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A Comparative Study of Multi-Thickness Zinc Telluride (ZnTe) Thin-Film Properties Fabricated Using a Software Controlled PLD Substrate Holder System at Different Deposition Temperatures

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Abstract:

Multi-thickness polycrystalline zinc telluride (ZnTe) thin films were successfully deposited on TEC-15 glass substrates at different deposition temperatures ranging from 200C^0 to 400C^0 by a pulsed laser technique. Two different sample sets of multi thicknesses (500nm, 750nm, and 1000nm) films have been fabricated on the same substrate using a designed software program to control a moving substrate holder that moves horizontally and vertically behind a metal blocker. This study shows the possibility of fabricating different thickness layers on the same substrate in one fabrication process using moving substrate PLD holder during the deposition. Atomic Force Microscopy indicated an improvement in the average crystallite size with the increase in film thickness and substrate deposition temperature. As well as higher surface roughness R_a was indicated for thicker layers fabricated at high temperature. XRD properties indicate that the fabricated samples are polycrystalline, and the films exhibit preferred orientation along the (111-cubic) direction, which is stronger at the highest substrate temperature and thicker layers. This study discusses the strong dependency of crystalline quality on the deposition temperature and thin film thicknesses.

Keywords: Zinc Telluride, Multi-thickness Thin Film, Polycrystalline Structure, Deposition Temperature, PLD, AFM, XRD.

Introduction

II–VI wide bandgap semiconductor materials have been very attractive to many scientific and industrial research groups [1, 2]. They have a broad range of bandgap that makes them capable of emitting different colors in the visible light spectrum [3]. Thus, they are very promising candidates in the field of data transfer and communication and for development of short wavelength light emitting diodes (LED) [4, 5], diode lasers and other optoelectronic devices such as solar cells, X-ray detectors and photo-resistors, etc [6]. Among these material, ZnTe has a direct 2.26 eV bandgap that makes it capable of emission light in the spectral region corresponding to the maximum sensitivity of the human eye at 550nm. ZnTe thin films have been fabricated by many research groups based on homo-junctions to fabricate LEDs [7] and also based on multi-junction in solar cells [8]. Also, it has been used in many different photovoltaic application such as a buffer layer and a back contact layer in solar cells to reduce mismatch and resistance [9-11]. Therefore, the thickness of this layer has been very critical and can affect the performance of the device [12]. ZnTe layers have been prepared by several deposition methods, such molecular-beam epitaxy [13] and E-Beam Evaporation [14] that produce high quality ZnTe epitaxial layers, however they have some disadvantages such as complicated and expensive and uncontrolled thickness. Pulsed laser deposition PLD has been also used to produce high quality ZnTe thin films at low temperature and short time [15, 16]. In this study, a novel technique is developed to enable us to fabricate multi-thickness layers of ZnTe thin films by PLD after arranging a major alteration on the fabrication device and connecting it to a software controlled moving substrate holder. This major change has allowed us to produce different thickness layers of ZnTe on the same substrate on each fabrication cycle which reduced lots of material loss and efforts. Three different ZnTe layers that have different thicknesses have been prepared on the same sample in different deposition substrate temperatures to study the effect between layers' thickness and deposition temperature on the properties of the samples.

Experimental Details

ZnTe samples were fabricated using a Pulsed Laser system that consists of a 248nm KrF-Excimer laser with 20 ns laser pulse duration. The range of 140–150 mJ pulse energy of the incident laser beam was directed at 45^0 degrees on the ZnTe target (99.99% purity). The substrate holder connected with a motor and a Python software program to make the holder is moveable during the deposition. This moving substrate holder can move in 2-D (horizontally and vertically) during the depletion of the target to produce a uniform multi-thickness film. A metal blocker has been placed in front of the sample holder to prevent the depletion of materials on the thinner layer. Two sets of ZnTe samples

that have multi thicknesses (500nm, 750nm, and 1000nm) were deposited on the same substrate (glass TEC-15) at two different temperatures, $200C^0$ and $400C^0$ as it is shown in Fig 1. Then, the samples left in the stainless multi ports chamber to cool down and moved next day to take the measurements. The thickness of all layers was measured by using a profiler (KLA-Tencor P16). Atomic Force Microscopy (AFM) was used to obtain the Micro-structure properties. After that, samples were subjected to XRD measurements for more investigations on the thin films' characterizations.

