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Diamond high-power and high-temperature SBDs

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1. Introduction

In recent years, wide-gap semiconductors such as SiC, GaN and diamond have attracted much attention due to the strong requirement for saving energy. Compared with other wide-gap semiconductors, diamond is the most promising material for future high power, low loss and high temperature devices [1] because of its superior material properties such as high carrier mobility (4500 cm^2/Vs for electrons, 3800 cm^2/Vs for holes, respectively) and high breakdown field (>10MV/cm). Accordingly, figures of merit (FOM) for high power or high temperature devices show quite high score. Up to now, high power (> 10kV [2], > 4kA/cm^2 [3]) or high temperature (>1000^{o}C [4], 1500hrs@400^{o}C [5]) Schottky barrier diodes (SBDs) have been demonstrated on single crystalline diamond. The fast switching characteristics, owing to the low dielectric constant of diamond, has been also reported [6]. Recently, the size of diamond wafer is increased more than 1 inch [7] and the quantitative analysis of residual defects has been carried out.

However, the reported performances are obtained by the small size of devices. Especially the actual current is less than 0.5A, even though the current density is high. In this work, to realize the higher power, we have fabricated vertical SBDs with adopting device fabrication techniques such as doping control in drift layer, field-plate (FP) structure, respectively.

2. Experimental

Figure 1 shows the cross sectional and top view of diamond VSBD. p-Type epitaxial layer with 12μm thickness was deposited as drift layer by chemical vapor deposition (CVD) on p+-type high-pressure and high-temperature synthesized (HPHT) single crystalline diamond (001) substrate.

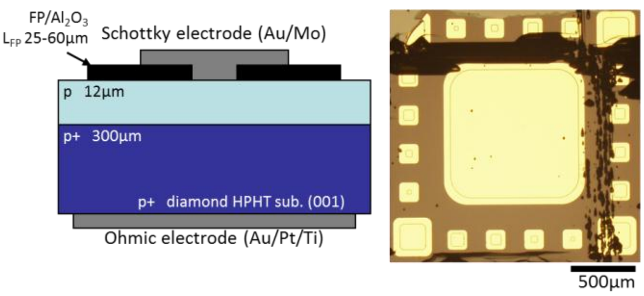

Figure 1. Cross section and top view of diamond SBD

The CH_4/H_2 ratio, the gas pressure, the plasma power and the growth temperature used were 2%, 120 Torr, 3.9 kW, and 1000 °C, respectively. To control the acceptor concentration (boron), 0.45ppm of tri-methyl-boron (TMB) is added during the growth. At the end of the growth, TMB gas flow was stopped to decrease the doping concentration at the surface. The grown film is cleaned by acid treatments to remove graphitic or amorphous layer to suppress the unintentional leakage current path. The Ohmic contact (Au/Pt/Ti) was formed on the backside of the substrate. After the surface oxidation by UV/O_3, Al_2O_3 field-plate was fabricated by photolithography and lift-off technique. Al_2O_3 with 1.8 μm thickness was deposited by r.f. sputtering. The dielectric constant and the tangent-delta of the sputtered Al_2O_3 film were 9.6 and 0.005 at 1 kHz, respectively. The field strength of FP was 1.3-3 MV/cm, which is characterized by metal-insulator-metal structure. The Schottky electrodes of (Au/Mo) were fabricated by photo lithography and lift-off technique. The FP lengths were 25-60μm. The size of Schottky electrodes were varied from 30 to 1,000μm. The capacitance-voltage and current-voltage performance was characterized by Agilent B1505A system. To suppress the surface discharge during the high temperature and high voltage measurement, on-wafer vacuum probe system by Nagase Techno-Engineering was utilized.

3. Results and discussion

The doping profile was characterized by capacitance-voltage measurement. The acceptor concentration was confirmed as 10^{15} /cm^3 at the surface and increased to 10^{16} /cm^3 at 1.2 μm depth. Figure 2 shows the current-voltage characteristics of diamond vertical SBD with 30μm electrode size. The measurement was carried out at 25 (room temperature, RT), 150 and 250 ^{o}C, respectively. Effective Schottky barrier height (at n=1) is estimated as 1.85eV, which value is almost comparable to that in previous report. As shown in fig. 1(a) the on-resistance is decreased at the elevated temperature due to the activation of carriers. The current density (J_F) at V_F = -8V and the specific on-resistance ($R_{on}S$) at RT and 250^{o}C are 160A/cm^2, 29.3mOhm-cm^2 and 600A/cm^2, 9.4mOhm-cm^2, respectively.

