High-speed optical modulation by III-V/Si hybrid MOS optical modulator with low parasitic capacitance.

°Qiang Li[1], Chong Pei Ho[1], Junichi Fujikata[2], Masataka Noguchi[2], Shigeki Takahashi[2]
Kasidit Toprasertpong[1], Shinichi Takagi[1], and Mitsuru Takenaka[1] (1.Univ. Tokyo, 2. PETRA)
E-mail: liqiang@mosfet.t.u-tokyo.ac.jp

【Introduction】 A high-speed Si optical modulator with low energy consumption is central to cloud data centers. Si metal-oxide-semiconductor (MOS) optical modulators are attractive in terms of the balance between modulation efficiency and modulation bandwidth. In our previous study, a high-efficiency III-V/Si hybrid MOS optical modulator, enabled by bonding a thin n-type InGaAsP membrane on a p-type waveguide, was reported [1, 2]. Compared with its Si counterparts, the modulation efficiency was enhanced by a factor of 5–8 with only one tenth optical absorption.

To achieve a high-speed optical modulation, a low resistance-capacitance (RC) constant is crucial. As shown in Fig. 1(a), in the previous demonstration, a 1-µm-wide Si rib waveguide was used for large fabrication tolerance. As a result, the RC constant was increased without benefiting the modulation efficiency. Moreover, a III-V membrane had to lay on Si terraces on the both sides of the Si waveguide to achieve robust wafer bonding, leading to large parasitic capacitances between the III-V membrane and Si terraces. In addition, an electrode was directly contacted with a moderately doped n-type InGaAsP layer, making it difficult to achieve a low contact resistivity. Similarly, the doping density of the Si layer was not high enough to enable a low-resistivity contact.

【Device structure】 In this study, a new design, as shown in Fig. 1(b) was adapted to address the problem of the large RC constant. Firstly, the width of Si rib waveguide was set to 400 nm to better balance modulation bandwidth and efficiency. Secondly, a Si rib waveguide embedded in SiO_2 layer was used. The embedded SiO_2 provided physical support for the III-V membrane, eliminating all the parasitic capacitances. Thirdly, a heavily doped n-type InGaAs/InP layer was inserted under the n-type contact, reducing the contact resistivity. Lastly, the doping densities of n-InGaAsP and p-Si layers were optimized to achieve further reduction in the parasitic resistance.

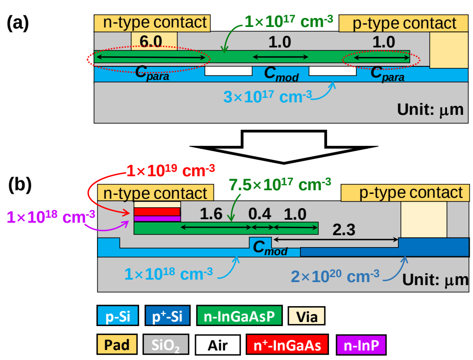

Fig. 1. Cross-sectional schematics of III-V/Si hybrid MOS optical modulators in previous demonstration (a) and this study (b).

【Result and Discussion】 The fabricated MZI optical modulator with 120-µm-long phase shifters, as shown in Fig. 2(a), was characterized near a wavelength of 1310 nm. A $V_{\pi}L$ of 0.37 Vcm was achieved, indicating an EOT of 17.2 nm. As shown in Fig. 2(b), a clear eye pattern was obtained at 12.5 Gbit/s. Figure 2(c) shows a benchmark between data rate and $V_{\pi}L$ among III-V/Si hybrid MOS optical modulators. Thanks to the advanced design and the InGaAsP membrane, we have successfully improved the trade-off relationship between data rate and $V_{\pi}L$ as compared with InP/Si hybrid MOS optical modulator reported in [3]. The measured capacitance was 5–6 times larger than expectation, which was attributed to the over-etching of contact vias. By improving fabrication process, further improvement is attainable as indicated by the red broken line in Fig. 2(c).

【Acknowledgment】 This work was partly commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

[1] J.-H., Han, F. Boeuf, J. Fujikata, S. Takahashi, S. Takagi, and M. Takenaka, Nat. Photon., vol. 11, no. 8, pp. 486–490 (2017).
[2] Q. Li, J.-H., Han, C.P. Ho, S. Takagi, and M. Takenaka, Opt. Express, vol. 26, no. 26, pp. 335003-335012 (2018).
[3] T. Thiessen, P. Grosse, J. Da Fonseca, P. Billondeau, B. Szelag, C. Jany, and S. Menezo, Opt. Express, vol. 27, no. 1, pp. 102-109 (2019).

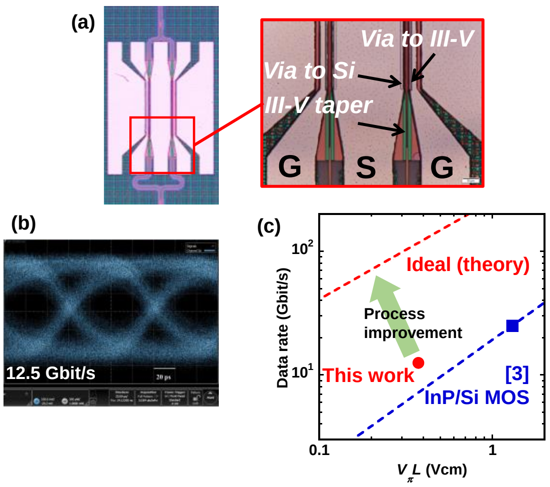

Fig. 2 (a) Microscope images of fabricated III-V/Si hybrid MOS optical modulator, (b) measured eye pattern at 12.5 Gbit/s, and (c) relationship between modulation efficiency and data rate.