ION-TRACK BASED SENSORS

Anuradha Sharma*

Mamta Sharma**

ABSTRACT

The sensor market is rapidly growing. With the increasing demand for better sensors of higher sensitivity and greater selectivity, intense efforts are being made to find more suitable materials with the required surface and bulk properties for use in gas sensors. Detection and quantification of gaseous species in air as contaminants (polluting gases) at low cost is becoming important. The present demand for sensors is not limited to gas sensors only. Scientists are already looking for better Physical, chemical and biological sensors and have obtained considerable success in the past few decades.

Keywords: *ion track, nanodevices, sensors, physical, chemical, biological, TEMPOS, tunable electronics*

*Deptt. of Humanities and Applied Sciences, YMCA University of Science and Technology, Faridabad, Haryana, India

**Department of Materials & Metallurgical Engineering, PEC University of Technology, Chandigarh, India;

1. INTRODUCTION

Over the past 20 years, a great deal of research effort has been directed toward the development of small dimensional sensing devices for practical applications ranging from toxic gas detection to manufacturing process monitoring. However, many of these efforts have not yet reached commercial viability because of problems associated with the sensor technologies applied to gas-sensing micro-systems. Inaccuracies and inherent characteristics of the sensors themselves have made it difficult to produce fast, reliable, and low-maintenance sensing systems comparable to other micro-sensor technologies that have grown into widespread use commercially. At present, the car industry has the maximum use for sensors, followed by the product processing industry, household and office equipment production, construction, machine building and aerospace industry [1]. Both sensor electronics and track-based-nano-electronics are rapidly developing areas of science and technology. Ion track based technology has been promising in the making of miniaturized sensors of all types. For this both latent and etched ion tracks can be employed.

In the last few years, a new type of electronics, based on etched tracks in insulators formed by individual or multiple swift heavy ions has been introduced. Due to the possibility of inserting any (semi)conducting material into these tracks, various active and passive electronic devices have been created. As many of these structures have sensing properties intelligent sensors have been made. One of them, TEMPOS (Tunable Electronic Materials with Pores in Oxide on Silicon) structures is currently the topic of an ever-increasing number of publications. They are a family of novel electronic structures realized on ion tracks, created by the impact of swift heavy ions of energy of the order of few hundred MeV onto dielectric layers such as SiO_2, SiON etc. on Si wafers, with subsequent etching [2]. Considerable work on sensors has been done using ion track based technology and need for a comprehensive review is thus felt. The present article throws light on ion track based physical, chemical and biological sensors.

2. LATENT ION TRACK BASED SENSORS

The radiochemical changes taking place along latent tracks can be utilized to make sensors. Radiochemical changes along the ion tracks in, e.g. polycarbonate lead to an increase of -OH and other groups to which protons from the ambient readily bond transiently, thus giving rise to a slightly enhanced conductivity. This signifies that such a material acts like a hydrogen sensor [3]. By combining ion track technology with ordinary low-resolution printed circuit board lithography it is possible at low cost to create high aspect ratios via

connectors, as solid plugs or consisting of bundles of sub-micron connector wires at a small total cross-section. Ion track enabled microwave circuits in flexible printed circuit boards are suggested to be used in applications like inductors, ferromagnetic resonance microwave filters, circulators and magnetoresistive sensors. Mikael Lindeberg et.al. have used two different flexible polyimide-based foils (Espandex and Kapton HN) in their work [4].

3. ETCHED ION TRACK BASED SENSORS

Various materials have been embedded in etched tracks and thus provide applications as physical, chemical and biological nano-sensors [5].

3.1 Physical sensors

The physical sensors can sense changes in variables like **voltage**, **temperature, pressure, light intensity** and **magnetic field intensity** etc. Ion-track-based **temperature, pressure and light sensors** have been built with fullerene as sensing material. In this case the proper choice of the contact material is important as many metals react with C_{60} to form compounds. Chromium and gold have been found to be the most suitable materials [6]. As the I/V characteristics of TEMPOS structures depends on the material which is inserted within the tracks, C_{60} filled TEMPOS structures have been found to be sensitive to **pressure**. TiO_2 filled in the etched tracks of TEMPOS structures can make them record the **photocatalytical** activity of anatase [D. Fink, Novel Ion Track-Based Electronic Structures – An Overview (ISL Information, HMI Berlin, 2005) 2-5]. Zn-phtalocyanine TEMPOS structures have been found to be good **photo** sensors. With increase in light intensity the rise of current is observed depending upon the gate voltage between the surface contacts [7].

