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Electronic Supplementary Information

Violet phosphorene as saturable absorber for controllable soliton molecules generation in a mode-locked fiber laser

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EXPERIMENTAL METHODS

Preparation of VP Nanoflakes

The few-layered VP nanoflakes were obtained via the liquid-phase exfoliation (LPE) route. The powdered samples ground from the violet phosphorus single crystals were firstly dissolved in the anhydrous alcohol and immediately sonicated for 10 hours using a water bath sonicator to disrupt the interlayer structure of violet phosphorus, producing thin VP nanoflakes with nanoscale thickness. Then the mixed solution was centrifuged at a high speed to obtain the supernatant containing layered VP nanoflakes.

Characterization

The topography of VP nanoflakes was determined with transmission electron microscopy (TEM, JEOL JEM 2100F) and atomic force microscopy (AFM, HORIBA Evo Nano). The crystal structure was investigated by the selected area electron diffraction (SAED, JEOL JEM 2100F) and the Raman spectrometer (HORIBA Evo Nano). A UV-VIS-NIR spectrophotometer (Hitachi UH4150) was used to measure the optical absorption property of VP.

Fabrication of VP-SPF SA Device

An ordinary single-mode fiber (SMF-28e, Corning) was side-polished precisely to fabricate a flatness plane for material deposition. The length of the planar region is about 15 mm and the distance from the core is about 2 mm. The few-layered VP nanoflakes were then deposited onto the SPF with the assistance of a 974 nm continuous-wave (CW) laser. Finally, the VP-SPF SA device was successfully fabricated and used for subsequent laser experiments.

Erbium-doped Fiber Laser Configurations

A 976 nm laser diode (LD) was utilized to provide pump energy, which was injected into the laser cavity through a 980/1550 nm wavelength division multiplexer (WDM). An erbium-doped fiber

(EDF, Er110-4/125) was used to provide intracavity gain. According to the full excitation of the EDF and the absorption losses, the length of the EDF was determined to be 46 cm. The output transmittance of the output coupler (OC) was 15%. To prevent unnecessary damage of fiber devices from the excessive echo power, and to ensure unidirectional operation, we incorporated a polarization-independent isolator (PI-ISO) in the resonator. Additionally, a PC was fused in the cavity to regulate the polarization state of laser pulses, thereby optimizing and stabilizing the mode-locking operation. To obtain laser pulses with a narrow pulse width and high stability, the mode-locking was set to operate in the conventional soliton form. Accordingly, the net intracavity dispersion needs to be negative. Through detailed calculations, we finally adopted a standard SMF with a total length of 21.2 m to connect all optical components, which resulted in a total net dispersion of approximately -0.46 ps^2 in the cavity.

Laser Measurements

The laser pulse waveform was detected by a digital oscilloscope (Tektronix, DPO 7104C) with an InGaAs photodetector (EOT, ET-5000). The output laser spectrum was detected by a spectrum analyzer (Anritsu, MS9740). The pulse width and modulation period were characterized and recorded by a spatially coupled second-harmonic-generation (SHG) autocorrelator (APE Pulse check 150). The radio frequency (RF) spectrum was recorded by an RF signal analyzer (Rohde & Schwarz, FPC1000).

The bandgap of prepared VP nanoflakes can be deduced from the Tauc plot using the optical absorbance of VP nanoflakes,[1, 2] as shown in Fig. S1. The bandgap of VP nanoflakes was approximately 2.35 eV.

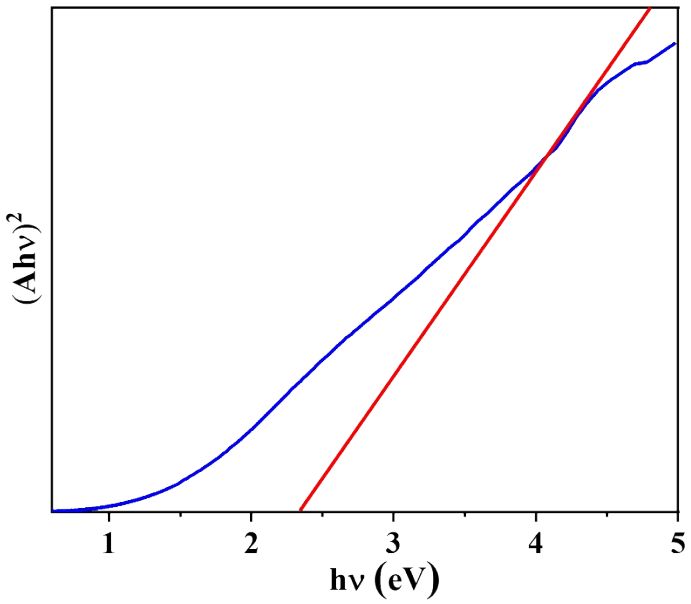

Fig. S1 Tauc plot converted from the absorbance of VP nanoflakes.

