Optical and electrical characterization of amorphous Si/Ge Layers

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This work reports on the characterization of Si and Ge layers deposited one after another using thermal deposition technique. The I-V characteristics of the Si/Ge samples were studied at different temperatures. The electrical resistance decreases with temperature in the range from 290K to 355K. The activation energy for electrical conduction was 0.31 eV. The temperature coefficient of resistance (TCR) was calculated for different temperatures and it was between 0.028 K^{-1} and 0.043 K^{-1}. Optical absorption was measured for the Si/Ge samples and used to study the optical characteristics. γ-irradiation induced effect on optical absorption of Si/Ge samples kept at room temperature was also investigated. The absorption coefficient increases up to a dose of 15 kGy, further increase of the irradiation dose leads to an opposite behavior. Optical energy gap was found to decrease as a result of γ-irradiation up to a dose of 15 kGy and starts to increase for higher doses.

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1. Introduction

Amorphous semiconductor materials have become of more interest in the last decades because of their physical properties for many applications in the area of optoelectronics, such as the fabrication of solar cells, photoconductors, and other optical devices [1, 2]. One of the interesting compounds in this line is the alloy system of Si-Ge. The advantage of this alloy material is the possibility to vary its band gap with the germanium concentration and thus improving its wavelength response [3–5]. Also, Si and Ge thin films were investigated by many workers for different applications such as thermo-resistive materials in infrared sensors [6-7]. The parameter of importance in thermo-sensitive materials is the temperature coefficient of the resistance (TCR). It measures how the resistance of a material responds to a change in temperature and is given by:

$$TCR = \frac{1}{R}\frac{dR}{dT} = -\frac{E_a}{KT^2} \qquad (1)$$

the resistance as a function of temperature is given by:

$$R(T) = R_0 \exp(\frac{E_a}{KT}) \qquad (2)$$

Where, E_a is the activation energy of electrical conduction, K is the Boltzmann's constant and R_0 is the nominal resistance. The activation energy can be determined from the relation:

$$LnR(T) = \frac{E_a}{K}(\frac{1}{T}) + LnR_0 \qquad (3)$$

by plotting LnR(T) versus 1/T, from the slop E_a can be easily determined. Investigations on the optical behavior of thin films deal primarily with reflection, transmission, absorption properties, and their relation to the optical constants. In the high absorption region of, Tauc [8] and Mott and Davis [9] proposed the following expression for the absorption coefficient:

$$\alpha(\nu)h\nu = B(h\nu - E_{opt})^n \qquad (4)$$

where, α is the absorption coefficient, E_g is the optical energy band gap, hν is the energy of the incident photons, and *B* is a constant. The constant *B* is inversely proportional to the film's amorphousity and is considered as a measure of disorder. The exponent *n* is a constant depending on the type of electronic transitions involved in the absorption process. The energy gap can be determined from plots of $(\alpha h\nu)^{1/n}$ versus hν by extrapolating the linear part and the intersection with the energy axis is E_g. Radiation induced effects due to cosmic environment, nuclear reactors, isotopes in chip packaging materials, or nuclear weapons can degrade semiconductor electronic devices and circuits, both in space and on ground. This is becoming highly important as electronics continue to scale down in size and increase in complexity. In general, after irradiation the occurrence of two main mechanisms can be observed, i.e., ionization damage due to the generation of electron-hole pairs resulting into trapping effects in the device dielectric layers and/or at its interface with the silicon, and displacement damage caused by the displacement of silicon atoms from their regular lattice sites. The amount of damage depends on the irradiation conditions (type of particle, fluence or dose, energy, temperature, etc) and has either a transient or a permanent nature. The aim of this work is to study some optical and electrical characteristics of Si/Ge layers prepared with the described method and the radiation induced optical effects.

2. Experimental

Si/Ge thin films were prepared by successive deposition of 5N purity Si and Ge onto clean dry glass substrates using thermal deposition process. The evaporation process was carried out using an Edwards E306 thermal evaporator, equipped with crystal oscillator thickness monitor for in-situ thickness measurements. Thin film growth process was carried out under a pressure of 10^{-6} torr and substrates were kept at room temperature during the deposition process. The growth rate of the film was about $10ÅS^{-1}$ and the thickness of each layer was 1000Å. The structure of the grown films was examined with XRD using Shimadzu X-ray diffractometer model XD-DI. Films were kept away from the light to avoid any possible effects due to exposure to direct light. Optical measurements, in the spectral range 700nm-1100nm, were carried out at room temperature using a double beam spectrophotometer type Shimadzu UV-VIS-160A. A blank glass substrate was used as a reference to eliminate the substrate effect. The (I-V) characteristics of the Si/Ge samples were measured under controlled equilibrium conditions in the temperature range from room temperature up to about 85^0C. A Keithly 617 electrometer together with a high precision power supply type Philips PE 1536DC were used for measurements. γ-irradiation at different doses was carried out in the cavity of a ^{60}Co γ-irradiator. The dose rate was 5 kGy/h and the temperature of the irradiation cavity was lower than 320K during irradiation.

