O 12: Nanostructures at Surfaces I

Time: Monday 15:00–17:45 Location: H6

O 12.1 Mon 15:00 H6

Imaging standing phonons within topological defect in strong coupling superconductor by scanning tunneling microscopy — •Qili Li, Thomas Gozlinski, Rolf Heid, Jörg Schmalian, and Wulf Wulfhekel — Karlsruhe Institute of Technology, Karlsruhe, Germany

Electron-phonon coupling plays an important role in conventional superconductors. Understanding the behavior of phonons will promote the applications of conventional superconductors. However, it is difficult to observe the spatial behavior of phonons. Here, we utilize inelastic scanning tunneling microscopy (ISTS) at 45 mK to investigate phonons within topological defect, i.e. stacking fault tetrahedron (SFT), in the strong coupling superconductor Pb(111) [1]. We find that the local Eliashberg function [2,3] is significantly enhanced by SFTs. Moreover, lateral standing waves of phonon are also observed on SFTs. Compared with phonon bandstructure, we find that the SFTs have strong confinement on transverse acoustic phonons, while the longitudinal acoustic phonons are less confined. Our findings pave the way to phonon engineering in strong coupling superconductors. [1] PRL 14, 108 (1965). [2] Sov. Phys. JETP 11, 696 (1960). [3] PRL 114, 047002 (2015).

O 12.2 Mon 15:15 H6

Directing far- and nearfield scattering with dielectric Mie Voids — •Benjamin Reichel[1], Mario Hentschel[1], Adrià Canós Valero[2], Thomas Weiss[2], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, 70569 Stuttgart, Germany — [2]Institute of Physics, University of Graz, and NAWI Graz, Graz 8010, Austria

Controlling the behavior of light at the nanoscale is a significant challenge in various applications such as metadevices, diffraction gratings, and resonant surfaces. Recently, Mie voids created in high-index dielectric host materials have emerged as a promising platform for confining electromagnetic waves in small values, possibly extending down to ultraviolet wavelengths in air. Therefore understanding and theoretical modeling the electromagnetic scattering behavior of Mie voids are crucial for their effective use.

In this study, we perform a spectral multipolar decomposition for the far- and near-field scattering behavior of dielectric Mie voids upon plane wave or local point dipole illumination. Dielectric Mie voids exhibit strong forward far-field scattering behavior, whereas in the near-field strong backscattering behavior is observed. These insights will be important in the development of resonance and meta structure designs, especially when deriving a generalized Kerker condition. Finally, leveraging the full resolution of electromagnetic Mie voids will open avenues for embedding quantum emitters in high index substrates.

O 12.3 Mon 15:30 H6

Influence of Plasma on the Electrode and the Electrolyte during Plasma Electrolysis — •Lukas Forschner[1], Jan-Luca Gembus[2], Peter Awakowicz[2], Andrew R. Gibson[3], Timo Jacob[1], and Albert K. Engstfeld[1] — [1]Ulm University, Institute of Electrochemistry, Ulm, Germany — [2]Ruhr University Bochum, Chair of Applied Electrodynamics and Plasma Technology, Bochum, Germany — [3]University of York, York Plasma Institute, Heslington, United Kingdom

During plasma electrolysis, a plasma is ignited in a thin vapor layer between the powered electrode and the liquid electrolyte. The plasma interacts with both the electrode[1] and the electrolyte, which can modify their properties.[2] In this work, we focus on a metal electrode used as a cathode, where nanoparticle formation can be observed during plasma electrolysis. To gain fundamental insight into nanoparticle formation, we studied the gas sheath surrounding the electrode (including the plasma) and the respective interfaces in detail. Specifically, we use optical emission spectroscopy and high-speed camera imaging to analyze the processes on a milli- to microsecond time scale. We elucidate the structural changes on the electrode induced by the plasma under these conditions with scanning electron microscopy imaging. Based on these results, we discuss mechanisms leading to the formation of nanoparticles in the solution from the electrode.

