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Fabrication and Characterization of 1mm Size Diamond SBD

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Abstract

Field plated diamond vertical Schottky barrier diodes with a 1000µm contact area have been developed. The VSBD shows low on-resistance of 10 mΩ-cm^2, which is almost comparable to 30 µm diode, and realizes high forward current >1A at 250 °C. The high current SBD shows fast switching less than 15ns even at high temperatures. However, due to the defects incorporation, degradation of blocking voltage with increasing device area is confirmed.

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 because of its superior material properties, such as high carrier mobility and high breakdown field. Accordingly, figures of merit (FOMs) for high-power or high-temperature devices show quite a high score. Up to now, high-power or high-temperature Schottky barrier diodes (SBDs) have been demonstrated on single-crystalline diamond [1,2]. The fast switching characteristics, owing to the low dielectric constant of diamond, has been also reported [3].

However, the reported performances are obtained by the small devices less than 100µm, especially the actual current is less than 0.5A, even though the current density is higher than 1kA/cm^2. Those small current devices cannot be installed to practical power electronics circuits and the accurate evaluations of switching performances are difficult. In this work, to realize the higher power operation, we have fabricated vertical SBDs with adopting device fabrication techniques such as doping control in drift layer and thick field-plate (FP) structure, respectively. The static and dynamic performances are characterized.

2. Experimentals

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

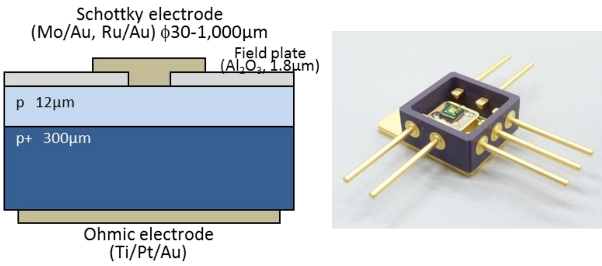

Fig 1. The cross sectional and packaged diamond VSBD

strate. The doping concentration is controlled by optimize the gas mixture (trimethyl boron, methane and carbon dioxide) during the growth. Increase of methane and trimethyl boron concentrations will increase acceptor, on the

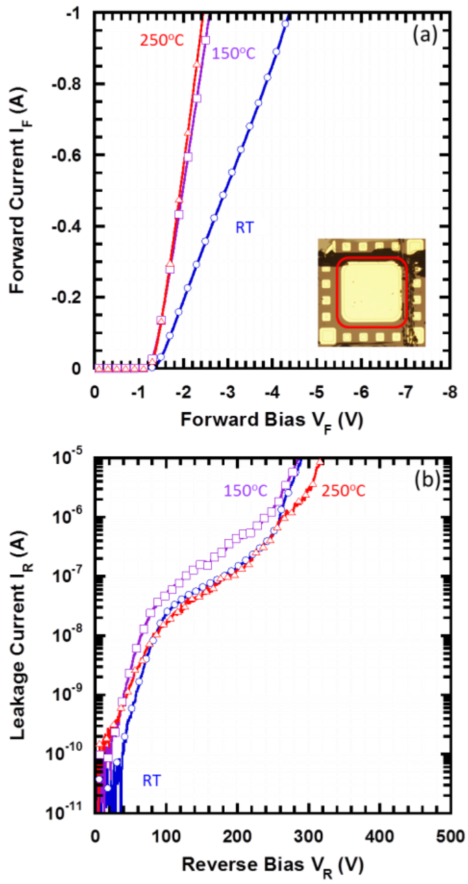

Fig 2. (a) Forward and (b) leakage characteristics of diamond VSBD with 1mm electrode.

other hand, addition of carbon dioxide will decrease the acceptor concentration. To improve the rectification, the acceptor concentration at the surface of drift layer is decreased.

The Ohmic contact (Ti/Pt/Au) was formed on the backside of the substrate. After the surface oxidation by UV/O_3, 1.8μm thick Al_2O_3 field-plate (FP) was fabricated by photolithography and lift-off technique. The Schottky electrodes were fabricated by photo lithography and lift-off technique. The FP lengths were 25 to 60μm depending on the size of the Schottky electrode. The size of Schottky electrodes were varied from 30 to 1000 μm. By capacitance-voltage characterization, 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.

