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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

Heteroepitaxial growth of diamond on Si substrate is an important technology for synthesizing diamond films with large area and low cost, for use in both next-generation power devices and high-sensitivity sensor devices. However, there are large lattice mismatch and surface energy difference between the Si substrate and diamond, making it difficult to form epitaxial nanoparticles of diamond directly on Si. To solve this problem, cubic silicon carbide (3C-SiC) could be used as an intermediate layer between Si and diamond for the diamond heteroepitaxy, because the 3C-SiC film can be grown on Si and its lattice constant and surface energy are close to those of diamond. The quality of heteroepitaxial diamond films on 3C-SiC/Si substrates has been improved using various methods, such as by increasing the nucleation density and biaxial stress relaxation through nanocomposite interlayers. However, the mechanism of heteroepitaxial growth of diamond films on 3C-SiC/Si remains unclear, and it is difficult to obtain epitaxial nanoparticles in a reproducible way. Moreover, heteroepitaxial diamond (111) on 3C-SiC/Si substrates has not been reported. This thesis describes the heteroepitaxial growth of diamond on both Si (001) and (111) substrates with the 3C-SiC intermediate layers, the performance of the resultant diamond films, and their potentials for both power and sensor devices.

Diamond nucleation on 3C-SiC/Si substrates by the bias-enhanced nucleation (BEN) method forms a non-crystalline layer at the interface between diamond and 3C-SiC. These non-crystalline regions inhibit the epitaxial nucleation of diamond. To selectively suppress these non-crystalline regions, we used microwave at high power density in antenna-edge microwave plasma assisted chemical vapor deposition (AE-MPCVD). The strong electric field in the AE-MPCVD method can accelerate the decomposition of molecular hydrogen species, and the decomposed hydrogen species inhibit the non-crystalline carbon regions at the interface. Moreover, we monitored the diamond nucleation during the BEN process in situ. The bias current variation during BEN reflects the surface coverage of diamond, and the diamond nucleation and growth processes can be estimated by the Kolmogorov-Johnson-Mehl-Avrami equation. Using this equation, we found that a bias current of up to 10 % higher than the minimum bias current was the optimum condition for diamond nucleation on both 3C-SiC (001) and (111) in terms of the density and epitaxial nucleation. As a result, we obtained epitaxial diamond nanoparticles on both 3C-SiC (001) and (111), using a combination of high plasma density nucleation and optimizing the nucleation time by in-situ monitoring during the BEN process.

After the nucleation process, the diamond (001) nanoparticles on 3C-SiC(001)/Si(001) were grown along controlled directions, in what is called the two-step growth process. We have achieved a tilt spread of 0.52°, which is smaller than previously reported values. The residual stress and dislocation in the heteroepitaxial diamond films decrease with increasing film thickness. The scaling laws of dislocation reduction are consistent with those of other semiconductor materials. Thus, the dislocation in the film reaches 10^8 cm^{-2}, which is much smaller than that of the interface (on the order of 10^{12} cm^{-2}). In contrast, the heteroepitaxial diamond (111) grains could not be used in the two-step growth process. Instead, we obtained highly oriented diamond (111) films using selective oxygen etching growth. The oxygen in the growth gas can selectively etch the non-crystalline carbon at the interface. After a growth time of 3 h, the 3C-SiC (111) surface was perfectly covered with diamond (111) facets. The tilt spread of diamond (111) of 2.4° is much smaller than that of diamond films grown directly on Si substrate.

Using the heteroepitaxial diamond (001) and (111), we have demonstrated power devices as Schottky barrier diodes (SBDs) and magnetic sensors, respectively. The diamond SBDs showed a high rectification of 10^8 at ± 5 V. The specific on-resistance (0.2 Ω cm^2) is comparable with SBDs using single-crystal diamond films. However, the leakage current at higher voltage (>10 V) was increased, due to the high dislocation density in the heteroepitaxial diamond films. Further improvements in the heteroepitaxial growth and device technology are necessary to suppress the leakage current. The sensor devices using nitrogen-vacancy (NV) centers in diamond were formed in both the heteroepitaxial diamond (111) particles and films. The NV centers in heteroepitaxial diamond could be preferentially aligned in the one-atomic direction, leading to improved sensitivity as confirmed in experiments. However, the calculated sensitivity was still lower than that of homoepitaxial films, so the crystal quality of heteroepitaxial diamond (111) films should be further improved. These developments in heteroepitaxial diamond films could be used as a platform to design cost-effective, large-area power and sensor devices.

備考 ： 論文要旨は、和文 2000 字と英文 300 語を 1 部ずつ提出するか、もしくは英文 800 語を 1 部提出してください。
Note : Thesis Summary should be submitted in either a copy of 2000 Japanese Characters and 300 Words (English) or 1copy of 800 Words (English).