O 110: Surface Magnetism

Time: Friday 10:30–12:45 Location: MA 144

O 110.1 Fri 10:30 MA 144

Artificially-constructed chains of magnetic adatoms on superconducting β-Bi2Pd — •Jinkyung Kim[1,2], Mireia Tena[3,4], Kyungju Noh[1,2], Piotr Kot[1], Yujeong Bae[1,2], Andreas Heinrich[1,2], Nicolas Lorente[3,4], and Deung-Jang Choi[3,4] — [1]Center for Quantum Nanoscience (QNS), Institute for Basic Science, South Korea — [2]Department of Physics, Ewha Womans University, Seoul 03760, South Korea — [3]Centro de Física de Materiales CFM/MPC (CSIC-UPV/EHU), 20018 Donostia-San Sebastián, Spain — [4]Donostia International Physics Center, 20018 Donostia-San Sebastián, Spain

Majorana bound state (MBS) has been studied in various condensed matter systems, such as one-dimensional topological superconductor, to realize topological quantum computation. Cr spin chains on superconducting β-Bi2Pd were suggested as one of the candidates of 1D topological superconductor, due to its combination of large magnetic moments and Rashba spin-orbit couplings of the superconducting substrate as shown in the simulation [1]. Taken advantage of atomic manipulation in STM, we artificially constructed a ferromagnetic Cr chain on a β-Bi2Pd surface. An evolution of in-gap states was carefully traced as we increase the length of the chain by attaching atoms one-by-one, and the results show excellent agreements with the simulations. We further investigate into topological phases of Cr chains based on the experimental discoveries, hinted as a formation of MBS at the edges of the chain. [1] Cristina Mier, et al., Physical Review B 104, 045406 (2021)

O 110.2 Fri 10:45 MA 144

Probing In-Gap States: Unveiling Pathways to Topological Superconductivity — •Deung-Jang Choi[1,2,3], Jinkyung Kim[4], Wonjun Jang[4], Yujeong Bae[4], Andreas Heinrich[4], and Nicolas Lorente[1,2] — [1]Centro de Física de Materiales CFM/MPC (CSIC-UPV/EHU), 20018 Donostia-San Sebastián, Spain — [2]Donostia International Physics Center (DIPC), 20018 Donostia-San Sebastián, Spain. — [3]Ikerbasque, Basque Foundation for Science, 48013 Bilbao, Spain — [4]Center for Quantum Nanoscience, Institute for Basic Science (IBS), Seoul 03760, Korea

Lately, there has been a growing interest in the introduction of impurity states within the superconducting energy gap. Notably, the pursuit of a novel superconducting state known as topological superconductivity heavily relies on creating nanostructures with magnetic impurities on conventional (s-wave) superconductors that arrange spins in a chiral manner. Our study presents the initial findings resulting from the deliberate manipulation of individual atoms, enabling the construction of a chain of Cr atoms on a Bi2Pd superconductor [1,2,3]. These magnetic impurities, situated on diverse substrates, provide an unique opportunity to investigate various many-body effects and unconventional phenomena within different experimental spin systems. This research contributes to an enhanced comprehension of the underlying parameters governing each distinct system. References: [1] Phys. Rev. B 104 (4), 045406 (2021). [2] Phys. Rev. B 104 (24), 245415 (2021). [3] Phys. Rev. Research 4, L032010 (2022).

O 110.3 Fri 11:00 MA 144

Moiré-induced interface electronic states and magnetic properties of monolayer $FeCl_2$ on Bi(111) — •Shigemi Terakawa, Jingrong Ji, Gabriele Domaine, Emily C. McFarlane, Stuart S. P. Parkin, and Niels B. M. Schröter — Max Planck Institute of Microstructure Physics, Halle, Germany

Two-dimensional van der Waals (vdW) magnets have attracted increasing attention because of their potential use in magnetic vdW heterostructures, leading to various novel quantum phases through their unique properties such as the magnetic proximity effect and the moiré superlattice. $FeCl_2$ is a layered antiferromagnet, where the magnetic moments aligned in the out-of-plane direction are coupled ferromagnetically in a unit layer and antiferromagnetically between adjacent layers. We have successfully grown monolayer $FeCl_2$ film on Bi(111) using molecular beam epitaxy. The high crystallinity of the film was confirmed by low-energy electron diffraction (LEED) and scanning tunneling microscopy (STM). LEED and STM show strong moiré patterns. Angle-resolved photoelectron spectroscopy (ARPES) revealed the insulating band structure of monolayer $FeCl_2$. We found metallic X-shaped crossing bands at the $\overline{K}$ points of the moiré Brillouin zone (BZ). The bands can be understood as the interface states originating from the Bi(111) surface states, which are modified by hole doping and back-folding according to the moiré BZ. The magnetic hysteresis curves of monolayer $FeCl_2$ measured by X-ray magnetic circular dichroism (XMCD) show a higher slope at zero field for in-plane configuration, suggesting a magnetic order with an in-plane easy axis.

