QMS2025

Symposium on

Quantum Materials Synthesis

Porto, October 21-24, 2025

GORDON AND BETTY MOORE FOUNDATION

PAUL SCHERRER INSTITUT PSI

UNIVERSITÉ DE GENÈVE

QMS2025 – Welcome

October 21, Tuesday – Pestana Douro hotel

	Arrival
18:30-20:00	**Registration (Douro V room)**
18:30	**Welcome drink (terrace in front of the Douro V room)**
20:00	**Dinner (Douro V room)**

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QMS2025 – Program

October 22, Wednesday – conference room Douro III - Pestana Douro

Session 1 – Membranes and flexible oxides
chair Greta Segantini

9:00 Invited Talk – Chang-Beom Eom (University of Wisconsin Madison)
Twisted oxide membrane interface by local atomic registry design

9:30 Invited Talk – Jacobo Santamaria (Universidad Complutense, Madrid)
Moiré polar topologies and interlayer interactions in twisted oxide membranes

10:00 Invited Talk – Varun Harbola (MPI Stuttgart)
New horizons for interfaces by oxide membranes

10:30 Coffee break

Session 2 – Complex magnetism I
chair Marta Gibert

11:00 Invited Talk – Ian Fisher (Stanford University)
Quadrupolar order in TmVO4: from fundamental physics to novel applications

11:30 Invited Talk – Bharat Jalan (University of Minneapolis)
Tricks of strain and treats of emergent phases: unraveling altermagnetism and polar metallic states in epitaxial RuO_2 Films

12:00 Contributed Talk – Maya Ramesh (Cornell University)
Designer enhanced magnon transport in epitaxial, multiferroic heterostructures grown by molecular-beam epitaxy

12:15 Contributed Talk – Yoony Baek (Harvard University)
Interplay of frustration and f–d exchange in a pyrochlore ferromagnet

12:45 Lunch break

Session 3 – Superconductivity in nickelates I

chair Jennifer Fowlie

14:30 Invited Talk – Harold Hwang (Stanford University)
Correlated phases in nickelates

15:00 Invited Talk – Charles Ahn (Yale University)
Superconducting $Nd_{1-x}Eu_xNiO_2$ thin films using in-situ MBE synthesis

15:30 Invited Talk – Karsten Held (Tu Wien)
Theory of infinite-layer nickelate superconductors

16:00 Contributed Talk – Sangjae Lee (Yale University)
Doping-dependent electronic structure of $Nd_{1-x}Eu_xNiO_2$

16:15 Coffee break

Session 4 – Growth control of electronic properties

chair Bharat Jalan

16:45 Invited Talk – Darrell Schlom (Cornell University)
Hot quantum materials—turning up the heat to achieve adsorption-controlled synthesis and improved perfection

17:15 Invited Talk – Eva Benckiser (MPI Stuttgart)
Directional imprinting of structural distortions drives spin-orbital order in a vanadate

17:45 Invited Talk – Duncan Alexander (EPFL)
Engineering symmetry breaking interfaces in orthorhombic perovskite thin films via structural-energetics

18:15 Contributed Talk – Arun Kumar Jaiswal (University of Geneva)
Epitaxial control of octahedral rotations in antiferromagnetic $DyFeO_3$

Dinner – not organized

October 23, Thursday – conference room Douro III - Pestana Douro

Session 5 – Topology and chirality
chair Karsten Held

9:00 Invited Talk – Sang-Wook Cheong (Rutgers)
Chirality, false chirality and time chirality

9:30 Invited Talk – Andrea Caviglia (University of Geneva)
The quantum metric of electrons with spin-momentum locking

10:00 Invited Talk – Seongshik (Sean) Oh (Rutgers)
Interface-engineered topological quantum matter

10:30 Coffee break

Session 6 – Complex ferroelectric domain patterns in oxide structures
chair Rui Vilarinho Silva

11:00 Invited Talk – Philipppe Ghosez (University of Liege)
Manipulation of inhomogeneous polar textures in ferroelectric perovskites and related nanostructures

11:30 Contributed Talk – Ludovica Tovaglieri (University of Geneva)
Domain and superdomain structures in ferroelectric $PbTiO_3$ based heterostructures

11:45 Contributed Talk – Fernando Gómez-Ortiz (University of Liege)
Dynamics of complex polar textures in ferroelectric nanostructures

12:00 Contributed Talk – Isabel Tenreiro (Complutense University of Madrid)
Flexoelectrically induced polar vortices in twisted $SrTiO_3$ bilayers

12:15 Contributed Talk – Greta Segantini (University of Geneva)
Electron-beam writing of atomic-scale reconstructions at oxide interfaces

12:45 Lunch break

Session 7 – Topological magnets

chair Sang Cheong

14:30 Invited Talk – Yuri Suzuki (Stanford University)
Spin and topological phenomena in low loss ferromagnetic insulator thin films

15:00 Invited Talk – Je-Geun Park (Seoul National University)
Triangular van der Waals topological magnet $Co_{1/3}$-TaS_2

15:30 Contributed Talk – Carlos A.F. Vaz (PSI)
Controlling the antiferromagnetic domain state of ultrathin $La_{0.45}Sr_{0.55}MnO_3$ films through oxygen vacancies

15:45 Coffee break

Session 8 – Superconductivity in nickelates II

chair Harold Hwang

16:15 Invited Talk - Julia Mundy (Harvard) – to be confirmed
Title to be announced

16:45 Contributed Talk – Lucia Varbaro (University of Geneva)
Infinite layer nickelates solid solutions: unusual magnetic field driven re-entrant superconductivity

17:00 Contributed Talk – Leonard Verhoff (TU Wien)
Surface effects in infinite-layer nickelate films

Session 9 – Food for thoughts

chair Stefano Gariglio

17:15 Invited Talk – Jochen Mannhart (MPI-Stuttgart)
Exploring the quantum–classical interface for revolutionary quantum materials and technologies

18:30 Bus transfer to the Graham's caves / Wine tasting and dinner

October 24, Friday – conference room Douro III - Pestana Douro

Session 10 – Transport properties of d^1 systems

chair Jochen Mannhart

9.00 Invited Talk – Masashi Kawasaki (RIKEN and University of Tokyo)
Metal-insulator transitions in double quantum wells of $SrVO_3$

9:30 Invited Talk – Marin Alexe (University of Warwick)
Negative differential photoconductivity and Gunn-like oscillations in $SrTiO_3$ single crystals

10:00 Contributed Talk – Evgenios Stylianidis (TU Wien)
Electrical properties of epitaxial capacitors based on compressively strained $SrTiO_3$

10:15 Contributed Talk – Chang-Jae Roh (University of Geneva)
Optical probing of in-plane dipolar textures in trigonal oxide heterointerfaces

10:30 Coffee break

Session 11 – Complex magnetism II

chair Andrea Caviglia

11:00 Invited Talk – Ramamoorthy Ramesh (UC Berkeley)
Magnon confinement in oxide heterostructures

11:30 Invited Talk – Marta Gibert (Tu Wien)
Engineering the magnetic phase diagram and unequal antipolar displacement in double-perovskite oxide heterostructures

12:00 Invited Talk – Jennifer Fowlie (Northwestern University)
Soft chemical dimensionality evolutions in complex oxides

12:45 Lunch

End of the workshop

QMS2025 – List of Participants

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Twisted oxide membrane interface by local atomic registry design

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Moiré interference between twisted complex oxides offers new prospects for fundamental research and the discovery of novel physical phenomena, such as 2D dipole crystals with moiré periodicity, non-collinear magnetism, coexisting moiré periodic antiferromagnetic and ferromagnetic order, and topological magnetic quasiparticles. We designed moiré crystals at the coincidence site lattice condition, providing commensurate structure within the moiré supercell arising from the multi-atom complex oxide unit cell. We fabricated such twisted bilayers from freestanding $SrTiO_3$ membranes and used depth sectioning-based TEM methods to discover ordered charge states at the moiré interface. By selectively imaging $SrTiO_3$ atomic planes at different depths through the bilayer, we clearly resolved the moiré periodic structure at the twisted interface and found that it exhibits lattice-dependent charge disproportionation in the local atomic registry within the moiré supercell. Our density-functional modelling of the twisted oxide interface predicts that these moiré phenomena are accompanied by the emergence of a two-dimensional flat band that can drive new electronic phases. Our work provides a novel guideline for controlling moiré periodicity in twisted oxides and opens pathways to exploit the new functionalities via moiré lattice-driven charge-orbital correlation.

