Ibn Al-Haitham Journal for Pure and Applied Sciences
Journal homepage: jih.uobaghdad.edu.iq
PISSN: 1609-4042, EISSN: 2521-3407
IHJPAS. 2025, 38 (1)

Studying the Physical Properties of Silver Telluride Films Doped with Aluminum by the Effect of Annealing

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Received: 30 June 2023 Accepted: 6 August 2023 Published: 20 January 2025
doi.org/00.000000.000000

Abstract
The structural and optical properties of silver telluride films with doped 2% aluminum (Ag_2Te:2%Al), prepared using the thermal evaporation technique, were studied on glass substrates with a thickness of (400 ±20) nm after changing the annealing temperature to (300° C) for one hour. The films were found to be polycrystalline, and monoclinic at room temperature (R.T.), the structure became cubic after annealing. In XRD test we found that the crystallite size of the doped films is larger before annealing than it is for the (Ag_2Te:2%Al) films, and AFM tests showed that the grain size increases after annealing It also shows that the structure is nano, UV-visible optical tests of Ag_2Te films revealed that absorbance values decrease after annealing while the absorption coefficient increases, ascertain the values of the absorption coefficient depending on the equation that links the values of the absorption coefficient with absorbance [α= (2.303)A/t]. The energy gap for pure films reduces after doping and annealing. The optical absorption coefficient (α) value for each film was greater than (10^4 cm $^{-1}$) this means all films have an optical energy gap with direct transmission.

Keywords: Ag_2Te thin films, doping, Annealing, thermal evaporation.

1. Introduction
The word thin film refers to a layer or layers of matter atoms that do not exceed it has the thickness of one micrometer or several nanometers(1) and, because of its thinness and brittleness (easily broken)(2), it must be deposited on a solid material such as glass, silicon, or certain salts or polymers(3) . The size gives it a unique "physical" composition that is sometimes comparable to and occasionally exceeds a monocrystal structure (4) . It contributed to the advancement of semiconductor research by providing a thorough understanding of many of its features (5). All

modern electronic devices depend entirely on their work on materials with physical and chemical properties of semi-conductive materials(6) that possess the properties of insulators at low temperatures and can conduct electrically when their temperature rises to a certain extent(7).The study of the properties of any material in the form of thin films, as it is known, is one of the very important topics(8) , as the material when it is in the form of a thin film has uses and applications in all sciences and industries(9), especially since modern electronics science is now based on the use of the material in the form of thin films(10) , especially in integrated electrical circuits and computers and in solar And Photovoltaic Cells(11) , Silver telluride is a chemical compound with the formula Ag_2Te(12) that is found in the form of crystals with a blackish-gray appearance(13) . The oxidation number of silver in this molecule is (+1) and it is regarded as a semi-stable compound(14). (Ag_2Te), a non-stoichiometric silver telluride compound(15) (meaning there are disproportionate ratios of silver ions to telluride ions), has a high magnetic resistance(16) and is a semiconductor that can be doped with the negative (n-) or positive (p-) type(17) and depends on the telluride to silver ratio(18) .

2. Materials and Methods

Composite alloy (Ag_2Te) was prepared with weight ratios equal to (1.8855 g) and (1.1149 g) for silver and tellurium, respectively, then the elements were mixed well and then placed in a quartz tube, and they were evacuated from the atmosphere for an hour. The tube was placed in a convection oven to reach (1000 °C), which represents the melting point of the compound, for five hours. The furnace temperature was raised at a rate of (5 °C/min), then it was cooled by the slow cooling method of the melt, after which the tube was taken out of the furnace and smashed. On the one hand, the composite ingot from it, and then ground with a special mill (laboratory mill) to obtain a powdery substance. Then, the prepared ingot was subjected to an (XRD) assay to ascertain the required material. Composite films (Ag_2Te) with a thickness of 400 nm were prepared in a (boat) of molybdenum metal, and when the pressure inside the evaporation chamber reached about (2.2 x 10-5) Torr using an E306 coating unit, and the material was deposited on glass bases and silicon deposits installed at a distance (18 cm) from the evaporation basin with an amount of precipitation rate (2.07813nm sec^{-1}) at room temperature. Deposition is carried out by passing a high current through a current transformer prepared for this purpose. The samples are left inside the evaporation chamber to cool, as they are ready for the next step, which is thickness measurement. Then laboratory tests are conducted, and their structural, optical, and electrical properties are studied. This is the impregnation of the films with the element (Al) prepared using the thermal evaporation technique.

