Impact of gate oxide thickness on modulation properties of graphene/III-V hybrid MOS optical modulator

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Introduction To satisfy the strong demand for datacenter traffic, designing an optical modulator with high efficiency, low loss, and acceptable modulation bandwidth is indispensable. Based on metal-oxide-semiconductor (MOS) optical modulators, attempts on integrating alternative materials beside conventional Si had been reported for the past few years. Our previous study revealed that with the combination of using graphene-based device at mid-infrared wavelength [1] and enhancing the phase shift contribution from waveguide materials such as III-V semiconductors [2, 3], the modulation efficiency up to $V_\pi L$ = 0.056 V·cm was expected while maintaining acceptable optical loss.

In this paper, we examine the impact of the gate oxide thickness on the modulation properties such as insertion loss and efficiency of the proposed graphene/III-V hybrid MOS optical modulator. We predict that the overall capacitance can be reduced by using a thick gate oxide while keeping the acceptable modulation efficiency because of the dominant contribution of the III-V waveguide on the phase modulation, possessing great potential in high-speed operation application.

Device structure Fig. 1 shows the optical modulator structure, with a graphene layer on a 220-nm-thick n-type $In_{0.53}Ga_{0.47}As$ rib waveguide fabricated on the III-V CMOS photonics platform. The width and height of the InGaAsP rib are 600 nm and 160 nm respectively, to ensure the single-mode operation for transverse-electric (TE) mode at a 2 μm wavelength. The donor concentration of InGaAs is assumed to be 1×10^{16} cm^{-3}. Here, the gate oxide (SiO_2) thickness of the MOS structure is varied from 5 to 1000 nm.

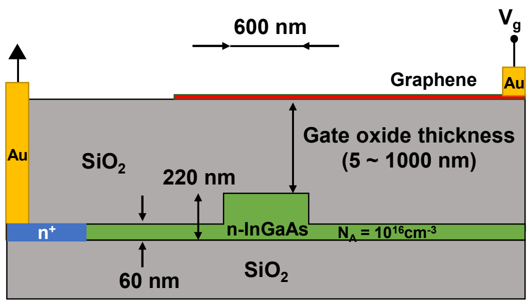

Fig. 1. Cross-sectional schematic of graphene/III-V hybrid MOS optical modulator.

Result and Discussion We revealed that the graphene/InGaAs hybrid MOS modulator exhibits approximately 3.5 times improvement in efficiency than the graphene/Si device in [3] when the gate oxide thickness is 5 nm. Fig. 2 shows the optical absorption of the graphene/InGaAs hybrid MOS optical modulator with varied gate oxide thicknesses. When the gate oxide thickness increases, the impact of graphene on the absorption decreases, and the absorption is no longer dependent to the gate voltage. The same trend can be observed for the phase shift shown in Fig. 3. When the gate oxide is thick, the phase shift is only induced by the free-electron effect in InGaAs. When the gate oxide thickness is 750 nm, the absorption is as low as 10^{-1} dB/mm while $V_\pi L$ is 6.2 V·cm. Even with the thick gate oxide, the modulation efficiency is still comparable to that of the carrier-depletion Si optical modulators.

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[1] Y. Yamaguchi et al. Jpn. J. Appl. Phys., vol. 57 no. 4S, 04FH06 (2018).
[2] J.-H., Han, F. Boeuf, J. Fujikata, S. Takahashi, S. Takagi, and M. Takenaka, Nat. Photon., vol. 11, no. 8, pp. 486–490 (2017).
[3] T. Piyapatarakul, H. Tang, K. Toprasertpong, S. Takagi and M. Takenaka, in Int. Conf. Solid State Device and Materials (2021).

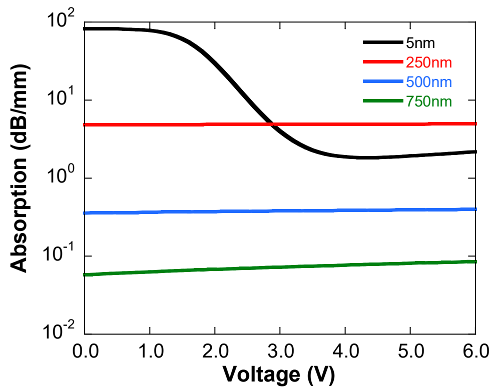

Fig. 2 Optical absorption as a function of gate voltage with varied gate oxide thicknesses.

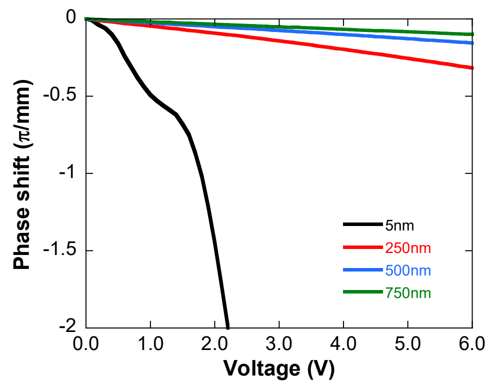

Fig. 3 Phase shift as a function of gate voltage with varied gate oxide thicknesses.