Effect of power variation on microstructure and surface morphology of HgCdTe films deposited by RF magnetron sputtering*

Wang Guanghua(王光华)[1], Kong Jincheng(孔金丞)[1], Li Xiongjun(李雄军)[1], Qiu Feng(邱锋)[2],
Li Cong(李悰)[2], Yang Lili(杨丽丽)[1], Kong Lingde(孔令德)[1], and Ji Rongbin(姬荣斌)[1,†]

(1 Kunming Institute of Physics, Kunming 650223, China)
(2 Department of Physics Science and Technology, Kunming 650031, China)

Abstract: Mercury cadmium telluride films were grown by the RF magnetron sputtering technique at different sputtering powers. In experiment, X-ray diffraction (XRD) and atomic force microscopy (AFM) have been used to characterize the microstructure of HgCdTe films. The experimental results showed that when the growth power increased, the growth rate of HgCdTe films increased; when the growth power was less than 30 W, the HgCdTe film deposited by RF magnetron sputtering was amorphous; when the growth power was more than 30 W, the films exhibited polycrystalline structure. Films deposited at different growth rates were found to have characteristically different formations and surface morphologies; as observed through AFM, the surface morphology is composed of longitudinal islands forming a maze-like pattern in the high deposition rate. AFM analysis also illustrated that a significant reduction in the areal density of large islands and characteristically smoother films was achieved using a low deposition rate.

Key words: HgCdTe films; semiconductors; growth rate; microstructure; surface morphology
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1. Introduction

Mercury cadmium telluride (HgCdTe) has a variable band gap, depending on Hg composition, photo detectors designed like this can have a wavelength from visible light to far infrared light[1,2]. HgCdTe thin films are widely used for high performance infrared focal plane array (IRFPA) detector devices which are very important in military strategy, and crystalline HgCdTe is the material of choice for many IR focal plane applications. Many methods have been used to grow HgCdTe thin films, such as molecular beam epitaxy (MBE)[3], metal organic chemical vapor deposition (MOCVD)[4], and liquid phase epitaxy (LPE)[5]. But there are some drawbacks and limitations in preparing IRFPA detectors due to the bad compatibility and mismatch between the substrate and HgCdTe thin films, which limit the far-ranging application of IRFPA with high performance and low cost[6,7].

While amorphous thin films have many features[8], they have a number of interesting physical properties as well as numerous potential applications, such as: they can be deposited on any substrate or even directly grown on devices[9]. The preparation method is simple and low in cost. It is easy to fabricate large area thin films, and there is no limitation of shape. They have excellent optical and electrical properties, especially for the photo absorption coefficient[10]. In order to take advantage of the long disorder of amorphous semiconductor materials and the feature of easily preparing devices, and in comparison with other methods (MBE, MOCVD, LPE etc), RF magnetron sputtering is a useful method to deposit amorphous or polycrystalline thin films on low-temperature substrates.

As shown in this paper, we have tried RF magnetron sputtering growth of HgCdTe on glass substrates at different sputtering powers and researched the effect of power variation on the material phase, structure, and surface morphology of thin films.

2. Experimental details

In this work, $7101^{\#}$ glasses were chosen as the substrates, which were clipped on the sample holder. Prior to growth, the $7101^{\#}$ glasses were first immersed in H_2SO_4: $KCrO_4$ solution for a while to eliminate oxide on the surface of the glass substrates, the system was washed in acetone, ethanol and deionized water with an ultrasonic instrument for 10 min, respectively, then blown dry with N_2 gas. The chamber was then evacuated to $(2-4.0)\times10^{-4}$ Pa and purged with argon (Ar) to reduce the residual water vapor and oxygen for 20 min. Then HgCdTe thin films were deposited with RF magnetron sputtering by MSP300B. The growth powers were controlled at 10, 20, 30, 40, 50 W, respectively, the sputtering pressures were approximately 1.0 Pa, the substrate temperatures were controlled at 10 °C, the target is polycrystalline $Hg_{1-x}Cd_xTe$ ($x = 0.66$) and the distance between the substrate and the sources was set to be 50 mm.