3. Results

3.1. Structural Properties

Figure 1. shows the X-ray diffraction pattern of pure films doped with aluminum (2%) and annealed at temperatures of 300° C. When comparing the diffraction pattern of the same pure film without doping and annealing, it is clear that the intensity of the peak (013) increases at the

expense of other peaks when doping, and annealing, and this indicates that some levels are favorable for the growth of crystals, so the intensity of this peak increases accordingly, which confirms that the structure of the films has better crystallization. That is, the doping with aluminum at a rate of 2% and annealing at that temperature (300°C) led to an increase in the degree of crystallization of the film material and a decrease in the crystalline defects formed in the film upon preparation. This indicates that the doping with aluminum and the annealing lead to an increase in crystalline regularity. the average size of the crystal was determined by using equation 1(19) .

$$C.S = (0.94\,\lambda) / \beta \cos \Theta \qquad (1)$$

Where:(λ) is the wavelength of XRD photons; is the full width at half maximum (FWHM), and (Θ) is the Brage diffraction angle in degrees(20) .

Table 1. All produced films' structural parameters were measured at a thickness of 400nm.

Samples	2 Theta (deg) (013)	β (deg)	C.S (nm)
Ag_2Te Pure	41.498	0.3464	**25.62466**
Ag_2Te: 2%Al (R.T.)	41.594	0.2558	**34.71163**
Ag_2Te: 2%Al (300°C)	41.5076	0.2198	**40.3852**

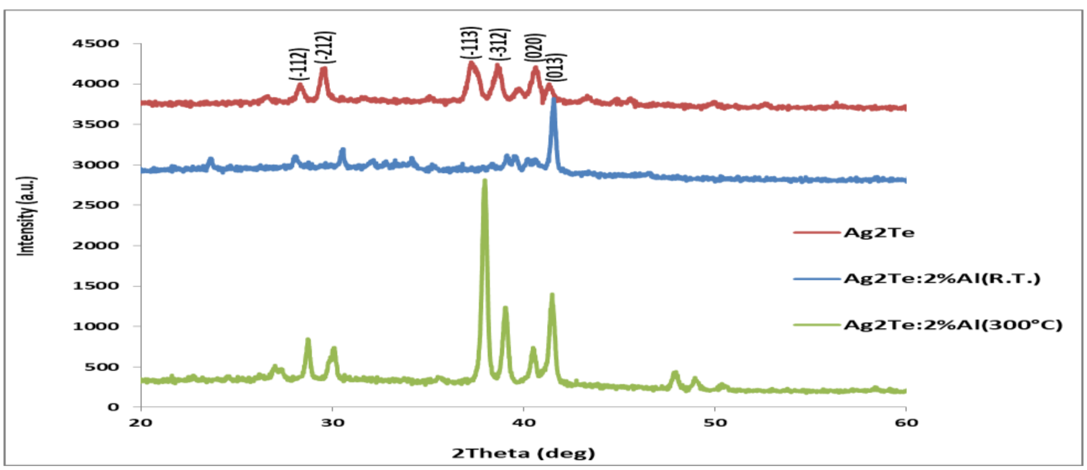

Figure 1. X-ray diffraction diagram of all prepared films

Figure 2. 3D AFM image of a silver telluride film doped with 2% aluminum, annealed at 300C, shows a homogeneous distribution with a vertical structure in all images. **Table 2** includes information on the average surface roughness (r.m.s) values and average surface particle size. It can be concluded that these parameters increase upon annealing for the pure film as a result of crystallization resulting from the thermal annealing of Ag_2Te films. Increasing the temperature can lead to recrystallization of the grains.

