Preliminary Study of CdTe and CdTe:Cu Thin Films Nanostructures Deposited by using DC Magnetron Sputtering

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Abstract. Growth and properties of CdTe and CdTe:Cu thin films nanostrucures deposited by using dc magnetron sputtering are reported. Scanning electron microscope (SEM) was used to observe the surface morphologies of the thin films. At growth conditions of 250 °C and 14 W, CdTe films did not yet evenly deposited. However, at growth temperature and plasma power of 325 °C and 43 W, both CdTe and CdTe:Cu(2%) have deposited on the substrates. In this condition, the morphology of the films indicate that the films have a grain-like nanostructures. Grain size diameter of about 200 nm begin to appear on top of the films. Energy Dispersive X-rays spectroscopy (EDX) was used to investigate chemical elements of the Cu doped CdTe film deposited. It was found that the film deposited consist of Cd, Te and Cu elements. XRD was used to investigate the full width at half maximum (FWHM) values of the thin films deposited. The results show that CdTe:Cu(2%) thin film has better crystallographic properties than CdTe thin film. The UV-Vis spectrometer was used to investigate the optical properties of thin films deposited. The transmittance spectra showed that transmittance of CdTe:Cu(2%) film is lower than CdTe film. It was found that the bandgap energy of CdTe and CdTe:Cu(2%) thin films of about 1.48 eV.

Keywords: CdTe, Cu doping, thin film, SEM, XRD, IV meter, UV-Vis spectrometer
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INTRODUCTION

Cadmium Telluride (CdTe) is one of the most fascinating semiconductors that have been intensively studied for photovoltaic applications especially for CdTe/CdS heterojunction solar cells configuration [1-7]. CdTe has direct band gap of ~ 1.5 eV that is nearly optimally match to the solar spectrum for photovoltaic (PV) energy conversion [1-4]. Besides, CdTe material has high absorption coefficient; 1 mm thick of CdTe film is enough for absorption of ~90% of incident photons with energy higher than material band gap [2, 4].

High performance of CdTe is absolutely dependent on utilizing window layer [4-7], back contact [2, 3], and doping [1-4]. Doping which usually added to CdTe thin film depositions are Cu, Si, and P. Cu is commonly used as dopant for CdTe because its ability to improve CdTe thin film conductivity [8]. Cu as a dopant acceptor in CdTe can aids the formation of a better ohmic contact by increasing p-doping of CdTe near the back contact interface [7-8]. Moreover, Cu can also improve the microstructure and optical properties of CdTe thus improving quality of the film [8-9]. Cu can be used as doping in CdTe bulk (solid) thereby increasing the concentration of carriers [3].

In this study, thin films were grown by using dc magnetron sputtering. Sputtering method has several advantages, including a layer was formed has a similar composition with the target material [8], plasma method such as magnetron sputtering required a low energy particle bombardment to achieve lower growth temperatures and the use of excited state species to improve the doping control during growth [9-10]. This paper reported preliminary study of properties of CdTe and CdTe:Cu thin films deposited by using dc homemade magnetron sputtering. The mechanism of deposition, elements structure, crystal structure, and optical properties of CdTe and CdTe:Cu films were studied.

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EXPERIMENTAL

In this study, CdTe:Cu(2%) films were deposited ITO substrate by using homemade dc magnetron sputtering. A series of pellets target were made by using pressing system. Mechanism of manufacture include: mixing CdTe and Cu_2Te with a total mass of 10 grams, then grinding the powder for 2 hours, compacting or pressing using a hydraulic pump system into pellets with a diameter of 2 cm, then sintered at 700°C temperature for 2 hours and then cooled. The properties of films were characterized using Scanning Electron Microscopy (SEM- JEOL JSM-6360LA), X-Ray Diffractometer Spectroscopy (XRD), and Energy Dispersive X-rays spectroscopy (EDX), respectively. The optical properties of the films were investigated by using UV-Vis Spectroscopy.

RESULT AND DISCUSSION

Figure 1 (a) and (b) shows the surface morphology of CdTe thin films grown at temperature of 250 ^{o}C with plasma power of 14 W and 25 W, respectively, while Figure 1 (c) shows the morphology of CdTe thin film grown at higher temperature and plasma power i.e. at 325 ^{o}C and 43 W. At growth conditions of 250 ^{o}C, 14 W, it was found that there is no CdTe deposited the substrate (Figure 1(a)). It indicated that at this condition the amount of sputtered atoms that reached the surface of substrate are less enough. Interesingly, when the plasma power was slightly increased from 14 W to 25 W but keep the growth temperature at 250 ^{o}C, the CdTe thin film can be evenly grown eventhough its morphology was like weaks stack flat-fragment configuration with diameter of about 100 nm as shown in Figure 1(b). It was indicates that the sputtered atoms that reach the surface of substrate did not strongly bonded each other yet. This phenomenon was considered due to the momentum of atoms that were spattered onto the surface of substrate are still low. Consequently, the sputtered atoms did not have enough energy to bind and penetrate to the substrate.

