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Effect of sputtering power on the structure and optical band gap of SiC thin films

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ABSTRACT

Amorphous SiC (a-SiC) thin films with a quartz plate as the substrate were prepared under different radio frequency (RF) powers through RF magnetron sputtering. Films structures were characterized by atomic force microscopy (AFM), X-ray photoelectron spectroscopy (XPS), X-Ray Diffraction (XRD) and Raman spectrum. The absorption spectra of the thin films were acquired with UV–visible spectroscopy. Results showed that thin films prepared under different RF powers have different structures. With the increase in power, the maximum peak height, mean roughness, and mean square roughness increase initially and then decrease. The thin films are mainly composed of SiC and SiO_2 bonds and contain abundant C. I_D/I_G increases as power increases. The UV–visible light absorption spectra confirmed that the thin films have strong UV absorption capacity but low absorption capacity in the infrared region. The optical band gap of the thin films ranges between 1.29 and 1.80 eV. With the increase in RF power, the sp^3/sp^2C hybrid bond in the thin films increases, resulting in a reduction of the optical band gap.

1. Introduction

SiC, an important material in the semiconductor industry, has the advantages of large forbidden bandwidth, high thermal conductivity, large critical breakdown electric field, small dielectric constant, and good chemical stability [1–3]. These qualities make a-SiC a good choice of transition layer for solar cell [4–7] and carbon fiber coating [8,9]. SiC has been widely applied in optoelectronics, aviation, aerospace, machinery, petrifaction, and other industrial fields. The other applications of SiC are also possible. For example, the low-dimensional SiC was applied as natural micro-cavities [10]. Nc-Pbs/a-$Si_{1-x}C_x$:H/pSi(1 0 0) heterostructures are applied for LED [11] and SiC thin films with different processing growth are applied for energetic application [12].

However, SiC cannot be melted under normal pressure because of its high thermal stability. Hence, monocrystal SiC is difficult and expensive to prepare. Consequently, preparing monocrystal, polycrystal, amorphous, and nanocrystal SiC thin films through various epitaxial growth technologies has become a popular research issue [13]. Manufacture of SiC thin films through high-temperature chemical vapor decomposition (CVD) generates a high concentration of thin film lattice imperfections. Magnetron sputtering can create SiC thin films under low temperature. This method has elicited much research attention [14–16] because of its low cost, high deposition rate, and good adhesion of the prepared thin film. However, SiC thin films prepared through RF magnetron sputtering under different substrate temperatures, RF powers, working gases, and gas pressures have significantly different structures [17,18], which possibly led to the non-stoichiometrical defect and phonon change, thus influencing the optical band gap of the thin films [19,20]. Anderson et al. [21] showed that the optical band gap of the a-$Si_{1-x}C_x$:H films increases from about 1.6 eV to 2.9 eV with carbon content up to $x = 0.7$ and then decreases to 2.2 eV with further increase in x. Dey et al. [22] found the optical band gap of the SiC films is increasing from 1.54 eV to 2.33 eV with the increase in substrate temperatures. Oppedisano [23] believed that E_g is related to sp^2C content in C thin films. However, plenty of C–C bonds exist in SiC thin films, and the manner of existence of C [15] may affect the optical band gap of thin films significantly.

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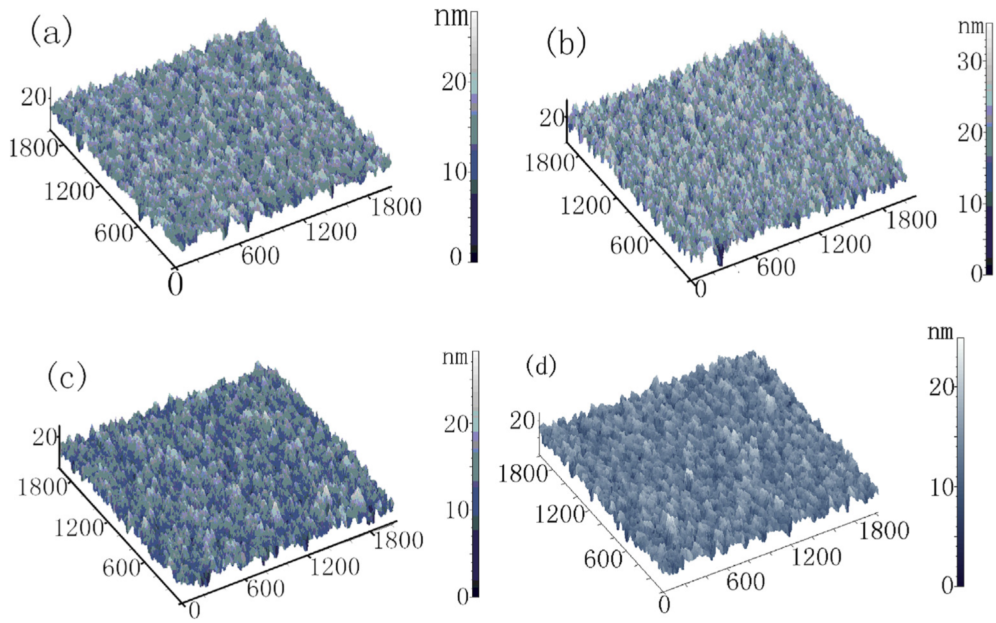

