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Electrical Stabilization of Diamond MIS Interface by Employing BaF_2 Insulator Film and Application to Diamond MISFETs

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1. Introduction

Semiconducting diamond has a number of superlative properties, including high thermal conductivity, wide band gap and large breakdown field, which make it suitable for high-temperature and high-power devices. For realization of the diamond electronic device, however, the electrical stabilization of diamond surface and/or metal/insulator/semiconducting diamond (MIS) interface is indispensable. Therefore, we have been focusing our researching on the electrical stabilization of MIS diamond interface.

Our previous results revealed that oxygen adsorption on the diamond surface induced a number of surface states, which degraded the electrical properties of MIS interface to a great extent [1][2]. Therefore, non-oxide gate insulator is required in order to electrically stabilize the diamond MIS interface. From our previous results, we confirmed that non-oxide CaF_2 gate insulator contributes to the electrical stabilization of the diamond MIS interface to some extent [3]. Considering the fact that calcium readily combines with oxygen, it can be said that calcium included in the gate insulator might also play an important role in the stabilization of MIS interface by taking the adsorbed oxygen away from diamond surface. However, CaF_2 is not sufficient to bring about the MIS interface to the acceptable level.

In the present work, metal/insulator/*i*-diamond structures were fabricated by employing BaF_2 insulator and their electrical properties were closely investigated by means of capacitance-voltage (*C-V*) measurements. In addition, diamond electronic devices employing various fluorides insulators were fabricated and their electrical properties were examined.

2. Experimental

Undoped homoepitaxial diamond films were grown on high-pressure-synthesized (100) diamond substrates by means of the electron-cyclotron-resonance (ECR) microwave plasma-assisted CVD method using a mixture of H_2 (220 sccm) and CO (12 sccm) at 800℃. To form an ohmic contact, Au electrodes were deposited on the diamond surface by resistively heated evaporation at room temperature. BaF_2 films were formed by resistively heated evaporation at the vacuum level of $\sim 10^{-6}$ Torr. The evaporation source material was stoichiometric fluoride bulk. In this case, BaF_2 films were deposited at room temperature in order to protect the diamond surface from the fluorine termination [3] and oxygen in-diffusion. Thus, diamond film surfaces were kept hydrogenated as they were just after the CVD [4][5]. Finally, Al electrodes (1.9×10^{-4} cm^2) were formed on insulating films.

3. Results and Discussion

The *C-V* characteristics measured from Al/BaF_2/*i*-diamond MIS diode, and the surface state density estimated by Terman method are plotted by solid and open circles in Fig. 1, respectively, where measured capacitances are normalized by the insulator-layer capacitance(C/C_i). From this figure, we can see an excellent electrical modulation of surface band from the accumulation to at least the flat-band condition (actually, it is very close to an ideal *C-V* characteristics), where the pinning of surface band and hysteresis indicating a high density of surface states are not observed.

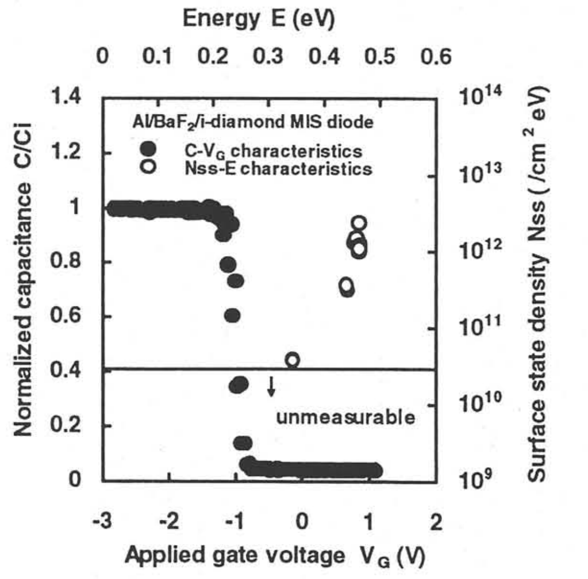

Fig. 1 *C-V* characteristics and surface state density distribution of Al/BaF_2/*i*-diamond MIS diode.

