

Dirac Semimetal Thin-film Mode-locked Fiber Laser

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Abstract: We report that MBE-grown three-dimensional (3D) topological Dirac semimetal Cd₃As₂ thin-film exhibits remarkable saturable absorption effects at 1, 1.5 and 2 μm . A mode-locked Tm fiber laser is demonstrated using such a SESAM-like material.

OCIS codes: (140.7090) Ultrafast lasers, (160.4330) Nonlinear optical materials, (060.3510) Fiber Lasers

1. Introduction

Low-dimensional materials like carbon nanotubes, graphene, transition metal dichalcogenides etc. have been intensively investigated for ultrashort pulse generation in the past few years [1-4]. Recently, cadmium arsenide (Cd₃As₂), a representative 3D topological Dirac semimetal (TDS) material, shows excellent ultrafast saturable absorption properties in the mid-infrared range [5]. Furthermore, Zhu and co-workers demonstrate that the relaxation times of Cd₃As₂ in the mid-infrared can be flexibly controlled over an order of magnitude via a novel element doping approach. Such a feature makes TDS a counterpart of the conventional near-infrared SESAMs. Although this material has been successfully used for mode-locking fiber laser at 3 μm , its optical switching properties and applicability at shorter, more popular laser wavelengths is of both fundamental and practical significance. In particular, investigation at shorter wavelengths may allow one to establish whether the higher lying excited states, with respect to the inter Dirac bands excitation, can be harnessed for mode-locked lasers.

Here, by performing broadband pump-probe measurements, we experimentally proved that Cd₃As₂ also exhibits remarkable saturable absorption effects at 1, 1.5 and 2 μm . For further validation, we demonstrate for the first time an ultrafast Tm/Ho-fiber laser that is mode-locked by the Cd₃As₂ saturable absorber. The output pulse duration is 1.63 ps with a center wavelength at 1961.1 nm. Our results highlight the capabilities of TDS on providing robust and tunable saturable absorption over the important 1-2 μm laser band.

2. Nonlinear optics results and discussion

High-quality Cd₃As₂ thin films were grown on mica substrate by the molecular beam epitaxy method (MBE) [5]. The nonlinear optical properties of the thin film sample are studied in a non-degenerate pump-probe experiment. The optical source of the experiment is from a high power Ti: Sapphire laser which delivers 1 kHz, \sim 100 fs ultrashort 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 near-infrared probe beam. Fig. 1 (a-c) shows transient probe transmission spectra for Cd₃As₂ sample with three typical probe wavelengths at 1.0, 1.5 and 2 μm . All the three measured results exhibit a sharp transmission increase at time zero, indicating that Cd₃As₂ has a saturable absorption over the entire near-infrared spectral range. Meanwhile, fitted by a mono-exponential decay function (black solid lines) the relaxation curves indicate the saturable absorber has a recovery time around 5 ps.

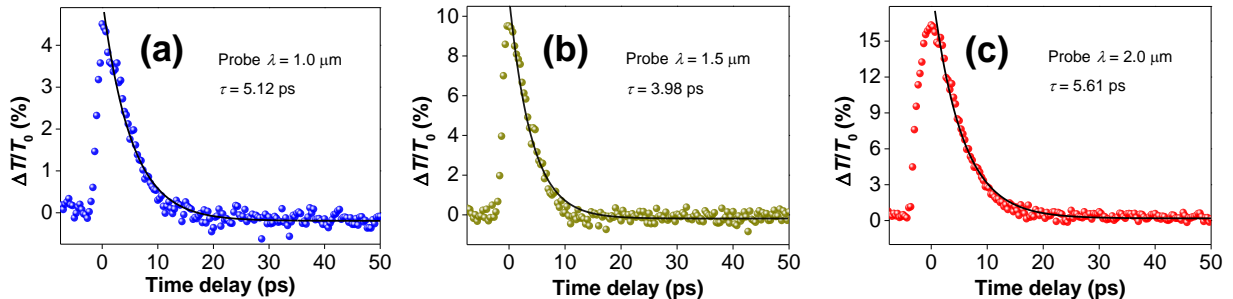


Fig.1 The transient transmission spectra for Cd₃As₂ thin film with three selected probe wavelengths at 1.0, 1.5 and 2 μm .

