SEMICONDUCTOR SOCIETY (INDIA)

Semiconductor News

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

March 2017

From the Editor's Desk

We have the pleasure of presenting this issue with the worldwide news of discovery of 'time crystals'. Nature loves symmetry and it is fascinating to the humankind from the beginning of the civilization. From James Clerk Maxwell's theory of electromagnetism to Einstein's General theory of relativity, symmetry is found in the physical laws including time symmetry that never breaks.

The Noble prize winning theoretical physicist Frank Anthony Wilczek (who admits vast influence of Einstein on his carrier) in 2012 coined the idea of a system that breaks time translation symmetry in its ground state. However Masaki Oshikawa at the University of Tokyo showed by his calculations that for a system in its ground state& in equilibrium it would be impossible to break the time translation symmetry but there is a possibility if the system is in non-equilibrium. This month, two research groups, one led by Christopher Monroe at the University of Maryland, USA and second led by Mikhail Lurkin Harvard University, USA, independently demonstrated the idea of time crystals. The Maryland team used ten charged atoms of ytterbium with the combination of four sets of lasers, while Harvard group used nitrogen vacancy centers in diamond to demonstrate the 'time crystals'.

This discovery has tremendous potential to become a milestone in the path of quantum computers research, as its creators are looking for exciting possibilities into it. Presently the quantum entanglement states can be achieved at extremely low temperatures but Mikhail Lurkin demonstrated the entanglement phenomena at room temperature. Thus it is highly probable that this discovery will have a great impact on the futuristic technologies.

In this issue we present the graphene/GaN Schottky diodes and nanoscale Schottky diodes based on individual vertically standing GaN nanorods. We further invite the members to contribute the scientific writings about Semiconductor research and related activities in their organization to this newsletter.

Dr. Rupesh K. Chaubey

Executive Committee of SSI

Unconventional graphene/GaN Schottky diodes and nanoscale Schottky diodes based on individual vertically standing GaN nanorods

Conventional Schottky diodes suffers from the problem of thermal degradation at higher temperatures as well as their barrier height is limited by Schottky-Mott limit. Due to high electrical conductivity and zero bandgap, graphene is analogous to a metal at the metal-semiconductor (MS) interface, which suggests that graphene-semiconductor (GS) junctions may have the underlying trend for replacing conventional MS junctions. The GS junctions allow the investigation of electrical transport mechanism at the interface of 2D and 3D materials with zero and definite band gap, respectively. In our recent work, graphene/GaN Schottky diodes are fabricated by selective transfer of exfoliated graphene on GaN. The diodes exhibited enhanced thermionic emission and low 1/f noise in comparison to conventional Ni/GaN diodes. The barrier height value obtained using thermionic emission theory is found to be higher than predicted barrier height as per the Schottky–Mott model. Unlike the conventional metal-Schottky diodes where Fermi level of metal always remains constant, Fermi level shifts in graphene on its interaction with metal or semiconductor due to low density of states in graphene. The higher barrier height of Gr/GaN Schottky diode, 0.6 eV instead of theoretically predicted value of 0.4 eV is explained by calculating the Fermi level shift in graphene due to graphene-GaN and graphene-Au interactions. The graphene-Au interaction resulted in downward Fermi level shift ~ 0.31 eV in graphene whereas an upward shift of ~ 0.04 eV is obtained due to graphene-GaN interaction. The higher Fermi level shift in graphene due to graphene-Au interaction increases the barrier height by ~ 0.3 eV and explains the discrepancy between predicted and experimentally observed barrier height of Gr/GaN Schottky diode. Fermi level shifts in graphene due to graphene-GaN and graphene-Au interactions with energy band alignment are shown in Figure 1. Fermi level shift resulted in higher barrier height in graphene/GaN in comparison to conventional Ni/GaN schottky diode. Enhanced thermionic emission current, lower level of inhomogeneities, and reduced flicker noise suggests that graphene–GaN Schottky diodes electronic transport in 2D/3D (graphene/GaN) system is different from conventional 3D/3D (Ni/GaN) system and one can reach beyond the Schottky-Mott limit in such systems.

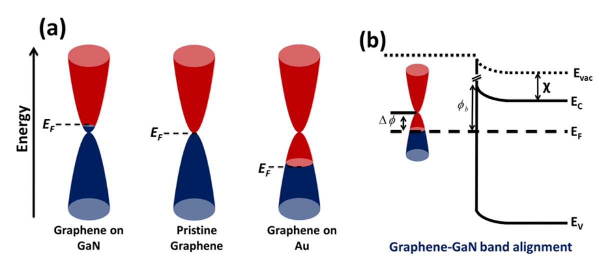

Figure 1:(a) Schematic representation of Fermi level shift in graphene due to graphene–GaN and graphene–Au interactions. (b) Band alignment configuration of graphene–GaN Schottky contact.

