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Microarticle

Terahertz transmission through TaAs single crystals in simultaneously applied magnetic and electric fields: Possible optical signatures of the chiral anomaly in a Weyl semimetal

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ABSTRACT

We report optical transmission measurements through a single crystal of the Weyl semimetal TaAs at terahertz frequencies. The measurements were performed at $T = 1.6$ K using intense coherent light from a free-electron laser in high magnetic fields. We detected small but measurable changes in the sample's transparency upon applying dc voltage (current) to the sample. In a constant magnetic field, the sign of the transmission change depends on the current direction. The effect disappears in zero magnetic field. These observations are qualitatively consistent with theory predictions for optical signatures of the chiral anomaly in a Weyl semimetal.

Weyl fermions – massless chiral particles proposed almost a century ago [1] – have recently been reincarnated as elementary excitations in solids [2,3]. Weyl fermions are 3D in nature and are believed to exist in the bulk of Weyl semimetals (WSMs) – materials, where the valence and conduction bands touch each other at a few points of the Brillouin zone, the Weyl nodes [2]. The chiral electronic excitations exist in the vicinity of these nodes, half of which possess the positive (election spin and momentum are parallel), another half negative (spin and momentum are antiparallel) chiralities. Simultaneous application of magnetic **B** and electric **E** fields is supposed to pump the electrons towards the nodes of a given chirality at the expense of the opposite chirality [4], the pumping effect being proportional to the scalar product **B**·**E**. The resulting chiral-particle misbalance is known from particle physics as the chiral anomaly [5,6].

Many theoretical investigations have been devoted to the solid-state realization of chiral anomaly, see Ref. [7] for a review. The experimental results reported on it are mostly based on electrical-transport measurements using direct current (dc) – the negative longitudinal magnetoresistance and the planar Hall effect, see, e.g., Refs. [8–10]. However, it has been argued that dc transport may suffer from other ("parasitic") effects, such as current jetting appearing in anisotropic and/or inhomogeneous samples [11,12]. Reports on detecting the chiral anomaly by other experimental methods are therefore of paramount importance, but remain very rare [13,14].

Theoretically, it has been shown [15,16] that low-frequency (terahertz or far-infrared) optical measurements may provide a way to observe the chiral anomaly in WSMs. Because the optical-spectra features induced by chiral anomaly are not expected to be huge, such experiments have to be performed in quite high electric and magnetic fields, at low temperatures, and using high-quality samples: impurities provoke electron scattering between the nodes with different chiralities, thus leveling off the effect of chiral pumping. Here, we report results of our optical measurements of the Weyl semimetal TaAs in simultaneously applied **B** and **E** fields. The observations are consistent with theoretical expectations for optical signatures of chiral anomaly [15,16].

In our experiments, we used the combination of a high-power terahertz free-electron laser (FLARE, 0.3–3 THz) and a Bitter magnet, available at Radboud University in Nijmegen, the Netherlands [17]. The measurements described below were performed at 0.63 THz (2.6 meV, 21 cm^{-1}). The THz light was partly polarized with an approximately 60:40 percent intensity ratio. The sample's transmission was measured in a magnetic field of 20 T in a tilted Faraday geometry, as shown in Fig. 1 (the tilt was necessary to provide **B**·**E** $\neq 0$). Fairly high ($\pm$ 100 mA) dc currents had to be utilized for this semimetallic material to create a reasonable electric field inside it. To prevent

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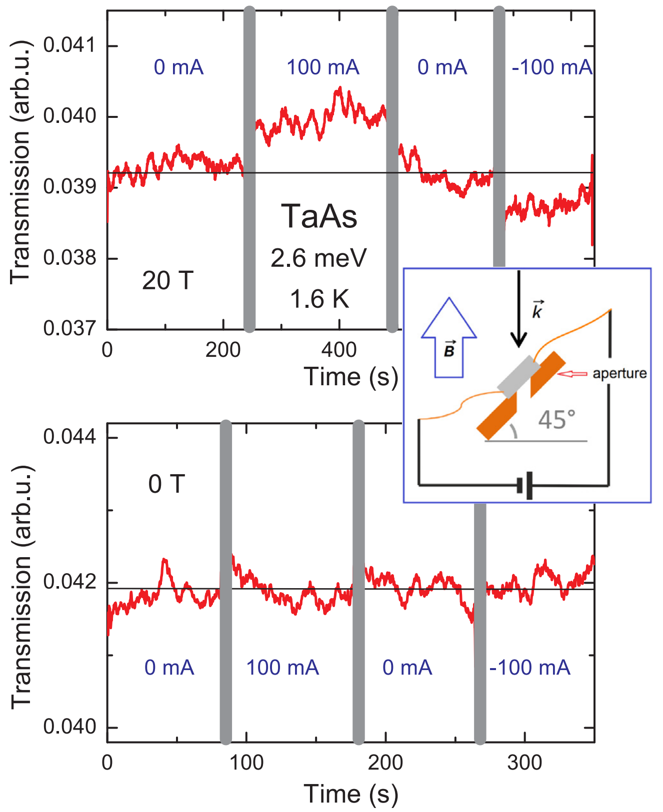

Fig. 1. Transmission through the TaAs sample in 20 T (upper frame) and in 0 T (lower frame) as a function of time. The applied currents are indicated. The inset schematically shows the measurement geometry.

possible heating and suppress impurity scattering, the sample was submerged in helium and its temperature was kept at 1.6 K. The sample was a (0 0 1)-plane oriented single crystal of TaAs with lateral dimensions of roughly 2.5 by 2.5 mm and a thickness of 200 micron. The crystal was synthesized via chemical vapor transport, as described in Refs. [12,18].

We have chosen to perform transmission measurements on thin single crystals using a very powerful radiation source, rather than more standard reflectivity measurements, because TaAs is highly reflecting in the THz and far-infrared frequency regions relevant for the chiral Weyl bands [14,19,20]. Hence, possible chiral-anomaly-induced changes would be extremely hard to detect on this high-reflectivity background.

The major results of this report are shown in the main panels of Fig. 1. It is evident from the figure, that there is an effect on the optical transmission upon simultaneous application of **E** and **B**: the effect is only present if $\mathbf{B} \neq 0$ and it reverses its sign if **E** changes the direction. We would like to note here that at 20 T TaAs is supposed to be in the quantum limit [21]. Thus, the low-field approximation used in Refs. [15,16] is not directly applicable.

It is still to be confirmed, whether the observed effect is (entirely) due to the chiral anomaly. For example, measurements with circular polarized light, rather than with only partial light polarization, as in the present experiment, are highly desirable. Nevertheless, it is evident that our observations are in line with the theoretical expectations for the optical signatures of this phenomenon.

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