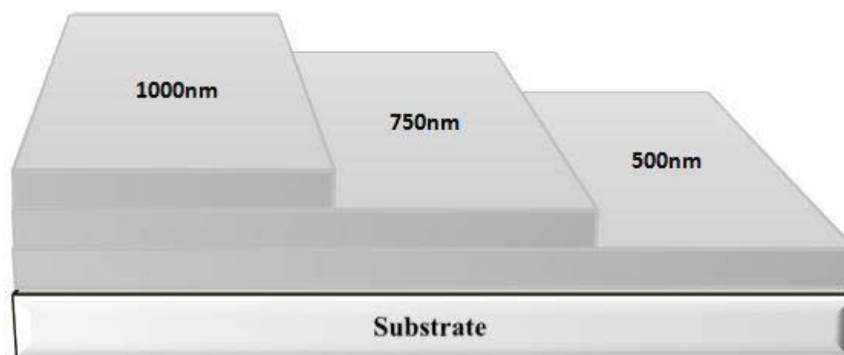


Figure (1): illustration of the fabricated samples shows the multi-thickness layers of ZnTe on the same substrate

Results and Discussion:

Microstructure properties of the fabricated ZnTe thin film layers have been studied using Atomic Force Microscopy analysis and are shown in the images of Fig 2. From these AFM micrographs, it is clearly observed that all ZnTe films have polycrystalline structures and consolidated grains. Group A represents AFM images of three ZnTe layers fabricated at low temperature $200C^0$, it shows that the films have relatively small grain size with rounded shapes and lots of grain boundaries. While group B represents AFM images of the same layers fabricated at higher temperature at $400C^0$. It shows considerable increment in grain size and many grain boundaries disappeared as a result of the higher temperature during the fabrication process. This higher temperature provides higher kinetic energy to the molecules that allow them to merge with each other, and that's why the films fabricated at high temperature look more compact. Also, ZnTe films fabricated with 750nm and 1000nm thickness seem to have similar properties in both groups A and B that fabricated at different temperatures. However, these layers in group B shows better structural properties over layers in group A, and from this we can conclude that the films became more compact when deposited at higher temperatures ($400C^0$) for all thicknesses. This result is in a good agreement with the result presented by A.E. Rakhshani [17].

Also, the ZnTe film surface roughness R_a of all layers of group A that fabricated at $200C^0$ temperature is in the range of 3.2-15.1nm. While, the ZnTe layers of group B that fabricated at $400C^0$ have higher surface roughness in the range of 25-48nm . This increment of the surface roughness at higher temperature is corresponding to the consolidation between the molecules and the formation of larger grain boundaries, as it was similarly mentioned by H.S Lees group [18]. It can also be noticed that thicknesses of 750nm and 1000nm of group B have the higher surface roughness value (> 40nm) and better structure quality as it is shown in B2 and B3 images of Fig 2. However, the possibility of forming holes may increase when fabricating thin films at high temperature as it will be stated in the cross section analysis.

