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The effect of annealing temperature on the characterization of Al/PbTe films

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The main purpose of this article is to study the effect of annealing temperature on the characterization of Al/PbTe films. The Al/PbTe films were prepared by RF magnetron sputtering and then annealed in the vacuum resistance furnace at different temperatures. The thicknesses of Al and PbTe are 20 nm and 300 nm respectively. Effect of annealing temperature on the characteristics of Al/PbTe films was investigated. We choose 1173 K, 1223 K and 1253 K as our annealing temperatures. Scanning electron microscope (SEM), X-ray diffraction (XRD) and Fourier transform infrared spectroscopy (FTIR) were carried out to characterize the deposited films. The sheet resistance of the samples was measured with a four-point probe. The experimental results show that annealing treatment has very big effect on the surface morphology, transmittance and resistivity of the Al/PbTe thin films.

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1. Introduction

As one of the important IV–VI semiconductor materials, the rock-salt (face-centered cubic) structured lead telluride (PbTe) nanostructure has been the object of particular attention, because of its narrow band gap of 0.31eV (in the bulk at room temperature) and strong quantum confinement effect owing to its large Bohr radius (about r_B = 46 nm) [1]. The PbTe thin films' refractive index up to 5.5, transparent band width, and the performance of lead tellurium will greatly improve after by doping. Lead telluride (PbTe) makes a good candidate material for photodetectors in the mid- and far- infrared bands and mid-infrared quantum well laser diode because of high quantum efficiencies,low noise level at working temperature and ability to tune peak wavelength by adjusting alloy composition [2-7]. PbTe has been applied in many fields and is considered to have a high potential for optoelectronic, thermoelectric, and other applications [8, 9]. Various methods have been utilized to prepare PbTe thin films such as vacuum evaporation [10], magnetron sputtering [11], molecular beam epitaxy [2,12], pulsed laser deposition[13], hot-wall epitaxy [14], chemical synthesis [15] and electrodeposition [16]. Among these various methods, magnetron sputtering method has many special characteristics, for example, membrane rate controllable and high quality, repeatability, comparative economic and massive preparation.

In the present work the growth of Al/PbTe thin film deposited on Si (111) substrates by RF magnetron sputtering is addressed, and then annealed in the vacuum resistance furnace with various experiment conditions. In order to stduy the effect of annealing treatment, Al/PbTe thin film was annealed by varying the annealing temperatures while maintaining the time constant.

2. Experimental process

In this experiment, experimental instruments include RF magnetron sputtering apparatus which produced by Shenyang Scientific Instrument Factory and S00-8.10 type quartz tube type resistance furnace. Both the PbTe target (φ 60 mm × 3 mm) with 99.99% purity employed and the Al target which has the same purity and size with PbTe target as source were purchased commercially (from Haite Materials). The target-to-substrate distance was 80 mm. Si (111) that single polished were used as a substrate.

The whole experiment is divided into two parts, one is sputtering coating, another part is annealing processing. The Si wafers were progressively cleaned in an ultrasonic bath with acetone, alcohol and then rinsed in deionized water before the deposition process, in order to remove organic contaminants. The base pressure before introducing Ar in the sputter chamber was ~ 5×10^{-4} Pa. The Al target was pre-sputtered in Ar ambient at a pressure of 0.9 Pa for about 10 min with the sputtering voltage and current were 280 V and 0.12 A respectively. The deposition of the Al films to a thickness of 20nm was performed with a deposition rate of ~ 0.05 nm s^{-1}. And then sputtering PbTe membrane layer upon the Al film. PbTe films were sputtered for 45 min with the working pressure was 0.25~0.3Pa in pure Ar and the input power was set at 20 W with zero reflected power. The thickness of the PbTe films was about 300 nm. The following is the second part of experimental. The samples which have disposed by the above steps were annealed in the quartz tube type resistance furnace at a constant time at various annealing temperatures at nitrogen atmosphere. The phase structure, surface morphology were obtained by X-ray diffraction (XRD) and Scanning electron microscopy (SEM), respectively. And the transmission rate of films was measured with Fourier transform infrared spectroscopy (FTIR). The sheet resistance of the samples was measured with a four-point probe.