Methacryloyl-L-alanine methyl ester (MA-L-AlaOMe)/diethyleneglycol-bis-allylcarbonate (CR-39) solution cast films (100μm thick) irradiated with gold ions and etched with NaOH solution act as good temperature sensors. They swell and shrink reversibly in water between **temperature** ranges 60°C to 0°C. The swelling capacity of the films increases with increasing MA-L-AlaOMe content [8]. A nanowire consisting of alternating layers of a magnetic and a non-magnetic metal, e.g. cobalt and copper serve as self-contacting **magnetic field** sensors. Based on the giant magnetoresistance (GMR) effect, its electrical resistance decreases quadratically with increasing magnetic field. It is produced by electrochemically filling an etched track nanochannel contained in a thin polycarbonate foil films of thickness 30 μm. The films are first irradiated with heavy ions by applying a flux of 10^8 ions cm^{-2}. The tracks thus formed are preferentially etched in sodium hydroxide solution to prepare cylindrical nanochannels. $Co_{81}Cu_{19}$ alloy nanowires are electrodeposited, while Co/Cu

multilayered nanowires, consisting of alternating Co and Cu layers are synthesized by means of a pulse plating technique in the channels. $Co_{81}Cu_{19}$ alloy nanowires show an anisotropic magnetoresistance effect and the giant magnetoresistance of Co/Cu multilayered nanowires is appreciable [9].

A conically shaped nanopore in a polyethylene terephthalate (PET) foil can behave as **voltage** sensor. The pore is produced by irradiation of the foil with a single heavy ion and subsequent etching in alkaline solution. The resulting pore functions as a voltage gate and rectifies ion current due to changes of its diameter in an electrical field. Ion currents through the pore show voltage-dependent fluctuations, whose kinetics are similar as in voltage-gated biological ion channels and pores [10]. There is a technique by which it is possible to produce a planar sensor for ion channel electrophysiology from glass substrates. Apertures with diameters in the low micrometer to submicrometer range are achieved by irradiation of a glass chip with a single heavy ion and subsequent wet track etching. The function of the device is demonstrated by recordings of single channel currents mediated by the model ion channel gramicidin A in lipid bilayers spanning the micromachined aperture [11].

3.2 Chemical sensors

The chemical sensors can sense **moisture, alcohol, acetone, hydrogen, ammonia, oxygen** etc. First ion-track-based sensors have been developed especially for oxygen as some biochemically important materials to be detected react with the enzyme glucose oxidase towards H_2O_2 which is transformed to water by anodic oxidation [12]. Such sensors can be realized in miniaturized form according to the following redox equation which describes a change of the oxidation state induced by charge transfer according to:

$O + ne^- \rightleftharpoons R$, where O is the oxidant, R is the reductant, e^- is the elementary charge and n is the number of electrons transferred per reaction. This charge transfer takes may take place at the sensor electrodes which can be produced as e.g. Au nanotubules [13]. If oxygen is to be probed, the latter is reduced at a cathode to hydroxide. Both Zn-phtalocyanine and C_{60} based TEMPOS structures have been found to be good humidity sensors.

TEMPOS structures inserted with both polymer electrolytes and semiconductor dispersed polymer electrolytes are good humidity and ammonia sensors. This behaviour is mainly due to the increased number of protons available on the exposure to the above gases. Their selectivity, sensitivity, reversibility and response time are moderately good [14, 15].

Microporous/nanoporous polymer foils with parallel pores have found applications as sensors. Solutions of organometals can either be intimately mixed with polymer solutions that

are subsequently dried and ion irradiated or they can be filled into etched tracks and then destroyed in situ by ion irradiation. Tin oxide layers that act as alcohol sensors are obtained by spin coating of Sn-ethylhexanoate solution doped with a, Sb, Pt or Ag compounds onto a substrate [16].

A sensor capable of detecting single DNA molecules has also been made. The sensor is based on a single nanopore prepared in a polymer film by a latent ion track-etching technique. For this purpose, a polymer foil was penetrated by a single heavy ion of total kinetic energy of 2.2 GeV, followed by preferential etching of the ion track. DNA molecules were detected as they blocked current flow during translocation through the nanopore, driven by an electric field. The nanopores are highly stable and their dimensions are adjustable by controlling etching conditions. For detecting DNA, conical nanopores with opening diameters of 2 μm and 4 nm were used. The nanopore sensor was able to discriminate between DNA fragments of different lengths [17].

3.2 Biological sensors

The biological sensors can sense the **germs, viruses, proteins, hormones, enzymes, sterilizing efficiency** etc.). Lately, a new type of protein biosensor based on a single conically shaped gold nanotube embedded within a polymeric membrane prepared by the track etching technique has been reported [18]. There are several applications of biosensors in food analysis. In food industry optic coated with antibodies are commonly used to detect pathogens and food toxins. The light system in these biosensors has been fluorescence, since this type of optical measurement can greatly amplify the signal.

In many industries gases have become increasingly important as raw materials and for this reason among others it has become very important to develop highly sensitive detectors. Such devices should allow continuous monitoring of the concentration of particular gases in the environment in a quantitative and selective way. With the advent of latest technology more advanced gas sensors will be fabricated in the future.

