10GHz All-Optical Gate on a Silicon Chip

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Abstract: We demonstrate a fast all-optical gate with a 5μm radius InP disk heterogeneously integrated on to a SOI waveguide circuit. Rise time and fall time together are 50ps.

OCIS-codes: (230.1150) All-optical devices; (130.4815) Optical switching devices

1. Introduction

All-optical signal processing is the way forward to meet the growing demand of high speed communication and ultrafast computing. Gates are important components for communication and computing devices. The speed of electronics based gates will not be sufficient for the next generation communication and computing devices, and hence faster gates will be required. In the recent years, microdisk and microring resonators have emerged as promising candidates for the realization of photonic components and devices. Microdisks, being small in size, offer the advantage of high speed, scalability and high density on chip integration. Since silicon manufacturing processes are in a mature state, integrating active devices on silicon allows harnessing the best features of active materials as well as of silicon. In this regard, adhesive die-to-wafer bonding with the divinylsiloxane-benzocyclobutene (DVS-BCB) polymer has been shown to be a viable solution [1]. In this paper we report on a high speed all-optical gate using an InP microdisk resonator heterogeneously integrated on to SOI waveguide circuit. The diameter of the microdisk is 10μm, and the device structure and waveguide circuit are as reported in [2], with the difference that this device has a drop port waveguide, under the microdisk, opposite to the through port waveguide. We worked with the through port though for the experiments reported here.

This approach to optical gating allows integration with other active devices such as all-optical flip-flops and ultimately realisation of more complex photonic integrated circuits using heterogeneously integrated InP microdisk on SOI.

2. Concept for All-optical Gate

Our gate is based on the carrier induced change in transmittance characteristics of the InP-based microdisk. It is realized using a pump-probe configuration with the pump tuned at one resonant wavelength and the probe at another. The spectral response of the microdisk used for the gating experiment is shown in figure 1. From figure 1, it is clear that there are two resonant modes with a FSR of 22.6nm. The higher wavelength mode (at 1586.5nm) has a

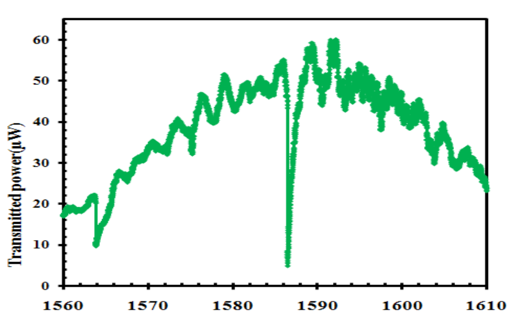

Fig. 1: Spectral response of microdisk resonator

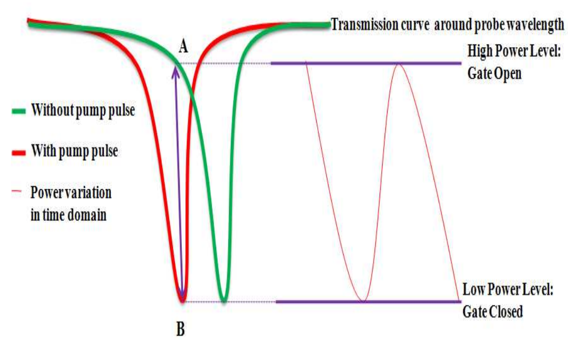

Fig. 2: Illustration of concept for all-optical gate

higher extinction ratio than the lower wavelength mode (at 1563.9nm). Obviously, tuning the probe light around this wavelength will give a higher extinction ratio for the gate. The ripples in the spectral response of the microdisk are due to a Fabry-Perot resonance formed between the two grating couplers used for coupling to fiber. Figure 2 illustrates the concept of the all-optical gate. To realize gating, the probe power should be smaller and the pump power larger. The green curve represents the transmission characteristic of the microdisk around the probe wavelength in absence of the pump pulse. With the arrival of the pump pulse, the transmission curve shows a blue shift due to the generation of carriers causing a decrease in the refractive index. This is represented by the red curve. If the arrival of the pump pulse is periodic, then the transmission characteristic will shift from the green to the red curve and back. This sequence will keep repeating itself in accordance to the time period of the pump pulses. If prior to the arrival of the pump pulse, the probe light wavelength is set off the resonance, marked as ‘A’ in figure 2, then the output will be high and the gate will be in the open state. As the pump pulse arrives, the resonance will be blue shifted and the output of probe light will be low and the gate will be in closed state. This is marked as ‘B’ in figure 2. This way the power of the probe light will vary periodically in the time domain between points ‘A’ and ‘B’ from high to low and vice-versa.

