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Laser Irradiation Effect on the Optical Properties of $Se_{88}Te_{10}$ Al_2 Thin Films

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Abstract

Laser irradiation effect on optical properties of $Se_{88}Te_{10}Al_2$ thin film has been studied. Thin films have been prepared by physical vapor deposition technique using thermal vapor evaporation unit. Transmission and Absorption spectra has been taken by double beam UV-VIS spectrophotometer. He-Ne laser has been used as irradiation source. Optical Analysis of thin films indicate indirect allowed transition and the optical band gap (E_g) decreases with increasing irradiation time. It is also observed that laser irradiation of 30 minutes time interval changes all optical constant harmonically. Such irradiation effect can be utilize in device applications for laser activated switches and memories.

Keywords: Laser Irradiation; Chalcogenide Glasses; Thin films; Irradiation effect; optical properties.

1. Introduction.

Recently, there has been an increasing interest in chalcogenide thin films due to their exceptional properties, which are remarkably different from the corresponding bulk materials [1-5]. Chalcogenide materials have wide range of technical importance in various solid-state devices. These materials have wide range of transparency in the far infrared region, making them interesting material for various applications. The interest in these materials is principally due to low phonon energy, extended infrared transparency, high refractive index, high photosensitivity, in reversible phase change optical recording etc [6-9]. Because of these properties, chalcogenide thin films are interesting candidates for applications in the integrated optics, thermoelectric and solar cell applications [10-12].Se-Te based alloys have created extreme interest due to their greater hardness, higher photosensitivity, higher crystallization temperature, and lower aging effects as in comparison to pure amorphous Se [13, 14].

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As addition of Te into Se improves the corrosion resistance [15] therefore, Se-Te based alloys are thought to be promising media and used to extend the utility of a-Se. Selenium–Tellurium based semiconductors have been the focus of interest in thin film form because of their properties suitable for device applications [16, 17]. These materials are optically non-linear and sensitive to the laser irradiation [18-20]. In the latest decade, many efforts have been done on the research of laser irradiation effect [21–29] on optical materials. The lifetime of optical elements in high power systems mainly depend on laser-induced damage of optical materials [30]. Absorption and luminescence are two significant methods which have been used in the research of laser-matter interaction. The material absorbs energy from the laser pulse and produces an ionized region that gives rise to broadband emission [31].The absorption of laser irradiation in chalcogenide thin film depends strongly on their electronic structure which in turn changes by the interaction with photons. The most important applications of chalcogenide are now in the field of optics [32 -37] and arising mainly from their exhibited infrared transmitting properties [38, 39]. The energy of the light quanta is expected to induce qualitatively new changes.

The aim of the present work is to synthesize $Se_{88}Te_{10}$ Al_2 Thin Filmsand to investigate the laser irradiation effect on optical properties of these films. This includes laser irradiation effect on important optical parameters such as; Absorbance, Transmission, Reflectance, Absorption coefficient, optical band gap, extinction coefficient, refractive index, real and imaginary part of dielectric constant.

2. Material and Methods

Alloy of $Se_{88}Te_{10}Al_2$ has been prepared by melt quenching technique. Highly pure (99.999%) source materials with desired compositional ratio of elements has been sealed in a quartz ampoules under a vacuum of 10^{-5} torr. The sealed ampoules are kept inside a programmable furnace where the temperature is raised up to 1200 K at the rate of 5 K / minute for 10 hours with frequent rocking to ensure the homogenization of the melt. The quenching has been done in ice-cool water. As-quenched Alloy has been grounded and the resulting fine powder has been used to prepare the thin films by Physical vapour deposition method. Thin films of $Se_{88}Te_{10}Al_2$ alloy of thickness 500 nm has been deposited on a well cleaned glass substrate in the shape of squares at room temperature and in a vacuum of $\sim 10^{-5}$ torr. Films have been kept inside the deposition chamber under vacuum for 24 h to achieve metastable equilibrium. The thickness of the film has been measured under a single-crystal thickness monitor. He-Ne laser with wavelength 632.8 nm has been used as irradiation source. The thin films have been irradiated for four different time duration of 30, 60, 90 and 120 minutes. Thin film has been placed in a specially designed sample holder, which kept at a distance of 10 cm from output laser head. For irradiation a spot of 5 mm diameter has been adjusted by focusing lens. Double beam UV/VIS/NIR Scanning Spectrophotometer (UV1900) has been used for optical measurements of the thin films. The optical spectrum has been measured as a function of wavelength (200-1100 nm) of incident light.

3. Results and discussion

Absorption spectrum of $Se_{88}Te_{10}Al_2$ with and without irradiation has been showed in figure 1. It can be seen that laser irradiation causes significantly changes in absorption edge. Absorbance has been decreases after laser irradiation however there are no well-defined pattern with laser irradiation time. A close look of absorption with irradiation time reveals an alternate relation of being increasing and decreasing absorption at every 30 minutes of irradiation time interval. This harmonic pattern of absorption with irradiation time can be seen in inset pic of figure 1 which is measured near absorption edge at 700 nm and given in table 1.

