High-efficiency silicon optical modulator based on silicon-nitride-loaded SOI waveguide

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Introduction: High-speed optical modulator is one of the most critical components in silicon photonic transceivers. Great efforts have been spent to enhance the modulation efficiency of silicon modulators because high-efficient modulators can bring benefits such as low power and small size. The depletion-type silicon modulator usually adopts silicon rib waveguide structures and various designs were reported with the efficiency ($V_\pi L$) of 1~4 V·cm [1,2]. It is difficult for the modulators of half etched silicon rib waveguides to further improve the efficiency because (1) the overlap between optical mode field and depletion region is small; (2) optimum doping profile cannot be achieved for both slab and rib simultaneously due to the thickness difference. In addition, the mode field is sensitive to the etching depth of silicon so that the deviation in etching depth greatly influences the efficiency. In this study, we propose a novel silicon modulator without half etching to the silicon-on-insulator (SOI) layer, which remains flat as it is without any structures fabricated.

Device structure: The modulator is shown in Fig. 1. A thick silicon nitride (SiN) rib is loaded on a flat SOI layer with vertical PN diode structure. In this device, there is only one time silicon etching to form the silicon channel waveguide. In the modulating part, the waveguide is not formed by conventional silicon rib waveguides, but by a thick SiN rib on the top which automatically induces a light confinement in the SOI layer below. The mode profile is shown as the inset in Fig. 1. The vertical PN junction is formed in the SOI layer with uniform thickness and can increase the overlap between optical field and depletion region. Hence, this SiN-loaded SOI waveguide modulator could have the following merits: (1) Larger overlap between optical field and depletion region. (2) Easier doping profile control and waveguide fabrication because of no sensitive half silicon etching. (3) High uniformity and robustness because the performance has weak dependence on SiN thickness.

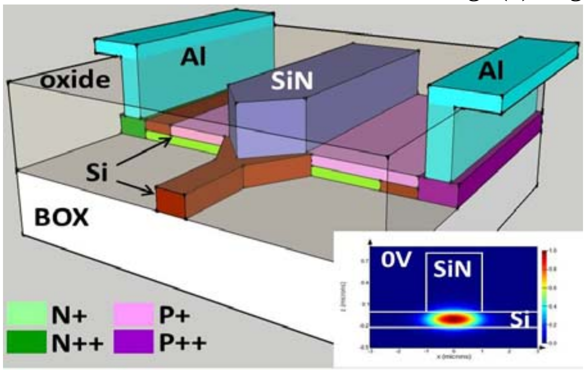

Fig.1. Proposed SiN-loaded silicon modulator. Inset: waveguide mode profile without bias.

Device performance: To verify the performance of the modulator, static opto-electronic simulation has been done for a typical device structure with a 220nm SOI, a SiN rib of 800nm in height and 2μm in width. For the vertical PN junction, both P and N carriers are uniformly doped with a density $1.5\times10^{18}\text{cm}^{-3}$. Highly-doped regions for contact electrodes are located 2.5-μm apart from the center of the waveguide. Device length is set to 5mm. For comparison, a conventional horizontal PN modulator was also simulated under the same condition except for the structure (etching depth of Si set to 110nm). The simulation was performed by using commercial opto-electronic simulation environment [3].

The simulated optical phase shift at 1.55μm in relation of voltage is given in Fig. 2. It can be obviously seen that the proposed new modulator has much larger slope than the conventional one, which indicates higher efficiency. Setting the DC bias to -2.5V, we obtained that V_π equals about 1.2 and 2.7V for the proposed and conventional modulators, respectively. Thus, the $V_\pi L$ of the proposed modulator is only about 0.6V·cm, less than the half of the conventional one (~1.35V·cm). The calculated loss at this bias is about 14dB for the length of 5mm. This simulated V_π for the conventional horizontal PN modulator is comparable to the reported values [2]. This novel modulator could generate a new record figure of merits for depletion-type silicon modulator.

References

[1] M.R. Watts, et al., IEEE J. Sel. Top. Quantum Electron **16**, 159 (2010).
[2] P. Dong, et al., Opt. Express **20**, 6163 (2012).
[3] Lumerical Solutions, Inc. http://www.lumerical.com/tcad-products/device/, and /mode/

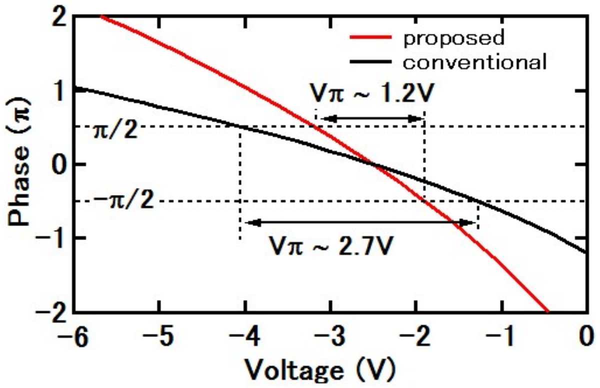

Fig. 2. Comparison of the phase dependence on voltage between conventional and the proposed modulators.