The corresponding deposition thin film thicknesses were determined by a surface profiler to evaluate the deposition rate of HgCdTe films deposited by RF magnetron sputtering at different powers. The phase and structure of HgCdTe films deposited by RF magnetron sputtering were tested by the XRD technique using a Philips X'Pert-MRD with a CuK ($\lambda = 0.15418$ nm) ray and a nickel filter. Diffraction was recorded from 5° to 70° in steps of 0.05. The working voltage and electricity were controlled at 40 kV and 120 mA, respec-

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† Corresponding author. Email: jrongbin@gmail.com

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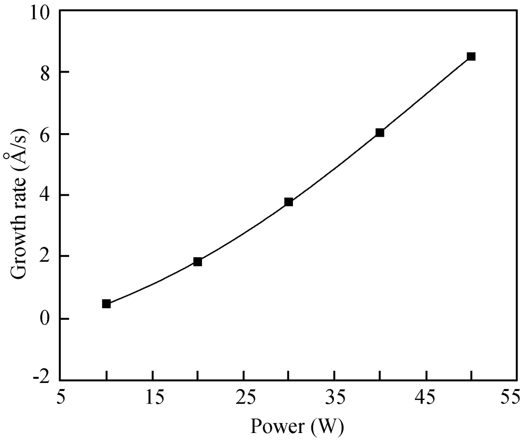


Fig. 1. Relation between sputtering power and growth rate.

tively. The surface morphologies of the HgCdTe films were investigated with atomic force microscopy (AFM) and scanning electron microscopy (SEM) measurements. All the measurements were performed at room temperature.

3. Results and discussion

3.1. Effect of sputtering power on growth rate

The relation between the sputtering power and the growth rate is shown in Fig. 1. As can be seen from Fig. 1, the growth rate of films increased linearly with increasing sputtering power. We all know that the growth rate of films is considered to be one of most important technical parameters in RF magnetron sputtering, and mainly depends on the variation in sputtering gas, sputtering gas pressure, target composition, operating voltage, operating current, substrate temperature and the distance between the target and the substrate etc[11, 12]. On the basis of the above invariable parameters, the growth rate of films rested with the Ar^+ amount and kinetic energy impacted target; when the growth power reached a certain value, the Ar^+ amount and Ar^+ kinetic energy increased rapidly due to ion colliding. Consequently, the ion amount and the sputtering rate of the target also increased in short order. According to sputtering theory, the sputtering deposition rate of films is proportional to the product of the sputtering rate of the target and the density of the ion stream. The density of the Ar^+ ion stream increased as the sputtering power increased, and the sputtering rate of the target also increased; finally, it was shown that the growth rate of films was enhanced according to sputtering power.

3.2. XRD analysis

The XRD spectra of HgCdTe film deposited by RF magnetron sputtering at different sputtering powers are shown in Fig. 2. From the figure, it can be clearly seen that when the sputtering power was controlled at less than 20 W, the diffraction angle (2θ) was 15°–35°, and the XRD spectra show wide peaks, which means that the HgCdTe thin films deposited by RF magnetron sputtering at 10 and 20 W were amorphous. When the sputtering power is controlled at 30 W, some special diffraction peaks begin to appear, and some nanocrystalline islands can be embedded in a matrix of amorphous HgCdTe thin films. When the growth power got to 40 W, some special diffraction peaks appeared at 23.7°, 39°, 46°, which gave crystalline HgCdTe a (111), (220) and (311) preferential orientation. The diffraction peak gradually became sharper, the sputtered films exhibited polycrystalline structure, and the crystalline quality changed from amorphous to crystalline film with increasing growth power[14, 15]. This means that the HgCdTe films have a face-centered cubic (fcc) structure, which has the lowest energy on the (111) plane; with the Scherrer formula, the grain size of HgCdTe films is evaluated. The Scherrer formula can be written as

