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Mach-Zehnder Interferometer Optical Modulator Based on Cascaded P/N Junctions at Forward Bias Operation

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Introduction

Silicon based optical modulator is regarded as a key component for chip level optical interconnection as its intrinsic compatibility with complementary-metal-oxide –semiconductor (CMOS) technology [1]. Light modulation in silicon is achieved by varying the carrier density to change the local index of refraction [2]. To date, there are three configurations that are used to modulate the light 1) carrier injection in forward bias PN junctions, 2) carrier accumulation in metal-oxide semiconductor (MOS) capacitors and 3) carrier depletion in reversed biased PN junctions [2]. We demonstrate MZI modulator with cascaded p/n junctions which are arranged as shown in Fig. 1 along the arms of modulator and operated at forward biased mode.

MZI optical modulator under carrier injection mode offers highest modulation efficiency than carrier depletion mode device. Overlap between optical mode and depletion region is relatively large in carrier injection based device at minimum driving voltages.

Fabrication process

The MZI optical modulator was fabricated on silicon-on-insulator (SOI) wafer. An oxidation layer of 100 nm is formed on the SOI wafer. The SiO_2 layer is then patterned to waveguide form using hard-mask of etching of top silicon layer. After that, p- and n-type regions are formed by electron-beam lithography and ion implantation. The impurities for p and n regions are “boron” and “phosphorus” respectively. The SiO_2 layer is deposited by atmospheric pressure chemical vapor deposition (APCVD) and this layer acts as an insulator as well as upper cladding layer. After that contact holes are formed by silicon dioxide etching. Finally, Al electrodes are fabricated after contact hole wet etching, by the DC magnetron sputtering and H_2+N_2 annealing is carried out. Optical micrograph of our fabricated device is shown in Fig. 2.

Results Discussion and Conclusion

At low voltages less than 1 V the simulated modulation is rather high whereas the experimental one was too small to measure. Also at high voltages larger (>1 V) the experimental modulation is smaller than the simulated one. The reason is not clear but the possible reason is that the current intensity at the center of the waveguide is not strong but flows at the fringes due to the surface defects caused by dry etching. Simulation and experimental optical modulation as a function of applied voltages is shown in Figure 3.

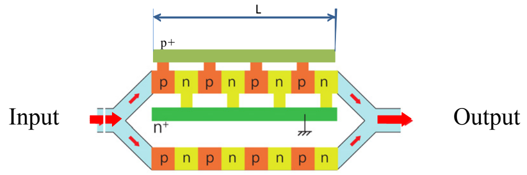

Fig. 1 Structure of Si MZI optical modulator with cascaded p/n junctions

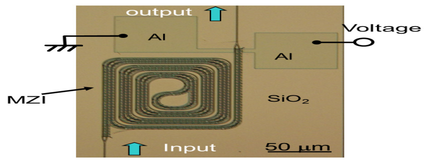

Fig. 2 Optical micrograph of the fabricated MZI (arm length is 5 mm)

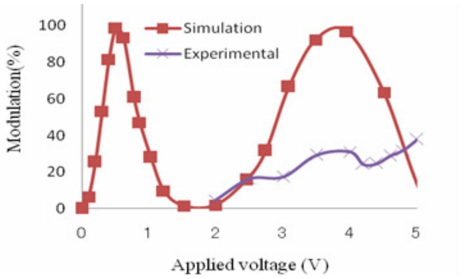

Fig. 3 Modulation versus applied voltage. The length of p and n regions are 0.3µm and N_A=N_D=5.0x10^{18} cm^{-3}.

References

1. Hao Xu *et al.*: OPTICS EXPRESS **20** (2012) 15094.
2. Zhi-Yong Li *et al.*: OPTICS EXPRESS **17** (2009) 15948.