A Study of Properties of 3C-SiC Films deposited by LPCVD with Different Films Thickness

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The electrical properties and microstructure of nitrogen-doped poly 3C-SiC films were studied according to different thickness. Poly 3C-SiC films were deposited by LPCVD(low pressure chemical vapor deposition) at 900 °C and 4 Torr using SiH_2Cl_2 (100 %, 35 sccm) and C_2H_2 (5 % in H_2, 180 sccm) as the Si and C precursors, and NH_3 (5 % in H_2, 64 sccm) as the dopant source gas. The resistivity of the 3C-SiC films with 1,530 Å of thickness was 32.7 Ω-cm and decreased to 0.0129 Ω-cm at 16,963 Å. In XRD spectra, 3C-SiC is so highly oriented along the (1 1 1) plane at $2\theta = 35.7$ ° that other peaks corresponding to SiC orientations are not presented. The measurement of resistance variations according to different thickness were carried out in the 25 °C to 350 °C temperature range. While the size of resistance variation decreases with increasing the films thickness, the linearity of resistance variation improved.

Keywords : Nitrogen-doped, 3C-SiC, LPCVD, Resistivity, Resistance variation

1. INTRODUCTION

Many measurement and control applications that require microsensors and micro actuator technologies are in the presence of harsh environments which include locations of high temperatures, intense vibrations, erosive flows, and/or corrosive media[1]. Electronic stability at high temperatures, mechanical stiffness, hardness, and chemical inertness make Silicon carbide (SiC) an exceptional material in those fields including, since similar devices based on silicon lack high-temperature capabilities with respect to both electrical and mechanical properties[2]. The development of microsensors(e.g. micro-heater, thermal flow sensors and chemical sensors) based on the 3C-SiC are very interesting because operating temperature of more than 400 °C can be achieved. 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[3-5]. In this research, 3C-SiC was deposited by LPCVD (low pressure chemical vapor deposition) using in-situ nitrogen doping, with different thickness. The physical properties of the 3C-SiC were investigated using scanning electron microscopy (SEM), X-ray diffraction (XRD), and atomic force microscopy (AFM). Finally, resistivity and TCR of each film were investigated as a function of the thickness.

2. EXPERIMENTAL

A conventional, hot-wall, horizontal furnace was used to deposit the nitrogen-doped, poly 3C-SiC films on 100 mm-diameter (100) silicon wafers electrically isolated by a thermally-grown silicon dioxide layer[6]. The reaction chamber was 2007 mm in length and 225 mm in inner diameter. Poly 3C-SiC films were deposited at 900 °C and 4 Torr using SiH_2Cl_2 (100 %, 35 sccm) and C_2H_2 (5 % in H_2, 180 sccm) as the Si and C precursors, and NH_3 (5 % in H_2, 64 sccm) as the dopant source gas. 3C-SiC films were deposited on SiO_2/Si substrate with different thickness from 207 Å to 16,963 Å by increasing deposition time.

Both precursor and dopant gases entered the chamber from the load-end during film deposition[6]. Figure 1 shows a cross-sectional scanning electron microscope (SEM) photo of a typical sample. Poly-SiC films are electrically insulated from the Si substrate by the SiO_2 layer so as to remove or reduce the substrate effect during testing at high temperature[4]. Film thicknesses were optically measured using a Nanospec 4000 AFT spectrophotometer and were verified by cross-sectional scanning electron microscopy. Sheet resistivity measurement was obtained by use of a Tencor RS35C 4-Point Probe. The poly 3C-SiC crystal orientation was studied by means of an x-ray diffraction system (XRD), using a Scintag X-1 diffractometer with a Cu K_α X-ray tube (λ=1.542 Å), configured in symmetrical θ - 2 θ mode. Resistances of the poly 3C-SiC films were measured in the 30 °C to 450 °C operating temperature range using a hot plate, an accurate multimeter, probe station, and a reference temperature sensor. The TCR was then calculated following :

$$TCR = \Delta R/R_0 \cdot \Delta T \text{ (ppm/°C)}$$

where R_0 is the resistance value at 0 °C, ΔR is the resistance change with respect to 0 °C resistance, and ΔT is the change in temperature. To obtain more accurate data, every measurement was carried out more than ten times, and the average value was used in each case. After measuring TCR, standard deviation of TCR for each sample was calculated.

