A Performance Comparison of ITO and Graphene-based Electro-optic Modulators

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Electro-optic modulators (EOMs) are used to change the amplitude and/or phase of the incident light beam by altering the optical properties of a material with an applied voltage. Even though silicon-based EOMs have been demonstrated experimentally, future chip-based optical communication and signal processing technologies require EOMs with a high modulation depth, compact footprint, large bandwidth, low power consumption and cost. In this direction, indium tin oxide (ITO) and graphene have attracted significant attention primarily due to their extraordinary electro-optic properties for the design of such high-performance EOMs.

Our recent studies show that enhanced optical mode confinement and light-matter interaction can be achieved by deploying a plasmonic metal-oxide semiconductor type optical hybrid-plasmon-polariton mode, which concentrates part of the propagating mode's field into a nanometer-thin region overlapping with the actively index-modulated material resulting in a compact, modulation-enhanced EOM design. The main advantages of combining a dielectric waveguide mode with a surface plasmon mode are strong sub-wavelength confinement and long propagation distances.

Another important parameter is the optical active (i.e. voltage bias-switched) material selection. Emerging materials with high-modulation capability have been proposed and demonstrated for EO applications, such as ITO and graphene. In this work, we compare performances of ITO and graphene based EOMs integrated into a silicon-on-insulator waveguide platform. Table I summarizes our findings, which will be discussed in details at the conference. Briefly, low insertion losses of 0.03 and 0.06 dB and energy per bit rates of 0.23 and 0.17 fJ are possible with ITO and graphene based EOMs, respectively.

TABLE I
QUANTITATIVE PERFORMANCE ANALYSIS

	ITO		Graphene	
	Signal	Speed	Signal	Speed
Device Length (μm)	2	0.5	2	0.5
Resistance (Ohm)	50 – 500		50 – 500	
Capacitance (fF)	0.94	0.23	2.64	0.66
Bandwidth (THz)	21.2 – 2.1	84 – 8.4	7.5 – 0.7	30.2 – 3.0
Insertion Loss (dB)	0.60	0.15	2.12	0.53
Extinction Ratio (dB)	12	3	18	4
Voltage (Volts)	2-3	2-3	1-2	1-2
Energy per bit (fJ)	1.88 – 4.25	0.47 – 1.06	1.32 – 5.29	0.33 – 1.32

Device is operating at the wavelength of 1.55 μm. The gate oxide thickness and width vary from 5 to 50 nm and 200 to 500 nm respectively. The bandwidth (BW) is calculated from BW=1/RC where R has values from 50 to 500 Ohm. Energy per bit (E/bit) is calculated by E/bit = $\frac{1}{2}CV^2$, where applied voltage is 1 to 2 V and 2 to 3 V for graphene and ITO respectively.