The gating experiment was done using the pump and probe configuration as discussed above. Figure 3 shows the schematic of the experimental set-up used. Low power TE probe light tuned off the resonance, marked as ‘A’ in figure 2, from a CW tunable laser is injected in to the microdsik from the right side of the waveguide. The power of the probe light injected into the waveguide is 170µW. Polarization controlling wheels (PCW) are used to control the polarization of the light. Using a circulator, the high intensity pump light from a short pulse source is injected into the microdisk from the left side of the waveguide. The average pump power in the waveguide is 4mW. The waveform of the short pulse used is plotted in figure 4. The drop port of the circulator is used to collect the probe light. The probe light obtained at the drop port of the circulator is amplified by an erbium doped fibre amplifier (EDFA). A bandpass optical tunable filter, tuned around the wavelength of the probe light, is used to partly supress the spontaneous emission noise from the EDFA. Finally the probe light is fed into the optical scope.

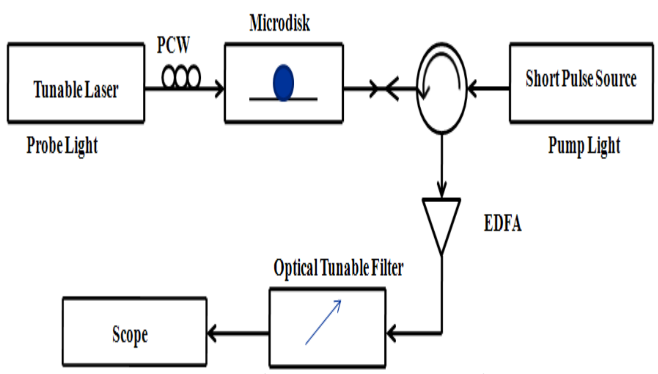

Fig. 3: Schematic of the experimental set-up for the gating measurements

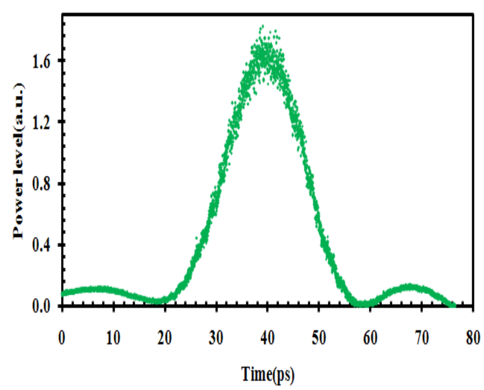

Fig.4: Waveform of the pump pulse

3. Results

Measurements were performed keeping the microdisk biased at 0V and -1V. 7.5ps wide pump pulses with repetition rate of 10GHz and extinction ratio of more than 20dB, plotted on the left side in figure 5, were injected into the microdisk while the probe light was already injected to the microdisk. Note that the pulse width in figure 4 looks much wider than 7.5ps due to the limited resolution of the optical scope used to record it. The gate output corresponding to the pattern of the pump pulses is plotted on the right side of Figure 5 while the microdisk was under a reverse bias of -1V. The rise time and fall time is 8.5ps and 41.5ps respectively. The extinction ratio is 4.5dB. This low extinction ratio may be partly due to spontaneous emission noise from EDFA, and also due to the low extinction ratio of the transmittance characteristic of the microdisk itself. Biasing the microdisk reverse results a shorter fall time due to fast sweeping of the carriers out of active region of the microdisk by the electric field. A similar approach has been used for high speed all-optical modulation [3]. Under the same pump power and a higher value of the reverse bias no further improvement in fall time was seen. The high speed of the gate can be due to surface-state recombination at the side walls of the microdisk, along with a contribution from the reverse bias.