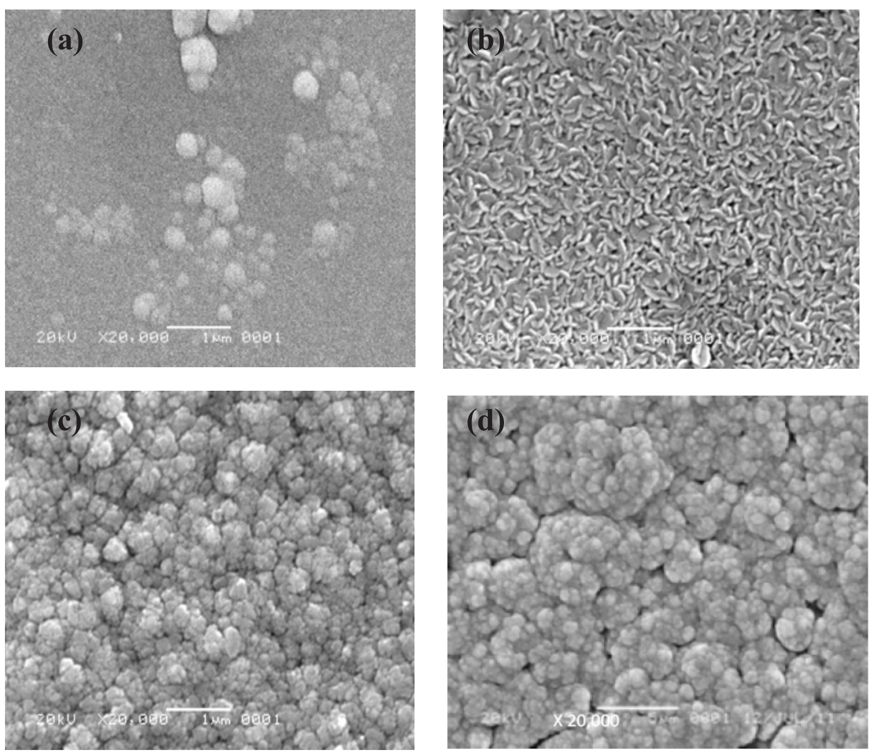

FIGURE 1. SEM images of (a) CdTe thin film grown at 250 ^{o}C, 14 W, (b) CdTe thin film grown at 250 ^{o}C, 25 W, (c) CdTe thin film grown at 325 ^{o}C, 43 W, and (d) CdTe:Cu(2%) thin film grown at 325 ^{o}C, 43 W.

When the growth temperature and plasma power were simultaneously further increased to 325 ^{o}C and 43 W however, the configuration of atoms on the substrate were rigidly constructed as shown in Figure 1(c)). It indicated that the sputtered atoms that reach the substrate were strongly bonded each other and deeply penetrate on the surface of substrate yield rigid grains stack configuration. Therefore, this parameters have been chosen to growth CdTe doped Cu (CdTe:Cu(2%) thin film with expectation that CdTe:Cu(2%) thin film would also has similar configuration with CdTe film. The morphology of CdTe:Cu(2%) thin film is shown at Figure 1(d). It can be seen that at growth temperature and plasma power of 325 ^{o}C and 43 W, both CdTe and CdTe:Cu(2%) thin films were truly grew with relatively similar grains configuration. The grain size diamater is about 200 nm.

Based on SEM images in Figure 1, it is found that the growth mechanism of CdTe:Cu(2%) and undoped CdTe thin films was strongly affected by its growth temperature and plasma power. CdTe films were preferentially grown at relatively high growth temperature and plasma power rather than at lower one. At low growth temperature and plasma power, the morphological structures of films were not perfect yet as shown in Figure 1(a) and (b). Hence, it can be interpreted that the use of relatively high plasma power contribute in the increasing the kinetic energy and momentum of atoms from the target towards the surface of substrate, whereas high growth temperature contribute to the increasing the atoms mobility on the surface of substrate [8]. In addition, high growth temperature leads to the atoms on the surface of substrate could be easy arranging themselves so that yield homogeneous surface morphology. However, it can be seen that the morphological structure of CdTe:Cu(2%) was more perfect than CdTe thin film. This is due to Cu atoms in CdTe single crystal is considered as interstitial ions (Cu^{+}) which will occupy Cd vacancy [5, 6]. CdTe single crystals have also a natural defect in the form of local Cd-vacancy defects, and the presence of Cu can fill these gaps therefore yielding film with more cohesive configuration [11-12].