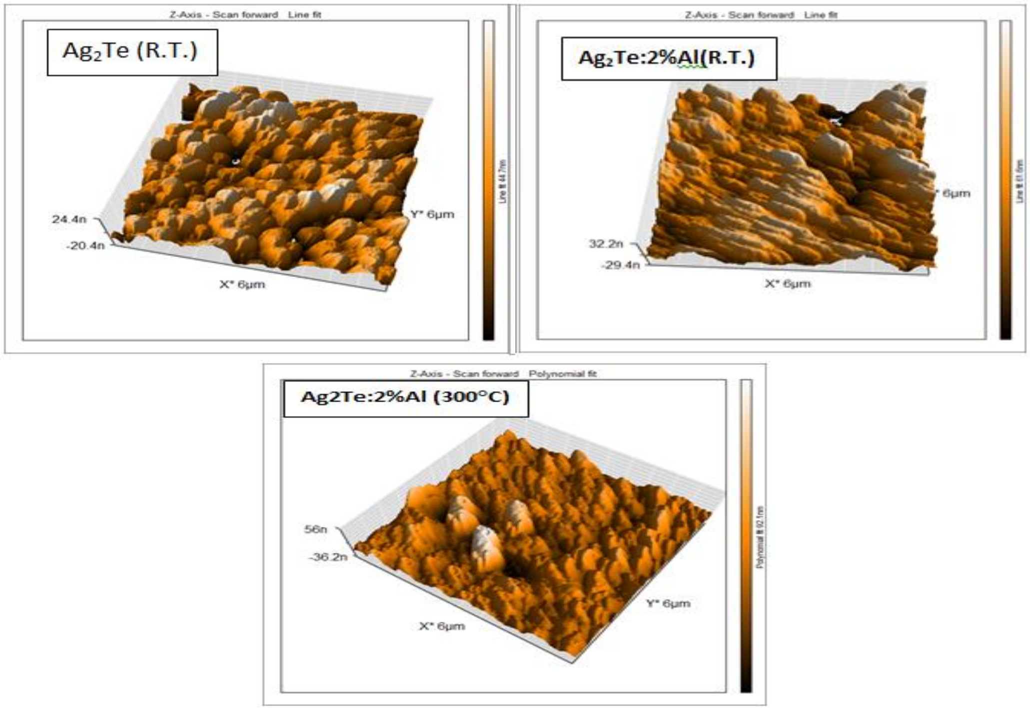

Figure 2. (3D) AFM images of all films were prepared

Table 2. All films' AFM information was created.

Sample	Size of grain (nm)	Roughnes s. (nm)	Root mean square. (nm)
Ag_2Te(R.T.)	**38.49**	**7.494**	**10.01**
Ag_2Te:2%Al (R.T.)	**40.01**	**18.63**	**25.49**
Ag_2Te:2%Al (300°C)	**59.24**	**26.2**	**31.22**

Figure 3. The surface morphology of all samples of (Ag_2Te) and Ag_2Te:2%Al films at room temperature and after annealing at 300°C was examined using (FESEM) technique with a magnification of 120 KX in order to know the nature of the film surfaces and to clarify the change in particle size. The pictures in Figure 3 show that the annealing has a great effect on the surface composition formation of the prepared films, annealing has a significant impact on the surface composition of the created films, and all of the prepared films have uniformly distributed granules(21) .