[1] Artmann et al., *ChemPhysChem* **22** (2021) 2429.

[2] Forschner et al. *J. Phys. Chem. C* **127** (2023) 4394.

O 12.4 Mon 15:45 H6

Structural, morphological and chemical characterization of plasma-treated NiCoO electrolyzer anodes — •Timo Wagner[1], Nicolas Wöhrl[1], Vineetha Vinayakumar[2], Christian Marcks[3], Anna Mechler[3], Doris Segets[2], and Axel Lorke[1] — [1]Faculty of Physics and CENIDE, University Duisburg-Essen, Germany — [2]IVG-PST and CENIDE, University of Duisburg-Essen — [3]AVT.ERT, RWTH Aachen University

Plasma surface pre and post treatment are important steps to tailor characteristics for later manufacturing steps, or as a finishing step to engineer surface characteristics for later applications. We developed a nitrogen microwave plasma process to be used as pre and post treatment for NiCoO coatings for electrolyzers. The plasma treatment resulted in significant modification of the NiCoO films. For example a porous structure, as measured by AFM, SEM and TEM, leads to enhanced accessibility of the active material. Organic species from the spray coating were removed and the plasma-treated NiCoO layers also exhibited a highly hydrophilic surface, which facilitated better interaction with the electrolyte. X-ray absorption spectroscopy (XAS) studies indicated a higher Fe uptake from the electrolyte, which is beneficial for the oxygen evolution reaction (OER). Raman studies showed a more reversible oxidation behavior in the plasma-treated layers. Overall, these modifications contributed to an enhanced OER performance of the NiCoO anodes due to the plasma post-treatment as characterized electrochemically by cyclic voltammetry (CV) and measuring the electrochemically active surface area (ECSA).

O 12.5 Mon 16:00 H6

Artificial Atoms: Energy-Level Engineering and Shape-Dependent Reactivity — •Marco Weiss, Fabian Stilp, Michael Roessner, Max Reinhart, and Franz J. Giessibl — Institute of Experimental and Applied Physics, University of Regensburg

Artificially arranged nanostructures can confine the quasi-free two-dimensional electron gas present on noble metal surfaces, giving rise to a series of resonant eigenstates [e.g. 1-3]. These structures, often referred to as artificial atoms, exhibit remarkable parallels to natural atoms, including the ability to form chemical bonds with natural atoms or repulsive interactions with chemically inert molecules. [4] In our previous investigations using atomic force microscopy (AFM), we successfully identified the occupation of resonant eigenstates that intersect the Fermi level. Notably, we observed a probe-tip-induced energy shift of these states during the measurements. [4] Building on these findings, we developed a method to estimate the energy of artificial atomic states based on their electron occupation. This approach enables precise tuning of the energy levels of these states with meV-scale accuracy. Additionally, we discovered that the distance-dependent repulsive interaction between a chemically inert molecule and the resonant eigenstates of the artificial atom is influenced by the geometric shape of the nanostructure. This holds the potential to tailor nanoscale interactions through precise structural design. [1] Crommie et al., Science 262 (1993), [2] Manoharan et al., Nature 403 (2000), [3] Freeney et al., SciPost Phys. 9 (2020), [4] Stilp et al., Science 372 (2021)

O 12.6 Mon 16:15 H6

Increasing the lifetime of confined electronic states in an artificial quantum structure — Marco Weiss, •Michael Schelchshorn, Fabian Stilp, Alfred J. Weymouth, and Franz J. Giessibl — Institute of Experimental and Applied Physics, University of Regensburg, 93053 Regensburg, Germany

Understanding and tuning the factors influencing the lifetime of confined electronic states is a basic concept of quantum mechanics, whereas achieving large lifetimes in artificial nanostructures holds great potential for advancing quantum technologies. An example of such artificial structures are CO-based quantum corrals. In this study, tunneling spectroscopy measurements reveal a strong correlation between the size of the quantum corral and spectral width, characterized by a predominant Gaussian line shape. We attribute this dominant Gaussian-shaped lifetime broadening to the interaction of surface state electrons with the corral boundary. To further investigate this phenomenon, we constructed corrals of varying wall densities. Our findings indicate that elastic processes, such as tunneling, are more sensitive to the wall density than coupling to the bulk.

