Diamond Power Devices Research and development on normally-off type diamond power switching devices

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Diamond is one of the promising materials for next generation semiconductor devices because of its superior material characteristics such as high breakdown field, high carrier mobility/saturation velocity, highest thermal conductivity and low dielectric constant. Thanks to these unique properties, extremely high output power with low loss devices operated at high temperature environment are expected on diamond. In this decade, diamond semiconductor devices such as high voltage or high current diodes and switching devices have been reported and showing superior device characteristics. However, the output power of the reported devices are still limited less than 1kW.

In this project, two research topics have been carried out to realize commercially available high power diamond devices. The first topic is to clarify the reasons of poor electrical field strength of the experimentally fabricated diamond device. Using electron beam induced current (EBIC), we have clarified that the hot spots, present in the laterally expanded depletion layer where the high electric field crowds, initiate inevitable breakdown (Fig. 1).

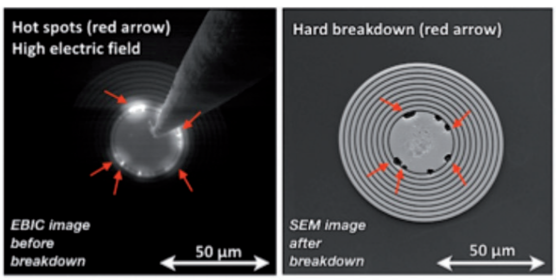

Fig. 1: High electric field regions (bright spots) viewed by EBIC before device breakdown and corresponding damaged regions after device breakdown.

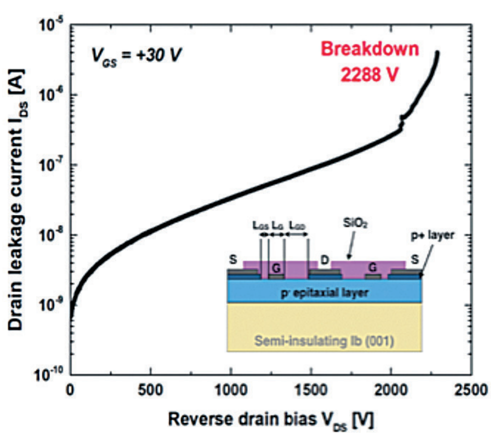

Fig. 2: Breakdown behaviour of diamond MESFET. Breakdown voltage > 2.2 kV has been realized.

The second topic is to fabricate high voltage diamond devices. By extending the gate-drain distance in diamond metal-semiconductor field-effect transistor (MESFET) to 50 µm, a breakdown voltage over 2.2kV has been realized (Fig. 2). This value is the best one in diamond switching devices to date. Reverse blocking MESFETs which are required for next generation matrix converter systems have been also realized for the first time. Schottky drain instead of Ohmic contact was used to resist high reverse voltage up to 3kV

OUTCOMES

[1] Characterization of breakdown behavior of diamond Schottky barrier diodes using impact ionization coefficients, Jpn. J. Appl. Phys. 56, 04CR12 (2017).

[2] Defect and field-enhancement characterization through electron-beam-induced current analysis, Appl. Phys. Lett. 110, 182103 (2017).

[3] Electric field distribution using floating metal guard rings edge-termination for Schottky diodes, Diam. Relat. Mater. 82, 160 (2018).

[4] Recent advances in diamond power semiconductor devices, Mater. Sci. Semicond. Process. 78, 147 (2018).

[5] Electric field characterization of diamond metal semiconductor field effect transistors using electron beam induced current, Mat. Sci. Forum 2018 (Accepted).

Book

"Power Electronics Device Applications of Diamond Semiconductors", Ed. by S. Koizumi, H. Umezawa, J. Pernot, M. Suzuki, Elsevier 2018.

Oral presentations: H. Umezawa, SBDD XX, Hasselt, Belgium 2015 (invited). H. Umezawa, ICDCM Xi'an, China 2016 (invited). H. Umezawa, 2016 MRS Spring, Arizona, USA 2016 (invited). H. Umezawa, ICDCM Gothenburg, Sweden 2017 (invited). K. Driche, H. Umezawa, F. Donatini, J. Pernot, D. Eon, E. Gheeraert, SBDD XXII Hasselt, Belgium 2017. K. Driche, S. Rugen, N. Kaminski, H. Umezawa, E. Gheeraert, ICDCM Gothenburg, Sweden 2017.

Collaboration

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Leverage

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An agreement is in discussion to continue the collaboration.