Semiconductor nanostructures have attracted growing attentions in past decade due to their superior properties and potential applications in nanoelectronics and nanophotonics. To realize a nanoscale device based on GaN nanorods (NRs), a thorough understanding of the current transport across interface is required as models which are used for explaining electrical transport in epitaxial films are not fully applicable to nano-devices because of small dimensions. In the present work, vertically standing GaN NRs have been fabricated using Ni nanomasking and reactive ion etching. The electrical behaviour of Schottky barrier diodes realized on vertically standing individual GaN NRs and array of NRs is investigated. The Schottky diodes on individual NR show highest barrier height in comparison with large area diodes on NRs array and epitaxial film which is in contrast with previously published work. Figure 2 shows the top-view of vertically standing GaN NRs before and after electrical contact, and electrical characteristics of Schottky contact realized using W tip on an individual GaN nanorod. The discrepancy between the electrical behaviour of nanoscale Schottky diodes and large area diodes is explained using cathodoluminescence measurements, surface potential analysis using Kelvin probe force microscopy and low frequency noise measurements.Relatively defect free top of the rod and limited role of barrier inhomogeneities resulted in improved ideality factor and Schottky barrier height as compared to previous reports on Schottky diodes fabricated on individual GaN nanostructures grown using bottom-up approach. Present study compares electronic transport in nanoscale diodes with large area diodes and may be useful for advancement of GaN into nanoelectronics and nano-photonics.

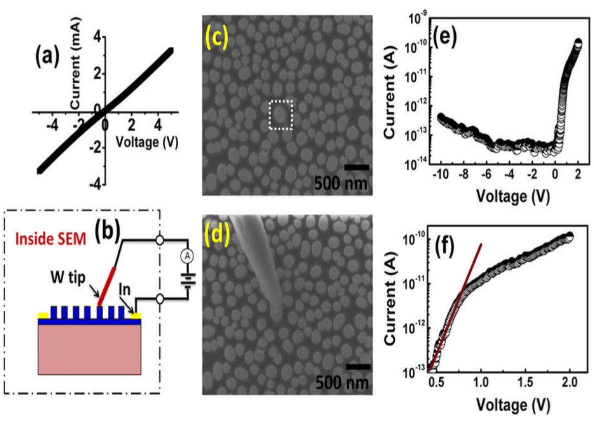

Figure 2:(a) Current-voltage (I-V) characteristics of In/GaN Ohmic contacts using two-probe method. Schematic of electrical characterization of nanoscale W/GaN Schottky contact is shown in (b). Top view FESEM images of vertically standing NRs before and after contact with W tip inside FESEM are shown in (c,d), respectively. Rectangular box in (a) shows the nanorod selected for electrical contact. I-V characteristics of nanoscale W/GaN Schottky diode on a single vertically standing GaN nanorod are shown in (e) whereas (f) shows initial region on expanded scale fitted in accordance with thermionic emission model.

More information about these works are given in following articles:

ACS Applied Materials and Interfaces 8, 8213 (2016) and *Scientific Reports* 6, 27553 (2016).

Dr. Asutosh Kumar, Prof. Vikram Kumar and Prof. Rajendra Singh, IIT Delhi

Recent news in semiconductors

1. A team led by Prof. Z. Lee of Materials Science and Engineering at Ulsan National Institute of Science and Technology (UNIST), South Korea has introduced a novel method for fabricating two-dimensional zinc oxide (ZnO) that is just one atom thick. This may open up new possibilities for thin, transparent and flexible electronic devices, such as ultra-small sensors (*Hyo-Ki Hong et al., Nano Letters (2017) 17 (1) p120*). The material is formed by directly growing a single-atom-thick ZnO layer on graphene, using atomic layer deposition (ALD). The research team demonstrated atom-by-atom growth of zinc and oxygen at the preferential zigzag edge of a ZnO monolayer on graphene through *in-situ* observation. They experimentally determined that the thinnest ZnO monolayer has a wide bandgap (up to 4.0eV), due to quantum confinement and a graphene-like 'hyper-honeycomb' structure, as well as high optical transparency. Existing oxide semiconductors have band gap, in the range of 2.9-3.5eV. The study can lead to a new class of

2D heterostructures, including semiconducting oxides formed by highly controlled epitaxial growth through a deposition route.

2. "MRSI Medal Lecture Award for 2017" has been conferred to Dr. Rajendera Singh this year. He gave an invited talk at AGM of MRSI held at IIT Bombay in February, 2017.

3. "International Symposium on Semiconductor Materials and Devices (ISSMD-4) was held at Jadavpur University, Kolkata during 8-10 March, 2017. It was organized under the aegis of Society for Semiconductor Devices (SSD) and Semiconductor Society India (SSI). Dr. R.K. Sharma, Director, SSPL delivered the keynote address during the Symposium. Moreover, about 23invited talks were also delivered by various prominent speakers from India and outside. About 300 posters were also presented and three best poster awards were given during the symposium."

4. The XIX International Workshop on The Physics of Semiconductor Devices (IWPSD 2017) is being jointly organized by Solid State Physics Laboratory and Indian Institute of Technology Delhi in collaboration with Society for Semiconductor Devices and in association with Jamia Millia Islamia, Delhi University and Semiconductor Society (INDIA). The last date for abstract submission for the workshop in June 15, 2017.For further details visit iwpsd.in.