PS-4-11
Extended Abstracts of the 2019 International Conference on Solid State Devices and Materials, Nagoya, 2019, pp743-744

Improved vertical Schottky barrier diodes characteristics by eliminating killer defects in heavily B-doped diamond substrates

Atsushi Kobayashi,[1,2] Shinya Ohmagari,[1*] Hitoshi Umezawa,[1] Daisuke Takeuchi,[1] and Takeyasu Saito[2]

*Corresponding author: shinya.ohmagari@aist.go.jp
[1]Advanced Power Electronics Research Center, National Institute of Advanced Industrial Science and Technology (AIST), 1-8-31 Midorigaoka, Ikeda, Osaka 563-8577, Japan
[2]Department of Chemical Engineering, Osaka Prefecture University, 1-1 Gakuen-cho, Naka-ku, Sakai, Osaka 599-8531 Japan

Abstract
It is desirable to reduce defects in semiconductor crystals as much as possible, as it may cause deterioration of various device characteristics. Diamond is expected as a next-generation ultra-low-loss power semiconductor, but it does not sufficiently meet the figure of merits (FOMs) which predicted from the physical constants. Recently, we demonstrated the large reduction of threading dislocation in diamond via CVD growth involving metal incorporations. The propagation of dislocations from substrate to epitaxial layer could be annihilated by the metal impurities. In this study, we grew metal-incorporated buffer layer to suppress the dislocation from heavily B-doped diamond substrates. Vertical Schottky barrier diodes (VSBDs) after insertion of buffer layer were prepared. The VSBDs showed highly uniform device performance with low leakage currents, indicating the proposed technique is effective way to suppress killer defects in SBDs.

1. Introduction
With the superlative physical properties of a high breakdown field exceeding 10 MV cm^{-1}, high carrier mobility, and high thermal conductivity, single-crystal diamond has attracted much attention as a material for next-generation low-loss power devices. High switching capabilities have been demonstrated for both unipolar and bipolar devices, Schottky rectifiers, p-i-n diodes, and field-effect transistors (FETs). To enhance the device performance further, vertical-channel utilizing low resistivity diamond substrates is required. Vertical architectures can withstand very high currents with large electrodes on the front and back sides of substrates. In addition, the potential distributions within vertical structures are more favorable than those in lateral architectures to support high voltages.

Threading dislocations are major defects in CVD-grown diamond, and they are generally taken over from a substrate to an epitaxial layer or even proliferated from its interface. The heavily B-doped, high-pressure high-temperature synthetic (type-IIb) diamond substrates contains high dislocation density.[1] The vertical-channel SBDs fabricated on type-IIb substrates typically induces large leakage currents which though to be originated from killer defects.[2,3] Suppression of these defects is a crucial issue to increase the device uniformity as well as achieving higher current capability. Recently, a technique to annihilate threading dislocations using metal impurity incorporations has been proposed, [4] –Metal-assisted termination (MAT). This technique is based on the CVD growth involving metal incorporation. The propagation of dislocations from substrate to epitaxial layer could be annihilated by the metal impurities. In this study, MAT buffer layer was homoepitaxially grown on heavily B-doped (type-IIb) diamond substrates. Vertical Schottky barrier diodes (VSBDs) were fabricated after MAT buffer layer insertion, and their impact of dislocation reduction was discussed.

2. Experimental
The schematic device structure is shown in Fig.1. We used heavily B-doped (type-IIb) substrates. The B concentration was approximately 10^{20} cm^{-3}. In order to mitigate the impact of dislocation, MAT buffer layer was prepared via CVD involving tungsten impurities. The typical concentration of tungsten was ~10^{18} cm^{-3}. The details of preparation procedure of MAT buffer layer was elucidated in Ref. 4. The p- drift layer (25 μm thick) lightly B-doped film was grown on the MAT buffer layer. Ti/Mo/Au contacts were deposited on the back of the p+ substrate as Ohmic electrodes. The Mo/Au Schottky electrodes with diameter of 100 μm were deposited on the p– drift layer. Current–voltage (I–V) characteristics were assessed at room temperature using a semiconductor parameter analyzer (Agilent Technologies, Inc., B1505A). Cathodoluminescence (CL) was performed to evaluate the quality of p– layer. The measurements was performed at 80K.

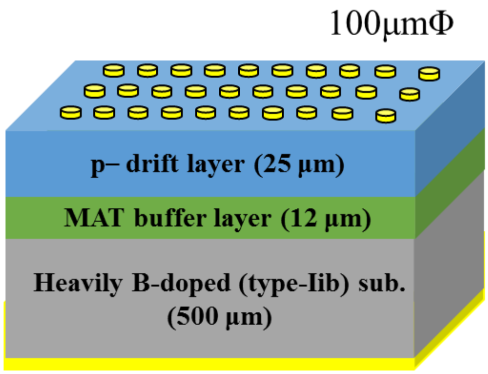

Figure 1. Vertical diamond Schottky barrier diodes (VSBDs) after insertion of the MAT buffer layer to suppress the dislocations from IIb substrate. The diameter of SBD electrodes was 100 μm.