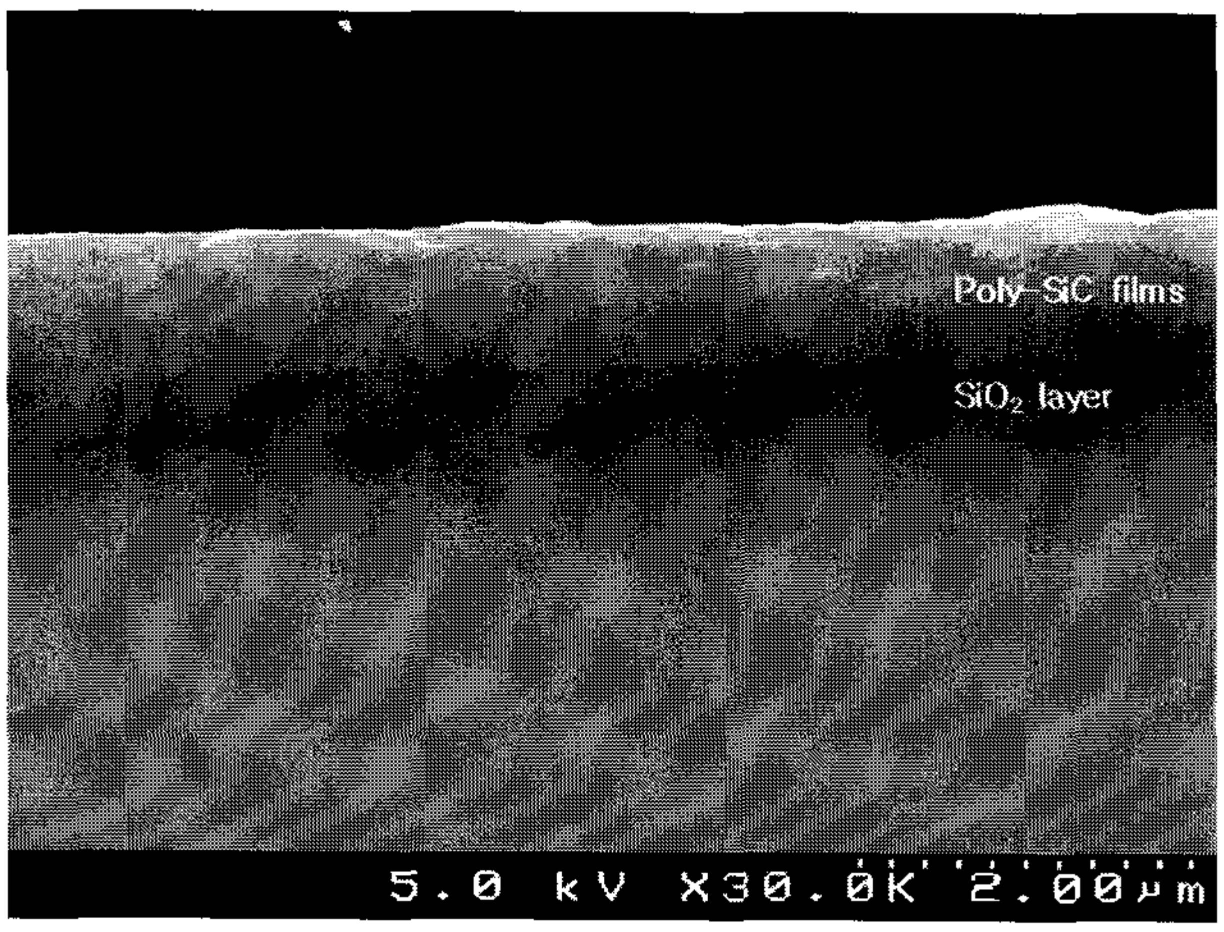

Fig. 1. SEM micrograph of a typical poly-SiC film deposited on a silicon substrate coated with SiO_2.

