MA 32: $SrTiO_3$: A Versatile Material from Bulk Quantum Paraelectric to 2D Superconductor: Poster (joint session TT/KFM/MA/O)

Strontium titanate ($SrTiO_3$) is a paradigmatic material that plays an important role in various fields of solid-state physics, surface science and catalysis: The pure bulk phase is a wide-band-gap semiconductor that upon cooling becomes a textbook quantum paraelectric. When slightly doped, $SrTiO_3$ turns into a Fermi-liquid-type metal that becomes superconducting at extremely low charge carrier density. $SrTiO_3$-based surfaces and interfaces host un-conventional electronic states such as quasi-two-dimensional electron liquid, magnetism and superconductivity. Despite intensive studies over the past decades, $SrTiO_3$ continues to reveal surprising new phenomena that challenge the established views on this material. To this end achieving light-induced nonequilibrium states and the recent preparation of a 2D oxide based on $SrTiO_3$ opens new playgrounds for research. This Focus Session will present exciting developments in the study of electronic states that are based on the peculiar properties of $SrTiO_3$.

Please note that this Focus Session comprises four parts: Posters are presented within the TT poster session TT58, Wed 15:00-18:00, poster area E. Invited talks are compiled in the session TT62 (Thursday, 9:30 to 12:45, H0104), Contributed talks will be presented in sessions TT72 (Thursday 15:00-18:00, H0104) and TT83 (Fri 9:30-12:30, H0104).

Organizers: Rossitza Pentcheva, University of Duisburg-Essen, Marc Scheffler, University of Stuttgart

Time: Wednesday 15:00–18:00 Location: Poster E

MA 32.1 Wed 15:00 Poster E

Optical conductivity of superconducting Nb:$SrTiO_3$ in magnetic fields at GHz frequencies — •Cenk Beydeda[1], Markus Thiemann[1], Martin Dressel[1], Hans Boschker[2], Jochen Mannhart[2], and Marc Scheffler[1] — [1]1. Physikalisches Institut, Universität Stuttgart — [2]Max-Planck-Institut für Festkörperforschung, Stuttgart

Doped $SrTiO_3$ was among the first unconventional superconductors, the application of the BCS theory is questionable due to the small Fermi energy. Here we present the optical conductivity ($1 - 30\,\mathrm{GHz}$) of superconducting Nb:$SrTiO_3$ in magnetic field. We observe features typical of an s-wave single-gap dirty type II superconductor. We attribute a kink in the magnetic field dependence to 2 distinct superconducting bands. We observe values of the real part of the optical conductivity exceeding the normal state value multiple times for rising magnetic field. Excessive losses at low frequency $hf \ll 2\Delta$ in dependence of temperature are a known feature of superconductivity and a result of coherence effects of the Cooper pairs in the superconducting state (coherence peak). The excessive losses we observe with rising magnetic field are substantially different from the coherence peak, especially in magnetic field dependence and absolute values. As far as we know, excessive losses of this type were not observed in any other superconductor. It is not clear whether Nb:$SrTiO_3$ is the only material that can show excessive losses of this type. We present an interpretation of our data in terms of Caroli-de Gennes-Matricon modes in the vortex state, reproducing the effect of excessive losses qualitatively.

MA 32.2 Wed 15:00 Poster E

Ultrafast second harmonic generation spectroscopy of $SrTiO_3$ surfaces and interfaces — Mahendra Kabbinahithlu, Newsha Vesalimahmoud, Tobias Lojewski, Ping Zhou, Katharina Ollefs, and •Andrea Eschenlohr — Faculty of Physics and CENIDE, University Duisburg-Essen, Lotharstr. 1, 47057 Duisburg, Germany

Perovskite oxide heterostructures can exhibit properties at their interfaces that are very different from the bulk, for example a two-dimensional electron gas [1]. These properties emerge from charge carrier localization or charge transfer, which motivates an interface-sensitive analysis of the charge configuration and charge carrier dynamics. Second harmonic generation (SHG) spectroscopy is an interface-sensitive probe in centrosymmetric materials, suitable for the investigation of $SrTiO_3$-based heterostructures [2]. We perform pump-probe SHG spectroscopy with < 30 fs time resolution in the visible wavelength range (1.9-2.5 eV) at $SrTiO_3$(001) surfaces as well as $LaTiO_3/SrTiO_3$ heterostructures, and discuss the polarization-, wavelength- and time-dependence of the observed SHG response.

