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Trench-channel MOSFET using C-H Diamond Surface

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Abstract

Hydrogen-terminated diamond metal –oxide-semiconductor field-effect transistors (C-H diamond MOSFETs) with trench channels were fabricated. The trench structure was formed by inductive coupled plasma etching. The side walls of the trenches can be used for p-channel. This result indicates that, in principal, a vertical diamond MOSFET with trench gate and bottom drain is feasible for power device application.

1. Introduction

Recently, large current durable semiconductor devices made of silicon carbide, gallium nitride, or diamond were eagerly studied. Power devices made of diamond have remarkable potentials based on the highest breakdown field and thermal conductivity. We have reported high-blocking voltage planar diamond MOSFETs. [1-3] The surface of channels in our devices are covered with C-H bonds. A thick Al_2O_3 passivation film was used as gate insulator inducing the additional conduction layer beneath the diamond surface. The planar FETs have well controlled the source-drain current, but have the difficulty in improving the current density normalized by the device lateral area including large drift region. To obtain the higher current density, it is inevitable to form vertical-shaped devices to avoid large drift area. In this study, we fabricated the test structure for the vertical diamond power FET by forming the trenches in the source-drain channels to estimate the conduction of C-H diamond sidewall.

2. Ubiquitous 2DHG

In this study, for the evaluation of 2DHG in the three-dimensional structure, we created a trench structure at the channel of MOSFET (Fig.1). The MOSFETs built on C-H diamond surface by using atomic layer deposition (ALD), as a passivation layer and a gate insulator sheet, which produce and control two-dimensional hole gas (2DHG),. GaN-HEMT is known as FET applying two-dimensional electron gas (2DEG) on its interface. In case of vertical structure, however, 2DEG is not formed on the sidewall of GaN because the 2DEG appears on a special surface having spontaneous and piezo polarization. In this point, the 2DHG on C-H diamond covered by Al_2O_3 can be formed on the sidewall easily regardless of crystal surface (Fig.2) That is why diamond trench-channel vertical MOSFET with 2DHG is freer to design than AlGaN/GaN devices.

3. Fabrication of trench channel MOSFET

At first, a mono-crystalline diamond is etched to form a trench by using inductively coupled plasma ion etching (ICP-RIE) (Fig.3) and regrew the un-doped layer by CVD to form 2DHG on the sidewall of trench (Fig.4) The un-doped layer must be re-grown after trench structure is fabricated by plasma etching to get damage free side wall conduction.. We covered inside the trench such as Fig.4. (Fig.3 is just after plasma-etched and before the un-doped layer is regrown.)

Ti/Au were put as a source and a drain electrode, Al as a gate and Al_2O_3 used ALD as a gate insulator sheet. The obtained trench shaped FET exhibit satisfactory results from the point of pinch-off and saturation behavior (Fig.5). They suggest that 2DHG at side wall is available as a FET channel with trench gate

We also have fabricated a vertical-shaped diamond MOSFET (Fig.6). The process is almost same to that of trench channel FET as shown above. At first, the un-doped layer is grown about 2 um on P+ diamond substrate (single crystalline diamond doped with boron concentration of $1x10^{19}cm^{-3}$). This substrate has high p-type conductivity so that the hole current is able to run through the substrate. Second, the homo epitaxial layer was etched to the bottom to form a trench. The rest of the process is similar to that of planar trench device. Finally, drain electrode is put at the bottom of the substrate. The hole current run from the source electrode and is controlled by the trench gate on the sidewall and inside the P+ substrate.

Acknowledgement

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References

References

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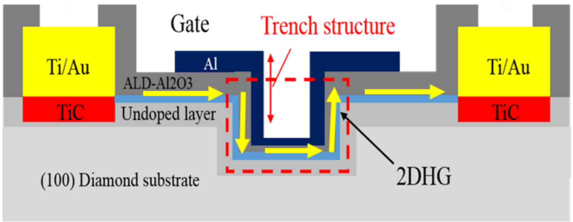

Fig.1 Trench channel C-H diamond MOSFET with Al_2O_3 oxid

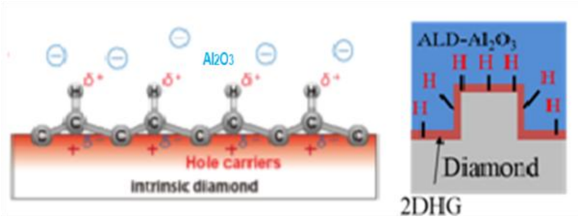

Fig.2 Images of ubiquitous 2DHG

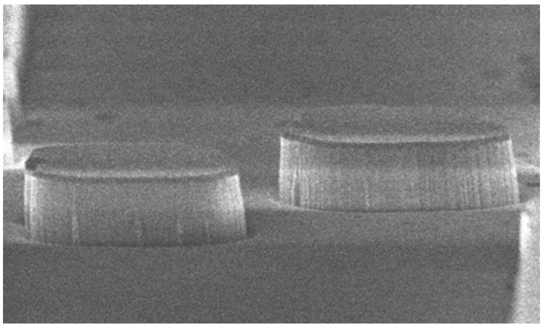

Fig.3 The inside of a trench before the un-doped layer is re-grown (taken by SEM)

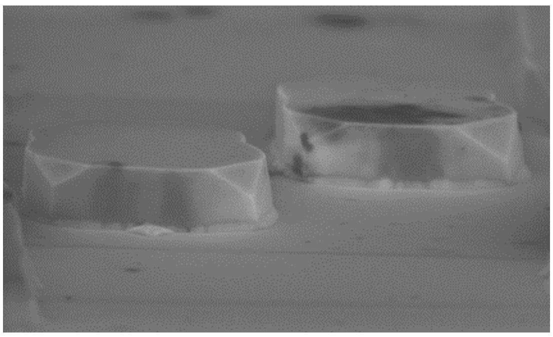

Fig.4 The inside of a trench after un-doped layer is re-grown (taken by SEM)

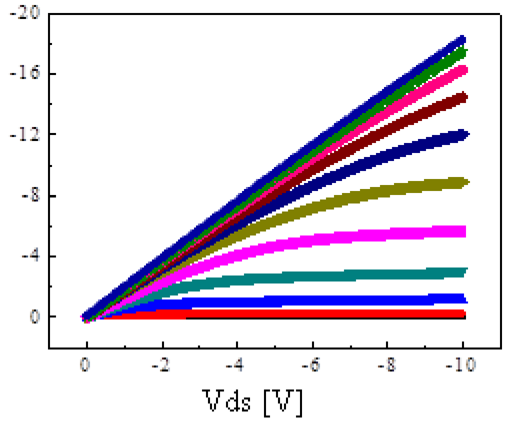

Fig.4 I_{DS}-V_{DS} characteristics of trench-channel diamond MOSFET

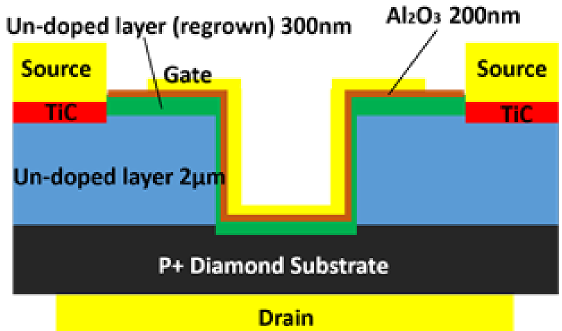

Fig.5. Vertical-shaped MOSFET with Al_2O_3 oxide