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Electrical Properties of Gamma-rays Exposed 1D Nanostructures

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Electrical properties of matter has a very significant role in characterization of a particular material to utilize it for device applications. One-dimensional nanostructures play an important role as interconnects in nanoscale based electronic devices. Hence, the flow of electric current is a very significant parameter to control the quality of electronic device. The electrical conductivity of nanomaterials is found to vary with diameter of 1D nanostructures. However, keeping the diameter of 1D nanostructures constant, and exposing them to radiations can also cause reduction in their electrical conductivity. In present work, we analyzed the consequence of gamma rays induced variation in current voltage characteristics and hence the electrical conductivity of 1D silver and zinc nanostructures. We synthesized the 1D silver and zinc nanostructures via TEMs and exposed them to gamma radioactive Cobalt-60 source. In the post exposure cases, I-V characteristics (IVC) are found to be severely affected that indicates the dampening of electronic flow across nano-needles. And around 2 Volts of applied potential difference, electronic flow across 1D nanostructures approaches to zero, however, a little variation in the potential is observed in different cases of irradiation with no specific pattern.

Keywords: Electrical Conductivity, Gamma Rays, Silver Nanowires, Structural Modification, X-Ray Diffraction (XRD)

1 Introduction

Since their inception, nanomaterials on behalf of their modified physical and chemical properties fascinate the interest of research community. Among different categories of nano materials, nanowires are of particular interest as far as application of nanomaterials in electronic devices is concerned[1] . Physical and geometrical properties of nanowires make them useful for various application in functional devices. Researchers spent enthusiastic efforts to understand the conduction behavior of electrons in metallic nanowires[2-9] .

Electrical conductivity of nanowires is one of the most important aspects of their electrical properties. Grain size in nanowires also has significant role in defining their electrical conductivity. The strength of metal also depends on size of grains and sub-grains[10], well explained on the basis of Hall-Petch equation[11] . Sometimes, during the manufacturing of a material, crystal grains assume certain randomly preferred orientations. Therefore, unless the orientations in a crystal grains are absolutely random, polycrystalline material so formed remain textured with some preffered crystallographic orientations[12] . A change in the granular size and as well as its orientation has a direct effect on electrical, mechanical and other physical properties[13-17] of the material.

The electrical conductivity of 1D nanostructures[18] is found to have a negative impact of the radiation fluence. Based on the experimental observations available in literature[19-23] , irradiation studies inform that materialistic properties get depreciates on bombardment with high energy particles by inducing the mechanism of defect creation[23-24] . Thus, radiation can cause reduction in conductivity and may also source the interruption and hence the errors in programming of the electronic devices. A similar investigation on the silver nanowires has been here. Silver being a costly metal, but emerges out as promising agent in terms of electric conduction, as observed at bulk scale. To cross check the non-linear nature of IVC, we apply similar treatment on Zn nanowires. And surprisingly, similar variation of IVC is observed there. Here, we observe the electrical and structural transformations in post (gamma rays) exposed silver nanowires, fabricated via electro-deposition in polycarbonate membranes.

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2 Materials and Methods

2.1. Synthesis *of 1D Ag Nanostructures*

The Ag nanowires are fabricated in to the pores of polycarbonate (PC) membranes via template-based method[25-27] . We used the PC track etched membranes of cylindrical geometry with pore size 100 nm as templates. Method of electrodeposition is utilized to fill up the membrane pores with silver atoms by fixing membrane on the cathode of electro-chemical cell. Thereby, an array of nanowires is obtained on Cu substrate. The electrolyte used for synthesis is 5 mM silver nitrate. The electro-deposition process is done at a potential (0.43 V) and at a pH of 2.0 for 20 minutes.

