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Effect of substrate on growth of nitrogen doped diamond film with plasma enhanced chemical vapor deposition

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Diamond has excellent properties such as wide bandgap, high thermal conductivity, and high hardness. Moreover, the semiconductor property exhibited through impurity doping is attracting attention as the ultimate semiconductor material. However, nitrogen-doped diamond (NDD), which exhibits n-type conductivity, is relatively difficult to synthesize due to the low efficiency of nitrogen doping and its tendency to alter the crystal structure of diamond.[1,2] In this study, the effect of substrate on the growth of nitrogen doped diamond films has been investigated using microwave plasma enhanced chemical vapor deposition (CVD). In the microwave plasma enhanced CVD, by causing high-energy electrons to collide with the precursor gases introducing into the process chamber, a large number of radicals are generated. The radicals continuously adsorb onto a substrate surface, and the thin films with chemical structures are synthesized by the surface reactions of radicals on the substrate.

The microwave plasma enhanced CVD was employed for both primary and secondary growth processes in this study. Figure 1 shows a schematic diagram of the microwave plasma enhanced CVD equipment. The generated microwave (2.45 GHz) transmitted in a waveguide and was introduced into the chamber, and a plasma with ball shape was generated above a substrate stage. In the primary growth, an undoped diamond (UDD) was grown on a silicon substrate for one hour, and then a NDD was deposited on the UDD layer for a hour as a secondary growth. Both growths were conducted under identical conditions: a stage temperature of 850°C, chamber pressure of 55 Torr, and microwave power of 800 W. For the primary growth, the methane (CH_4) flow rate was varied at 2, 4, and 6 sccm, although the Hydrogen (H_2) flow rate was fixed at 200 sccm. On the other hand, for the secondary growth of NDD, H_2, CH_4, and an H_2+N_2 mixture were used N_2 concentration in the H_2+N_2 mixture was 1% relative to amount of H_2 was used. The gas flow rates for the secondary growth were set at 190 sccm for H_2, 4 sccm for CH_4, and 10 sccm for the H_2+N_2 mixture. In this study, the secondary growth condition was fixed, and effects of substrate pretreatment and primary growth condition on the nitrogen doping rate were investigated. Furthermore, in the seeding process, which is the substrate pretreatment step, the density of diamond seed crystals was controlled by varying the amount of colloidal solution used for seeding to 2.0, 1.5, and 1.0 μL in three different conditions.

Raman spectroscopy, photoluminescence (PL) spectroscopy, and scanning electron microscopy (SEM) were used to evaluate the synthesized diamond films. The film crystallinity was evaluated from the full width at half maximum (FWHM) of a Raman spectrum of diamond structure at 1332 cm^{-1}[3]. The narrower FWHM indicates higher crystallinity of diamond film. Moreover, presence of nitrogen-vacancy complexes (N-V) was confirmed from a PL spectrum at 2.16 eV[4], and magnified images of the surface and cross-section of film were observed by SEM.

Figure 2 shows the intensity of PL spectrum at 2.16 eV originated from N-V centers per unit film thickness of NDD as a function of FWHM of a Raman spectrum at 1332 cm^{-1} of UDD. As shown in Fig. 2, decreasing in the FWHM of Raman spectrum at 1332 cm^{-1} of UDD, the intensity of the PL spectrum at 2.16 eV originated from N-V centers per unit film thickness of NDD became higher. This indicates that higher crystallinity of UDD leads to improved nitrogen doping efficiency.

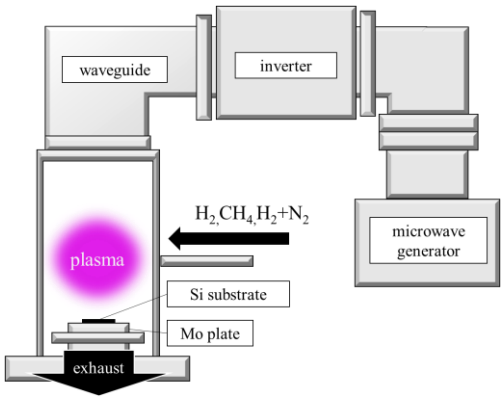

Fig. 1 Schematic diagram of microwave plasma enhanced chemical vapor deposition equipment.

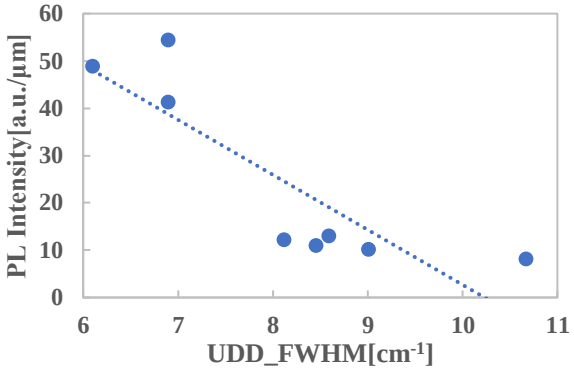

Fig. 2 Intensity of PL spectrum at 2.16 eV originated from N-V centers per unit film thickness of NDD as a function of FWHM of a Raman spectrum at 1332 cm^{-1} of UDD

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