Abstract

The fabrication of quantum confined and alloyed Group-IV semiconductor nanostructures is a promising field of research due to their potential for the cost-effective manufacturing of monolithic optoelectronic ICs compatible to Si CMOS technology. In this regard, the growth of Ge islands on virtual substrates or silicon-on-insulators, using the Stranski-Krastanov growth mechanism is of immense interest for different kinds of optoelectronic devices. Furthermore, the one-dimensional growth of GeSn alloy can be effective to improve the crystalline quality and photo responsivity of the devices in comparison to their thin-films counterpart. In this dissertation, we have studied the optical and electronic characteristics of Ge islands, and core-shell GeSn nanowires for infrared photonics and Si nanowire templates for photovoltaic devices. The growth and optical characteristics of relatively large-sized (∼7.0–8.0 μm) but low aspect ratio Ge microdisks on a virtual $Si_{0.5}Ge_{0.5}$ substrate using molecular beam epitaxy (MBE) have been demonstrated. The self-assembled Ge microdisks exhibit quantum-confined enabled direct band gap (~0.8 eV) photoluminescence at an optical commination wavelength, which is sustainable up to room-temperature. To investigate the electroluminescence and photodetection characteristics at ~1550 nm, *p*–*i*–*n* diodes with an intrinsic layer containing Ge microdisks have been fabricated and the results are discussed in detail. Moreover, the optical emission and photodetection characteristics of MBE grown Ge/GeSi islands on silicon-on-insulator substrates have been studied. The effect of excitation power and temperature on photoluminescence characteristics has been investigated. A three-terminal back-gated field-effect transistors based on Ge/GeSi islands/Si NW have been fabricated to achieve the broadband photodetection (300-1600 nm) with a low dark current by exploiting the optical absorption of both Ge/GeSi islands and Si. In addition to that, chemical vapor deposition-grown high Sn-content (~8%) Ge-GeSn core–shell-based single nanowire photodetectors have been fabricated to achieve the improved photodetection characteristics at the optical communication wavelength. A photoconductive gain of more than unity (~57) of the fabricated single nanowire-based photodetectors lead to a superior photo-responsivity value of ~70.8 A/W at ~1550 nm, which is found to be much higher in comparison to their thin-film counterpart. Along with the optical emitters and detectors, Si/CZTS NCs heterojunction-based photovoltaics devices have been fabricated by directly spin coating of solution-processable different-sized CZTS NCs inks, on bulk and nano-textured (black-Si) substrates. The devices fabricated with the smallest sized CZTS NCs, having an average diameter of ~6 nm, exhibit an enhancement in power conversion efficiency of ~61% in comparison to that of the device fabricated with the nanocrystals of ~40 nm in diameter. Besides that, CZTS NCs layer numbers have been found to be a pivotal parameter in controlling the power conversion efficiency and other key parameters of the photovoltaic device. The result from the present study indicates the potential of Group-IV nanostructures for CMOS-compatible silicon photonic devices.

Keywords: Molecular beam epitaxy, Ge microdisks, Ge/GeSi islands, Ge-GeSn core-shell nanowires, photoluminescence, electroluminescence, photodetector, solar cell.