DPSK Demodulation using Mach-Zehnder Delay-Interferometer on Silicon-on-Insulator Integrated with Diffractive Grating Structure

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Abstract: A novel integrated waveguide grating is proposed for the dual functions of coupling light to fiber and as a variable split ratio splitter/combiner. A Mach-Zehnder delay-interferometer was fabricated using the grating coupler/splitter/combiner for DPSK demodulation.

OCIS codes: (130.3120) Integrated optics devices; (060.1810) Buffers, couplers, routers, switches, and multiplexers.

1. Introduction

The high index contrast and compatibility with complementary metal-oxide-semiconductor (CMOS) technologies of silicon-on-insulator (SOI) make it a promising platform for making photonic integrated circuits (PIC) [1, 2]. Integrated Mach-Zehnder delay-interferometers (MZDI) may be used to demodulate differential phase-shift-keying (DPSK) modulation formats [3]. MZDI comprise a 1X2 splitter, a 2x1 combiner and two waveguides connecting them with different lengths. Integrated 1X2 splitters/combiners have been implemented using Y-branches [4], multimode interference couplers [5] and star coupler [6] and there has been much work on minimizing the excess loss and device sizes of such splitters/combiners. Recently, the planar waveguide vertical grating coupler was also proposed to efficiently coupling light from standard single mode optical fibers to submicron-sized waveguides. The advantages of having waveguide gratings for coupling light to optical fibers include improved wafer scale testability of devices and the prospect of increased yield by making it unnecessary to polish the end facets of waveguides for packaging [7-9].

In this paper, we propose and implement a novel 1X2 splitter/combiners that is based on the same waveguide grating used for fiber-waveguide coupling. The waveguide grating comprises a shallow etched one dimensional diffraction grating which serves to couple light from/to optical fiber and splitting/combining the light at the same time. 36% coupling efficiency was achieved from fiber to submicron-sized waveguide for the splitter without additional excess loss. The splitting ratio may be adjusted by changing the fiber position without introducing much excess loss.

2. Waveguide coupler/splitter/combiner design

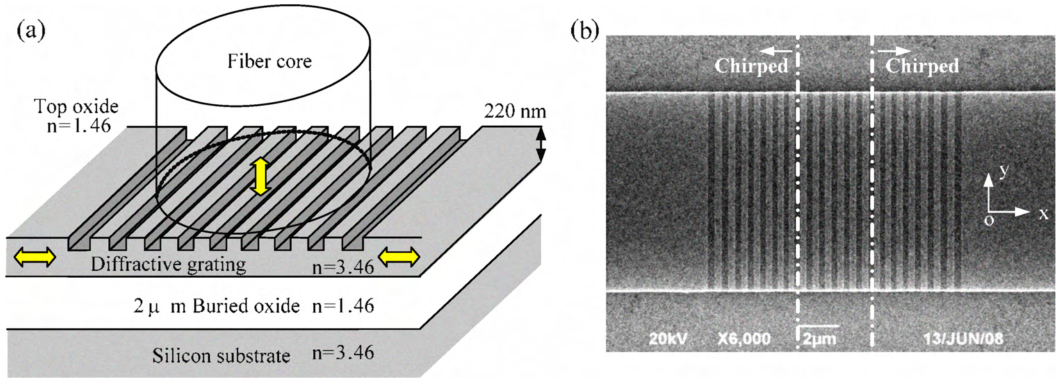

Fig. 1. (a) Schematic of the fiber-waveguide coupler and splitter/combiner. (b) SEM image of the shallow etched diffractive grating on planar waveguide for coupling and splitting light. This symmetric structure include uniform grating in the middle and 7 slits linearly chirp at both ends.

The proposed splitter/combiner is shown in Fig. 1. It was fabricated using deep UV lithography at IMEC [10] on a SOI wafer with 220nm top silicon layer and 2µm thick buried oxide. There is 750nm deposited oxide on top. A standard single mode fiber, perpendicular to the waveguide surface, may be attached to the center of the grating structure on top of the 12µm-width waveguide. The grating structure was formed by a dry etching to 70nm depth. As illustrated in the Fig.1(a), light coming from optical fiber will be diffracted bi-directionally and coupled into the fundamental mode of the 12µm-width waveguide by the one dimensional grating. The mode field profile of the diffracted light from the 12µm-width waveguide was designed to match the mode field profile from a single mode fiber. The modes in the waveguide were then compressed laterally by an adiabatic taper to a waveguide with 500nm width. The proposed design was optimized for coupling to the TE mode in the waveguide.

The period needed for vertical out-of-plane coupling is $\Lambda = \lambda/n_{eff}$ [8], where n_{eff} is the average effective index of the waveguide in the grating region. However when the grating is designed for vertical coupling, large back reflections from the grating structure back into waveguide will also occur, leading to Fabry-Perot (FP) spectral resonances. This FP effect may be observed experimentally and can affect the stability of the many functional components in PIC, including MZDI. Thus we linearly chirped the grating period at the both end of the grating structure to reduce the back reflection when light coming from a submicron-sized waveguide to a vertical optical fiber [9]. We employed two dimension finite-difference time-domain simulations to optimize the design parameters in the x-z plane. As shown in Fig.1(b) the structure consists of 7 periods with linearly chirped at each end of the grating. The chirp introduced with a change of 120nm in the grating period. The grating periods were 640nm, 620nm, 600nm, 580nm, 560nm, 540nm, 520nm respectively, counting from the end towards center. The widths of the 7 slits at the center were uniform with 305nm width and 275nm spacing. The slit:tooth duty cycle was 53%. The splitting ratio was tunable from 0.3 to 0.7 by varying the fiber position along x axis with the change of coupling efficiency <0.6dB.

