Microfibre deposited NiS$_2$ for all-fibre optical thresholding

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Abstract. We demonstrate a microfibre deposited NiS$_2$ for optical thresholding. By employing the fabricated NiS$_2$ device, an all-optical thresholding function based on the saturable absorption effect has been successfully realized. The signal-to-noise ratio of the input pulse signal can be improved from 2.7 dB to 14.5 dB. The results achieved indicate that this NiS$_2$-based microfibre device could be operated as an excellent nonlinear photonics device for all-optical signal processing.

1. Introduction
Saturable absorption (SA) effect has been widely used in nonlinear photonics and ultrafast optics. The excellent performance of SA effect results in that “high-intensity light” passes through and “low-intensity light” is efficiently absorbed [1]. The unique performance of the SA effect promotes numerous SA device found and investigated. The mostly investigated method to achieve SA effect is using real saturable absorber materials. Recently, numerous materials with saturable absorption capacity have been developed including graphene [2], black phosphorus [3] and transition metal dichalcogenides (TMDs) [4] etc.

Graphene is the most investigated materials for ultrafast photonics and optical modulators. In addition, due to its saturable absorption capacity and optical nonlinearity, the graphene-based device has been developed as loss and phase modulator, respectively [2]. However, graphene has drawbacks of weak absorption, complex fabrication and environmental instability, which weaken its modulation ability a lot [2]. Compared to graphene, TMDs has the non-zero bandgap and are more flexible. Furthermore, TMDs have been investigated and confirmed with nonlinear optical absorption, which indicates that TMDs can be used for ultrafast pulse operation and optical switching. WS$_2$ [4], SnS$_2$ [5], TiS$_2$ [1], three types of TMDs have been widely investigated in the fibre laser applications and optical thresholding. Research on the application of TMDs to achieve mode-locked pulse operation and optical modulation remains in progress. Hence, it is of great interest to explore new TMDs for ultrafast photonics and optical modulation.

Nickel disulfide (NiS$_2$), another new type of TMD, has attracted significant attention in recent years owing to its superior electrical and optoelectronic properties [6-10]. NiS$_2$ is a semiconductor, similar to WS$_2$ and MoS$_2$. Compared with typical large bandgap TMDs (above 1 eV), the bandgap of NiS$_2$ is 0.3 eV [11]. However, the nonlinear optical properties of NiS$_2$ and its application in fibre laser or optical...
thresholding have seldom been reported. Thus, it is a very valuable work to investigate the applications of NiS₂.

In this paper, a microfibre deposited NiS₂ has been investigated to achieve all-optical thresholding. The signal-to-noise ratio (SNR) of the input pulse signal can be improved from 2.7 dB to 14.5 with long-term stability, which indicates the NiS₂ device can be used as a high-quality all-optical thresholding device to suppress the noise and improve the SNR. Our results suggest that NiS₂-deposited SA could be used as an effective highly nonlinear photonic device for optical communication.

2. Experiment and results
In order to measure whether the microfibre deposited NiS₂ could be used for all-optical thresholding, the experimental setup was proposed and demonstrated as shown in Fig. 1(a). The pulse laser was a 10 MHz mode-locked fibre laser with 800 fs pulse duration at 1550.3 nm centre wavelength. The noise source is centred at 1550 nm with a 30 MHz radio frequency modulated low-power. The lights came from the noise and pulse sources were coupled into an optical coupler (50:50). The output of the three points marked as N, P and I in this figure corresponded to the three inset oscillograms. The variable optical attenuator (VOA) was adopted to modulate the input signal incident to the sample. Another optical coupler (10:90) was used to separate the light into two different segments: 10% port connected with an optical power meter to measure the output power, which can confirm the total output power; the 90% port connected with the NiS₂-based microfibre SA device. The microfiber deposited NiS₂ was shown in the inset of Fig. 1(a). The diameter of the microfibre is about 3 μm.

Fig. 1. (a) Schematic diagram of the experiment setup for all-optical thresholding with NiS₂-coated microfibre. (b) The waveform corresponding to the point marked with P. (c) The waveform corresponding to the point marked with N. (d) The waveform corresponding to the point marked with I.
By adjusting the VOA, a pulse with notably suppressed noise was successfully obtained and shown in Fig. 2. Fig. 2(a) and 2(b) show the pulse waveform before and after the introduction of this nonlinear photonics device when the VOA value set as 17.5 dB. The SNR of the oscillograph was 2.7 dB before the sample and 14.5 dB after the sample. The SNR after the sample is significantly much higher than before. Meanwhile, the noise is significantly suppressed. The long-term stability of the NiS$_2$ as an optical thresholding device was also verified, as shown in Fig. 2(c). The pulse SNR remains unchanged for 8 h, which strongly suggests the excellent stability of this device. Fig. 2(d) recorded the corresponding SNR with the increasing value of VOA. The SNR increased from 4 dB to 14.5 dB with the VOA value from 6 dB to 17.5 dB. It is also clear that before the NiS$_2$ sample, the SNR has no change with the increasing VOA value. Our experiments indicate that NiS$_2$ is suitable for all-optical thresholding devices.

3. Conclusion
In conclusion, a microfibre deposited NiS$_2$ was successfully demonstrated for all-optical thresholding. The signal-to-noise ratio of the input pulse signal can be improved from 2.7 dB to 14.5 dB. The achieved results indicate that this NiS$_2$-based microfibre device could be operated as an excellent nonlinear photonics device for all-optical signal processing.

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