[1] H. Y. Hwang, Y. Iwasa, M. Kawasaki, B. Keimer, N. Nagaosa, Y. Tokura, Nat. Mater. **11**, 103 (2012).
[2] A. Rubano, D. Paparo, Materials **16**, 4337 (2023).

MA 32.3 Wed 15:00 Poster E

Low-temperature GHz response of quantum paraelectrics $SrTiO_3$ and $KTaO_3$ — Vincent T. Engl, Nikolaj G. Ebensperger, Cenk Beydeda, Lars Wendel, Marius Tochtermann, Ilenia Neureuther, Ishan Sarvaiya, Martin Dressel, and •Marc Scheffler — 1. Physikalisches Institut, Universität Stuttgart, Stuttgart, Germany

The low-temperature dielectric properties of $SrTiO_3$ and $KTaO_3$ are characteristic of their quantum paraelectric nature: upon cooling, the real part ϵ_1 of the dielectric function strongly increases, but eventually levels off at high values of ≈ 20000 for $SrTiO_3$ and ≈ 4000 for $KTaO_3$. In particular for $SrTiO_3$ it is very demanding to combine such dielectric bulk material with conventional GHz circuitry. We present superconducting coplanar Nb resonators on $SrTiO_3$ and $KTaO_3$ substrates, where in the case of $SrTiO_3$ we employ a distant flip chip geometry. Taking advantage of several resonator modes, we determine the dielectric properties of the two materials at frequencies around 1 GHz and at temperatures down to 25 mK. We thus access regimes of frequency and temperatures, where the dielectric properties of $SrTiO_3$ and $KTaO_3$ have barely been studied.

For the case of $SrTiO_3$, we find an unexpected temperature dependence of the real part ϵ_1 of the dielectric constant: at temperatures below 5 K, where ϵ_1 is expected to vary little upon further cooling, we find a clear maximum around 3 K and a weak minimum around 200 mK. We also observe a strong suppression of microwave losses in both $SrTiO_3$ and $KTaO_3$ for temperatures down to the mK range.

MA 32.4 Wed 15:00 Poster E

ferromagnetic two-dimensional electron gas in oxide interfaces — •Yu Chen[1], Maria D'Antuono[1,2], Martando Rath[1], Cinthia Piamonteze[3], Daniele Preziosi[4], Benoit Jouault[5], Daniela Stornaiuolo[1,2], and Marco Salluzzo[1] — [1]CNR-SPIN, Napoli, Italy — [2]Università di Napoli "Federico II", Italy — [3]Photon Science Division, Paul Scherrer Institut, Switzerland — [4]Université de Strasbourg, CNRS, IPCMS UMR, France — [5]Laboratoire Charles Coulomb, UMR 5221, CNRS, Université de Montpellier, France

Interfacial inversion symmetry breaking triggers novel phenomena not observed in bulk materials, such as unconventional superconductivity and magnetism. Here, we report on the realization of ferromagnetic two-dimensional electron gas (2DEG) at (001) and (111) interfaces between $LaAlO_3$, $EuTiO_3$, and $SrTiO_3$. At variance with the octahedral and quasi-octahedral symmetry in bulk $SrTiO_3$ and (001) interface, trigonal crystal field is reconstructed at (111) interface. The experiments of transport, magnetic and x-ray spectroscopy indicate that the filling of Ti $3d$ bands in the $EuTiO_3$ layer and at the interface with $SrTiO_3$ induces an exchange interaction between Eu-$4f^7$ magnetic moments. We observe carrier density-dependent ferromagnetic correlations and anomalous Hall effect, sizable in-plane orbital moment possibly related to Ti-$3d$ electrons occupying bands with the main $3d_{xz,zy}$ and a_{1g} orbital characters at (001) and (111) interfaces,

respectively. Our findings show intriguing interplay between ferromagnetism, spin-orbit coupling, and symmetry breaking at oxide 2DEG, serving as a guide for the materials design of advanced spintronics.

