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PHOTOVOLTAIC PROPERTIES OF SILVER-DOPED NANOCRYSTALLINE CdTe–SiO_2–Si HETEROSTRUCTURES

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Abstract
This study investigates the photovoltaic properties of silver (Ag)-doped nanocrystalline CdTe–SiO_2–Si heterostructures. It was found that increasing the tilt angle of the texture axis enhances the photo-EMF, confirming a strong correlation between the crystalline structure and the optoelectronic efficiency of CdTe:Ag films.

Keywords: Thin films, texture, photo-EDS, photoconductivity, cubic and hexagonal modifications, cadmium telluride.

Introduction

Cadmium telluride layers obtained by vacuum oblique-angle deposition on unoriented substrates have attracted great attention due to the abnormally high photo-EMF observed. Earlier studies [1] associated the photovoltaic properties of CdTe films obtained by this method with the texture of these films, which depends on the deposition angle. Subsequent research [2–4] confirmed this view, showing that depending on deposition conditions, CdTe films can have two types of textures corresponding to different signs of generated photo-EMF. Important factors affecting film structure include substrate type, deposition angle, deposition rate, and substrate temperature. However, comprehensive studies on the dependence of film structure and photoelectric properties on thickness were lacking. Investigating the variation of texture character with film thickness and the dependence of texture axis inclination on deposition angle helps establish the mechanism of preferred orientation formation in obliquely deposited CdTe films—potentially common for all A_2B_6 compounds.

1. Experimental Methods

The CdTe thin films were deposited on oxidized silicon (SiO_2–Si) and glass substrates using a high-vacuum thermal evaporation technique under a pressure of approximately 10^{-6} mmHg. The purity of CdTe powder used as the source material was 99.999% (5N), which ensured

minimal contamination and uniform deposition. Prior to deposition, the substrates were subjected to an ultrasonic cleaning procedure in acetone, ethanol, and deionized water, followed by drying in an inert nitrogen atmosphere to eliminate organic residues and surface contaminants.During the deposition process, the substrate temperature (Ts) was maintained in the range of 250–300°C, controlled by a thermocouple feedback system to ensure reproducibility of film growth conditions. The deposition rate (v) was adjusted between 0.35 and 1.0 nm/s, monitored continuously using a quartz crystal thickness monitor. The film thickness (d) was varied from 0.5 to 1.5 μm by changing the deposition time and was verified using an interference microscope (MII-4). For the study of structural properties, X-ray diffraction (XRD) measurements were carried out on a Shimadzu XRD-7000 diffractometer using Cu Kα radiation (λ = 1.5406 Å). The obtained diffraction patterns were analyzed by the Rietveld refinement method using PowderCell 2.4 software, allowing the determination of lattice parameters, phase composition, and crystallite size. The average grain size of the CdTe:Ag films was found to be approximately 0.14 μm, as calculated from the Debye–Scherrer equation. To investigate the influence of the deposition angle (α) on the formation of the crystallographic texture, a specially designed rotating substrate holder was employed, enabling oblique-angle deposition at increments of 10° within the range of 0°–80°. This configuration ensured simultaneous preparation of multiple samples under identical conditions, differing only by the incidence angle of the vapor flux. The use of this technique provided valuable insights into the relationship between the preferred orientation of crystallites and the induced photoelectromotive force (photo-EMF).The photoelectric measurements were performed using an IKS-14 infrared spectrophotometer equipped with a monochromator and temperature-controlled sample chamber. The photo-EMF was measured under monochromatic illumination with variable wavelengths ranging from 400 to 1200 nm, corresponding to the fundamental absorption edge of CdTe. The light intensity was calibrated with a standard silicon photodiode detector, and the polarity of the induced photo-EMF was determined with respect to the evaporator position.

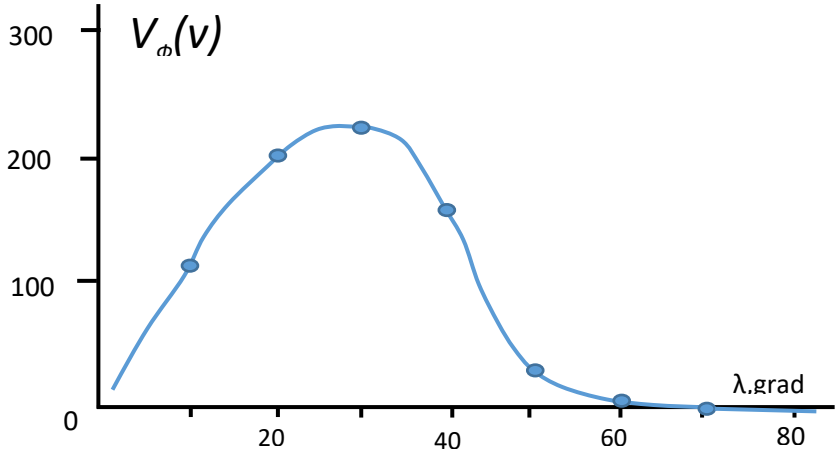

Figure 1: Dependence of photo-EMF on deposition angle of CdTe films(d=0.26–0.30 μm, v=0.40–0.46 nm/s).

All samples in this series exhibited a photoinduced electromotive force (photo-EMF) of positive polarity, with the end of the sample remote from the evaporator being positively charged. The polarity and the functional dependence are consistent with those previously reported in our earlier study [1]. The maximum photo-EMF was recorded at an incidence angle of $\alpha = 30°$. Electron diffraction analysis revealed that the films deposited at incidence angles $\alpha \leq 20°$ possess a structural morphology similar to that described in Ref. [1] (see Fig. 3).

