Hybrid Graphene-WS_2 Mach-Zehnder modulator on passive silicon waveguide

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2D materials such as graphene have attracted a lot of interest in recent years because of their unique electrical and optical properties [1-3]. For example, a graphene Mach-Zehnder modulator (MZM) with 2.8Vmm modulation efficiency and 5GHz bandwidth has been demonstrated in the literature [2]. However, one of the challenges for current graphene MZM is graphene's relatively high insertion loss. Potential solutions have been proposed, such as engineeringly improving the quality of graphene or operating the device under graphene's transparency region [4]. Recently, transition metal dichalcogenides (TMDC) have shown a strong electro-refraction effect in the C band, accompanied by a limited loss increase [3], which is promising for high efficiency, low loss Mach-Zehnder modulators and switches.

In this work, we demonstrate a MZM that consists of a WS_2-oxide-graphene stack integrated on a silicon waveguide. The device cross-section is shown in Fig. 1a. First, the silicon waveguides are patterned on an SOI substrate with 220nm silicon and 2µm buried oxide, fabricated in a CMOS semiconductor fab. The waveguides are then embedded in oxide, with 10nm thermal oxide on top of the Si waveguides. After oxide planarization, the wafers are cleaved in pieces for WS_2 transfer and patterning. Next, 30nm aluminum oxide is deposited by ALD to serve as the gate oxide. After that, graphene is transferred on top of the AlO_x layer by an electro-chemical method and patterned. Finally, a nickel side contact to the WS_2 layer and a palladium top contact with the graphene layer are defined. The fabricated MZM has WS_2-oxide-graphene active areas in both arms, with length varying from 100µm to 500µm. A top-down microscope image of a fabricated device is shown in Fig. 1b.

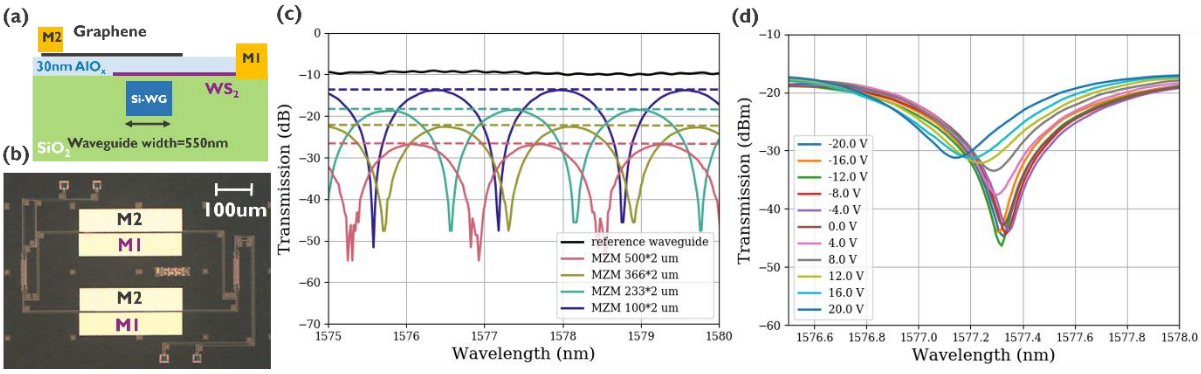

Fig. 1 (a) Schematic of the hybrid WS2/Graphene modulator on passive silicon waveguide. (b) Top-down microscope image of fabricated MZM device with 233um phase shifters and 550nm waveguide width. (c) Transmission of unbiased C band TE mode MZM with active lengths varying from 100 to 500um. The dashed lines in the picture are used to calculate the devices' insertion loss relative to the reference waveguide (black line). (d) Transmission of the C band TE mode MZM with 233um phase shifter under different bias conditions.

From the transmission measurements of unbiased devices (Fig. 1b), we can clearly observe the interference fringes due to the length difference between the MZM arms (Fig. 1c). The FSR is 1.6nm. From comparing the peak transmission (the dash lines in Fig. 1c) with a reference waveguide, a propagation loss of ~160dB/cm is extracted for our 2D-MOS phase shifter with a 550nm wide Si waveguide. The electro-optic response of the MZM with 233um-long phase shifters is plotted in Fig. 1d. The $V\pi L$ is calculated to be ~1.5Vcm with 6.8dB as the device total insertion loss at 12V, excluding the loss of the grating couplers. This work paves the way to the realization of hybrid 2D material MZM on the silicon platform.

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