Graphene Phase Modulators for Optical Communications

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Graphene in photonic integrated circuits is a material that can be operated both in electro-absorption and in the electro-refraction regime. These two regimes depend on the amount of carrier doping of the material. Interestingly in the electro-refractive regime the main effect is a change of index of refraction with minimum contribution of the absorption counterpart. This property indicates that graphene can be used as phase modulator also for complex modulation formats. In terms of electrical properties graphene shows an electrical mobility dependent on carrier density largely superior than Si, InP and InGaAs and this property may influence the transparency in high doping regime. The combination of efficient electro-refractive effect and possible low absorption due to the high carrier mobility makes graphene a good candidate for good figure of merit phase modulators of potential importance for optical communications.

In the electro-absorption regime graphene shows simultaneous occurrence of absorption and phase change. This property, negligible for short reach interconnects, plays a role in fiber transmission for the chirp contribution. Electro absorption and electro refraction regimes can be independently selected on the base of the bias applied to graphene. For comparison in plasma dispersion effect, commonly used in Si Photonics, the electrically induced change in the carrier concentration provides a simultaneous change in material absorption and refractive index proportional to the carrier density. Absorption and refraction effects in plasma dispersion based devices cannot be separated. The same holds for Franz–Keldysh effect and the quantum confined Stark effect (QCSE) that are alternative mechanisms used in Ge p-i-n or III-V quantum wells. In addition in these cases the effect is limited to the spectral band near the semiconductor band edge. As for plasma-dispersion-based devices, even in this case insertion loss due to carriers must be traded off with a large extinction ratio. The unique property of bias-induced separation of electro-absorption and electro-refractive modulation, along with the wavelength independence of graphene, makes this material suitable for any modulation scheme.

The cross section of the single layer graphene modulator is illustrated in the scheme of Fig.1. The Si photonic ridge waveguide can be realized in SOI, SiN or even silica platforms with no need of dopings as for Si photonics or InGaAsP modulators. Graphene layers are grown by chemical vapor deposition (CVD) on copper foil and then transferred on the waveguide. Phase modulation has been demonstrated with a Mach Zehnder modulator with graphene phase shifters on the two arms. With this modulator a modulation efficiency as small as $V_\pi L$~0.28Vcm has been demonstrated, about 10 times better than charge depletion silicon modulators. This Mach Zehnder modulator has been successfully tested at 10Gb/s for a transmission on a 50km single-mode fiber link.[1] Graphene used as electro absorption modulator was realized on the same SOI waveguides. In this case graphene permitted the modulation of absorption to encode a 10Gb/s signal resulting in the modulation of the complex index of refration of graphene (absorption and refraction). The index variation added a positive chirp to the amplitude modulated signal that permitted an unprecedented transmission on a 100km long SMF optical link.[2]

References

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