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Ultrafast Broadband Optical Spectroscopy of Complex Materials.

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Remarkable properties of complex materials, such as multiferroics and topological insulators, often emerge from strong interactions among charge, lattice, spin and orbital degrees of freedom. Labyrinthine pattern of these competing interactions has prevented development of predictive theoretical frameworks and basic principles required to harness materials properties for technological applications. In this regard, the femtosecond temporal resolution, combined with spectral selectivity available with ultrafast optical spectroscopy offers an unmatched ability to temporally discriminate the dynamics of various degrees of freedom, and more importantly, the dynamics of the coupling among them. Here, we discuss an application of powerful ultrafast spectroscopic techniques to investigate the non-equilibrium behavior of several classes of complex materials. In actinide materials, hybridization between localized f-electrons and itinerant d-electrons result in a wide spectrum of exotic states. We probed the quasiparticle relaxation dynamics in URu_2Si_2 in a broad temperature range, and demonstrated an appearance of pseudogap state as a possible precursor to the enigmatic hidden-order phase. Topological insulators represent a new state of matter where insulating bulk is surrounded by a conducting surface. We applied terahertz spectroscopy at low temperatures to separate the bulk from the surface transient responses in Bi_2Se_3, and showed that short-lived bulk carriers co-exist with the long-lived surface carriers which feature significantly higher mobility. Finally, we revealed energy transfer pathways from electrons to magnons in multiferroic HoMnO3 compound where ferroelectricity and magnetism co-exist and are strongly coupled. Our measurements show that energy of photoexcitation is initially transferred from electrons to phonons and subsequently to magnons through spin-lattice relaxation.