Properties of thin silicon carbide films prepared by rapid thermal annealing

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Abstract. We report experimental results related to the structural and electrical properties of thin SiC films. Thin carbon films with thicknesses 50 Å and 300 Å were deposited by R.F. sputtering and processed by rapid thermal annealing (RTA) for 3 min at temperatures of 800 °C and 1400 °C in a vacuum chamber at 2×10⁻⁵ Torr. The thin films properties were studied by Raman spectroscopy and electrical cross-conductance.

1. Introduction
Silicon carbide combines a wide band gap, high thermal conductivity, high breakdown field and high saturated electron drift velocity, thus proving to be the best choice for a semiconductor for high-power, high-temperature and high-frequency devices, where Si and GaAs devices cannot be used [1]. SiC is also appropriate for devices operating in aggressive environments because of its stability to ionizing radiation and chemical attacks due to the high energy Si–C bond.

SiC layers fabricated by sublimation [2], chemical vapor deposition (CVD) [3, 4], magnetron sputtering [5] and laser ablation [6] have a relatively large thickness, which makes them unattractive for certain device applications.

In this work, we report the preparation of thin SiC nano-layers by rapid thermal annealing (RTA) of carbon films on silicon substrates. The samples were investigated by Raman spectroscopy and electrical conductivity measurements.

2. Materials, experimental procedure and equipment
We used P type (100) silicon substrates with resistivity 40 - 60 Ω cm. The silicon wafers were cleaned by a standard chemical procedure. Carbon films with thicknesses of 50 Å and 300 Å were deposited by RF sputtering at 0.5 Pa pressure in a gas mixture of 30 % H₂ and Ar. The thicknesses of the films were determined ellipsometrically. The target-substrate distance was fixed at 70 mm.

Further, the samples were submitted to RTA in vacuum of 5×10⁻⁵ Torr (6.7×10⁻³ Pa) for 3 min at temperature of 800 °C and 1400 °C. The heating from room to annealing temperatures was performed

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in 2 s, while cooling down to 650 °C required 3 - 5 s. For the Raman measurements, a Raman SPEX spectrometer (RAMLOG) system was used. The electrical conductivity was determined by measuring the cross-conductance of the layers. These measurements were carried out by a mercury probe with a contact area of 7×10^-2 cm^2 to the layers. Good ohmic contact to the backside of the silicon substrate was ensured by a silver sealing covering the entire backside area of the wafer.

3. Experimental results and discussion

Raman spectra of the layers were been taken before and immediately after the rapid thermal annealing procedure. Figure 1(a) shows the Raman spectrum of a carbon layer with thickness of 300 Å before the RTA process; a large peak can be clearly seen in the range 1500 - 1550 cm^-1, which is characteristic for amorphous carbon [7]. The Raman spectrum of the layer after RTA at 1400 °C for 3 min presented in figure 1(b) show the presence of rounded peaks in the ranges 910 - 1050 cm^-1 and 775 - 850 cm^-1, which is indicative of the existence of hexagonal and cubic SiC polytypes [8-10], respectively. The spectrum in figure 1(a) consists of the TO and LO phonon modes for both phases, which are not resolved.

Typically, the cubic phase is considerably less in quantity. Calculated as a percentage with respect to the basic phase (the hexagonal SiC), it is about 14%. We can thus assume that the cubic SiC phase is distributed in the basic matrix of hexagonal silicon carbide.

Figure 2 shows a Raman spectrum of the SiC layer with initial thickness of 50 Å subjected to RTA at 800 °C for 3 minutes. A further increase of the annealing temperature does not change the Raman spectra intensity, indicating that the solid-state reaction has been completed. The most clearly expressed peaks are those of the layer with thickness 300 Å and annealed at 1400 °C, which indicates that both phases increase as the annealing temperature and layer thickness are increased.

The analysis of the electrical cross-conductance of the carbon and SiC layers deposited onto silicon substrates were carried out for samples with thicknesses of 300 Å because of their good homogeneity, as assessed by scanning electron microscopy (SEM) images (not shown here). The current-voltage characteristics are shown in figure 3. The I-V curves are typical for a Schottky type diode with high density of defects at the interface between the metal (a mercury contact with an area of 7×10^-2 cm^2) and the p-type silicon substrate.

The analysis of the curve displayed in figure 3 for an as-deposited sample shows that it behaves simply as an additional resistance connected in series with the rectifying contact between the carbon layer and the silicon substrate. After the RTA procedure at 1400 °C for 3 min, the SiC layer behaves as a semiconductor with a large density of defects.
defects. The rectifying properties of the structure are due to the contact between the mercury probe and the SiC layer. The high current observed under reverse biasing is generated by the defects in the SiC layer.

![Figure 2. Raman spectrum of SiC layer with thickness of 50 Å after annealing for 3 min at 800 °C.](image)

![Figure 3. Effect of rapid thermal annealing on I-V characteristic of Hg-C-Si and Hg-SiC-Si structures.](image)

Conclusions
The effect of RTA in vacuum on the properties of carbon and SiC layers were studied using both Raman and electrical conductivity measurements. The experiments show that samples annealed at temperatures as high as 1400 °C exhibit a large current in the forward direction. Therefore, at 1400 °C formation of SiC/Si hetero-junctions by RTA takes place. The changes discussed of the electrical properties of the SiC layers are correlated with the Raman spectra which reveal peaks corresponding to hexagonal and cubic SiC phase after RTA treatment.

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