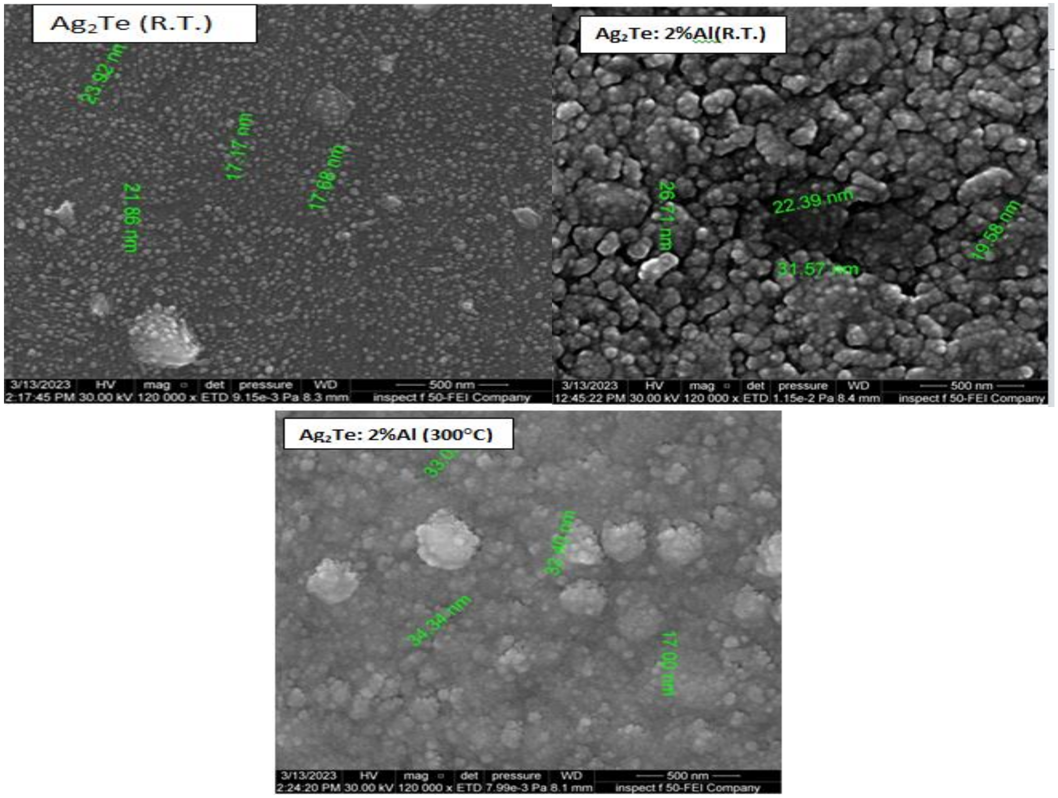

Figure 3. FESEM images s of all films were prepared

3.2. Optical Properties

Figure 4. Absorption generally depends on the energy of the photons that fall on the semiconductor material(22), the type of material, the nature of its crystal structure, the surface roughness, and the locations of impurities in the material(23) . the absorption spectrum has the opposite behavior of the transmittance spectrum (24) **Figure 4** depicts the absorption spectrum of silver telluride films doped with aluminum at room temperature and annealed at temperatures of 300 °C as a function of wavelength. As can be seen from the figure, the absorption values of the film decrease after annealing until they reach (35%) at wavelengths shorter than (700 nm), that is, when the wavelength of the incident radiation is shorter than the wavelength of the film. cut-off wavelength (λ). Which is within the visible part of the electromagnetic spectrum, this is because of the high absorption in this region(25) .

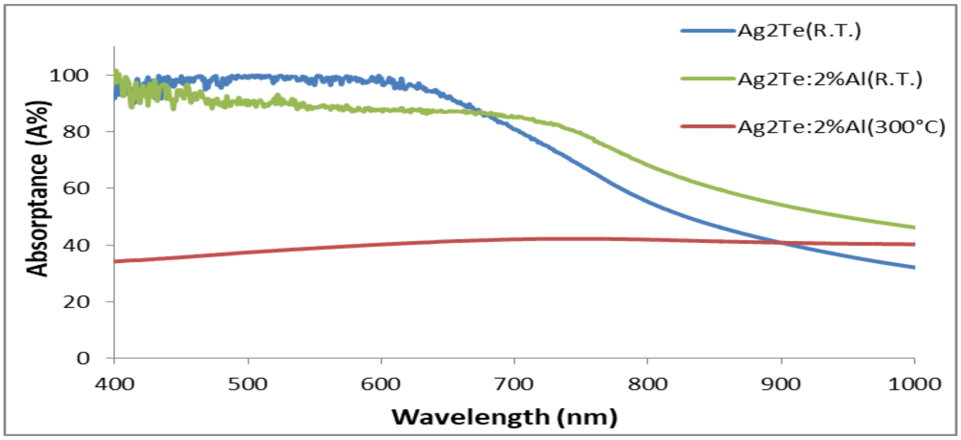

Figure 4. Optical absorption of each film's VS wavelength was created.

Figure 5. The optical absorption coefficient (α) was calculated using the absorption spectra of the generated films, which were measured using a UV instrument. (VIS) Spectrophotometer(26) . According to **Figure 5.** , all films have an optical energy gap with direct transmission because the computed absorption coefficient value for each film was greater than (10^4 cm^{-1}) in the first part of the visible spectrum (27). After annealing, we observe a drop in the absorbance coefficient value of the aluminum-doped films. The absorption edge was limited to the range of 800–880 nm. Be aware that alternative absorbents exist and that their availability depends on the topography of the films.