This work has been done in collaboration with Min-Su Kim, Kyoungjun Lee, Ryo Ishikawa, Kyung Song, Naafis Ahnaf Shahed, Ki-Tae Eom, Mark S. Rzchowski, Evgeny Y. Tsymbal, Teruyasu Mizoguchi, Si-Young Choi.

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Moiré polar topologies and interlayer interactions in twisted oxide membranes

J. Santamaria[1], G. Sánchez-Santolino [1], V. Rouco [1], S. Puebla[2], H. Aramberri[3], V. Zamora[1], M. Cabero[4], F. A. Cuellar[1], C. Munuera[2], F. Mompean[2], M. Garcia-Hernandez [2], A. Castellanos-Gomez[2], J. Íñiguez [3], C. Leon[1]

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The recent realization of freestanding membranes of perovskite oxides, has enabled their deterministic mechanical assembly into twisted homo bilayers. Twisted oxide membranes surpass the limitations of epitaxial growth, which lock the direction of the crystalline axes of the growing layer to the substrate. Twisted interfaces gives rise to completely novel strain patterns though the strong long range ionic bonding in the non coherent atomic registry. Twisted ferroelectric membranes unlock a "chirality" degree of freedom opening an unprecedented opportunity to tailor topological polar landscapes in a way determined by the lateral strain modulation driven by twisting [1].

To examine the strength of interlayer interaction we have examined how strain and polar lanscapes are modified when graphene layers inserted in between of the twisted layers. We will show that, as in remote epitaxy, graphene layers partially screen the atomic potential and interlayer interaction, reducing the footprints of induced strains below the detection limit, yet ferroelectric vortices are detected for graphene thickness in the range of 3 nm suggesting the possibility of remote moiré interaction between the twisted layers. This finding opens exciting opportunities to manipulate the remote moiré interaction between the layers allowing for the exploration of novel physical effects and functionalities.

Since flexoelectricity has been demonstrated to induce polar features in a wide set of materials, a second question tackled in this presentation is whether polar topologies can be induced in twisted bilayers of non-ferroelectric materials. In this communication we explore the effect of non-homogeneous moiré strains in twisted bilayers made of $SrTiO_3$, a quantum paraelectric developing polar response at very low temperatures. We have found that twisted $SrTiO_3$ bilayers also display an array of polarization vortices. DFT simulations show polar vortex arrays in close agreement with experimental results and confirm the stability of the polar vortex state, indicating that the origin of the polar topology is a flexoelectrically induced polar state driven by a highly anomalous negative flexoelectric coefficient.

References:

[1] G. Sanchez-Santolino et al. Nature 626, 529 (2024)

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New horizons for interfaces by oxide membranes

Varun Harbola[1]

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The study of thin films has been a cornerstone of experimental research at reduced dimensions. Furthermore, the interest in 2d materials and heterostructures has grown rapidly in the last two decades since the discovery of graphene, and has really exploded after highly correlated electronic phases and superconductivity were found in twisted bilayer graphene. However, there exists a whole other class of materials, namely oxides, where precise control over stoichiometry, interfaces and thickness can be achieved at the nanoscale using a variety of growth techniques. These oxides exhibit nearly all flavours of physical phases from magnetic to ferroelectric to superconducting to even exotic multiferroic ground states. I will take this opportunity to focus on recent developments in oxide growth enabling the separation of the grown thin film from the growth substrate, resulting in free standing oxide membranes[1]. These membranes have allowed for unprecedented access to avenues in oxides, with novel symmetry disallowed interfaces, which go beyond the epitaxially possible atomically sharp interfaces. I will show striking phenomena we have observed with an exemplary $SrTiO_3$ (001) on a sapphire (0001) interface [2], through which I hope to convey how these developments in oxides promise a fertile ground for remarkable discoveries in physics and materials science.

References:

[1] D. Lu *et al.*, *Nat. Mater.* 15, 1255 (2016).

[2] Wang*, Harbola* *et al.*, *Adv. Mater.* 35, 2210989 (2024).

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Multipolar order: materials and applications

Ian R. Fisher

Department of Applied Physics, Stanford University, CA 95305

I will review and discuss some of our recent work exploring multipolar order in quantum materials, including applications.

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Tricks of Strain and Treats of Emergent Phases: Unraveling Altermagnetism and Polar Metallic States in Epitaxial RuO_2 Films

Bharat Jalan

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RuO_2, a rutile 4d-transition metal oxide, exhibits a unique crystal structure with both edge- and corner-sharing octahedra. This intrinsic anisotropy, when combined with strain engineering, provides a powerful avenue for tuning anisotropic electronic and optical properties. However, from a synthesis perspective, challenges such as variable Ru valence states, Ru/O stoichiometry control, anisotropic strain states, and structural defects can make it difficult to distinguish intrinsic properties from extrinsic effects in RuO_2 thin films—a classic trick in the pursuit of novel functionalities in quantum materials.

In this talk, I will highlight our group's efforts in overcoming these synthesis challenges while demonstrating metallicity in epitaxial RuO_2 films down to the unit cell scale. Through a combination of advanced X-ray scattering, X-ray absorption spectroscopy, transmission electron microscopy, temperature-dependent transport, magneto-optical measurements, and density functional theory (DFT) calculations, we uncover robust magnetism in epitaxially strained RuO_2, consistent with an altermagnetic metallic phase [1-3]. Additionally, we reveal a novel polar phase in strained films with significant implications for electrical transport—an unexpected treat in the realm of functional oxides. I will discuss these findings in detail, emphasizing their sensitivity to material defects and structure—key ingredients that are often overlooked but crucial in determining emergent quantum phenomena.

