All-optical directional coupler switching in chalcogenide glass

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Abstract

The waveguide-based directional couplers in As_2S_3 glass were fabricated by using inductively coupled plasma (ICP) etching. Their ultrafast all-optical switching operation was demonstrated at 1.53 μm with switching peak power of 55 W.

Summary

The potential applications of nonlinear directional couplers (NLDCs) in all-optical processing have attracted extensive interests since they were firstly introduced by Jensen in 1982.[1] Presently, the investigations of the integrated NLDCs for switch applications are mainly focused on semiconductor materials such as AlGaAs and GaInAs[2, 3]because of its easy fabrication by using conventional integration circuit processes. However, when these materials are operating at 1.55 μm, two-photon absorption can significantly attenuate signals, and reduce power efficiency.

Chalcogenide glasses are known to posses high third order optical nonlinearity, (up to 27000 times of that of silica has been reported[4]) and generally good nonlinear figures of merit. The application of single mode As_2S_3 chalcogenide fibres to all-optical processing at sub-watt power was in fact reported more than a decade ago.[5] Instead of using the conventional photosensitivity to directly write waveguides in the chalcogneide films, we have successfully fabricated As_2S_3 rib waveguides with losses as low as 0.2 dB/cm at 1.55 μm using standard photolithography and ICP etching.[6] The large refractive index contrast between the chalcogenide core (n = 2.3 ~ 2.8) and a polymer or air cladding allows chalcogenide waveguides to have very small mode area thus enhancing the optical field intensity for fixed optical power. Recently, the nonlinear phase shift as large as 4.7π has been observed in a 6-cm long As_2S_3 waveguide with its effective mode area ~ 4.2 μm^2, and is enough for detuning a cross-state directional coupler.[7]

In this summary, we report the design, fabrication and characterization of a NLDC in As_2S_3 glass based on our latest ICP etching processes. A clear all-optical switching was observed.

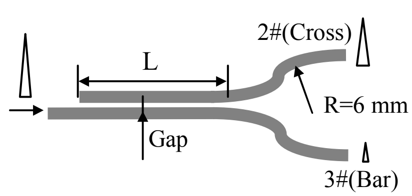


Fig. 1 (a) Schematic view of the fabricated As_2S_3 DC

Table I The structure and output parameters of the studied DCs

DC No.	Core size (μm) W	H	h	Gap (μm)	L (cm)	Output ratio (2/3)
1	4.8	2.64	1.5	7.25	5.4	0.8/0.2
2	4.3	2.64	1.5	5.8	3.17	0.68/0.32

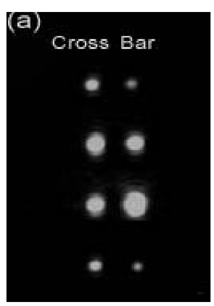
The schematic structure of the directional coupler (DC) is illustrated in Fig. 1. The DC consists of two parallel waveguides. At input ends, the guide in the bar channel is about 0.5 mm longer for signal input. At output end, the s-bends with a radius of 6 mm were applied. In the design of the DC structure, commercial C2V Mode Solver and BPM modules were employed. A series of DCs with different structures were designed and laid out in a mask. One wafer was fabricated. As_2S_3 films about 2.6 μm thick were deposited by using Ultra-Fast Pulsed Laser Deposition (UFPLD) onto oxidized silicon wafers. The As_2S_3 rib waveguides were etched by using ICP etching described in ref. 6 and 7. The whole length of the devices is 6.2 cm. The two

DCs with different output ratios were chosen for all-optical switching experiments. Their structure (waveguide width-W, height-H and etch depth-h) and output parameters are listed in Table I.

In the measurements of the devices, a low repetition (1.5 MHz) and high peak power (1300 W) pulsed laser was employed. The operating wavelength is at 1.53 μm, and the pulse duration is about 7 ps. The measure system used is the same as that in ref. 7.

Fig. 2(a) shows the recorded images of the two output channels of sample 1# when the peak power in the waveguide increased from low value to the high level and then reduced to a low value again. It can be seen from Fig. 2(a) that at low intensity, with no nonlinear phase shift, the cross channel had higher output. When the intensity was increasing, the output ratio started changing, more power was coupled back to the bar channel. When the average power increased to about 0.7 mW, the intensities of the two spots switched with higher output in the bar channel. When the power decreased to low level, the output ratio switched back. Therefore, the whole process exhibited a reversible switching behavior.

The average output powers from both channels were measured versus the input average power for Sample 2[#]. The peak power can be calculated by using the repetition rate of 1.5 MHz and pulse duration of 7 ps of the pulsed laser. Fig. 2(b) shows a plot of the normalized output transmission of the cross and bar states of Sample 2[#] as a function of the peak power in the waveguide. The data clearly indicated a switching effect. We defined the switching power as the peak power which produces the highest extinction ratios. As can be seen in Fig. 2(b), the extinction ratios reached their maximum value when the peak power was 55 W, and remained almost constant even when the peak power was further increased. Therefore, the switching power was considered to be about 55 W, corresponding to an intensity of 0.9 GW/cm^2 (the effective mode area of A_{eff} for Sample 2# is 6.3 μm^2). Complete switching (higher extinction ratio) from the cross to the bar state was not possible with pulsed signals due to pulse breakup which occurred when the response time of the nonlinearity was shorter than the pulse duration.[8]



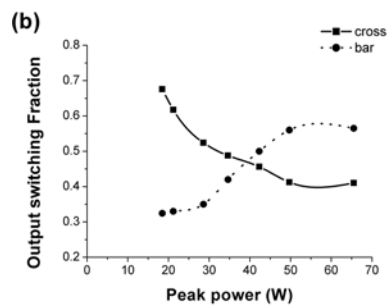


Fig. 2 (a) The recorded switching processes for Sample 1#; (b) Measured switching curve of Sample 2# as a function of peak power.

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