3. Ultrafast photonics applications

In order to further demonstrate the Cd_3As_2 can be used as saturable absorber for passive mode-locking laser with the above-mentioned wavelengths, a Tm/Ho co-doped all fiber laser experiment is implemented. The experimental setup is shown in Fig. 2 (a). The pump source is provided by an amplified continuous wave laser at $1.56 \mu\text{m}$. The pump is coupled into the cavity via a 1550/2000 nm wavelength-division-multiplexer (WDM). 2 m of Tm/Ho co-doped fiber (TH512, CorActive) with 9/125 core/cladding geometry, is used as the gain medium in the laser. A polarization insensitive isolator is spliced after the gain fiber to ensure unidirectional running and a 10% coupler is used as the output of the ring cavity. The prepared Cd_3As_2 -SA sample is sandwiched between two fiber connectors.

The laser starts continuous mode-locking with the pump threshold of 283 mW. At this condition, the output average power is 1.23 mw. Fig. 2 (b) shows the optical spectra of the output pulses by an optical spectrum analyzer (OSA, Yokogawa AQ6375). The output spectrum is centered at 1961.1 nm with a 3 dB bandwidth of 4.6 nm. The Kelly sidebands are clearly visible on the optical spectrum, indicating the laser is working in the soliton mode-locking regime. Then, in order to characterize the pulse width, the autocorrelation trace of the laser is measured by a mid-infrared autocorrelator (APE, Pulsecheck MIR) in Fig. 2 (c). The trace shows a typical FWHM width of 2.52 ps. Assuming a sech^2 pulse profile, the corresponding pulse duration is calculated to be 1.63 ps. The time-bandwidth product is 0.58, larger than the transform limited value of 0.315, indicating that the mode-locked pulses are slightly chirped.

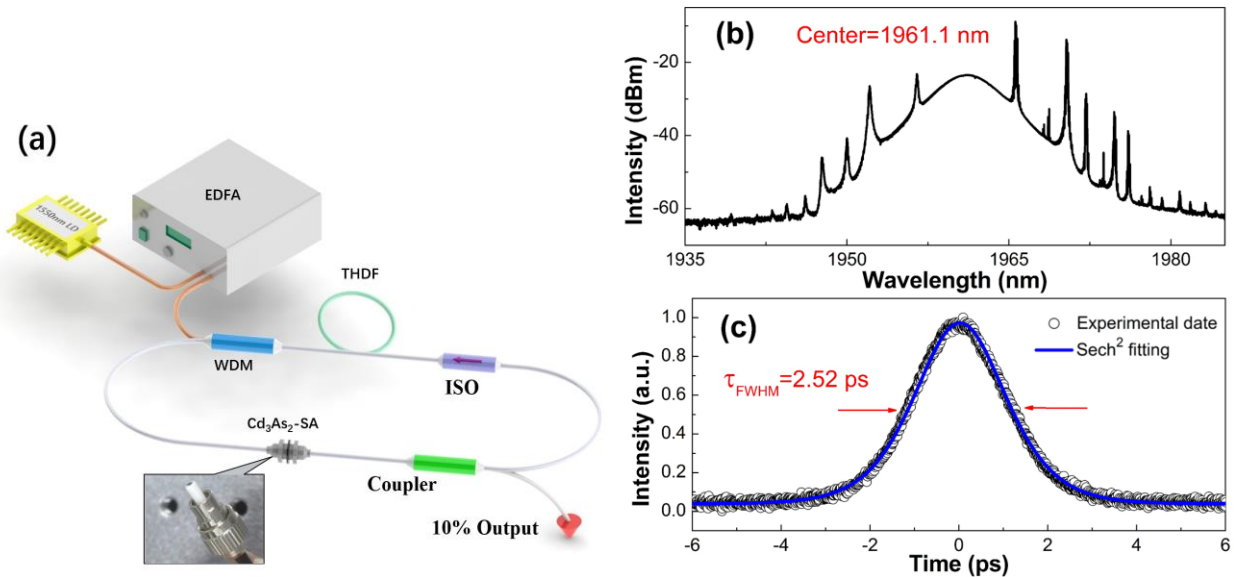


Fig.2 (a) Experimental setup of the mode-locked Tm-Ho fiber laser with Cd_3As_2 -SA. (b) The optical spectrum and (c) autocorrelation trace of the pulses.

4. Conclusion

In summary, we have proved that MBE-grown 3D TDS Cd_3As_2 thin film exhibits ultrafast nonlinear absorption at 1, 1.5 and $2 \mu\text{m}$. We demonstrated 1.63 ps pulse generation in a mode-locked Tm/Ho fiber laser at 1961.1 nm. Combined with our previous results, we show that Cd_3As_2 film is a robust and broadband mode-locking device that is highly applicable for the entire 1-6 μm range.

5. References

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