Characteristics of Polycrystalline β-SiC Films Deposited by LPCVD with Different Doping Concentration

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The physical and electrical properties of polycrystalline β-SiC were studied according to different nitrogen doping concentration. Nitrogen-doped SiC films were deposited by LPCVD(low pressure chemical vapor deposition) at 900 °C and 2 torr using 100 % H_2SiCl_2 (35 sccm) and 5 % C_2H_2 in H_2(180 sccm) as the Si and C precursors, and 1 % NH_3 in H_2(20~100 sccm) as the dopant source gas. The resistivity of SiC films decreased from 1.466 Ω·cm with NH_3 of 20 sccm to 0.0358 Ω·cm with 100 sccm. The surface roughness and crystalline structure of β-SiC did not depend upon the dopant concentration. The average surface roughness for each sample 19-21 nm and the average surface grain size is 165 nm. The peaks of SiC(111), SiC(220), SiC(311) and SiC(222) appeared in polycrystalline β-SiC films deposited on Si/SiO_2 substrate in XRD(X-ray diffraction) analysis. Resistance of nitrogen-doped SiC films decreased with increasing temperature. The variation of resistance ratio is much bigger in low doping, but the linearity of temperature dependent resistance variation is better in high doping. In case of SiC films deposited with 20 sccm and 100 sccm of 1 % NH_3, the average of TCR(temperature coefficient of resistance) is -3456.1 ppm/°C and -1171.5 ppm/°C, respectively.

Keywords : β-SiC, LPCVD, Doping concentration, Poly crystalline, TCR

1. INTRODUCTION

Silicon carbide(SiC) based semiconductor electronic devices, circuits and sensors are presently being developed for use in high-temperature, high-power, and/or high-radiation conditions under which conventional semiconductors cannot adequately perform[1,2]. Compared to Si which is generally limited in electronic device performance to below 250 °C, SiC demonstrates higher chemical inertness and radiation resistance as well as single and polycrystalline SiC can be grown on large area substrates and are compatible with batch-fabrication process used in Si micromachining and integrated circuit (IC) industries[3,4]. Polycrystalline β-SiC, in particular, is a motivating consideration as a structural material since a variety of substrate materials such as polysilicon, SiO_2 and Si_3N_4[4]. The development of thermal sensors(e.g. micro-heater, thermal flow sensors and chemical sensors) based on the β-SiC is very interesting because temperature of more than 400 °C can be achieved. For example, optimized engine performance in aerospace and automotive systems requires a stable, high-temperature material for solid-state sensors and electronics[3]. To achieve these purposes β-SiC is more suitable than Si.

In sensors using a thermal mechanism, resolution and accuracy are mainly dependent on the sensing material's TCR(temperature coefficient of resistance), resistivity, and linearity of resistance variation, respectively. And also the operation of such sensors within a wide temperature range requires temperature compensation, as the change of offset and sensitivity of the sensor with the temperature cannot be neglected. So resistance variation according to temperature and TCR have been studied for sensors applications[5-7]. Using resistor with a known R vs. T-characteristic is the most convenient and accurate way to take temperature[8].

In this study, β-SiC was deposited by LPCVD(low pressure chemical vapor deposition) according to different insitu doping conditions. The physical properties of β-SiC were investigated using scanning electron microscopy(SEM), X-ray diffraction(XRD) and

Table 1. Deposition conditions of poly β-SiC fims.

	Temperature (°C)	Pressure (Torr)	Thickness (Å)	Precursors (sccm)		Dopant (1 %NH_3 in H_2) (sccm)
				H_2SiCl_2(100 %)	C_2H_2(5 % in H_2)	
Sample 1	900	2.0	10,284	35	180	20
Sample 2	900	2.0	10,543	35	180	80
Sample 3	900	2.0	10,254	35	180	100

atomic force microscopy(AFM). Finally, resistivity and TCRs of each β-SiC film for thermal sensors application were investigated as a function of the dopant concentration.

2. EXPERIMENTALS

A conventional, hot-wall, horizontal furnace was used to deposit nitrogen-doped polycrystalline β-SiC films on 100 ㎜ diameter (100) silicon wafers with thermal oxide layer[9]. The reaction chamber was 2007 mm in length and 225 mm in inner diameter. Nitrogen-doped SiC films were deposited at 900 °C and 2 Torr using SiH_2Cl_2 (100 %) and C_2H_2 (5 % in H_2) as the Si and C precursors, and NH_3 (1 % in H_2) as the dopant source gas. Both precursor and dopant gases entered the chamber from the load-end flange during film deposition[9,10]. The H_2SiCl_2, C_2H_2, flow rates were fixed at 35 sccm, 180 sccm, while NH_3 flow rates were changed from 20 to 100 sccm in order to achieve different doped nitrogen concentrations. Nominally approximately 10,000 Å-thick films were deposited. The deposition conditions for polycrystalline β-SiC films are summarized in Table 1. As the structure shown in Fig. 1, polycrystalline β-SiC films were deposited on SiO_2/Si substrate with about 10,000 Å of thickness. Polycrystalline β-SiC films are insulated from Si substrate by SiO_2 layer so as to remove or reduce the substrate effect during testing at high temperature. Film thickness were optically measured using a Nano spec 4000 AFT spectrophotometer and were verified by cross-sectional scanning electron microscopy (SEM). Sheet resistivity measurements were obtained by use of a Tencor RS35C 4-Point Probe. The polycrystalline SiC crystal orientation was studied by means of an x-ray diffraction system (XRD), using a Scintag X-1 diffractometer with a $Cu\ K\alpha$ X-ray tube (λ=1.542 Å), configured in symmetrical θ – 2 θ mode. Resistances of SiC films were measured in the temperature range of 30 °C to 450 °C using a hot plate, a accurate multimeter, prove station and reference temperature sensor. After measuring TCR, standard deviation of TCR for each sample was calculated.