2.2. Synthesis *of 1D Zn Nanostructures*

By applying the process of electrodeposition[25], 1D Zn nanostructures of 100 nm diameter synthesized on Cu substrate. Electrolyte used to synthesize Zn nanostructures consists of $ZnSO_4.7H_2O$, NH_4Cl, $Na_2CO_3.3H_2O$ and glucose in milli Q water. A Zn strip of 1 inch×1 inch is taken as anode of the electrochemical cell. The experiment is performed at normal temperature

2.3. Radiation exposure parameters

The synthesized nanostructures of silver are exposed to the diverse doses of photons from radioactive Cobalt-60 source at Inter University Accelerator Centre, New Delhi, India. The radiation doses utilized in the current work are 10, 40, 80, 100 KGy.

2.4. Characterization

Synthesized 1D nanostructures are considered for their current voltage characteristics and spectra of XRD spectra so as to inspect the modifications in their physical properties, before as well as after their exposure to gamma rays. To plot the current voltage characteristics[28] and XRD spectra of original as well as gamma rays exposed nanostructures are obtained via Keithley source meter and Rigaku XRD spectra measuring instrument. To draw the current voltage characteristics, a substrate of copper at the base acts as one of the electrode whereas a steel tip that covers 300 pores at a time is on membrane that embeds 1D nanostructures. Hence, the plotted current voltage characteristics here shows cohesive result of 300 parallel 1D nanostructures. The surface morphology of synthesized pristine 1D nanostructures is observed with SEM.

3 Results and Discussion

On first, I-V characteristics of 1D nanostructures are measured by Keithley source meter. Further, to observe the surface morphology, Cu substrate containing silver 1D nanostructures embedded within the membrane was positioned in to solvent Di-chloro-methane to dissolve the membrane. 1D nanostructures were further cleaned with de-ionized water. SEM image divulges an array of the 1D nanostructures with cylindrical shape which is facsimile to membrane pores (Fig. 1). The SEM image of nanowires also contains some traces of non-dissolved polycarbonate membrane.

The average resistance of nanowires was calculated from slope of observed current voltage graphs (Fig. 2)

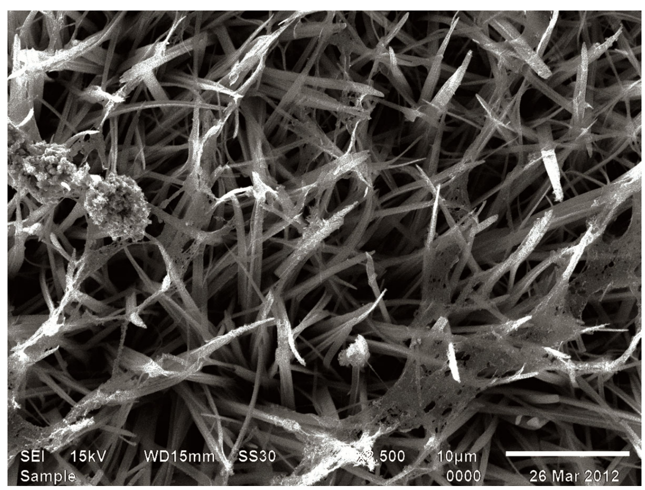

Fig. 1 — SEM image of silver 1D nanostructures.

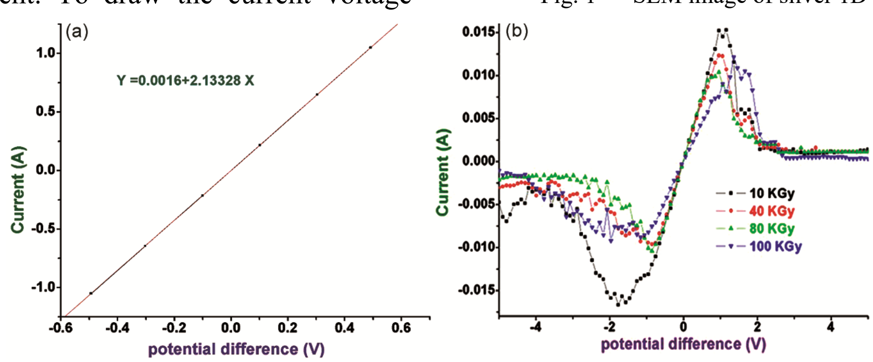

Fig. 2 (a-b) — I-V graphs of (a) pre-exposed, and (b) radiation exposed silver 1D nanostructures.

