Ultrafast manipulation of tunneling electrons via single-cycle THz-STM

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The ultrafast manipulation of electrons using carrier-envelope-phase (CEP) locked ultrashort laser pulses is a promising way to overcome the bandwidth limitation in modern electronics [1,2]. The use of single-cycle terahertz (THz) electric fields with a tunnel junction is expected to provide a new platform for controlling the motion of electrons - either at the atomic scale or on the sub-picosecond timescale.

In the present work, using THz scanning tunneling microscopy (THz-STM), we demonstrate that CEP-controlled single-cycle terahertz electric fields can coherently drive the electron tunneling [3]. Figure 1 shows the number of rectified electrons as a function of the THz electric field strength with different CEPs. The number of electrons increases nonlinearly with increasing the THz electric field strength. As shown in the inset images, the direction of the electron tunneling could be controlled by tuning the CEP of the THz electric fields either from the nanotip to the sample (ϕ_{CEP} = 0) or vice versa (ϕ_{CEP} = π). Based on the Simmons model analysis, we fond that the extremely large field enhancement at the junction (100,000 ± 10,000) induces a dramatic modulation of the potential barrier between the nanotip and the sample on the sub-picosecond timescale.

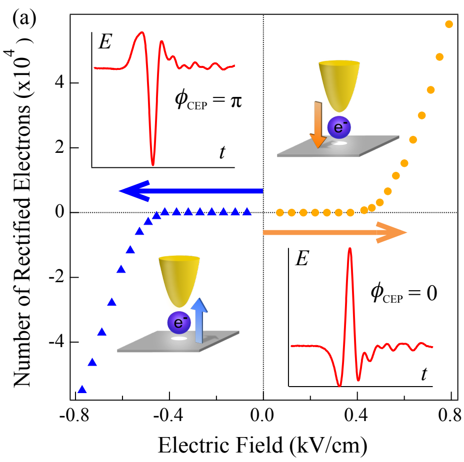

Fig. 1. Number of rectified electrons as a function of the THz electric field strength. The single-cyclic THz waveforms with different phases (ϕ_{CEP} = 0 and π) were also shown. The inset images show the schematics of the electron tunneling processes through the junction.

[1] M. Krüger, M. Schenk, and P. Hommelhoff, Nature **475**, 78 (2011).

[2] A. Schiffrin *et al.*, Nature **493**, 70 (2013).

[3] K. Yoshioka *et al.*, Nat. Photon., *in press*.