Reference:

1. S. G. Jeong[†], I. H. Choi[†], S. Nair, L Buiarelli, B. Pourbahari, J. Y. Oh, N. Bassim, A. Seo, W. S. Choi, R. M. Fernandes, T. Birol, L. Zhao, J. S. Lee, and B. Jalan, **Altermagnetic polar metallic phase in ultra-thin epitaxially-strained RuO_2 films**, (2025) [arxiv] *[†]Equal contribution*

2. S. G. Jeong, S. Lee, B. Lin, Z. Yang, I. H. Choi, J. Y Oh, S. Song, S. W. Lee, S. Nair, R. Choudhary, J. Parikh, S. Park, W. S. Choi, J. S. Lee, J. M. LeBeau, T. Low, and B. Jalan, **Metallicity and Anomalous Hall Effect in Epitaxially-Strained, Atomically-thin RuO_2 Films,** *(2025)* [arxiv]

3. S. G. Jeong, I. H. Choi, S. Lee, J. Y. Oh, S. Nair, J. H. Lee, C. Kim, A. Seo, W. S. Choi, T. Low, J. S. Lee, and B. Jalan, **Anisotropic Strain Relaxation-Induced Directional Ultrafast Carrier Dynamics in RuO_2 Films**, (2025) [arxiv]

Designer enhanced magnon transport in epitaxial, multiferroic heterostructures grown by molecular-beam epitaxy

Maya Ramesh[1,*], Sajid Husain[2,3,4,*], Xinyan Li[4], Sergei Prokhorenko[5], Shashank Kumar Ojha[4], Yousra Nahas[5], Lucas Caretta[6], Lane W. Martin[2,4,7], Zhi Yao[8], Yimo Han[10], Rogerio de Sousa[11,12], Laurent Bellaiche[5,13], Manuel Bibes[14], and Ramamoorthy Ramesh[2,3,4,9,15], and Darrell G. Schlom[1,16,17]

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Bismuth ferrite (BFO) is a room temperature magnetoelectric multiferroic with antiferromagnetic order and a large spontaneous polarization. In recent years, it has gained interest in the spintronics community for its use in non-volatile logic-in-memory devices. However, efficiently controlling the magnons in this material remains a challenge. Using molecular-beam epitaxy, we can precisely control the thickness and quality of each layer allowing for the creation of designer magnon transport. For this work, we grew samples of $REFeO_3/BiFeO_3/REFeO_3$ (RE = rare earth elements such as La, Dy) and observed highly efficient magnon transport in an all-antiferromagnetic system that can be controlled electrically due to the coupling of the ferroelectric and antiferromagnetic ordering in $BiFeO_3$. Leveraging spin-orbit-driven spin-charge transduction, we demonstrate that this material architecture permits magnon confinement in ultrathin antiferromagnets, enhancing the output voltage generated by magnon transport by several orders of magnitude, which provides a pathway to enable magnetoelectric memory and logic functionalities. Additionally, its non-volatility enables ultralow-power logic-in-memory processing, where magnonic devices can be efficiently reconfigured via electrically controlled magnon spin currents within magnetoelectric channels. Notably, by changing the thickness and rare earth elements of the $REFeO_3$ layers can modulate the enhancement of the spin transport.

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Interplay of frustration and *f–d* exchange in a pyrochlore ferromagnet

Kyeong-Yoon Baek[1], Margaret A. Anderson[1], Charles M. Brooks[1], Julia A. Mundy[1]*

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In quantum materials, colossal responses can emerge near phase boundaries. Molybdate pyrochlores, $R_2Mo_2O_7$, exhibit a transition from a ferromagnetic metal to a spin glass insulator as a function of the R^{3+} radius [1,2], where a spin chirality-driven anomalous Hall effect emerges due to the *R*–Mo coupling. Among this family of compounds, $Gd_2Mo_2O_7$ is a metallic ferromagnet that shows re-entrant spin glass disorder at low temperature due to the emergence of Gd–Mo interactions. We synthesized the first thin films of $Gd_2Mo_2O_7$ via molecular beam epitaxy and identified a 20K magnetic transition linked to Gd-induced Mo spin reorientation. Transport measurements of angle-dependent magnetoresistance reveal intriguing behaviour above 10T, suggesting manipulation of high-field interactions. This study will offer crucial insights into correlating evolution of spin orientation to transport anomalies and potential topological effects in molybdate pyrochlores.

References:

[1] J. S. Gardner, M. J. P. Gingras, J. E. Greedan, *Rev. Mod. Phys.* **82**, 53 (2010)
[2] T. Katsufuji, H. Y. Hwang, S.-W. Cheong, *Phys. Rev. Lett.* **84**, 1998 (2000)

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Correlated phases in nickelates

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Nickel oxides have long been of interest due to their strong electron interactions, dating back to the question of why NiO is an insulator, not a metal. In perovskite and infinite-layer structures (as well as related derivatives), the Ni oxidation state can range from 3+ to 1+ via structural and chemical doping - although all are commonly referred to as nickelates. This family of compounds exhibit a wide range of correlated phenomena, such as metal-insulator transitions, magnetism, density-wave/stripe instabilities, and recently superconductivity. We will present recent progress on using topochemical processes and strain to synthesize and probe some of these phase transitions and ground states.

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Superconducting Nd1-xEuxNiO2 (NENO) Thin Films Using In-Situ MBE Synthesis

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The rare-earth nickelates display a broad range of phenomena, including functional behavior such as antiferromagnetism and superconductivity. The ability to synthesize heterogeneous epitaxial thin film structures out of nickelates enables one to control and modify these functional properties via the creation of atomically abrupt interfaces. Advanced synchrotron characterization can then be used to measure the resulting electronic and magnetic properties of these atomically engineered systems. Here, we discuss synchrotron characterization of the square-planar nickelates, which are a novel class of superconductors. We use in situ aluminum reduction of the perovskite nickelates to achieve superconducting $Nd_{1-x}Eu_xNiO_2$ (NENO) thin films grown by molecular beam epitaxy (MBE). Atomic structure is characterized using crystal truncation rod (CTR) analysis, and electronic structure is characterized using diffraction-based X-ray absorption near edge structure (dXANES). We also report on unusual superconducting transport properties of NENO films, including magnetic field enhanced superconductivity.

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Theory of infinite-layer nickelate superconductors

Karsten Held

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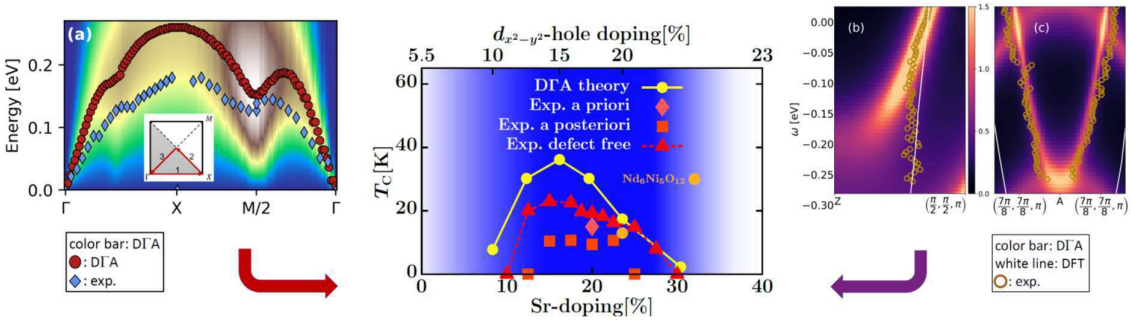
The discovery of superconductivity in infinite-layer nickelates [1] marked a new age of superconductivity: the nickel age. Using density functional theory, dynamical mean-field theory and dynamical vertex approximation (DΓA [2]), we successfully predicted the phase diagram T_c vs. Sr-doping of $Nd_{1-x}Sr_xNiO_2$ with -for an unconventional superconductor- unprecedented accuracy with "defect free" films synthesized only 3 years later [4]. Also, the normal state spin spectrum well agrees with resonant inelastic x-ray spectroscopy (RIXS) [5] and the one-particle spectrum with angular-resolved photoemission spectroscopy (ARPES) [6], which both enter into the calculation of T_c (as indicated by the arrows)

With this excellent agreement to later experiments, we can now with some confidence calculate the phase diagram of finite-layer nickelates [7] and predict that infinite-layer nickelates have a much higher T_c under 100GPa of pressure even without any chemical doping [8].



Center: Superconducting T_c vs. Sr-doping of $Nd_{1-x}Sr_xNiO_2$ comparing DΓA with experiments ("a priori" [1]; "defect free" [3]; $Nd_6Ni_5O_{12}$ [9]). **Left:** DΓA vs. RIXS [10]. **Right:** DΓA vs. ARPES [11].