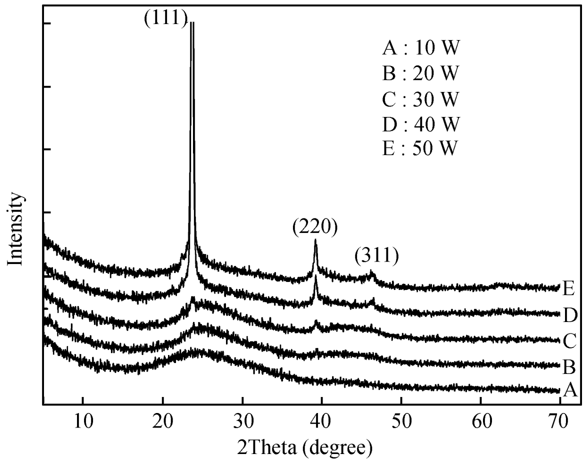


Fig. 2. XRD spectra of HgCdTe films deposited by RF magnetron sputtering at different powers.

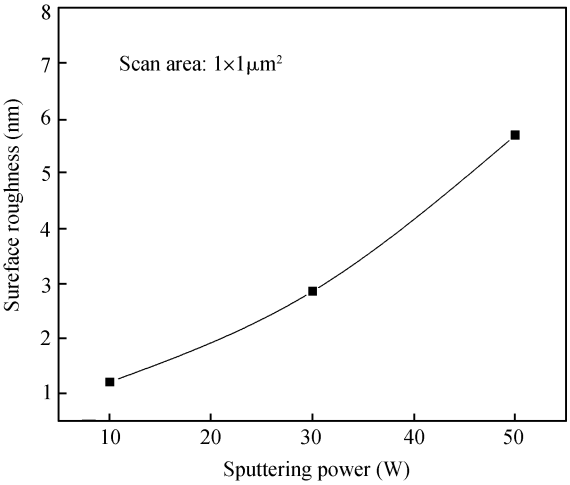
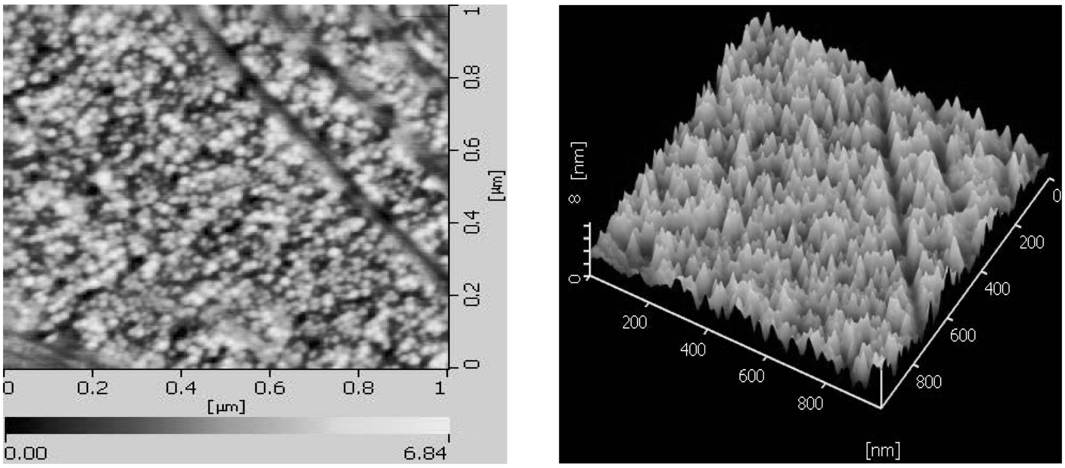


