Enhanced All-optical Modulation in MoS_2-coated Side-polished Fibres

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Abstract: A side-polished optical fibre platform is used to access the nonlinear optical properties of MoS_2. Experiments show its nonlinear response which is enhanced via resonant coupling, allowing for the observation of significant optical modulation.

1. Introduction

Molybdenum disulfide (MoS_2), whose electronic bandgap structure is dependent on the number of layers, displays promising applications in optoelectronics, photonics, and lasers. The layer-dependent bandgap structure puts MoS_2 into an important position for fabricating a variety of optoelectronic devices, including gigahertz transistors [1], high-sensitivity sensors [2], and integrated circuits [3]. Furthermore, the layer thickness can also be used to control the size of the material's nonlinear coefficients, which is significant for applications involving high-power signals. Here, we focus our investigations on the nonlinear properties of few-layer molybdenum disulfide (MoS_2) materials, especially for it use in all-optical modulation.

2. Design and Fabrication

A schematic representation of the MoS_2-coated side-polished fibre device is shown in Fig. 1. This geometry allows for the light propagating in the fibre to couple to the material over extended interaction lengths (on the order of ~10mm) to enhance the light-matter interactions. The MoS_2 films were grown by chemical vapor deposition onto a 280nm SiO_2/Si substrate [4]. The films were subsequently coated with a 1-μm-thick PVB layer to support the material and improve its durability. Significantly, the PVB coating helps to improve coupling to the films by drawing the core guided mode into the high-index layer. The PVB-coated MoS_2 was separated from the SiO_2/Si substrate using an ultrasonic bubbling method [5], and then positioned onto specially designed low-loss side-polished optical fibre. A cladding buffer of 1μm was retained above the core across the polishing region to suppress the transmission loss. Polishing to this depth permitted access to 30dB of the light propagating in the fibre, and this was confirmed by monitoring the change in transmission when a high-index liquid was dropped onto the polished surface. More details of the side-polishing method can be found in [6].

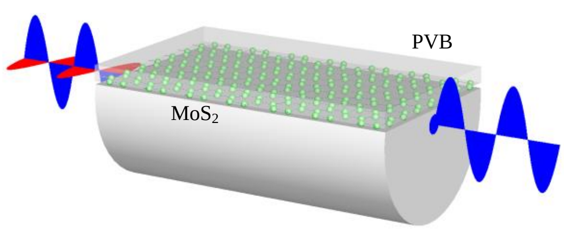

Fig. 1 Schematic model of the PVB-coated MoS_2 device based on a side-polished optical fibre.

3. Results and Discussion

The transmission properties of both the TM and TE modes for the MoS_2 fibre device were characterized. The experimental setup has been described in [6], where the laser output power was changed using a variable optical attenuator and its polarization state was varied using a polarization controller. A polarized high-power 1540nm pulse laser (duration of 750fs FWHM and repetition rate of 40MHz) was used. Fig. 2 shows the transmittance of the TE and TM modes as a function of increasing average power coupled into the devices, which clearly exhibits the onset of nonlinear absorption saturation of TE modes. Specifically, the transmittance of the TE mode stays around -38dB up to 3mW input. For higher input powers, the absorption becomes nonlinear and the transmitted light starts to increase rapidly, eventually reaching a saturable transmittance of -11dB for 36mW input, meaning a 27dB change of the TE mode transmittance. In contrast, the transmission of the TM mode remains linear and changes less than 0.5dB even the input power reaches the highest value. This is due to the minimal interaction between the TM mode and the MoS_2 sheet [7], identifying polarization dependent saturable absorption properties. This result indicates the suitability of MoS_2 materials for the development of high-speed all-optical modulators. The high transmittance of the TM mode also proves that there is almost no insertion loss of the side-polished fibre itself.

A further experiment was undertaken to test the suitability of the MoS_2 material for the development of high-speed all-optical modulators. In this experiment, a time-resolved optical pump-probe technique was used to determine the fast temporal resolution of all-optical modulation in the PVB-coated MoS_2 fibre device. Details of the experimental setup can be found in [8]. The output beam from a pulsed laser was split into a high-power pump (~35.3mW) and a weak probe component (~711μW). The probe was modulated at 100Hz using an optical chopper connected to a lock-in amplifier to discriminate between the two signals. Polarization controllers were used to ensure that both the pump and probe were aligned so that they were efficiently coupled into the MoS_2 layer. A 10ps adjustable delay was inserted into the probe path to control the overlap between the two pulses. The pump and probe pulses were then recombined using a fused tapered coupler before being connected to the input arm of the device. Fig. 3 shows that the power of the transmitted probe signal can be modulated over a timescale of 2ps, as the pump-probe overlap is tuned. A remarkable modulation depth of 20dB was achieved, calculated as the ratio between the maximum and minimum transmittance. Compared to the graphene-based counterpart device [8], the 11dB higher modulation depth measured in the MoS_2 device is believed due to the resonance-enhanced light-matter interaction within the telecom band.

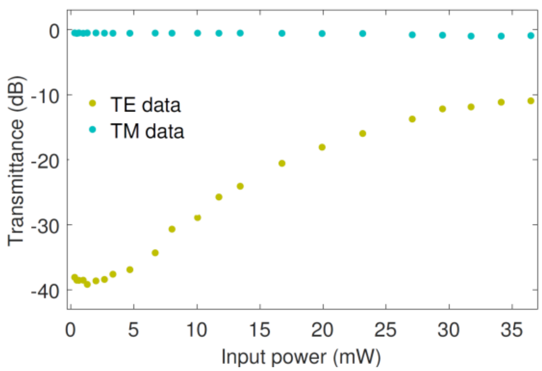

Fig. 2 Transmittance as a function of input power.

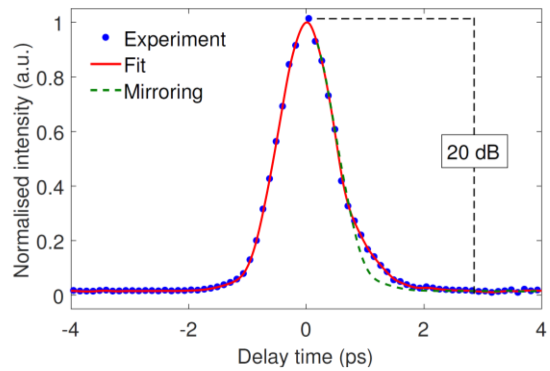

Fig. 3 Probe intensity as a function of pump-probe delay.

4. Conclusions

In conclusion, a MoS_2-based all-optical modulator with a high modulation ratio of 20dB and a low loss of 0.5dB has been designed and experimentally demonstrated in the telecoms band. This level of light modulation is remarkable considering the incredibly small volume of MoS_2 that the light is interacting with. We believe that the strong interaction measured in this device in this wavelength region is due to the resonance-enhanced light-matter interaction. Thus, with further optimization of the device design and number of material layers, we predict that these structures will find use in wide-ranging nonlinear optical applications, including those based on the second order processes (e.g., second harmonic generation). This route to access the nonlinear properties of two-dimensional materials promises to yield new insights into their photonic properties.

5. References

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