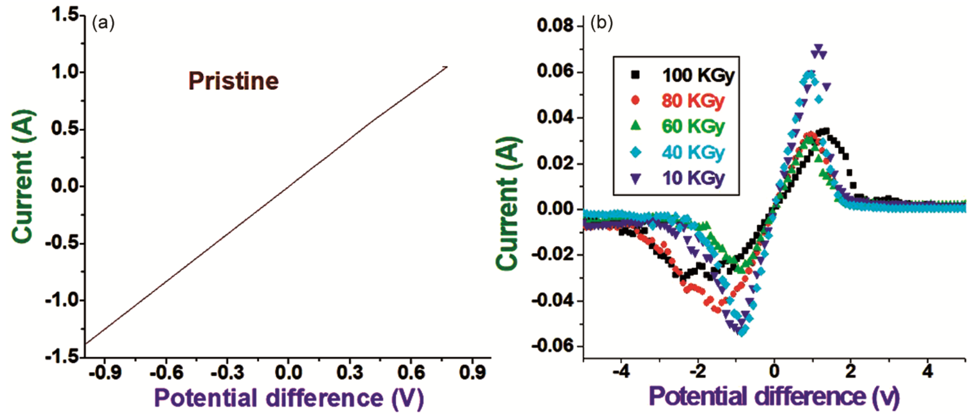

Fig. 3 (a-b) — I-V characteristics of (a) pristine, and (b) gamma ray exposed zinc 1D nanostructures.

indicates the average resistance of 1D nanostructures. For pre-exposure case, the I-V pattern was a straight line. The conductivity (σ) of the 1D nanostructures are evaluated from slope of the linear part of plotted I-V graphs. As the geometrical parameters length and area are constant, therefore the conductivity of pristine nanowires could be estimated from linear portion of the slope of graphs as per Equation (1)

$$\boldsymbol{\sigma} = \frac{\boldsymbol{l}}{\boldsymbol{R.A}} = \frac{\boldsymbol{dI}}{\boldsymbol{dV}} \cdot \frac{\boldsymbol{l}}{\boldsymbol{A}} \qquad \ldots (1)$$

The geometrical parameters of membrane pores and hence the synthesized 1D nanostructures are 10 micron long and diameter 100 nm. The electrical conductivity on behalf of plotted current voltage graphs and calculated for one wire of above-mentioned parameters is found to be 0.239×10^7/ohm*m whereas this value for 3D silver wire is 6.29×10^7/ohm*m. Nearly, 25 times reduction in the conductivity is observed here in case of Ag from bulk to one dimensional material.

The conductivity here for the case of Zn (previously mentioned geometry) is found approximately 1.66×10^7/ohm*m whereas this value for bulk silver wire is 0.091×10^7/ohm*m. Almost 18 times reduction in conductivity of zinc wires is observed from bulk to one dimensional material.

The IVC pattern of gamma rays exposed nanowires were also a straight line, but follow sharp decline in electric current as we increase the applied voltage approximately 1.5 V onwards. As per equation (1) the electrical conductivity of the post gamma irradiated 1D nanostructures is made on behalf of linear part of respective I-V graphs. A straight forward and simple opinion about the decrease of conductivity could be drawn by comparing the scale on y-axis of pre and post gamma rays exposed nanowires.