3. RESULTS AND DISCUSSION

Figure 2 presents the resistivity variation as a function of the thickness of poly 3C-SiC. The resistivity of SiC films with 201 Å is too big to be measured due to the grain isolation so the data is ignored in Fig. 2. This property can be explained in Fig. 3 clearly. In this study, the initial variation of resistivity drops suddenly with increasing films thickness, then gradually stabilizes as the thickness increases further. The resistivity of the 3C-SiC films with the thickness of 1,530 Å was 32.7 Ω-cm and decreased to 0.0129 Ω-cm at 16,963 Å.

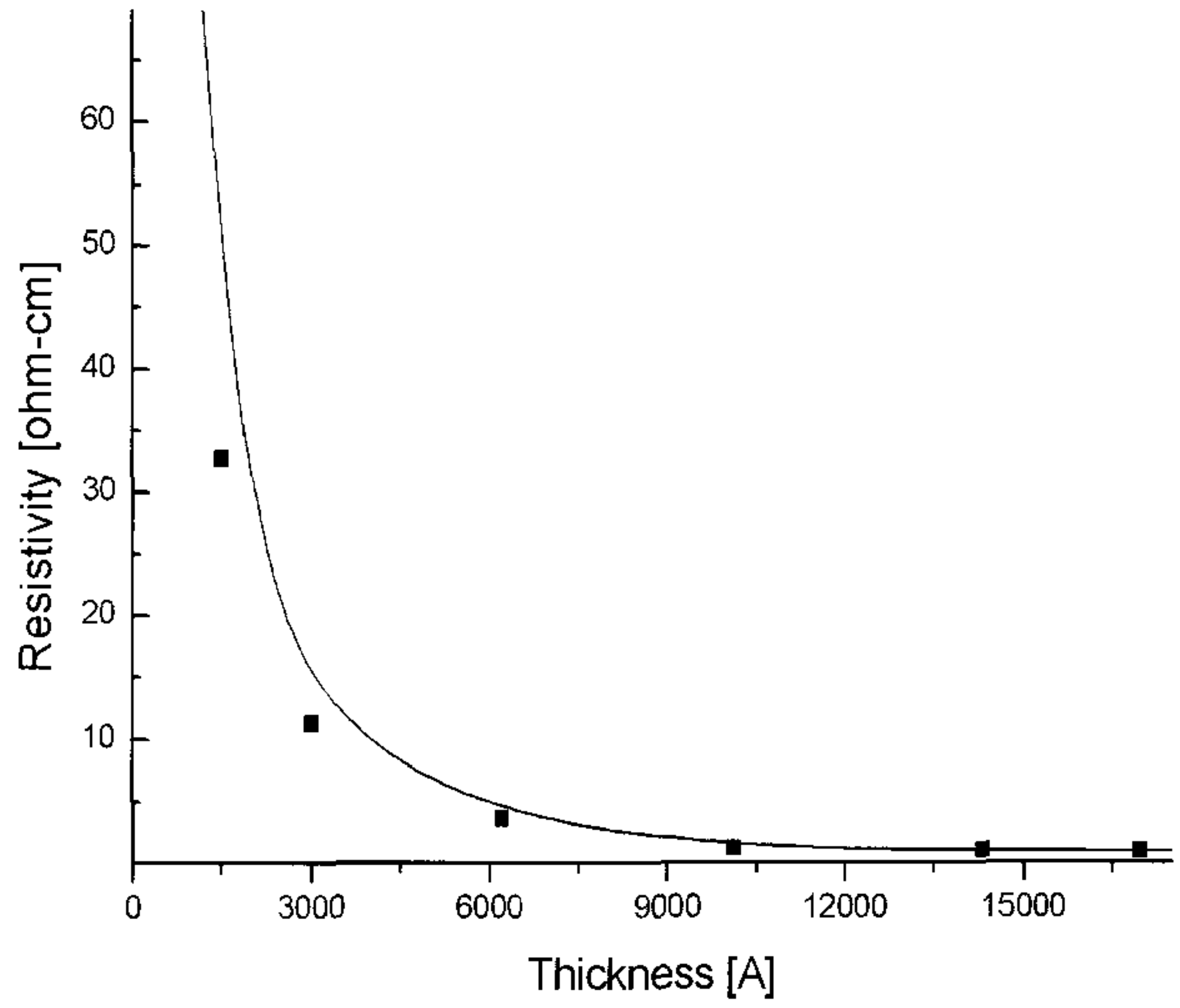

Fig. 2. Resistivity variations according to the thickness of poly 3C-SiC films.

Figure 3 show SEM micrographs of 3C-SiC films with different thickness. It shows that the surface morphology of 3C-SiC films consists of spherical grains and the grain size increases as the films thickness increases. In case of 10,115 Å, the average surface roughness for each sample 19-21 nm and the surface grain size is 165 nm ~ 200 nm[4].

