Pressure effect of superconducting transition temperature for Boron-Doped (111) Diamond films

N. Oki¹, T. Kagayama¹, K. Shimizu¹ and H. Kawarada²

¹KYOKUGEN, Osaka University 1-3, Machikaneyama, Toyonaka, Osaka, 560-8531, Japan
²School of Science and Engineering, Waseda Univ. 3-4-1, Okubo, Shinjuku, 169-8555, Japan

Abstract. Many studies on superconductivity of boron-doped diamond (BDD) have been done, and it is well known that the superconducting transition temperature \( T_c \) of BDD films depend on the boron concentration and the growth direction. Uniaxial like pressure along (111) direction was applied on boron-doped (111) diamond films synthesized by CVD method using a diamond-anvil cell (DAC) up to 18.5 GPa. The \( T_c \) was decreased as previous report, however the changing rate is smaller than other experiments with hydrostatic pressures and a theoretical prediction.

1. Introduction

Pure diamond is well known as an insulator with a wide gap of 5.5 eV, and very hard material with a high Debye temperature of 2,230 K. Boron atom is smaller and has one less electron than carbon atom and is easily incorporated into diamond. By doping boron into a diamond, a diamond becomes a p-type semiconductor and higher boron-concentrated diamond \( (n_B > 3 \times 10^{20} \text{ cm}^{-3}) \) shows metallic behavior [1]. Recently the boron-doped diamond (BDD) was synthesized at high pressure and high temperature (HPHT), and was discovered to become a superconductor with \( T_c \sim 4 \text{K} \). [2] A superconducting homoepitaxial (111) and (100) films of BDD were also synthesized using chemical vapor deposition (CVD). By using this method, which enable us to control the concentration of boron, it was found that the \( T_c \) has a tendency to rise by the boron concentration and the \( T_c \) of (111) films is higher than that of (100) films.

The pressure effect on \( T_c \) on BDD HPHT method and BDD synthesized by CVD method were reported by Ekimov [2] and Tomioka [4], respectively and both showed that the \( T_c \) decrease by applying hydrostatic pressure up to 5 GPa. And Ma predicted by using first principle calculation [5] that the \( T_c \) decrease with applying pressure up to 40 GPa by reduction of the density of states at Fermi level N(0) by pressure.

In this experiment, we applied uniaxial like pressure along (111) direction to BDD (111) films and measured the pressure dependence of the \( T_c \) up to 18.5 GPa.

2. Experimental

The homoepitaxial (111) film was deposited with the thickness of 250 nm on synthetic Ib (111)
diamond by the concentration of $7.0 \times 10^{21}/\text{cm}^3$. The original size of the substrate was $2.5 \times 2.5 \times 0.5 \text{ mm}^3$, which is too large to put into a diamond-anvil cell (DAC). We broke the specimen into pieces by a diamond anvil and used the piece of suitable size.

We measured temperature dependence of electrical resistance of BDD in the DAC made of CuBe alloy. Figure 1 shows schematic drawing of sample setting in the DAC. We used diamond anvils with the culet of 500 µm in diameter. Dimensions of sample were $160 \times 55 \times 30 \text{ µm}^3$ and was implanted in the c-BN and NaCl in Run 1 and Run 2, respectively. Pressure was applied up to 5 GPa in Run 1 and 18.5 GPa in Run 2. The electrical resistance measurements were performed by a four-probe method with a measuring current of 10 µA at all experiments. Small ruby balls were put at measuring positions to determine the pressure by means of a ruby fluorescence method.

![Figure 1. Schematic drawing of sample setting.](image)

### 3. Results and discussions

Figure 2 shows the temperature dependence of electrical resistance at 1.2 GPa to 18.5 GPa. At 1.2 GPa, the resistance started to fall rapidly near 7 K with decreasing temperature, and reached to zero at 6.5 K. The temperature width of superconducting transition was almost same at Run 1 and Run 2. The residual resistance at 7 K increased by pressure.

We defined $T_c$ as the temperature at the midpoint of the resistive transition. The $T_c$ slightly shifted to lower temperature with increasing pressure. The $T_c$ decreasing rate by applying pressure in this experiment was smaller than those of other previous works under hydrostatic pressure and theoretical prediction as shown in Fig. 3.

![Figure 2. Temperature dependence of electrical resistance at each pressure.](image)
4. Acknowledgment

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5. References

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