Light-field-driven STM using subcycle mid-infrared pulses

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Recent femtosecond laser technologies have revealed interesting ultrafast phenomena on non-equilibrium electron system such as photo-induced phase transition, bandgap renormalization *etc*. Scanning tunneling microscopy (STM) combined with sub-monocycle (subcycle) terahertz (THz) field has enabled to measure density of state (DOS) of electrons with atomic spatial resolution and pico-second temporal resolution [1]. Here, we developed subcycle mid-infrared (MIR) optical pulses with the center frequency of 30 THz and applied them to STM. We demonstrate a high potential of MIR-STM system to reveal photo-induced dynamics of non-equilibrium electron on surfaces.

The light source was a Ti-based optical parametric chirped pulse amplifier (OPCPA) with the wavelength range from 680 to 940 nm, the pulse duration of 8.2 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 as shown in Fig. 1(a). Figure 1(b) 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, which reaches to the time-scale of non-equilibrium electronic distribution. This technique will pave a new way for studying ultrafast and atomic-scale dynamics on surfaces.

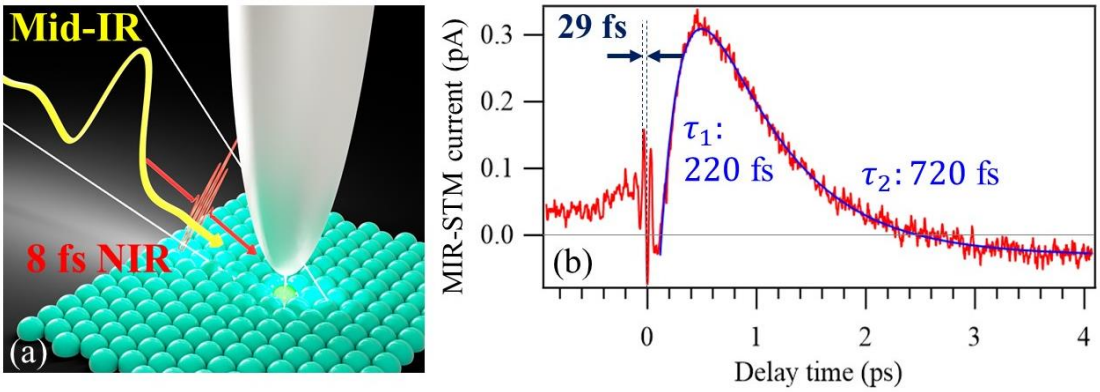

Fig. 1, (a) Schematic of 8 fs NIR-pump MIR-STM. (b) Ultrafast modulation of tunneling current in a tunnel junction of $MoTe_2$ and Pt/Ir tip. The pump pulses were incident at delay time = 0 ps.

[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).