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Investigation of microstructure and photoluminescence of Mn and Co co-doped SiC films

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Mn and Co co-doped SiC films were fabricated on Si (100) substrates by RF-magnetron sputtering. The lattice structure, composition, chemical valences and photoluminescence of the films were investigated. The lattice structure analysis shows that the films are composed of 3C–SiC and the doped Co atoms form CoSi secondary phase compounds in the films. The analyses of composition and valences display that the doped Mn and Co atoms are in the form of Mn^{2+} and Co^{2+} in the films, respectively. The analysis of local structure reveals that the doped Mn substitute for C sites in SiC lattice and no Co or Mn clusters, and Mn- and Co-related compounds except CoSi appear in the films. A violet peak located at 413 nm for all the films can be observed in photoluminescence spectra, and the peaks become stronger with the increase of Mn concentration, which should be associated with C clusters.

1. Introduction

Due to the unique optical and electrical properties, SiC is an ideal material for devices used in high power, high temperature electronics and microwave communication [1–3]. Owing to its band gap, SiC is not sensitive to long-wavelength light ranging from most of the visible to the infrared region [4,5]. So many methods are used to improve its luminescent efficiency in different types of SiC, such as amorphous SiC, porous crystalline SiC and nanometer SiC [6–9]. Furthermore, doping is an effective

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method to improve the physical properties of SiC. Preparation of SiC films by sputtering is also applied to improve the stability and efficiency [10,11]. Generally, the optical properties are dominated by defects and impurities. The defect concentration cannot easily be controlled, so the intensity of luminescence generated by defects also cannot be controlled easily. But we can attempt to adjust the luminous intensity by controlling defects through changing the doping concentration. Therefore, it is important to study the relations of structure and compositions of the doped SiC films with the photoluminescence from the viewpoint of practical applications.

In this paper, a series of Mn and Co co-doped SiC films were fabricated by RF-magnetron sputtering. The lattice structure, composition, valences and local structure of the films were studied in detail. The effect of Mn doping concentration on photoluminescence (PL) and luminescence mechanism of the SiC films were also investigated.

2. Experimental details

Mn and Co co-doped SiC films about 300 nm were deposited on Si (1 0 0) substrates by RF-magnetron sputtering. Firstly, the Si (square in 5 mm × 5 mm) substrates were washed several times utilizing acetone and ethyl alcohol to remove organic pollutants and using de-ionized water to clear the water soluble impurities. Then, the substrates after being dried were put into magnetron sputtering chamber. A high-purity SiC target with some Mn and Co chips (square in 2 mm × 2 mm) symmetrically attached was used to deposit SiC films on Si substrates by co-sputtering method. The base pressure of the chamber was 6×10^{-5} Pa. Ar (99.99%) was used as sputtering gas and the sputtering time was 40 min. Before the films were deposited, the substrates were heated to 200 °C. By adjusting the quantity of Mn and Co chips, the $SiMn_xCo_{0.04}C_{0.96-x}$ films with $x = 0$, 0.02, 0.04 and 0.07 were fabricated. In order to improve the crystalline quality of the films, all of the films were annealed at 1200 °C for 2 h in a vacuum of 8×10^{-5} Pa.

The lattice structure of the films was examined by X-ray diffraction (XRD) using Cu Kα radiation ($\lambda = 0.15406$ nm). The compositions and element valences of the films were determined by X-ray energy dispersive spectroscopy (EDS) and X-ray photoelectron spectroscopy (XPS). The local structure of the films was investigated by X-ray absorption near edge structure (XANES) and extended X-ray absorption fine structure (EXAFS) at Beijing Synchrotron Radiation (RSRF) on the 4B9 W beam line of the X-ray diffraction station. The photoluminescence of the films were excited with a Xe lamp light source.

3. Results and discussion

Fig. 1 shows the XRD curves of the $SiMn_xCo_{0.04}C_{0.96-x}$ ($x = 0$, 0.02, 0.04 and 0.07) and un-doped SiC films annealed at 1200 °C. According to the standard cards of XRD, the films were indexed as cubic silicon carbide (3C–SiC). From Fig. 1, it is clear that the diffraction peak of the un-doped SiC film is located at $2\theta = 35.6°$, which is from 3C–SiC (1 1 1) and that of the $SiMn_xCo_{0.04}C_{0.96-x}$ films shifts to the lower angles. With the increase of Mn doping concentration, the peak shift becomes obviously, as shown by dash line in Fig. 1, which indicates that the Co and Mn atoms are doped into the SiC lattice. From Fig. 1, it can be seen that the (1 1 0), (2 1 0) and (2 1 1) diffraction peaks of CoSi emerge as secondary phase in the films, which may be caused by the chemical reaction between the doped Co atoms and Si atoms in high temperature annealing process. In addition, the peaks at $2\theta = 33°$ are caused by Si (1 0 0) substrate and no Mn–Si secondary phase compounds can be observed in all of the films.

In order to confirm the valences of the constituent elements of the films, an XPS analysis was performed. Fig. 2(a) shows the C 1s XPS spectra of the as-deposited and 1200 °C annealed films of $SiMn_{0.04}Co_{0.04}C_{0.92}$. The XPS spectra can be resolved into two components at 283.5 and 284.3 eV, which are from the Si–C bond and C–C bond, respectively. In Fig. 2a, it can be clearly observed that the peak of Si–C bond increases and that of C–C bond decreases after being annealed at 1200 °C. This suggests that high-temperature annealing improves the formation of SiC, but there exist some C clusters in the annealed films. Fig. 2(b) shows the Si 2p XPS spectra of the as-deposited and 1200 °C annealed films of $SiMn_{0.04}Co_{0.04}C_{0.92}$. For the Si 2p XPS spectrum of the as-deposited films, it can be