3. Experimental test of the MZDI

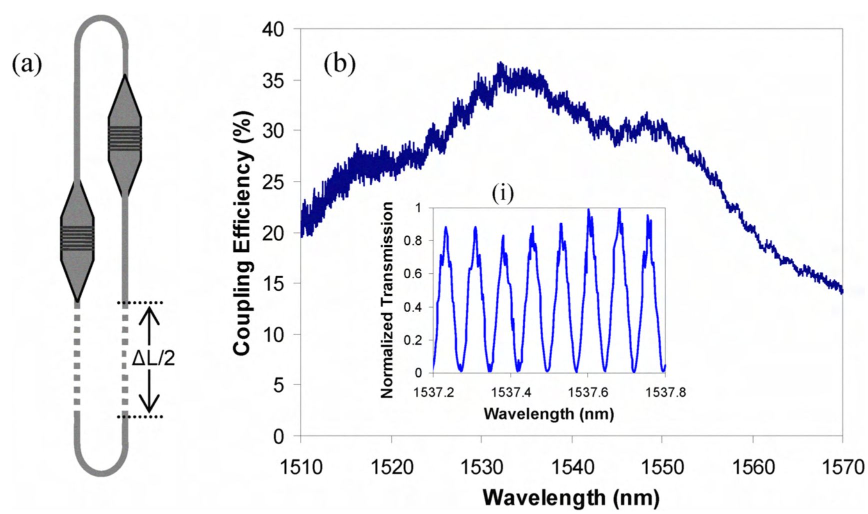

Fig. 2. (a) Illustration of the fabricated MZDI design. (b) Measured coupling efficiency versus wavelength and the inset (i) show the transmission of the MZDI

The fabricated MZDI is shown in Fig.2(a). The device used two grating splitters/combiners for input and output coupling respectively. The splitters/combiners each had a grating in the center and 1.05mm-longed adiabatic taper to the 500nm-width waveguides. The lengths for the two waveguide arms are 1.72mm and 9.16mm respectively. The length difference (ΔL = 7.44mm) was designed to introduce a bit length delay (100ps) for the 10Gb/s signal. The coupling efficiency was measured with broad-band ASE source coupled with standard single mode optical fiber. The propagation loss for the 500nm-width waveguide was estimated to be ~0.2 dB/mm [10]. The measured coupling efficiency with 0.5 splitting ratio is shown in Fig.4(b). About 36% coupling efficiency over a ~37nm 1dB bandwidth was achieved. The performance of the MZDI was characterized using spectral scanning around 1537nm. Strong interference pattern was obtained. By adjusting the fiber position to change the splitting ratio, we could compensate the different propagation losses of the two arms. The extinction ratio of the interferometer was over 20dB as shown in the inset of Fig.4(b).

4. DPSK demodulation using MZDI

Fig.3(a) shows the experimental setup for DPSK demodulation. The CW light at the wavelength of 1535nm was generated by a tunable laser. It was then phase modulated with the data generated form a pseudo-random binary sequence (PRBS) pattern generator at 10Gb/s data rate. After amplification and filtering, the light signal would be coupled into and out of the integrated MZDI on SOI chip using cleaved single mode fibers. Clearly opened eye diagrams were obtained after demodulation as shown in Fig.3(b).

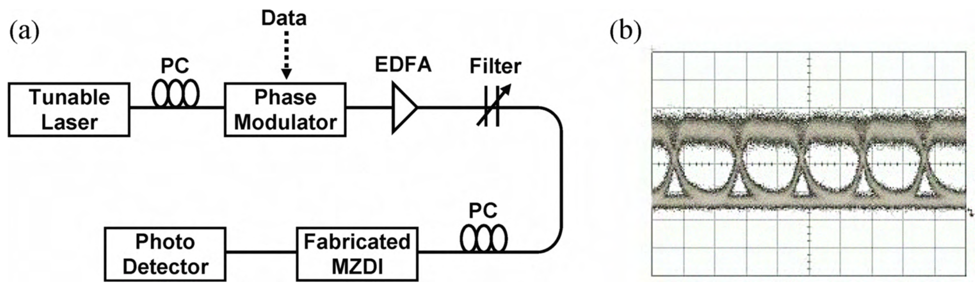

Fig. 3. (a) Experimental setup for DPSK demodulation testing. (b) Measured eye diagram after DPSK demodulation using the proposed MZDI at 10Gb/s.

5. Conclusion

In summary, we demonstrated DPSK demodulation at 10Gb/s using a MZDI on silicon-on-insulator with >20dB extinction ratio of the interference pattern. The MZDI was based on a novel 1X2 splitter/combiner that also served as a grating coupler for coupling light vertically to a single mode fiber. Light was coupled directly from/to cleaved optical fiber with the grating splitter/combiner without additional excess loss. Over 36% coupling efficiency was experimentally measured and the splitting ratio was tunable by adjusting the fiber position. The proposed coupler/splitter/combiner is a promising component for photonic integrated circuits. The device can be easily packaged with cleaved fiber or fiber arrays vertically attached to the wafer surface. The MZDI could be implemented in PIC with potentially low cost packaging techniques. The coupling efficiency is mainly limited by the bi-directionality of the grating diffraction. Further improvement could be achieved by adding a bottom mirror or adjust the waveguide height and etching depth to enhance the directionality.

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6. References

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