References:

[1] D. Li et al., Nature 572, 624 (2019).
[2] G. Rohringer et al., Rev.Mod. Phys.90, 25003 (2018).
[3] M. Kitatani et al., npj Quantum Materials 5, 59 (2020).
[4] K. Lee et al., Nature 619, 288 (2023).
[5] L. Si et al., Phys. Rev. Res.6, 043104(2024).
[6] P. Worm et al., Phys. Rev. B109, 235126 (2024).
[7] A. Hausoel et al. arXiv:2502.12144.
[8] S. Di Cataldo et al., Nature Comm. 15, 3952 (2024).
[9] G. A. Pan et al., Nature Materials 21, 160 (2022).
[10] H. Lu et al., Science 373, 213 (2021).
[11] W. Sun et al. Science Adv. 15, eadr5116 (2025).

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Doping-dependent electronic structure of $Nd_{1-x}Eu_xNiO_2$

Sangjae Lee[1], Dung Vu[1], Wenzheng Wei[1], Frederick J. Walker[1], Charles H. Ahn[1,2]

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The discovery of superconductivity in infinite-layer nickelates has opened a new frontier for exploring unconventional superconducting mechanisms in transition metal oxides [1]. Depending on the choice of primary rare-earth ions and its substituents for doping, the system exhibits distinct electronic ground states and superconducting mechanisms [2, 3]. In this study, we investigate the superconducting and electronic phase behavior of Eu-doped $Nd_{1-x}Eu_xNiO_2$ (NENO) thin films [4], which display markedly different properties from Sr-doped counterparts. The multivalent Eu valence states (coexisting Eu^{2+} and Eu^{3+} oxidation states) and large magnetic moment of Eu due to partially filled 4*f* orbitals are believed to play a crucial role in the unconventional superconductivity in NENO systems. To better understand the phase diagram of NENO which exhibits a superconducting dome between x = 0.2 and x = 0.35, we systematically study the electronic structure as a function of Eu concentration using x-ray absorption spectroscopy (XAS) and resonant inelastic x-ray scattering (RIXS). These measurements reveal a detailed evolution of Ni and Eu valence states, with varying orbital and spin configurations as well as interactions between Ni and rare-earth sites. Our findings provide new insights into the role of magnetic rare-earth dopants in tuning superconductivity and highlight the importance of their interactions with Ni sites on the electronic structure of infinite-layer nickelates. This work advances the broader effort to uncover the microscopic mechanisms behind high-temperature superconductivity in layered transition metal oxides.

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Symposium on Quantum Materials Synthesis, Porto, October 22 - 24, 2025

Hot Quantum Materials—Turning up the Heat to achieve Adsorption-Controlled Synthesis and Improved Perfection

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It has long been known that molecular-beam epitaxy (MBE) works best for materials that can be grown in an adsorption-controlled regime where thermodynamics automatically provides composition control. This is where MBE started—for GaAs and other compound semiconductors—and underlies its success for producing semiconductor films with the highest purity and mobility. The same holds for the growth of thin films of oxide quantum materials by MBE, but the issue has been that it has not been possible to grow that many oxides in such a regime. In this talk I will describe how high substrate temperature opens the door to this desired growth regime for the growth of thin films of oxide quantum materials. Using a powerful CO_2-laser capable of heating to substrate temperatures of 2000 °C, we have grown an increasing number of oxide quantum materials in an adsorption-controlled regime by MBE. In this talk I will show multiple examples ranging from the growth of excellent conductors ($SrMoO_3$) to incipient ferroelectrics ($SrTiO_3$) to ferroelectrics ($BaTiO_3$).

*This work was performed in collaboration with the following people: Dylan Sotir, Anna S. Park, Vivek Anil, Matthew R. Barone, Brendan D. Faeth, Evan Krysko, Albert Suceava, Sankalpa Hazra, Aiden Ross, Ian R. Philippi, Francisco Guzman, Chaojie Du, Benjamin Gregory, Yorick Birkholzer, Wolfgang Braun, Steffen Ganschow, Jochen Mannhart, David A. Muller, Andrej Singer, Xiaoqing Pan, Long-Qing Chen, Venkat Gopalan, Shun-Li Shang, Zi-Kui Liu, Dmitri Tenne, and Kyle M. Shen.

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Directional imprinting of structural distortions drives spin-orbital order in a vanadate

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The flexible perovskite structure of many transition metal oxides allows different compounds to be combined in atomically sharp epitaxial heterostructures. Targeted manipulation of the different quantum phases by electronic and magnetic reconstruction at the interfaces between two compounds can lead to the realisation of new functionalities. Due to the strong coupling of the electronic degrees of freedom to the lattice, structural changes are equally influential. Small shifts in the oxygen positions can significantly alter the macroscopic properties. An example of this is our study of YVO_3 epitaxial films on different substrate facets [1]. The difference in the direction of the displacements induced in YVO_3 films grown on orthorhombic (110) and (001) facets of $YAlO_3$ substrates alone leads to the stabilisation of different spin-orbitally ordered phases.

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Engineering Symmetry Breaking Interfaces in Orthorhombic Perovskite Thin Films Via Structural-Energetics

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The orthorhombic perovskite lattice with *Pnma* space group constitutes one of the most common crystal structures for transition metal oxide compounds displaying properties that are interesting for quantum materials applications. When a crystal is grown as an epitaxial thin film, the film's orientation is typically set by that which minimises its macroscopic strain energy. Nevertheless, it is well established that, when a *Pnma* orthorhombic film is grown on the (101) plane of a substrate that is also *Pnma* orthorhombic, the connectivity of oxygen octahedra across the interface plays a key role in defining the final orientation of the film.

Here, we explore the consequences of setting up an energetic conflict between these two influences, by growing films of $LaVO_3$ under ~0.5% epitaxial tensile strain on (101) $DyScO_3$, using pulsed laser deposition [1]. Under these conditions, misfit strain energy favours the film growing with its orthorhombic long axis b_{orth} out-of-plane. In contrast, oxygen octahedra connectivity favours b_{orth} remaining in-plane, as for the substrate. X-ray diffraction identifies that the film indeed keeps the substrate symmetry, up until a critical growth thickness of 60–70 unit cells. At this thickness, misfit strain energy dominates over interfacial connectivity, and the film switches to having b_{orth} out-of-plane. Detailed, "forensic", analysis of films using aberration-corrected scanning transmission electron microscopy (Cs-STEM) on different zone axes finds that the switch in orientation does not occur at the film–substrate interface, but instead at an atomically sharp plane some ~10 unit cells into the film. At this interface—that we term the *switching plane*—mismatched orthorhombic distortions tend to zero, in order to couple them between the initial intermediate layer of the film having b_{orth} in-plane, and the film bulk with b_{orth} out-of-plane. As a result, the symmetry of the parent orthorhombic lattice is inherently broken at the switching plane.

By using innovative second-principles simulations involving 1000s of atoms to investigate the structural-energetics behind this phenomenon, we successfully rationalise the experimentally observed critical thickness and switching plane behaviour. Moreover, the simulations enable us to study the modulations in local atomic structure distortions going from the intermediate layer, across the switching plane, and into the film bulk; details that compare favourably to the measurements made with Cs-STEM. The symmetry-breaking switching plane interface, that contacts two phases of the same compound that would never otherwise co-exist, presents new opportunities for creating functional properties, such as synthesizing a quantum material that is chemically uniform but magnetically inhomogeneous.

