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Defect Reduction in Homoepitaxial Diamond Films for High Breakdown Voltage Schottky Diodes

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Abstract

Quality of homoepitaxial diamond films was sufficiently improved by simultaneous oxygen feeding. Reasonably high growth rate of 3 μm h^{-1} was realized by increasing methane concentration drastically. Dislocations originating from polishing marks were mainly suppressed under the growth condition. Schottky diodes fabricated using the high-quality diamond films showed breakdown voltage of 2.5 kV. .

1. Introduction

Studies on semiconducting diamond for the power device application have intensively been conducted in several research groups. Diamond-based Schottky di-odes and p(i)n junction diodes are mainly employed for characterizing rectification properties [1, 2]. Here, a use of higher quality of diamond crystals is crucial for obtaining superior device performance. Growth of high quality diamond with reasonably high growth rate and better reproducibility is, then, desired. Well control of etching phenomena during diamond growth, generally by atomic hydrogen, is a key to suppress defect formation [3].

In this study, we focus on the effect of oxygen addition to the diamond growth [4].The quality of non-doped homoepitaxial diamond films was investigated by both luminescence and electrical properties.

2. Experimental

(100)-oriented HPHT grown type-Ib crystals were used as substrates. Homoepitaxial diamond (100) films were deposited on these substrates using the homebuilt microwave plasma-assisted chemical-vapor-deposition (MPCVD) apparatus [2]. In this study, two different source gas compositions, either oxygen addition during growth or not, were applied for homoepitaxial diamond (100) film growth. The diamond sample named S1 was grown on a type-Ib substrate under the following condition; total gas pressure, microwave power, methane concentration (flow ratio of CH_4 to the total gas flow), oxygen concentration (flow ratio of O_2 to the total gas flow), and substrate temperature were 120 Torr, 1.4 kW, 10 %, 2 %, and 1000±10 °C, respectively. Higher methane concentration of 10 % was necessary to obtain reasonably-high growth rate of >1 μm h^{-1} under the high oxygen concentration of 2 %. The diamond sample named S2 was grown on a type-Ib substrate under the following condition; the total gas pressure, microwave power, methane concentration, oxygen concentration and substrate temperature employed were 120 Torr, 1.4 kW, 4 %, 0 %, and 960±10 °C, respectively. Diamond film was grown for 10 hr. The thickness of homoepitaxial diamond films were ~25 μm for the sample S1 and ~30 μm for the sample S2. Diamond films were characterized by using an optical microscope equipped with Nomarski-mode filters, a UV laser microscope, cathodeluminescence (CL) measurements were performed.

Schottky barrier diodes was fablication on a homoepitaxial (100) diamond film, which was grown on a HPHT grown boron-doped type-IIa (100) diamond single crystals with the same dimension and surface polishing. Boron concentration of the substrate estimated by SIMS was ~10^{20} cm^{-3}. The same growth condition as that for the sample S1 was applied for the homoepitaxial diamond growth. The thickness of the homoepitaxial layer was estimated to be 25 μm.

The grown diamond sample was first chemically cleaned by boiling acid to remove graphitic components, followed by deionized water rinse. Then the sample surface was hydrogenated by plasma. Subsequently, using an electron-beam evaporator, titanium contact capped with Au was deposited on the four corner of the specimen sample for the ohmic contact formation. Diameter of the circular shape ohmic contacts is 500 µm. The sample was then annealed at 500°C in vacuum, followed by oxidized their surface by the VUV/ozone treatment at room temperature. Deposition of tungsten carbide, WC, Schottky contacts on the homoepitaxial film surface was finally carried out by mean of conventional magnetron sputtering whose base pressure was less than 10^{-6} Pa. Diameter of the Schottky contacts is 150 µm.

3. Results and Discussion

Figures 1(a) and 1(b) show CL images for the sample S1 and S2 respectively taken at the monochromator wavelength of 235 nm. This luminescence originates from the free exciton (FE) recombination. As shown in Fig. 1(b), characteristic line-shape non-emission pattern was observed from the sample S2, meaning that defects are formed along the polishing lines. This line-shape luminescence pattern was not observed from the sample S1.

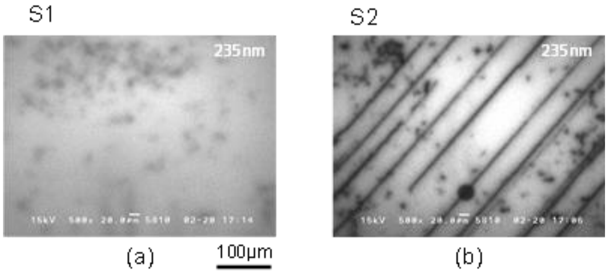

Fig. 1 Cathodoluminescence images of samples S1 and S2 taken at 300 K. The wavelength of 235 nm corresponds to the free-exciton recombination luminescence.

Since Ib (100) substrates used for the samples S1 and S2 were processed with equivalent polishing conditions, this result indicate an oxygen addition with high concentration is effective to remove defects localized near the surface such as polishing defects. Oxygen plasma etching or hydrogen/oxygen mixture plasma etching are basically anisotropic etching process. It means that substrate surfaces after these etching processes become much rougher than the original ones. As a result, it is not easy to obtain homoepitaxial diamond films with better flatness when surfaces of diamond substrates are processed by the oxygen-plasma etching, especially in the case of longtime process.

A schematic side view of diamond Schottky diodes was shown in inset of Fig. 2. Boron concentration of in the homoepitaxial layer was below detection limit of SIMS. Capacitance was constant towered reverse bias voltage. The acceptor concentration is considered to be much smaller than 10^{15} cm^{-3}.

An ideality factor and the barrier height at the interface was 1.2 and 1.49 eV, respectively. As shown in the inset of Fig. 2, forward current density increased to 5 A cm^{-2} at forward bias voltage of 8 V. Reverse current was relatively smaller, shown in Fig. 2. No characteristic feature sometimes appeared for lateral-type WC Schottky diodes was observed from the vertical-type one. Finally, breakdown was observed at the reverse bias voltage of 2.5 kV. This value is relatively higher as a diamond-based vertical-type diodes which have no diode electrode edge termination. This result assists the quality of homoepitaxial diamond films grown under the conditions proposed in this study.

4. Conclusions

High quality diamond films were grown by proper feeding of oxygen. Growth rate of 3 μm h^{-1} was higher under relatively low microwave power condition of 1.4 kW. Diamond films thus grown showed homogeneous free-exciton

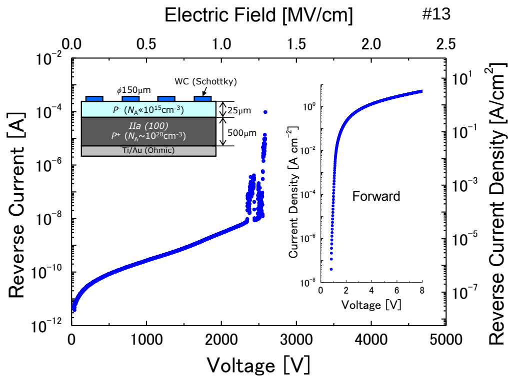

Figure 2 Reverse characteristic of diamond Schottky diodes. Inset is a device configuration and forward characteristic.

recombination luminescence as an evidence of low dislocation density. High breakdown voltage of 2.5 kV was obtained using the high quality diamond films.

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