3. Results and discussion

3.1 X-ray diffraction (XRD) analysis

The XRD patterns of the films annealed for 20min at different temperatures are shown in Fig. 1. After annealing the color of the samples form dark grey become brass. Only the (200) peak can be seen in the Fig. 1, this shows Al/PbTe films deposited by magnetron sputtering have strong < 100 > optimizing orientation direction, the change of the annealing temperature did not cause the preferred orientation change. This is mainly due to the lattice spacing of PbTe (200) is close to that of Si substrate (111) surface, making films prefer growing along the <100> direction. When the annealing temperature to 1173 K, the relative intensity of the (200) diffraction peak reduced significantly compared with the sample of the unannealing, and when the annealing temperature to 1223 K and 1253 K, (200) diffraction peak continue to decline, it shows that the number of the grains with same size decreased in certain dierection. In addition, the half-peak width is narrower, this illustrate that after annealed the grain size is smaller than before. This is due to heat treatment can make the film grows again along certain faces to enable the material transfer among lattices in the internal of polycrystalline thin films, the lattice defect decrease and more neatly arranged.

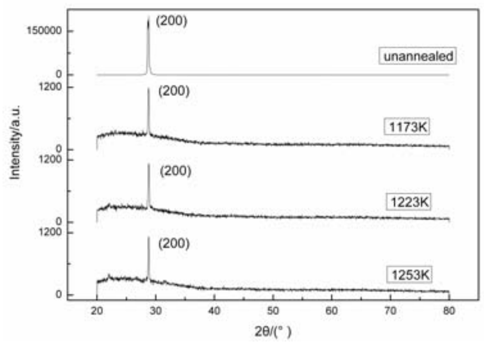
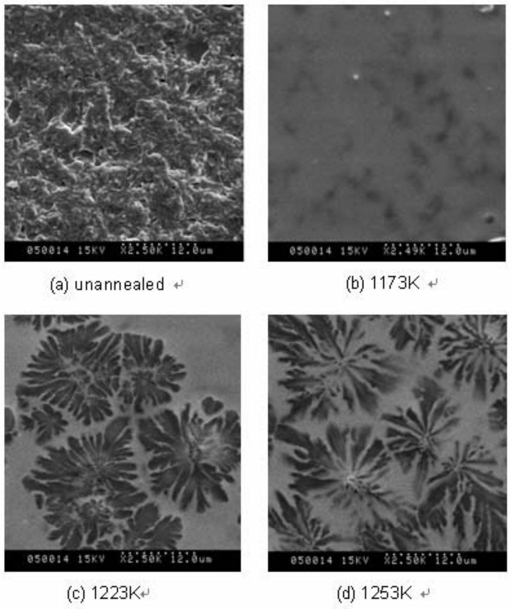


Fig. 1. XRD of Al/PbTe thin films annealed for 20 min at various temperatures.

3.2 Scanning electron microscopy

The SEM attempts of AI/PbTe thin films annealed for 20 min at different temperatures are shown in Fig. 2. From the graph Fig. 2(a), we can see that the surface of the sample which not under annealing treatment present a flake stack structure, while the surface of the sample which annealed at 1173 K (Fig. 2(b)) appears some black substance dimly. Fig. 2(c) shows that some black flower gatherings appear on the face of the specimen and irregular in the shape. With the rise of temperature the black flower gatherings become much and more regular in the shape. From the fourth picture we can attention that the surface of the sample is basically covered with black flower shape gather. This phenomenon indicates that aluminum film heat to melt, PbTe film gathered with the center of aluminum, with the rise of temperature, the liquid particles of aluminum becomes smaller and more uniform, making the black flower gathering becomes more uniform with the increasing of temperature.



