PhD THESIS DEFENSE: Graphene based photodetectors for on-chip and free-space data communication applications

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Elements Room

Moore's law, a longstanding guide for the semiconductor industry, successfully predicted the exponential growth in computing power by doubling transistor counts every two years. However, recent challenges in maintaining this pace, attributed to physical limitations, energy consumption, and escalating costs, have prompted a shift in focus towards two-dimensional (2D) materials in semiconductor technology. This thesis aims to bridge the gap in understanding the complexities of incorporating 2D materials, such as Graphene (Gr), Transition Metal Dichalcogenides (TMD), and hexagonal boron nitride (hBN), into Complementary Metal-Oxide-Semiconductor CMOS platforms, paving the way for innovative

optoelectronic devices with improved functionality to overcome these challenges.
High-quality heterostructures:

This thesis investigates the crucial role of encapsulants and substrates in Gr-based heterostructures, highlighting their impact on electronic transport characteristics, such as hysteresis (?n), carrier mobility ( ), and residual charge carrier concentration (n*). Owing t the quality and integration complexity of scalable large-area thick hBN, this thesis explore the utilization of TMD-like tungsten diselenide (WSe2) and tungsten disulfide (WS2) a substrates and encapsulants, respectively, for Gr. The hybrid heterostructures fabricate with WSe2/Gr/hBN and WS2/Gr/hBN exhibited a high of ~170,000 and ~140,000 cm2V-1s 1 with a n^*of ~7 and 8 x 1010 cm-2 respectively. This study underscores the significance f substrate engineering, particularly for WS2. A successful demonstration of the effectivene s of TFSI-treated WS2 in encapsulating Gr and its role as a gate dielectric has been establishe . The treated devices exhibited remarkable stability and resilience, leading to a low ?n of ~2 x 109 cm-2 with a of ~62,000 cm2V-1s-1 and a n^* of ~1.7 x 1011 cm-2.
Waveguide-integrated photodetectorsThe exponential growth of internet users and data traffic necessitates higher bandwidth capabilities in communication systems. Optical transceivers play a pivotal role in meeting this demand, particularly in data centers and broadband access networks. This thesis focuses on the crucial components of optical transceivers, specifically photodetectors (PD), optimized for a wavelength of 1550 nm, a standard for long-distance communication in optical fibers. This thesis explores a photothermoelectric (PTE) WSe2 encapsulated Gr photodetector on a waveguide to address this challenge. Up on a comprehensive analysis of the device's design, the fabricated PD with different widths exhibited a responsivity up to ~12 V/W (long) or 0.1 A/W and ~32 mA/W or 18 V/W (short) with a setup limited bandwidth of 110 GHz. PDs also demonstrated direct detection of NRZ and PAM-4 optical signals up to 120 and 160 Gbps, respectively.
Wireless receivers:

Meanwhile, in wireless telecommunications, efforts must be directed towards boosting data rates to accommodate growing data traffic, as indicated by Edholm's law. The proposed 6G wireless devices are expected to achieve peak data rates of up to 1Tbps. To overcome speed bottlenecks, this thesis proposes exploring the terahertz (THz) range, with a focus on the sub-THz (~200GHz-300GHz) window, exhibiting low-attenuation demands for short-range (<200m) wireless applications. We performed an extensive investigation and optimization of the performance of a PTE-based Gr photodetector using various encapsulants. Among these, the hBN-encapsulated Gr PDs exhibited superior performance compared to their counterparts (PD with CVD Gr), with an elevated responsivity of ~240 (~30) V/W and low noise equivalent power (NEP) of ~1 (~9) x 10-11 W/?Hz. The fabricated PDs exhibited a bandwidth of approximately 1.9 GHz, enabling data rates of 2 Gbps. Finally, we developed a Gr-based

receiver, establishing a sub-terahertz wireless communication link that achieved data rates of up to 3 Gbps and efficiently operated over a distance of 2.5 meters.

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