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Epitaxial control of octahedral rotations in antiferromagnetic $DyFeO_3$

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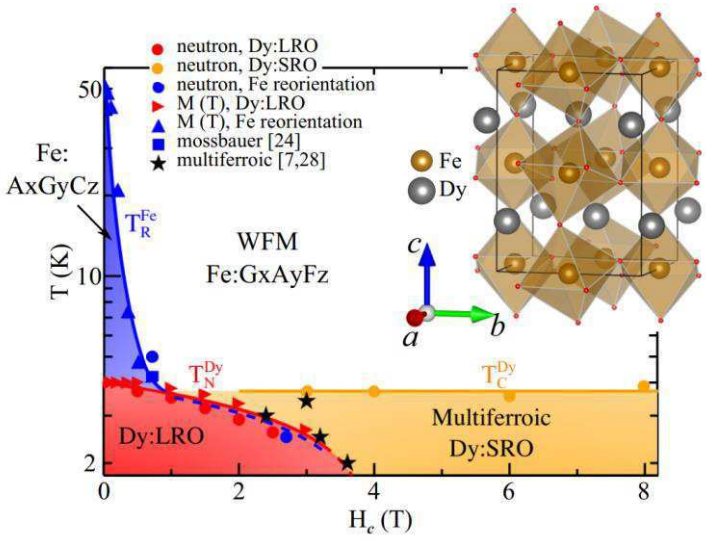
Multiferroic materials, where two or more "ferroic orders" coexist in a single phase, offer great potential in technological applications. In this regard, rare earth orthoferrites (*e.g.*, $DyFeO_3$, DFO) have shown a very rich phase diagram. Besides the antiferromagnetic transition associated with Fe^{3+} and Dy^{3+} orders ($T_{N,Fe}$ ~ 645K, $T_{N,Dy}$ ~ 4K), DFO shows a spin-reorientation (of Fe lattice) phase transition defined by the strong exchange interaction between Fe^{3+} and Dy^{3+}(T_{SR} ~ 50K) [1]. In addition, a magnetic field induces a ferroelectric (FE) state below $T_{N,Dy}$, making DFO a multiferroic, where the weak ferromagnetic and polar orders are aligned parallel to each other. A recent theoretical calculation predicts the strain-induced FE state in DFO thin films even well above the room temperature and thus realizing a strong multiferroic material above room temperature [2]. In this work, we report on the growth of DFO thin films on different substrates with various orientations. A detailed structural investigation allowed us to resolve the epitaxial relation between the film and substrates and highlights the strong influence of the strain on the structural properties, *e.g.*, the c-axis of the DFO films is found to switch from out-of-plane to in-plane direction as a function of thickness. Finally, we report on the magnetic properties of DFO thin films.



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Symposium on Quantum Materials Synthesis, Porto, October 22 - 24, 2025

Chirality, False chirality and Time chirality

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Chirality describes a property where an object or a state and its mirror image cannot be superimposed, regardless of spatial rotations, translations, and even time reversal (**T**). This means that the object lacks mirror symmetry in any spatial orientation or position. Since space inversion (parity, **P**) can be represented as a combination of mirror reflection and a 2-fold spatial rotation, true chirality implies the absence of both **P** and **PT** (combined parity and time reversal) symmetries. This concept can be generalized further. A system that breaks **P** and **T** symmetries—regardless of spatial rotations and translations— is known as *False Chirality*. Conversely, when **T** and **PT** symmetries are broken, the system is said to possess *Time Chirality*. A special case in which all three symmetries (**P**, **T**, and **PT**) are broken is referred to as *Super-Chirality*. We have identified magnetic point groups corresponding to each of these chirality types and their distinct physical properties and phenomena.

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The quantum metric of electrons with spin-momentum locking

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Quantum materials are characterized by electromagnetic responses intrinsically linked to the geometry and topology of the electronic wavefunctions. These properties are encoded in the quantum metric and Berry curvature. While Berry curvature-mediated transport effects such as the anomalous and nonlinear Hall effects have been identified in several magnetic and nonmagnetic systems, quantum metric-induced transport phenomena remain limited to topological antiferromagnets. Here we show that spin-momentum locking -- a general characteristic of the electronic states at surfaces and interfaces of spin-orbit coupled materials -- leads to a finite quantum metric. This metric activates a nonlinear in-plane magnetoresistance that we measure and electrically control in 111-oriented LaAlO3/SrTiO3 interfaces. These findings demonstrate the existence of quantum metric effects in a vast class of materials and provide new strategies to design functionalities based on the quantum geometry [1,2].

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Interface-Engineered Topological Quantum Matter

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Topology has emerged as a new paradigm in quantum materials over the past two decades, and a series of topological materials, such as topological insulators (TIs), topological semimetals (TSMs), and topological superconductors (TSCs), have been predicted and subsequently identified experimentally. In these topological materials, even though their topological properties are insensitive to marginal disorders, many of their electronic, such as transport and optical, properties can still be significantly affected by disorders. Moreover, in these materials, the very topological protection mechanism pushes the active carriers to reside on the interfaces and this makes their electronic properties particularly vulnerable to interfacial disorders. Since interfaces generally harbor substantially more disorders than the bulk does, interface control plays a key role in defining the transport and optical properties of many topological materials [1].

Along this line, my group introduced a series of interface engineering schemes over the past decade and uncovered hidden topological quantum signatures such as the quantum Hall effect [2], quantized Faraday/Kerr rotations [3], high-temperature quantum anomalous Hall effect [4], etc., in several topological materials. Furthermore, with similar interface control schemes, we also discovered that the ground state of a Hund metal (FeTe) can be switched from an antiferromagnetic to a superconducting state, showing that small perturbations such as interfaces can be utilized to select one of the competing ground states when the barriers between them are sufficiently small [5].

In this talk, I will overview these findings over the past decade and show how interface engineering schemes have helped discover hidden or unexpected signatures in various topological quantum materials.

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Manipulation of inhomogeneous polar textures in ferroelectric perovskites and related nanostructures

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During the last few years, a plethora of unexpected topological polar textures (skyrmions, merons, vortices, …) and related exotic phases have been reported in ferroelectric materials and nanostructures, opening a totally new field of investigations [1]. The interest for those polar textures is not only academic since they are often accompanied by unusual properties such as negative capacitance, chirality or can exhibit a particle-like behaviour, as relevant for a wide variety of potential applications. Although many advances have been reported recently, the practical generation and manipulation of such polar textures remains nowadays very limited. Here, relying on first- and second-principles theoretical methods [2], we propose to achieve dynamical control of inhomogeneous polar textures from acoustic [3] or electric pulses [4] and report unexpected results in conventional ferroelectrics like $BaTiO_3$ and $PbTiO_3$. Going further, we also consider the motion of such inhomogeneous polar textures [5] and discuss how they could possibly be linked to extra electrical charges, envisioning an interplay and coupled dynamics.

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Domain and superdomain structures in ferroelectric $PbTiO_3$ based heterostructures

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$PbTiO_3$ is a ferroelectric material that undergoes a bulk paraelectric-to-ferroelectric phase transition at a critical temperature (T_c) of 765 K, with a polarization that develops along the c-axis primarily driven by ionic displacements. Theoretical studies of domain structures in $PbTiO_3$ thin films reveal complex phase diagrams, with distinct domain configurations as a function of different parameters such as epitaxial strain, film thickness, electrostatic boundary conditions, and deposition temperature [1].

In prior work on $PbTiO_3$ heterostructures grown epitaxially on $(110)_o$-oriented $DyScO_3$ substrates with both top and bottom $SrRuO_3$ electrodes [2,3], we demonstrated an evolution in domain structure—from flux-closure configurations to an a/c-phase—as the film thickness increased. Beyond a critical $PbTiO_3$ thickness, these domains were observed to organize into larger-scale superdomain structures [2,3].