O 12.7 Mon 16:30 H6

Template-Assisted Synthesis of Fe_3O_4 Nanodots for High-Density Resistive Switching Memory — •Yifan Xu[1,2], Connie Bednarski-Meinke[2], Erkai Wang[3], Asmaa Qdemat[2], Emmanuel Kennzinger[2], Felix Gunkel[3], Regina Dittmann[3], Yen-Po Liu[3], Oleg Petracic[2,1], and Mai Hussein Hamed[2,4] — [1]Heinrich Heine University Düsseldorf, Faculty of Mathematics and Natural Sciences, 40225 Düsseldorf, Germany — [2]Jülich Centre for Neutron Science (JCNS-2), JARA-FIT, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany — [3]Peter Grünberg Institute and JARA-FIT, Forschungszentrum Jülich GmbH, Jülich, Germany — [4]Faculty of Science, Helwan University, 11795 Cairo, Egypt

The growing demand for high-density memory solutions has driven the exploration of innovative fabrication techniques. We introduce a bottom-up approach for synthesizing ordered Fe_3O_4 nanodots for nanoscale resistive switching memory applications. Using anodic aluminum oxide (AAO) templates as masks, Fe_3O_4 nanodots on Nb:$SrTiO_3$ substrate were fabricated via pulsed laser deposition. Scanning electron microscopy (SEM) confirms the nanodots' uniformity. Grazing incidence X-ray scattering (GISAXS) reveals a high degree of long-range ordering. Magnetometry measurements show that the Verwey transition temperature (T_V) and coercivity are preserved compared to continuous thin films. Conductive atomic force microscopy (cAFM) confirms well-defined nanodots using current maps. By sweeping the voltage on a single nanodot, set and reset processes are observed within ±2V.

O 12.8 Mon 16:45 H6

Intercalation of graphene nanoribbons — •Lüthi Dominik[1], Lin Yang[2], Ji Ma[2], Akimitsu Narita[3,4], Xinliang Feng[2], Klaus Müllen[3], Pascal Ruffieux[1], Roman Fasel[1], and Gabriela Borin Barin[1] — [1]Empa, Ueberlandstrasse 129, 8600 Dübendorf, Switzerland — [2]Center for Advancing Electronics Dresden, TU Dresden, 01062 Dresden, Germany — [3]Max Plank Institute for Polymer Research, 55128 Mainz, Germany — [4]Okinawa Institute of Science and Technology, Okinawa 904-0495, Japan

Atomically precise graphene nanoribbons (GNRs) exhibit unique properties due to electron confinement and tunable band gaps, making them ideal for applications ranging from transistors to spintronics. Precise fabrication is critical, and on-surface synthesis enables the creation of various GNR types with tailored edge topologies, giving rise to intriguing properties such as spin-polarized edges and topological quantum states.

For device integration, GNRs must be transferred from metallic to insulating substrates. However, the high chemical reactivity of zigzag edges has hindered studies of their transport properties. To address this, we explore intercalation to decouple GNRs from metallic substrates, enabling dry-transfer in ultra-high vacuum. This preserves intrinsic properties and facilitates integration into device architectures.

We investigate intercalation with transition metal halides, providing a platform to study interactions with magnetic layers, combining decoupling benefits with potential applications in quantum technologies.

