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Terahertz Spectroscopy of Complex Materials

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Terahertz time-domain spectroscopy is a powerful tool to investigate complex materials broadly defined. This includes artificial electromagnetic composites such as metamaterials, and correlated electron materials where the interplay between microscopic degrees of freedom leads to phenomena such as superconductivity or metal-insulator transitions. I will discuss our recent results in these areas. Metamaterials are a relatively new type of artificial composite with electromagnetic properties that derive from their sub-wavelength structure. The judicious combination of metamaterials with MEMS technology enables reconfigurable metamaterials where artificial “atoms” reorient within unit cells in response to an external stimulus. This is accomplished by fabricating planar arrays of split ring resonators on bimaterial cantilevers designed to bend out of plane in response to a thermal stimulus. In this way we can control the electric and magnetic response of these metamaterials. Vanadium dioxide (VO_2) exhibits a metal-insulator transition (MIT) at a temperature (340K) that coincides with a structural phase transition. This leads to the “chicken and egg” problem. Is it the structural change or electron correlations that lead to the MIT transition? Uniaxially strained VO_2 films have been fabricated to help solve this problem. In unstrained VO_2 crystals the insulator to metal transition enables the electrons move freely in three dimensions. Non-contact THz-TDS conductivity measurements of strained samples reveal that the electrons prefer to move in one direction. That is, strain induces a quasi one-dimensional metallic conductivity. These results reveal the utility of terahertz spectroscopy to investigate complex materials and point the way towards future studies of hybrid composites incorporating metamaterials with quantum-based complex matter. Such multi-scale structures may offer complementary benefits where quantum materials confer additional functionality to artificial electromagnetic composites or, conversely, metamaterials serve as a novel tool to facilitate fundamental studies of the electrodynamic response of complex quantum materials.