3. Results

The XRD pattern of the as-deposited Si/Ge sample is shown in figure (1), no sharp peaks characteristic of the crystalline phase were detected and hence confirming its amorphous nature. The temperature dependence of the electrical resistance of Si/Ge films in the temperature range from 290K to 355K is shown in Fig. 2. It is clear from Fig. 2 that the resistance, R, decreases with temperature in the studied range. The activation energy of conduction was found to be 0.31 eV. The temperature coefficient of the resistance, TCR, at different temperatures was also determined using equation (1). Fig. 3 shows the variation of TCR with temperature, which was found to increase linearly with temperature. At room temperature the studied sample has resistance of about 5.3×10^7ohm and TCR of about $-0.042K^{-1}$. The negative sign of the TCR indicates that R decreases with temperature.

In order to determine the optical band gap and the associated radiation induced effects, on the basis of the recorded transparency (absorption) spectra for the studied Si/Ge samples, an analysis was carried out of the absorption coefficient, α, as a function of the energy of incident photons hν, Fig. 4.

The absorption coefficient for each sample increases with the incident photon energy. It can also be seen from Fig. 4 that α increases, in general, with irradiation dose. Also, the absorption edge shifts towards lower energies with irradiation dose up to a dose of 15 kGy. Further increase of dose leads to a shift of the absorption edge towards higher energies. The optical energy gap, E_g, was determined from plot of $(\alpha h\nu)^2$ versus hν, figure (5). E_g was found to be 1.44 eV for the as-deposited sample and decreases to 1.08 eV for the 15 kGy irradiated sample. The optical energy gap then starts to increase with further increase of irradiation dose up to a dose of 50 kGy.

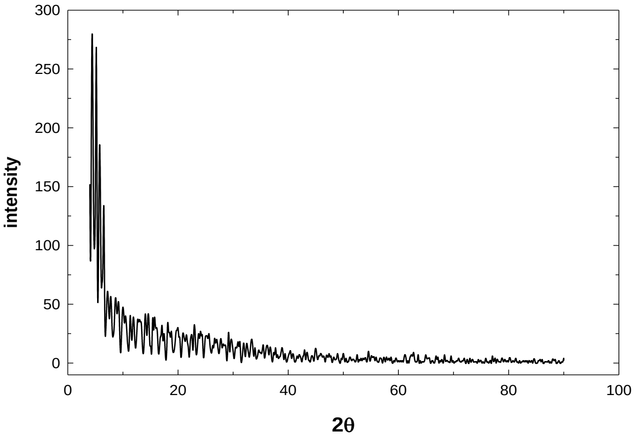

Fig. 1. X-ray diffraction pattern for the as-prepared Si/Ge layers.

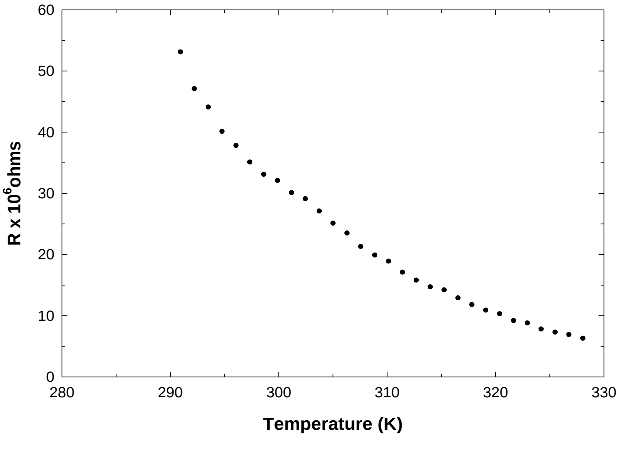

Fig. 2. Variation of the resistance of Si/Ge samples with temperature.

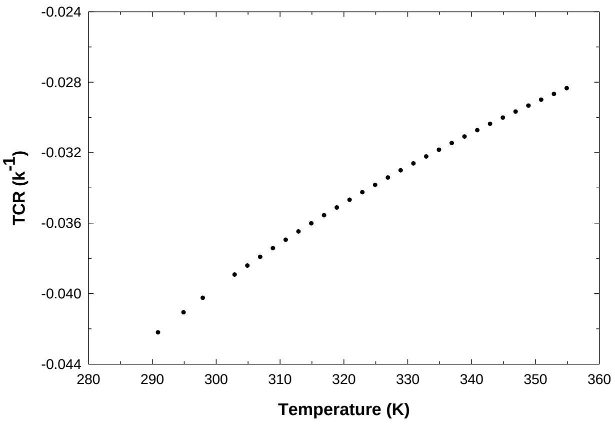

Fig. 3. Variation of the temperature coefficient of resistance, TCR, with temperature.