Tabel 1 shows the Energy Dispersive X-rays spectroscopy (EDX) spectra of CdTe:Cu(2%) thin film. Based on EDX result, it can be confirmed that Cu was successfully doped on CdTe configuration with percentage ratio of Cd, Te, and Cu are 43.52% , 56.37% and 0.11%, respectively. This result verify that CdTe:Cu(2%) thin film has been successfully grown by using dc magnetron sputtering.

TABEL 1. The EDX results of CdTe:Cu(2%) thin film

Element	Massa %	Atom %	Error %
Cu	0.06	0.11	1.04
Cd	40.45	43.52	0.46
Te	59.49	56.37	0.76
Total	100.00	100.00	0.00

To evaluate the crystal quality of the thin film, the full width at half maximum (FWHM) values were calculated and were shown in Figure 2. The peak of films appears on the diffraction angle 2θ = 28.66° for CdTe film and 2θ = 28.28° for CdTe:Cu(2%) film. The intensity of diffraction peaks 2θ of both the films are revert to (101) plane. XRD peak of CdTe:Cu(2%) film is higher than CdTe peak. It indicate that the atoms that constructed the CdTe:Cu(2%) film were properly arranged. This result highly agree with SEM image of CdTe:Cu(2%) film that has cohesive configuration which is previously discussed. The FWHM of CdTe and CdTe:Cu(2%) thin films are 0.40 and 0.50, respectively. It can be seen that CdTe:Cu(2%) thin film has higher peak intensity and narrow of FWHM. This means that CdTe:Cu(2%) thin film has better crystallographic properties than CdTe thin film. Based on XRD analysis, it can be calculated that the lattice constants of CdTe thin films are a = 4.038 Å dan c = 6.598 Å, while a = 4.093 Å dan c = 6.684 Å for CdTe:Cu(2%) thin film. Therefore by confirmation with JCPDS data, it is clearly seen that both the films grown with hexagonal structure.

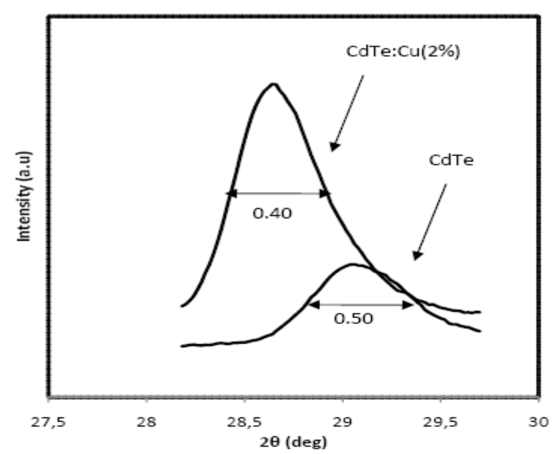

FIGURE 2. FWHM of XRD spectra of CdTe and CdTe:Cu(2%) thin films at (101) peak.

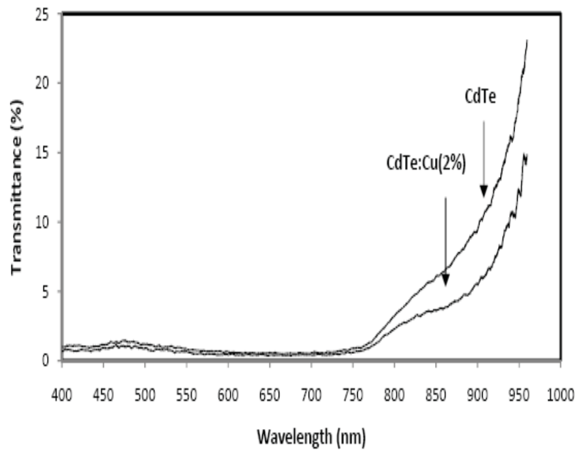

FIGURE 3. Transmittance spectra of CdTe and CdTe:Cu(2%) thin films.

