Extended Abstracts of the 2015 International Conference on Solid State Devices and Materials, Sapporo, 2015, pp1074-1075

1.7 kV Breakdown C-H Diamond MOSFETs with high drain current density

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Abstract

Diamond has high physical properties. It's expected to be the next generation power device material. We fabricated hydrogen-terminated (C-H) diamond MOSFETs using Al_2O_3 insulator by high temperature ALD method. C-H MOSFETs showed over breakdown voltage of 1.6 kV at room temperature and 1.5 kV at 200℃. In addition, the highest breakdown voltage of 1.7 kV and high current density (over 190 mA/mm) has been obtained with thicker Al_2O_3 (400nm) on channel and drift region.

1. Introduction

Wide band gap semiconductor, SiC, GaN and Diamond, are expected to next generation power device applications. Especially, diamond has wide band gap energy (5.5 eV), high thermal conductivity (20 W/cm・K) and high breakdown field (10 MV/cm). It's important for power MOSFETs to rise breakdown voltage. We fabricated MOSFETs using the hole accumulation layer (2DHG) induced by coating the hydrogen-terminated (C-H) diamond surface with Al_2O_3 insulator by high temperature ALD method [1,2]. We have reported 1000 V breakdown voltage characteristics and 10 K~673 K operations [3].

In this paper, we obtained high breakdown voltages by changing gate-drain length. In addition, high breakdown voltage and high current density were obtained by thicker oxide (400nm) structure on channel and drift (C-D) region.

2. 2DHG Implementation in C-H Diamond MOSFET

Fig.1 shows schematical image of C-H diamond MOSFETs with field plate structure. C-H diamond MOSFETs was prepared in the following method. First, undoped layer was deposited on 1b (001) diamond substrate by chemical vapor deposition (CVD) and Ti/Au (30 nm/100 nm) were deposited as source and drain electrode. Second, the diamond surface was hydrogen-terminated by remote plasma and isolation by O-terminated. Third, Al_2O_3 film as insulator and passivation were deposited by high-temperature ALD method (Oxidation; H_2O, Temperature; 450℃)[1,2]. Fourth, Al_2O_3 on the channel region etched by NMD-3 to make thicker oxide structure and the second Al_2O_3 film was deposited. Finally, Al was deposited as gate electrode.

3. Result and discussion

3.1 200nm Al_2O_3 on channel-drift region

The maximum breakdown voltages at each gate-drain length (L_{GD}) with 200nm Al_2O_3 are summarized (Fig.2). Nearly 1 kV breakdown voltage V_B is achieved at L_{GD} of 9 μm and the average electric field strength (V_B/L_{GD}) is along 1 MV/cm [4]. The highest breakdown voltage of 1646 V was obtained at L_{GD} of 22 μm. However, V_B/L_{GD} decreased to 0.75 MV/cm. Moreover the average electric field strength reaches 3.7 MV/cm at L_{GD} of 1 μm. It's over SiC and GaN properties limit.

Higher temperature off stage shows similar high breakdown voltage as that of room temperature from the I_{DS}-V_{DS} characteristics at 200℃ (Fig.3). It exceeds the maximum breakdown voltage of diamond FETs at room temperature [5]. The maximum current drain density was 82.0 mA/mm is also as high. Low off current (10^{-11} ~ 10^{-6} A) was maintained even at 200℃ until breakdown.

3.2 400nm Al_2O_3 on channel-drift region

Thicker oxide structure with 400nm Al_2O_3 layer has been introduced in the present C-H diamond MOSFET. Off states I_{DS}-V_{DS} characteristics shows the highest V_B of diamond FET (Fig.4). V_{GS} step (ΔV_{GS}) was 4 V. The length of device were L_{GD} = 16 μm and L_G = 11 μm respectively. 1708 V was the highest breakdown voltage of diamond FETs ever reported. The V_B/L_{GD} increased to 1.05 MV/cm. The maximum current drain density was 97.2 mA/mm (V_{DS} = -50 V) by I_{DS}-V_{DS} characteristics.

High breakdown voltage and high current density is a trade off in general. The highest current density near 200 mA/mm obtained. Fig.5 shows high current density 187.2 mA/mm (V_{GS} = -50 V) characteristics. The length of device were L_{GD} = 16μm, L_G = 11 μm. It exceeds to that of boron doped diamond channel by 2 orders of magnitude and become equivalent to that of AlGaN/GaN at similar L_{GD} of Breakdown voltage.