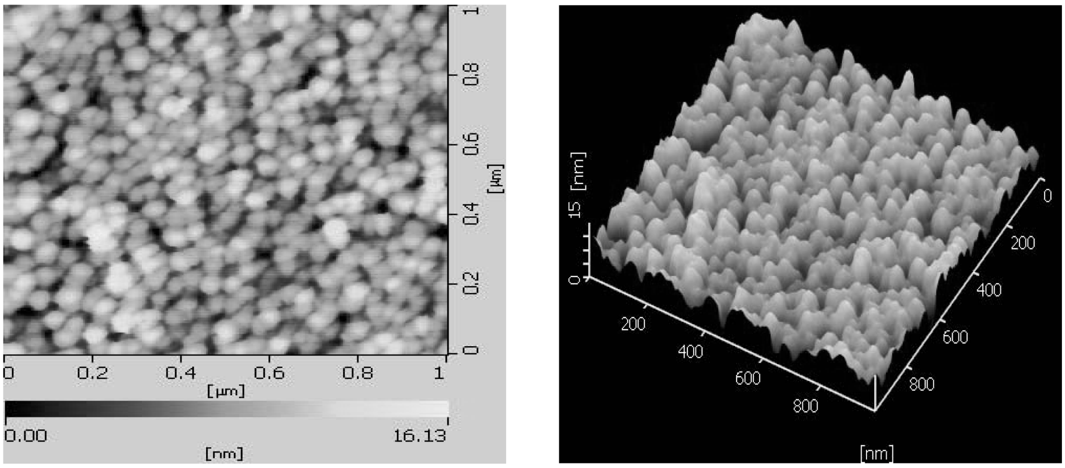
Fig. 3. Relation between sputtering power and surface roughness of HgCdTe thin films.

$$d = \frac{0.9\lambda}{B\cos\theta_{\mathrm{B}}}, \tag{1}$$

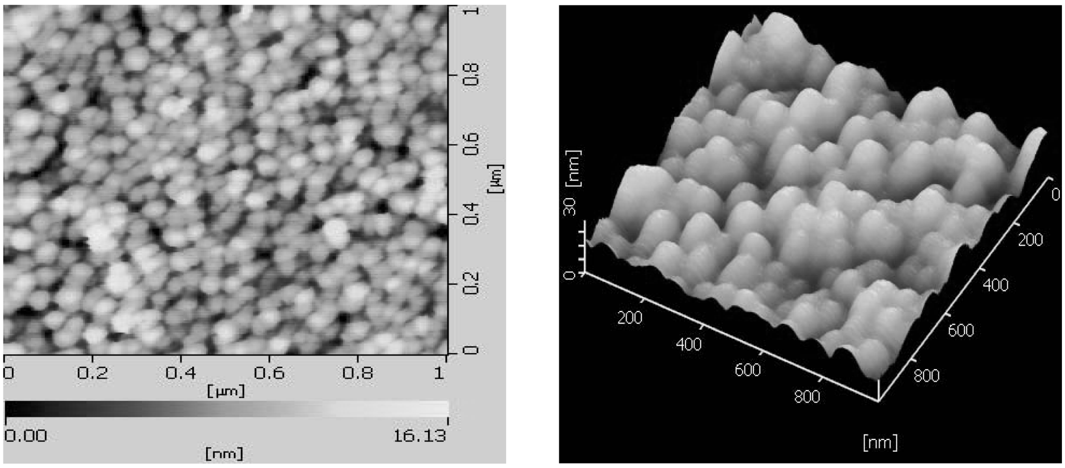
where d is the crystal size, λ is the X-ray wavelength used ($\text{CuK}\alpha = 1.54\times10^{-10}$ m), B is the full width at half maximum (FWHM) in rad, and θ_{B} is the Bragg angle. We calculated that d = 41 nm and 49 nm, respectively. The X-ray diffraction studies revealed the optimized sputtering power for the growth of HgCdTe films with different crystal structures.



