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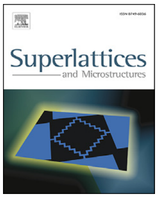

Investigation of transport and magnetic properties of SiC/Cu diluted magnetic semiconductor nano-multilayer films

Ning Sun, Chunjing Li, Yuting Fu, Yanghua Li, Dechong Bu, Yukai An**, Jiwen Liu*

Tianjin Key Laboratory for Photoelectric Materials and Devices, School of Material Science and Engineering, Tianjin University of Technology, Tianjin, 300384, China

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The SiC/Cu nano-multilayer films were deposited on Si substrates using radio frequency and direct current alternative sputtering technique. In this paper, the transport and magnetic properties of the films were investigated. XRR shows the SiC/Cu periodical structures of the films. XRD confirms that the 3C-SiC crystal structure is formed in the films without heating substrates. The XPS indicates that the Cu atoms substitute for Si sites of the SiC lattice and exist in a mixed valance state of Cu^{+} and Cu^{2+}. The best fitting for the plots of ln ρ versus $T^{-1/4}$ using the combination of the Mott and the band gap VRH models suggests that the carriers in the films are strongly localized. The films have a typical semiconductor characteristic and an obvious room temperature ferromagnetism which should arise from the bond magnetic polarons. The maximum values of saturation magnetization and carrier concentration are up to 15.2 emu/cm^3 and 1.86E + 22/cm^3 respectively.

1. Introduction

Since T. Dietl et al. reported that room temperature (RT) ferromagnetism could be obtained using transition metal (TM) doped into zinc-blended semiconductors [1], many efforts have been focused on the diluted magnetic semiconductors (DMSs), especially the wide band gap DMSs due to their potential application in spintronic devices [2–4]. As the third generation semiconductor, SiC received recently more attention for its properties such as high power, high critical electric breakdown field, high saturation electron drift velocity and high thermal conductivity [5–9], which gives a potential application in the high temperature, high frequency electronic devices. Because it is easy to be doped as n-type or p-type semiconductor, SiC becomes more noticeable in DMSs. Although the ferromagnetism in doped SiC has been obtained, some magnetic elements or magnetic secondary phases in the doped SiC will influence the SiC intrinsic magnetism. Kim et al. [10] obtained the RT-ferromagnetism in the Fe doped SiC samples and found that the RT-ferromagnetism is mainly contributed due to the Fe_3Si secondary phase formed in the samples. In the report [11], Sha et al. found that the CoSi or Co_2Si secondary phases were easily formed and led to the redundant C atoms to form C clusters in the Co doped SiC. To avoid this problem, Zheng et al. [12] investigated the ferromagnetism of Cu doped SiC by Cu ions implanting into SiC single crystal. Since whatever

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* Corresponding author.
** Corresponding author.
E-mail addresses: ykan@tiut.edu.cn (Y. An), jwliu@tjut.edu.cn (J. Liu).

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the Cu or Cu base secondary phases are non-ferromagnetic, these can not produce the parasitic magnetic signals. In additional, for the SiC DMS, the doping concentration is also an important issue because it influences the spin injection efficiency related to the transport and magnetic properties of DMSs. Quan et al. [13] investigated the RT-magnetoresistance and spin injection of Co-ZnO multilayer films prepared by alternatively depositing an ultrathin Co layer (1 nm) and a ZnO layer (3 nm). They found that the spin polarization at room temperature for the Co/ZnO film is up to 30.2%, because the interfacial magnetic semiconductor formed between Co layer and ZnO layer improves effectively the spin injection efficiency into ZnO layer. In this paper, SiC/Cu DMS nano-multilayer films were prepared by the RF and DC magnetron alternative sputtering technique and the transport and magnetic properties of the films were investigated.