REFERENCES

[1] A. V. Petrov, D. Fink, G. Richter, P. Szimkowiak, A. Chemsedine, P. S. Alegaonkar, A. S. Berdinsky, L. T. Chadderton and W. R. Fahrner, Creation of nanoscale electronic devices by the swift heavy ion technology, 4th Siberian Russian workshop and tutorials EDM 2003, 1-4 July, Erlagol, 40-45.

[2] D. Fink, A. V. Petrov, K. Hoppe, W. R. Fahrner, R. M. Papaleo, A. S. Berdinsky, A. Chandra, A. Chemseddine, A. Zrineh, A. Biswas, F. Faupel and L. T. Chadderton,

Etched ion tracks in silicon oxide and silicon oxynitride as charge injection or extraction channels for novel electronic structures, Nucl. Instr. Meth. in Phys. Research B, 218 (2004) 355-361.

[3] D. Fink and L. T. Chadderton, Ion-solid interactions: current status, new perspectives, Radiat. Eff. Def. Solids, 160 (2005) 67-83.

[4] Mikael Lindeberg, Hanna Yousef, Erik Öjefors, Anders Rydberg and Klas Hjort, Materials Research Society, 2004.

[5] [D. Fink and L. T. Chadderton, Ion-solid interactions: current status, new perspectives, Radiat. Eff. Def. Solids, 160 (2005) 67-83].

[6] A. V. Petrov, D. Fink, G. Richter, P. Szimkowiak, A. Chemsedine, P. S. Alegaonkar, A. S. Berdinsky, L. T. Chadderton and W. R. Fahrner, Creation of nanoscale electronic devices by the swift heavy ion technology, 4th Siberian Russian workshop and tutorials EDM 2003, 1-4 July, Erlagol, 40-45.

[7] A. Petrov, D. Fink, W. Fahrner, K. Hoppe, S. Demyanov, A. Fedotov and A. Zrineh, Sensors on the base of Zn-phtalocyanine TEMPOS structures, Sixth International Symposium on Swift heavy ions in Matter SHIM 2005.

[8] [M. Tamada, M. Yoshida, M. Asano, H. Omichi, R. Kakaki, R. Spohr and J. Vetter, Thermoresponse of ion track pores in copolymer films of methacryloyl-L-alanine methyl ester and diethylene glycol bisallyl carbonate, Polymers, 33 (1992) 3169-3172].

[9] T. Ohgai, K. Hjort, R. Spohr and R. Neumann, Electrodeposition of cobalt based ferro-magnetic metal nanowires in polycarbonate films with cylindrical nanochannels fabricated by heavy-ion-track etching, J.Appl. Electrochem., 38 (2008) 713-719.

[10] Z. Siwy, Y. Gu, H. A. Spohr, D. Baur, A. Wolf-Reber, R. Spohr, P. Apel and Y. E. Korchev, Rectification and voltage gating of ion currents in a nanofabricated pore, Europhys. Lett., 60 (2002) 349-355.

[11] N. Fertig, Ch. Meyer, R.H. Blick, Ch. Trautmann and J.C. Behrends, Microstructured glass chip for ion - channel electrophysiology, Phys. Rev. E 64 (2001) 040901].

[12] A. Schulz, Miniaturized Clarc sensors for oxygen determination in solution, Product information, 2000-2002, SDK-Technik GmbH, Quedlinburg, Germany.

[13] A. V. Petrov, D. Fink, G. Richter, P. Szimkowiak, A. Chemsedine, P. S. Alegaonkar, A. S. Berdinsky, L. T. Chadderton and W. R. Fahrner, Creation of

nanoscale electronic devices by the swift heavy ion technology, 4th Siberian Russian workshop and tutorials EDM 2003, 1-4 July, Erlagol, 40-45.

[14] M. Saroch, S. Srivastava, S, D. Fink, A. Chandra, TEMPOS devices as humidity sensors. Radiat. Eff. Def. Solids, 163 (2008) 645-653.

[15] Mamta Saroch, Sunita Srivastava, Dietmar Fink and Amita Chandra, Room Temperature Ammonia Gas Sensing Using Mixed Conductor based TEMPOS Structures, Sensors, *8*(2008) 6355-6370.

[16] D. Fink (Editor), Fundamentals of Ion Irradiated Polymers, Volume 63 (Springer Series in Materials Science, ISBN 3-540-04027-7, 2004

[17] Abraham Mara, Zuzanna Siwy, Christina Trautmann, Jackson Wan, and Fredrik Kamme, An Asymmetric Polymer Nanopore for Single Molecule Detection, Nano Letters, *4* (2004) 497–501.

[18] Z. Siwy, L.Trofin, P. Kohli, L. A. Baker, C. Trautmann and C. R. Martin, Protein Biosensors based on biofuctionalized conical gold nanotubes, J. Am. Chem. Soc., 127 (2005) 5000-5001.