FM 3: Focus Session: Novel mechanisms of ferroic switching (joint session MA/FM)

This focus session highlights recent advances in ferroic switching across ferroelectric, multiferroic, ferroaxial and magnetic systems. Topics include topologically protected order-parameter dynamics, ultrafast non-thermal switching, and complex domain-wall phenomena revealed by atomistic modeling, ultrafast optics and advanced imaging. Contributions span machine-learning-based simulations of domain kinetics, optical control of ferroaxial and structural orders, multiferroic multi-cell memory concepts, and theoretically predicted unidirectional domain-wall motion with time-crystal behavior. Together, these works uncover new switching pathways and robust functional mechanisms, offering promising routes toward energy-efficient memory and quantum devices.

Organizer: Andrei Pimenov, andrei.pimenov@tuwien.ac.ac

Time: Monday 9:30–12:00 Location: POT/0151

Invited Talk FM 3.1 Mon 9:30 POT/0151

From ML to Kinetics: Modeling the Switching in Ferroelectric Wurtzites — •Andrew Rappe, Drew Behrendt, Atanu Samanta, and Von Braun Nascimento — Department of Chemistry, University of Pennsylvania, Philadelphia, PA 19104-6323 USA

We present a series of works, from the development of a new force field (MLFF) for multi-scale simulations of bulk AlN, through application of MLFF to understand the atomistic switching mechanism, to the development of a new kinetic model to uncover how switching changes as a function of experimental conditions.

We train our MLFF to 1000s of DFT calculations, so the underlying calculations are as accurate as DFT with the flexibility in simulation size of classical MD. Powered by the MLFF, we can predict the energies, forces, and phonon dispersions of AlN at dramatically lower cost, thus enabling the study of emergent and long-range effects, such as the frequency-dependent dielectric functions and multiple FE domains.

Applying the AlN MLFF, we uncover the atomistic mechanism of domain wall (DW) migration and domain growth in wurtzites. We find that the critical nucleus is a single broken Al-N bond along the polar axis; this creates a cascade of bond breaking in a single column of atoms due to the stability of the 180° DW in wurtzites. We reveal the switching mechanism of 1D atomic columns propagating from a slow-moving 2D fractal-like DW in the basal plane.

Finally, we develop an analytical extension to the KAI model that accounts for fractal FE domains. To do this, we take the traditional model of circles that can nucleate and grow and add a budding term.

Invited Talk FM 3.2 Mon 10:00 POT/0151

Topological order parameter switching — •Sergey Artyukhin — Quantum Materials Theory, Genova, Italy

Ferroic orders are widely used to encode information in data storage devices and may provide a beneficial way to circumvent Boltzmann tyranny affecting conventional MOSFET memory [1]. However, information writing involves order parameter switching, facilitated by domain nucleation and motion of domain walls across a disordered material, which leads to energy dissipation. Recently, an alternative order parameter switching paradigm has been introduced, where the ordered state tracking the free energy minimum continuously rotates the order parameter direction as the free energy surface is deformed by an external driving [2]. The process is analogous to Thouless pumping and is topologically protected. A related mechanism allows pumping of topological spin textures in space [3].

[1] S. Manipatruni, D. E. Nikonov, I. A. Young, Nature Physics 14, 338 (2018)

[2] L. Ponet et al., Nature 607, 81-85 (2022)

[3] L. Maranzana et al., arXiv:2502.13083

Invited Talk FM 3.3 Mon 10:30 POT/0151

Optical Control of Ferroaxial Order via Circular Phonon Excitation — •Zhiyang Zeng[1,2], Michael Först[1], Michael Fechner[1], Dharmalingam Prabhakaran[2], Paolo Radaelli[2], and Andrea Cavalleri[1,2] — [1]Max Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany — [2]Department of Physics, Clarendon Laboratory, University of Oxford, Oxford, United Kingdom

Ferroaxial order is a distinct ferroic order in crystal systems characterized by a rotational texture of electric dipoles. Its unique symmetry prohibits direct coupling to static fields or stress, making conventional control approaches ineffective.

Based on symmetry analysis, we identify a coupling between the ferroaxial order and circularly driven optical phonons, which can be resonantly excited with circularly polarized mid-infrared light. Exploiting this coupling, we experimentally achieve reversible, deterministic switching of the ferroaxial order in the prototype material RbFe(MoO4)2 using single-shot excitation.