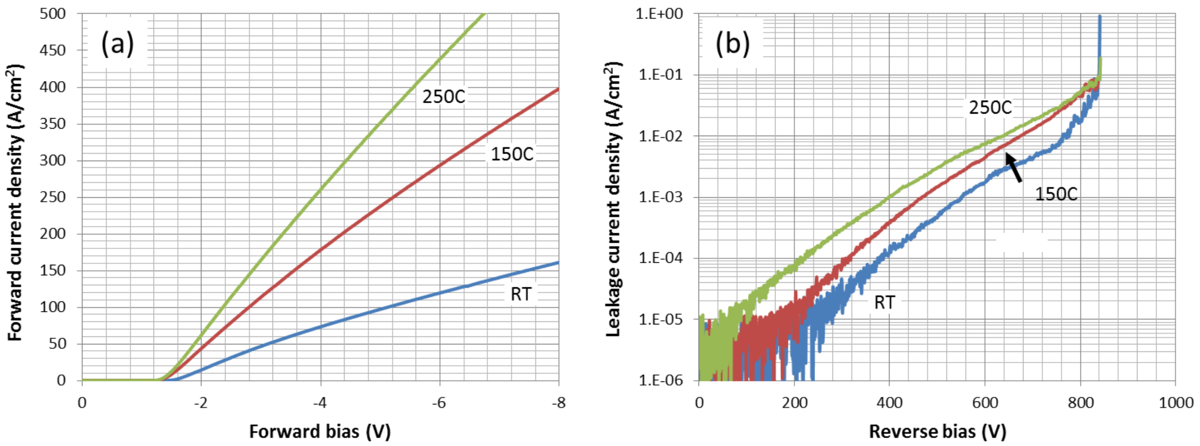

Figure 2. (a) Forward and (b) reverse characteristics of diamond VSBD with 30μm electrode.

On the other hand, the leakage current of SBD is kept low even at 250°C as shown in fig. 2(b). The breakdown voltages at the different three temperatures are almost constant as 840V. The calculated Baliga's figure of merit ($BV^2/R_{on}S$) is 75.1 MW/cm^2, which is the best value in diamond diode at present. Supposing the acceptor concentration is almost constant as 10^{16}/cm^2 in the deeper side in drift layer, the estimated depletion layer depth and the maximum electrical field at the Schottky interface are 7.3μm and 2.1 MV/cm, respectively. The estimated maximum field is much lower than the expected value. And also leakage current is higher than the estimated value from thermionic emission with barrier lowering model [8] or thermionic field emission model [9]. The potential reasons of the high leakage current and the low breakdown field are (1) defects induced leakage current and (2) current leakage and breakdown at the field plate region.

Figure 3 shows forward current-voltage characteristics of diamond VSBD with 1,000μm electrode, measured at 250°C. RonS of 1,000μm electrode is 10.2mOhm-cm^2, which is almost comparable to that of 30μm electrode, indicating the series resistance of the VSBD is small.

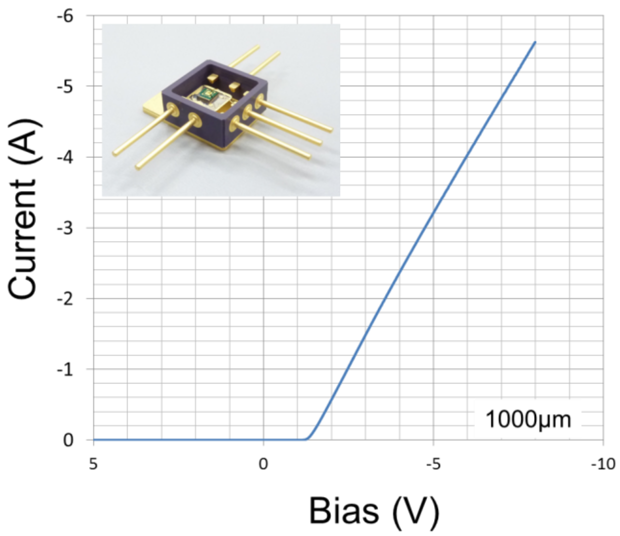

Figure 3. Forward current-voltage characteristics of diamond VSBD with 1,000μm electrode.

4. Conclusions

Diamond vertical Schottky barrier diode with a doping controlled drift layer and a field-plate structure has been fabricated. VSBD with small electrode shows $R_{on}S$ of 9.4mOhm-cm^2 and BVBD of 840 V at 250°C. The Baliga's figure of merit ($BV^2/R_{on}S$) of 75.1 MW/cm^2 is the vest value in diamond SBDs at present. 5A of forward current is realized at 250°C with the large electrode size of 1,000μm. However, the estimated maximum electrical field is 2.1 MV/cm, which is much lower than the expected value. The potential reasons of low break down field are (1) defect induced leakage current and (2) current leakage and breakdown at the field plate region.

Acknowledgements

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