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Leakage Current Analysis of Diamond SBDs Operated at High Temperature

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Abstract

A Schottky barrier diode (SBD) fabricated by using high-quality diamond shows a low reverse leakage current of less than 0.1 μA/cm^2 in a reverse electrical field of 1.5 MV/cm at room temperature. The leakage current of this diamond SBD is found to be low even at an elevated temperature of 142 °C. The leakage current of this diamond SBD is 2–4 orders of magnitude lower than that of a SiC SBD thanks to the higher barrier height. The leakage characteristics of the diamond SBD are described by the thermionic-field emission model, which well agrees with the experimental results.

1. Introduction

Diamond is a promising material for the fabrication of high-power semiconductor devices because of its wide bandgap, high breakdown field, and high bulk carrier mobility. Accordingly, the figures of merit (FOMs) of diamond for high-power applications, such as Baliga's or Huang's FOM, are extremely high [1,2]. The largest advantage of the diamond power device compare to other wide-gap semiconductors is the low-loss and fast switching operation at high temperature conditions [3,4]. However, the reverse leakage currents of the diamond SBDs at high temperature conditions are higher than the expected current modeled by thermionic emission phenomena. In this study, we have fabricated a diamond pseudo vertical SBD and analyzed high temperature leakage current by thermionic-field emission (TFE) model.

2. Experimental

The cross-sectional structure of the diamond pVSBD is shown in Fig. 1. This diamond SBD was fabricated on p–/p+ layers of homoepitaxially grown diamond by chemical vapor deposition (CVD). These layers were deposited on a high-pressure and high-temperature synthetic (HPHT) Ib (001) single-crystal diamond substrate by plasma assisted CVD. The acceptor concentrations on p+ and p- layers are controlled by changing the doping gas (trimethyl boron) during the growth.

Ohmic contacts were formed on the p+ layer by depositing Ti/Pt/Au and annealing the sample at 420°C. Mo Schottky electrodes with a diameter of 50 μm was patterned by lithography and lift-off techniques.

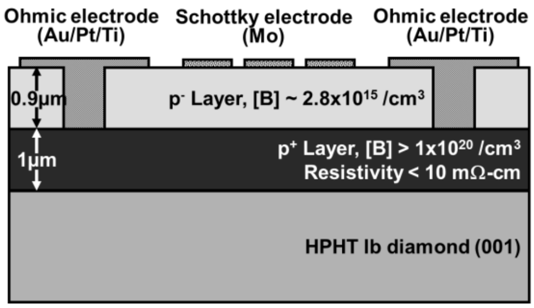

Fig 1. Schematic cross section of diamond

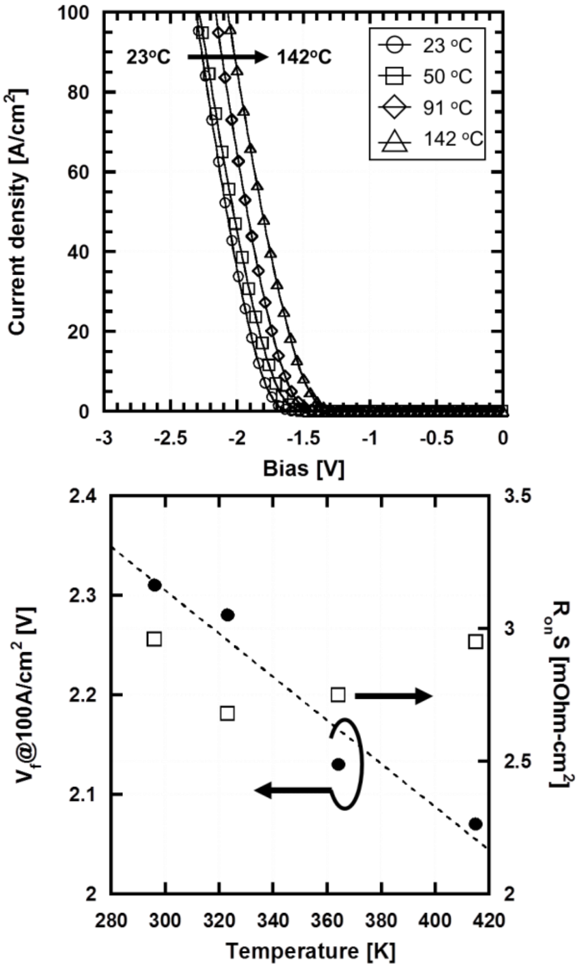

Fig 2. (a) Forward characteristics and (b) Vf and RonS of Mo/diamond pVSBD at various temperatures

4. Results and Discussion

The static forward I–V characteristics of the diamond pseudo-vertical SBD at various temperatures from 23 to 142 ^{o}C are shown in Fig. 2. The ideality factor of the SBD is found to be less than 1.1 at all these temperatures. The effective Schottky barrier height of the SBD is obtained to be 1.9 eV. In this temperature range, RonS is almost constant and is equal to 2.7–2.9 m Ω-cm^2, respectively. Ron remains constant irrespective of the changes in the temperature mainly due to the parasitic resistance on p+ layer.

