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Characteristic Analysis of Normally-off Al_2O_3/H-diamond MOSFET with 40-μm Gate Length

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Abstract

A normally-off Al_2O_3/H-diamond metal-oxide-semiconductor field effect transistor (MOSFET) with a gate length of 40 μm was characterized. The device metrics include a threshold voltage of -1.42 V, a maximum drain current of -2.2mA/mm, a peak transconductance of 1.78 mS/mm and a maximum capacitance of 3.9 μF/cm^2. On the basis of C-V characteristics, a quirt high density of the positive fixed charge present in the Al_2O_3 layer (5.48×10^{12}cm^{-2}) and interface traps of 9×10^{11} cm^{-2} at Al_2O_3/H-diamond interface have been calculated. An empirical formulation expressed the dependence of effective mobility on the gate voltage are proposed.

1. Introduction

Hydrogen-terminated diamond (H-diamond) field effect transistor (FET) with holes accumulate spontaneously on the diamond surface is the mainstream structure for diamond devices. To date, a 200 nm-gate diamond FET with a maximum drain current (I_{DS}) of -1 A/mm and an RF output power density of 2 W/mm [1] has been reported and more normally-on devices continue to be explored and optimized.

The normally-on diamond devices have already achieved a great process. In comparison, normally-off devices need more attention to realize the advantages of higher security and lower power. Yuya Kitabayashi et al. exhibited normally-off operation of a partial C-O channel C-H diamond MOSFETs with ALD-Al_2O_3 as gate dielectric. [2] J. W. Liu et al. realized normally-off $LaAlO_3$/Al_2O_3/H-diamond MOSFET by annealing the sample at 180 ℃ for 10 min. [3] Inspired by all these facts, we fabricated a partial C-O channel Al_2O_3/H-diamond MOSFET with 3 nm Al_2O_3 dielectric layer formed by thermal oxidation of Al at 100 ℃. In this letter, we repot the current-voltage (I-V) and capacitance-voltage (C-V) characteristics of the 40-um device. The fixed charge and interface traps in MOSFET are analyzed and the μ_{eff} affected by drain and gate voltage are exhibited.

2. General Instructions

Experiment

The material used for our study is (001)-oriented single-crystal of irregular polygon, which grown by a microwave plasma-enhanced chemical vapor deposition (MPCVD) method on the Ib-type substrate ourselves. The surface of the sample was exposed to the hydrogen plasma at 890 ℃ for 20 min to obtain hydrogen terminated diamond. A 100-nm-thick gold layer was deposited by electron beam evaporation (e-beam) on the H-diamond surface to protect the surface during the following process and to provide source and drain ohmic contacts. Then we realized isolation process by exposing a portion of diamond surface to oxygen plasma after photolithography and wet etching used KI solution. The source and drain electrodes was obtained simultaneously when gate window was etched, and a partial C-O channel was formed at gate window by 3-min UV ozone treatment. E-beam technique was used to deposit 3nm Al on sample followed by oxidation in air at 100 ℃ for 8 min to form Al_2O_3 dielectric layer. Finally, a 100-nm-think aluminum were sequentially deposited by e-beam and lifted off to achieve gates of the devices. The gate length (L_G) and width (W_G) are 40 and 50 μm, respectively. The schematic cross-section view of the device structure is shown as the inset of Fig.1.

DC operation

The output characteristics for the Al_2O_3/H-diamond device with large gate length of 40μm are shown in Fig.1. A I_{Dmax} of -2.2 mA/mm are obtained at V_{GS} = -3.5 V. The drain current (I_{DS}) as well as the corresponding transconductance (G_m) versus V_{GS} are shown in Fig.2. A threshold voltage of -1.42 V and a maximum G_m of 1.78 mS/mm are achieved.

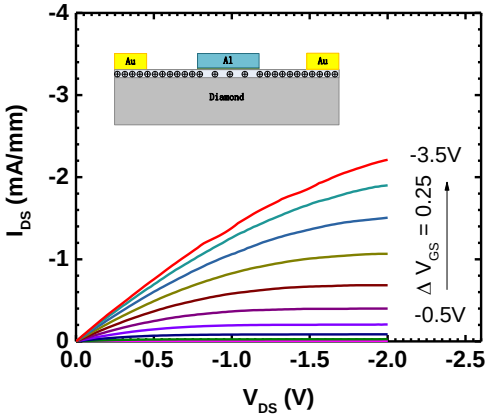

Fig.1 output characteristics and (inset) device structure of the 40-um normally-off H-diamond FET with Al_2O_3 gate dielectric.