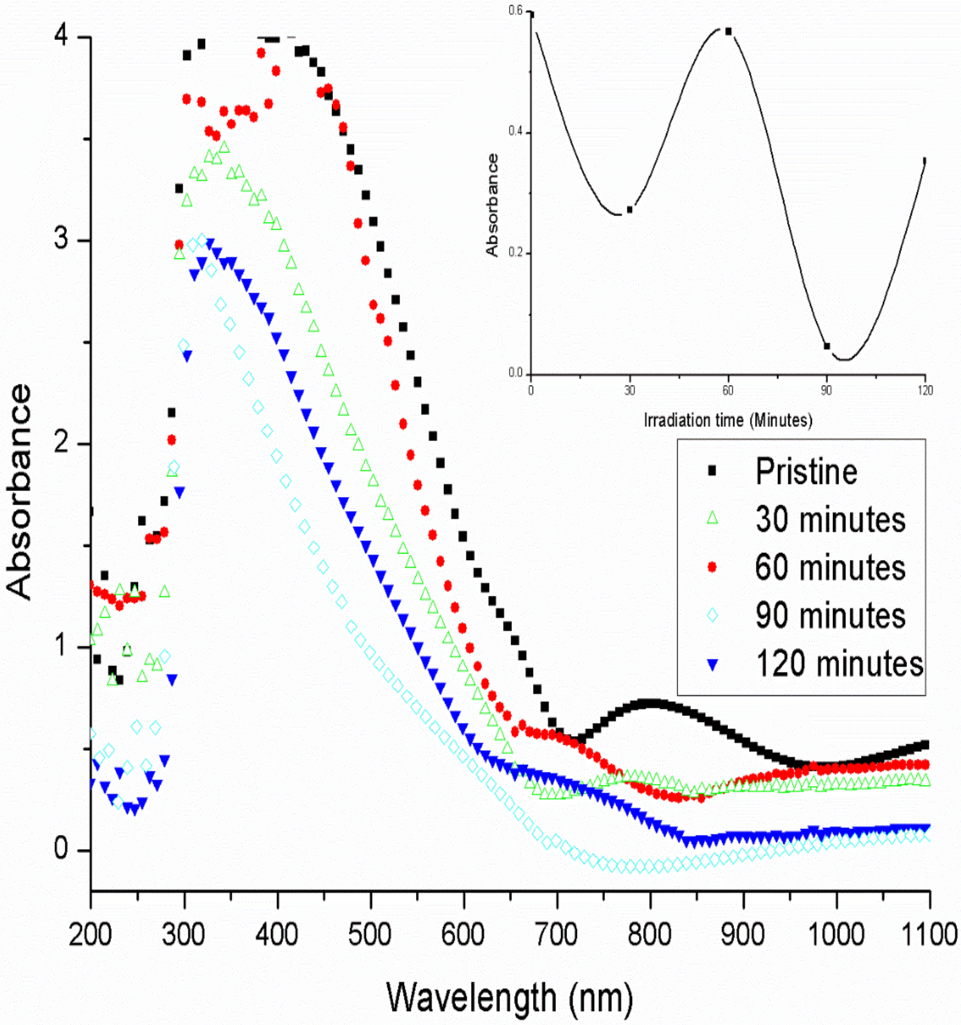

Figure 1: Variation of Absorbance with wavelength for $Se_{88}Te_{10}Al_2$ with and without laser irradiation.

Table 1: Absorbance of $Se_{88}Te_{10}Al_2$ with and without laser irradiation at 700 nm

Sample (s)	Pristine sample	Irradiated sample			
		30 minutes	60 minutes	90 minutes	120 minutes
Absorbance	0.5952	0.2722	0.5677	0.0468	0.3535

Transmittance spectrum of these films before and after laser irradiation has been shown in figure 2.Transmittance is almost zero up to 500 nm and then started increasing with increasing wavelength. It suggests that this material can be used as blocking film for wavelength up to 500 nm. Analysis of spectrum reveals that laser irradiation with a time duration of 30 minutes produces harmonic pattern in transmittance as shown in inset figure 2.

