Graphene Photonics for High Data Rate Modulators and Detectors

Marco Romagnoli
Consorzio Nazionale Interuniversitario per le Telecomunicazioni, via Moruzzi 1, Pisa, Italy
Contact: marco.romagnoli@cnit.it

Integrated photonics is an established technology that combines high performances, miniaturization, low cost and in some application large volume manufacturing. Si Photonics and III-V compound semiconductor are the two platforms for transmitters and receivers in both telecommunication systems (few tens km to thousands km) and in short reach links in data centers (from few meters to 2km). Both systems operate in the NIR (1280nm – 1310nm and 1525nm – 1560nm) spectral regions with the III-V technology providing in a single platform modulators, detector and light source whereas in Si Photonics with external light source or hybridized even though hybridization on the waveguides is a process not established yet. In Si photonics both SOI Mach-Zehnder modulators and SiGe Franz-Keldysh modulators along with Ge p-i-n photodetector are already used in products. Graphene is a more recently discovered material and it is studied for light modulation and detection. Graphene can be integrated on any type of waveguide (Si, SiN, SiO2, etc.) and, being gapless, can easily work at any wavelength. Contrary to Silicon Photonics modulators graphene does not need implantations because the doping concentration is obtained with a bias voltage. Moreover the advantage of graphene in modulators is also the large electrooptic efficiency which permits, if integrated on Si Photonics passive waveguides, an improved miniaturization which matches the requirements for very high speed interfaces.
Graphene-based photodetectors removes the need the Ge epitaxy, replacing the Ge p-i-n photodetectors used in Si Photonics with a single or double layer graphene. Graphene photodetectors are not spectrally limited, unlike Ge p-i-n photodetector, that operate below ~1,600 nm. Graphene-based photodetectors can reach, in principle, EO bandwidths >>100 GHz, as a consequence of the high carrier mobility of the material and ultrashort decay time of the hot carriers. Finally graphene photothermal effect detectors generate a voltage rather than a current and this eliminates dark currents.
From fabrication point of view, graphene photonics is post processed on passive waveguides. Graphene Photonics can be realized on SOI but also on SiN or silica waveguides that being wider than Si nanowires uses more relaxed litho nodes. All these factors contribute to simplification of the technology and cost reduction. Graphene photonics is compatible with CMOS fabrications and thanks to this compatibility is suitable for Si foundries.
Today many concept demonstrations of graphene photonics modulators and detectors have shown a good level of comprehension and a reasonable technological maturity has been achieved. Beyond this step the next challenge is the reliable wafer scale engineering of the four key aspects that can feel the gap with competition technologies. The aspects to be optimized are: 1 – growth of single layer graphene with high carrier mobility, 2 – transfer of graphene without deterioration of the mobility values, 3 – graphene layer integration in a full fabrication process flow, and finally 4 - low contact resistance.
A more extensive discussion on the perspective of Graphene Photonics can be found in ref.[1].

Reference

[1] Romagnoli M., Sorianello V., Midrio M., Koppens F.H.L., Huyghebaert C, Neumaier D., Galli P., Templ W., D'Errico A., Ferrari A.C, Nat Rev Mater. 3 (2018), 392.