Terahertz-driven irreversible topological phase transition in two-dimensional $MoTe_2$

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Stabilizing a novel transient or metastable phase of quantum materials in equilibrium has long been an attractive goal for ultrafast science. Recent experimental advances in terahertz (THz) field generation (~0.17-17 THz spectral range) have set the stage for dramatic advances in our ability to coherently drive quantum materials into novel states that do not exist as equilibrium phases by pumping key low-frequency electronic and structural degree of freedoms.[1-5] However, THz-driven irreversible topological phase transitions are still unexplored. Large and doping-tunable energy barriers between multiple phases in two-dimensional transition metal dichalcogenides (2D TMDs) provide a testbed for THz polymorph engineering.[6,7] Here we report the first experimental demonstration of an irreversible topological phase transition in 2D $MoTe_2$ from a semiconducting hexagonal phase (2H) to a predicted topological insulator distorted octahedral (1T′) phase[8] induced by metamaterial-enhanced ultrahigh-field terahertz pulses[9]. This is achieved by a transient high carrier density due to carrier liberation and multiplication processes induced by a terahertz electric field, which is inaccessible to traditional electrostatic doping methods. Single-shot time-resolved second harmonic generation (SHG) microscopy following THz excitation reveals the topological phase transition dynamics with a timescale between 20 ps and 1 ns. This observation opens up new possibilities of THz-metamaterials-based phase patterning and has implications for ultrafast THz control over topological phases in layered materials.

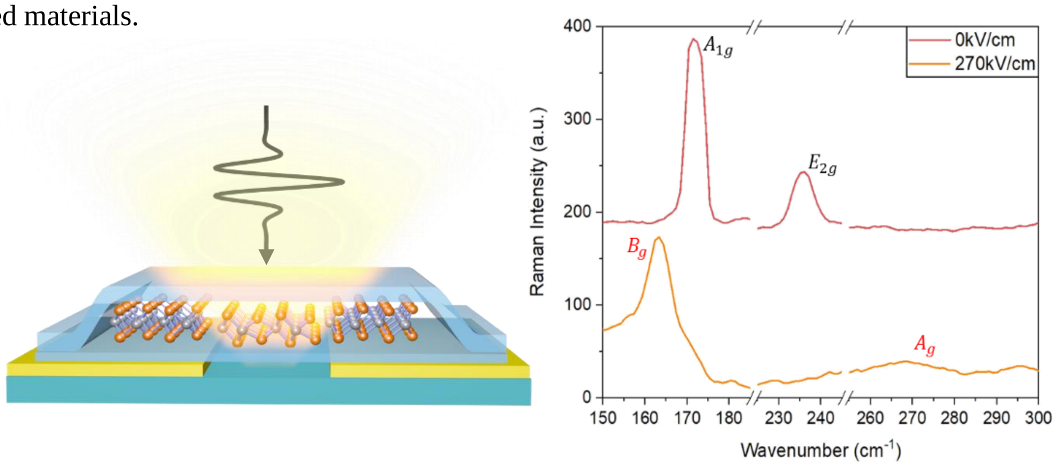

Figure 1: (Left panel) $MoTe_2$ THz metamaterial structure. $MoTe_2$ is encapsulated with top and bottom h-BN layers. THz field is enhanced by THz metamaterial by a factor of 20-100 and is found to drive and stabilize the 1T′ phase in $MoTe_2$. (Right panel) Raman spectrum of monolayer $MoTe_2$ before and after THz irradiation. $\mathbf{B_g}$ mode at 163.5 cm^{-1} and $\mathbf{A_g}$ mode at 268.6 cm^{-1}, the characteristic peaks of 1T′ $MoTe_2$, appear after THz irradiations with incident THz field amplitude of 270 kV/cm. The characteristic peaks of 1T′ $MoTe_2$ are labeled red and those of 2H $MoTe_2$ are labeled black.

References:

[1]*Nature* 487, 345-348 (2012) [2]*Nature* 449, 72 (2007) [3]*Nature* 530, 461-464 (2016) [4]*Science* 331, 189-191 (2011) [5]*Nature Materials* 12, 535 (2013) [6]*Nature Reviews Materials* 2, 17033 (2017) [7]*Nature* 550, 487 (2017) [8]*Science* 346, 1344-1347 (2014) [9]arXiv:1910.13609