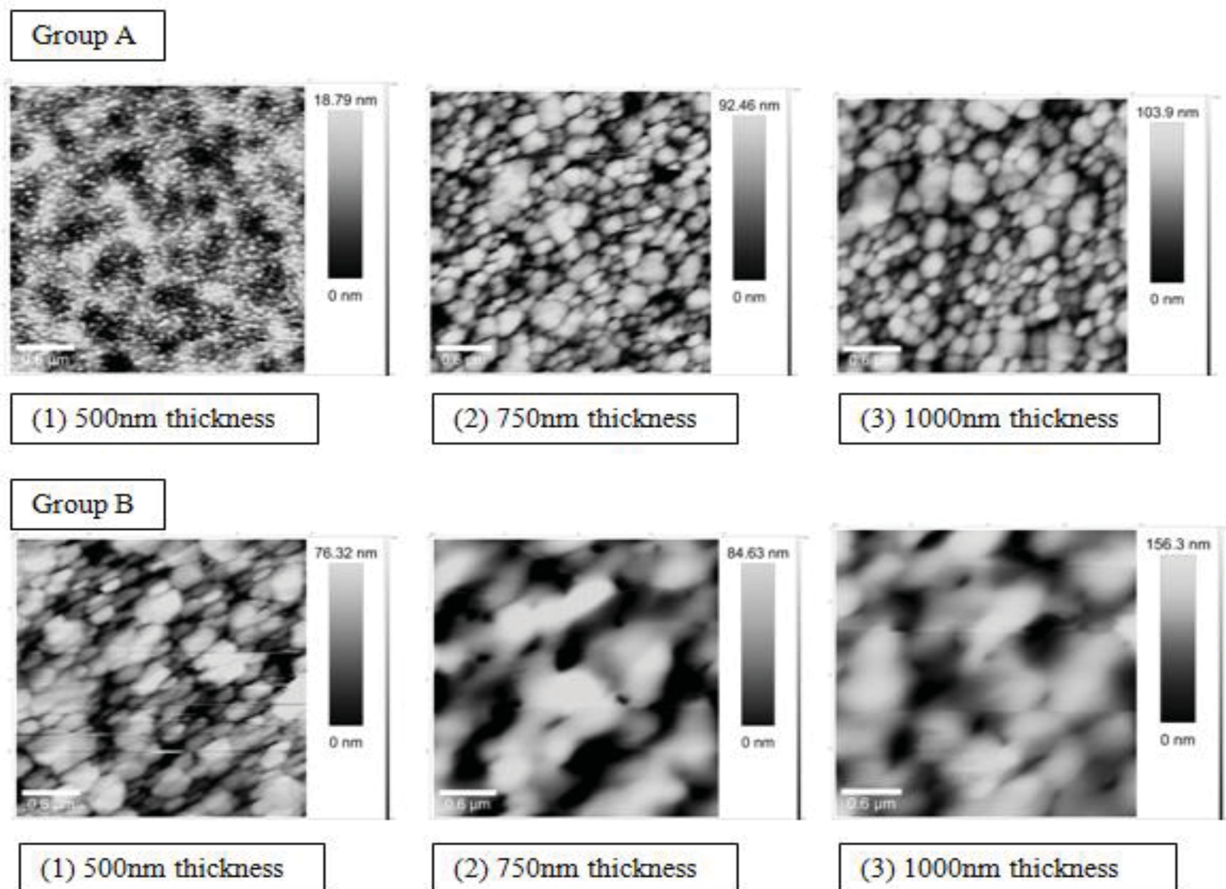


Figure (2): AFM images of multi-thickness ZnTe thin films fabricated at $200C^0$ (Group A) and at $400C^0$ (Group B)

The height profile cross section of all fabricated ZnTe thicknesses was obtained from AFM images analysis as shown in Fig 3. The thinnest layer (500nm) that shown in image A1 shows high peaks frequency along x-axis which reflexes the small grain size polycrystalline structure, and low dimensions on y-axis which represents low possibility of forming holes or defects at low temperature. This is due to the short fabrication time that needed to fabricate the thinnest layer.

