Photocarrier dynamics in Weyl semimetal WTe_2 thin films

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Abstract: We report the first photocarrier dynamics investigation on type-II Weyl semimetal WTe_2. A transient feature where an initial photo-bleaching signal is found followed by a persistent photoinduced absorption over the 1.8-2.5 μm range is revealed.

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1. Introduction

Understanding the optical properties of Dirac and Weyl semimetals has drawn significant attention recently [1, 2]. Type-II Weyl semimetal (WSM) exhibits signatures distinct from the conventional Weyl semimetal (type-I) and other materials, as manifested in the predicted anisotropic chiral anomaly, anomalous Hall effect, and magneto-optical spectrum [3-5]. Tungsten telluride (WTe_2) has been a research focus since it was first proposed as a candidate for type-II WSM with Weyl points appearing at the boundary of electron and hole pockets [3]. This prediction was subsequently experimentally verified by addressing the fermion state in angle-resolved photoemission spectra (ARPES) [6]. Experimental investigations showed that WTe_2 exhibits an extremely large non-saturating magnetoresistance as well as fascinating pressure-induced superconductivity [7, 8]. Very recently, Wang *et al.* demonstrated that the Fermi energy of this novel material can be in-situ tuned through the Weyl points via the electric field effect [9]. Despite extensive investigations on WTe_2, the optical properties, i.e. carrier dynamics, of this emerging material remain largely unexplored.

Here, we perform broadband femtosecond pump-probe spectroscopy to investigate the carrier relaxation dynamics in Type-II WSM WTe_2. Different from features of other semimetals, the relaxation dynamics of the investigated WTe_2 thin films exhibits an initial photo-bleaching (PB), and is followed by a photoinduced absorption (PA) signature that lasts over several hundreds of picoseconds. The fast PB decay, occurring on a picosecond timescale, is attributed to the relaxation of the higher-lying excited-states to the lower one, while the much longer PA signal may be induced by this lower occupied states in which carrier-photon reabsorption leads to the transitions to the higher energy levels.

2. WTe_2 film growth and characterizations

WTe_2 films were grown on 5×5 mm mica substrate by pulsed laser deposition (PLD) technique followed by 48 hour annealing at 700 °C in tellurium atmosphere. The thickness of the investigated film is about 35 nm. Fig. 1a shows the X-ray diffraction (XRD) pattern, where a series of peaks are well resolved and indexed as {001} crystalline plane, indicating a perfect *c*-axis oriented growth. The un-indexed peaks just come from the mica substrate. Raman spectroscopy with a 514 nm laser excitation was also performed to examine the crystalline quality. As shown in Fig. 1b, the five Raman phonon vibrational peaks agree well with the previous data that confirm the high quality of our sample [10].

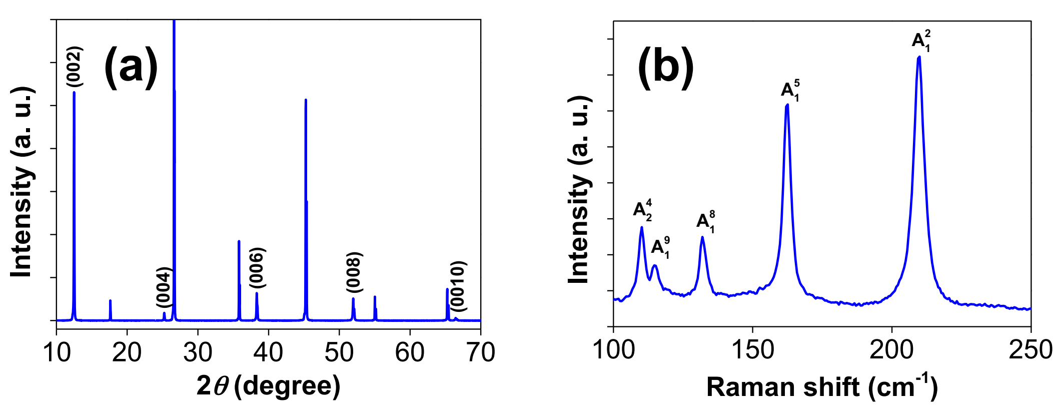

Fig.1 **(a)** XRD pattern of the WTe_2 thin film on mica substrate. **(b)** Raman spectrum of the same sample.

