Development of field-driven time-resolved STM using subcycle mid-infrared pulses

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Recent femtosecond laser technologies have revealed interesting ultrafast phenomena such as photo-induced phase transition, bandgap renormalization, and non-equiliblium electron-electron interaction, *etc*. Scanning tunneling microscopy (STM) combined with sub-monocycle (subcycle) terahertz (THz) pulses has enabled to measure snapshots of atomic images with pico-second temporal resolution [1]. Here, we developed subcycle mid-infrared (MIR) optical pulses with the center frequency of 25 THz and applied them to STM. We demonstrate a high potential of MIR-STM system to reveal ultrafast photo-induced dynamics on solid surfaces with atomic resolution.

The light source was a Ti-based optical parametric chirped pulse amplifier (OPCPA) with the wavelength range from 640 to 960 nm, the pulse duration of 8.5 fs, the repetition frequency of 4 MHz, and the pulse energy of 1 μJ. The fundamental beam was incident into a thin GaSe crystal and then subcycle MIR pulses were generated by optical rectification [3]. The MIR beam was focused on a STM in an UHV chamber through a diamond window. Modulation of the bias voltage can be achieved by illuminating the MIR (probe) on the tunnel junction of a bulk $MoTe_2$ and a Pt/Ir tip. Figure 1 shows ultrafast modulation of the tunneling current after photocarrier excitation by the fundamental beam (pump). After 100 fs, we can see increasing and decreasing of the current with the time-scale of 220 fs and 720 fs. In the fast regime less than 100 fs, the tunneling current resulted from hot-electrons changes with the resolution of 29 fs. This value can reach to the time-scale of non-equilibrium electronic distribution [4]. This technique will pave the way for studying the local dynamics of non-equilibrium electronic states on surfaces.

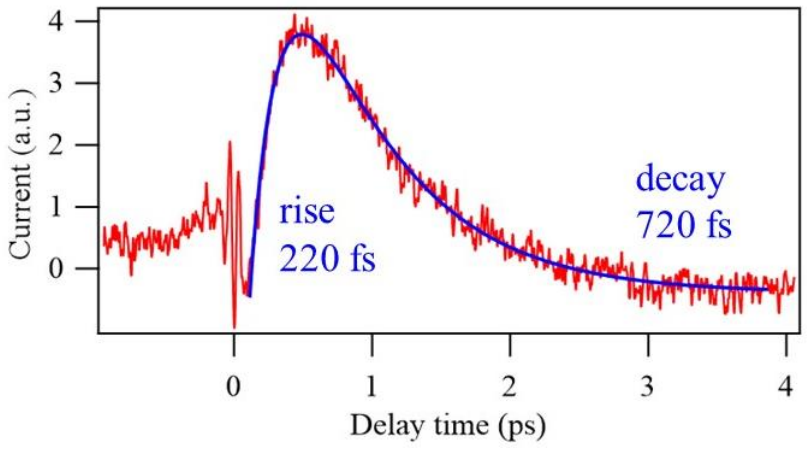

Fig. 1, ultrafast modulation of tunneling current in a tunnel junction of MoTe2 and Pt/Ir tip. The pump pulses were incident at delay time = 0 ps.

References: [1] M. Woerner, *et al., EPJ Web of Conferences, 205,* 05007 (2019). [2] T. L. Cocker, *et al., Nat. Photon.* 7, 620 (2013). [3] K. Yoshioka, *et al., Opt. Lett.* 44, 5350 (2019). [4] I. Gierz, *et al., Nat. Mat.* 12, 1119 (2013).