HUMIDITY AND TEMPERATURE SENSOR PROPERTIES OF p-Si/POLYIMIDE/C_{60} NANOSTRUCTURES WITH SWIFT HEAVY ION TRACKS

A. V. PETROV, E. Yu. KANIUKOV, S. E. DEMYANOV

Scientific-Practical Materials Research Center NASB
P. Brovka 19, 220072 Minsk, Belarus
Petrov@physics.by

A. NOCKE, M. GÜNTHER, G. GERLACH

Dresden University of Technology, Hermholtzstr. 18, D-01062 Dresden, Germany

A. S. BERDINSKY

Novosibirsk State Technical University, Karl Marx Ave. 20, 630092 Novosibirsk, Russia

D. FINK

Hahn-Meitner-Institute, Glienicker Str. 100, D-14109 Berlin, Germany

Nanostructures based on C_{60} (fullerite) deposited into swift heavy ion (SHI) tracks in a polyimide layer on a silicon substrate have revealed the pronounced sensitivity to humidity and temperature, which can be associated with the mobility of H^+ and OH^- ions within the fullerite lattice and electrochemical corrosion in humid environment in the presence of moisture. These sensor effects are larger in the structures with SHI tracks as compared with the structure without the tracks.

1.Introduction

At present an intensive search for new technologies to reduce dimensions of electronic devices down to the nanometric size range takes place worldwide. In this concern, an interest increases to the development of non-traditional technologies of nanomaterials fabrication. In this way, the swift heavy ion (SHI) track technology is actively used. It consists of formation of narrow trails of radiation damages (latent ion tracks) as a result of the high-energy ions impact [1-6]. By means of the dissolution of latent track material by suitable chemical agents (chemical etching), pores of various forms (such as cylindrical or conical) and dimensions (typically 10 to 1000 nm) can be produced. The etched SHI tracks can be subsequently filled with any material. The embedded matter can be arranged as either massive wires or tubules, or it just can be dispersed discontinuously as small nanoparticles along the track length. Later on, functional elements for nanoelectronics can be created on the basis of SHI irradiated structures [3-6]. The SHI track technology has been employed in the present research for improvement of conventional sensor properties.

1. Experimental

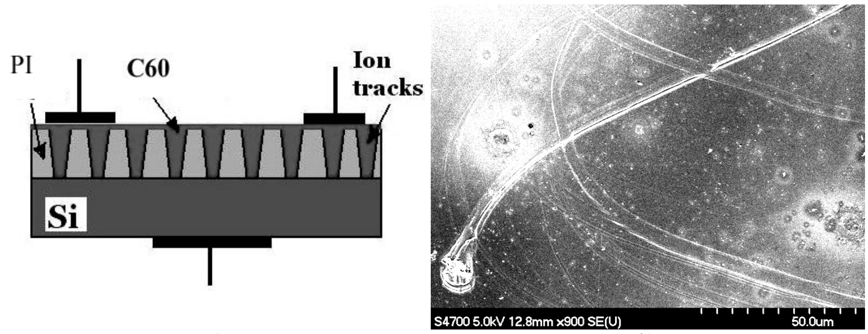
Preparation of experimental samples included the fabrication of polyimide (PI) 2611(BPDA – PPD) layers with thickness of 1.50 μm on p-Si substrates by spin coating. Irradiation by $^{129}Xe^{21+}$ ions (energy 390 MeV, fluence 10^8 cm^{-2}) of initial samples has been carried out at the ISL accelerator center (Hahn-Meitner-Institute-Berlin, Germany). The chemical etching of SHI tracks (ion tracks) was carried out in NaOCl solution at 70ºC during 18 min resulting in formation of stochastically distributed nanopores in the form of truncated cones with base diameter of 200÷300 nm at the Si/PI boundary and 500-700 nm on the top.

Further treatment of the samples included the deposition of fullerite by precipitation from a saturated toluene solution. A continuous C_{60} layer has been formed on the sample surface and in ion tracks, similarly to previous works [4,7]. For a comparison, another structure consisting of SiO_2 layer covered with the fullerite on p-Si substrate has been fabricated.

A series of current-voltage characteristics under the influences of humidity and temperature has been measured with the use of a climate chamber HC0020 (Voetsch, Company). Electrical measurements were performed using a electrometer Keithley 617 with a testbox Keithley 8002A, specially designed for high ohmic samples. Electrical contacts were made with a special conducting Ag paste. The sketch of samples is given in Fig. 1.

