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The effect of substrate rotation rate on physical properties of cadmium telluride films prepared by a glancing angle deposition method

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ABSTRACT

Physical properties of cadmium telluride thin films, deposited on glass substrates by modified glancing angle deposition (GLAD) technique with various substrate rates of rotation, were investigated in this study. In contrast to obliquely columnar thin films fabricated by the conventional GLAD technique, in which higher columnar angle is coupled to higher degree of porosity, this study introduces obliquely deposited thin films which have packed columnar structures despite their highly tilted columns. Structural and optical properties and surface morphology of the CdTe thin films deposited by this technique were studied using X-ray diffraction, UV–visible spectroscopy and field emission scanning electron microscopy.

1. Introduction

It has been shown that the morphology of thin films has a great influence on their physical properties [1]. One of the versatile methods, capable of producing columnar structures and therefore effective in manipulating optical, mechanical, and electrical properties of thin films, is physical vapor deposition (PVD) [2]. Among the PVD methods, thermal evaporation technique is the most desirable one, owing to its capability in controlling the morphology of columns by changing some parameters such as vapor pressure, deposition rate, substrate temperature, and vapor flux direction [1].

In a thermal evaporation process with low substrate temperature and hence limited adatom diffusion, if the vapor flux is vertically directed towards the substrate surface, the incident atoms will be condensed on the nearest sites of nucleation or in the vicinity of them; consequently, conventional columnar structure would be formed [3]. In the case of a non-perpendicular angle of deposition with low substrate temperature, another feature is introduced.

As it can be seen in Fig. 1, when a flux of the atomic vapor comes up with the angle of α, deposition rate will have a lateral as well as a vertical component with respect to the substrate surface. The lateral component helps the nucleation sites intercept the incident particles and causes a shadowing effect to happen. During this process, a growth competition occurs among the columns, which lets the tallest nucleated islands keep growing by receiving more atoms than the shorter ones. Eventually, a tilted columnar film with an angle (β) and level of porosity depending on β is formed [3–6]. This technique, in which the vapor flux is directed towards a stationary substrate at an angle α with respect to its normal, is called oblique angle deposition (OAD) and can significantly affect the layer's properties [1].

The relation between the angle of tilted columns (β) and the incident angle (α) has been broadly studied [5–8]. β is found to be dependent on some factors such as substrate temperature, deposition rate, angular distribution of deposition vapor flux, and vacuum chamber pressure; however, it is universally observed to be smaller than α and follow the empirical tangent rule for small α ($\alpha \leq 50°$) [6]:

$$\tan(\beta) = (1/2)\tan(\alpha). \tag{1}$$

Or the cosine rule for higher α:

$$\beta = \alpha - \arcsin\left[(1-\cos(\alpha))/2\right]. \tag{2}$$

These formulas indicate that, if a highly tilted columnar structure is desired, the vapor flux must be directed towards the substrate at a large incident angle, resulting in a porous film owing to the shadowing effect. Conversely, if a nearly vertical columnar film is desired, the flux must arrive more perpendicularly to the substrate, resulting in a tightly packed structure [5,6]. Consequently, porosity cannot be produced independently by OAD technique and increases with the raise of α and β.

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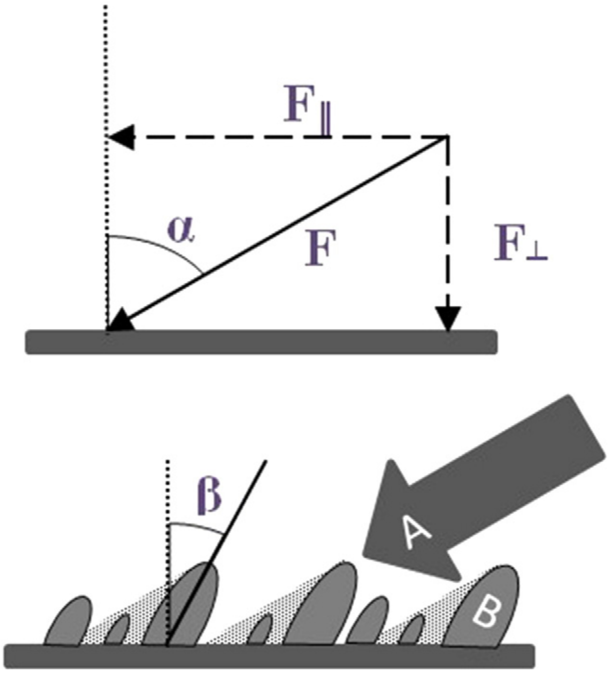

Fig. 1. Oblique angle deposition, competition between columns and shadowing effect; F: deposition rate vector, $F_{\parallel}$: lateral component of deposition rate, $F_{\perp}$: vertical component of deposition rate, α: the angle between the deposition rate vector and normal of substrate, A: incident flux, B: column, β: the angle between tilted column and normal of substrate, dot region: shadowing effect.

