Semiconductor News

A quarterly publication of the Semiconductor Society (India), www.ssindia.org.in

June 2018

From the Editor's Desk

Here, we present the seventh issue of Semiconductor News, an e-newsletter of SSI. In the last issue properties of Ga_2O_3 from device point of view had been discussed. Researchers are trying hard to grow this material for optoelectronic devices which essentially require p and n type nature of the material for device applications.

The photodetector is one of the most widely used and frequently needed optoelectronic device. The wideband optical response with excellent electronic transport properties, high quantum efficiency, low noise, large bandwidth and high speed are essentially required for photodetectors,. In current scenario, size of the device is critical feature in semiconductor industry. Scientists are putting efforts to reduce the size and weight of the photodetector and at the same time enhancing the performance levels. Shrinking the size is restricted by thin film layer quality and transparency of film towards light. Among various materials, Graphene is particularly attractive for futuristic detectors. The nearly gapless structure results into broadband absorption and high carrier mobility enables fast response. Various applications viz. infrared imaging, spectroscopy, terahertz imaging, telecommunications can be covered with the material. Quantum dot for photodetection is one of the flourishing area for innovations. Various schemes are being developed for photodetection applications such as single photon detectors.

Based on end-use industry, the global photodiode market comprises of telecommunication, healthcare, consumer electronics, aerospace & defense and others. India is a growing market for semiconductor industry (which includes photodetectors) with boost from government and its ómake in indiaô programme. Recently, few reports have been published on development of semiconductor fabless ecosystem and aiming design led manufacturing. However, much work is required to achieve material growth and fabrication of devices.

In this issue the work on photodetectors using semiconductor nanostructures at one of the premier laboratory of IIT Kharagpur is highlighted. We further invite the members to contribute the scientific writings about Semiconductor research and related activities in their organization to this newsletter.

Kamal Lohani

Executive Committee of SSI

Enhanced Performance Photodetectors using Group-IV Semiconductor Nanostructures

In the last decade, research group at Microscience lab., Dept. of Physics, IIT Kharagpur, India has worked extensively on photodetectors using semiconductor nanostructures, which are superior compared to their bulk counterparts. It includes a wide variety of materials like SiGe quantum dots, Si nanowires, dichalcogenide 2D materials and semiconductors on biocompatible silk platforms.

A photodetector is a device which measures the photon flux by converting the energy of the absorbed photons into a detectable voltage or current. Photoconductive detectors operate by registering the photocurrent, which is proportional to the photon flux, or the voltage drop across a load resistor R placed in series with the circuit. Optical detection by any kind of device depends on: (i) light absorption, (ii) carrier separation at the junction and (iii) carrier collection at the contacts. An optical detector can be characterized through noise, quantum efficiency, linearity, spectral and temporal response. All these parameters must be known in order to build a theoretical model that can correctly depict the nature of the detector during a measurement. Nanotechnology has enabled the realization of different kind of detector devices, which are superior to their bulk counterparts. They exhibit superior charge collection efficiency by increased surface to volume ratio, enhanced photon trapping by nanostructures and wavelength tunability due to the quantum size effect. Some of the salient results using group-IV semiconductor nanostructures are presented below.

1. Ge Quantum dot infrared photodetectors (QDIP):

The photocurrent of a Ge QDIP arises due to the intersubband transitions in the mid-infrared wavelength, where the normal incidence photons could be detected without fabricating a grating structure due to favourable selection rules. Fig.1 shows the photocurrent (PC) response at different temperatures for the detectors at 3.1 and 6.2 µm, fabricated using MBE grown Ge quantum dots of two different sizes on Si. PC peak at 6.2 µm is attributed to the intersubband transition in quantum dots, while the one at 3.1 µm is due to the transition between the quantum dot heavy-hole (hh1) ground states to the continuum.

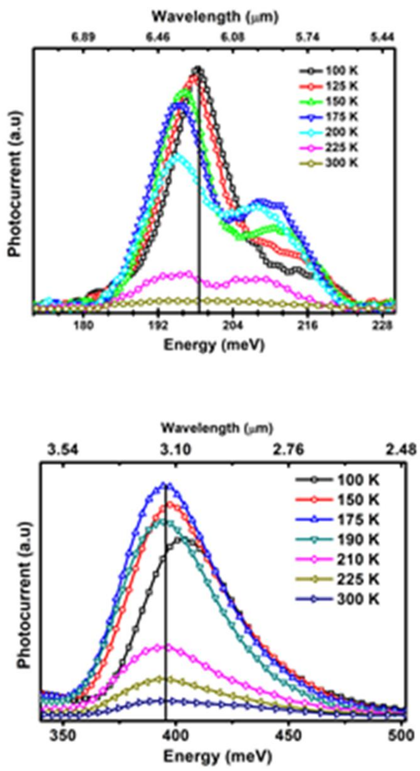


Fig. 1 Photocurrent response in the mid-IR region using Ge quantum dots

2. Nanowire based detectors

a) Radial heterojunction nanowire *detector*:

We have fabricated n-Si/p-CuS nanowire photodiodes using cone-like Si nanowires prepared by wafer scale metal assisted chemical etching. A peak responsivity of 0.32 A/W with a maximum EQE of 40% was found for the nanostructured device at 990 nm with zero applied bias (Fig.2), showing significant improvement over the control planar device. The nano-textured device shows improved responsivity and EQE due to enhanced light absorption and efficient photo-carrier extraction in the nanocone radial heterojunction.