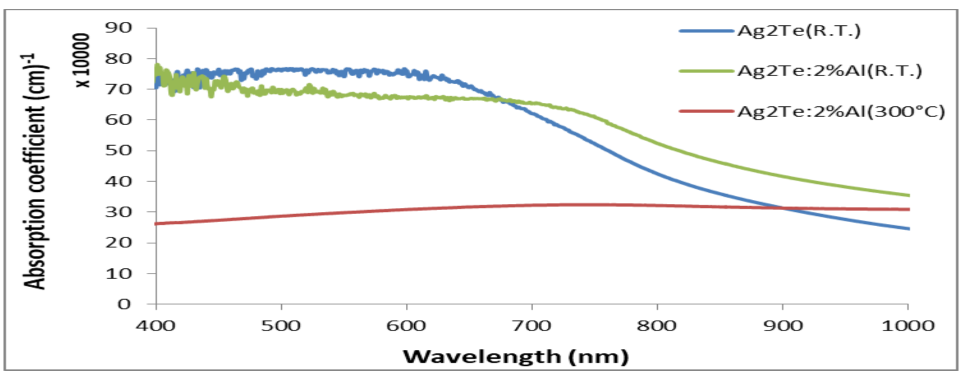

Figure 5. The absorption coefficient of all films was prepared

Figure 6. For illustration, a value is chosen from a relationship diagram. graphs with (hv) on the x-axis, the incident photon's energy(28), and $(\alpha hv)^2$ on the y-axis, the straight line extrapolated from the curve(20). The direct optical energy gap of this membrane is where the output will cut the x (hv) axis (29). **Figure 7.** shows that the optical energy gap value of the Ag_2Te:2%Al films decreased at the 300 °C annealing temperature. This is because annealing causes the composition of the films to change from the monoclinic phase to the cubic phase(30).

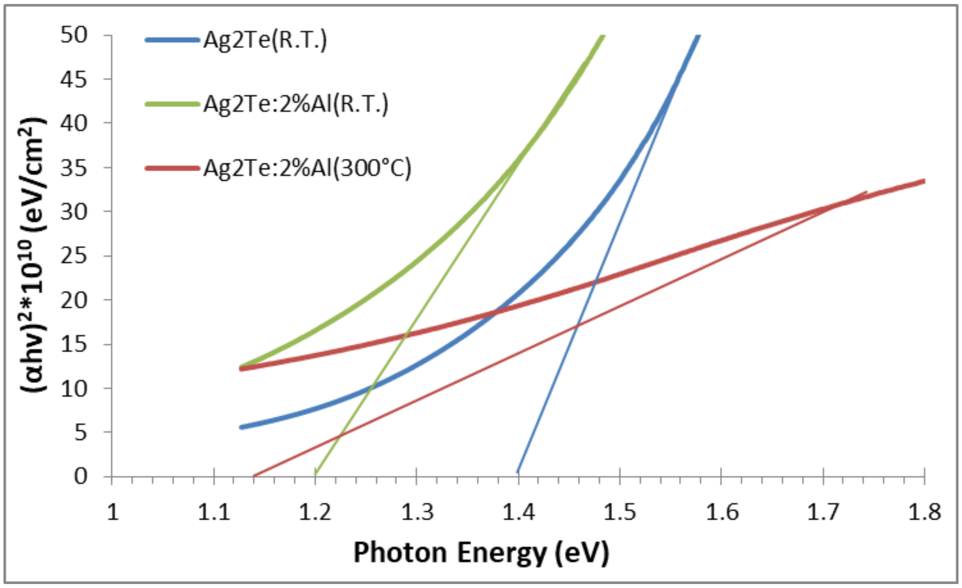

Figure 6. A Plot of $(\alpha h\nu)^2$ VS. Photon energy (hν) for each film was created.

Table 3. Thin films optical energy band gap

Sample	Direct Allowed Transition E(eV)
Ag_2Te (R.T.)	1.4
Ag_2Te:2%Al (R.T.)	1.2
Ag_2Te:2%Al (300°C)	1.14

4. Discussion

In our experiment, we studied the structural and morphological properties of the silver telluride films crystallized as prepared and doped with aluminum impurity. The mean interference colors in the films decrease, and the diffraction patterns become clearer by doping the silver telluride films with aluminum. The densities of the synthesized silver telluride films have refrained from a significant change with a doping amount of aluminum, which indicates an increase in porosity with aluminum or a change in the texture of the films. The lattice constant in the films obtained by X-ray diffraction decreased with the addition of doping, in some percentages compared to previous tests. The spectrum shows that Al is introduced into the crystal structure of the compound.

5. Conclusion

The Ag_2Te:2%Al thin films at room temperature and annealed at 300°C, respectively, were polycrystalline and had a monoclinic structure, changing to cubic structure after annealing. According to the AFM results, the film surface is very smooth. The surface roughness of the film increases with the rise in the annealing temperature. The results of the optical examination showed a decrease in the absorbance of the films prepared after annealing, as well as the energy gap.

Acknowledgment

Thanks, and appreciation to everyone who assisted in preparing this research

Funding

None.

Conflict of Interest

The authors declare that they have no conflicts of interest.

Ethical Clearance

The local ethical committee at the University of Baghdad approved the project.

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