Table 1 — Conductivity of pre and post gamma-rays exposed silver 1D nanostructures

S. No.	Dose (KGy)	σ_{Ag} (* 10^2/ Ohm cm)	$\sigma_{pristine}/\sigma_{irradiated}$
1	Pristine	239.10	-
2	10	6.01	39.78
3	40	6.04	39.59
4	80	3.68	64.97
5	100	3.12	76.64

Table 2 — Conductivity of pristine and gamma irradiated zinc 1D nanostructures

S. No.	Dose (KGy)	σ_{Zn} (* 10^2/ Ohm cm)	$\sigma_{pristine}/\sigma_{irradiated}$
1	Pristine	91.61	-
2	10	4.32	21.21
3	40	4.22	21.71
4	80	1.21	75.72
5	100	0.98	93.48

The upper limit of source meter i.e., a current of 1.05A through the nanowires is attained at potential difference of 0.6 V (approx.) but the same limit of current was never accomplished even up to 5 Volts instead a sharp turn down of current is evident form experimental observations. The decline in slope of current voltage graphs of gamma irradiated 1D nanostructures[29] indicates more decline in their conductivity (Figures 2(b) & 3(b) and Tables 1 & 2). However, the sharp decline of the current is pragmatic in each case of irradiated nanowires and even carrying out in frequent measurements. Consequently, it seems to have some significance. The non-linear character of the IVC cannot be explained at the moment because no such results has cited in the literature. Further investigations are on in order to draw meaningful conclusions. On the whole, we can say that IVC are not exactly Ohmic but instead a mix of Ohmic and Schottky nature of IVC. The inclusion of Schottky nature in IVC suggests a about the semiconducting behavior of irradiated nanowires.

To assess the structural modifications induced in 1D nanostructures after gamma ray exposure, X-ray spectra are drawn for respective cases (Fig. 4). Different peaks from different family are detected in the XRD pattern which suggests the silver 1D nanostructures are polycrystalline. A strong n peak around 50 degrees ('2 theta') is recorded in almost each XRD spectra that corresponds to Cu substrate acts as base. The Miller indices corresponding to different peaks in the X ray spectra are marked by using the standard JCPDS card: 01-1167. After comparing with this standard card, observed XRD spectra of Ag 1D nanostructures indicates to be cubic unit cell of nanowires with F type lattice having lattice parameter 4.08 angstrom. The "2 theta" positions are almost same in all the cases, but relative intensity variation found to be different in the different XRD spectrum. Whenever, we observe this kind of discrepancy in observed cases, then it is on behalf of the change in the orientation preferred during the synthesis process[30]. The assessment of preferred orientation can be made by calculating their texture coefficient (TC)[31-32] as

$$TC = \frac{I(hkl)}{I_0(hkl)} \Big/ \frac{1}{n} \sum \frac{I(hkl)}{I_0(hkl)}$$

Where I(h k l) here indicates the measured value of relative intensity. And I_0(h k l) is the relative value of intensity of the respective plane in JCPDS card. Whenever the value of texture coefficient for a particular plane (Table 2) is greater than one, it specifies the preference assumed/given at the time of synthesis[33] . We evaluated the preferred orientations that are shown here in the Table 3 as underlined values. However, the grain size on basis of Scherer's equation is almost same and is 31 nm for pre-exposed Ag 1D nanostructures while it fluctuates between 27-32 nm in the irradiated samples.

Poly-crystalline silver 1D nanostructures indicates reduction in the conductivity in post gamma ray exposure cases[34-35] . However, no creation of Frankel defects would be expected due to encounter of photons with atoms in crystal grains. As a well fact, we know that gamma rays interact only with orbital electrons and not with nuclei of atoms, so photons would be unable to eject out atom from its lattice position, but on the account of energy deposited by it in the target material, properties of target material may change. As a fact, it is known that hardness of metals changes upon irradiation[36] and this change in the hardness of metal could be accounted for induced strain in crystal lattice due to gamma ray exposure. Strain induction in the lattice could change the orientation of grain and hence grain properties as also evident from Table 2.