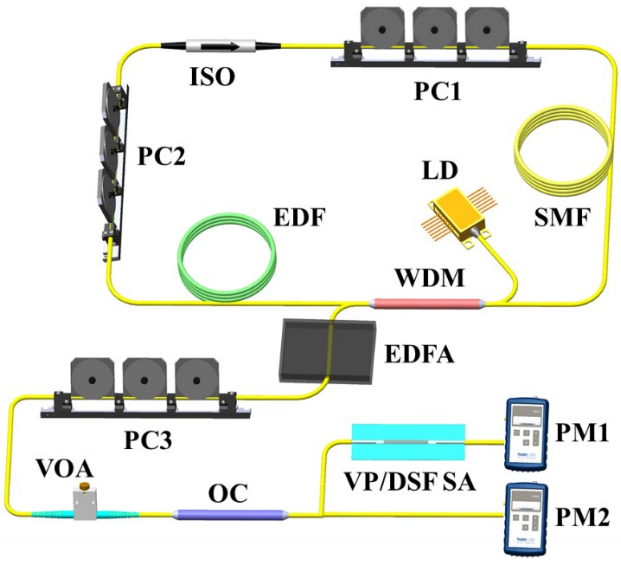

Fig. S2 The balanced twin-detector fiber setup.

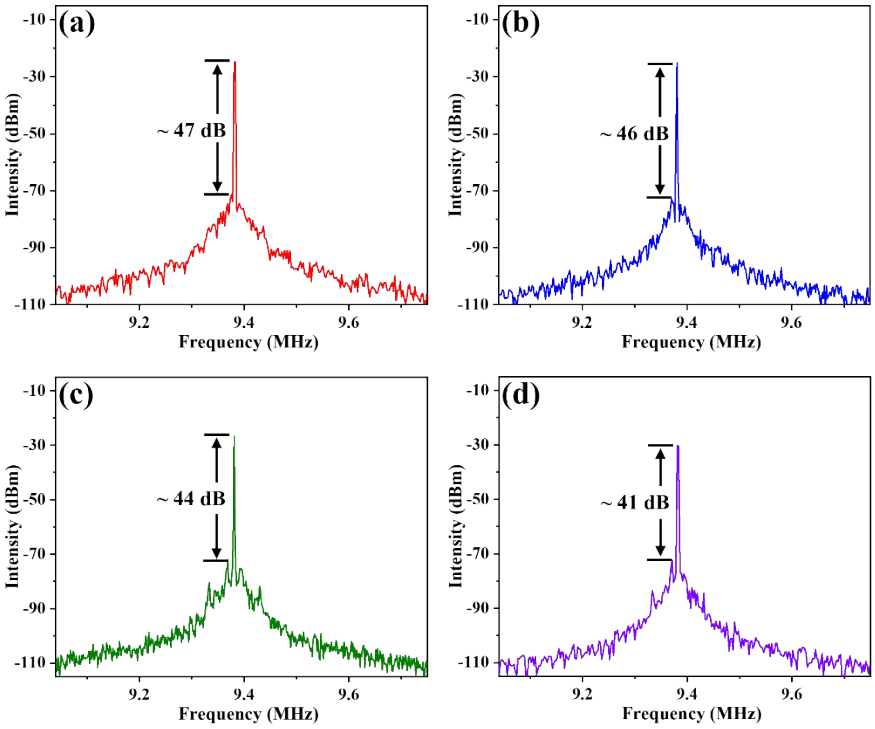

Fig. S3 The SNRs of (a) the tightly bound two-pulse soliton molecule, (b) the loosely bound two-pulse soliton molecule, (c) the three-pulse bound soliton molecule, and (d) the four-pulse bound soliton molecule.

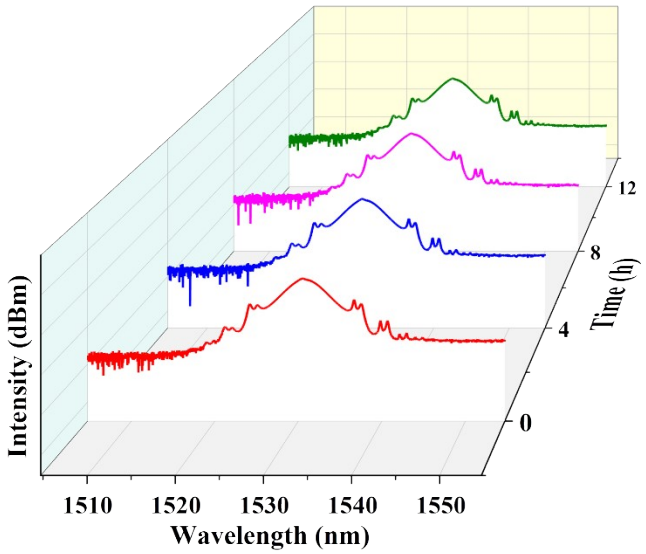

Fig. S4 Optical spectra of mode-locked laser pulses recorded every 4 hours.

REFERENCE

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