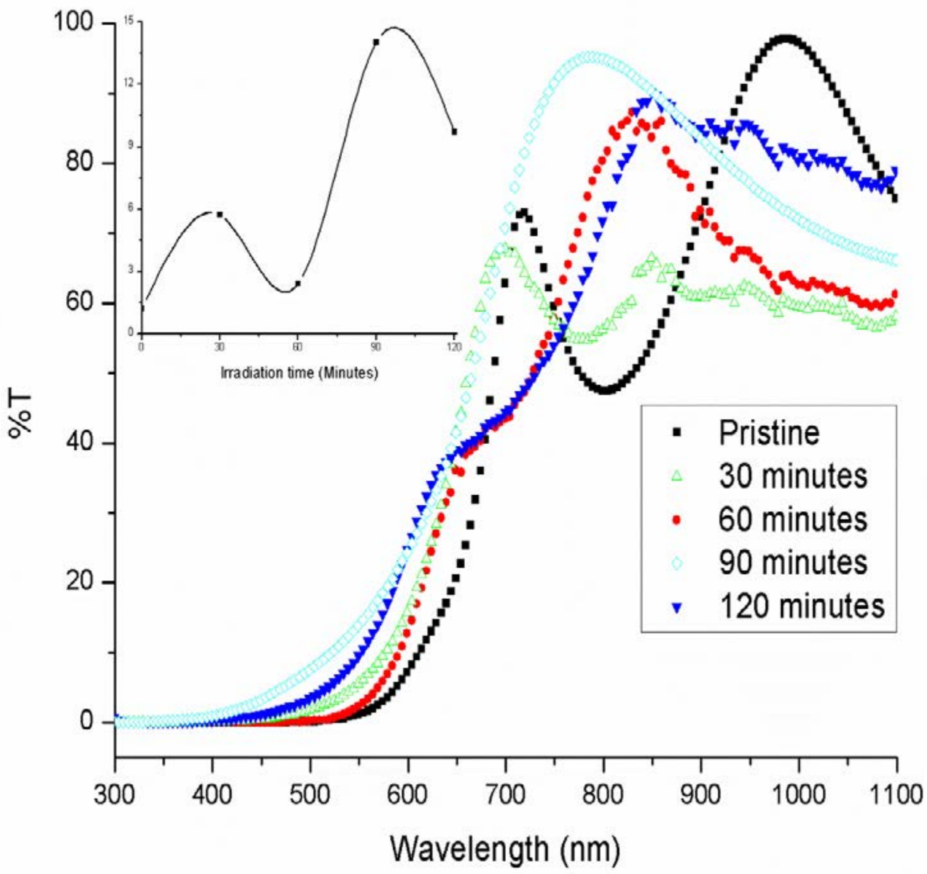

Figure 2: Variation of Transmittance with wavelength for $Se_{88}Te_{10}Al_2$ with and without laser irradiation.

Table 2: %Transmittance of Se88Te10Al2 with and without laser irradiation at 550 nm

Sample (s)	Pristine sample	Irradiated sample			
		30 minutes	60 minutes	90 minutes	120 minutes
% T	1.2063	5.7195	2.4139	14.0159	9.7256

Reflectance of thin films can be calculated as below [40]-

$$R = 1 - A - T$$

Reflection spectra for $Se_{88}Te_{10}Al_2$ thin films before and after laser irradiation has been shown in figure 3. Laser irradiation effect with time on reflectance can be seen from inset figure 3.

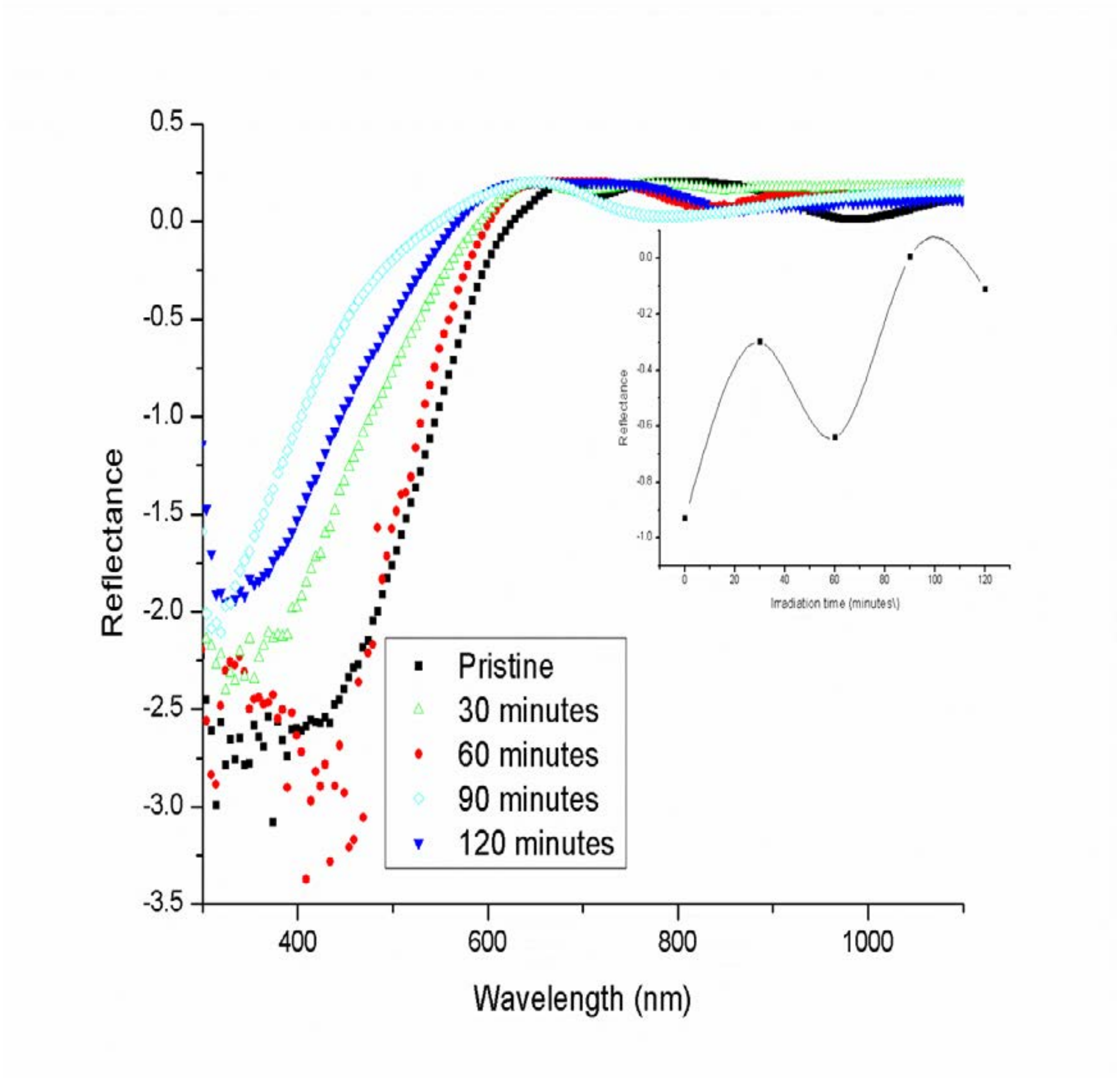

Figure 3: Reflectance of $Se_{88}Te_{10}Al_2$ with and without laser irradiation

Here also irradiation of 30 minutes time interval produces harmonic effect in reflectance. Values of reflectance with different irradiation time is given in table 3 below.