(a) unannealed (b) 1173K
(c) 1223K (d) 1253K

Fig. 2. SEM of Al/PbTe films annealed in different temperatures.

3.3 FTIR spectroscopy

The transmittance of the thin films of Al/PbTe films were measured at room temperature using a Fourier transform infrared spectrophotometer（FTIR）at normal incidence. The relationship between the transmittivity and wavelength are shown by Fig. 3. It was found that annealing treatment has some effect on the transmission rate of Al/PbTe thin films. Samples which annealed at different temperatures have noticeably absorption peaks between 4.2 um ~ 4.3 um. Also the absorption band of the samples annealed at 1173 K and 1223 K respectively toward to the long wave direction compared with unannealing sample, while the result of sample annealed at 1253 K has opposite trend. In general, transmittance increase after annealing treatment, especially in 1173 K the transmittivity is much better than other a few samples, it means at the right annealing temperature, the film transmission rate will get the big improvement. This series of changes show that microscopic structure of films occurred superfine chang after annealing processing, so that the optical properties of the films changed.

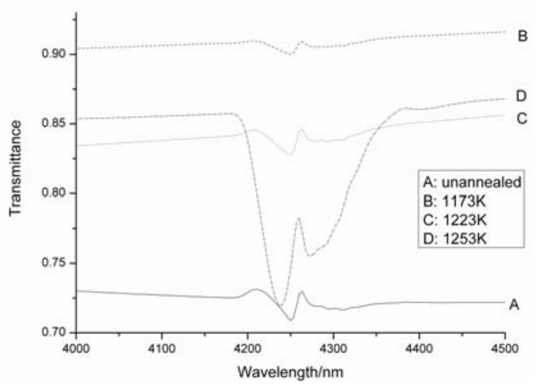


Fig. 3. Transmittance of the thin films of Al/PbTe films annealed in different temperatures.

3.4 Resistivity

The resistivity of the samples which annealed at different temperatures for 20 min obtained from four-probe method, test results are shown in Table 1. From the data we can see that compared with not under annealing treatment the resistance of sample which annealed at 1173 K increase obviously, but when the annealing temperature rise to 1223 K and 1253 K, the resistance fall rapidly. According to the resistance(R) calculation formula formula $R = \rho \frac{l}{}$, where, l is material length, s the sectional area and ρthe resistivity. The change trend of the resistivity and resistance is consistent when l and s remain unchanged, namely after annealing treatment the resistivity is first increases, and then decreases. Analysis the reason is lattice scattering exacerbate with the rise of temperature, transfer rate of carriers decreases, so resistivity increases. Resistivity and impurities concentration into a simple inverse correlation, the higher concentration, the smaller the resistivity. As the temperature increases, some Te of the film will be evaporation, the rich Pb can cause the increase of electron, then in semiconductor carrier mobility muon increase, thus cause resistivity reduce.

Table 1. Resistance of the films under different annealing temperatures.

	unannealed	1173 K	1223 K	1253 K
Current(mA)	6	6	6	6
Voltage(mV)	62	195	0.5	0.3

4. Conclusions

In the present work, Al/PbTe films were deposited on si (111) substrate by RF magnetron sputtering, and then annealed in the vacuum resistance furnace with various experiment conditions. The results show that all the samples have obvious < 100 > direction optimizing orientation; after annealed, the height of the diffraction peak (200) markedly reduced. After annealed, some flower shape gathers appear on the surfaces of the specimens, with the annealing temperature increases, flower shape gathers become more and more intensive and evenly. FTIR analysis show that samples which annealed at different temperatures have noticeably absorption peaks between 4.2 um ~ 4.3 um, transmittance increase after annealing treatment, especially at 1173 K the transmittivity is much better than other a few samples. The resistivity of sample which annealed at 1173 K compared with that of not under annealing treatment increases obviously, but when the annealing temperatures rise to 1223 K and 1253 K, the resistivity fall rapidly.

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