Linearly polarized ultrafast pulse generation based on black phosphorus

Diao Li[1,2],Henri Jussila[1],Lasse Karvonen[1],Guojun Ye[3,4],Harri Lipsanen[1],Xianhui Chen[3,4,5],& Zhipei Sun[1]
[1] Department of Micro- and Nanosciences, Aalto University, Tietotie 3, FI-02150 Espoo, Finland
[2] Institute of Photonics & Photo-Technology, Northwest University, Xi'an, 710069, China
[3] Hefei National Laboratory for Physical Science at Microscale and Department of Physics, University of Science and Technology of China, Hefei, 230026, China
[4] Key Laboratory of Strongly-coupled Quantum Matter Physics, University of Science and Technology of China, Chinese Academy of Sciences, Hefei, 230026, China
[5] Collaborative Innovation Center of Advanced Microstructures, Nanjing, 210093, China
Diao.li@aalto.fi

Abstract

Recently, a rediscovered layered material, black phosphorus (BP), has drawn a rising attention in the electronic and photonic communities due to its unique material properties[1]. For instance, BP possesses a broadly tunable band gap (varies from ~0.3 eV in bulk to ~2 eV in mono-layer[2]) with number of layers well suited for the near and mid-infrared photonics and optoelectronics, and thus, bridges the gap between the zero band gap graphene and relatively large band gap TMDs[3]. Furthermore, the phosphorus atoms distributed in a puckered plane could result in an anisotropic optical response[2,3], completely different with other two dimensional layered materials[4-7].

Pulsed laser sources based on nonlinear saturable absorbers (SAs) are reliable platforms for various applications, ranging from the basic research to industrial applications in telecommunication, medicine, and materials processing. Here, we experimentally investigate the optical absorption properties of BP films. We show that both the linear and nonlinear optical absorption are strongly polarization dependent, and can be tuned by the thickness of the BP flakes, different from the extensively studied graphene[4-6] and TMDs flakes[7,8]. BP films are further employed as SAs at the 1.55 μm telecommunication band for ultrafast light generation (shown in Fig. 1). Ultrafast fiber laser with a pulse duration down to ~786 fs, and pulse energy up to 18 nJ are demonstrated from a BP based SA device through mode-locking and Q-switching methods, respectively. The pulsed laser output is always linearly polarized, giving a degree-of-polarization (DOP) of ~99% in Q-switching, and ~98% in mode-locking (Fig. 1d), respectively. We attribute the linearly polarized output to the intrinsic anisotropic optical absorption property. Our investigation underscores the relatively large optical nonlinearity of BP with unique polarization and thickness dependence, and its potential for polarized optical pulse generation, paving the way to BP based nonlinear and ultrafast photonic applications such as ultrafast all-optical polarization switches, modulators and frequency converters.

References

[1] F. Xia *et al.*, Nature Communications, **5** (2014) 4458.
[2] Tran Vy *et al.*, Physical Review B, **89** (2014) 235319.
[3] D. Li *et al.*, Scientific Reports, **5** (2015) 15899.
[4] A. C. Ferrari *et al.*, Nanoscale, **7** (2015) 4598.
[5] A. Martinez *et al.*, Nature Photonics, **7** (2013) 842.
[6] Z. Sun *et al.*, Physica E, **44** (2012) 1082.
[7] Z. Luo *et al.*, Nanoscale, **8** (2016) 1066.
[8] Z. Sun *et al.*, Optical modulators with two-dimensional layered materials, arXiv (2016).

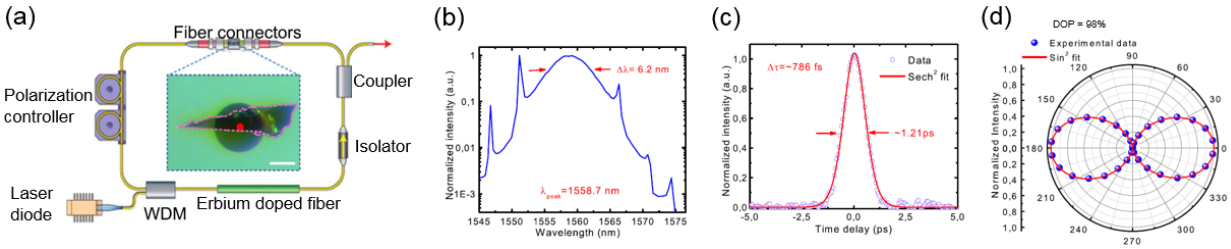

Figure 1. (a). Laser setup. Inset: BP SA film on fiber facet. WDM: wavelength division multiplexer. (b). Mode-locking laser output spectrum. (c). Output autocorrelation trace. (d). Polarization characterization result.