Heteroepitaxial Growth of Diamond Films on 3C-SiC(001)/Si substrates by Antenna-Edge **Microwave Plasma CVD** Junya Yaita^{1,2}, Takayuki Iwasaki^{1,2,3}, Meralys Natal⁴, Stephen E. Saddow⁴, Mutsuko Hatano^{1,2,3},

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Abstract

Diamond films were heteroepitaxially deposited on 3C-SiC(001)/Si(001) substrates for power device applications. Antenna-edge microwave plasma chemical vapor deposition was utilized for the nucleation and growth of diamond film. A highly oriented diamond film was successfully synthesized by a two-step growth process which suppresses the growth of non-aligned grains. Sharply-defined diffraction patterns of diamond were observed by reflection high energy electron diffraction, indicating that the grown diamond films (001) crystal structure following possess the 3C-SiC(001) surface orientation.

1. Introduction

Diamond has superior electrical characteristics for power device applications such as a wide band-gap, a high thermal conductivity, high carrier mobilities, and a high breakdown electric field. Generally, diamond devices have been fabricated on substrates synthesized by a high pressure and high temperature (HPHT) process. However, the HPHT substrates were very small, usually in millimeter scale, and very expensive. Therefore, methods to grow a thin films of diamond on non-diamond substrates have attracted great interest due to its enormous potential for diamond power devices [1]. 3C-SiC is a promising candidate for the buffer layer of the heteroepitaxial growth of diamond, since it can be grown on Si and the lattice mismatch with diamond (18 %) is smaller than that of Si (32 %) [2, 3]. In this study, heteroepitaxial growth of diamond on 3C-SiC(001) / Si (001) was performed by antenna-edge microwave plasma chemical vapor deposition (AE-MPCVD) using a bias enhanced nucleation (BEN) method [4] and two-step growth process [5]. AE-MPCVD has the following features [6]: (1) Since the microwave power is concentrated at a tip of the antenna, a high density plasma can be obtained, leading to a fast nucleation rate. (2) The CVD conditions such as pressure, temperature, and microwave power can be independently controlled. Although the AE-MPCVD system has been demonstrated to be useful for the diamond nucleation on Ir films [6], this is the first time to show its usability on 3C-SiC thin films.

2. Experimental

Single crystal 3C-SiC(001) films deposited on Si(001)



Fig. 1 Schematic illustration of AE-MPCVD

wafers by hot-wall CVD were used as a substrate [7]. Diamond nucleation was performed by AE-MPCVD with a negative voltage of -50 V and a distance of 8 mm between the antenna tip and substrate. The conditions for the nucleation are shown in Table I. The diamond films were grown via a two-step process (Fig. 2). First, diamond nuclei were forced to grow in the <001> direction. In this process, diamond grains tilted from the <001> direction are buried in aligned grains because of the difference in the growth rate in the substrate normal direction (Fig. 2(a)). The diamond grains possess a pyramid-shaped structure with exposed (111) faces after the first process. At the next step, the preferential growth in the <111> directions enhances the lateral growth and leads to the formation of a continuous diamond film. Here, the growth direction was controlled by the α parameter, which is given as $\alpha =$ $\sqrt{3} V_{001}/V_{111}$, where V₀₀₁ and V₁₁₁ are the growth rate of (001) and (111) crystalline plane, respectively [8]. When the α parameter is higher (lower) than 1, the growth in the <001> (<111>) direction preferentially occurs. The α parameter can be adjusted by the CH₄ concentration, N₂ concentration, and temperature (Table I).



Fig. 2. Schematic images of two-step diamond growth. Preferential growth in the (a) <001> and (b) <111> directions. The red arrows indicate the preferential growth direction

	BEN	<001> growth	<111> growth
Pressure [kPa]	10	6	6
Power [w]	200	200	200
Blas voltage [v]	-50	-	-
N_2 ratio [%]	0.5	0.01	0.5
Temperature [°C]	750	600 - 670	600 - 670

Table I. AE-CVD conditions for heteroepitaxial diamond growth.

3. Results and Discussion

Figure 3(a) and (b) show a RHEED pattern and an SEM image after the 10 min BEN treatment on 3C-SiC(001). Ring-like diffractions from diamond were observed as well as 3C-SiC spots (Fig. 3(a)). The ring diffraction indicates that the diamond nuclei are not perfectly aligned on the 3C-SiC surface. The SEM image shows 3C-SiC stripes typically observed after BEN (Fig. 3(b)) [1, 2]. At this stage, clear diamond nuclei are not observed by SEM.

After the 2 h growth under the <001> CVD conditions, the RHEED pattern and morphology are dramatically changed (Fig. 3(c, d)). The diffraction displays spots rather than rings, indicating that diamonds are aligned on the surface. The SEM image in Fig. 3(d) shows aligned pyramid-shaped diamond grains. Since the α parameter is higher than 1 for this growth, the preferential growth in the <001> direction occured. Thus, tilted nuclei are buried in the (001) aligned diamond grains.

Finally, the lateral growth was performed under the <111> growth conditions for 4 h to obtain a continuous diamond film. As shown in Fig. 3(e), the diffraction spots from diamond becomes stronger than those from 3C-SiC(001). The SEM image also shows a highly-oriented diamond film covering the whole 3C-SiC surface (Fig. 3(f, g)). Although grain boundaries are still observed, the grains would merge after longer deposition.

4. Conclusions

Heteroepitaxial growth of diamond on 3C-SiC(001) / Si(001) substrates was performed by AE-MPCVD. Diamond was nucleated by the BEN method and a highly-oriented diamond film was synthesized by the two-step growth process. The <001> growth condition enabled us to bury the non-aligned diamond grains in the oriented ones. Then, a continuous diamond film was obtained under the <111> growth condition. A longer growth time could further improve the film quality, and then, fabrication of power devices are expected on a large substrate.

Acknowledgements

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Fig. 3. RHEED patterns (beam along <100>) and SEM images of diamond grown on 3C-SiC(001) after (a, b) BEN process, (c, d) 2 h growth under the <001> growth conditions and (e - g) 4 h growth under the <111> growth conditions. The orientation down left is for the RHEED patterns. The yellow triangles indicate diamond diffraction spots (002), (02-2) and (022). Other diffraction spots come from 3C-SiC.