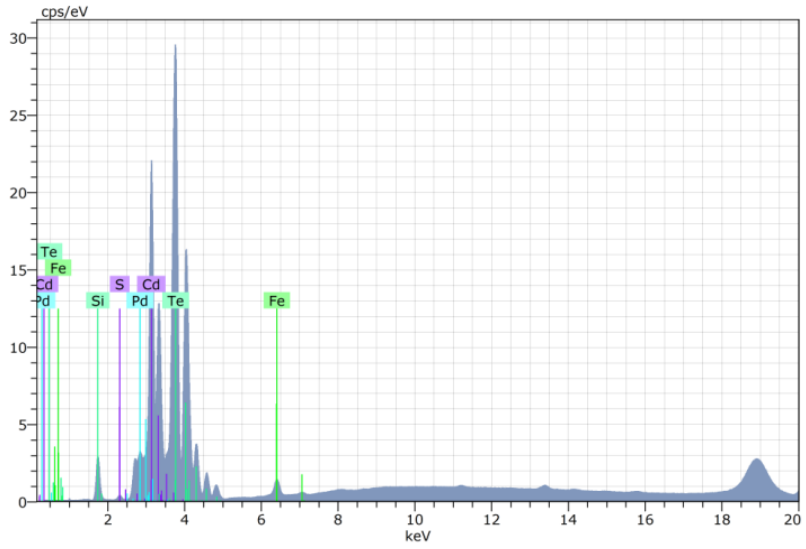

Fig. 2. X-ray diffraction analysis of polycrystalline CdTe–SiO_2–Si films without silver

Figure 2 presents the X-ray diffraction (XRD) pattern of the initial polycrystalline CdTe–SiO_2–Si film. As can be seen from Fig. 2, several diffraction peaks with varying intensities are observed. The XRD peaks of the initial CdTe–SiO_2–Si polycrystalline film correspond to the main atomic planes of CdTe in its crystalline lattice. As evident from Fig. 2, no peaks associated with silver are present, and only the intense peaks of Si, Cd, and Te are observed..

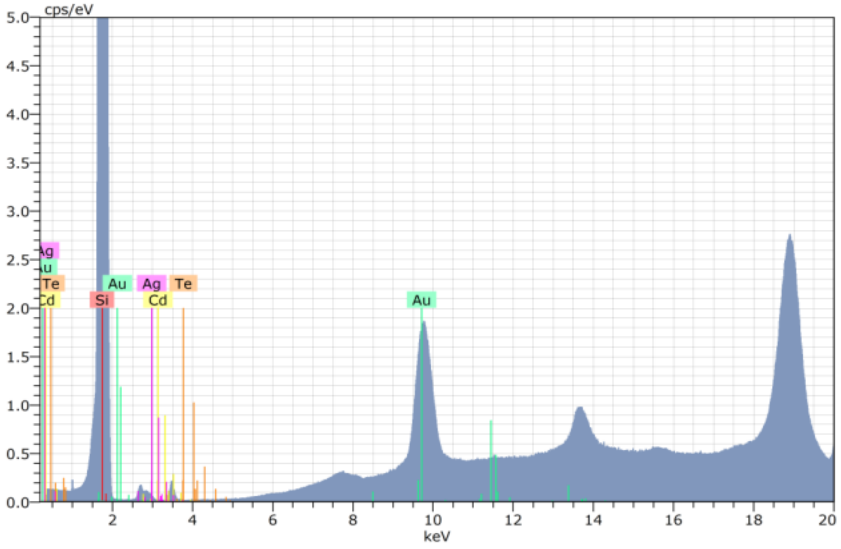

Fig. 3. X-ray diffraction analysis of polycrystalline CdTe–SiO_2–Si films with silver.

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Figure 3 shows the X-ray diffraction peaks of the first group of samples, with prominent peaks at 2θ = 28.5° and 95°, corresponding to silver and gold, respectively. The film predominantly consists of the hexagonal modification of CdTe with two texture axes [001] oriented in opposite directions. In addition, the surface morphology of the deposited films was examined using a scanning electron microscope (SEM, JEOL JSM-6610LV) to visualize grain boundaries and detect surface irregularities. The elemental composition and the presence of dopant atoms (Ag) were confirmed by energy-dispersive X-ray spectroscopy (EDX). To analyze the optical characteristics, UV–Vis transmission and reflection spectra were recorded using a Shimadzu UV-2600i spectrophotometer, allowing the estimation of the optical band gap via Tauc's relation.The combination of these experimental techniques provided a comprehensive understanding of the structural, morphological, and photoelectric behavior of Ag-doped CdTe thin films. The obtained data served as the basis for establishing the correlation between the deposition parameters, crystallographic texture, and the resulting optoelectronic performance of the CdTe–SiO_2–Si heterostructures

Conclusions

Based on the research results, it has been revealed that CdTe:Ag nanocrystalline heterostructures have promising applications in solar cells, infrared detectors, and highly sensitive optoelectronic sensors. In particular, the structural stability, dominance of the cubic phase, and controllability of the texture orientation in CdTe layers formed on SiO_2–Si substrates make these materials highly suitable for practical device applications. In future studies, it is advisable to theoretically model diffusion processes in CdTe:Ag systems, compare the effects of different dopants (Na, Cu, Au), and investigate the photoresponse kinetics through the formation of p–n heterostructures

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