Serhii Shafraniuk, J Material Sci Eng 2014, 3:3
http://dx.doi.org/10.4172/2169-0022.S1.013

OMICS Group Conferences
Accelerating Scientific Discovery

3rd International Conference and Exhibition on
Materials Science & Engineering
October 06-08, 2014 Hilton San Antonio Airport, USA

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Atomic monolayer materials and their applications

Many areas of human activity critically depend nowadays on discovery and study of novel materials. The nanotechnology research is directed towards a variety of applications which include industry, medicine, security, defense, and space research. The new materials make structural revolutionary changes in technology of various nanodevices like nanosensors, digital logic elements, quantum dots, THz signal processors and sensors, quantum bits and circuits, etc. At Northwestern, experimental and theoretical study of atomic monolayer materials were conducted. The work is focused on the following topics. (a) Quantum dots as elements of the THz and magnetic field nanosensors. (b) Andreev reflection as a probe of interface properties. (c) Efficient thermoelectric nanocoolers and energy generators based on atomic monolayer (AM) materials and nanotubes. The AM materials are represented by graphene, transition metal dichalcogenides, molybdenum disulfide, titanium disulfide, transition metal oxides, graphitic carbon nitride (g-C3N4), and the topological insulator (Bi_2Te_3). The current efforts are focused on the former three materials. Using the unique intrinsic properties of novel AM materials allows creating of devices which were not available in the past. In particular, resonant character the chiral tunneling and low inelastic scattering rates in graphene both are serving as reasons why the electric current density can be much higher than in ordinary semiconducting devices. Another example is Klein tunneling paradox which makes graphene and nanotubes as being intrinsically "clean" and perspective for electronic applications. The experimental devices are based on multi-terminal AM field effect transistors (A-FET). An important stage of the A-FET fabrication process assumes obtaining the good quality AM sheets and nanotubes. The obtained quantum dot devices had been used for experimental testing in respect of their performance and suitability for the aforementioned purposes. The A-FET is controlled with source-drain and gate voltages applied via the metallic electrodes deposited on AM. The voltages affect the low energy electronic spectrum and hence they modify the transport properties of AM material. When exposing the A-FET device to an external THz field it was found that the resonant a.c. transport strongly depends on the polarity and magnitude of the source-drain and gate voltages. Besides, the THz field induces transitions between the quantized levels which are pronounced in the experimental current voltage characteristics. By measuring the d.c. current-voltage curves of A-FET quantum dots which are exposed to an external THz field it was possible to determine the THz field parameters. In this way the A-FET was utilized which actually works as a very sensitive and efficient THz field sensor. Besides, the thermoelectric cooling and energy co-generating phenomena in AM were studied. It can be concluded that the AM based setups can perform much better than other known devices.

Biography

Serhii Shafraniuk is Research Associate Professor at Department of Physics and Astronomy, Northwestern University. At Northwestern (2002-present) he serves as a PI in research projects related to electromagnetic properties of carbon nanotube and graphene field effect transistors, thermoelectric transport in carbon nanotube and graphene multi-barrier devices, and qubits. He has received the BA degree (cum laude) and the PhD degree in physics from Kiev State University, Ukraine, in 1980 and 1985, respectively. Besides, Serhii had been honored the Doctor of Sciences degree from the Institute of Metal Physics, Academy of Sciences of Ukraine in 2001. His thesis work has focused on non-equilibrium phenomena in inhomogeneous superconductors. Before coming to USA, Serhii had been working in various leading research centers in Europe and Japan (1990-2002). In particular from 1995 to 1999, he was a Foreign Research Staff Member at the Research Institute of Electrical Communication, Tohoku University, Japan. Prof. Shafraniuk has served as organizing committee member of several International Symposiums and Conferences related to the superconductivity nanoscience, and condensed matter.

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