Sang Hoon Chae*
Ipshita Datta*, Gaurang R. Bhatt, Mohammad A. Tadayon, Bichang Li, Yiling Yu, Chibeom Park, Jiwoong Park, Linyou Cao, Dmitri N. Basov, James Hone, and Michal Lipson
Department of Mechanical Engineering, Columbia University, New York, New York 10027, USA
sc4190@columbia.edu

Ultra-low Loss Electro-refractive Modulation of Monolayer WS_2 Embedded in Photonic Structures

Integrated Electro-Optic Phase modulators play a vital role in the field of dynamic switching, network reconfiguration, phased arrays and optical communication. The need of the hour is to demonstrate efficient low power, high-speed integrated phase shifters, where the index modulation is significant, but with minimal absorption. In traditional accumulation and depletion based silicon modulators, the measured $V_\pi L$ is in the range 1.2 - 3.5 V cm with the doping absorption loss of about 5 - 10 dB/cm. The recently demonstrated graphene on silicon capacitive modulators have a very low $V_\pi L$ of 0.28 V · cm, but come at the expense of a very high absorption loss of 236 dB/cm. The metal-oxide-semiconductor based capacitive devices on silicon on insulator platform similarly have low $V_\pi L$, but have a very high modulation loss of 50 - 60 dB/cm.

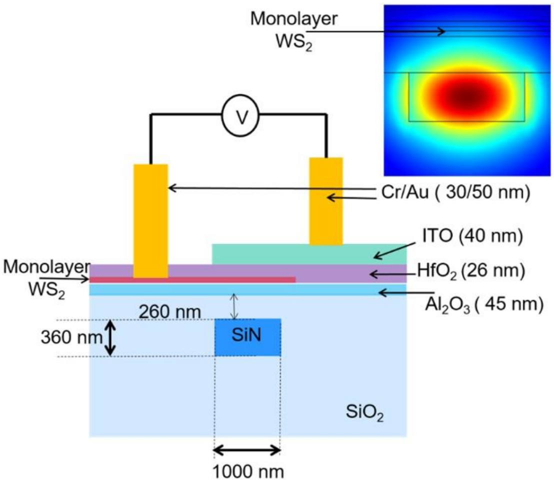
2D materials such as monolayer transition-metal dichalcogenides (TMD) have been predicted to experience massive changes in optical response with carrier densities [1]. This can overcome the limitation of today's integrated photonics by providing electro-optic properties to traditionally passive optical materials. Recently discovered TMDs are atomically thin semiconductors with unique electrical and optical properties [2]. These materials enable strong light–matter coupling, with optical absorption around 10–20% in layers as thin as 0.6 nm [3] at visible wavelengths and extremely efficient Coulomb interactions, as manifested in the exciton binding energies on the order of 0.5 eV [1] [4].

Here, we show a platform independent, integrable phase modulator designed to endow electro-optic properties to optically passive materials. We demonstrate the electrostatic doping of monolayer WS_2 integrated on a Si_3N_4 photonic structure by embedding a WS_2–HfO_2–ITO capacitor on nitride waveguide. We measure a $V_\pi L$ of 1.33 V · cm with an absorption modulation of 0.004 dB/cm for a mode overlap of 0.2 % between the waveguide and monolayer WS_2. The extracted change in the optical sheet conductivity of the monolayer WS_2 is about (63 ± 4) % with an electrostatic doping of $2.8 \pm 0.2 \times 10^{13}$ / cm^2. By designing photonic structures, where the monolayer WS_2 overlaps more with the optical mode, the TMD/photonic structure can open up avenues to explore low power efficient phase modulators, with minimal absorption.

References

[1] Steinhoff, A.et al, Influence excited carriers on the optical and electronic properties of MoS2. Nano Lett. 14, (2014).
[2] Li, Y. et al. Measurement of the optical dielectric function of monolayer transition-metal dichalcogenides: MoS2 , MoSe2 , WS2 , and WSe2. Phys. Rev. B 90 (2014).
[3] He, K. et al. Tightly bound excitons in monolayer WSe2. Phys. Rev. Lett. 113, 026803 (2014).
[4] Chernikov, A. et al. Population inversion and giant bandgap renormalization in atomically thin WS2 layers. Nat. Photonics 9, 466-470 (2015).

Figures



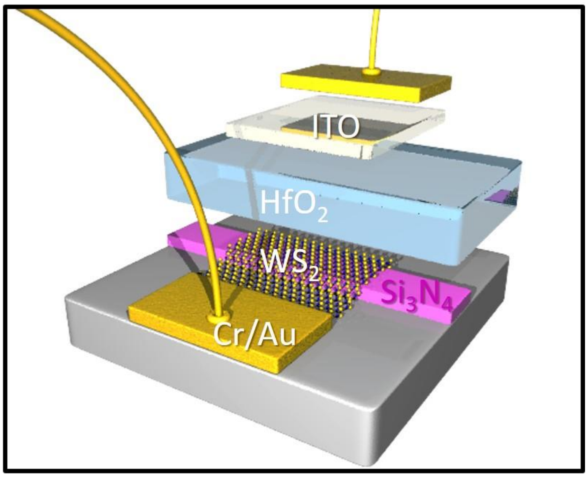


Figure 1: Schematic of monolayer WS2 phase modulator