Terahertz Field-Induced Electron Tunneling and its Future Applications toward Nanoscopy

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Ultrafast control of material properties has been one of the fundamental goals for material science. Ultrashort laser pulses are generally used for the studies, yet it has been difficult to control the materials at nanoscales because of the diffraction limit. Furthermore, the electric-field strength of laser pulses is averaged over multi-cycle waveforms, suppressing the controllability of the motion of electrons/carriers in materials. Recently, we demonstrated that the combination of sub-cycle terahertz pulses with a scanning tunneling microscope enables to realize ultrafast unidirectional electron tunneling at a single tunnel junction[1, 2)]. Because terahertz pulses are generated at a nonlinear crystal via optical rectification process, the electric field waveform whose spectrum spans over a few octaves has a stable carrier envelope phase (CEP). By delivering the phase-locked terahertz pulses into a single tunnel junction, we can implement the terahertz-field induced electron tunneling. The typical example of the terahertz-induced electron tunneling is shown in Fig. 1, where terahertz pulses with the opposite CEP induce the tunneling current either from a sample (HOPG) to a nanotip (Pt/Ir) or vice versa. The result clearly shows that electrons can be injected to or subtracted from the sample, indicating that our method becomes a promising tool to induce electron transport, chemical reactions, phase transitions, etc. at nanometer and femtosecond spatiotemporal scales. The characterizations and applications of the experimental method will be discussed.

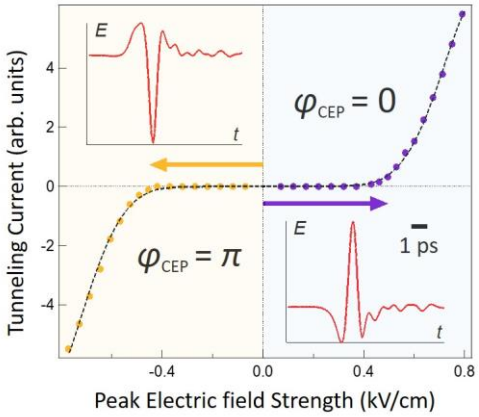

Fig. 1. Electric-field dependence of terahertz-induced tunneling current between two electrodes: a nanotip (Pt/Ir) and a sample (HOPG). Inset shows the waveforms of applied terahertz pulses.

References: 1) K. Yoshioka et al., *Nat. Photon.* 10, 762 (2016), 2) K. Yoshioka et al., *Nano Lett.* 18, 5198 (2018).