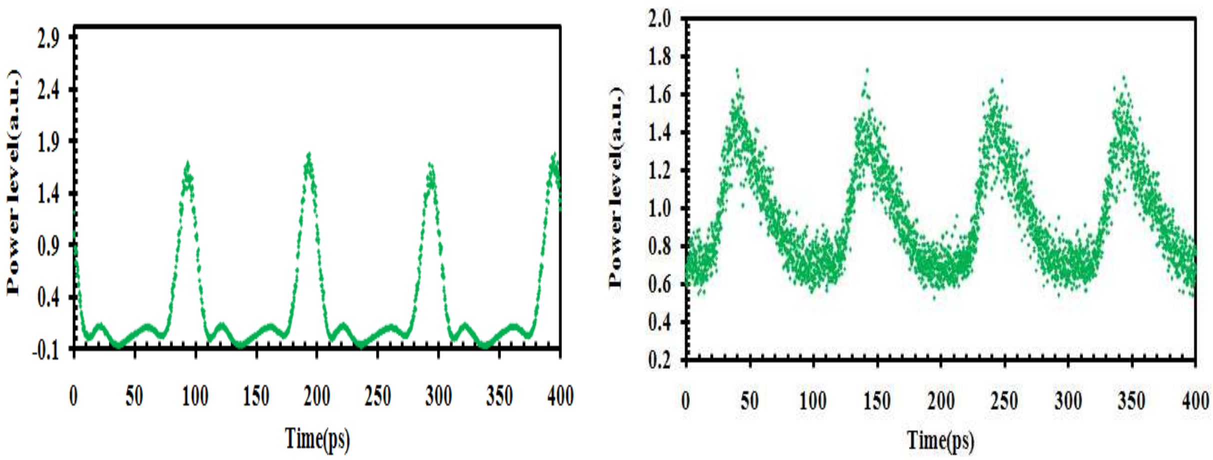

Fig. 5: Pump pulse pattern (left) and corresponding gate output (right)

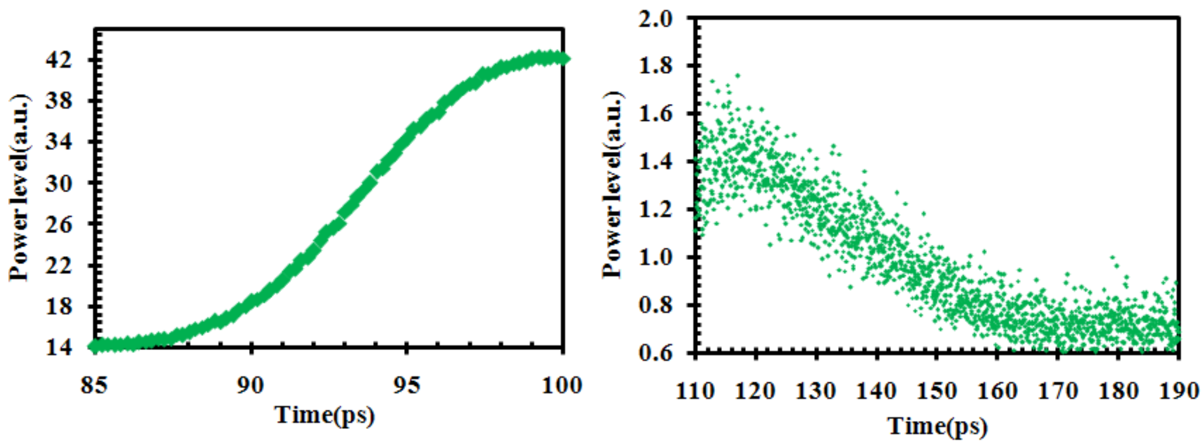

Fig. 6: Transient response of gate output-rise (left) and fall edge (right)

4. Conclusion

We have demonstrated a small size all-optical gate with an InP microdisk of 10µm diameter working at a speed of 10GHz. On the basis of rise time and fall time measurements we estimate that this gate can work up till the speed of 20GHz.

Acknowledgement

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