(a) Sputtering power 10 W



(b) Sputtering power 30 W

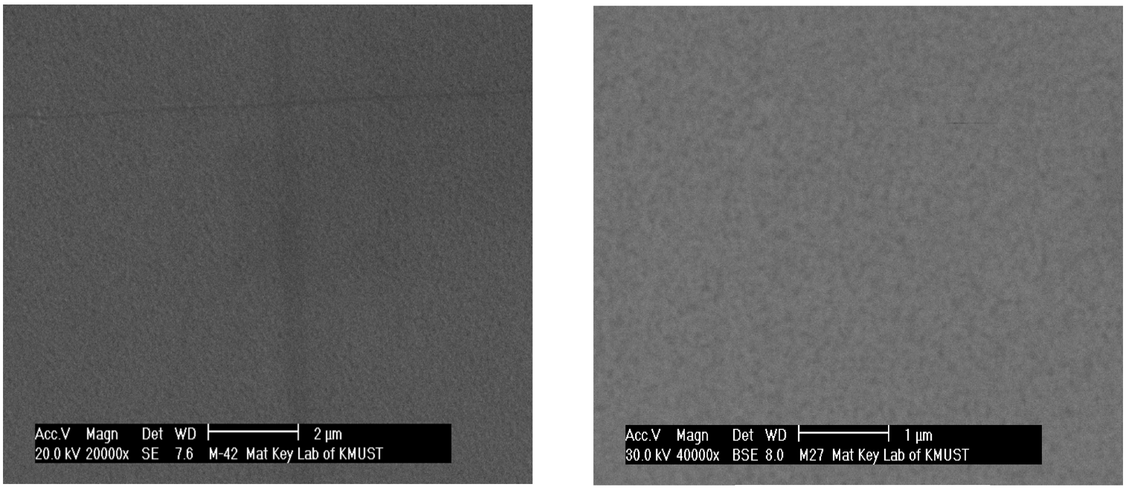


(c) Sputtering power 50 W

Fig. 4. Two- and three-dimensional AFM images of HgCdTe films deposited by RF magnetron sputtering.

3.3. Surface morphology

First, we examine whether variations in the deposition rate would affect surface roughness. To perform this task, we used AFM to inspect the surface morphology of the HgCdTe thin films, over a scan area of 1 × 1 μm^2; the characteristic morphology observed is composed of large islands or protrusions from an otherwise smooth surface[16]. Figure 3 shows the surface roughness of HgCdTe films deposited at different sputtering powers as measured over a scan area of 1 × 1 μm^2. Here, we have found a significant improvement in the film's smoothness when the deposition rate is lowest. Therefore, we can suc-



(a) Sputtering power 10 W

(b) Sputtering power 50 W

Fig. 5. SEM images of HgCdTe films deposited by RF magnetron.

ceed in significantly decreasing the surface roughness of the films by sufficiently lowering the deposition rate. Next, we inspect the effect of deposition rate on the areal density of surface outgrowths of the films. Figure 4 shows a typical AFM image of films representative of the surface morphology for different growth rates. From Fig. 4 some protrusions or outgrowths can be observed on the surface of the films; when the sputtering power increased, the areal density and height of the larger islands increased significantly.

The film formation is also affected by deposition rate[19, 20]. It has been observed that smoother films can be achieved by depositing at a lower growth rate of 10 W in Fig. 4. The basic mechanism for the formation of large islands is the reduction of the surface energy, and the minimum surface energy is attained when all the islands are joined in one, single island. In the case of the 10 W samples, the combined effects of increased ripening and low surface mobility of the species on the surface has led to the formation of comparatively smaller islands and increased island boundaries. Thus, the coalescence of these smaller islands is energetically favorable even at a comparatively earlier stage. However, low surface mobility and ripening at a low deposition rate also essentially limits the areal density and height of these larger islands, both of which are comparatively lower than those at 30 or 50 W.

Film growth starts with nucleation of evaporated species on the substrate's surface. Extensive ripening and low surface mobility considerably delay the growth and increase in size of the islands. At a certain thickness, the surface becomes completely covered by the film having a significant amount of island boundaries. This is the critical thickness for this regime. Further deposition leads to the formation of larger islands through coalescence. In contrast, high surface mobility in the high deposition rate regime leads to the growth of islands in a maze-like pattern (Fig. 5).

4. Conclusions

The effects of power variation on microstructure and surface morphology of HgCdTe films deposited by RF magnetron sputtering were investigated. It was found that the microstructure of HgCdTe films is strongly related to sputtering power. Analysis of the experiment results indicated that HgCdTe films grown directly on glass substrates had high quality, and the growth rate of the film increased with the increasing of growth power. When the growth power was lower than 30 W, the HgCdTe film deposited by RF magnetron sputtering was amorphous. When the growth power got to 40 W, the diffraction peak became sharper, and the films attained a polycrystalline structure with preferential orientation in the (111) direction. Two main processes (ripening and surface mobility) arising from variation of the deposition rate were considered to be factors influencing the surface morphology; it is believed that this is the optimum growth condition giving a balance between the number of the HgCdTe molecules arriving at the surface of the substrate and the surface diffusion of the HgCdTe molecules on the substrate.

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