Abstract

Integration of low-dimensional semiconductor nanostructures with existing silicon technology has enabled researchers to develop sensitive photodetectors. Incorporation of nanostructures namely nanowires (NWs), nanocrystals and two-dimensional materials (graphene, transition metal dichalcogenides, etc.) with Si demand precise control over the chemical compositions, morphologies, and critical dimensions. A large dedicated research work is ongoing to explore the size and shape dependent electrical and optical properties of these nanomaterials. Still, a large number of questions regarding the performance of nanostructure-based devices and scalability in fabrication process need to be addressed.

In this dissertation, high efficient photodetectors using Si/Ge nanowires and transition metal dichalcogenides (TMDCs) heterojunction have been developed for Si-photonics. The photoresponse of single Si nanowire junctionless phototransistor has been investigated in the visible to near-infrared region. A CMOS compatible top-down approach has been used to fabricate Si nanowire phototransistor. The fabricated device shows excellent sensitivity (~5 pW) with a very low dark current of 1 pA at room temperature. The measured gain was 35 for 860 nm light illumination. The photocurrent was 300 times larger than the dark current for low incident power (30 nW). To investigate the size-dependent photo-gain of Si NWs, single NW back-gated phototransistors have been fabricated. The device having smallest diameter shows the maximum gain of $1.2 \times 10^4$ with a rise time of 120 µsec. Finite-difference time-domain (FDTD) simulation results show that the confinement of incident optical energy is prominent in the smaller NWs due to waveguiding effect. Further to improve the photo-responsivity of NW-photodetectors, NW-network architecture has been used. A complete study on the diameter dependent photoresponse of high-speed Ge NW network based metal-semiconductor-metal (MSM) photodetector has been explored. Ge NWs with different diameters (30 nm– 100 nm) were grown by a vapor-liquid-solid method on SiO$_2$/Si (100) wafers. It was observed that a large population of surface states results in higher responsivity and gain in the smaller diameter NWs device. The 30 nm Ge NWs detector shows a fast photoresponse with a rise time of 95 µsec and a fall time of 100 µsec. The observed diameter-dependent time response in network NWs devices has been explained using barrier-dominant photo-conductance.

In the later part of this dissertation, the heterostructures of transition metal dichalcogenides (TMDCs) with Si and Ge have been investigated for high speed and broadband photodetector applications. Si/MoS$_2$ (p-n) heterojunction photodetector has been
fabricated with a very simple and scalable process. The large area nanostructured MoS$_2$ thin film on silicon has been synthesized by sulfurization of radio-frequency sputtered MoO$_3$ films. The fabricated nanostructured-MoS$_2$/p-Si heterostructure offers high responsivity up to 8.75 A/W (at 580 nm and 3 V bias) with the ultra-fast response of 10 μsec (rise time). Later on, MoS$_2$ on porous Si (PSi) has been explored to increase the efficiency in near-infrared wavelengths of the heterostructure photodetectors. Fabricated MoS$_2$/PSi shows superior characteristics compared to planar MoS$_2$/Si, as the responsivity of the MoS$_2$/PSi heterojunction gets improved by ~ 2 times compared to MoS$_2$/Si in the infrared region. Furthermore, the MoSe$_2$/Ge lateral heterojunction has been fabricated by patterning germanium on insulator (GeOI) substrate to improve the efficiency of the broadband detector in the infrared wavelengths. This 2D/3D structure exhibits high responsivity of 35 A/W for 1550 nm light at room temperature. The interfacial charge transfer at the Ge-MoSe$_2$ heterojunction enables self-powered photo-detection in fabricated devices with zero bias responsivity 400 mA/W for 1550 nm lights respectively. Transient photoresponse measurements of the MoSe$_2$/Ge heterojunction under the modulated light reveal that the devices are capable of working up to 20 kHz with a fast rise/fall time of 13.5/1.2 μsec. These results demonstrate the feasibility of achieving a high-performance photodetector derived from the MoSe$_2$/Ge heterojunction for broadband infrared detection. In summary, a series of high efficient photodetectors have been developed here with the improved figures of merit (better sensitivity, responsivity, and speed), using nanostructure-embedded configuration and large area scalable process.
Publications

A) Journals

B) Publications from International Conferences

C) International Conferences