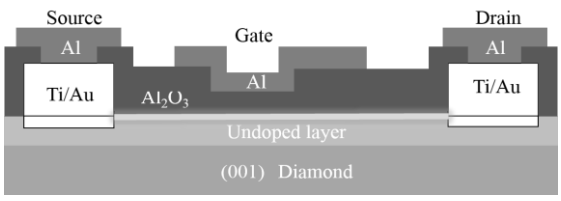

Fig.1 Image of C-H diamond MOSFETs structure

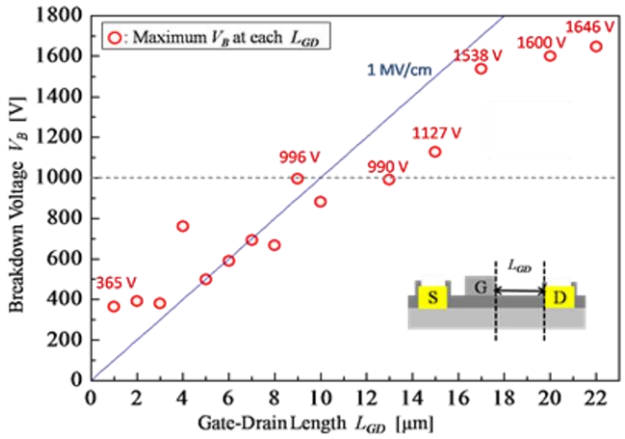

Fig.2 Breakdown voltages at each L_{GD} with 200nm Al_2O_3

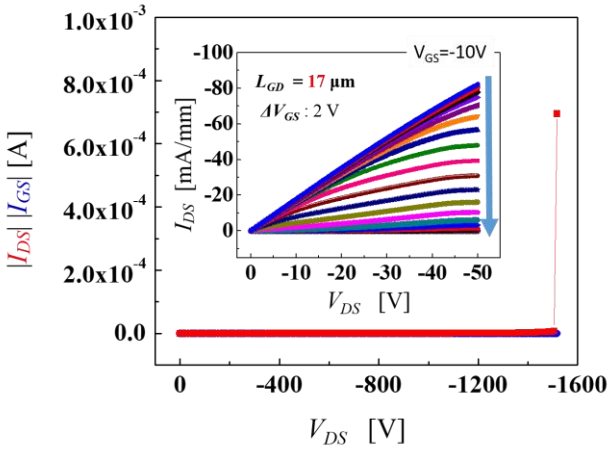

Fig.3 I_{DS}-V_{GS} and I_{DS}-V_{DS} characteristics of 200℃ operation

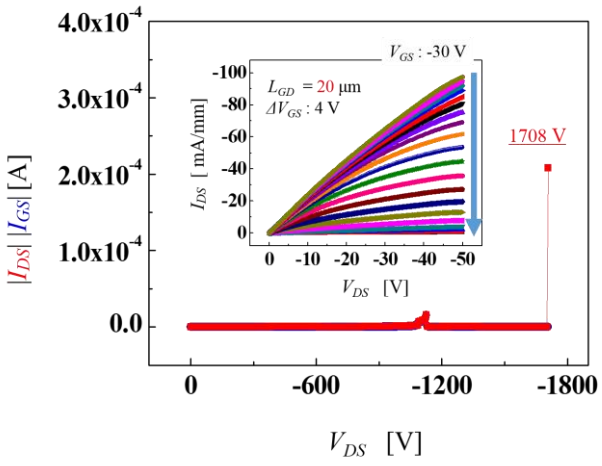

Fig.4 I_{DS}-V_{GS} and I_{DS}-V_{DS} characteristics of high breakdown voltage device with thicker Al_2O_3 (400nm) structure

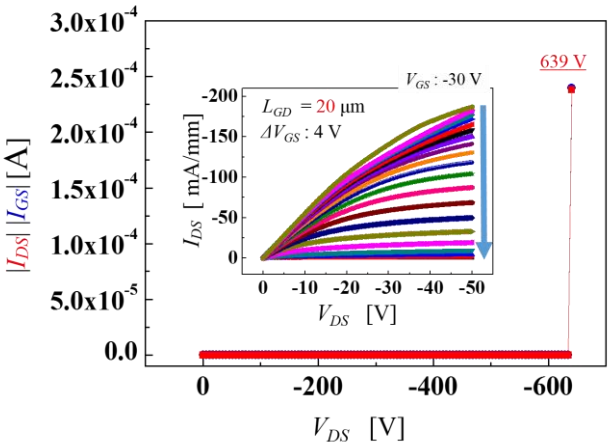

Fig.5 I_{DS}-V_{GS} and I_{DS}-V_{DS} characteristics of high current density device with thicker Al_2O_3 (400nm) structure

3. Conclusions

C-H diamond MOSFETs with Al_2O_3 reaches 1.6 kV (@RT) and 1.5 kV (@200℃) breakdown voltage. The maximum average electric field strength reaches 3.7 MV/cm without field plate structure. Over 1.7 kV breakdown voltage and high current density 190 mA/mm was obtained with thicker Al_2O_3 (400nm).

Acknowledgements

This study was supported by research grants from Advanced Low Carbon Technology (ALCA) of JST and Gran in Aid for Fundamental Research S of JSPS.

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