

Controlling Magnetism in RuO₂ through Strain and Surface Engineering

Jong Seok Lee^{1,2,+}

¹*Department of Physics and Photon Science, Gwangju Institute of Science and Technology (GIST), Gwangju 61005, Republic of Korea*

²*Department of Physics, Korea Advanced Institute of Science and Technology (KAIST), Daejeon 34141, Republic of Korea*

Altermagnetism has recently emerged as a distinct class of magnetic order that combines key characteristics of ferromagnets and antiferromagnets. Its compensated antiparallel spin structure, intertwined with crystallographic rotational symmetry, gives rise to momentum-dependent spin splitting and unconventional magnetic responses, offering new opportunities for next-generation spintronic applications. Despite these intriguing properties, direct observation and control of the altermagnetic order remain challenging. In particular, the magnetic ground state of RuO₂, one of the most intensively studied candidate altermagnets, remains under active debate due to conflicting experimental observations.

In this presentation, I will discuss two complementary approaches to stabilizing and controlling altermagnetism in RuO₂: anisotropic strain engineering in thin films and chemical modulation of surface electronic states. In epitaxial RuO₂ films, anisotropic strain provides a means to modify the structural and electronic environment governing magnetic order, enabling control of the altermagnetic state. Beyond strain engineering, carrier doping offers another route to stabilizing compensated magnetic order. We show that modification of the surface chemical state of RuO₂ can induce a distinct surface magnetic state while leaving the bulk largely unaffected. Surface-sensitive X-ray photoemission spectroscopy, optical second-harmonic generation, and Kerr effect imaging reveal pronounced temperature-dependent changes and domain formation in oxygen-containing-species-modified RuO₂, in clear contrast to stoichiometric RuO₂. These observations indicate the emergence of surface magnetism associated with chemically induced electronic modulation. Together, our results demonstrate that both lattice strain and surface electronic engineering provide effective pathways for manipulating magnetism in RuO₂, highlighting the importance of structural and electronic degrees of freedom in understanding its debated magnetic ground state and providing new opportunities for nanoscale altermagnetic spintronics.

⁺ Author for correspondence: jslee1@kaist.ac.kr