3. Broadband photocarrier dynamics in WTe_2

The ultrafast carrier dynamics of WTe_2 thin films was investigated over a broad spectral range from 1.8 to 2.5 μm. For the non-degenerate pump-probe measurements, an 800 nm, 1 kHz, Ti: sapphire amplifier is used as the optical source. The infrared probe pulses from 1.8 to 2.5 μm are obtained by feeding part of the laser output into an optical parametric amplifier (OPA) system. The change of probe intensity is detected by a PbSe photodetector and a lock-in amplifier referenced to a 500 Hz mechanically-chopped pump. The used pump fluence is about 300 μJ/cm^2. Fig. 2a plots the 2D mapping of pump-induced differential transmission ($\Delta T/T_0$) as a function of time delay and probe wavelength. Clearly, the signal exhibits an initial PB, which quickly turns into a PA signature. The PB signal is typically associated with Pauli blocking effects caused by the state filling. As presented in the inset of Fig. 2b, the peak value of the PB signal obtained from 2.5 μm measurements is found to scale linearly with the pump fluence. This rules out any significant nonlinear optical effects, e.g., two-photon absorption, in the transient photoresponse. The timescales of the PA are much longer than that of PB. Fig. 2b shows that the PA can not recover within 600 ps (the maximum scan range of our setup). Such a timescale indicates that the PA signal is likely to be associated with excited-state absorption [11]. Further experiments are underway for elaborating the physical origin of this general PB-PA transition feature.

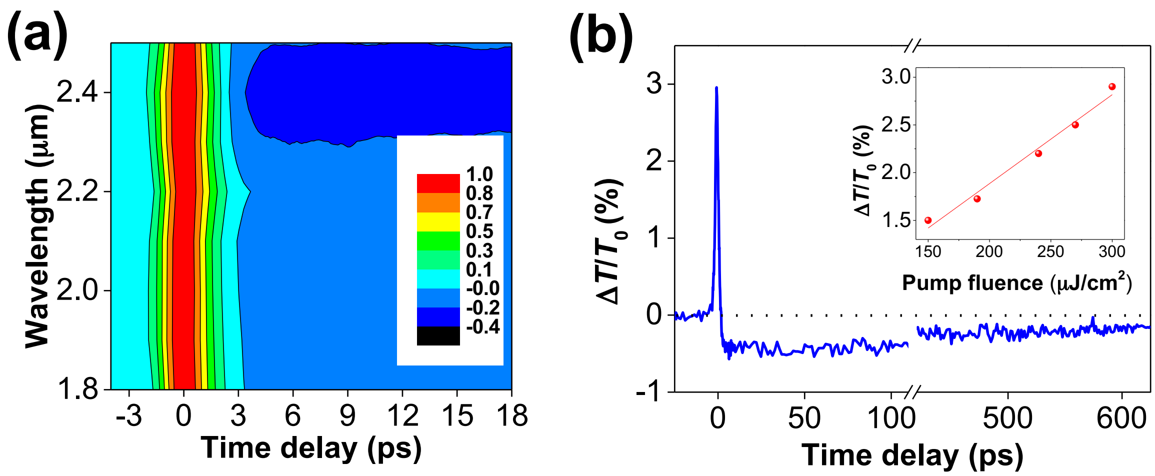

Fig.2 **(a)** 2D map of $\Delta T/T_0$ (normalized) as a function of probe wavelength and pump-probe time delay for WTe_2. **(b)** Time-resolved $\Delta T/T_0$ traces at 2.5 μm. The inset of **(b)** shows the linear dependence of the peak value of $\Delta T/T_0$ on the pump fluence.

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4. Conclusion

In summary, we have for the first time probed the broadband photocarrier dynamics of type-II WSM WTe_2 large-scale thin films. A unique feature of an initial photo-bleaching (PB) followed by a slow photoinduced absorption (PA) signature is identified. The fast PB occurs on a picosecond timescale, while the slow PA signal relaxation lasts on a nanosecond timescale.

5. References

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