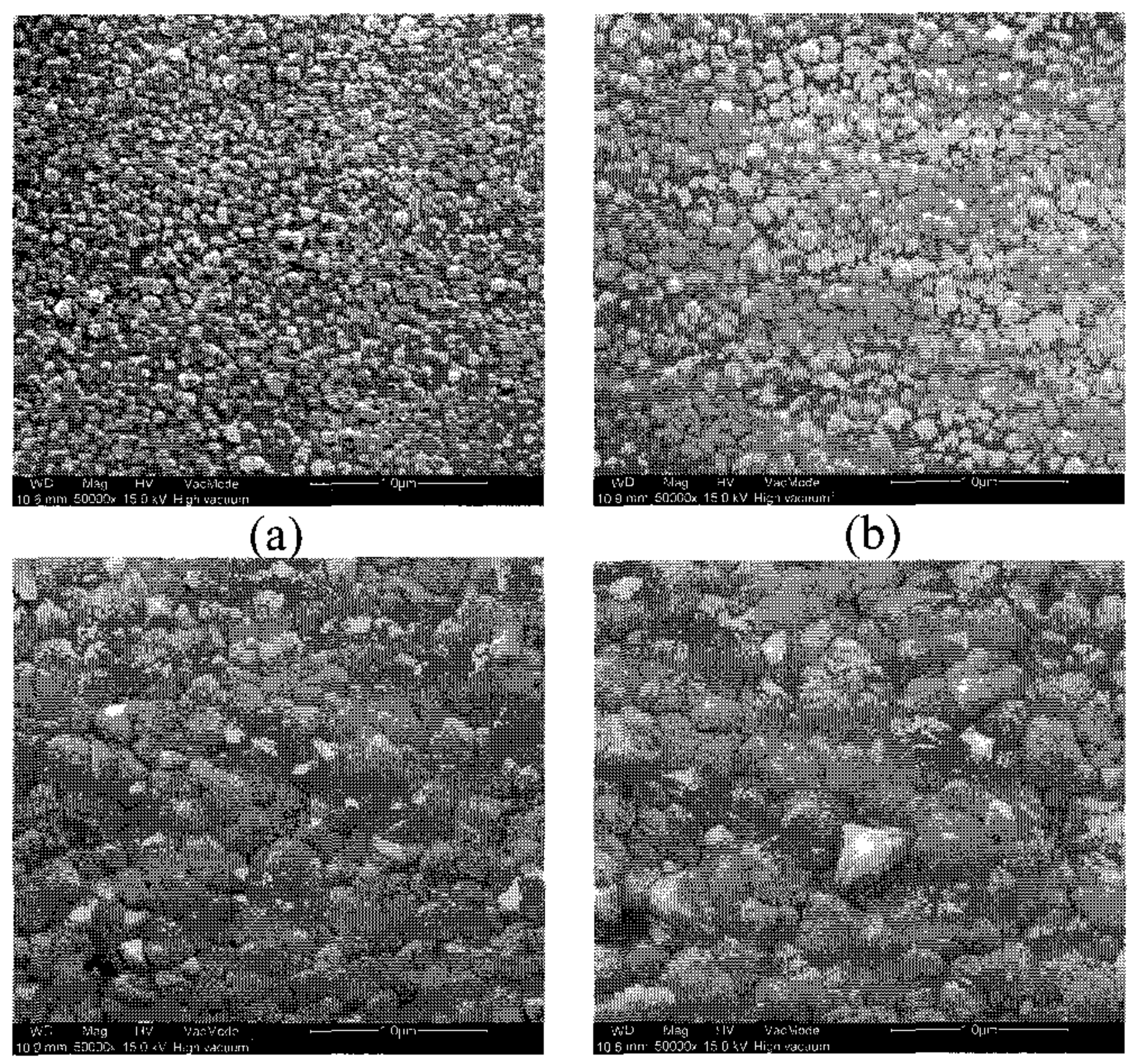

Fig. 3. Surface SEM micrographs of 3C-SiC films with the thickness of (a) 201 Å, (b) 3,017 Å, (c) 10,115 Å, and 16,963 Å.

