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Vertical-Type 2DHG Diamond MOSFETs with a Few Micro Meter Length Trench Structure

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Abstract
We fabricated vertical-type 2-Dimentional Hole Gas (2DHG) Diamond Metal-Oxide-Semiconductor Field Effect Transistors (MOSFETs) with 2 or 4 μm trench opening length. By miniaturizing the device structure, we obtained high current density and confirmed the reduction of on-resistance.

1, Introduction
Vertical-type devices have advantages for integration and miniaturization for lateral-type devices. We fabricated 2DHG Diamond MOSFETs using 2DHG for channel. By using Al_2O_3 formed by the high temperature Atomic Layer Deposition (ALD) method as a gate insulator and passivation film [1], the 2DHG Diamond MOSFET are able to perform stable operation in a wide temperature range (10~673K) [2] and have high breakdown-characteristics (~2000 V) [3][4]. 2DHG is induced by unoccupied site of Al_2O_3 near the interface, where diamond surface has been hydrogenated [5][6], so it is also possible to fabricate a vertical-type 2DHG Diamond MOSFET with drift region on trench side walls [7]. We reported high current density and drain current on/off ratio in vertical-type 2DHG Diamond MOSFET comparable to lateral-type devices [8]. In this work, we miniaturized vertical-type 2DHG Diamond MOSFET with trench opening length (L_T) of 2 or 4 μm. We aimed at the improvement of current voltage characteristics by miniaturization of devices.

2, Results
The cross-sectional view of vertical-type 2DHG Diamond MOSFET is shown in Fig.1. The undoped layer and nitrogen doped layer are epitaxially grown on the p+ diamond substrate by Microwave Plasma Chemical Vapor Deposition (MPCVD) method. The nitrogen doped layer has a function as a block layer suppressing leakage current in the vertical direction. The total thickness (undoped layer and N doped layer) is 2 μm and the nitrogen concentration is changed stepwise from 2.0×10^{18} to 8.0×10^{18} cm^{-3} in order to assuage the electric field overconcentration. The trench is formed on the surface of the diamond by the Inductive Coupled Plasma Reactive Ion Etching (ICP-RIE). The trench opening length is 2 or 4 μm and the depth (D_T) is 4 μm. After the trench formation, the undoed layer (200 nm) is epitaxially grown again to recover the etching damages and to induce the 2DHG. Ti and Au are deposited as source electrodes on the surface and as a drain electrode on the back side. Al_2O_3 is deposited as a gate insulator and passivation film by high temperature ALD method. Finally, Al is deposited on the Al_2O_3 as gate electrodes.

The length between source and source electrodes (L_{SS}) is 10 ~ 16 μm and the width of the channel area (W_G) is 25 μm. These device sizes are 1/3~1/2 smaller than those of conventional devices [8]. Fig.2 (a) shows the I_{DS}-V_{DS} characteristics of a device with 2 μm trench opening length and Fig.2 (b) shows that with 4 μm trench opening length. From Fig.2, the maximum current density of both devices is about −200 ~ −250 mA/mm at V_{DS} = −50 V and V_{GS} = −20 V. Both devices operate as p-channel FETs, where the current is suppressed by the positive gate voltage. Fig.3 shows the normalized current density in the active area, which is defined by the product of L_{SS} and W_G. The maximum current density is −2400 A/cm^2 at the active area of 4.0×10^{-6} cm^2. It is the highest current density in vertical-type diamond FETs. From this characteristic, on-resistance is calculated to be 20.8 mΩcm^2, and we confirmed the improvement of current voltage characteristics by relatively small trench opening length. Fig.4 shows the I_{DS}-V_{GS} characteristics in the range of RT ~ 573 K. The on/off ratio is 10^8 in RT ~ 423 K and 10^6 in 473 ~

573 K. In the region of 473 ~ 573 K, the on/off ratio has been improved compared to that of conventional devices [8].

3, Conclusion

We fabricated the vertical-type 2DHG Diamond MOSFET in a few micro meter trench opening length. By the miniaturization of the device, the current density and on/off ratio characteristics has been improved.

