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Electrical Properties of phosphorous–Implanted Homoepitaxial Diamond Film

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Electrical properties produced by phosphorous implantation in homoepitaxial diamond film grown by chemical vapour deposition have been studied. A hydrogen plasma treatment technique was employed to anneal out implantation damage. We obtained resistivity of the order of 1 kΩ·cm for a sample implanted with 5×10^{15} cm^{-2} of phosphorous ions.

1. INTRODUCTION

Activation of electrically active n- and p-type dopants in diamond is indispensable for diamond device fabrication. This is, however, complicated by the extremely low solubility and low diffusivity of impurities in diamond.[1] Ion implantation, widely used in Si device technology, is a useful technique for doping diamond with the desired ions in a controlled manner. Since the success of diamond synthesis by chemical vapour deposition (CVD),[2] ion implantation in CVD diamond has become an important subject. Many investigations have been conducted on ion implantation in natural and CVD diamonds to date.[3-6] Although this method has yielded some success concerning the boron implantation,[3-6] it is still difficult to implant n-type dopants, *i.e.*, phosphorous, because of their heavy mass and higher implantation damage.

In the present work, we have studied the electrical resistivity of homoepitaxial diamond films implanted with phosphorous ions to a dose of 5×10^{15} cm^{-2}. This large dose would ordinarily produce implantation damage that could not be thermally annealed. We have employed a hydrogen plasma treatment to remove the implantation damage in the diamond, since diamond can grow and graphite can be etched off in this ambient. The effect of hydrogen plasma treatment on the damaged layer has previously been reported by the present authors.[7] Significant conductivity has been observed for the CVD diamond after phosphorous implantation followed by hydrogen plasma treatment.

2. EXPERIMENTAL

We grew homoepitaxial diamond films on (100) high-pressure synthesized (HPS) diamond, $3 \times 3 \times 1$ mm^3 in dimension, by microwave plasma CVD. The process parameters used were as follows: 2.45-GHz, 200-W microwave source, 900 -°C substrate temperature (as determined by an optical pyrometer), 30-Torr pressure, 5% CO in H_2, and 100-sccm gas flow. The microwave reactor and growth have been described in detail previously.[8, 9] It is important in this study to obtain highly insulating diamond films without any doping. We found that the surface resistance of the undoped diamond films vary with the ambients used during cooling and that insulating films ($> 10^{13}$ Ω) were obtained by cooling in an oxygen ambient.[10] The specimen was successively implanted at room temperature with phosphorous ions at three different energies and respective doses: 350 keV (2.5×10^{15} cm^{-2}), 200 keV (1.5×10^{15} cm^{-2}), and 100 keV (1.0×10^{15}

cm^{-2}). After implantation, the sample was exposed to a hydrogen microwave plasma at 30 Torr. Hydrogen plasma treatment caused the temperatures of these specimens to rise to 900 °C. After the hydrogen plasma treatment, the specimen was exposed to air at high temperature in order to remove the surface conductive layer by reaction with oxygen.[10] Therefore, the resistivity of CVD diamond without implantation could not decrease after hydrogen plasma treatments. Electrical contacts to the sample were made by evaporation of Ti dots.[11] For resistivity measurement, the van der Pauw configuration was used. The current–voltage characteristics were measured using a Keithly 237 high–voltage source measurement unit. Care was taken to ensure that samples were exposed to nitrogen gas during measurement.

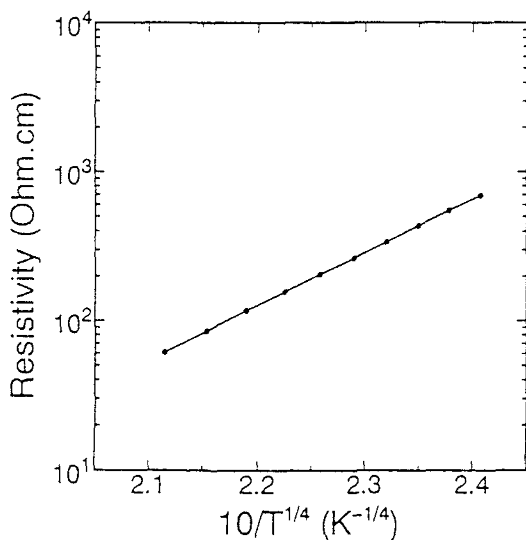

Figure 1. Electrical resistivity as a function of inverse absolute temperature for CVD diamond (100) film doped by phosphorous implantation followed by hydrogen plasma treatment.

3. RESULTS AND DISCUSSION

Figure 1 shows the electrical resistivity as a function of inverse temperature for the (100) films after phosphorous implantation followed by hydrogen plasma treatment. The specimen shows a relatively low resistivity of 1 kΩ·cm at room temperature (RT). The resistivity values show a linear relationship with $T^{-1/4}$ which is characteristic of variable range hopping conduction, as shown in fig.1. There have been some reports that radiation damages produced by the carbon implantation in diamond can cause the n–type and hopping conductivities.[12, 13] It seems that the conductivity of this specimen is attributed to redidual damages which would remain even after hydrogen plasma treatment.

4. COCLUSIONS

We have studied electrical properties produced by phosphorous implantation in CVD diamond (100) film. The relatively low resistivity of 1 kΩ·cm was observed for this specimen at room temperature.

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