3. Results and discussion

Figure 2 shows the typical current-voltage characteristics of diamond vertical SBD with 1000μm electrode. The measurement was carried out at room temperature, 150 and 250°C, respectively. The on-resistances is decreased at the elevated temperature due to the activation of carriers. The forward current at Vf=-3V and the specific on-resistance (RonS) at RT and 250°C, are 0.5A, 29.2mΩ-cm^2 (Ron=3Ω) and 1.5A, 10.2mΩ-cm^2 (Ron=1Ω), respectively. The forward current reaches 5A when Vf is increased up to -8V. The forward characteristics of 1000μm SBD are almost constant to that of smaller SBDs [4].

As shown in fig 2(b), comparable to forward characteristics, the reverse characteristics is almost constant to the temperature. A good rectification ratio >10^6 is obtained up to 250V at 250°C. However, the blocking voltages are limited to 290-320V, which is only 40% of 30μm's. The degradation of blocking voltage might be due to the incorporation of defects. Figure 3 shows the blocking voltage of diamond VSBDs as a function of Schottky contact area. The

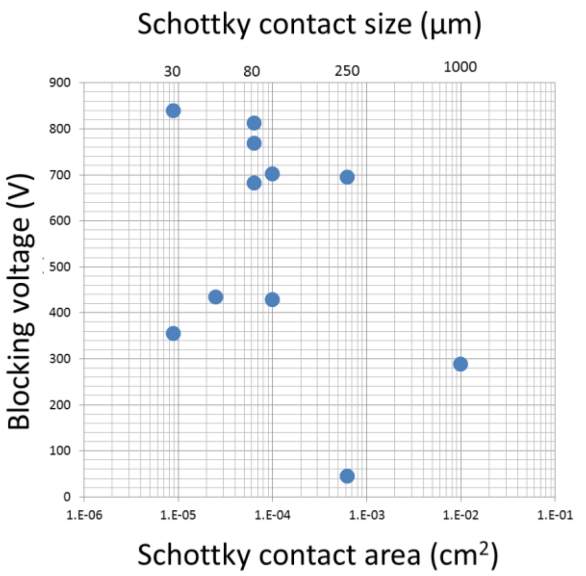

Fig 3. Blocking voltage of diamond VSBDs as a function of Schottky electrode size.

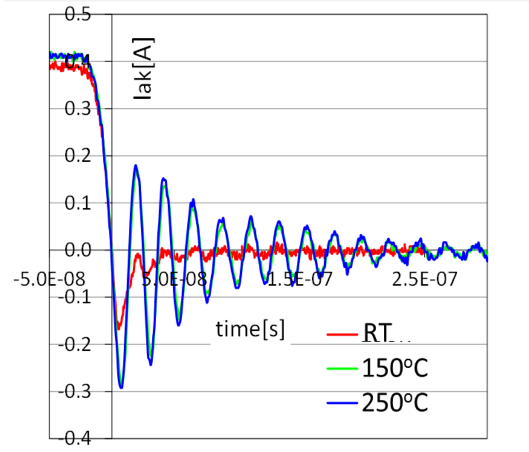

Fig. 4. Switching behavior of diamond VSBD characterized by double pulse

degradation of blocking voltage is clearly observed by increasing device area. It is known that the dislocations of more than 10^4/cm^2 exist in HPHT substrate and will be continued through the drift layer as a threading dislocation during the epitaxial growth. The decrease of density of dislocation, especially threading mixed dislocation, is the next task to improve device performances.

Figure 4 shows the typical turn-off characteristics of diamond VSBD with 1000μm electrode as a function temperature. The turn-off characteristics are measured by a double pulse method [5]. The reverse recovery time of the device is 15ns which is almost constant to the temperatures. We also confirmed that the reverse recovery time is constant to forward current injections. The calculated recovery charge using the time integral of the recovery current are 3.4 and 4.24nC at RT and 250°C, respectively.

4. Conclusions

Diamond vertical Schottky barrier diode with a doping controlled drift layer and a field-plate structure has been fabricated. 5A of forward current and 1 Ω of Ron are realized at 250°C with the large electrode of 1000 μm. However, the blocking voltage is limited to 290-320 V which is almost 40% of that of 30μm SBDs. The potential reason of suppressed blocking voltage is the incorporation of defect such as threading dislocations. The reverse recovery time of the 1000 μm diamond SBD is 15ns, which is constant to the temperatures and forward current injections.

5. Acknowledgement

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