Graphene Integrated Photonics for Next Generation Optical Communications

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Abstract

Datacom and Telecom are continuously evolving in terms of bandwidth, consumption and cost. The general request is bandwith increase with no change or even reduction of overall consumption and cost. According to the Ethernet roadmap the bandwidth doubles every two years [1]. The actual candidate technology for large volume and low cost is Si Photonics [2]. With Si Photonics it is possible to realize electro-refractive modulators and Ge based detectors exceeding 56Gb/s bandwidth in a single channel and at 28Gb/s this is already a product [3]. This technology has been widely studied and, for large volumes and for bandwidth of 28Gb/s or more is competitive with respect to III-V technologies or discrete photonic micro assemblies. However the Datacom roadmap requires cost /performance continuous improvements and technological limits may limit the scalability of the existing technologies.
Graphene offers electro-absortption [4] and electro-refraction [5] effect for modulators and thermo-electric effect for the detection [6]. Graphene layers can be transferred on waveguides in the post-processing phase, the supporting waveguide has very limited requirements because no dopants are required for operating the devices. Silica, Si, or even polymer waveguides are all devisable because active functionalities will depend on the post-processed graphene layers. Graphene based photonics is proven by design on the base of material models verified by characterizations.[7] From theory graphene photonics can be competitive with respect to Si Photonics but experimental verifications have to confirm this claim. Even though modulators and detectors have been proven, a new generation of designs is required to improve further performances. One issue is that graphene modulators are limited by the electron mobility of the transferred graphene. In order to increase mobility graphene has to be encapsulated with a barrier material that decouples graphene from the external materials. h-BN encapsulation can maintain mobility as large as 10^4 $m^2/(Vs)$. Lack of large mobility induces both insertion loss and dynamic range reduction in the modulator, increase of resistivity in the contacts and in the graphene fingers from the active region to the electrode. [8]
Graphene electro-optical properties are also interestingly independent of the wavelength. In comparison Si Photonics is limited in the spectral range to 1600nm in which Ge detectors can absorb and to Si absorption edge at 1100nm on the other hand. In fact Si Potonics is mainly used for the O (1265 – 1390nm) and C (1530 – 1560nm) band of the telecom windows. Graphene spectral range can be easily extended from visible through 2000nm and beyond. This offers a great advantage in terms of power consumption because a course wavelength separation in a very wide range allows many channels operating in uncooled systems with no thermal control.
Graphene fabrication on a large area is another important topic that would allow wafer scale manufacturing. Presently CVD graphene transfer from Cu substrate on the final wafer ensures best performance in terms of uniformity and electron mobility even though the method requires further developments to increase reproducibility and stability. Other alternative methods are considered but presently those are not mature yet.
In this presentation all aspects of graphene technology and photonics devices for Datacom applications will be reviewed with focus on feasibility and compliance with existing technologies.

References

[1] J. D'Ambrosia, S. G. Kipp, 'The 2015 Ethernet Roadmap', www.ethernetalliance.org
[2] Y. Arakawa et al. "Silicon Photonics for Next Generation System Integration Platform', IEEE Communications Mag., p.72, March 2013.
[3] Cisco CPAK for 100-Gbps Solutions, www.cisco.com.
[4] Liu, M., X. Yin, X. Zhang, 'Double-layer graphene optical modulator', Nano Lett. **12,** 1482 (2012).
[5] M. Mohsin, D. Neumaier, D. Schall, M. Otto, C. Matheisen, A. L. Giesecke, A. A. Sagade, H. Kurz, 'Experimental verification of electro-refractive phase modulation in graphene', Scientific Reports **5**, 10967 (2015);

[6] R. J. Shiue, Y Gao, Y. Wang, C. Peng, A. D. Robertson, D. K. Efetov, S. Assefa, F. H. L. Koppens, J. Hone, D. Englund, 'High-Responsivity Graphene–Boron Nitride Photodetector and Autocorrelator in a Silicon Photonic Integrated Circuit', Nano Lett, (September 2015)
[7] Y.-C. Chang, C.-H. Liu, C.-H. Liu, Z. Zhong, and T. B. Norris, "Extracting the complex optical conductivity of
mono- and bilayer Graphene by ellipsometry," Appl. Phys. Lett. 104(26), 261909 (2014)
[8] V. Sorianello, M. Midrio, M. Romagnoli, 'Design Optimization of Single and Double Layer graphene Phase Modulators in SOI', Opt. Expr. **23**, 6478 (2015)