2. Experimental details

The SiC/Cu DMS multilayer films were deposited on Si (001) substrate by RF and DC magnetron sputtering alternately using a SiC target (99.99%) and a Cu target (99.99%) without heating the substrate. Before sputtering, the chamber was evacuated to 1.5×10^{-4} Pa. The flow rate of Ar as sputtering gas, the sputtering pressure and the sputtering power were 10 sccm, 1.0 Pa and 20 W respectively. In order to obtain the sputtering rate of SiC and Cu in above sputtering conditions, the SiC film and the Cu film were individually deposited for 30 min. A step profiler was used to measure the thicknesses of SiC film and Cu film individually, then the SiC and Cu sputtering rates were calculated by the thicknesses (SiC and Cu) dividing the sputtering time. By means of adjusting the sputtering time, the different thicknesses for SiC or Cu layers can be prepared. In the experiment, the Cu layer thickness was fixed at 0.6 nm and the SiC layer thickness was changed, ranging from 0.6 nm to 3.5 nm and the SiC/Cu layers were prepared for 70 periods for every sample, noted by $[x - 0.6]_{70}$ ($x = 0.6, 1.0, 1.5, 2.0, 2.5, 3.0$ and 3.5), the first number is the single layer thickness (nm) of SiC, the secondary one is the single layer thickness (nm) of Cu, and the third one is the period number of SiC/Cu.

The periodical structures of the films were examined by $\theta/2\theta$ X-ray reflectivity (XRR) with Cu Ka radiation. The crystal structures of the films were examined by $\theta/2\theta$ X-ray diffraction (XRD) with Cu Ka radiation. X-ray photoelectron spectroscopy (XPS) of the films was obtained on a PHI5000Versa probe photoelectric spectrometer and Al Ka X-ray was used as the emission source. The dependence of resistivity (ρ) on temperature (T) was measured by the standard four probe method on a Physical Property Measurement System (PPMS). The electrical properties of the films were measured by a Hall effect measurement system with the van der Pauw method. The magnetic properties were recorded with a superconducting quantum interference device (SQUID) magnetometer at room temperature with a sensitivity of 10^{-8} emu at a magnetic field ranging from −15000 Oe to 15000 Oe.

3. Results and discussion

Fig. 1 is the XRR spectrum of the SiC/Cu multilayer film $[3.5–0.6]_{70}$. The small waves from 0.7° to 1.7° indicates a periodical structure of the film, consistent with the designed periodical structure in the experiment. The thickness of one period (one SiC layer and one Cu layer) of the film can be calculated by XRR spectrum using Bragg formula. The calculated result is 4.5 nm for the one period, slightly thicker than the designed thickness (4.1 nm). The error maybe result from the diffusion and the interface roughness between the SiC and Cu layers.

Fig. 2 shows XRD patterns of the SiC/Cu multilayer films $[x - 0.6]_{70}$ ($x = 0.6, 1.0, 1.5, 2.0$ 3.0). From Fig. 2, it can be seen that the typical 3C-SiC (111) and Cu (111) diffraction peaks are located at 35.8° and 43° from the SiC layer and the Cu layer of the films for the thickness of SiC layer is less than 2 nm. It has not been reported that the SiC crystallization occurs in the

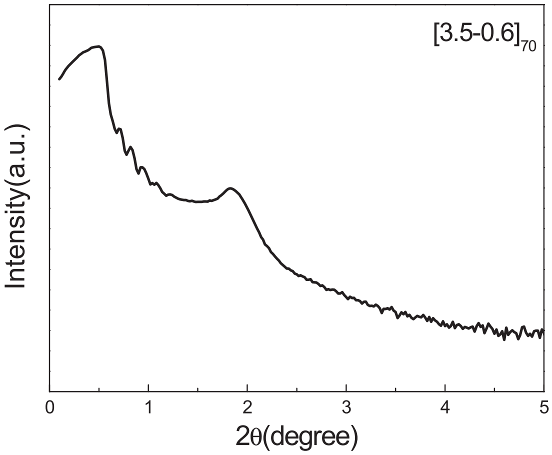

Fig. 1. XRR spectrum of the SiC/Cu multilayer film $[3.5–0.6]_{70}$.