Fiber All Optical Phase Shifter and Switch near 1550 nm Based on Two-dimensional Nanomaterial Tungsten Disulfide (WS_2)

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Abstract: A fiber all optical phase shifter and switch near 1550nm is realized by depositing two-dimensional nanomaterial tungsten disulfide (WS_2) to tapered fiber. The device has a slope efficiency of 0.0174π/mW.

Two-dimensional (2D) materials have attracted intense attention after the discovery of graphene for their abundant photonic and optoelectronic properties. In various applications based on 2D materials, all optical devices are of special interest for future all optical signal processing. In this work, a proof-of-concept all optical phase shifter operating near 1550 nm is fabricated by depositing few-layer transition metal dichalcogenides (TMDs) material tungsten disulfide (WS_2) to a tapered fiber. When the pump light at 980 nm is injected to the deposition area, WS_2 absorbs the light, generates heat and then changes the refractive index of the tapered fiber due to thermal-optic effect and thus modifies the optical phase of 1550 nm signal light. The maximum phase tuning range is 6.1π with a slope efficiency of 0.0174π/mW. By incorporating the phase shifter to a fiber Mach-Zehnder interferometer (MZI), an all optical switch is obtained. The switch has an extinction ratio of 15 dB and a switch time of 7.5 ms. Noting the deposition area of WS_2 is only ~300 μm, this multi-functional device based on WS_2 has the potential to be a compact, fiber compatible and low-cost all optical device for many all optical applications including all optical routing, optical logic gate and all optical signal processing.

Different from graphene with uniform absorption in a wide spectrum, WS_2 has non-uniform absorption. This property is important because we can choose a pump (control) wavelength at high absorption wavelength (e.g., 980 nm) to enhance the control efficiency and choose a signal wavelength at low absorption wavelength (e.g., 1550 nm) to reduce the device loss. WS_2 nanosheets are prepared by liquid-phase exfoliation and deposited to a tapered fiber. Transmission electron microscope (TEM) image of the WS_2 nanosheets, microscopic image of the WS_2 deposited tapered fiber and Raman spectrum are shown in Fig.1(a)-(c), respectively. The all optical phase shifter (red frame) shown in Fig.1(d) consists of two 980/1550 wavelength demultiplexers (WDMs) to inject and extract 980 nm pump light, and a WS_2 deposited tapered fiber in the middle as core interaction component. The phase shifter is embedded into one arm of a fiber MZI to measure the phase shift. Fig.1(e) shows the spectral drift of the MZI when pump power applied, which can be used to calculate the pump induced phase shift. Fig.1(f) shows the relation between phase shift and pump power. A phase shift of 6.1π is obtained at 350 mW maximum pump power and the slope efficiency is ~0.0174π/mW. The MZI is also an all optical switch. In Fig.1(g), the yellow waveform is the applied pulsed pump power for switch control and the blue waveform is the switch output from port “output 1”. Fig.1(h) shows the detailed waveform of a single output period and the exponential fit is also plotted (red line) to extract the time coefficients of rising and falling edges, which are 7.3 ms and 3.5 ms, respectively. Fig.1(i) is the complementary output from port “output 2”.

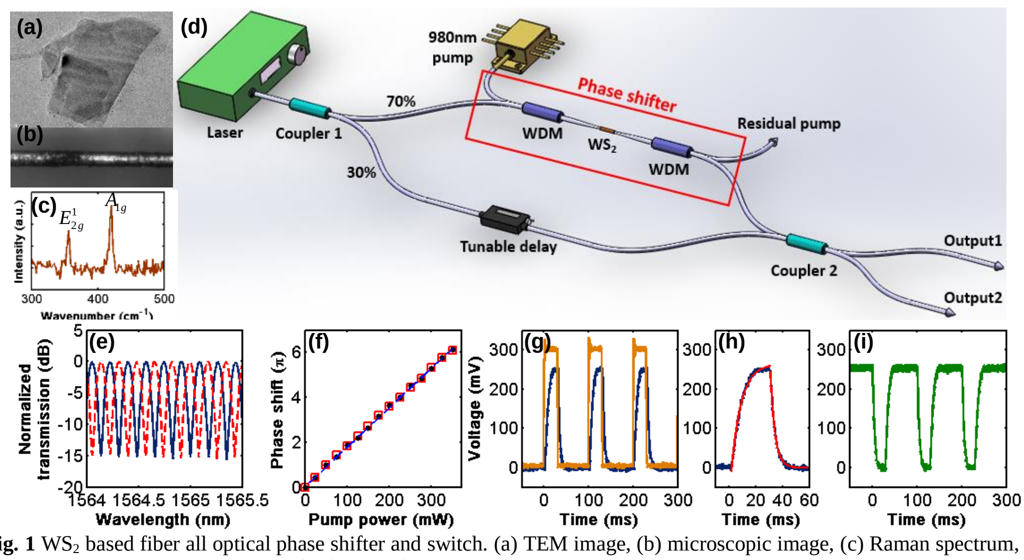

Fig. 1 WS_2 based fiber all optical phase shifter and switch. (a) TEM image, (b) microscopic image, (c) Raman spectrum, (d) experimental setup, (e) spectrum drift of MZI, (f) phase shift vs pump power, (g) control pump pulse (yellow) and switch output (blue), (h) fit for rising and falling edges, and (i) complementary switch output

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