In the present study, we examine a series of heterostructures with $PbTiO_3$ layer thicknesses ranging from 18 to 720 unit cells, with a 22 nm-thick $SrRuO_3$ bottom electrode [4]. Using a combination of atomic force microscopy, vertical and lateral piezoresponse force microscopy, scanning transmission electron microscopy, and x-ray diffraction, we reconstruct the three-dimensional domain configurations and identify distinct superdomain types. Our analysis reveals that the superdomain periodicity scales with film thickness, and we observe the formation of superdomain walls. These walls exhibit potentially unique switching characteristics compared to conventional domain walls, suggesting a route toward enhanced functional properties in ferroelectric heterostructures.

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Dynamics of complex polar textures in ferroelectric nanostructures

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Nanostructured ferroelectrics display exotic multidomain configurations resulting from the reduced dimensionality. In fact, the past decade has witnessed dramatic progress related to various aspects of emergent topological polar textures in oxide nanostructures which can display vortices, skyrmions, merons, hopfions, among others under suitable mechanical or electric boundary conditions [1]. These particle-like objects lead to interesting functional properties such as negative capacitance [2], chirality [3] or stochastic ultrafast dynamics [4].
Understanding and controlling such particle-like dynamics is crucial for their usage in nanoelectronic devices, akin to the meticulous control achieved with their magnetic counterparts [5]. Although many advances have been reported recently, the practical generation and manipulation of such polar textures remains nowadays very limited. In this talk, we shall explore different approaches based on temperature, mechanical stimuli and electric fields [6-8] to achieve domain dynamics of such complex polar textures. Moreover, the atomistic resolution of our second-principles molecular dynamics simulations will provide unique insights of these transformations. Finally, we will also discuss recent theoretical findings revealing unconventional responses of topological textures under the effect of electric fields, offering promising avenues for tunable dielectric functionalities in nanoscale devices.

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Flexoelectrically induced polar vortices in twisted $SrTiO_3$ bilayers

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The mechanical assembly of freestanding oxide membranes in twisted bilayers has led to the recent discovery of polar topologies in twisted $BaTiO_3$ homojunctions [1]. A ferroelectric vortex array is generated by the pattern of non-homogeneous shear-strains via flexoelectric coupling of polarization to strain gradients. Since flexoelectricity has been demonstrated to induce polar features in a wide set of materials, an important question is whether polar topologies can be induced in twisted bilayers of non-ferroelectric materials. In this communication we explore the effect of non-homogeneous moiré strains in twisted bilayers made of $SrTiO_3$. $SrTiO_3$ is a quantum paraelectric developing polar response at very low temperatures. Yet, it has been reported that in thin films ferroelectricity is induced by epitaxial strain. We have found that twisted $SrTiO_3$ bilayers display an array of polarization vortices. Inhomogeneous strain patterns with the periodicity of the moiré lattice measured from high resolution electron microscopy images have been used to set initial conditions for first principles simulations. Full structural relaxation shows polar vortex arrays in close agreement with experimental results. The results of DFT simulations, apart from confirming the stability of the polar vortex state, indicate that the origin of the polar topology is a flexoelectrically induced polar state.

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Electron-Beam Writing of Atomic-Scale Reconstructions at Oxide Interfaces

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Transition metal oxides exhibit a variety of functionalities and epitaxial growth enables the synthesis of high-quality films. However, it confines the choice of substrates to those meeting symmetry and lattice parameter constraints. A way to overcome these constraints is releasing epitaxial oxides from their growth substrate, by means of sacrificial layers [1], thus obtaining oxide membranes.

Here, we report on the controlled formation of interfacial ionic bonds between a 30 nm-thick $SrTiO_3$ membrane and a niobium-doped $SrTiO_3$(001) carrier substrate. Scanning transmission electron microscopy in electron energy-loss spectroscopy mode (STEM-EELS) was used to investigate electronic/bonding state of Ti and O going across the interface from the substrate to the membrane as a function of annealing temperature. For a certain annealing temperature, and for a certain flux of STEM electron-beam, rastering it across the interface between the membrane and the substrate induces a perfect interface reconstruction with formation of ionic bonds between the membrane and the substrate. STEM-EELS analysis confirmed a change of Ti valence from Ti^{2+} to Ti^{4+}, and restoration of oxygen octahedral coordination in the interface region [2].

This study presents a method for selectively creating ionic bonds between perovskite oxides using electron beams. This approach opens new pathways for synthesizing artificial heterostructures beyond epitaxial constraints and for locally manipulating physical properties at their interfaces.

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Spin and Topological Phenomena in Low Loss Ferromagnetic Insulator Thin Films

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Ultra-thin ferromagnetic insulators with low magnetic damping enable emergent magnetic and topological phenomena at interfaces but also can efficiently generate and control pure spin currents, thereby changing the landscape of spin wave devices. We have developed a new class of nanometer thick low loss spinel ferrite thin films with Gilbert damping parameter as low as $\alpha \sim 2 \times 10^{-4}$. By incorporating a high spin orbit coupled overlayer, we can electrically detect spin waves generated in the spinel ferrite and find efficient spin pumping from these spinel ferrites into the adjacent layer through measurement of the spin-mixing conductance, Gilbert damping enhancement and electrical voltage peaks that appear at ferromagnetic resonance. We also demonstrate that we can efficiently switch the magnetic state of the ferromagnetic insulator via spin-orbit torque switching or electrical current in an adjacent high spin orbit coupled metal. Both magnesium aluminum ferrite and lithium aluminum ferrite exhibit low magnetic loss but the latter shows bulk saturation magnetization even in films four-unit cells thick. Compositional studies of aluminum doping in these ferrites suggests that minimizing disorder and strain correlates with low loss and bulk-like saturation magnetization. These spinel ferrite-based bilayers are also an excellent model system for the demonstration of fluctuation driven topology. Surprisingly we find definitive magnetotransport signatures of topology in the paramagnetic state of the spinel ferrite. We performed a detailed transport study as a function of field, temperature, field angle and ferrite thickness and found novel scaling behaviors consistent with fluctuation driven topology as predicted by Monte Carlo simulations.

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Triangular van der Waals topological magnet $Co_{1/3}$-TaS_2

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2D magnets, particularly van der Waals magnets, have been attracting much attention worldwide since they were first reported by a series of papers in 2016 [1, 2]. Over the past few years, much of the attention has been on discovering new materials with novel ground states, and the current focus is on topological magnets. Antiferromagnetic metallic Co1/3-TaS2 is the latest addition to this new class of 2D magnets [3]. It exhibits a considerable anomalous Hall effect (AHE), which was recently assigned to a rather unusual form of 3Q tetrahedral structure, a highest-density Skyrmion phase [4]. We also found that this 3Q phase is extremely sensitive to external variables like Co concentration and drastic Fermi surface change [5, 6]. As another demonstration of this controllability, we demonstrated that the ground state can be changed dramatically by controlling carrier density via gating.

