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Threshold control of diamond MESFET by MWCVD growth conditions

Hiroyuki Kawashima[1], Hitoshi Umezawa[1], Shinya Ohmagari[1],
Rika Tamano[2], Takeyasu Saito[2] and Yoshiaki Mokuno[1]

[1]ADPERC, AIST
Midorigaoka 1-8-31, Ikeda, Osaka, 563-8577, Japan
Phone: +81-72-751-9916 E-mail: hiroyuki-kawashima@aist.go.jp
[2]Osaka Prefecture Univ.
Gakuen-cho 1-1, Naka-ku, Sakai, Osaka, 599-8531, Japan.

Abstract

A practical diamond metal-semiconductor field-effect transistor (MESFET) is required to have a low threshold voltage. By changing only the microwave plasma assisted chemical vapor deposition (MWCVD) growth condition, the threshold voltage of 4.4 V was obtained.

1. Introduction

A diamond has the resistance of high temperature and radiation for the strong materials. Therefore, a diamond device operation in the severe environment such as nuclear power plants is expected [1]. The diamond device study advances steadily, and various devices are developed now. A diamond MESFET, which is expected to be applied as a radiation detector, is one of them [2]. However, in the previous research, the gate threshold voltage of the diamond MESFET was very high with around 30 V [3]. This high threshold voltage was a problem to use as a detector. As the first step to solve the problem, the CVD growth conditions were changed. Due to this change, the boron dope concentration and the crystal quality of the drift layer were changed. By this change, we aimed to fabricate the diamond MESFET having the lower gate threshold voltage. In addition, by controlling the CVD growth conditions, we aimed to control the threshold voltage.

2. Experimental procedures

Diamond MESFETs such as figure 1 were fabricated on diamond substrates. The diamond substrates were high pressure and high temperature (HPHT) synthetic Ib diamond (001) crystals. First, p-type diamond films as the drift layer were grown on diamond substrates by MWCVD. Then, several CVD growth conditions of the drift layer were prepared. Table 1 shows representative CVD growth conditions. Secondary ion mass spectrometry (SIMS) results and Cathodoluminescence (CL) measurements show that almost the same boron concentration and almost the same film thickness were obtained under these two CVD growth conditions. These boron concentration was about 1×10^{16} cm^{-3}. These drift layer thickness was about 2.6 μm. Next, heavy boron doped layer was grown on the source electrode place and the drain electrode place by filament CVD. About the heavy boron doped layer, the boron concentration was over 2×10^{20} cm^{-3} and the layer thickness was about 0.5 μm. After that, each electrode was fabricated. The electrode shape is a Corbino (circular) type structure as shown in figure 1 (a). This structure doesn't need device isolation. This electrode shape was fabricated by photolithography and lift-off techniques. The electrode metal was formed by sputtering. The source and drain electrode were formed by Ti/Pu/Au multilayers as ohmic electrode. On-the other hand, the gate electrode was formed by Ru/Au multilayers as a Schottky electrode. For the gate length (L_G) and the gate-drain length (L_{GD}), diamond MESFET having these several lengths were fabricated on the same substrate. These device fabrication processes of sample A and sample B were exactly the same except for drift layer growth.

The current-voltage (I-V) characteristics of these MESFETs were measured by a parameter analyzer (Agilent 4156C).

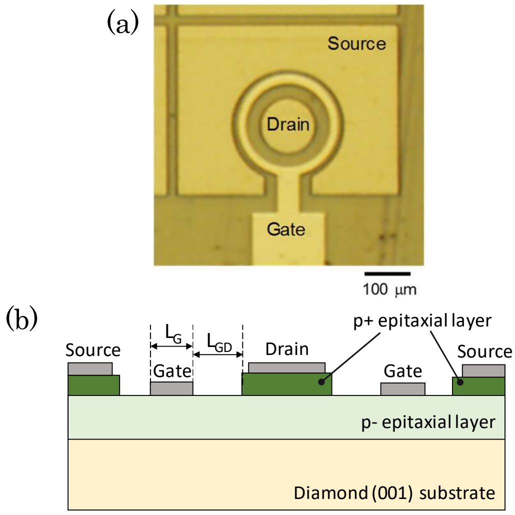

Figure 1 (a) Top view and (b) cross sectional figure of the diamond MESFET structure.

Table 1 CVD growth conditions of the drift layer.

	Sample A	**Sample B**
Micro wave power [W]	3900	3900
Pressure [Torr]	120	120
CH_4 concentration	2%	3%
O/C ratio	0.4	0.4
Total gas [sccm]	1000	400
During time	6 hr	2 hr
Growth rate [mm/hr]	0.42	1.34

3. Results and discussion

Figure 2 shows the drain current (I_{DS}) and the drain bias (V_{DS}) characteristics of the diamond MESFETs on sample A and B. These MESFETs have L_G = 20 μm and L_{GD} = 20 μm. These results are at room temperature. In figure 2 (a), for sample A, the gate bias (V_{GS}) was varied from 0 to 10 V with voltage step of 1 V. In figure 2 (b), for sample B, V_{GS} was varied from 0 to 30 V with voltage step of 3 V. These results show the usual characteristics of MESFET. However, Sample A got cut-off state in less gate voltage than sample B.

