Mid-infrared saturable absorber mirror (MIR-SAM) based on Dirac semimetal thin films

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Abstract: We have for the first time fabricated a Dirac semimetal saturable absorber with a mirror structure. The centimeter-scale, SESAM-like device can operate across 3-5 μm, and mid-infrared pump-probe spectroscopy is used to study the nonlinear absorption characteristics.

OCIS codes: (190.4400) Nonlinear optics, materials; (300, 1030) Absorption; (300, 6420) Spectroscopy nonlinear

1. Introduction

Short-pulsed lasers operating in the mid-infrared (>3 μm) are important for a wide range of applications [1]. Semiconductor saturable absorber mirrors (SESAMs) are one of the most importance short pulse generation devices, but they are typically operating below 3 μm [2]. Fabricating a SESAM-like device that can operate over important mid-infrared bands, *i.e.* 3-5 μm, is of crucial importance for the development of mid-IR photonics and spectroscopic systems. Recently, MBE-grown three-dimensional (3D) Dirac semimetal Cd_3As_2 is identified as a capable mid-infrared optical switching materials [3-6]. And it was found that via an element doping approach the photocarrier relaxation time can be flexibly and accurately tuned [3]. It would be highly desirable to fabricate a mirror or optically-resonant structure based on theses emerging materials, as it would make strategies that had been developed to fine control the nonlinear absorption in SESAMs readily applicable.

Here, we successfully prepare the first mid-infrared saturable absorber mirror (SAM) based on Dirac semimetal Cd_3As_2. By performing pump-probe spectroscopy, we experimentally proved that Cd_3As_2 based SAM can operate across mid-wave infrared 3-5 μm. Furthermore, we characterized the corresponding modulation depth of the device at 3 μm. Our mid-infrared SAM opens up the opportunity for the development of a new generation of compact and efficient mid-infrared mode-locked lasers.

2. Experimental

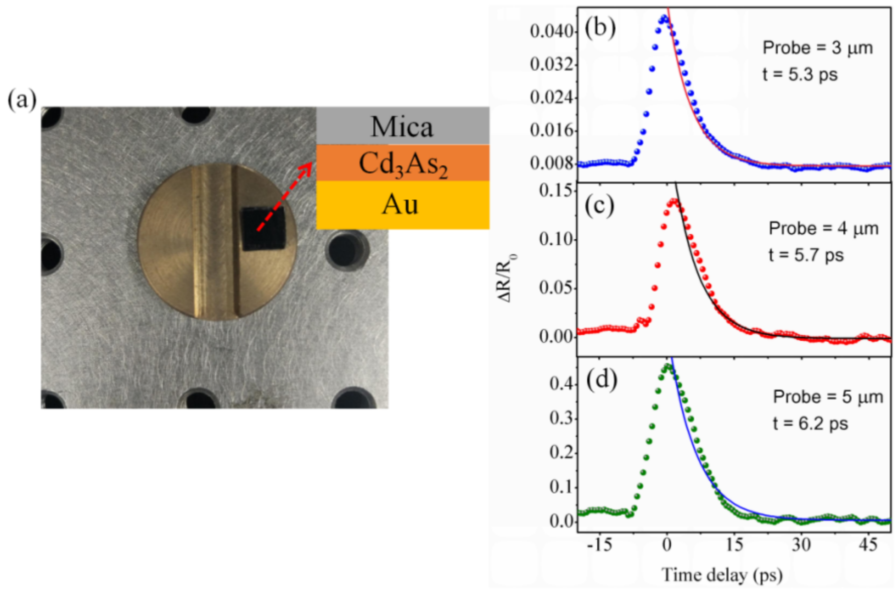

Fig. 1 (a) Photograph of the Dirac semimetal SAM, the inset schematically shows the layer arrangement in the sample; (b-d) Transient reflectance spectra for the Dirac semimetal SAM, with three selected probe wavelengths at 3, 4 and 5 μm.