Figure 2b shows the temperature dependence of forward voltage drop (Vf). Due to the high Vbn of the Mo/diamond interface, Vf is 2.31 V; however, Vf decreases with increasing temperature because of the enhancement of carrier transport through the barrier in the thermionic-emission (TE) mode. As a result, the forward characteristics of diamond SBD has a negative temperature coefficient (dVf/dT) equal to –2.17 mV/K.

Figure 3(a) shows the leakage current characteristics of the diamond SBD as a function of the reverse electrical field (E_R) at various temperatures. Here, E_R is estimated based on the one-dimensional geometry of uniform doping concentration and the thickness of the p– layer. The reverse leakage current density (J_L) is within the measurement limit when E_R is below 1.5 MV/cm at room temperature. Then, J_L starts increasing and reaches 10 μA/cm^2 (>10^8 rectification) at 2 MV/cm. Even at 142 ^{o}C, J_L is less than the measurement limit at E_R is 0.5MV/cm. This leakage current is 4 orders of magnitude lower than the leakage current of SiC SBDs [5]. When TFE is the dominant current transport mechanism through a single Schottky barrier, J_L is determined from the following equation [6]:

$$J_L = \frac{A^* T q \hbar E_{1D}}{k_B} \sqrt{\frac{\pi}{2 m k_B T}} \exp\left[-\frac{q}{k_B T} \left(V_{bn} - \sqrt{\frac{q E_{1D}}{4\pi\varepsilon_S}} - \frac{q(\hbar E_{1D})^2}{24 m (k_B T)^2} \right) \right] \qquad (1)$$

Based on an assumption that the Vbn is decreased to be 1.29eV due to the barrier lowering at reverse operation, the TFE model shows good agreement with the experimental results in the field range of 1.0–1.5 MV/cm.

The leakage currents of a SiC SBD (Vbn = 1.0 eV [5]) and the fabricated diamond pVSBD are compared in Fig. 3(b). The fitting on diamond pVSBD is carried out utilizing 1.29 eV of Vbn. The leakage current of the diamond pVSBD is 2–4 orders of magnitude lower than that of the SiC's, particularly in a low electric field. When the Vbn is kept 1.9eV at reverse condition, the TFE model indicates that the leakage current will be less than 1 μA/cm^2 at 250 ^{o}C and 2.5 MV/cm.

4. Conclusions

pVSBD on high quality diamond with high SBH of 1.9 eV and showing extremely low reverse leakage current of less than 10^{-7} A/cm^2 in a reverse electrical field of 1.5 MV/cm at room temperature. The leakage currents at an elevated temperatures are even low because of high Vbn. The leakage current of this diamond SBD is 2–4 orders of magnitude lower than that of SiC SBD's. The TFE model shows a good agreement with the leakage characteristics of the diamond SBD modeled by using Vbn equal to 1.29 eV as the fitting parameter.

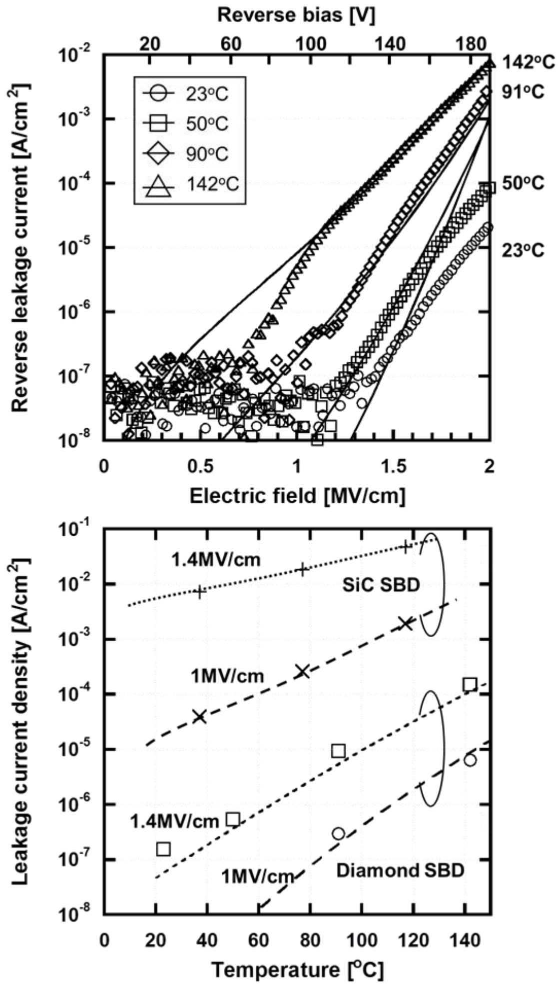

Fig 3. (a) Leakage current characteristics of diamond pVSBD at various temperatures. The solid line is obtained by the TFE model. (b) Comparison of leakage currents of SiC SBD [5] and diamond pVSBD.

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