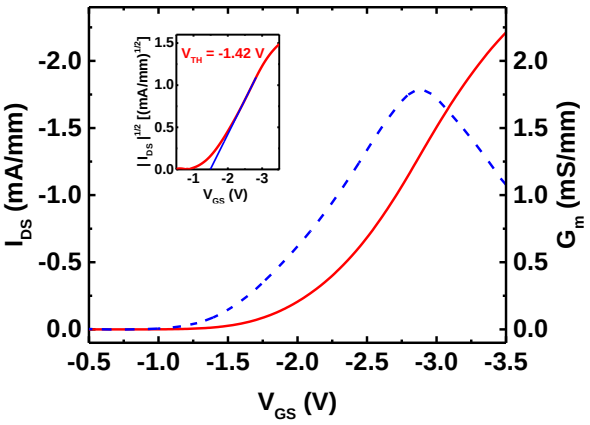

Fig.2 Transfer characteristics of the H-diamond FET.

C-V Characteristics

Figure 3 shows C-V characteristics measured at the frequency of 1MHz for the Al_2O_3/H-diamond MOS structure with gate voltage scanning from positive to negative and then back to positive. The maximum capacitance of 0.39 μF/cm2 is comparable to the value (0.361 μF/cm2) of the large gate length MoO_3/H-diamond MOSFET. [4] The fixed charge value is 5.48×10^{12} cm^{-2} calculated by $C_{OX}(V_{FB2}-V_{FB0})/e$. The summed density of interface traps is 1.12×10^{12} cm^{-2} calculated by $C_{OX}(V_{FB2}-V_{FB1})/e$.

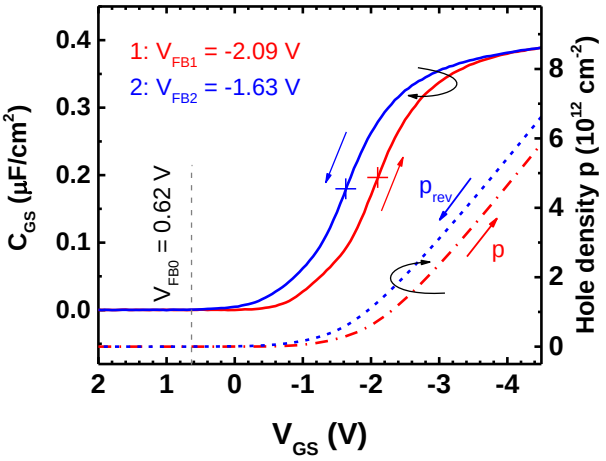

Fig.3 C-V characteristics of the normally-off device, and the hole density corresponding to the capacitance.

Mobility analysis

Besides the scattering mechanisms in bulk semiconductors such as lattice and impurity scattering, the hole in the channel is additionally scattered by collisions with the walls of the channel, which reduces the low-field mobility. And the low-filed mobility for holes can be fitted as $\mu \approx 2485F_{eff}^{-0.23}$. A similar relationship for Si p-channel MOSFET is independent of substrate doping, substrate bias, and oxide thickness.

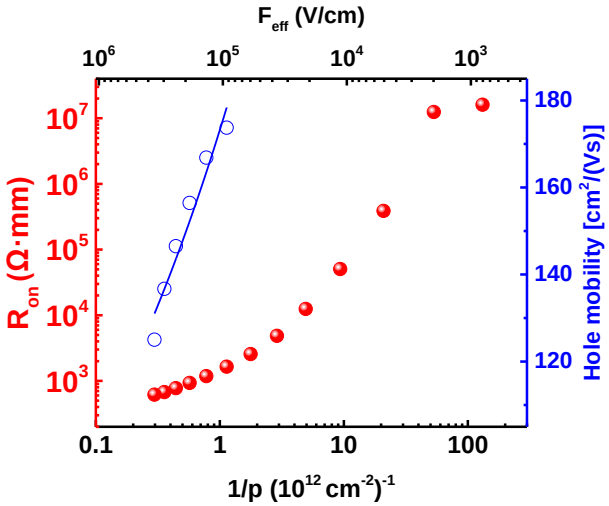

Fig.4 On-resistance as a function of the reciprocal of hole density and the hole mobility as a function of the effective vertical field. The effective vertical field is corresponding to the reciprocal of hole density.

3. Conclusions

In conclusion, the 40-μm normally-off H-diamond MOSFET with Al_2O_3 gate dielectric formed by thermal oxidation of Al has been fabricated. A UV ozone treatment purposing to accomplish the enhanced FET implemented before gate dielectric layer deposited. The I_{Dsat}, V_{TH}, g_m and C_{GS} for the 40-μm FET were determined to be -2.2 mA/mm, -1.42 V, 1.78 mS/mm and 3.9 μF/cm^2, respectively. The C-V characteristics reflect the existence of the fixed charge (5.48×10^{12}cm^{-2}) and the interface traps (9×10^{11} cm^{-2}). The effect vertical field dependence of the μ_{eff} was fitted inspired from the experience of the analysis of Silicon based MOSFETs.

References

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