O 110.4 Fri 11:15 MA 144

Magnetic dichroism and spin polarization in threshold photoemission — •Frank O. Schumann[1], Jürgen Henk[2], Friederike Elisa Wühl[2], David Huber[2], and Wolf Widdra[2] — [1]Max-Planck Institut für Mikrostrukturphysik, Halle, Germany — [2]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, Germany

An emitted photoelectron can be analyzed with respect to energy, emission direction and spin polarization. The latter parameter is of particular interest for magnetic materials. The photoemission intensity depends on the polarization state of the light and magnetization direction leading to magnetic dichroism usually expressed as asymmetry. This can be used for magnetic contrast in domain imaging. For a microscopic description of spin polarization and magnetic dichroism it is vital to include both the spin-orbit and exchange interaction on an equal footing. We performed an appropriate one-step photoemission calculation for threshold photoemission from a Fe(100) surface. We found good agreement to the experimental magnetic dichroism data obtained with a photon energy of 5.2 eV. Apart from the intensity we obtain the theoretical spin polarization spectra. These are decomposed into an exchange and spin-orbit part. We find a sizable spin-orbit polarization and observe a resemblance to the asymmetry spectrum. We bring this into relation to analytical work, which demonstrated a connection between magnetic dichroism and the spin-orbit polarization in the limit of vanishing exchange interaction [1].
*[1] J. Henk et al., J. Phys.: Condens. Matter **8**, 47 (1996).

O 110.5 Fri 11:30 MA 144

Multi-orbital interactions and spin polarization in single lanthanide adatoms — •Massine Kelai[1], Stefano Reale[1], Jaehyun Lee[1], Philippe Ohresser[2], Deung-Jang Choi[3], Fabrice Scheurer[4], Aparajita Singha[5], and Fabio Donati[1] — [1]Center for Quantum Nanoscience, Institute for Basic Science, Seoul, Republic of Korea — [2]Synchrotron SOLEIL, L'Orme des Merisiers, France — [3]Donostia International Physics Center, Donostia-San Sebastián, Spain — [4]Institut de Physique et Chimie des Matériaux de Strasbourg, Strasbourg, France — [5]Max Planck Institute for Solid State Research, Stuttgart, Germany

Lanthanide atoms on surfaces show enormous potential for quantum information technologies. The use of a specific atom as an atomic-scale memory unit or qubit depends on the magnetic quantum level structure, which arises from the interaction between the atom and the substrate. Understanding the magnetic and electronic properties requires insight into the $4f$ and $5d6s$ orbitals, as well as their mutual interaction. Here, we investigate Nd atoms on Ag(100), HOPG, and Pb(111) using X-ray absorption and magnetic circular dichroism spectroscopies. The results show electronic transitions from atomic-like to bulk-like configurations with increased coordination on Ag(100) and HOPG, while Pb(111) remains bulk-like even for single atoms, and demonstrate that the Coulomb repulsion drives the electronic transition. We also reveal the existence of a fraction of spin-polarized $5d$ electrons for single atoms. This research enhances the understanding of the magnetism of surface-supported lanthanides.

O 110.6 Fri 11:45 MA 144

Long Range Magnetic Order in a Lanthanide, Fe-Porphyrin Metal-Organic Coordination Networks — •Dasom Choi[1,2], Massine Kelai[1,2], Serim Jeon[1,2], Stefano Reale[1,2], Corina Urdaniz[1,2], Andreas J. Heinrich[1,2], Dominik Lungerich[3,4], Christoph Wolf[1,2], Fabio Donati[1,2], and Luciano Colazzo[1,2] — [1]Center for Quantum Nanoscience, Institute for Basic Science (IBS), Seoul, South Korea — [2]Ewha Womans University, Seoul, South Korea — [3]Center for Nanomedicine, IBS, South Korea — [4]Graduate Program of Nano Biomedical Engineering, Advanced Science Institute, Yonsei University, South Korea

This research provides the electronic and magnetic characterization of a metal-organic networks formed using Iron-Tetrakis-(4-Cyanophenyl) Porphyrin (Fe-TCPP) and Dysprosium (Dy). By carefully depositing specific amounts of Fe-TCPP and Dy on Au(111), coordinated bonding between Dy and cyano-groups led to organized structures, forming extensive 2D islands and showcasing significant long-range ferromagnetic order. We used scanning tunneling microscopy/spectroscopy, x-ray magnetic circular dichroism and density functional theory to explore the structural and magnetic attributes of a metal-organic coordination network based on lanthanides. This method of fabrication lays the groundwork for creating magnetic 2D architectures on surfaces capable of storing and manipulating quantum information. This advancement propels the boundaries of quantum computing and information processing, potentially enabling the development of multiqubit systems.