Table 3: Reflectance of $Se_{88}Te_{10}Al_2$ with and without laser irradiation at 550 nm

Sample (s)	Pristine sample	Irradiated sample			
		30 minutes	60 minutes	90 minutes	120 minutes
R	-0.93061	-0.29984	-0.64143	0.00646	-0.10934

Absorption coefficient α can be calculated as – [41, 42]

$$\alpha = \frac{OD}{t}$$

Where OD is optical density and t is thickness of film in cm. The relation between absorption coefficient and photon energy is shown in figure 4 below.

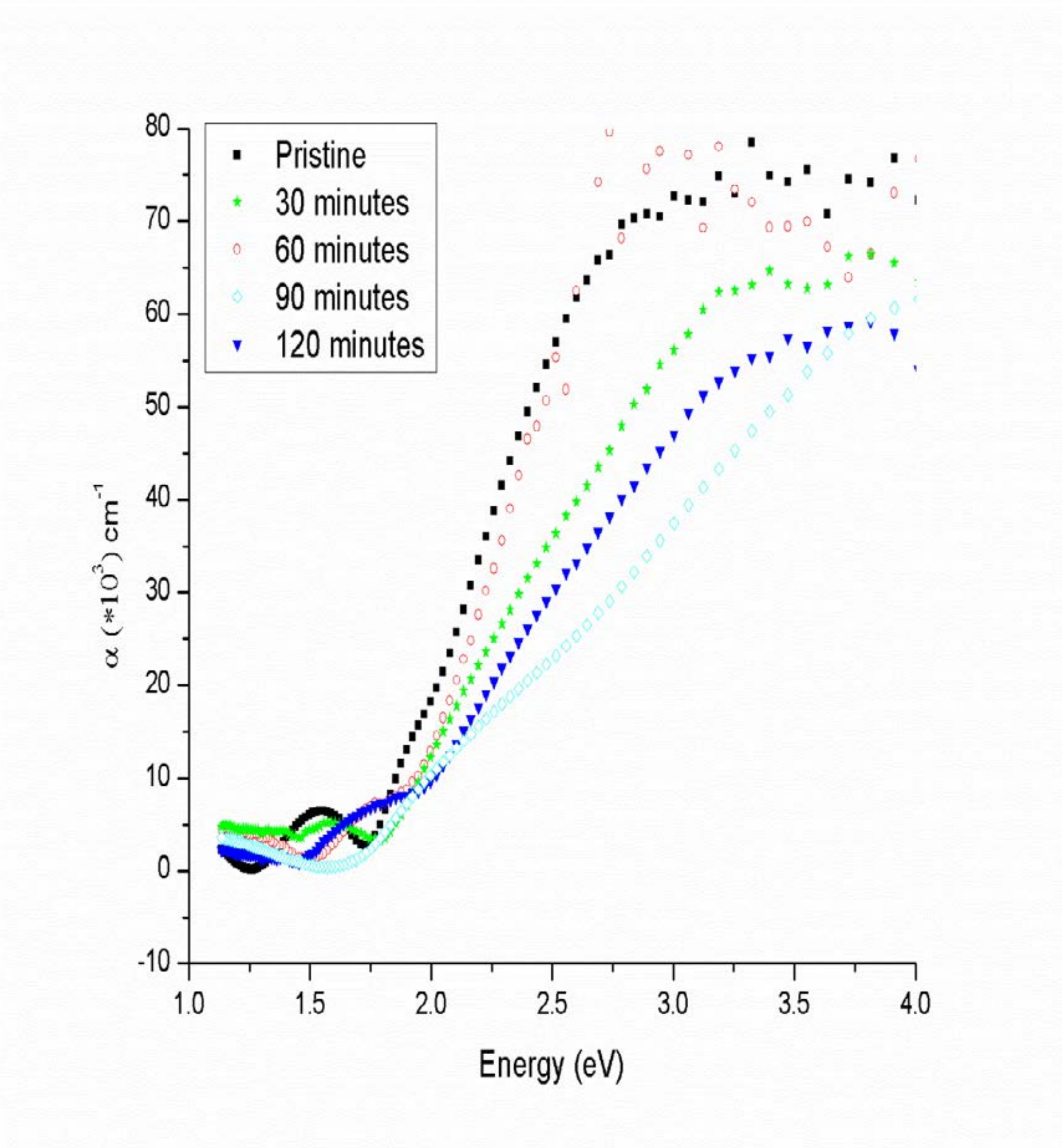

Figure 4: Variation of absorption coefficient with photon energy for

$Se_{88}Te_{10}Al_2$with and without laser irradiation.

Optical energy gap Eg can be calculated by following expression [43-45]

$$\alpha h\nu \quad = \quad A\left(h\nu - E_g\right)^n$$

Where A is the constant, E_g is the optical energy gap of the material and n is a number which characterizes the transition process involved, n has the value $1/_2$ for the direct allowed transition and 2 for an indirect allowed transition. According to Tauc [46] the absorption tail related to localized states into the pseudo-gap, which localized states can arise from the existence of vacancy defects and/or impurities. The optical band gap (E_g)

have been measured from the plot $(\alpha h\nu)^{1/2}$ versus $h\nu$ by extrapolating the curves to $h\nu$ axis at $(\alpha h\nu)^{1/2} = 0$ for all samples before and after laser irradiation with different time as shown in figure 5 below .