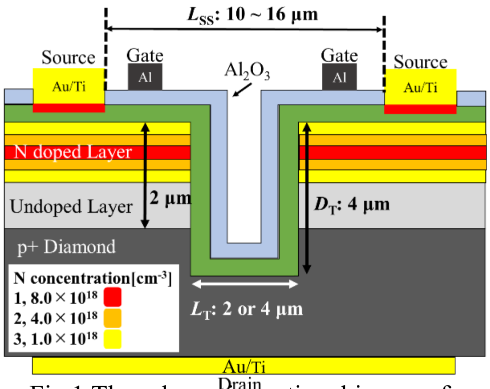

Fig.1 The schematic sectional image of Vertical-type 2DHG Diamond MOSFET

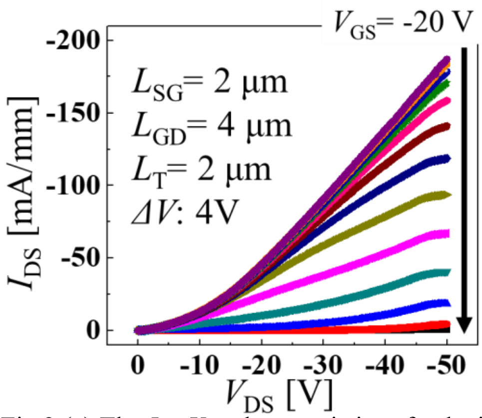

Fig.2 (a) The I_{DS}-V_{DS} characteristics of a device with 2 um trench length

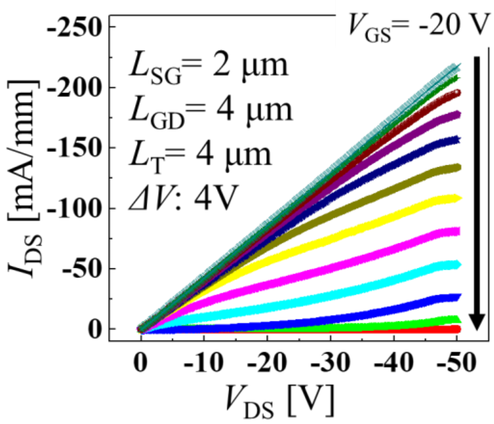

Fig.2 (b) The I_{DS}-V_{DS} characteristics of a device with 4 um trench length

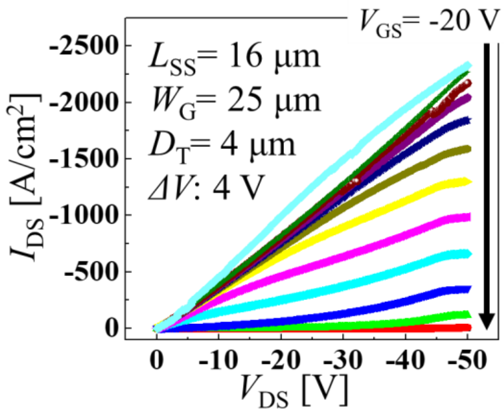

Fig.3 The I_{DS}-V_{DS} characteristics with normalized in the active area

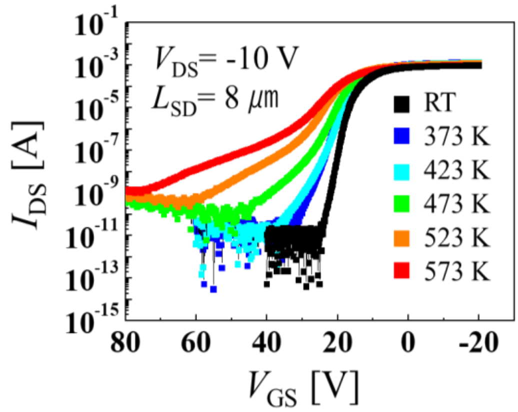

Fig.4 The temperature characteristics of the device.

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