Figure. 1 shows the photograph of the Dirac semimetal SAM mounted on a copper base and the corresponding non-degenerate pump-probe experimental results. The inset of Fig.1(a) presents the layout of thin films in the sample. The high-quality Cd_3As_2 thin films are grown on mica substrates by molecular beam epitaxy (MBE), and then an 80nm-thick Au film is coated on the cadmium arsenide surface by using Electron Beam Evaporator (EBE). Excellent interface is formed between the active absorber layer and the gold reflective layer as observed under SEM. With respect to the non-degenerate pump-probe experiment, the laser source is a high power Ti:Sapphire laser delivering 1 kHz, ~100 fs ultra-short pulses at 800 nm. One part of the laser output is used as the pump to excite photocarriers in the sample and the remaining is fed to an optical parametric amplifier (OPA) to generate wavelength-tunable mid-infrared probe beam. The measured transient reflected spectra are shown in Fig.1 (b), (c) and (d), which show appreciable saturable absorption effects of the device at 3, 4 and 5 μm. Through a mono-exponential fitting of the spectra, it can be seen that the delay time (carrier relaxation time) increases from 5.3 ps to 6.2 ps, consistent with previous reports [3, 4].

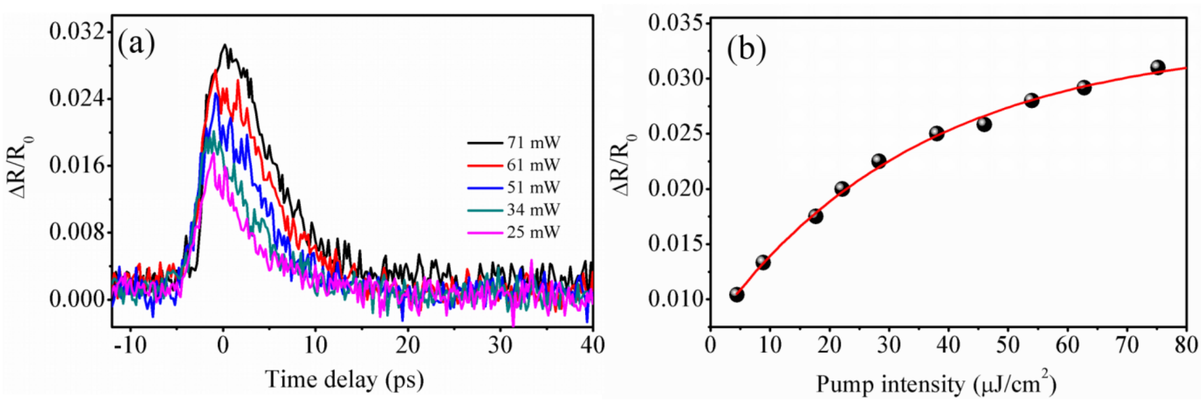

Fig. 2 (a) The transient reflectance spectra of the proposed device with the variety of pump intensity. (b)The measured modulation depth curve.

To further investigate the saturable absorption properties of the device, we perform a nonlinear absorption measurement at a probe wavelength of 3 μm. Fig.2(a) shows the power-dependent reflected spectra with different pump intensities. It can be clearly seen that the reflected signals are strongly pump power dependent. Fig.2 (b) illustrates the peak amplitude of the transient reflectance signal as a function of the pump intensity. We fitted the nonlinear absorption curve with a simple saturation model [3], where a modulation depth of 0.031 and a saturation intensity of 35 $\mu J/cm^2$ are obtained, respectively. It should be noted that as a non-degenerate pump-probe scheme is used, the value for the modulation depth is expected to be underestimated. This is because the population of photocarrier created by the 800 nm pump pulse experiences unavoidable loss through various relaxation processes. Experiments are underway to measure the mid-infrared response using a degenerate pump-probe scheme.

3. Conclusion

In summary, we have prepared the first mid-infrared saturable absorber mirror using large-area, uniform, and crystalline Dirac semimetal Cd_3As_2. The device exhibits excellent nonlinear absorption at 3, 4 and 5 μm. Our results represent an important step forward in engineering mid-infrared saturable absorber with sophisticated optical structures.

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