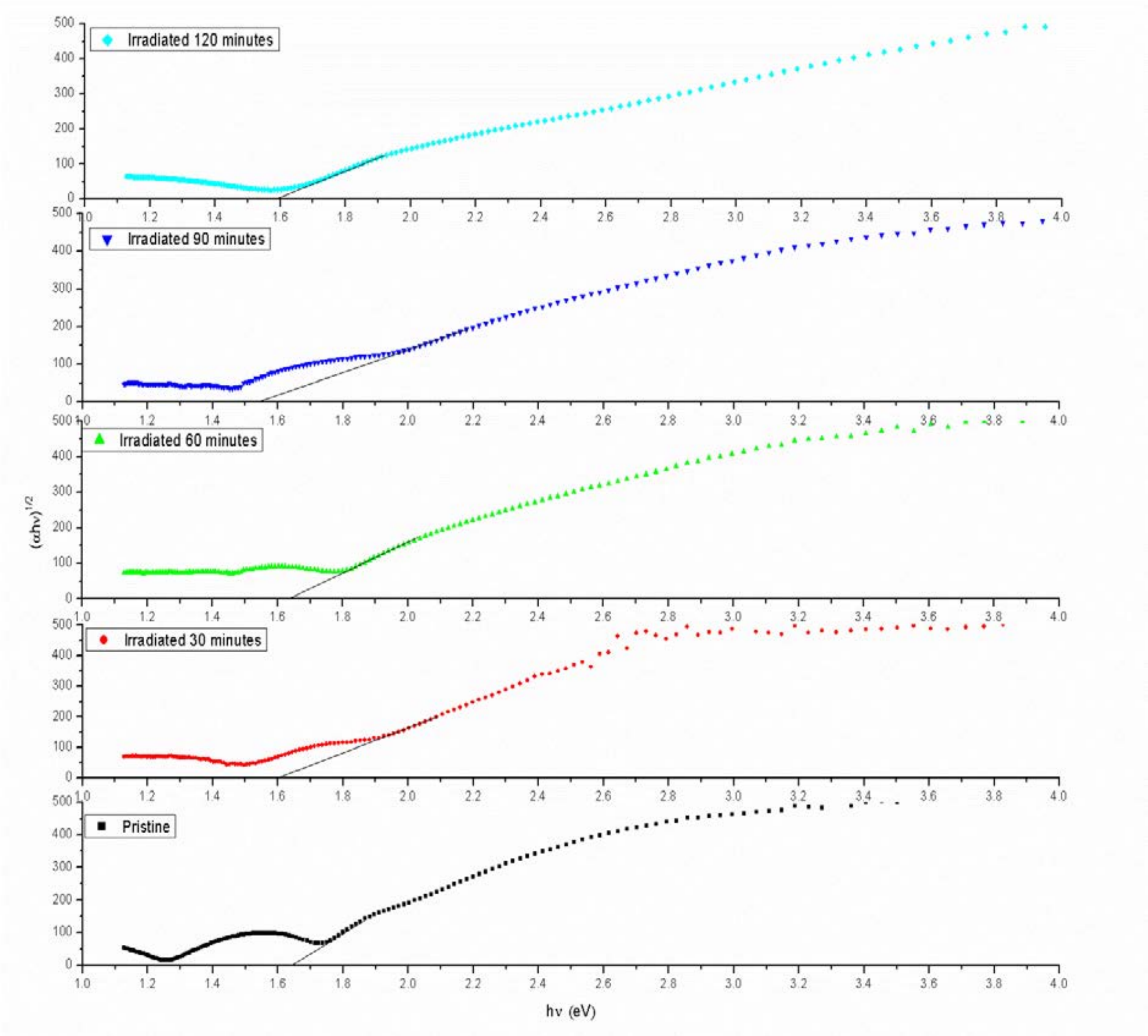

Figure 5: Variation of $(\alpha h\nu)^{1/2}$ versus $h\nu$ for $Se_{88}Te_{10}Al_2$ with and without laser irradiation.

The calculated data shows that the optical energy gap decreases and increases alternately with laser irradiation time interval of 30 minutes and given in table 4 below.

Table 4: Optical band gap of $Se_{88}Te_{10}Al_2$ with and without laser irradiation.

Sample (s)	Pristine sample	Irradiated sample			
		30 minutes	60 minutes	90 minutes	120 minutes
Eg (eV)	1.65	1.61	1.63	1.55	1.59

Valance band of chalcogenides forms by lone pair orbital whereas conduction band is formed by anti-bonding orbital. Laser irradiation excite the electron from the lone pair of bonding state to higher energy states and hence vacancies created in these states are immediately filled by the outer electrons by Auger process that in turns induce more holes in the lone pair bonding orbitals leading to a vacancy cascade process which makes easier bond breaking and ionization of atoms and changes the local structure order of the amorphous network causing a decrease in the optical energy gap. Influence of laser irradiation on the optical properties is connected with higher degree of disorder in the alloy. Hence the increase in transition probability due to disorderness produced by laser irradiation leads to narrowing the optical band gap of $Se_{88}Te_{10}Al_2$ alloy.

