Photo-induced insulator-to-metal transition in Ta_2NiSe_5 studied by time-resolved ARPES

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Ta_2NiSe_5 has been long proposed as an excitonic insulator, in which remarkable band flattening below the structural transition temperature at 328 K occurs as a result of the strong Coulomb attractive interactions between the conduction and valence bands. Recently, photo-excitation has been intensively employed to explore non-equilibrium phases, and many exotic phenomena have been reported such as photo-excitation of a collective mode or the photo-induced enhancement of an excitonic order. Our previous result also confirms that Ta_2NiSe_5 is an excitonic insulator from the characteristic dynamical behavior. In this work, we have used time-resolved ARPES (TARPES) to investigate the photo-excited non-equilibrium phases in Ta_2NiSe_5. We have discovered that intense photo-excitation can induce an insulator-to-metal transition and a transient semimetalic state emerges as shown in Fig. 1(a), which could not be realized under equilibrium [1]. In order to gain insight on the mechanism of this phase transition, we have pursued the TARPES measurements with better signal-to-noise ratio enabled by use of the higher repetition rate laser system. We have found that multiple coherent phonons are excited by analyzing the oscillation behavior of time-dependence of TARPES intensity, and the amplitude for each phonon is significantly dependent on the momentum and energy in the ARPES images. Furthermore, we have proceeded to map out the amplitude for each frequency of the coherent phonons in energy-momentum space, of which technique we define as frequency-domain ARPES (Fig. 1(b),(c)). This technique relies on electron-phonon couplings, where coherent phonons generated by photo-excitation induce the modulations of TARPES intensity of the relevant bands, and allowed us to clearly identify the most relevant lattice modulation for the metallic state [2].

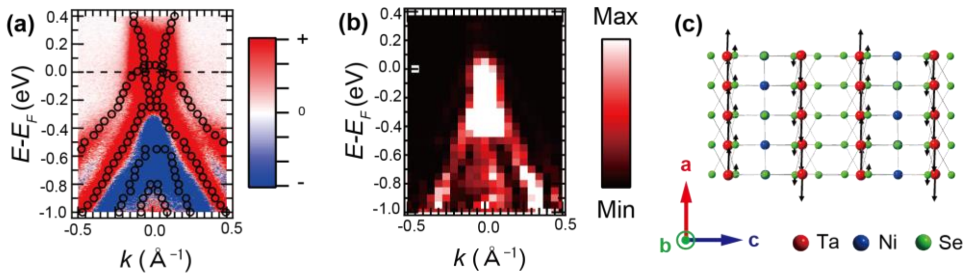

Figure 1: (a) Difference ARPES image after photo-excitation. **(b)** Frequency-domain ARPES for 2 THz and **(c)** corresponding phonon motion.

References:
[1] K. Okazaki, *et al.*, Nat. Commun. **9**, 4322 (2018).

[2] T. Suzuki, *et al.*, Phys. Rev. B **103**, L121105 (2021).