Extended Abstracts of the 2019 International Conference on Solid State Devices and Materials, Nagoya, 2019, pp745-746

Diamond Schottky barrier diodes on half-inch single-crystal wafers fabricated by Minimal Fab System

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Abstract

Diamond is a promising material for future high power devices due to high breakdown field, low dielectric constant and high carrier mobility, respectively. One of the important challenging for industrial implementation of diamond electronics is realization of large-scale wafers for device integration. Recently, a novel concept for fabricating microelectronics via Minimal Fab System has proposed. This system employs 0.5-inch wafers without cleanroom facilities. In this study, diamond Schottky barrier diodes (SBDs) were fabricated by Minimal Fab System using half-inch single-crystal diamond wafers. The SBDs showed the clear rectifying action with low leakage currents and high uniformity.

1. Introduction

Power electronics based on low-loss semiconductor devices is the key technology expected to play a leading role in the world from the view point of efficient use of energy. Diamond is considered to be the best candidate material for power semiconductor devices due to its excellent material properties such as high breakdown field (>10 MV/cm), high mobility (4500 and 3800 cm^2 /Vs for electrons and holes, respectively), low dielectric constant (5.7) and the highest thermal conductivity in the materials. However, one of the big challenging for industrial implementation of diamond electronics is realization of large-scale wafers. At present, research on enlarging of diamond wafers has been progressed worldwide. The large diameter diamond substrates up to 2 in and 3.5 in have demonstrated for mosaic [1] and heteroepitaxy [2] technique. The advanced photolithography processes for device manufacturing requires at least 4-6 in wafers or above.

Recently, a novel concept for fabricating microelectronics via Minimal Fab System has proposed [3]. This system employs 0.5-inch wafers without the requirement of cleanroom facilities. The high-performance complementary metal-oxide-semiconductor (CMOS) transistors has been demonstrated.

The purpose of this study is to investigate the device uniformity using 0.5-inch diamond wafers. The p+/p– stack structure was fabricated via standard chemical vapor deposition (CVD) growth process, and pseudo-vertical Schottky barrier diodes (pVSBDs) were fabricated by Minimal Fab System. The device characteristics and in-plane uniformity of wafers were statistically evaluated.

2. Experimental

CVD-grown, nitrogen-doped, semi-insulative diamond mosaic wafers (001) with 0.5-inch diameter were derived from EDP corporation. The substrate surface was mechanically polished for epi-ready smoothness. Then, heavily boron-doped (p+) film was homoepitaxially grown as a contact layer. The lightly boron-doped (p-) film was grown on the top surface. The typical B concentration of p+ and p– layers were $10^{20}/cm^3$ and $10^{16}/cm^3$, respectively. The details of film preparation were explained in Ref. [4].

The pVSBDs were fabricated via Minimal Fab System. Firstly, p- drift layer was partially removed by dry etching to expose the p+ contact layer. Then, SiO_2 (500 nm) passivation layer was deposited as a field-plate to mitigate the electrical concentration. Finally, Al (500 nm) electrode patterns were fabricated via photolithography process. The Al electrodes deposited on p- and p+ surface act as Schottky and Ohmic contacts, respectively. The schematic device structure was displayed in Fig. 1. The current-voltage (I-V) characteristics were evaluated by Semiconductor parameter analyzer (Keysight Technologies B1505A).

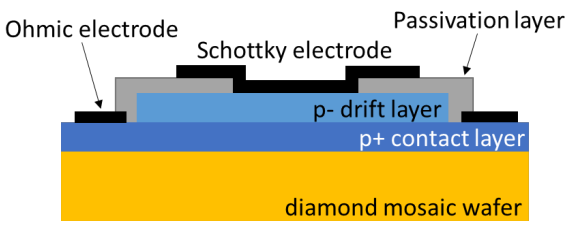

Figure 1. Cross-sectional schematic device structure of pseudo-vertical Schottky barrier diodes fabricated on diamond mosaic wafers.

3. Results and discussion

Figure 2 shows the photograph of pVSBDs fabricated on 0.5-inch diamond mosaic wafer. We have fabricated different shape of Schottky barrier electrodes with diameter ranging from 25 and 700 μm. The in-plane uniformity of diamond substrates were evaluated.

