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

Yusuke Arashida, Hiroyuki Mogi, Masashi Ishikawa, Ippo Igarashi, Akira Hatanaka, Naoki Umeda, Jinbo Peng, Shoji Yoshida, Osamu Takeuchi, and Hidemi Shigekawa

Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba 305-8573, Japan

Recent femtosecond laser technologies have revealed interesting ultrafast phenomena such as photo-induced phase transition, bandgap renormalization, and non-equilibrium 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.