Optimization of modulation efficiency of InGaAsP/Si hybrid MOS optical modulator

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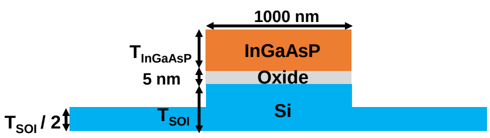
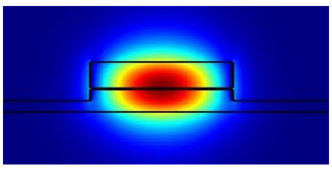
【Introduction】Si optical modulators suffer from low modulation efficiency and high absorption loss. To improve the modulation efficiency, we have proposed to use an InGaAsP/Si hybrid metal-oxide-semiconductor (MOS) structure for a phase shifter by using direct wafer bonding [1]. Owing to the large electron-induced refractive index change in InGaAsP, we have successfully demonstrated extremely high modulation efficiency of approximately 0.05 Vcm [2]. In this study, we conducted the optimization of the device structure to further improve the modulation efficiency through increasing the overlap between the optical mode and accumulated electrons at the InGaAsP MOS interface.

【Device structure】Figure 1(a) shows a cross-sectional schematic of the InGaAsP/Si hybrid MOS phase shifter. An n-type InGaAsP layer is bonded on a p-type Si waveguide using wafer bonding. The fundamental TE mode is shown in Fig. 1(b). When the gate bias is applied between the InGaAsP and Si layers, electrons accumulate at the InGaAsP MOS interface which modulate the refractive index. The thicknesses of the InGaAsP and Si layers are optimized to achieve high modulation efficiency.



(a)



(b)

Fig. 1 (a) Cross-sectional schematic of InGaAsP/Si hybrid optical modulator and (b) 2D field distribution of TE mode.

【Result and Discussion】Figure 2 shows the phase modulation efficiency $V_\pi L$ as a function of the ratio of the InGaAsP and Si thicknesses. The total thickness of the InGaAsP and Si layers was fixed to be 220 nm. When the ratio reached 1.2, the mode shifted toward the center of the waveguide, resulting in increasing the mode overlap to the accumulated electrons, and therefore the highest modulation efficiency of 0.038 Vcm was achieved.

Figure 3 presents the phase shift and absorption as a function of gate voltage. Through the optimization of the InGaAsP and Si thicknesses, the $V_\pi L$ was improved to 0.038Vcm from previously unoptimized $V_\pi L$ of 0.055 Vcm while the optical loss at π phase shift was only increased by 0.02 dB/mm compared with the unoptimized case, benefiting from the low optical absorption in InGaAsP. This study demonstrated the great potential of InGaAsP/Si hybrid MOS optical modulator.

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[1] J. Han, M. Takenaka, and S. Takagi, *International Conference on Group IV Photonics (GFP)*, ThP16, 2016.
[2] J. H. Han, M. Takenaka and S. Takagi, *IEEE International Electron Devices Meeting (IEDM)*, 25.5, 2016.

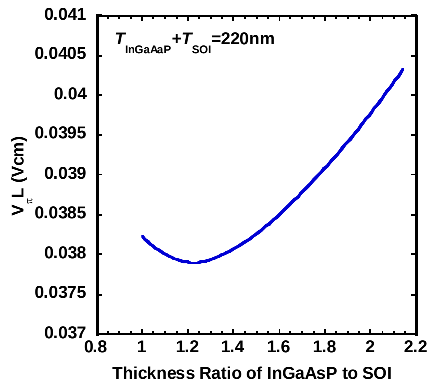

Fig. 2. The phase modulation efficiency $V_\pi L$ with the thickness ratio of InGaAsP to SOI.

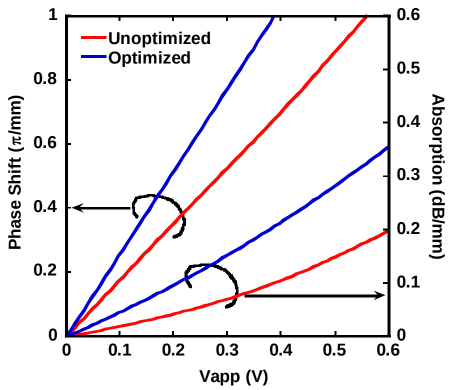

Fig. 3. The phase shift and absorption as a function of gate voltage.