Table 3 — Texture coefficient (TC) of the Miller planes in pre and post gamma irradiated silver 1D nanostructures

planes	pristine	10 KGy	40 KGy	80 KGy	100 KGy
111	0.8	0.4	0.2	-	0.1
200	0.8	1.3	1.8	1.7	2.1
220	0.2	0.2	-	-	-
311	2.1	2.3	2.2	1.3	1.0
222	1.0	0.9	0.8	1.2	1.9

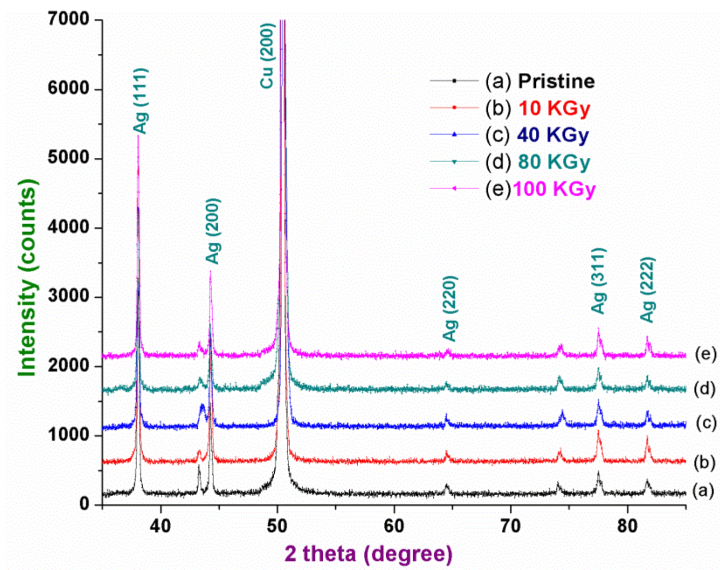

Fig. 4 — X-ray spectrum of (a) pre & post gamma irradiated silver 1D nanostructures with different doses of, (b) 10 KGy, (c) 40 KGy, (d) 80 KGy, and (e) 100 KGy.

It is, therefore, the change in grain properties after gamma ray exposure can be accountable for decrease in their conductivity. For electronic flow through nanowires, electrons have to cross grain boundaries also. One can signify here the dislocations grain boundaries that can hinder the electronic movement. Gamma radiation here, seems not only to harden the material but also segregates the grain boundaries[37] . We are familiar that inter-grain interface is a region of significant resistance as compared to the resistance of intra-grain region. This radiation induced segregation would further increase resistance of the inter-grain regions. This apparent rise in the resistivity could be a reason for inclusion of some sort of Schottky nature of I-V characteristics and not because of formation of defect pairs. With rise in the exposure time and hence the dose of gamma ray photons to 1D nanostructures would consequently increase the of radiation induced grain hardening (increased strain) and grain boundary segregation and hence the resistance between inter-grain boundary regions or alternatively their resistivity.

The observed decrease in conductivity of the 1D nanostrucutres could also be explained from Mayadas and Shatzkes (MS) model that describes the conductivity in nanomaterials[38] . As evident that free path of electrons in silver metal is 52 nm[39] and average grain size calculated here is up around 31 nm, so, the scattering from grain boundaries would dominate over surface scattering. The decrease in electrical conductivity of a nano-material as per the MS model is a consequence of variation in the reflection coefficient (R) of grain boundaries. Hence, we can estimate from present observations that in post gamma irradiation of 1D nanostructures, reflection coefficient of grain margins was increased and hence the diffusive type of scattering of the electrons from grain boundaries. Therefore, in case of gamma irradiated 1D nanostructures, intra-grain resistance would increase that may cause the strengthening of grain boundaries. Consequently, the momentum carried by electrons across the granular boundaries in direction of flow get decreased and hence the electrical conductivity of 1D nanostructures.

4 Conclusion

As a consequence of gamma irradiation, electrical conductivity of the silver 1D nanostructures is examined by drawing their current voltage characteristics. A sharp decline in the IVC indicates inclusion Schottky type of characteristics in Ohmic IVC of gamma irradiated 1D nanostructures. The conductivity of nanostructures is found to be affected inversely due to photons exposure. Modification in the degree of granular orientations of grains was observed when 1D nanostructures are examined from their XRD pattern. Gamma rays induced strengthening of granular boundaries and consequent reduction in their reflection coefficient may be the root for decreased conductivity of silver 1D nanostructures.

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