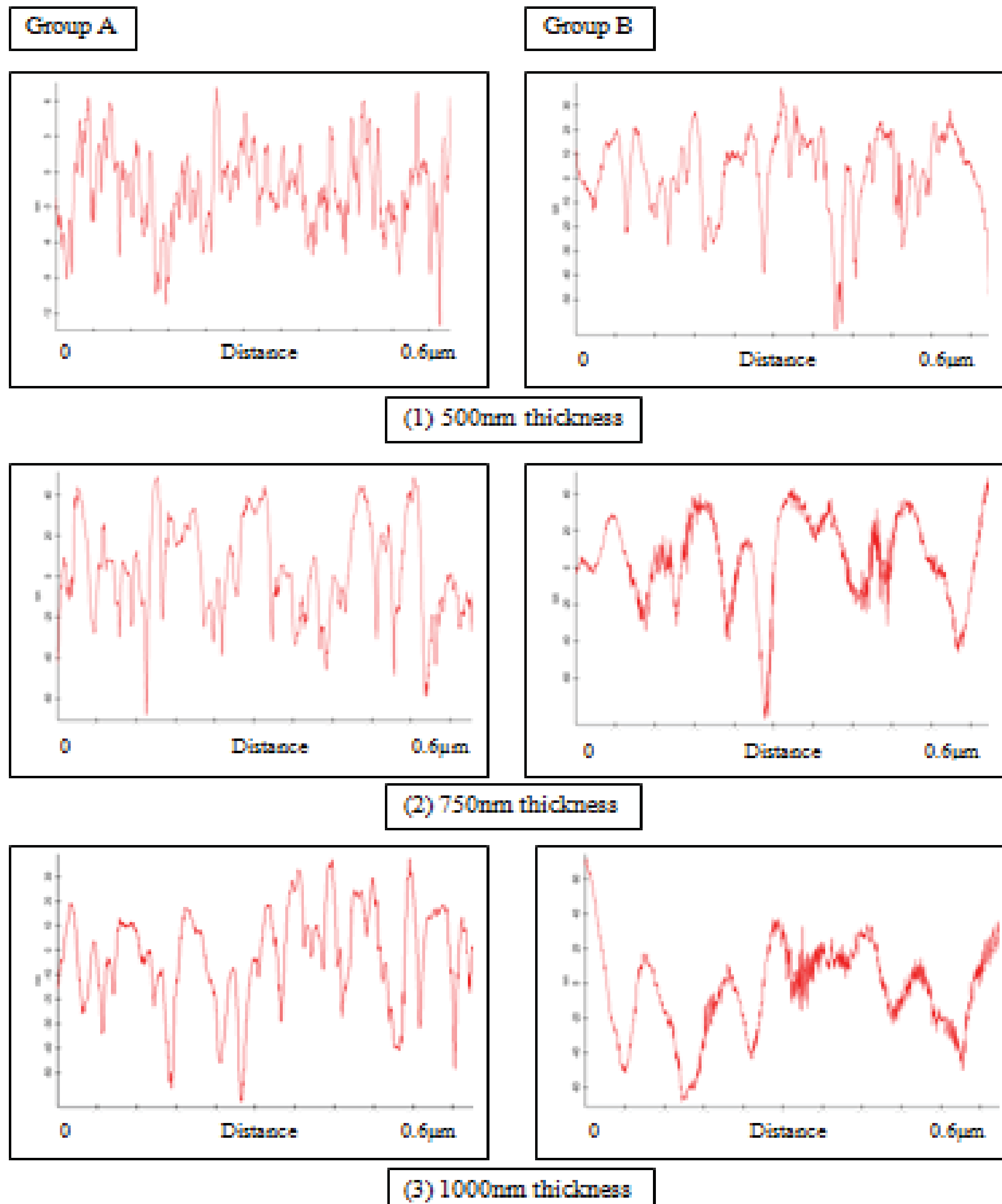
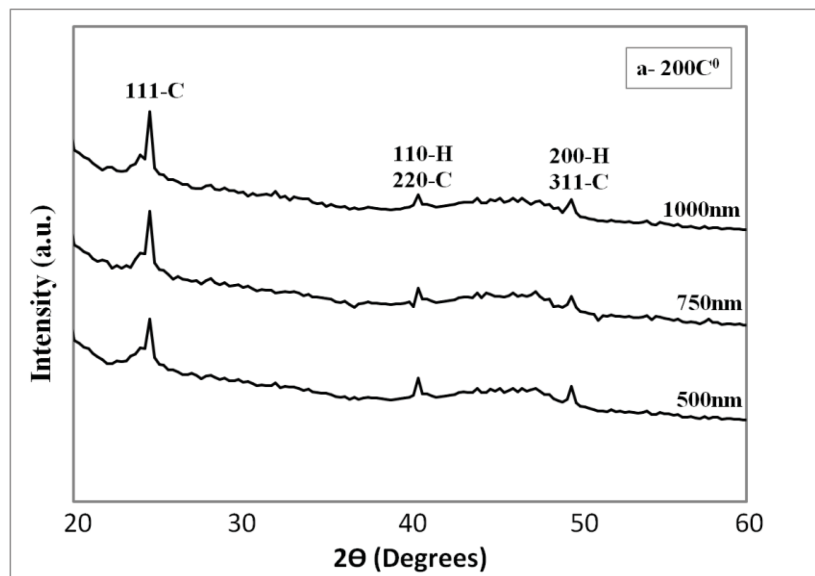


Figure 3: Height Profile Cross Section analysis of different ZnTe thicknesses fabricated at 200C^0 temperature (Group A) and 400C^0 (group B)

Also, it can be seen that there is a noticeable difference in these two factors mentioned above between images of group A and group B, as in group B all curves show low peaks frequency along x-axis, which corresponds to the increment of molecules merge and decrement of grain boundaries due to the high temperature and higher dimensions on y-axis which shows the possibility of holes formatting at high temperature. These results in perfect agreement with AFM analysis shows in Fig 2. From this point of view, it can be dedicated that using high fabrication temperature will enhance the re-crystallization of the thin film structure [15]. Also, layers with 500nm and 1000nm thicknesses seem to have similar and improved structural quality when fabricated at high temperature, 400C^0.

