolution EFTEM at very low accelerating voltages — •Martin Linck[1], Michael Mohn[2], Johannes Biskupek[2], Heiko Müller[1], Stephan Uhlemann[1], and Max Haider[1] — [1]CEOS GmbH, Englerstr. 28, D-69126 Heidelberg, Germany — [2]Central facility of electron microscopy, Ulm University, Albert-Einstein-Allee 11, D-89081 Ulm, Germany

Simultaneous correction of both, spherical and chromatic aberration in a dedicated low-voltage transmission electron microscope (TEM) has enabled atomic resolution TEM observations on beam sensitive materials at beam energies from 20 to 80 keV (SALVE project). The reduction of focus spread due to chromatic aberration correction, however, not only allows for highest resolution atomic phase contrast (elastic zero-loss imaging) but also enables high-resolution imaging capabilities over significant energy windows in energy-filtered (EF)TEM. In order to provide a significant field of view on the energy filter's camera device, it is essential that the corrector is free of chromatic distortions, i.e. image distortions which change with electron energy. It has been shown that the SALVE corrector is well-suited for such ambitious investigations. First experimental results, in fact, show that high-resolution EFTEM is feasible in the SALVE microscope. The subsequent interpretation of such data, however, is very challenging due to the multiple scattering, i.e. mixture of elastic and inelastic scattering.

HL 11.9 Mon 18:20 PHY 5.0.20

Plasmonics in topological insulators — •Johannes Schultz[1], Axel Lubk[1], Flavio Nogueira[2], Darius Pohl[3], and Bernd Büchner[1] — [1]IFF, IFW Dresden, Helmholtzstraße 20, 01069 Dresden — [2]ITF, IFW Dresden, Helmholtzstraße 20, 01069 Dresden — [3]Dresden Center for Nanoanalysis, TU Dresden, 01062 Dresden

Surface plasmons are self-sustaining resonances occuring at interfaces between media whose permittivities have a different sign. They are associated with strongly enhanced, localized electrical fields, which may be coupled to external optical excitations. Surface plasmons can be used for the sub-wavelength control of electromagnetic fields. Based on this, novel electronic devices can be realized, for instance on-chip light spectrometers and linear accelerators, plasmonic rectennas for the harvesting of light or LEDs and photovoltaics with a higher efficiency. We study the properties of these surface plasmons when they are localized on a surface of a topological insulator like Bismuth selenide.

Surfaces of topological insulators contain conducting states which leads to negative permittivity on the surface and positive permittivity in the bulk. Consequently topological insulators can in principle sustain surface plasmons if they are embedded in a dielectric environment with positive permittivity. To characterize this localized surface plasmon-modes on the surfaces of topological insulators we use low loss spectroscopy techniques in the TEM.