Controlling interfaces of quantum materials with light

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Exerting control over quantum materials is one of the main goals in condensed matter physics. Oxide interfaces have emerged as a versatile platform for material design, where new fundamental properties can be controlled by assembling condensed matter at the atomic scale. Light plays a pivotal role in this scientific exploration. Probing materials with light reveals the collective excitations and the energy landscapes that underpin correlated dynamics. Recently we have come to the realisation that light not only reveals the organisation of condensed matter, it can also unlock new properties and promote phase transitions. The overarching goal of the field is to control macroscopic material properties, paving the way to new scientific insights and future emerging technologies. We will discuss two examples of material design at oxide interfaces, focusing on the control of geometric phases and magnetic order.

In the first example, we will discuss the manipulation of topological charges at oxide interfaces. Three-dimensional strontium ruthenate ($SrRuO_3$) is an itinerant ferromagnet that features Weyl points acting as sources of emergent magnetic fields, anomalous Hall conductivity, and unconventional spin dynamics. Integrating $SrRuO_3$ in oxide heterostructures is potentially a novel route to engineer emergent electrodynamics, but its electronic band topology in the two-dimensional limit remains unknown. We will show that ultrathin $SrRuO_3$ exhibits spin-polarized topologically nontrivial bands at the Fermi energy. Their band anticrossings show an enhanced Berry curvature and act as competing sources of emergent magnetic fields. We control their balance by designing heterostructures with symmetric and asymmetric interfaces [1,2].

In the second example, we will consider the control of magnetic ordered states using light. We will show that light-driven phonons can be utilized to coherently manipulate macroscopic magnetic states. Intense mid-infrared electric field pulses, tuned to resonance with a phonon mode of the antiferromagnet $DyFeO_3$, induce ultrafast and long-living changes of the fundamental exchange interaction between rare-earth orbitals and transition metal spins. Non-thermal lattice control of the magnetic exchange, which defines the stability of the macroscopic magnetic state, allows us to perform picosecond coherent switching between competing antiferromagnetic and weakly ferromagnetic spin orders [3-6].

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