Atomic scale ultrafast dynamics at surfaces imaged by time-resolved THz-STM

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Recently, THz-STM has attracted much attention as a novel technique to probe ultrafast dynamics of photo-induced phenomena with atomic scale spatial resolution. Carrier relaxation dynamics of single InAs quantum dot[1] and vibrational motion of single pentacene molecule[2] have been measured by the technique. In this study, we have developed time resolved THz-STM by combining low temperature UHV-STM system with THz optical system. We employed industrial fs pulse laser (Monaco, f_{rep} < 50 MHz , I < 40uJ) to generate intense THz pulse train with high repetition rate. THz pulses were generated via optical rectification in $LiNbO_3$ crystal. A peak electric field of THz pulse over 400 V/cm was obtained at 50 MHz repetition rate, which is sufficient for THz-STM experiments.

In THz-STM (Fig. 1), a THz pulse induces transient voltage across STM tunneling junction (V_{THz}). STM tip couples with THz electric field through an antenna effect, which leads to strong near field formation at the STM tip apex. Because of its huge field enhancement factor on the order of 10^5, induced V_{THz} can drive ultrafast tunnel current I_{THz}, which is used to probe ultrafast dynamics of the sample with the ps time resolution. Fig. 2 shows THz driven STM image of 1T-$TiSe_2$, obtained by maintaining I_{THz} constant while tunneling bias voltage is set to be zero. The image shows atomic lattice structure at the surface with 2x2 spatial modulation due to charge density wave, which clearly demonstrate atomic resolution of THz-STM. In addition, ultrafast electron dynamics of C_{60} thin film was imaged with sub-ps time resolution.

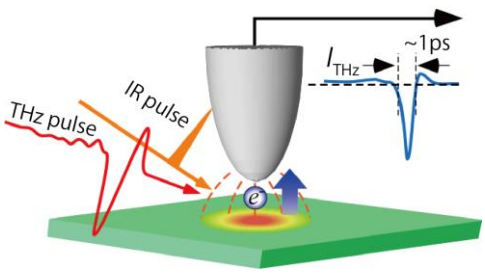

Fig. 1. schematics of THz-STM

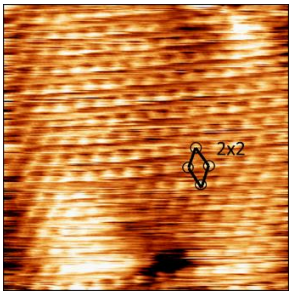

Fig. 2. THz driven STM image of 1T-$TiSe_2$

[1] T. L. Cocker *et al.*, Nature Photonics, 7, 620-625 (2013)

[2] Tyler L. Cocker,et al: Nature 539, 263–267 (2016)