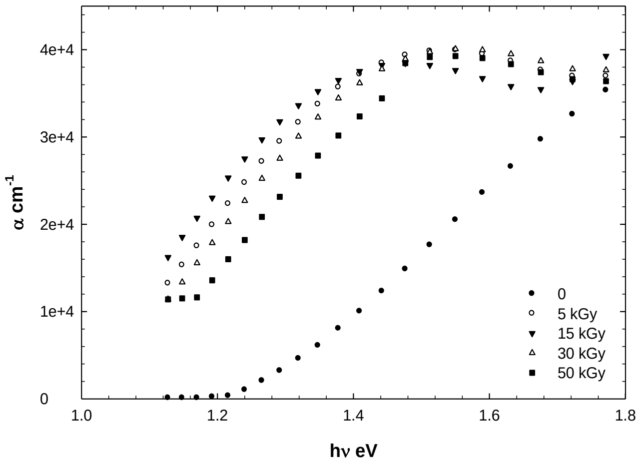

Fig. 4. Variation of the absorption coefficient of the Si/Ge sample with energy of the incident light for as-deposited and irradiated samples.

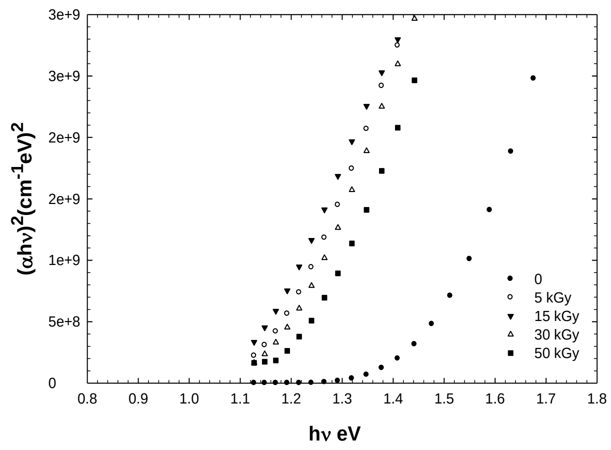

Fig. 5. Variation of $(\alpha h\upsilon)^{1/2}$ with energy of the incident light for as-deposited and irradiated samples.

Table 1.

Dose, kGy	0	5	15	30	50
E_{opt}, eV	1.44	1.1	1.08	1.12	1.16

4. Discussion

The Si/Ge samples in the studied temperature range appear to exhibit activated conduction mechanism, the electrons are excited beyond the mobility edge into extended states. This result is in agreement with the results obtained in ref [10]. Comparing the value of E_g for the as-deposited sample with the activation energy of dc conduction, it is found that $E_g > 2E_a$. This observation is in agreement with the Mott viewpoint that the position of the Fermi level in amorphous materials is not exactly in the middle of the forbidden band because of the differences in the smearing of the valence and conduction bands [9,11], also indicating active participation of localized defect states in electron transfer processes. Upon irradiation of the samples local structural changes take place in the layers. Radiation-induced structural changes may be in the form of bond breaking, bond angle fluctuations and bond rearrangement. The radiation induced structural defects may lead to the increase of the density of localized states into the gap and hence an increase of the depth of localized states tail into the gap. The increase of the density of localized states will consequently increase the transition probabilities and hence may lead to narrowing of the band gap. Decrease of E_g is observed up to a certain dose further increase of the irradiation dose leads to an increase of E_g. The temperature during irradiation is about 50^{o}C. This is not sufficient to cause crystallization or diffusion of the Si and Ge layers. The diffusion coefficient of Si into Ge layers at a temperature of 100^{o}C is ($\approx 10^{-28}$ m^2/s) (Si diffuses much faster in Ge than the Ge in Si layer) [12]. So that, the heating effect during irradiation can not be considered the reason for changes of optical parameters upon irradiation. The increase of the optical energy gap with irradiation doses above 15 kGy might be attributed to structural changes leading to some rearrangement of atoms towards nucleation of crystallization in any of the layers. XRD patterns of the irradiated samples showed no crystallization peaks, which indicates that the nucleation was too tiny to be detected. Irradiation may also have the effect of causing diffusion of the Si and Ge layers at a threshold dose due to the incidence of the energetic photons of the γ-rays. This may lead to changes in optical parameter of the samples.

5. Conclusions

The Si/Ge layers studied in this work have shown some interesting properties regarding the variation of electrical resistance with temperature and radiation induced effects. The room temperature resistance was in the range of other reported work. Also, the temperature coefficient of resistance, TCR, at room temperature is considered good in comparison with results of other materials. This may suggest the possibility of utilizing this system for applications such as bolometry. The results obtained of as-deposited and γ-irradiated samples showed interesting behavior for the optical parameters. For doses up to 15 kGy radiation will cause structural defects leading to increase of randomness and hence decrease of the energy gap. While higher doses may cause some structural order or cause some diffusion of the Si and Ge layers. The optical energy gap of the as-deposited samples was found to be greater than double the activation energy for electrical conduction.

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