In order to avoid the restricted relation between the angle of tilted columns and porosity, another approach called glancing angle deposition (GLAD) has been introduced [1,9–14]. It is a physical vapor deposition technique, in which OAD technique is combined with the rotation of substrate. By rotating the substrate around its normal and setting various deposition conditions, Robbie et al. [5] fabricated tilted columnar films, the porosity of which was found independent from the angle of tilted columns. Their noticeable achievement was producing porous films with vertical columns.

The present study introduces an approach which seems to be applicable for producing highly packed tilted columnar films of cadmium telluride (CdTe).

Semiconductor thin films with tilted columns having less porosity can be applied in examining the models of anomalous photovoltaic effect [15, 16]. This effect refers to a condition in which photo voltage is larger than the band gap of the corresponding semiconductor. This phenomenon has been observed in obliquely deposited semiconductor films, but not well-understood yet. Magnitude of photo voltage depends on the angle of columns which should be preferably higher than 30° [15–17].

Tilted columnar films of cadmium telluride, a semiconductor with a direct optical band gap of 1.5 eV, has been reported to present an anomalous photovoltaic effect [18–20]. CdTe is usually considered as one of the most promising absorber layers for solar cells owing to its large light absorption coefficient of $>10^5$ cm^{-1} in the visible range [21]. It is commonly known to be a p-type semiconductor; however, under some circumstances, it can be self-doped by Cd and act as an n-type semiconductor, which makes it a good candidate for preparing homojunction solar cells [22].

Fig. 2 represents both the conventional GLAD technique and the one used in the present investigation. The main difference between these two systems, as observed in the figure, is the way by which the substrate is rotated. In conventional GLAD technique, the substrate is coupled directly to the step motor but it is not so in the case of the system used in this work. This means that the cylinder is coupled to the step motor; hence the substrate is rotated off center. In the previous study [23,24], effect of different deposition flux angles ($\alpha = 0°$, 20°, and 70°) with the fixed rate of rotation on the optical and structural properties of CdTe films was investigated, while the emphasis of the present study is on the effect of different rotation rates on those properties of CdTe films.

2. Experimental details

CdTe films were deposited on glass substrates in a Hind Hi Vac coating unit (Model 15F6). The substrates were cleaned in acetone using ultrasonic bath and then dried by purified nitrogen gas. Further, the substrates were subjected to glow discharge cleaning before deposition. Base pressure of the vacuum chamber was about 10^{-4} Pa. CdTe powder of 99.99% purity, supplied by Aldrich Company, was evaporated from a molybdenum boat. Deposition rate was measured and controlled in situ using Hind HiVac thickness monitor (Model DTM101). Typical growth rate was 10 Å/s on average. All the films were deposited at ambient temperature in a vacuum chamber, in which an invented vapor controlling equipment registered by the authors [25,26] was mounted.

The equipment, as shown in Fig. 2, consisted of a hollow cylinder with 10 cm diameter, which was used for angled mounting and rotating the substrates. The substrates were mounted on the substrate holder on the inner wall of the cylinder with an angle of 45° with respect to the horizontal axis. Therefore, an angle of about 15° between the normal of substrate and vapor flow direction was made. The distance between the substrate and boat was about 9 cm.

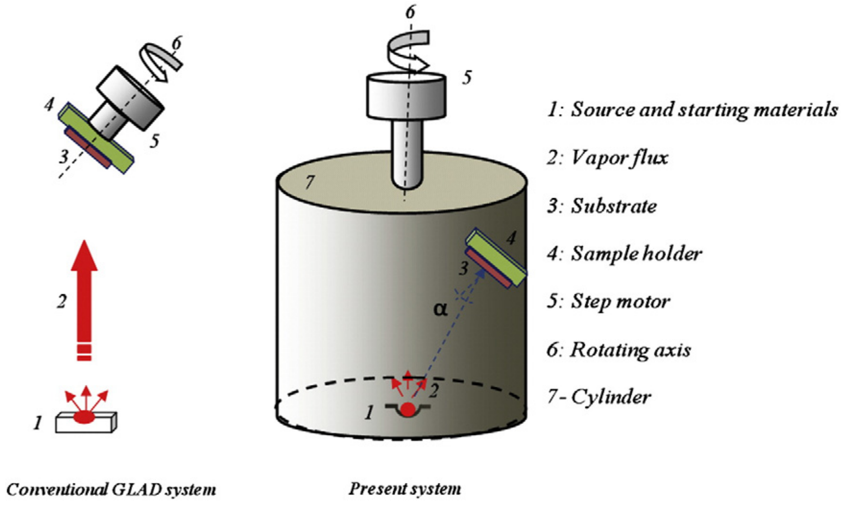

Fig. 2. Left: conventional GLAD technique [24]; right: present system [23].