Tracking Electron & Hole Dynamics in 3D Dirac Semimetals

Jessica L. Boland[1], Djamshid A. Damry[1], Chelsea Q. Xia[2], Marina Filip[2], Piet Schönherr[2], Thorsten Hesjedal[2], Laura M. Herz[2], and Michael B. Johnston.[2]

[1]Photon Science Institute, Department of Electrical and Electronic Engineering, University of Manchester, M13 9PL, UK

[2] Clarendon Laboratory, Department of Physics, University of Oxford, Oxford, OX1 3PU, UK

***Abstract* — Using ultrafast optical-pump terahertz-probe spectroscopy (OPTP) and ultrafast terahertz emission spectroscopy, we showcase the electron and hole dynamics in Cd_3As_2 nanowires (NWs), a well-known 3D Dirac semimetal. A temperature-dependent photoconductivity spectra was carried out yielding an incredible high electron mobility ~ 16,000 cm^2/Vs at 5K. Strong THz emission was also observed for both nanowires and single crystal (SC) which is highly desirable for devices.**

I. INTRODUCTION

Dirac semimetals (DSMs) [1] is a class of topological materials that have emerged as candidates for next-generation devices. Dirac semimetals preserve both time-reversal and inversion symmetry and feature two cones (valence and conduction bands), one of which is inverted, that touch at the tips with a zero bandgap. They therefore form 3D analogues of graphene – with comparable optoelectronic performance (e.g. strong optical nonlinearities for all-optical switching, intrinsic high electron mobility and doping tuneability), yet maintaining all the structural benefits of bulk metals (e.g. reduced plasmonic losses, ease of fabrication, enhanced responsivity). Such semimetals provide platforms for interesting phenomena, and efforts to harness their potential within a device have so far been hindered by a lack of understanding and control of their optoelectronic properties. We seek to unveil these characteristics by employing ultrafast optical- pump terahertz-probe technique thereby giving a broader insight into DSMs.

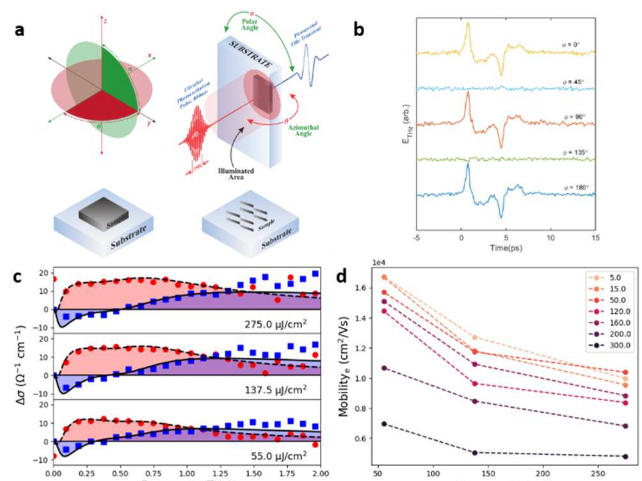

Fig.1 (a) Experimental setup for the OPTP, (b) THz emission, (c) Photoconductivity Spectra at 5K for 3 fluences. The black lines are the fits for a modified surface plasmon model. The red circles and blue square are the real and imaginary parts for the photoconductivity, and (d) Temperature-dependent electron mobility for all fluences.

THz spectroscopy has already begun to provide key discernments into electronic transport in DSMs, yet to explore the emergence of various exotic optoelectronic responses, such as nonlinear ultrafast chiral photocurrents, further studies are required. In this work, we demonstrate the first ultrafast THz study on a DSM Cd_3As_2 nanowire ensemble, and THz emission mechanisms for both NW and SC.

II. Carrier Dynamics & THz Emission

First, we conduct THz emission spectroscopy of a Cd_3As_2 bulk single crystal and NW ensemble to probe their exotic ultrafast surface circular photogalvanic and bulk photon-drag effects. For both, we observe strong THz emission with a linear dependence on optical pump fluence. The polarity of the emitted THz waveform were found to be strongly dependent on the optical pump polarization as well as the incident angle, as has been seen for other Dirac materials (Fig.1 a,b) [3]. Cd_3As_2 and other DSMs are therefore promising candidates for ultrafast optical polarization control in the THz range.

Second, we conduct temperature-dependent ultrafast OPTP measurements on Cd_3As_2 NW ensembles (Fig.1c,d) to investigate their ultrafast carrier dynamics. We determine the electron mobility, scattering rates and photoconductivity lifetimes at room temperature and in the temperature range 5-300K. Due to an asymmetry in the electron-hole population along the Dirac cone [1], a modified surface plasmon model [2] that includes hole concentration was used to fit the photoconductivity spectra. Furthermore, previous study has shown that upon photoexcitation, the electrons and holes establish two separate quasi-Fermi energy levels [4] and electron-hole recombination dominate the carrier dynamics, hence the necessity to include hole concentration in our analysis. We extract a room-temperature mobility of ~ 6,000 cm^2/Vs and ~ 16,000 cm^2/Vs at 5K. While lower than values reported for bulk Cd_3As_2 [3], this mobility value is high for NW structures, highlighting the potential of Cd_3As_2 NWs for high speed, nano-device applications.

III. Summary

In summary, we have shown that Cd_3As_2 nanowires are an ideal candidate for high speed electronic integration owing to the high electron mobilities and their inherently small sizes. In addition, the THz emission paves the way for future nanowire/single crystal laser sources.

References

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