O 12.9 Mon 17:00 H6

Facilitating On-Surface Synthesis on Inert Surfaces by Using a Noble Gas Atmosphere — •Lukas Grossmann[1], Sascha Korn[2], Rochus Breuer[3], Michael Schmittel[3], Heiko Weber[2], Wolfgang Heckl[1], and Markus Lackinger[1] — [1]Deutsches Museum, Munich, Germany — [2]Friedrich-Alexander University, Erlangen, Germany — [3]University of Siegen, Siegen, Germany

A decisive milestone of On-Surface Synthesis (OSS) is the transition from reactive to inert surfaces for the covalent coupling of molecules. This is desirable, because conventionally used metal surfaces strongly interact with organic adsorbates. Thus, adsorption on metals alters the intrinsic properties of the synthesized nanostructures, compromising their applicability. In contrast, inert surfaces leave the adsorbed nanostructures unperturbed. But synthesis is aggravated since activation energies for coupling reactions on inert surfaces are generally higher than on metals. Consequently, reactants desorb before the activation temperature required for their covalent coupling is reached. Here, we explore the OSS of covalent thioether-linked Sierpinski triangles from 1,3,5-tris(4-mercaptophenyl)benzene on inert graphite surfaces. As shown by Scanning Tunneling Microscopy, covalent coupling is feasible by annealing in an argon atmosphere of 1 bar instead of in a vacuum. This protocol kinetically inhibits the premature desorption of reactants, and could be successfully transferred to even more weakly interacting graphene surfaces. The adsorbed Sierpinski triangles exhibit superior thermal stability compared to identical structures on gold and are air stable, underscoring the advantages of inert surfaces.

O 12.10 Mon 17:15 H6

Functionalization of Surfaces with Ordered Arrays of Fullerenes — •Lukas Spree, Caroline Hommel, Pierre Josse, and Andreas Heinrich — IBS Center for Quantum Nanoscience, 52 Ewhayeodae-gil, Daehyeon-dong, 03760 Seoul, South Korea

Endohedral fullerenes are a fascinating class of compounds that facilitate the stabilization of exotic configurations of few-atom structures within the confines of a carbon cage. Depending on the combination of carbon cage and encapsulated species, they provide very stable compounds with highly desirable physical properties. Among the compounds isolated and characterized so far are single molecule magnets with high blocking temperatures and promising candidates for spin qubits with long coherence times.

The exceptional chemical stability of endohedral fullerenes makes them very promising candidates for real-world applications. To achieve their full potential as nanometer sized magnets or quantum sensors, it is necessary to characterize and control the spatial orientation and surrounding of each individual molecule. Scanning probe microscopy techniques lend themselves well for the characterization of ordered assemblies on atomically flat substrates, as they offer an unparalleled combination of spatial and energy resolution.

In this presentation we will show our ongoing efforts of preparing ordered low-dimensional assemblies of endohedral fullerenes on surfaces through chemical functionalization and on-surface synthesis approaches, and discuss possibilities to preserve their desirable properties, like slow magnetic relaxation and potentially long coherence times.

O 12.11 Mon 17:30 H6

Well-defined nanostructures for energy storage and conversion applications — •Ningxiang Wu, Huaping Zhao, and Yong Lei — Fachgebiet Angewandte Nanophysik, Institut für Physik & IMN MacroNano, Technische Universität Ilmenau, 98693 Ilmenau, Germany

Template-based technique provides a perfect approach to realize well-defined arrayed nanostructures within large-scale.[1]We have developed nanostructuring techniques mainly using anodic aluminum oxide templates with scalable, parallel and fast processes for fabricating different three-dimensional and surface nanostructures.[2]The obtained well-defined nanostructures possess large-scale arrayed configuration, high structural density, perfect regularity and cost-effectiveness, and are highly desirable for constructing different nano-devices especially for energy storage and conversion applications, including rechargeable sodium-ion and potassium-ion batteries, supercapacitors, and photo electrochemical devices.[3-4]The device performances demonstrated that the obtained nanostructures benefit these applications through the precise control over the structural features enabled by the geometrical characteristics of the templates. These achievements indicate the high potential and importance of template-based nanostructuring techniques for both basic research and device applications.[1] Nat.Commun.,2022,13,2435, [2] Nat.Nanotechnol.,2017,12,244, [3] Nat.Commun.,2018,9,1720, [4] Nat.Commun.,2016,7,10348