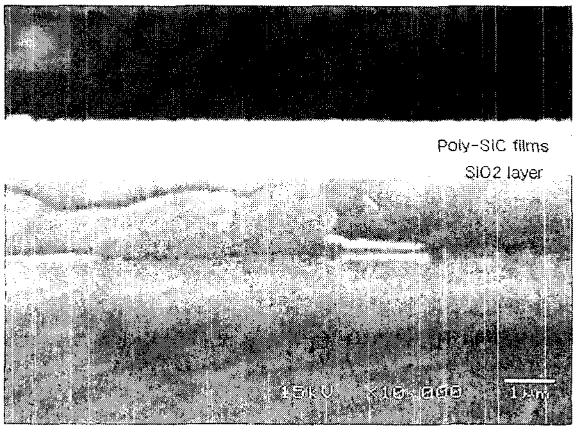

Fig. 1. SEM micrographs of polycrystalline β-SiC films deposited on SiO_2/Si substrate.

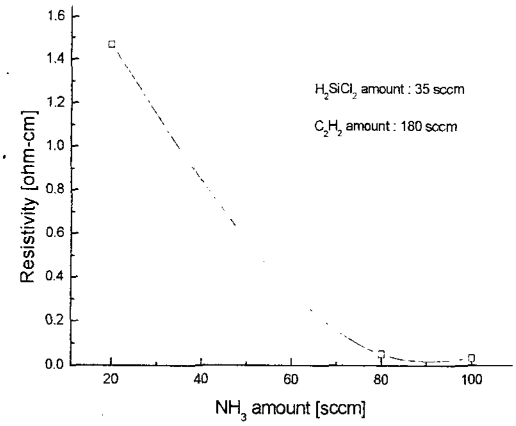

Fig. 2. Resistivity variations of polycrystalline β-SiC films with increasing 1 % NH_3 in H_2.

3. RESULTS AND DISCUSSION

The resistivity of polycrystalline β-SiC films changed naturally according to the amount of dopant gas, NH_3 at 35 sccm of H_2SiCl_2 sccm and 180 sccm of C_2H_2 as seen in Fig. 2. The resistivity of SiC films with NH_3 of 20 sccm was 1.466 Ω·㎝ higher than 0.0358 Ω·㎝ with 100 sccm. AFM analysis was carried out to compare with the

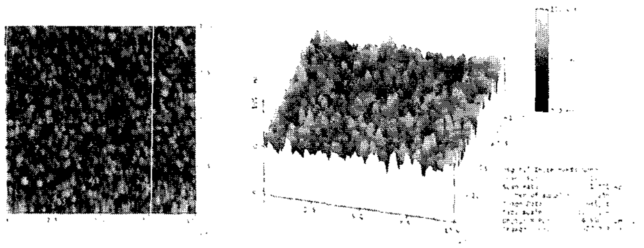

Fig. 3. AFM micrographs of polycrystalline *β-SiC* films deposited on SiO_2/Si substrate.

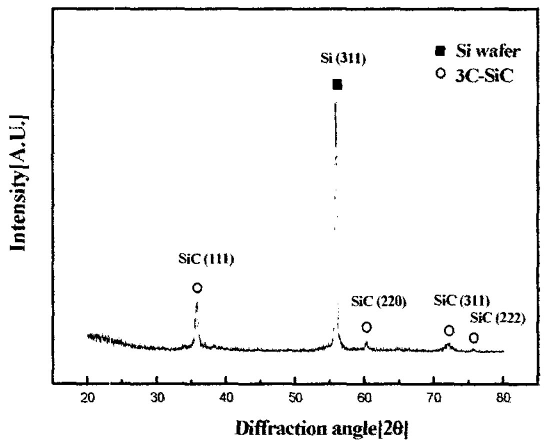

Fig. 4. XRD patterns for polycrystalline *β-SiC* films deposited on SiO_2/Si substrate.

roughness of each sample.

The roughness didn't depend upon the dopant concentration. The surface profiles of each sample were similar.

