PhD THESIS DEFENSE: Graphene based optical interconnects and IR photodetectors

HITESH AGARWAL

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Despite the extensive research in the semiconductor industry, Moore's law is finally slowing down due to increased complexity. Hence, intense efforts are being carried out to explore hybrid solutions by adding additional functionalities to the existing silicon plat- form to keep up with the growing demand. It is colloquially called as 'Beyond Moore' phase. This thesis is a humble attempt to propose graphene, a single atomic sheet of carbon, as an excellent candidate for the 'Beyond Moore' phase optoelectronic applications. In particular, we demonstrate graphene-based optical interconnects: photodetectors and modulators for data communication applications and broadband infrared sensors for hyperspectral space astronomy.
Graphene has the highest room temperature mobility known to us, is complementary

metal-oxide semiconductor (CMOS) compatible, and has rich electronic and optoelectronic properties. In the first part of this thesis, we used graphene as an active element with a passive silicon waveguide platform to demonstrate electro-absorption modulators and photodetectors. We developed a novel dielectric combination by integrating 2D material with 3D oxides, which enabled us to build a high-quality clean interface with graphene and high-? properties. This helped us to overcome fundamental limitations and demonstrate a high modulation efficiency (? 2.2 dB/V) and high speed (39 GHz) in the same device, surpassing other CMOS-based modulators. In the case of the photodetector, we demonstrated a photo thermoelectric effect (PTE) based detector with high responsivity (55 mA/W) and a set up limited bandwidth of 40 GHz.
In the second part of the thesis, we address the perpetual issue of limited light absorption in graphene by demonstrating the first 3D photoconductor based on decoupled bilayer graphene layers with 2D-like properties. Due to the asymmetric environment experienced by our decoupled bilayer graphene layers, they perceive a strong internal crystal field, which results in an intrinsic bandgap opening. We exploited this bandgap to observe a giant photoconductive photoresponse in a broad wavelength range from 2 to 150 ?m. This is the first reported alternative to slow and expensive thermal detectors for broadband operation and could be instrumental for hyperspectral imaging and infrared astronomy, bringing us one step closer to unveiling the secrets of the universe. Finally, we reported a strong photoresponse in the out-of-equilibrium criticality state in graphene superlattices at high bias. We found that the criticality state shifts with a change in temperature or light, resulting in a photoresponse, impersonating transition-edge behaviour, which can be potentially interesting for THz single-photon detection in future.

Thesis Director: Prof Dr. Frank Koppens
Hosted by: Frank Koppens