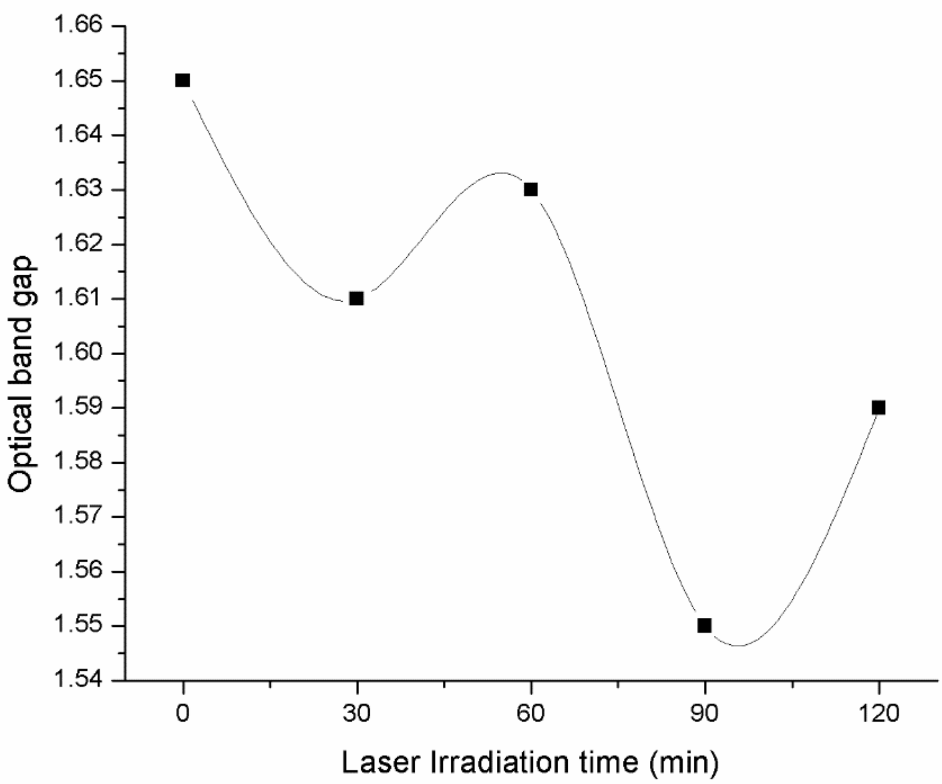

Figure 6: Variation of optical band gap with laser irradiation time in $Se_{88}Te_{10}Al_2$

The overall band gap has been decreases from 1.65 eV to 1.59 eV by laser irradiation but this change is not so smooth. A harmonic pattern has been observed as a laser irradiation effect on optical band gap as shown in figure 6. Every 30 minutes time interval of laser irradiation shows remarkable harmonic pattern which might be useful for switching devices.

The optical properties of the solid are governed by the interaction between the solid and the electric field of the electromagnetic wave. The extinction coefficient k is related to the damping of the oscillation amplitude of the incident electric field. The extinction coefficient (k) is a measure of the damping factor, which indicates the amount of absorption loss when the electromagnetic wave propagates through the material, has been calculated using well known relation [47, 48]

$$k = \frac{\alpha\lambda}{4\pi}$$

Variation of extinction coefficient with incident energy as well as with laser irradiation time is shown in figure 7 below.

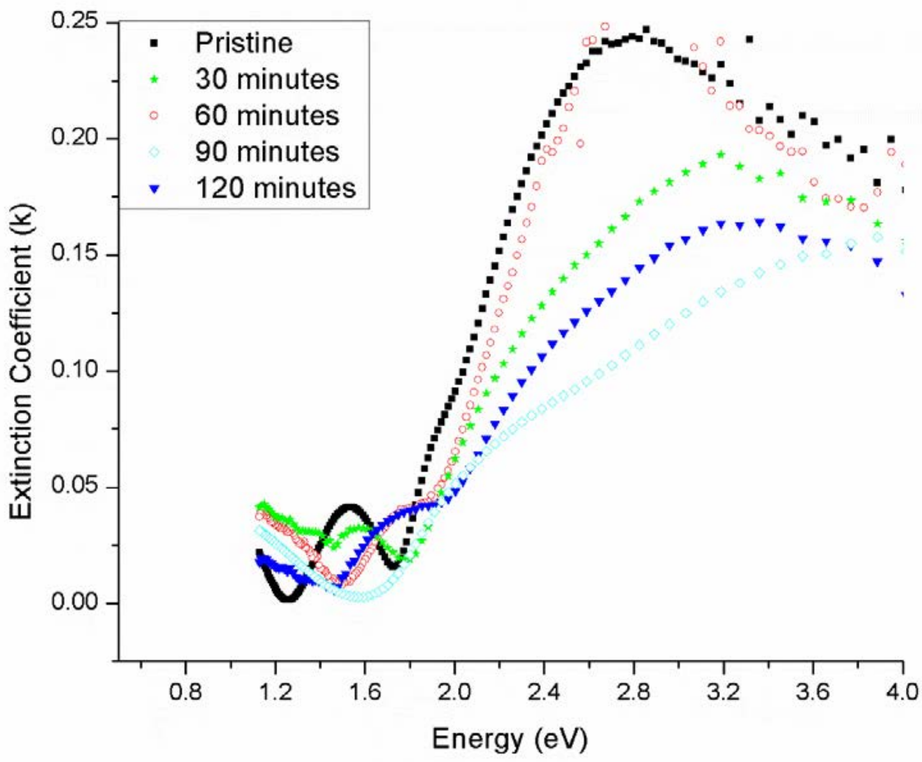

Figure 7: Variation of extinction coefficient with incident energy for different time of laser irradiation.

Extinction coefficient increases with increasing incident photon energy however laser irradiation causes harmonic pattern with remarkable overall decrease in extinction coefficient.