3. Results and discussion

Figure 2 shows VSBDs characteristics after insertion of the MAT buffer. The VSBDs characteristics showed homogeneous properties with suppressed leakage currents. Ohmic-like leakage currents were not observed among all examined 135 diodes. The forward characteristics were analyzed using a thormionic emission model. The ideality factors and Schottky barrier heights were ranged between 1.1–1.3 and 1.5–1.7 eV.

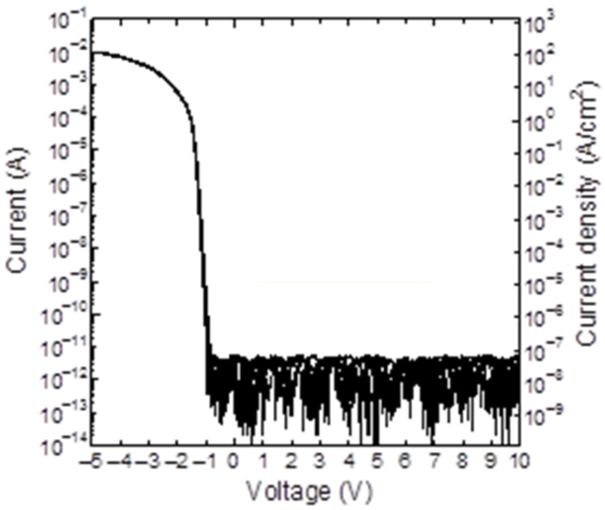

Figure 2. *I-V* characteristics of vertical p–type SBDs and shows the cumulative frequency of the Schottky barrier heights.

Figure 3 shows CL spectrum of VSBDs. The electron-beam was irradiated from p– drift layer surface. The spectrum exhibited strong peak due to free-exciton (FE) at 235 nm and their replica at 470 nm. Band-A luminescence (420 nm) due to dislocation in diamond was not observed at all in whole sample surface. A large reduction of dislocation from IIb substrate has demonstrated. The improved crystalline quality predominantly contribute to suppress the killer defects in VSBDs.

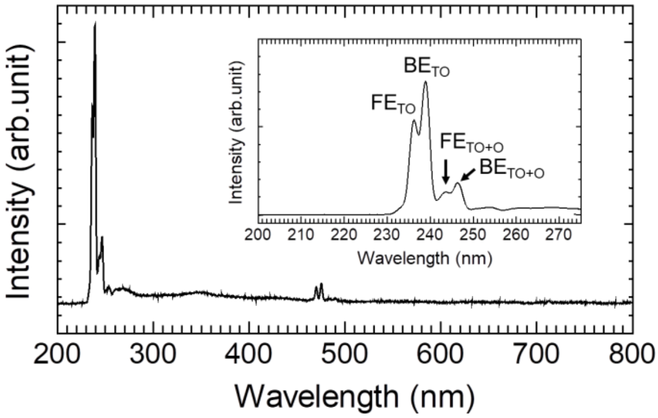

Figure 3. Cathodoluminescence spectrum of VSBD taken at 80K. The quality of p– drift layer was investigated.

4. Conclusion

Owing to the large reduction of dislocation from IIb substrate, vertical SBDs showed improved uniformity with suppressed leakage current. Cathodoluminescence spectra of drift layer showed strong peak from free-exciton only, indicating the improved crystallinity. The Band-A luminescence due to dislocation was not observed. This dislocation reduction technique using metal-assisted termination (MAT) will accelerate for the realization of high-power diamond power devices.

Acknowledgements

This study was supported in part by JSPS KAKENHI (Grant No.19K15295). The film preparation involving HFCVD was performed using an apparatus provided by the Kansai Bureau of Economy, Trade, and Industry. The film characterization and device processing were partly supported by Osaka University and Kyoto University,respectively, through a “Nanotechnology Platform Project” from the Ministry of Education, Culture, Sports, Science, and Technology (MEXT), Japan. We thank all staff members in our laboratory for their technical support in the fabrication and characterization of the diamond films.

5. References

1. K. Srimongkon *et al.*, Diam. Relat. Mater. **63**, 21 (2016).
2. S. Ohmagari *et al.*, J. Appl. Phys. **110**, 056105 (2010).
3. T. Shimaoka *et al.*, Phys. Stat. Solid. A **214**, 1700180 (2017).
4. S. Ohmagari *et al.*, Appl. Phys. Lett. **113**, 032108 (2018).