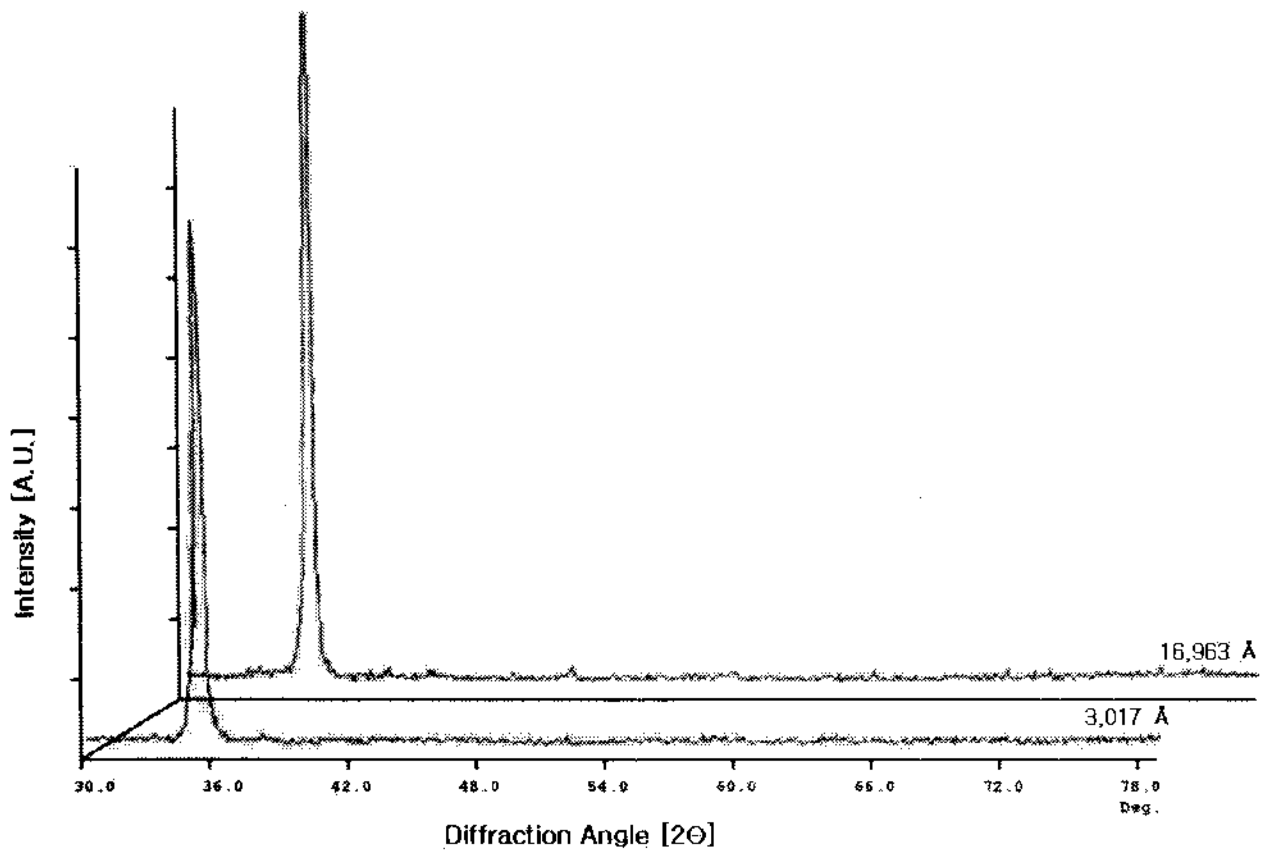

Fig. 4. XRD patterns for poly 3C-SiC films deposited on SiO_2/Si substrate.

In order to analyze the crystalline structure of the 3C-SiC films, XRD spectra was used. The spectra exhibit a strong peak of SiC(111) at 36.69 °. And as thickness increases, the intense of peak also increases, but otherwise is shows no difference. Figure 4 shows that the XRD spectra of poly 3C-SiC films with 3,017 Å and 16,963 Å. The SiC(111) peak of poly 3C-SiC films with thickness of 16,963 Å is somewhat more intense than that of 3,107 Å. Peaks corresponding to SiC (200), (220), (222) and (311) orientations are not present because 3C-SiC is highly oriented along the (111) plane[6-8].

For the application of poly 3C-SiC films to sensors, resistance variations of the films were measured, and the data is shown in Fig. 5. The grain boundaries in a polycrystalline film lead to electrical properties that are different from the single-crystalline form of the same semiconductor. With increase in temperature, thermionic emission of energetic carriers over a potential barrier is activated, resulting in a decrease of the resistivity[9]. As known in Fig. 5, with increasing the films thickness, the linearity increases while the size of resistance variation decreases. Comparing the variations of 1,530 Å films with 10,115 Å films, the magnitude of resistance ratio change is much larger in 1,530 Å films. On the other hand, the linearity of resistance variation is better in 10,115 Å films. But these variations according the films thickness are saturation little by little as the films thickness increases over 1 ㎛ in Fig. 5.

TCR value of each sample was measured, and its average and standard deviations were calculated in order to understand the distribution of TCR values. In case of 1,530 Å and 10,115 Å, the average TCR is -1838.8 ppm/°C and -1325.9 ppm/°C, respectively. In case of 1,530 Å, TCR changes from -2051.1 ppm/°C at 50 °C to to -1488.1 ppm/°C at 350 °C. TCR standard deviations of 1,530 Å and 10,115 Å are 517.3 ppm/°C and 292.0 ppm/°C, respectively. It's known from these facts that the size of TCR variation decreases with increasing the films thickness but the linearity improved.