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Controlling the antiferromagnetic domain state of ultrathin $La_{0.45}Sr_{0.55}MnO_3$ films through oxygen vacancies

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Antiferromagnetic (AFM) materials are drawing significant interest as building blocks for spintronics on account of their faster spin dynamics compared to conventional ferromagnets (in the THz instead of GHz range), the absence of stray fields and their immunity to external magnetic field perturbations [1]. However, for such applications, control of the equilibrium antiferromagnetic domain state down to the nanometer or atomic scale and a good understanding of the domain formation process remain challenging. Here, we report the evolution of the antiferromagnetic domain structure of epitaxial $La_{0.45}Sr_{0.55}MnO_3$ (LSMO) ultrathin films with thickness, using x-ray photoemission electron microscopy (XPEEM). We find that, while the 5 uc thick LSMO shows no magnetic contrast down to 50 K, thicker films display a multidomain antiferromagnetic configuration with a nonmonotonic variation in the characteristic domain size, from 0.3 μm at 10 uc, to 3-5 μm at 15-16 uc and 1 μm for 50 uc. Post-growth annealing impacts strongly the magnetic domain state, leading to much larger domain sizes, 15-30 μm wide, and to the presence of well-organized stripes in the ferromagnetic contrast images. The latter arise from alternating spin terminations of the A-type antiferromagnetic configuration due to atomic steps in the substrate [2]. We attribute the impact of the post-growth annealing on the domain structure to a reduction in the density of point defects, in particular oxygen vacancies, that pin the antiferromagnetic domain walls and which determine the equilibrium domain configuration. Our results demonstrate control of the domain size by tuning the film thickness and the density of oxygen vacancies, constituting a steppingstone in controlling the antiferromagnetic domain state required for oxide antiferromagnetic device applications.

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Symposium on Quantum Materials Synthesis, Porto, October 22 - 24, 2025

Topotactic oxidation of Ruddlesden-Popper nickelates

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Layered perovskites — including the Dion–Jacobson, Ruddlesden–Popper, and Aurivillius families— exhibit a wide range of correlated electron phenomena, from high-temperature superconductivity to multiferroicity. Here, we report a new family of layered perovskites realized through topotactic oxidation of $La_{n+1}Ni_nO_{3n+1+\delta}$ (n = 1 − 4) Ruddlesden–Popper nickelate thin films. Post-growth ozone annealing induces a substantial c-axis expansion — 17.8% for $La_2NiO_{4+\delta}$ (n = 1) — that monotonically decreases with increasing n. Surface X-ray diffraction and Coherent Bragg Rod Analysis reveal that this expansion arises from the intercalation of approximately 0.7 oxygen atoms per formula into the rock salt spacer layers, far exceeding the previous record of $\delta \sim 0.3$ for any Ruddlesden–Popper oxide. These oxygen-intercalated phases form a new structural class, with a spacer layer composition intermediate between the Ruddlesden–Popper and Aurivillius phases. Oxygen intercalation induces metallicity, suppresses oxygen octahedral rotations, and enhances nickel-oxygen hybridization — features associated with high-temperature superconductivity. Our work establishes topotactic oxidation as a powerful approach to accessing highly oxidized, metastable phases across a broad range of layered oxide systems, offering new platforms to engineer electronic properties via intercalation chemistry

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Infinite layer nickelates solid solutions: unusual magnetic field driven re-entrant superconductivity

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We explore the synthesis and emergent electronic behavior of infinite-layer nickelate thin films, focusing on $Nd_{1-x}Eu_xNiO_2$ (NENO) and $Sm_{1-2x}Nd_x\ Eu_xNiO_2$ (SNENO) solid solutions. These compounds are derived from perovskite nickelates via topotactic reduction, first demonstrated by D. Li [1] using CaH_2 or NaH to selectively remove apical oxygens and induce a square planar NiO_2 coordination. Following the solid-state route proposed by W. Wei [2,3], we implement the reaction $2Al + 3NdNiO_3 \rightarrow Al_2O_3 + 3NdNiO_2$ to obtain the 112 phase. All thin films were synthesized via RF off-axis magnetron sputtering, with the aluminum layer deposited in situ on-axis.

This method leverages our established expertise in growing high-quality 113 nickelate films and heterostructures [4,5,6], enabling successful reduction and stabilization of the 112 phase in NENO and SNENO on LSAT and $NdGaO_3$ (NGO) substrates, respectively.

We investigate the interplay between magnetism and superconductivity in these infinite-layer systems under out-of-plane magnetic fields. While the higher-T_c SNENO exhibits a monotonic suppression of superconductivity with field, the lower-T_c samples displays a striking re-entrant superconducting behavior. In such samples, distinct superconducting domes in the magnetic phase diagram are observed, consistent with the Jaccarino–Peter effect [7] arising from compensation between the applied field and an internal exchange field induced by Eu^{2+} and Nd^{3+} moments. Hall effect data can be modeled by including an anomalous Hall term proportional to the spin paramagnetic response of the two aforementioned magnetic ions, further supporting our hypothesis.

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Surface effects in infinite-layer nickelate films

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Nickelates show intriguing similarities to cuprates, and have emerged as a compelling platform for studying high temperature superconductivity [1]. Infinite-layer rare-earth (R) nickelates, $RNiO_2$, consist of an alternating stacking of NiO_2 layers and rare-earth spacing layers along the crystallographic *z*-axis. While their bulk structure has been extensively studied computationally, the samples that exhibit superconductivity in experiments are thin nickelate films synthesized through a chemical reduction process. The topotactic reduction removes apical oxygen from perovskite $RNiO_3$, grown on substrates such as $SrTiO_3$ (001) [2].
Here, we explore emerging surface effects in $RNiO_2$ films by studying the formation and electronic structure of various surfaces within the framework of density functional theory (DFT) and dynamical mean-field theory (DMFT).
While perfect stoichiometry favors a NiO_2-terminated surface, the presence of excess apical oxygen in the surface region – possibly a remnant of the chemical reduction process – might stabilize an RO-terminated surface. Furthermore, the atomic structure at the surface is found to strongly influence the local electronic structure. These surface effects indicate the absence of an electron pocket around the Γ point – even for $NdNiO_2$ surfaces, in contrast to DFT and DMFT bulk calculations for $NdNiO_2$ [1].

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Exploring the Quantum–Classical Interface for Revolutionary Quantum Materials and Technologies

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Does nature fundamentally prohibit valves from operating without an external driving force —i.e., functioning in the linear response regime? We have developed quantum devices and metamaterials that achieve precisely this, leveraging breakthroughs at the intersection of quantum and classical physics. These advances challenge conventional physical principles and open the door to transformative innovations. By defying established concepts such as the Landauer erasure principle, these novel approaches pave the way for revolutionary quantum materials and technologies (see, e.g., [1,2]).

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Metal-insulator transitions in double quantum wells of $SrVO_3$

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We report on the in-plane conductivity control of $SrVO_3$ double quantum wells by a magnetic field or an electric field. First, we describe metal-insulator transitions in $SrVO_3$ single quantum wells confined with a band-insulator of $SrTiO_3$. Thick films of SVO are a Pauli paramagnetic metal with a quite low residual resistivity. Confinement turns $SrVO_3$ from correlated metal to Mott insulator and electron doping as $Sr_{1-x}La_xVO_3$ recovers metallicity at around x=0.17 [1, 2]. We attempted to control this phase transition by external fields with employing double quantum wells. By employing a magnetic insulator barrier $EuTiO_3$ between $SrVO_3$ quantum wells, hybridization of wave functions could be controlled by a magnetic field. Application of magnetic field lowers effective barrier hight due to exchange splitting of Ti 3*d* conduction bands induced by the ferromagnetic alignment of Eu^{2+} ions. Back gating could control the relative position of quantized levels in two quantum wells separated by $SrTiO_3$, leading to switching of hybridizations. In addition to conventional accumulation/depletion actions in field effect transistors, stepwise drops of conductivity with hysteresis are observed in both positive and negative bias voltages. This switching is ascribed to on-off of resonant tunnelling between two quantum wells. These examples are metal-insulator transitions controlled not by filling but by effective bandwidth through the resonant tunnelling.