O 110.7 Fri 12:00 MA 144

Recent Progress in the Investigation of the Magnetic Properties of Individual Lanthanide-Based Dimetallofullerene Single-Molecule Magnets — •Tobias Birk[1], Fabian Paschke[2], Vivien Enenkel[1], Fupin Liu[3], Jan Dreiser[4], Vladyslav Romankov[4], Stanislav M. Avdoshenko[3], Alexey A. Popov[3], and Mikhail Fonin[1] — [1]Department of Physics, University of Konstanz, 78457 Konstanz, Germany — [2]IBM Research Europe, 8803 Rüschlikon, Switzerland — [3]IFW Dresden, 01069 Dresden, Germany — [4]SLS, PSI, 5232 Villigen, Switzerland

Due to their rich and versatile chemical and physical properties, single-molecule magnets (SMMs) are in focus of a diverse and broad research community. Especially lanthanide based SMMs are promising candidates for future electronic devices because of long relaxation times and high blocking temperatures. Here we present a dimetallofullerene SMM with a single-electron lanthanide-lanthanide bond within its magnetic core, which shows chemical robustness and a blocking temperature of about 21 K [1]. We perform scanning tunnelling microscopy (STM) and spectroscopy (STS) measurements in order to investigate its electronic and magnetic properties. By investigating two different lanthanides, we demonstrated access to the magnetic core of the molecule [2]. Based on this, we perform inelastic electron tunnelling spectroscopy (IETS), which reveals symmetric conduction steps and additionally a prominent conductance peak due to a Kondo resonance.

[1] F. Paschke *et al.* Adv. Mater. 2102844 (2021).
[2] F. Paschke *et al.* Small 2105667 (2022)

O 110.8 Fri 12:15 MA 144

Tip-assisted motion of Co and Rh atoms on the antiferromagnet Mn/Re(0001) — •Felix Zahner, Kirsten von Bergmann, Roland Wiesendanger, and André Kubetzka — Institut für Nanostruktur- und Festkörperphysik, Universität Hamburg

The diffusion of adatoms on surfaces is a fundamental process, governing the growth and self-assembly of thin films and nanostructures. Adatom diffusion on non-magnetic surfaces has been investigated in real-space by local probes such as field ion microscopy [1] and scanning tunneling microscopy (STM) [2], whereas diffusion on magnetic surfaces has so far only been addressed theoretically [3].

In this contribution, we have studied Co and Rh atoms on a single fcc-stacked layer of Mn on Re(0001). The ground state of this hexagonal layer is a row-wise antiferromagnetic state [4], which reduces the symmetry and results in a uniaxial system. We use the tip of an STM at $T = 4.2$ K to induce adatom motion and investigate to what extent the magnetic state influences the movement of magnetic Co atoms and non-magnetic Rh atoms.

[1] G. Antczak, G. Ehrlich, Surface Science Reports **62**, 39 (2007).
[2] J. Li, R. Berndt, W.-D. Schneider, Phys.Rev.Lett. **76**, 1889(1996).
[3] S. Dennler, J. Hafner, Phys. Rev B **72**, 214414 (2005).
[4] J. Spethmann, S. Meyer, K. von Bergmann, R. Wiesendanger, S. Heinze, A. Kubetzka, Phys. Rev. Lett. **124**, 227203 (2020).

O 110.9 Fri 12:30 MA 144

Shape and magnetism of $Fe_{3-\delta}O_4$ nanoislands on $SrTiO_3$ — •Steffen Tober[1], Yifan Xu[1], Mohammad Tehrani[2,3], Mai H. Hamed[1], Asmaa Qdemat[1], Nadine Seidel[1], Jan-Christian Schober[2,3], Vedran Vonk[2], Connie Bednarski-Meinke[1], Ulrich Rücker[1], Andreas Stierle[2,3], and Emmanuel Kentzinger[1] — [1]Jülich Centre for Neutron Science (JCNS) and Peter Grünberg Institut (PGI), JARA-FIT, Forschungszentrum Jülich — [2]Deutsches Elektronen-Synchrotron DESY, Centre for X-ray and Nanoscience, Hamburg — [3]Universität Hamburg, Fachbereich Physik

The magnetic properties of $Fe_{3-\delta}O_4$ nanoparticles for medical applications depend on the synthesis route influencing their defect structure, ligand shell and shape [1]. Optimisation of the magnetisation requires disentangling preparation-specific influences from intrinsic size effects. $Fe_{3-\delta}O_4$ nanoislands on $SrTiO_3$ are introduced as a ligand-free model system with defined structure and orientation to study the magnetic properties of iron oxide nanostructures. Characterisation by diffraction, grazing incidence small angle X-ray scattering, neutron reflectivity and SQUID indicates the formation of crystalline, uniformly shaped nanoislands with a distinct magnetic shape anisotropy [2]. Our results form the basis for ongiong *in situ* studies probing interdependencies between composition, shape, defect structure and magnetisation of nanostructured iron oxides.

[1] D. Zákutná et al., PRX 10, 031019 (2020),[2] A. Devishvili et al., Rev. Sci. Instrum. 84, 025112 (2013).