Figure 3 shows the results of AFM analysis of sample 2. It says that the surface morphology of the polycrystalline *SiC* films consists of spherical grains. The average surface roughness for each sample 19-21 nm and the surface grain size is 165 nm ~ 200 nm. In order to analyze the crystalline structure of polycrystalline *SiC* films deposited on SiO_2/Si, XRD analysis was carried out. The result is shown in Fig. 4. *SiC* films deposited on SiO_2/Si had polycrystalline structure as shown in Fig. 4 ; *SiC*(111), in addition to *Si*(311) at 55.88 ° used as a substrate, *SiC*(220), *SiC*(311) and *SiC*(222) appeared as result from XRD analysis[10,11].

C films to sensors, resistance variations of *SiC* films were measured and depicted in Fig. 5. Resistance of each sample decreased with increasing temperature. It is supposed that the concentration of donors increase as temperature increases because of thermal ionization. Eventually, with increasing temperature the resistivity decreases in other words, electric conductivity decreases.

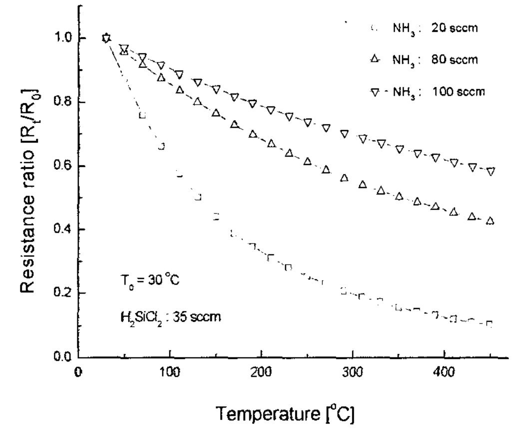

Fig. 5. Resistance ratio of polycrystalline *β-SiC* films with increasing temperature.

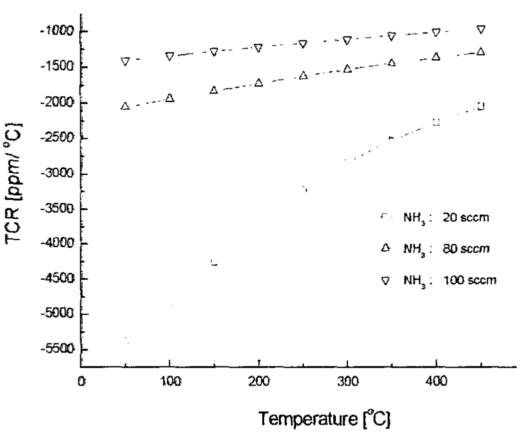

Fig. 6. TCR of polycrystalline *β-SiC* films with increasing 1 % NH_3 as function of temperature.

The variation of resistance ratio depended upon the dopant concentration. Compared with sample 1 and sample 3, the variation of resistance ratio is much bigger in sample 2, the linearity of resistance variation is better in sample 2. TCR value of each sample was measured and its average and standard deviation were calculated in order to compare with the distribution of TCR value. In case of sample 1 and sample 3, the average of TCR is -3456.1 ppm/°C and -1171.5 ppm/°C, respectively. In case of sample 1, TCR changes from -5374.5 ppm/°C at 50 °C to -2050.3 ppm/°C at 450 °C, implying that the donors in the *SiC* were not fully ionized at 450 °C. The temperature of full ionization depends upon dopant concentration of material[5,12]. TCR standard deviation of sample 1, 2 and 3 is 1105.3 ppm/°C, 250.5 ppm/°C and 144.2 ppm/°C. Compared with each sample relatively, it is known that sample 1 is right for the application in which high output is required in narrow temperature range and sample 3 is suitable for the application in which linear property is required in wide temperature range.

4. CONCLUSION

The characteristics of polycrystalline *β-SiC* films deposited SiO_2/Si substrate by LPCVD were studied according to different doping concentration. Nitrogen-doped polycrystalline *β-SiC* films were deposited at 900 °C and 2 Torr using SiH_2Cl_2 (100 %) and C_2H_2 (5 % in H_2) as the *Si* and *C* precursors, and NH_3 (1 % in H_2) as the dopant source gas.

The resistivity of *SiC* films with NH_3 of 20 sccm was 1.466 Ω·cm higher than 0.0358 Ω·cm with 100 sccm. The surface roughness and polycrystalline structure of *β-SiC* didn't depend upon the dopant concentration. Resistance of nitrogen-doped *SiC* films decreased with increasing temperature. The variation of resistance ratio decreased and the linearity improved as doping concentration increased In case of *SiC* films deposited with 20 sccm and 100 sccm of 1 % NH_3 in H_2, the average TCR in the range of 30 °C ~ 450 °C is -3456.1 ppm/°C and -1171.5 ppm/°C, respectively.

Therefore, in the design of sensors that use the resistance variation of *β-SiC* films according to temperature, the compromise between a higher sensitivity and linearity have to be considered.

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