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Negative differential photoconductivity and Gunn-like oscillations in $SrTiO_3$ single crystals

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SrTiO3 (STO) holds significant potential for application in the field of oxide electronics as a wide band gap semiconductor, displaying a plethora of effects that include metallic-like conductivity by n-type doping, high electron mobility exceeding 10^4 $cm^2V^{-1}s^{-1}$, superconductivity at 0.28K, large Seebeck coefficient, quantum paraelectric state under 37K, and room temperature ferroelectricity under compressive strain. The STO-based heterostructures, the most relevant being the epitaxial $LaAlO_3$ grown on STO (100), are showing even more interesting properties spanning from 2D electron gas to ferromagnetism and superconductivity. Notably, STO and its heterostructures in the low-temperature regime, overlapping with the quantum paraelectric state, display remarkable photoelectric activity featuring anomalous photoconductivity and photoluminescence or coherent photo-electron emission.

Here we show that when photo-excited with band gap energy photons, $SrTiO_3$ exhibits non-linear transport of photocarriers and voltage-controlled negative resistance, resulting from an intervalley transfer of photo-induced electrons. As a consequence of the negative resistance, the photocurrent becomes unstable and spontaneously gives rise to low-frequency Gunn-like oscillations.[1,2] These effects are coupled with the field quenching of the main photoluminescence, revealing a complex band structure.

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Electrical properties of epitaxial capacitors based on compressively strained $SrTiO_3$

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Since ferroelectricity was first predicted in strained $SrTiO_3$ in 2000 [1], numerous experimental studies have reported ferroelectric switching in tensile strained $SrTiO_3$ films [2]. For compressively strained $SrTiO_3$, however, reports of ferroelectric switching are rare [3] and experimental consensus on the nature and stability of the strain-induced ferroelectric phase is lacking. We here present a detailed study of the electrical properties of a series of epitaxial metal-$SrTiO_3$-metal heterostructures with $SrTiO_3$ coherently strained up to -3% compressive strain. We find that although our samples show no evidence of ferroelectricity down to 10 K, they exhibit a rich electrical activity with a strong temperature and time dependence. To explore the temporal aspect of the underlying processes we perform transient capacitance measurements and find a thermal crossover between different regimes with distinct mechanisms. Finally, we discuss the possible origins of the observed non-equilibrium behavior within the framework of defect-mediated internal fields in capacitors.

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Optical probing of in-plane dipolar textures in trigonal oxide heterointerfaces

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The crystalline symmetry of quantum materials plays a critical role in governing their physical properties—including electronic structure and magnetism—according to Neumann's principle. In oxide heterostructures, epitaxial growth techniques have enabled precise control of crystal symmetry for material design. Recently, (111)-oriented oxide heterostructures have drawn significant attention due to their unique symmetry, electronic behavior, and interfacial characteristics. Notably, the trigonal symmetry along the (111) direction exhibits broken mirror symmetry in both out-of-plane and in-plane directions, giving rise to exotic phenomena such as polar metallicity[1], Berry curvature[2,3], and quantum metric effects[4] at the oxide heterointerfaces.

In this work, we investigate the emergence of two-dimensional dipolar textures at the (111)-oriented $LaAlO_3/SrTiO_3$ (LAO/STO)heterointerface through nonlinear optics. By probing and analyzing the symmetry evolution under varying external conditions, such as temperature, position, and gate voltage, we characterize the electric polarization states at the conducting interfaces. Particularly, our experimental findings highlight the role of structural symmetry in governing interfacial electronic properties, such as the orbital Rashba effects.

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Magnon Confinement in oxide heterostructures

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A few years ago, an intriguing new spin based logic-in-memory architecture, MESO, was described which used magnetoelectric multiferroics (ME) and spin-orbit (SO) metallic oxides as key building blocks. Over the past year, there have been some new developments in SOT based manipulation of magnets. Particularly, the role of epitaxy and atomically perfect interfaces with spin and/or orbital current enhanced oxides has been shown to significantly impact the spin-to-charge conversion (or vice versa). We are studying spin transport in La-BFO using a combination of NV imaging and spin Hall measurements. Over the past year, we have discovered the powerful role of magnon confinement as a pathway to enhance spin transport (and thus the spin-to-charge conversion efficiency) by 100X. This talk will give you a summary of our progress so far.

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Engineering the Magnetic Phase Diagram and Unequal Antipolar Displacement in Double-Perovskite Oxide Heterostructures

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The double-perovskite RE_2NiMnO_6 (*RE*= rare earth) family is characterized as being insulating ferromagnets, an unusual combination of properties. The Curie Temperature of La_2NiMnO_6 is T_c=280K, and for the other members of the family, T_c decreases linearly with the size of the *RE* ionic radius.

When grown as thin films [1], the ferromagnetic behavior occurs down to ultra-low thicknesses of (at least) 3 unit cells [2,3]. However, below 10 unit cells, the magnetic properties deteriorate due to an interfacial charge transfer caused by the polar discontinuity at the film/substrate interface.

The growth of tailor-made superlattices employing 2 distinct double perovskites RE_2NiMnO_6 (La and *RE* = Nd or Sm) featuring distinct Curie temperatures allows us to engineer the magnetic phase diagram and investigate the couplings at the magnetic interfaces [4]. Large periodicity superlattices conserve the individual para- to ferromagnetic transitions of the parent compounds. However, the Curie temperatures of the superlattice constituents collapse into a single transition for the lowest period samples, illustrating that low-periodicity samples behave as a unique material. This is a consequence of the magnetic order parameter propagating across the superlattice interfaces, as supported by a minimal Landau theory model. We also show that the superlattice interfaces enhance the Nd–Ni–Mn exchange interaction.

Further, scanning transmission electron microscopy combined with first-principles calculations confirms the predicted unequal antipolar displacement in our superlattices, strongly suggesting the presence of electric polarization. This is an important step towards establishing hybrid improper ferroelectricity in artificially layered heterostructures. In combination with our demonstration of robust ferromagnetism, the double perovskite superlattices bear large potential for future multiferroic systems.

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Soft chemical dimensionality evolutions in complex oxides

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Synthesis of complex oxides is challenging: Coordination, connectivity, cation ratio and oxygen stoichiometry must all be correct but conventional synthesis relying on thermodynamics often addresses a subset of these features at the expense of the others. Thermodynamically stable phases are usually straightforward to realize, while a host of adjacent or similar phases remain out of reach. Chimie douce, or soft chemistry, is a set of tools for low temperature, kinetics-based post-processing to achieve phases outside of thermodynamic stability starting from a stable precursor [1, 2].

Redox-active soft chemistry on complex oxides has mostly focussed on topotactic oxidation and reduction – where oxygen stoichiometry and coordination can be modified, but connectivity and cation ratio must be preserved [3].

Here I will present an additional tool for the soft chemistry toolbox: Redox-active dimensionality evolutions, where quasi-2D layered compounds can be achieved by post-processing their 3D counterparts, and vice versa. For example, evolutions between different members of the same Ruddlesden-Popper series, $A_{n+1}B_nO_{3n+1}$, and the perovskite end compound, ABO_3.

The $LaCoO_3 \rightarrow La_2CoO_4$ evolution is taken as a test case. 3D $LaCoO_3$ is thermodynamically stable, while quasi-2D La_2CoO_4, an interesting strongly correlated magnet, is not. We grow epitaxial single crystal thin films of $LaCoO_3$ by pulsed laser deposition, then post-process to realize the single-layer Ruddlesden-Popper La_2CoO_4. I will present our preliminary work on understanding the fundamental materials chemistry of this evolution by in-situ probes and advanced microscopy, as well as promising solid-gas reaction control knobs and potential for generalization.

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