Field-driven ultrafast STM using sub-cycle mid-infrared pulses

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Combination of phase-controlled sub-cycle terahertz (THz) pulses and scanning tunneling microscopy, called as THz-STM [1-3], have attracted much attention to study exotic surface phenomena with sub-picosecond (ps) temporal resolution and atomic resolution. We have developed a field-driven STM with the temporal resolution of femtosecond (fs) regime by using sub-cycle mid-infrared (MIR) pulses to study non-equilibrium dynamics of electrons on surfaces. Previously, we succeeded to generate sub-cycle MIR pulses with the pulse duration of ○○ fs using a light source of an optical parametric chirped pulse amplifier (OPCPA) [4]. In this report, we performed an ultrafast modulation of tunneling current driven by the MIR pulses.

The OPCPA has the pulse duration of 8.2 fs, the wavelength range from the 660nm to 940 nm, the average power of 3.0 W, repetition frequency of 4 MHz [4]. The fundamental beam was split into two beams. One of them was used to generate the MIR pulses by optical rectification using a GaSe crystal with the thickness of 30 μm. The other beam was collinearly aligned with the MIR beam and entered into the tunnel junction of a STM in an UHV chamber through an optical window of poly-crystalline diamond. We used a Pt/Ir tip and a bulk 2H-$MoTe_2$ under 77 K for the tunneling junction.

The far-field waveform of the MIR pulses measured by a photoconductive antenna at the STM is shown in Fig. 1(a). The asymmetric shape of the waveform was achieved. Figure 1(b) shows the ultrafast change of tunneling current probed by the MIR pulse, where the tunneling junction was excited by the fundamental pulses of the laser. From the result, we achieved to modulate the tunneling current down to 21 fs and to observe dynamics of electrons excited in the $MoTe_2$ which have the relaxation time of approximately 1 ps.

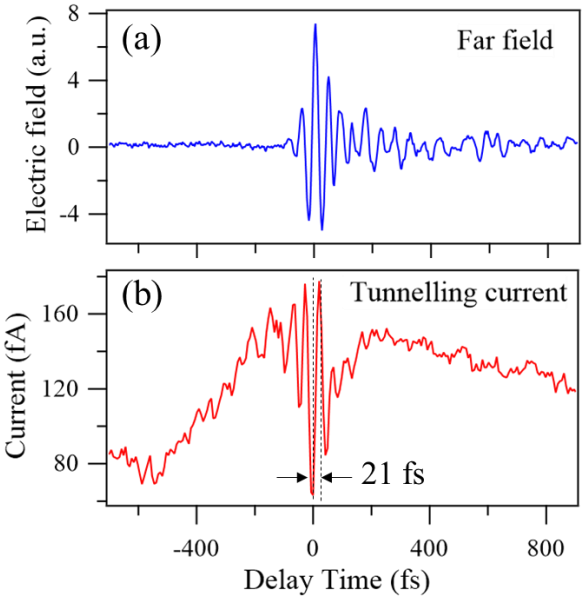

Fig. 1: (a) The waveform of the MIR far-field at the STM. (b) The waveform of tunneling current.

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[4] K. Yoshioka, *Optics Letters* 44, 21, 5350 (2019).