High-speed silicon optical modulator using α-Si:H strip loaded waveguide

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Introduction: Large-scale production with high uniformity and reproducibility is the ultimate barrier for silicon photonic devices to enter the supply chain. Such a problem for high-speed silicon optical modulator is largely determined by the shallowed etched rib waveguide structure which requires etching stopping in the middle of SOI layer. The etching depth cannot be so precisely controlled due to the lack of ending point that even a small fluctuation in the etching depth could induce the deviation of the optical mode from the optimal overlapping position with the depletion layer of the PN diodes and thus induce the performance degradation. In addition, the thickness difference between waveguide core and slab makes it difficult to obtain the uniform doping profile in the PN diodes which is believed important for high modulation efficiency. To deal with this issue, we proposed the silicon modulator using the heterogeneous strip loaded waveguides as the phase shifter and reported the high-efficient SiN-loaded modulator [1]. As another CMOS compatible material, α-Si:H could be also suitable for this purpose. The SiN-loaded modulator show high efficiency due to the large pn overlap, while its speed is around several GHz. In comparison, α-Si:H has a much larger refractive index than SiN so that the pn overlap is smaller which results in not only an enhanced modulation efficiency, but also a high speed. In this study, we demonstrated the α-Si:H strip loaded phase shifter for silicon modulator towards high speed applications. Since α-Si:H photonic wire waveguide has been well established [2], it is basically no barrier in process point of view to fabricate α-Si:H loaded modulator. Because the SOI layer does not experiences any etching, the uniformity and productivity can be improved compared to the conventional shallowed etched modulators.

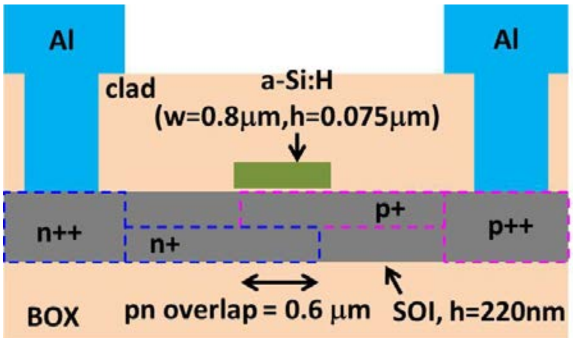

Fig.1. Cross section schematic of the α-Si:H strip-loaded phase shifter for silicon modulator. w: width. h: thickness.

Device structure: The cross section of the α-Si:H loaded phase shifter is shown in Fig. 1. A 75 nm thick α-Si:H is loaded on a flat SOI layer with vertical PN diode structure formed below. This structure features an etchless SOI and a α-Si:H strip. A 10 nm oxide exists between SOI and α-Si:H strip. For fabrication of the phase shifter part, the waveguide is formed by loading α-Si:H to induce a light confinement in the SOI layer below and doping is done prior to forming strip. This waveguide has an effective index of ~2.97.

Device simulation: We performed the device simulation by using commercial opto-electronic environment [3] for the structure in Fig. 1. Both P and N carriers are uniformly doped with a density of $1.0\times10^{18}cm^{-3}$. Highly-doped regions for contact electrodes are located 1-μm apart from the center of the waveguide. Device length is set to 5mm. In this simulation, the pn overlap distance is set to 0.6 μm. As a DC bias of -2.5 V, for this loaded modulator, the $V_\pi L$ and loss are 1 V·cm and 9 dB, respectively, while for the conventional modulator, the typical $V_\pi L$ is about 1.6 ~ 4 V·cm. Thus, the modulation efficiency was improved by at least >1.5 times and this enhancement does not scarify the loss in this α-Si:H loaded phase shifter. The electro-optical response was compared between SiN and α-Si:H strip loaded modulators in Fig. 2. As compared, the α-Si:H strip loaded modulator shows a 3dB bandwidth >20GHz, ~13GHz faster than the SiN loaded one. In summary, this study enables a high-speed strip loaded modulator with efficiency improvement.

References

[1] G.W. Cong, et al., the 63th JSAP Spring Meeting, 2016, 21p-S611-3.
[2] M. Okano et al., in Proc. GFP 2015, paper WH4.
[3] Lumerical Solutions, Inc. DEVICE and MODE.

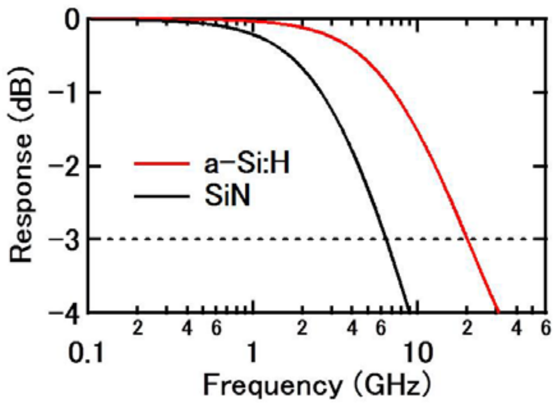

Fig. 2. Comparison of electro-optical response between the α-Si:H and SiN strip-loaded modulators.