This work establishes a new mechanism for manipulating ferroaxial order via light-driven phonons, enabling dynamic control of ferroic properties in complex materials.

15 min break

FM 3.4 Mon 11:15 POT/0151

Coherent Control of Competing Structural Orders in SrTiO3 — •M. Fechner[1], H. Wang[2], M. Foerst[1], G. Orenstein[2], A. Disa[3], M. Trigo[2], and A. Cavalleri[1] — [1]Max Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany — [2]Stanford Pulse Institute, SLAC National Accelerator Laboratory, Menlo Park, CA, USA — [3]School of Applied & Engineering Physics, Cornell University, Ithaca, NY USA

The interplay between antiferrodistortive (AFD) rotation and polar instability prevents the formation of ferroelectric order in SrTiO3 yet keeps the paraelectric-to-ferroelectric transition on the verge of emerging. Light excitation has been shown to induce metastable ferroelectricity[1], but the response of the AFD order to such optical driving remains unclear. Here we use time-resolved X-ray scattering to track AFD-order dynamics, launched by mid-infrared excitation of the Ti-O stretching vibration, from 10 K to 135 K above the cubic transition. In the tetragonal phase below 110 K, the AFD order transiently increases before the AFD angle is reduced, whereas in the cubic phase rotational fluctuations initially grow before being strongly suppressed[2]. A unified lattice model, incorporating nonlinear coupling of the excited infrared phonon to the AFD mode and to strain, captures both regimes. With a single set of coupling parameters, we reproduce behaviors for both phases, indicating a common underlying mechanism that also constrains explanations for the light-induced ferroelectric state.

[1] T.F., et al. Nova Science 364, 1075 (2019), [2] M. Fechner, et al. NatMat, 23, 363 (2024)

FM 3.5 Mon 11:30 POT/0151

Multi-cell unit storage based on a multiferroic — •Maksim Ryzhkov[1], Alexey Shuvaev[1], Maxim Mostovoy[2], Andrei Pimenov[1], Anna Pimenov[1], and Sergey Artyukhin[3] — [1]Institute of Solid State Physics, Vienna University of Technology, Vienna, Austria — [2]Zernike Institute for Advanced Materials, University of Groningen, Groningen, The Netherlands — [3]Quantum Materials Theory, Istituto Italiano di Tecnologia, Genova, Italy

Recent advances in multiferroic materials offer promising prospects for next-generation memory and data-processing devices. Previous studies [1,2] have shown that rare-earth manganates RMn_2O_5, particularly with R = Gd, are strong candidates for storage applications due to their topologically protected four-state magnetoelectric switching and the efficient electric-field control of this switching.

In this work, we demonstrate that this system enables the realization of a multi-cell storage unit capable of encoding and decoding at least five bits. We show that only two key ingredients are required:

(i) the four-state magnetoelectric switching observed during magnetic-field sweeps, and

(ii) a ferroelectric domain structure in the bulk together with local inhomogeneities (e.g., internal mechanical stresses) that produce a distribution of the spin-flop critical field H_c across different domains.

Thus, the magnetoelectric domains in $GdMn_2O_5$ are not an unwanted

bug but an essential feature enabling multi-cell functionality.
[1] L. Ponet, et al., Nature 607, 81-85 (2022)
[2] H. Wang, et al., PRL 134, 016708 (2025)

FM 3.6 Mon 11:45 POT/0151

E-field induced unidirectional motion of domain wall in a ferromagnet and time crystals — •Margherita Parodi[1,2], Sergey Artyukhin[1], and Maxim Mostovoy[3] — [1]Quantum Materials Theory, Italian Institute of Technology, Genova, Italy — [2]Physics Department, University of Genova, Italy — [3]Theory of Condensed Matter, Zernike Institute for Advanced Materials, Groningen, The Netherlands

Noncollinear spin textures may break inversion symmetry and induce ferroelectric polarization, giving rise to multiferroicity. Here we study the most basic noncollinear spin texture: a domain wall in a collinear (anti)ferromagnet. The spin chirality of the domain wall is analogous to that in spiral multiferroics and likewise leads to ferroelectric polarization. Here we find that oscillating magnetic and electric fields can drive a unidirectional motion of the magnetic texture, similar to how electrons are transported by the Thouless pump. Furthermore, for certain periods of a driving field, the domain wall demonstrates complex behaviour akin to a time crystal, with the period equal to an integer multiple of the driving periods. The phenomenon arises due to a mismatch between the natural timescale of the domain wall motion and the driving field period.