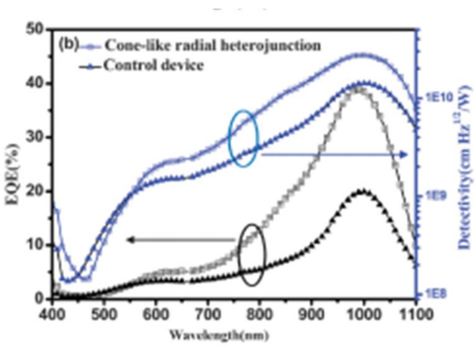
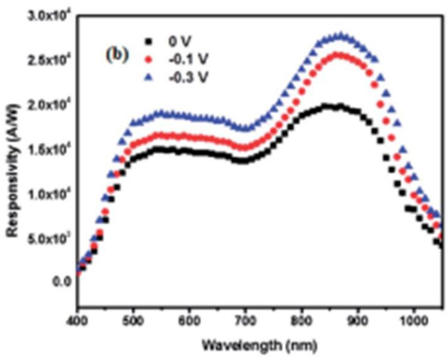


Fig. 2. Broadband photoresponse of n-Si/p-CuS nanowire radial heterojunction detector

***b) Single Si nanowire detector*:**
A single Si nanowire (diameter 80 ï 100 nm) based photodetector exhibits ultrahigh responsivity and polarization sensitivity as shown in Fig. 3.



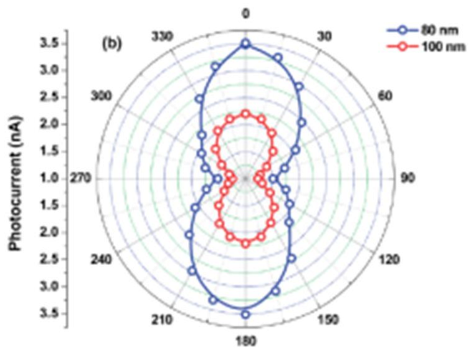


Fig. 3 (a) Spectral response of a single Si nanowire (~100 nm dia) detector with ultra-high responsivity and (b) polarization selectivity of the detectors fabricated with NW dia of 80 and 100 nm.

The single nanowire MSM detector was fabricated using focussed ion beam lithography technique. A single NW is a perfect example of a photoconductor detector, with ultrahigh gain. The device with ~100 nm dia Si nanowire shows a peak responsivity of 15,000 A/W even at zero bias (Fig. 3a), as compared to that of 0.5 A/W for a bulk Si detector The photocurrent also exhibits strong polarization sensitivity (Fig. 3b), with superior performance for a lower diameter nanowire.

Dr. Samit K Ray

Recent news in semiconductors

1. Van der Waals heterostructures, in which two-dimensional materials are stacked on top of each other, allow different materials and properties to be combined and for multifunctional devices to be created. Ruiqing Cheng et al. show that an asymmetric van der Waals heterostructure device, which is composed of graphene, hexagonal boron nitride, molybdenum disulfide and molybdenum ditelluride, can function as a high-performance diode, transistor, photodetector and programmable

rectifier. Due to the asymmetric structure of the device, charge-carrier injection can be switched between tunnelling and thermal activation under negative and positive bias conditions, respectively. [Ruiqing Cheng et al., Nature Electronics, vol 1, June 2018, pp 356-361.

2. Wide-bandgap semiconductors (WBG) are expected to be applied to solid-state lighting and power devices, supporting a future energy-saving society. Ekaterine Chikoidze et al presented evidence of *p*-type conduction in the undoped WBG β-Ga_2O_3. Hole conduction, established by Hall and Seebeck measurements, is consistent with findings from photoemission and cathodoluminescence spectroscopies. The gallium vacancy was identified as a possible acceptor candidate based on thermodynamic equilibrium Ga_2O_3 (crystal) ï O_2 (gas) system calculations (Kroger theory) which revealed a window without oxygen vacancy compensation. The possibility of fabricating large diameter wafers of ϐ-Ga_2O_3 of p and n type nature, provides new avenues for high power and deep UV-optoelectronic devices. [Ekaterine Chikoidze et al., Materials Today Physics Volume 3, December 2017, Pages 118-126].

3. Groups from US and South Korea (US-based Bolb Inc and Semicon Light Co of South Korea) have carried out research leading to increased efficiency and reduced forward voltage for 280nm-wavelength deep ultraviolet (DUV) light-emitting diodes by creating a two-dimensional hole gas at the p-contact surface using variously strained layers of magnesium (Mg)-doped aluminium gallium nitride (AlGaN). The hole gas was formed at the surface of a strained heavily doped AlN layer due to strong polarization electric fields, which raised the valence band states above the Fermi level. The electric field arises from the spontaneous charge polarization of the III(Al,Ga)-nitride bond. An added component to the field comes from strain-dependent piezoelectric effects. The technique is designed to overcome the problem of hole injection from the wider-bandgap high-Al-content AlGaN needed to emit DUV light. Magnesium doping becomes less effective at producing holes as aluminium content increases. The details can be looked into a recent publication: Zhang et al, Semicond. Sci. Technol., 33, (2018) p07LT01.

Forthcoming Events

1) The International Conference on Emerging Electronics (ICEE) will be held at Bangalore during December 16-19, 2018. The theme of the conference is "From Materials To Devices".
2) The fifth International Symposium on Semiconductor Materials and Devices (ISSMD-5) will be organized under the aegis of Semiconductor Society (India) in VNIT, Nagpur. From 30^{th} Nov to 2^{nd} Dec, 2018. The society for Semiconductor Devices (SSD) will be a co-organizer of this symposium. Prof. Rajendra Patrikar from VNIT, Nagpur will be the Convener of this symposium.