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High Frequency Performance of Diamond Field-Effect Transistor

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1. Introduction

Diamond is a promising semiconductor material for high power, high temperature and high-frequency electronic devices, due to its high breakdown field (~10^7 V/cm), highest thermal conductivity (20 W/cm K) and low dielectric constant (5.7) [1]. When diamond films are fabricated by plasma assisted chemical vapor deposition (CVD), the diamond surface is terminated by hydrogen. The hydrogen-terminated diamond surface forms a p-type thin conductive layer in the absence of doping impurities [2]. Metal semiconductor field-effect transistors (MESFET) utilizing hydrogen-terminated diamond surface have been reported [3]. However, high-frequency performance has not been reported for diamond FETs.

In this study, Hydrogen-terminated diamond MISFETs are compared with MESFETs from the point of high-frequency operation.

2. Experimental

Homoepitaxial diamond films were fabricated on high-pressure-synthetic type Ib diamond (001) substrates by microwave plasma-assisted CVD. MESFETs were fabricated on the undoped diamond substrate using a recess-type self-aligned gate fabrication process. The sequence of the entire process has been described elsewhere [4].

MESFETs with gate length of 2-3 μm and MISFET using CaF_2 gate insulator with gate length of 0.7-1.5 μm were fabricated. The microwave performance of the FETs was characterized by S-parameter measurement using an HP8720 network analyzer and a Cascade wafer probing system.

3. Results and Discussion

Fig. 1 shows the drain current (I_{DS}) as function of drain-source bias (V_{DS}) of 2 μm gate diamond MESFET and 0.7 μm gate MISFET.

I_{DS}-V_{DS} characteristics of 2 μm gate diamond MESFET are shown in Fig. 1(a). A maximum transconductance (g_m) of 70 mS/mm is obtained. The I_{DS}-V_{DS} characteristics of 0.7 μm gate MISFET using CaF_2 gate insulator is shown in Fig. 1(b). A maximum transconductance (g_m) of 40 mS/mm is obtained.

Fig. 2 shows the current gain, maximum available gain (MAG) and maximum stable gain (MSG) of 2 μm gate diamond MESFET and 0.7 μm gate MISFET. A cut-off frequency (f_T) of 2.2 GHz and a maximum oscillating frequency (f_{max}) of 7 GHz were obtained, respectively for MESFET. A cut-off frequency (f_T) of 11 GHz and a maximum oscillating frequency (f_{max}) of 18 GHz were obtained, respectively for MESFET.

In spite of lower transconductance, the diamond MISFETs exhibit higher cut off frequency than MESFETs. The relationship $f_T = g_m/2\pi Cgs$ shows lower gate-source capacitance (Cgs) of MISFET which raises cut off frequency. When MISFET is compared with MESFET using an equivalent circuit, the Cgs of MESFET is represented by capacitance of depletion region. In the other side, the Cgs of MISFET is represented by series capacitance of depletion region and gate insulator and is lower than MESFETs. The Cgs at unite width as function of gate length is shown in Fig. 3.

Conclusion

The high frequency performance of a diamond is reported. A 0.7 μm gate MISFET shows f_T of 11 GHz.

Acknowledgements

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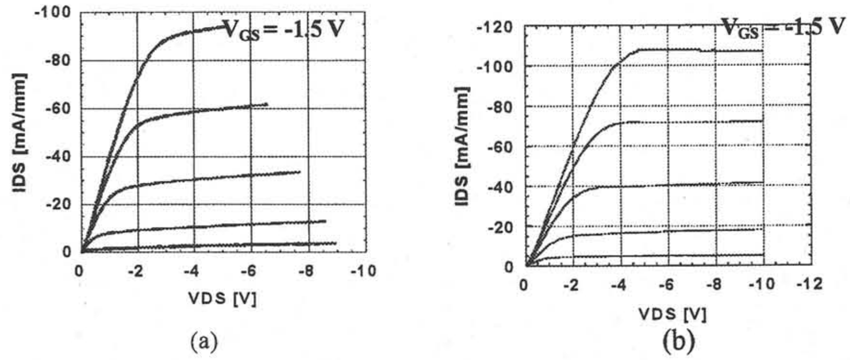

Fig. 1. IDS-VDS characteristics of diamond MESFET (a) and MISFET (b). The gate voltage was applied in 0.5 V step.

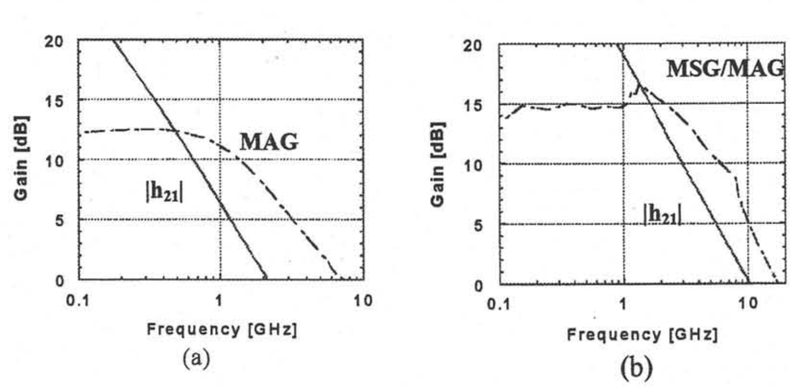

Fig. 2. The current gain ($|h_{21}|$), maximum available gain (MAG) and maximum stable gain (MSG) of 2 μm MESFET (a) and 0.7 μm MISFET (b).

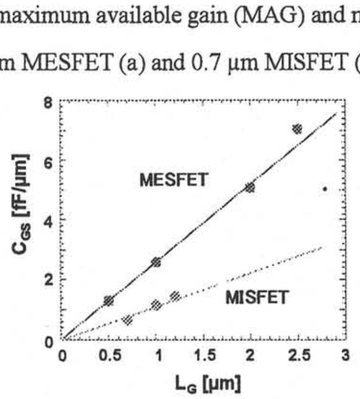

Fig. 3 Cgs as function of gate length.