2. Results and discussion

Measurements of current-voltage (I/U) characteristics have been made with an account of the concept of tunable electronic material with pores in oxide of semiconductors (TEMPOS) [3-6]. TEMPOS structures, depending on the preparation details, may resemble the features of resistors, capacitors, diodes, transistors, photocells or sensors. It is worth noting that similar I/U characteristics under the influence of humidity were observed earlier [4] on the TEMPOS samples consisting of a SiO_2 layers with ion tracks covered with continuous fullerite layers on Si substrates. This structure has got the name of MOSBIT (moistutre sensor with buckminsterfullerene in the tracks).



a) b)

Figure 1. Principal sketch (a) and SEM image (b) of the TEMPOS (MOSBIT) structure based on the p-Si/PI/C_{60} nanosystem with etched SHI tracks.

I/U characteristics of the p-Si/PI/C_{60} samples with SHI tracks up to 15 V have shown the expressed sensitivity with respect to humidity and temperature both in the negative and positive voltage range (Fig. 2). The similar effects were observed for the p-Si/SiO_2/C_{60} system without SHI tracks, but they were much smaller. Possibly, this observation can be connected with a fact that the fullerite layer was evaporated but not chemically deposited on the PI surface.

The observed I/U characteristics turn towards the behavior of antiparallel Schottky-type double diodes. A complex behavior of the I/U curves upon humidity, may indicate that two mechanisms might play the key role: the mobility of H^+ and OH^- ions within the fullerite lattice at high voltages and electrochemical corrosion of the fullerite in humid environment, which makes the MOSBIT structure like a galvanic battery [4,5].

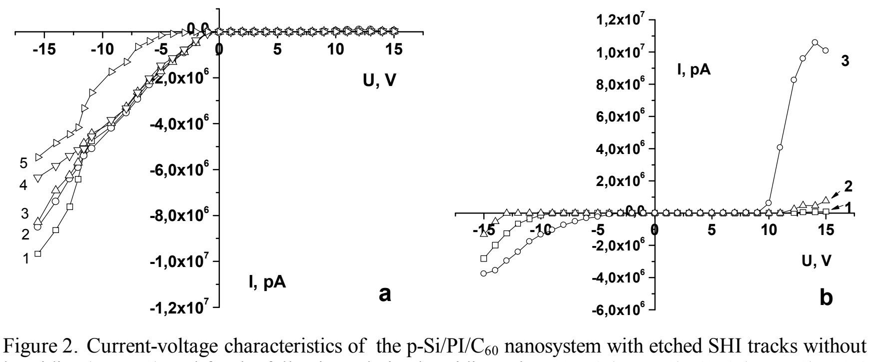


Figure 2. Current-voltage characteristics of the p-Si/PI/C_{60} nanosystem with etched SHI tracks without humidity (curve 1) and for the following relative humidity values: 20% (curve 2), 40% (curve 3), 80% (curve 5), 100% (curve 6) (a), and current-voltage characteristics of the C_{60}/PI(tracks)/p-Si sample at temperatures: 20°C (curve 1), 40°C (curve 2), 60°C (curve 3) (b).

The temperature dependence of I/U characteristics for the p-Si/PI/C_{60} nanosystem with etched SHI tracks is rather complicated in the present research. The most clear current rise is observed only at 60ºC. This current increase can indicate narrowing of the energy band gap due to diffusion of silver from the contacts into the fullerite and formation of C_{60}-Ag compounds, which should facilitate the current transport.

3. Conclusion

On the basis of the above results, one can suggest the development of the prototypes of nanosized resistors, thermoresistors and humidity sensors. In a TEMPOS (MOSBIT) device of 1 cm^2 area, typically ~ 10^6 to 10^8 of such nanodevices would operate simultaneously and parallel to each other.

Acknowledgments

The authors are grateful to Mr. A. Heinzig from the Semiconductor and Microsystems Technology Laboratory of the Dresden University of Technology for the scanning electron microscopy characterization of experimental samples. The present work was supported by German Academic Exchange Service "DAAD" and Belarusian Foundation for Basic Research, Grant No.T08MC-043.

References

1. *Ion Irradiation of Polymers: Fundamentals and Applications*, Springer Series in Materials Research, **65**, Ed. by D. Fink (Springer, Berlin/Heidelberg, 2004).
2. D. Fink, A. Petrov, W.R. Fahrner, K. Hoppe A.S. Berdinsky *et al*., *Nuclear Instrum. Meth. Phys. Res. B* **218,** 355 (2004).
3. D. Fink, P.S. Alegaonkar, A.V. Petrov *et al., Int. J. Nanosci.* **4,** 965 (2005).
4. D. Fink, A. Chandra, A. Berdinsky, A. Petrov *et al*., *Radiation Effects and Defects in Solids* **162,** 151 (2007).
5. K. Hoppe, W.R. Fahrner, D. Fink, A. Petrov, A. Chandra *et al*., *Nucl. Instrum. Meth. Phys. Res. B* **218,** 355 (2008).
6. A.S. Berdinsky, Yu.V. Shevtsov, A.V. Okotrub, D. Fink *et al*., *Chem. Sust. Devel.* **8,** 141 (2000).