The refractive index (n) has been calculated using-

$$n = \frac{1 + \sqrt{R}}{1 - \sqrt{R}}$$

Figure 8 shows variation of refractive index with energy for different time of laser irradiation. After irradiation dose for 30 minutes refractive index increased rapidly and for next irradiation of 60 minutes it decreases. This pattern considerable repeated at every 30 minutes of irradiation time. This shows that $Se_{88}Te_{10}Al_2$ acts as laser irradiation time dependent switching material.

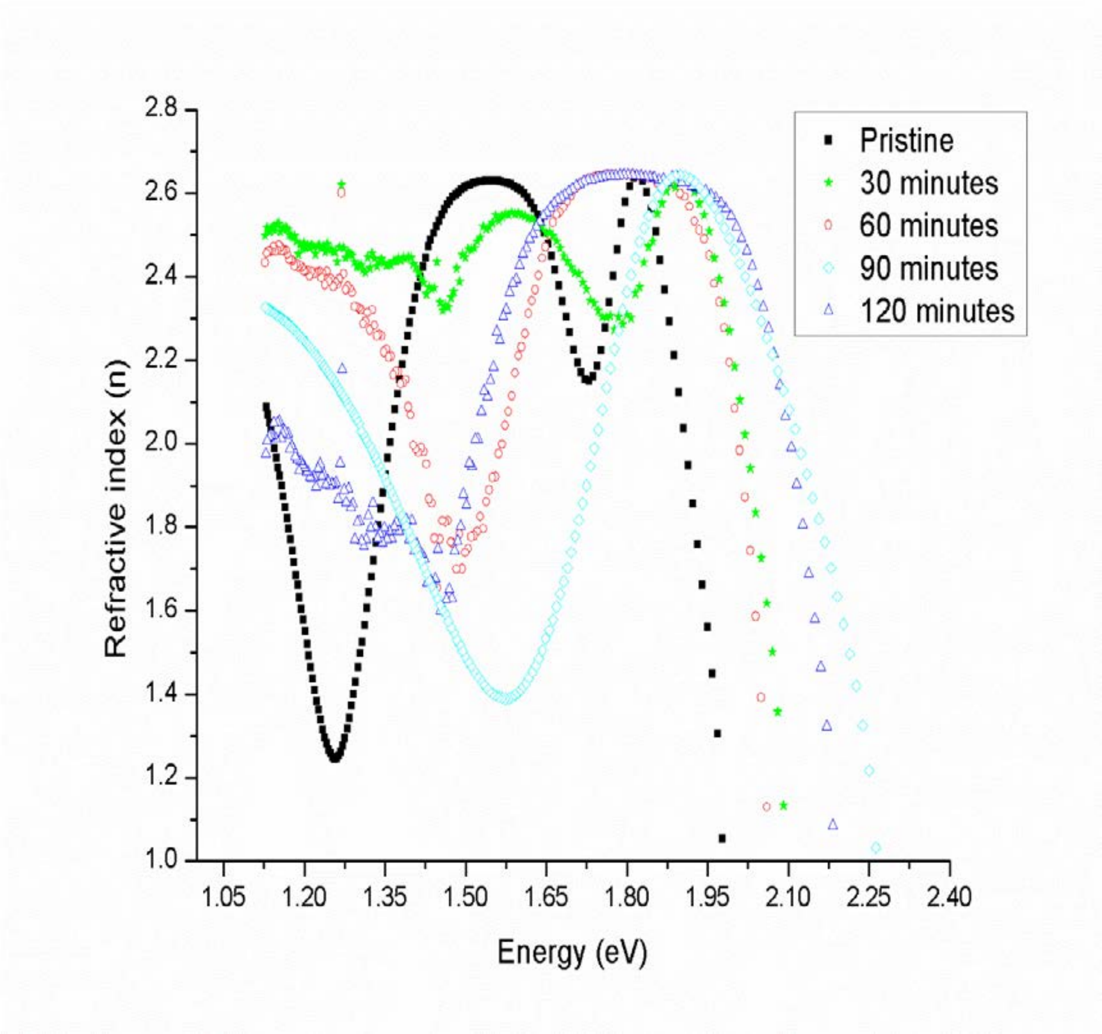

Figure 8: Variation of refractive index with energy for different time of laser irradiation

Also, the complex dielectric constant εdescribed the optical properties of material and calculated in the following equation

$$\varepsilon = \varepsilon_r + i\varepsilon_i$$

Where ε_r and ε_i represent the real and imaginary parts of dielectric constant respectively, and determined by the following equations

$$\varepsilon_r = n^2 - k^2$$

and, $\varepsilon_i = 2nk$

Variation of these constants with photon energy for different irradiation time has been plotted in Figures 9 and 10 respectively.