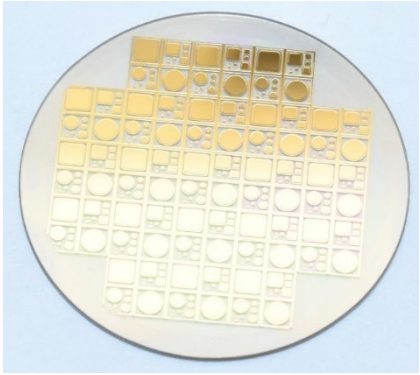

Figure 2. Photograph of pVSBDs fabricated on diamond 0.5-inch mosaic wafers via Minimal Fab System.

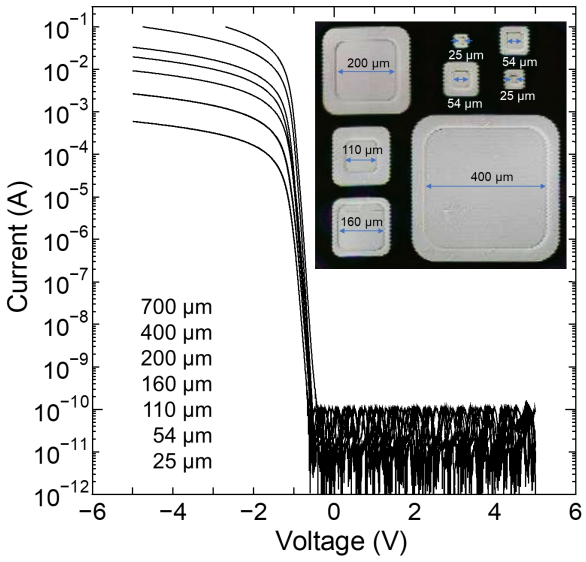

Figure 3. Typical I-V characteristics of diamond pVSBDs with different electrode size.

Figure 3 shows the I-V characteristics of pVSBDs. The clear rectifying actions were obtained. The examined pVSBDs showed low leakage current which is below the detection limit of analyzer, even larger electrodes. The saturation forward current was enhanced with increasing electrode size of SBD. The forward current density J is explained well using a thermionic emission (TE) model,

$$J = J_s\left\{\exp\left(\frac{q(V-R\cdot J)}{nk_BT}\right)-1\right\}$$
$$J_s = A^*T^2\exp\left(-\frac{qV_{bn}}{k_BT}\right).$$

Here, Js, Rs, n, A^*, and qV_{bn} are the saturation current density, series resistance, ideality factor, Richardson constant (= 90 A/cm^2 K^2 for diamond) and Schottky barrier height, respectively. The measured I–V characteristics are in good agreement with the TE model.

4. Conclusions

To evaluate the in-plane uniformity of 0.5-inch diamond mosaic wafers, pVSBDs were fabricated by Minimal Fab System. The pVSBDs showed the clear rectifying action, low leakage current, regardless of the larger electrode pad.

Acknowledgements

This paper includes some results obtained in the project "Development of diamond electric devices for nuclear power reactors withstanding a severe accident" under the auspices of the Ministry of Education, Culture, Sports, Science, and Technology of Japan. The authors also would like to thank Dr. S. Hara, Dr. S. Khumpuang, and Dr. K. Nemoto for all the help for using the Minimal Fab Systems.

References

[1] H. Yamada, A. Chayahara, Y. Mokuno, Y. Kato, S. Shikata, A 2-in. mosaic wafer made of a single-crystal diamond, Appl. Phys. Lett. 104 (2014) 102110. doi:10.1063/1.4868720.

[2] M. Schreck, S. Gsell, R. Brescia, M. Fischer, Ion bombardment induced buried lateral growth: the key mechanism for the synthesis of single crystal diamond wafers, Sci. Rep. 7 (2017) 44462. doi:10.1038/srep44462.

[3] S. Khumpuang, H. Maekawa, S. Hara, Photolithography for Minimal Fab System, IEEJ Trans. Sensors Micromachines. 133 (2013) 272–277. doi:10.1541/ieejsmas.133.272.

[4] S. Ohmagari, H. Yamada, H. Umezawa, N. Tsubouchi, A. Chayahara, A. Seki, H. Saitoh, Y. Mokuno, Diamond pseudo-vertical Schottky barrier diodes fabricated on mosaic wafers Diamond wafers for ultimate electronics, (n.d.) 1–13.