Figure 3 showed the optical properties of CdTe and CdTe:Cu films. The films were investigated by using UV-Vis spectrometer. The transmittance spectra of CdTe and CdTe:Cu(2%) thin films were slightly different even though both films have similar absorption edge at ~780 nm. Consequently, at the wavelength regions below the absorption edge, both the films showed similar characteristic i.e. they totally absorb the incident photons with wavelength below smaller than 780 nm. However, at the region above the absorption edge, both films showed different characteristic. In this region, the transmittance spectra of CdTe:Cu(2%) film is lower than CdTe film. It indicated that the absorption capability of undoped CdTe film at wavelength region above its absorption edge is lower than CdTe:Cu(2%) film. It can be known that the optical properties of CdTe:Cu(2%) film is better than undoped CdTe film. This due to the morphological and crystal stucture of CdTe:Cu(2%) film were better than undoped CdTe film that was previously proved by using SEM and XRD analysis. It has long been known that physical properties of a thin film at macro scale are strongly determined by micro scale properties of thin film i.e. its crystal quality and surface area.

The bandgap energy of CdTe and CdTe:Cu(2%) thin films were then determined based on the absorption spectra of films. The absorption spectra of CdTe and CdTe:Cu(2%) thin films are showed in Figure 4. It can be seen that CdTe and CdTe:Cu(2%) have identical bandgap energy of 1.48 eV but different absorption capability. Another researcher ere reported that the band gap energy of CdTe film are in the range of 1.44 eV to 1.57 eV [1-7].

The absorption spectra trend is basically similar to the transmittance spectra results that were previously discussed. The indistinguishable of bandgap energy of films was considered as a consequent of the identical of they absorption edge at 780 nm, while the difference of the absorption capability was due to dissimilarity of the transmittance spectra above they absorption edge. A like as a transmittance spectra result, CdTe:Cu(2%) film showed higher absorption capability than undoped CdTe film. Indeed, this result give one more evident that besides be able to improve the morphological, structural and electrical properties of CdTe film, presenting the Cu atoms in the CdTe configuration was also enhance the optical properties of film. Even though the properties of CdTe thin film was not significantly yet enhanced in this study, it can be note that the properties of film are possible to be manipulated and controlled by using Cu as doping material.

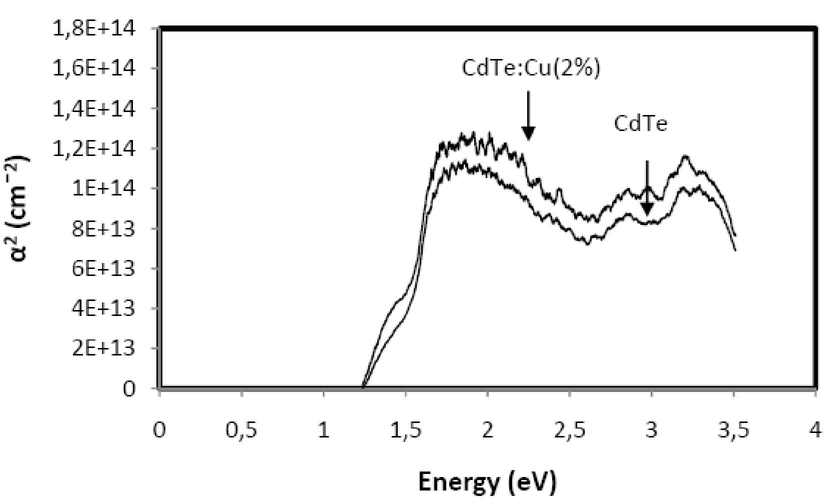

FIGURE 4. Absorption spectra of CdTe and CdTe:Cu(2%) thin films.

CONCLUSIONS

Preliminary studies of properties of CdTe and CdTe:Cu(2%) thin films deposited by using dc magnetron sputtering are reported. At growth conditions of 250 ^{o}C and 14 W, CdTe did not yet evenly deposited. However, at growth temperature and plasma power of 325 ^{o}C and 43 W, both CdTe and CdTe:Cu(2%) were grew on substrates. The morphology of the films indicates that the grain-like nanostructures with grain size diameter of about 200 nm begin to appear on top of the films. The deposited films consist of Cd, Te and Cu elements. The CdTe and CdTe:Cu(2%) films have hexagonal structures with highest peak intensity revert to (101) plane. The CdTe:Cu(2%) thin film has better crystallographic properties than CdTe thin film. The transmittance spectra showed that transmittance of CdTe:Cu(2%) film is lower than CdTe film. Moreover, it was found that the bandgap energy of CdTe and CdTe:Cu(2%) thin film is similar i.e. 1.48 eV.

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