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Ultrafast and Ultrasmall Spectroscopy of Phase Transition in VO_2

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Recent advances in optical spectroscopy facilitate the probing of vibrational and electronic properties of materials with unprecedented spatial and time resolution (down to $\sim$ 10 nanometers and $\sim$ 10-s femtoseconds, respectively). In this talk, we report on ultrafast and ultrasmall aspects of the insulator-to-metal transition (IMT) in a canonical correlated electron material, vanadium dioxide (VO_2). Using scattering-type scanning near-field optical microscopy (s-SNOM) and spectroscopy (nano-FTIR), we revealed unidirectional conducting stripes in strained VO_2 films at sub-micrometer scale over a wide temperature range (320K-380K). Investigating the formation of this microscopic stripe state, we resolved the enigma of the macroscopic electronic anisotropy and disentangled three distinct stages of the VO_2 phase transition [Phys. Rev. Lett. 111 (9), 096602 (2013) and follow-up studies]. Furthermore, with newly developed terahertz (THz) pump THz probe spectroscopy, we demonstrated the first THz-field-induced insulator-to-metal switching experiments. We show that high-field THz pulses can effectively reduce the Coulomb-induced potential barrier for carrier transport and lead to subsequent rapid lattice heating. The fundamental electric-field-switching time of VO_2 can be in the order of a few picoseconds, with which the direct current measurements are incapable to measure due to instrumental limitations [Nature, 487, 345–348 (2012)]. With these comprehensive studies we offer unique insights into the electron and phonon evolution at fundamental time, energy and length scales. These novel spectroscopic techniques also provide universal methodologies for studying many other classes of transition metal oxides and phase transition materials.