Dual single layer graphene Mach-Zehnder modulator with high efficiency and gigahertz bandwidth.

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Mach-Zehnder modulators (MZMs) play an important role in enabling high-speed and high-capacity optical communication systems as they could be implemented to generate complex modulation formats [1]. Due to the relatively poor phase modulation efficiency ($V_{\pi}L$), Si-based MZMs typically require a millimeter length to accumulate a π-phase shift with a conventional CMOS driving voltage (< 2V), which impedes the development of high-density integrated circuits. Additionally, the longer device length results in a greater capacitance and, consequently, a greater power consumption. To address this issue, graphene-based phase modulators have been proposed and simulated to be an excellent choice. Along with its inherent high mobility, they are anticipated to have a large bandwidth and high efficiency [1, 2]. In this work, we experimentally show dual single layer graphene (DLG)-based high-efficiency MZMs with gigahertz bandwidth. We investigate DLG MZMs on two types of waveguides, where "MZM-STRIP-DLG" and "MZM-SLOT-DLG" refer to the strip and slot waveguides based DLG MZM, respectively. Fig. 1a and 1b depict the top-down perspective and DC performance of a MZM-SLOT-DLG. The effective index change (ΔN_{eff}) can be calculated from the shift of interference fringes and is depicted in Fig. 1c. Due to the enhanced mode confinement by using slot waveguides, the MZM-SLOT-DLG exhibits a better modulation efficiency (0.79 Vmm), compared to the MZM-STRIP-DLG (0.95 Vmm). Both values outperform literature's state-of-the-art graphene (2.8 Vmm) [2] and silicon-insulator-silicon (2 to 7 Vmm) [3] based MZMs. Lastly, as shown in Fig. 1d, gigahertz electro-optic bandwidth has been confirmed in MZM-STRIP-DLG (4 GHz) and MZM-SLOT-DLG (6 GHz), proving the high speed of the devices.

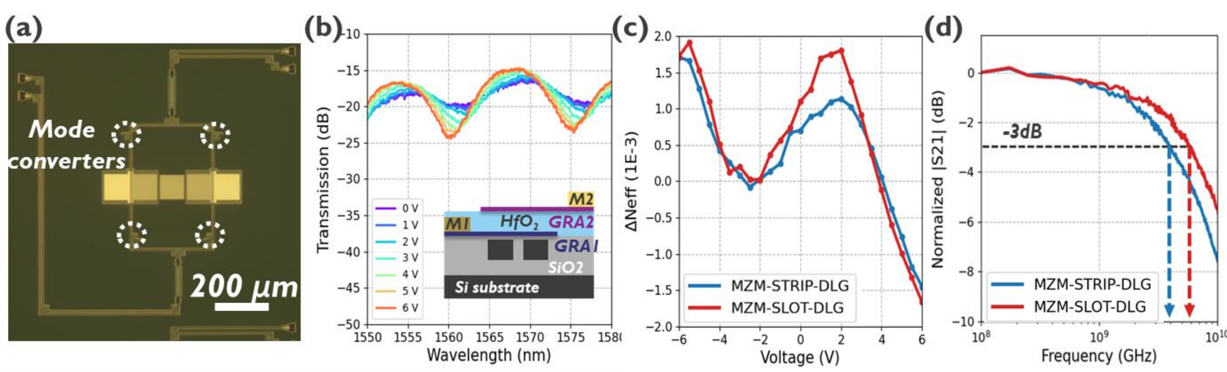

Fig. 1 (a) Top-down microscope image and (b) transmission under different bias conditions of MZM-SLOT-DLG. (c) Calculated ΔNeff as a function of applied bias and (d) frequency response on both MZMs.

References: [1] M. Romagnoli, A. C. Ferrari et al., Nat. Rev. Mater. 3, 392 (2018). [2] V. Sorianello, M. Romagnoli et al., Nat. Photon 12, 40 (2018). [3] A. Abraham, L. Vivien et al., GFP (2014).

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