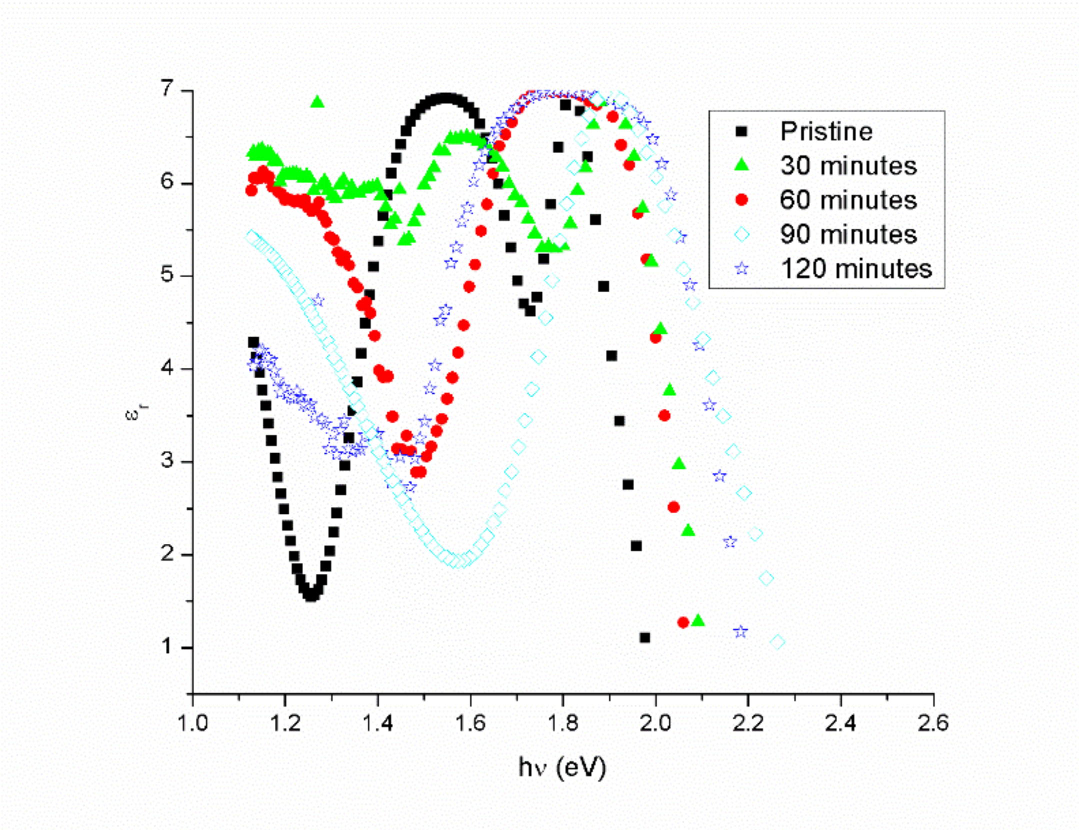

Figure 9: Variation of ε_r with photon energy for different time of laser irradiation.

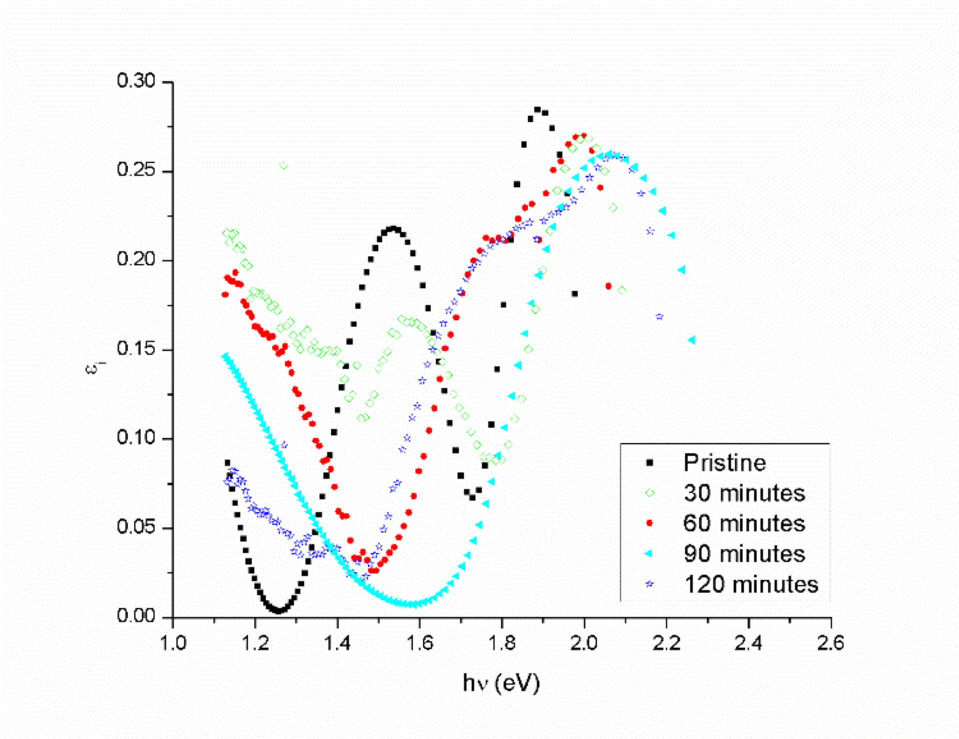

Figure 10: Variation of ε_i with photon energy for different time of laser irradiation.

It has been observed that the behavior of these constants is the same of refractive index and extinction coefficient; however the value of real dielectric constant is higher than all other constants.

4. Conclusion

In this study the effect of laser irradiation on optical properties of $Se_{88}Te_{10}Al_2$films in different irradiation times have been studied. The absorbance, transmittance, reflectance, absorption coefficient, optical band gap, extinction coefficient, refractive index, real part of dielectric constant and imaginary part of dielectric constant this alloy has been affected with exposed to He - Ne laser. All optical constant studied here shows interesting pattern after Laser irradiation of 30 minutes time interval. These constants are changing in a harmonic pattern which can be of great interest for laser activated switches and memories. These changes can be utilized as 0 and 1 stages in laser tuned digital memory devices fabrication.

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