Next, to investigate the threshold voltage (V_{th}), when V_{DS} was -20 V and I_{DS} was saturated, the relationship between I_{DS}-V_{GS} characteristics were measured. Figure 3 shows $\sqrt{I_{DS}}$-V_{GS} characteristics. V_{th} is derived from the slope of the curve in the on-state. V_{th} of sample A was 4.4 V. In other hand, that of sample B was 18 V. Thus, it was found that the threshold voltage changes even when the device structure and boron doping concentration are the same.

The reason why the threshold value is different is considered as the difference in crystallinity of the drift layer. Since sample A grows slower at lower CH_4 concentration than sample B, it is considered that sample A has fewer defects and better crystallinity. In addition, from electrical characteristics, the acceptor concentration (N_A-N_D) of sample A was estimated to be 8.4×10^{14} cm^{-3}. That of sample B was estimated to be 2.4×10^{15} cm^{-3}. The cause of the difference between the two acceptor concentrations is considered to be due to that the defect functions as an acceptor.

4. Conclusions

The threshold voltage of the diamond MESFET could be changed only by the CVD condition despite the same structure and the same boron concentration. In particular, the very low threshold voltage (V_{th} = 4.4 V) was obtained about sample A in which the drift layer was grown slowly. The reason is considered to be influence of the crystal quality. In addition to this result, further improvement of MESFET performance can be expected by optimizing device structure and boron concentration.

Acknowledgements

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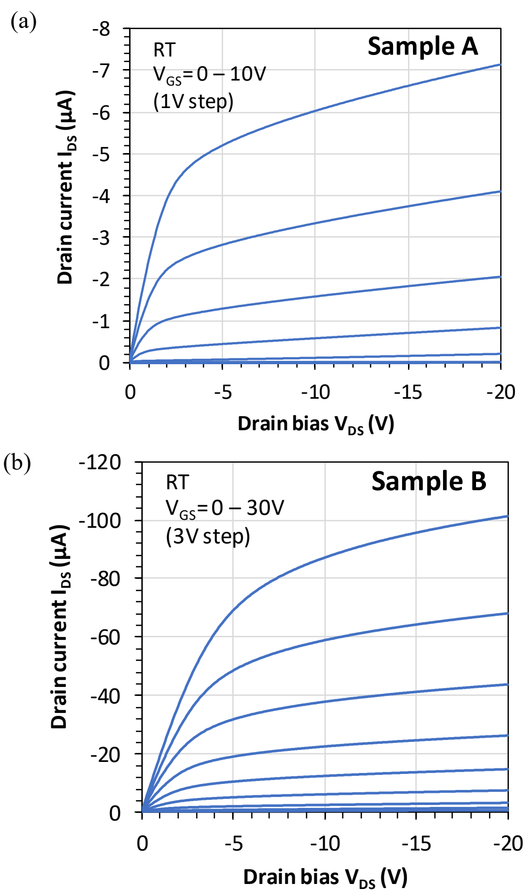

Figure 2 I_{DS}-V_{DS} characteristics of (a) sample A and (b) sample B.

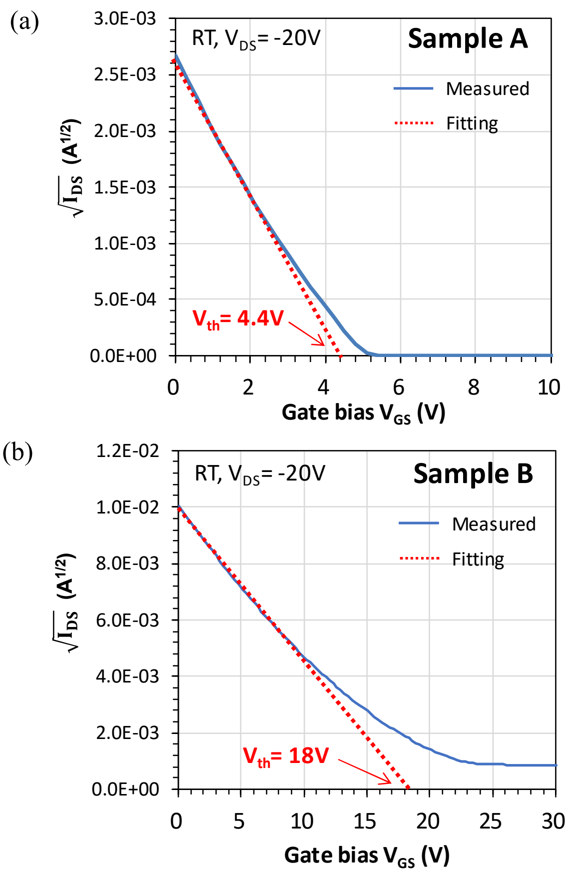

Figure 3 $\sqrt{I_{DS}}$-V_{GS} characteristics of (a) sample A and (b) sample B.