Investigation of impact of InGaAsP quantum well on the modulation efficiency of III-V/Si hybrid MOS optical modulator

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Introduction: Si photonic circuits have been scaled up very rapidly in the past decade to meet the strong demand of data traffic. One of the key building blocks is an efficient optical phase shifter. Recently we have demonstrated an efficient low-loss optical phase modulator based on III-V/Si hybrid MOS capacitor where an InGaAsP (λ_g=1.37 μm) bulk was used [1]. The measured voltage-length product ($V_\pi L$) in the reported InGaAsP/Si hybrid modulator, was as low as 0.047 V·cm. To achieve further improvement in the modulation efficiency, narrower bandgap InGaAsP is preferable because of its lighter electron effective mass which enhances the plasma dispersion effect and band-filling effect [2], while the optical absorption increases simultaneously. To achieve greater electron-induced refractive index change and smaller optical absorption, we can use a quantum well (QW) structure. Here, we report a numerical analysis of the impact of InGaAsP QW on the modulation efficiency.

Device structure and performance: Fig. 1 shows the cross-sectional schematic of III-V/Si hybrid MOS optical modulator with an InGaAsP QW at the MOS interface. We assume an InP layer as the barrier of QW. For bulk InGaAsP, its bandgap should be at least 0.88 eV to avoid much absorption at a 1.55 μm wavelength [3], which limits the composition below Q1.41. Thanks to the quantum confinement energy in QW, we could use even narrower bandgap InGaAsP. Moreover, the band-filling effect would be enhanced in QW as the electron density of states is reduced, where we could expect better modulation efficiency in QW than in bulk, as shown in Fig. 2. However, the QW should be thick enough to assure enough overlap with the optical field. By taking into account these preconditions, we adopt a 15nm-thick InGaAsP (Q1.49) QW, which exhibits the electron-induced change in refractive index as shown in Fig. 2. Fig. 3 shows $V_\pi L$ as a function of the phase shifter length. We could see that the QW phase shifter shows a higher modulation efficiency than the bulk ones when the phase shifter length exceeds 500μm, where a relatively low electron density is employed at π-phase shift. The estimated $V_\pi L$ could be as low as 0.04 V·cm in a 1mm-long device. By introducing the QW into a III-V/Si hybrid MOS optical modulator, the modulation efficiency can be improved by more than 20%.

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References

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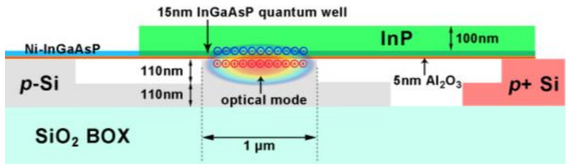

Fig. 1. Device structure of the proposed III-V/Si hybrid MOS optical modulator with an InGaAsP QW.

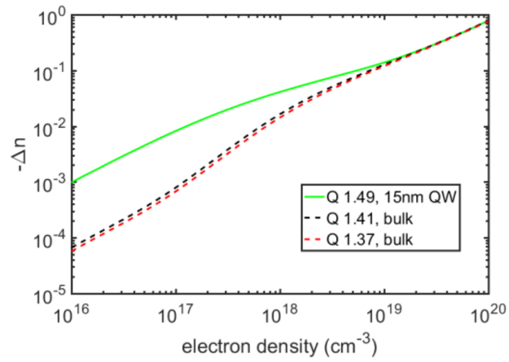

Fig. 2. Electron-induced refractive index change in InGaAsP bulk and QW.

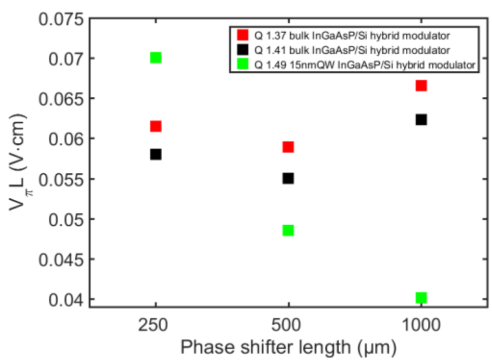

Fig. 3. $V_\pi L$ of III-V/Si hybrid MOS optical modulators with InGaAsP bulk and QW.