For the clear analysis about the electrical properties of the MIS interface, we estimated the surface state density distributions *Nss* from the *C-V* characteristics by Terman method. The results are also shown in Fig. 1, where the energy is measured from the valence band edge into the forbidden band. From this result, it was found that there exist surface state of $\sim 10^{10}/cm^2eV$ near the valence band edge (MISFET operation region), which is comparable with conventional Si MOS interface. Above results indicate that BaF_2 electrically stabilizes the diamond MIS interface to a great extent.

Now, we should think about what the electrical stabilization of BaF_2/*i*-diamond MIS interface was originated from. According to our previous results, it was found that oxygen adsorption on the diamond surface yielded a number of surface states, which degraded the electrical properties of the diamond MIS interface to a great extent. Namely, the electrical performance of MIS structure strongly depended on to what extent diamond surface escaped from oxygen adsorption. From this view point, above result might be explained by the high chemical reactivity of barium atom included in gate insulator to the adsorbed-oxygen on the diamond surface. In other words, it can be said that barium of BaF_2 played an important role in the electrical stabilization of MIS interface by taking the adsorbed-oxygen away from the diamond surface.

In order to observe to what extent the diamond MIS interface are electrically improved by excluding the oxygen adsorption on the diamond surface, we also fabricated the diamond MISFET by reduced-oxygen process [2]. An optical micrograph and the drain current versus drain voltage (I_D-V_D) characteristics of the diamond MISFET by reduced-oxygen process are shown in Fig. 2(a) and (b), respectively. The electrical properties of the diamond MISFET fabricated by reduced-oxygen process were remarkably improved in comparison with conventional ones. Above results indicate that the electrical properties of diamond MIS interface can be improved to a great extent by excluding the oxygen adsorption on the diamond surface. Therefore, we can say that BaF_2/*i*-diamond MIS structure is recommendable as a promising candidate for application to the diamond electronic devices.

4. Conclusions

We fabricated the diamond MIS structure by employing BaF_2 insulator films and closely investigated the electrical properties of the diamond MIS interface. The *C-V* characteristics of Al/BaF_2/*i*-diamond MIS structure exhibited outstanding electrical properties (there exist surface state of $\sim 10^{10}/cm^2eV$ near the valence band edge). From this result, BaF_2/*i*-diamond structure is expected to be a promising candidate for application to diamond MIS electronic devices. From the chemiphysical point of view, above result might be explained by the strong chemical reaction of Ba atom included in gate insulator to adsorbed-oxygen on the diamond surface. Besides, by obtaining the electrically stabilization of diamond MIS interface, we fabricated diamond MISFETs, and characterized their electrical properties.

References

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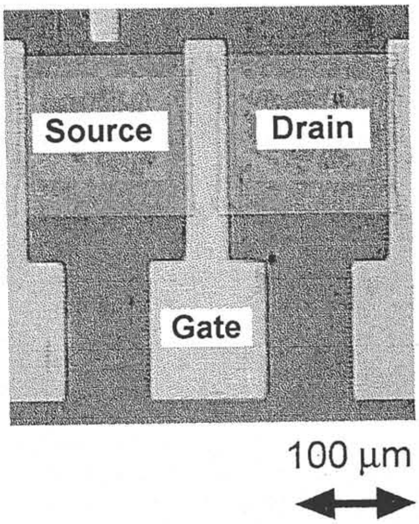
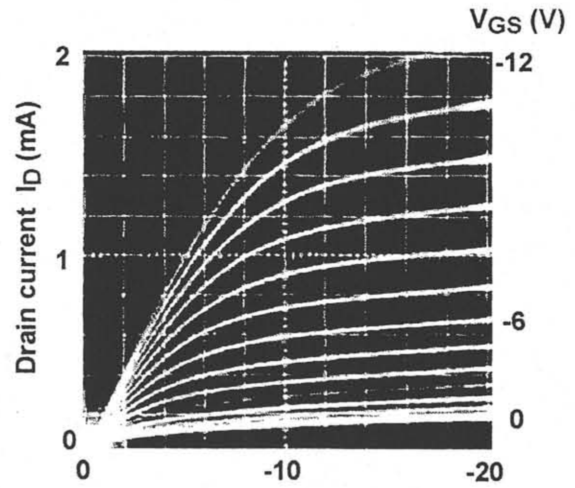


(a)



(b)

Fig. 2 (a) Optical micrograph and (b) I_D-V_D characteristics of the diamond MISFET.