Fig 4a and 4b show the corresponding XRD patterns for the three multi-thickness ZnTe thin films fabricated in the range of 200C^0 and 400C^0 respectively. It can be seen that all thin films that have different thicknesses and deposited at 200C^0 substrate temperature shown in Fig 4a contain three peaks located at 2ϴ~ (25.4^0 , 41.9^0 , 49.4^0). These may correspond to the signature of peaks reflected from (111, 220, 311) planes of cubic ZnTe and (110, 200) planes of hexagonal ZnTe, which indicate a mixed phase of polycrystalline structure of the fabricated films. While the XRD traces of different thicknesses of ZnTe thin films deposited at high temperature 400C^0 shown in Fig 4b indicate the presence of a very strong peak at 2ϴ~25.4^0 (especially for 750nm and 1000nm thicknesses) for reflections from (111) planes only, that represents cubic ZnTe. This indicate that there is a significant grain growth with the increase in substrate temperature during deposition as it was confirmed by previous AFM images. Similar results were presented by NA Shah group [19]. The other peaks corresponded to hexagonal ZnTe observed in films deposited at 200C^0 substrate temperatures are not shown here. Therefore, thin films deposited at 400C^0 substrate temperature contained cubic phases of ZnTe and large grain growth, which enhanced the crystallinity of the films significantly. This improvement of the crystallinity with the increase in substrate temperature during deposition can be also explained from the significant increment of adatom mobility and the culminated in grain growth through the adjacent grains coalescence. Further, the lattice constant calculated from the XRD patterns was 0.605 nm for all films, that is in a good agreement with that has been already reported in the literature (0.610 nm) with zinc blende structure [20, 21] .



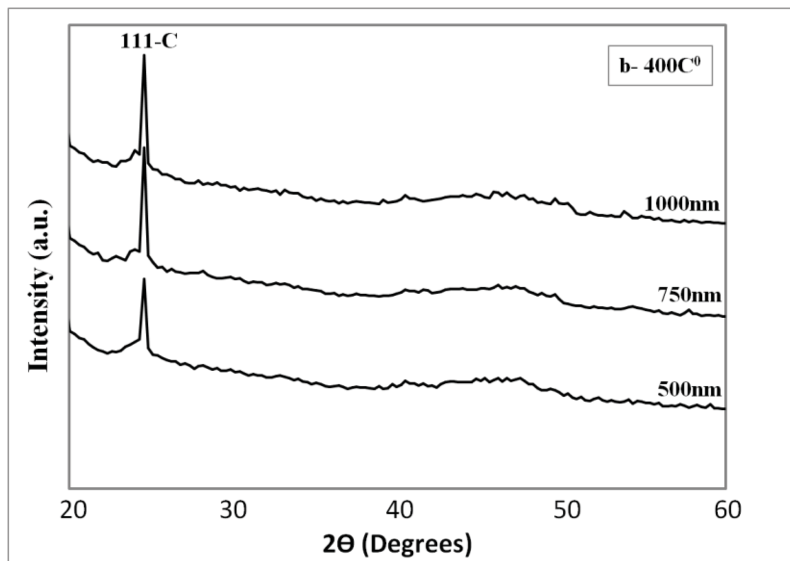


Figure 4: XRD patterns of different ZnTe thicknesses fabricated at (a) $200C^0$ and (b) $400C^0$ substrate temperature

Conclusion

Different thicknesses (500nm, 750nm, and 1000nm) of polycrystalline zinc telluride (ZnTe) thin films were fabricated on the same glass substrate by using a modified pulsed laser system controlled by a software program to control a moving substrate during deposition. Substrate temperatures ranging from $200C^0$ to $400C^0$ were applied to investigate the effect of fabrication temperatures on multi-thickness thin films. Atomic Force Microscopy study shows that re-crystallization and grain growth improved significantly with the increase in film thickness and substrate deposition temperature. ZnTe thin films with thicknesses of 750nm and 1000nm show similar properties and good crystal quality when fabricated at $400C^0$ due to the high kinetic energy that produces large grain size and merged and compact structure, as well as high surface roughness R_a. XRD analysis reveals that the films fabricated at the highest substrate temperature and thicker layers show considerable improvements of the crystal structure as is evident from the development of the (111-cubic) direction. A strong correlation and dependency between deposition temperature and thin film thicknesses on crystalline quality are stated, that is very critical of ZnTe application.

Acknowledgments

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