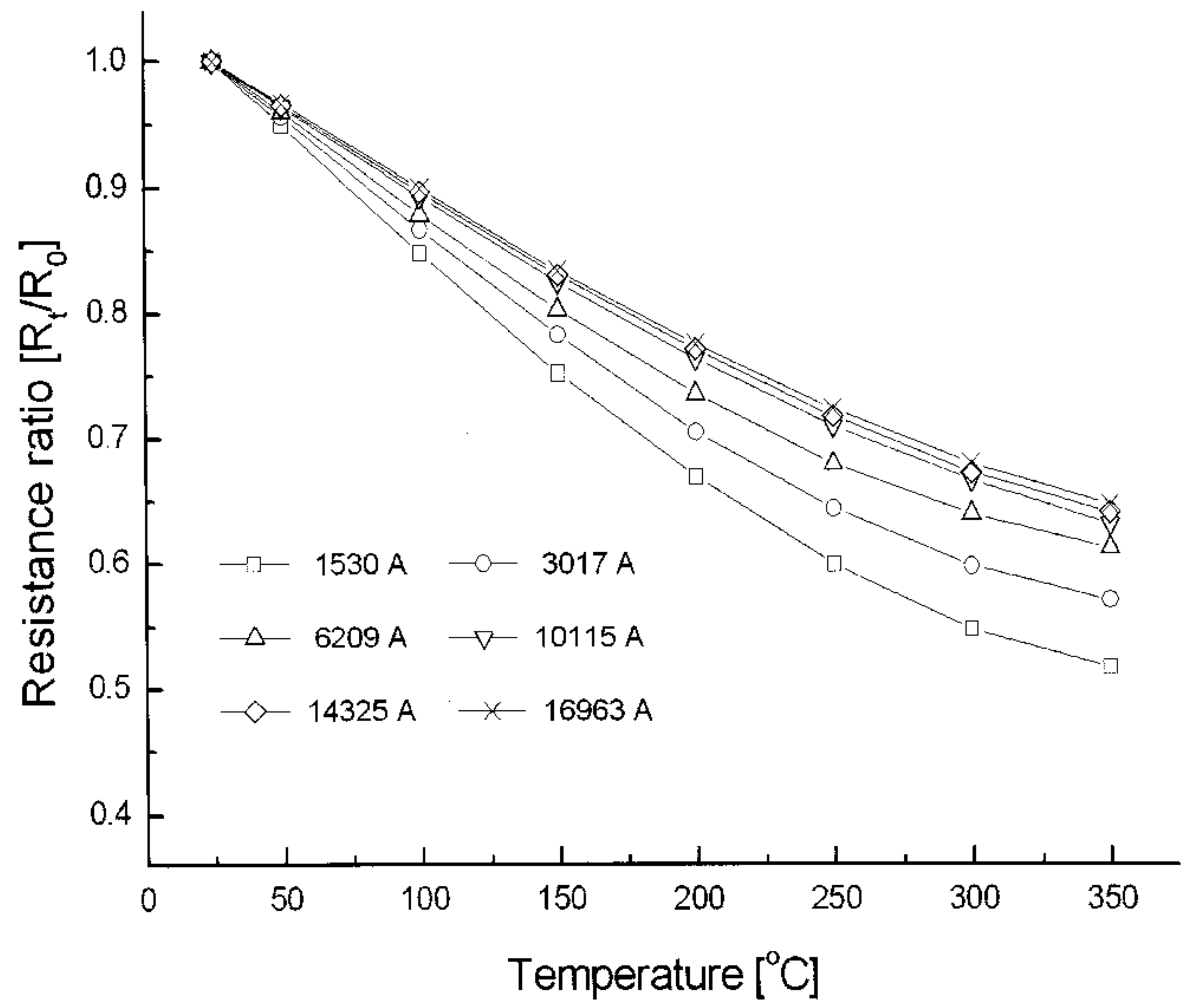

Fig. 5. Resistance ratio of poly 3C-SiC films with increasing temperature.