MA 32.5 Wed 15:00 Poster E

Role of excitonic effects in optical and x-ray absorption spectroscopy of $SrTiO_3$: insights from a combined first principles and many-body theory approach — •V. Begum-Hudde[1], M. E. Gruner[2], and R. Pentcheva[2] — [1]University of Illinois Urbana-Champaign, USA. — [2]University of Duisburg-Essen, Duisburg, Germany.

We present a comprehensive study of the optical[1] and x-ray absorption spectrum[2] (XAS) in the paradigmatic oxide, $SrTiO_3$. Our results demonstrate that inclusion of the quasiparticle effects with single-shot G_0W_0 as well as the electron-hole (e-h), and electron-(core)hole interactions by solving the Bethe-Salpeter Equation (BSE) is integral to accurately describe both the valence and core electron excitations. For the optical spectra, the effect of the exchange-correlation functional is observed to progressively reduce from 1.5 eV variance in the onset of the spectrum in the independent particle picture to 0.3 eV upon inclusion of excitonic corrections. The Ti-$L_{2,3}$ XAS edge is concurrent with experiment w.r.t. the energetic positions of the four-peak structure which is characteristic of Ti octahedral coordination in $SrTiO_3$. We also analyze the origin of prominent peaks in the spectra and identify the orbital character of the relevant contributions by projecting the e-h coupling coefficients from the BSE eigenvectors on the band structure. The spatial distribution of the first bound exciton wave function of the O K edge exhibits an intriguing two-dimensional spread in the x-y plane despite the three-dimensional nature of the material.

[1] Phys. Rev. Mater. **3**, 065004 (2019)
[2] Phys. Rev. Res. **5**, 013199 (2023)

MA 32.6 Wed 15:00 Poster E

Boosting the Edelstein effect of two-dimensional electron gases by ferromagnetic exchange — •Gabriel Lazrak[1], Annika Johansson[2], Börge Göbel[2,3], Ingrid Mertig[2,3], Agnès Barthélémy[1], and Manuel Bibès[1] — [1]Laboratoire Albert Fert, Université Paris-Saclay, CNRS, Thales, Palaiseau, FRANCE — [2]Max Planck Institute of Microstructure Physics, Halle, GERMANY — [3]Martin Luther University Halle-Wittenberg, Halle, GERMANY

In this work, we show that making STO 2DEGs ferromagnetic significantly boosts the conversion efficiency of charge and spin currents through direct and inverse Edelstein effects (EE/IEE). Starting from the experimental band structure of non-magnetic SrTiO3 2DEGs, we mimic magnetic exchange coupling by introducing an out-of-plane Zeeman term in a tight-binding model. We then calculate the band structure and spin textures for increasing internal magnetic fields and compute the Edelstein effect using a semiclassical Boltzmann approach. The conversion efficiency initially rises with magnetic field strength, reaching a maximum before declining. This behavior results from the interplay between exchange coupling and the effective Rashba interaction. Our experimental focus is on the 2DEG at the SrTiO3/EuO interface to introduce ferromagnetism into the system.

MA 32.7 Wed 15:00 Poster E

Impact of a Si(001) substrate on the electronic reconstruction and two-dimensional electron gas formation at $LaTiO_3/SrTiO_3$(001) — •Andri Darmawan and Rossitza Pentcheva — Department of Physics, University of Duisburg-Essen

The two-dimensional electron gas (2DEG) formed at oxide interfaces e.g. between the band insulator $SrTiO_3$ and the Mott insulator $LaTiO_3$ has attracted a lot of attention [1]. However, despite the high carrier density at the interface, the carrier mobility is lower compared to semiconductor materials. A strategy to overcome this shortcoming is the integration of the oxide system on a semiconductor substrate [2]. Based on density functional theory calculations with a Hubbard U term we modeled $LaTiO_3/SrTiO_3$(001) with and without a Si(001) substrate. We explore systematically the sample geometry and the effect of the termination to Si(001) on the electronic reconstruction at the $LaTiO_3/SrTiO_3$(001) interface. The comparison between the two systems indicates lower effective masses and consequently higher mobility of the 2DEG at $LaTiO_3/SrTiO_3$/Si(001).

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[1] A. Ohtomo et al., Nature 419, 378 (2002)
[2] E. N. Jin et al., APL Mater. 2, 116109 (2014)