Abstract

Terahertz (THz) technology has witnessed rapid advancements in recent years, unlocking a wide range of potential applications across diverse fields such as imaging, wireless communication, material spectroscopy, security screening, and biomedical diagnostics. To fully harness the capabilities of THz waves, it is essential to develop efficient devices and components that operate reliably within the THz frequency range. THz modulators, in particular, play a vital role by enabling dynamic control over THz wave propagation. However, existing modulators often suffer from limitations such as low modulation depth, narrow bandwidth, high insertion loss, and the need for high optical or electrical power. On the other hand, currently available THz detectors—including field-effect transistors, Schottky diodes, and photoconductive antennas—fall short of achieving high bandwidth, responsivity, and sensitivity, especially when operating at room temperature. To address these challenges, this thesis focuses on the development of efficient THz modulators and detectors that operate reliably at room temperature. The study specifically explores devices based on low-dimensional Group-IV (Ge quantum dots and silicon grating microwires) and chalcogenide materials ($MoTe_2$ and As_2Te_3).

The first part of this thesis focuses on the development of optically pumped THz modulators based on low-dimensional Group-IV (Ge quantum dots) and chalcogenide ($MoTe_2$) materials, both grown using molecular beam epitaxy (MBE). The first chapter presents MBE-grown germanium (Ge) quantum dots(QDs) on silicon-on-insulator (SOI) substrates, demonstrating enhanced THz amplitude modulation of up to ~77% at 0.1 THz, attributed to increased photocarrier generation and confinement at the Ge QDs/Si interface. This behavior is supported by theoretical modeling using the non-equilibrium Green's function (NEGF) method. The following chapter explores scalable van der Waals heterostructures of molybdenum ditelluride ($MoTe_2$)/silicon, which exhibit broadband modulation, achieving a maximum modulation depth (MD) of 74.6% at 0.25 THz under 355 nm optical excitation, with fast rise and fall times in the microsecond (μs) range. These modulators offer strong potential for high-speed, broadband THz applications, including enhanced imaging resolution and secure detection of pharmaceutical counterfeits. The combined experimental and theoretical results underscore the potential of optical modulator based on these devices to advance next-generation THz technology for emerging applications in wireless communication, sensing, and

imaging.

In the next part, this thesis presents two room-temperature terahertz (THz) detectors based on distinct materials and architectures. The first device employs a self-powered, log-periodic antenna-coupled arsenic telluride (α-As_2Te_3): a low-bandgap pnictogen chalcogenide, demonstrating broadband detection from 0.1 to 1.2 THz. It achieves a peak responsivity of 248 mA/W at 1.1 THz and a detectivity of 0.25×10^7 Jones at 0.2 THz under zero-bias, with responsivity enhanced by 2.2 times under applied bias. These devices achieve a decent low noise equivalent power (NEP) of 9.7×10^{-9} $W\cdot Hz^{-1/2}$ at room temperature, highlighting their potential for high-frequency applications in wireless communication and low-power electronics. The following chapter introduces the second device, a silicon microwire (MW) channel grating junctionless FET detector, fabricated using a simple and cost-effective approach. Devices with 1, 5, and 7 microwire channel FETs were demonstrated, with the 5 microwire channel device showing the best performance: 25.5 mA/W responsivity, 1.1×10^9 Jones detectivity, and 2.5×10^{-12} $W\cdot Hz^{-1/2}$ NEP at 0.29 THz under a 1V gate bias. The grating architecture offers enhanced sensitivity and polarization-dependent response, confirmed through simulations. These findings highlight the potential of these architectures for developing efficient, scalable THz detectors suitable for future sensing and imaging technologies.