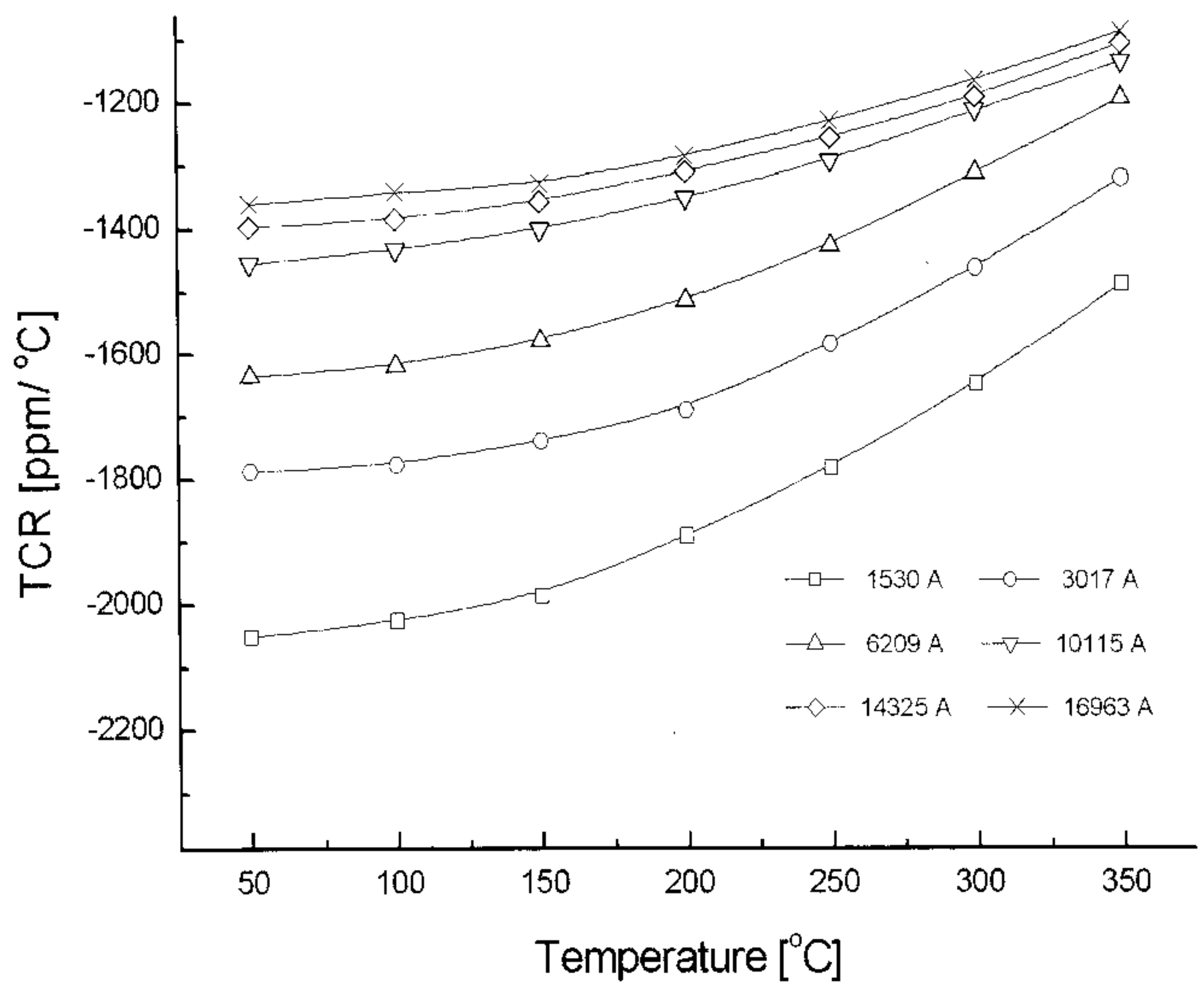

Fig. 6. TCR variations of poly 3C-SiC films with different thickness.

4. CONCLUSION

The characteristics of polycrystalline poly 3C-SiC films deposited by LPCVD on a Si substrate coated with SiO_2 were studied for different films thickness. Poly 3C-SiC films were deposited at 900 °C and 4 Torr using

SiH_2Cl_2 (100 %, 35 sccm) and C_2H_2 (5 % in H_2, 180 sccm) as the Si and C precursors, and NH_3 (5 % in H_2, 64 sccm) as the dopant source gas.

The resistivity of the poly 3C-SiC films with the thickness of 1,530 Å was 32.7 Ω-cm and decreased to 0.0129 Ω-cm at 16,963 Å. SEM micrographs of poly 3C-SiC films showed that the surface morphology consists of spherical grains and the grain size increases as the films thickness increases. Resistance of nitrogen-doped 3C-SiC films decreased with increasing the films thickness. The size of resistance variation decreased, while linearity improved, as the films thickness increased. These properties of poly 3C-SiC films according the films thickness became insensitive over 1 μm so the films thickness, approximate 1 um is effective for the application using the relation between resistance variations of poly 3C-SiC films and temperature.

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