Fig. 1. AFM appearance of SiC thin films prepared under different RF powers (a: 150 W; b: 200 W; c: 250 W; and d: 300 W).

In this study, SiC thin films were prepared on a quartz plate through RF magnetron sputtering. The structures of these thin films were analyzed through Raman spectrum, XPS and XRD. Their optical adsorption properties in the wavelength range of 330–1100 nm were acquired with a UV–visible light transmission spectrograph. The optical band gaps of the thin films were also calculated. Key attention was devoted to analyzing the influences of RF power on the spC structure and optical band gap of SiC thin films.

2. Experimental

The experiment used a sintering SiC target (diameter: 60 mm; thickness: 5 mm; purity: 99.99%). SiC thin films were prepared with the JGP-450a magnetron sputtering deposition system. Pure argon (99.999%) was applied as the sputtering gas, and a quartz plate was used as the substrate. Before the deposition of thin films, the substrate was rinsed with deionized water for 10 min, followed by 10 min of rinsing with acetone and absolute ethyl alcohol in ultrasonic cleaners. Then, the substrate was rinsed with deionized water again and dried in an oven. Before deposition, 100 W RF power was applied to impact the substrate surface in a 2 Pa Ar environment for 10 min. The background vacuum and deposition pressures for each deposition were set to 1×10^{-3} Pa and 1.2 Pa, respectively. RF powers were set to 150, 200, 250, and 300 W. The deposition time was adjusted according to the deposition speed of the thin films in Ref. [7] to retain the 100 nm thickness of the thin films at room temperature for deposition.

The surface appearance of the films was observed with a Solver P47 AFM, and chemical structures were analyzed with a Dilor LabRam-INFINITY Raman spectrometer with excitation light of 532 nm (spectral resolution: 2 cm^{-1}). XPS was performed at a resolution of 0.5 eV (Thermo Fisher Scientific Company). The crystal phases were characterized by grazing incident XRD (GIXRD, Pert PRO, the Netherlands) operating with Cu Kα radiation. The transmitted and absorption spectra of the samples were acquired with a TU1800 UV–visible spectrophotometer.

3. Results and discussion

3.1. AFM analysis of SiC thin films

The surface appearance of thin films affects their optical properties significantly. Fig. 1a–d shows SiC thin film samples prepared at 150, 200, 250, and 300 W. Fig. 1 shows that thin films grow in columnar or particle shapes and have compact structures. Different sputtering powers contribute to different surface appearances. The maximum peak height, mean roughness, and mean square roughness of the deposition samples prepared under different RF powers are listed in Table 1. As RF power increases, the maximum peak height, mean roughness, and mean square roughness increase initially and then decrease. According to the relationship between sputtering power and roughness as well as particle size, sputtering particle energy increase with the increase of sputtering power, which leads to the increase of average kinetic energy of the particles. The migration rate of particles on the substrate surface become faster, which is beneficial to grain growth. At the same time, because of sufficient energy diffusion and migration, the sputtered particles can nucleate and form large clusters. With the further increase of sputtering power, on the one hand, sputtering a high-energy particle is beneficial to the rapid growth of particles. On the other hand, a higher sputtering yield results in a large number of particles reaching the surface in a short period and rapidly filling the voids in the film, resulting in a decrease in the roughness of the films.

Table 1
Maximum peak height, mean roughness, and root-mean-square (RMS) roughness under different powers.

Power (W)	Maximum peak height (nm)	Mean roughness (nm)	RMS roughness (nm)
150	27.759	15.618	2.888
200	35.283	20.520	4.304
250	28.215	13.509	3.287
300	24.852	13.224	2.500