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MIM Switching Devices Using Diamond-Like-Carbon Films

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DLC films were prepared by the conventional plasma CVD method from the mixture of CH_4 and H_2 gases. The structure and properties of the films were studied as a function of rf power. The resistivity decreased almost 4 orders of magnitude with increasing rf power in spite of undoped conditions. We consider the change is due to an increase of graphite portion in films. We have attempted to apply DLC films as an insulator layer for MIM device. The switching characteristics of our device was satisfactory and controllable by the film thickness and the deposition condition (rf power). Ion/Ioff was more than 4 orders of magnitude and symmetry (R) was nearly 1.0. DLC films are quite suitable to the insulator layer for MIM device.

1. Introduction

Recently, extensive studies [1)-3)] have been carried out on Diamond-Like-Carbon (DLC) films because of high resistivity ($>10^{11}$ Ω cm) and hardness (>2000 kg/mm^2). Moreover, the various applications to electronic devices are strongly expected. Since their electrical properties are controlled over a wide range by changing the deposition conditions and they have superior smoothness and uniformity, we have attempted to apply DLC films as an insulator layer for Metal-Insulator-Metal (MIM) switching device. As a result, we could obtain the excellent switching characteristics. In addition, we demonstrated to drive the active matrix LCD (Liquid Crystal Display) using our MIM devices.

2. Experimentals

DLC films were prepared by the conventional plasma CVD method from the mixture of CH_4 and H_2 gases. Pyrex glass (#7740) and Si-wafer (100) subustrates were held on the rf electrode on which ion bombardment is activated by negative self-bias voltages. The film thickness was about 7000A. Deposition conditions are shown in table 1.

Table 1 Deposition conditions

rf power	25W~200W	
H_2 dilution (H_2/CH_4+H_2)	50	vol.%
Total flow rate	10	sccm
Electrode area	113	cm^2
Electrode distance	75	mm
Total pressure	0.035	torr
Substrate temp.	room temp.	

The several samples were fabricated by changing rf power from 25W to 100W, keeping other conditions constant. We investigated the relationship between the properties and the film structure using them. We examined optical band gap (Egopt), hydrogen content (C_H), resistivity (ρ), activation energy (Ea) of the electrical conductivity and spin density (Ns). Furthermore, we measured Raman spectra to confirm the structural change.

The Al/DLC films/Al layers were deposited on the pyrex glass substrate with thicknesses of 1000A, 800A and 1000A. The active area of the MIM device was 1X1mm^2. We measured the I-V characteristics to ±10V by 0.2V step. In order to analyze its electrical conduction mechanism, we investigated the I -V characteristics of several MIM devices with various kinds of upper electrode metals. Moreover, we made MIM devices changing DLC film thickness from 500A to 1250A using a constant rf power 25W and rf power from 25W to 100W for a constant thickness. From these samples the dependence of the I -V characteristics on film thicknesses and rf power was estimated.

3. Results and Discussion

Fig.1 shows the rf power dependence of each property. We observed a significant change in ρ , which decreased almost 4 orders of magnitude with increasing rf power in spite of the impurities undoped condition.

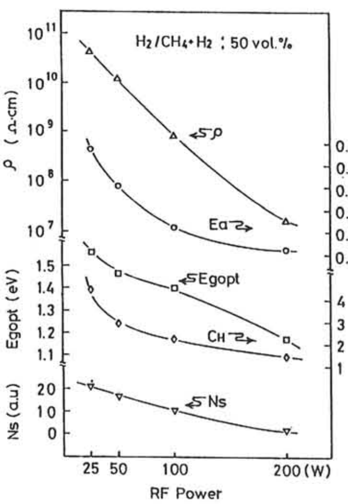

Fig.1 RF power dependence of each property.

Since optical band gap (Egopt) and activation energy (Ea) decreased, ρ decreased consequently. However, from the following results that spin density (Ns) decreased in spite of decrease in C_H and the remarkable decrease in ρ earlier described, we consider that structural change occurred with increasing rf power.

The details of Raman spectra of samples prepared at different rf powers are illustrated in Fig.2.

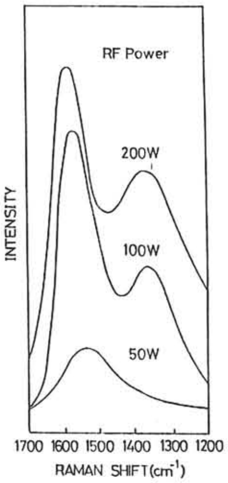

Fig.2 Change of Raman spectra.

The horizontal scale provides the Raman shift (in wave numbers). The broad band assigned by DLC film is measured nearly at 1550 cm^{-1} in the lower rf power (less than 50W) region, while in the higher rf power (more than 50W) region new Raman band appears at 1350 cm^{-1} which refers to the defective graphite. Moreover, intensity of this Raman band increases with increasing rf power and the broad band at 1550 cm^{-1} shifts to higher wave number with decreasing line width. These results indicate that the graphite portion increases in films with increasing rf power.

Temperature dependence of electrical conductivity is presented in Fig.3.

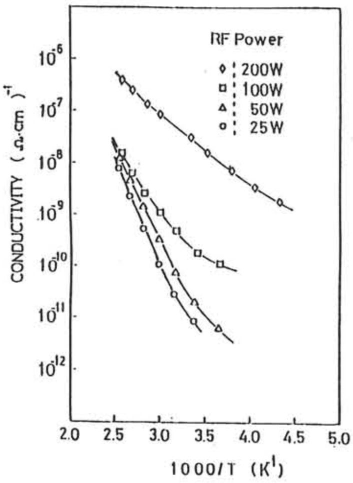

Fig.3 Temperature dependence of electrical conductivity.

Curves of ln σ show linear dependence in the lower rf power region, indicating that conductivity obeys a thermal activation mechanism. However, in the higher rf power region, curves deviate from the linear relationship, thus we speculate that change of the transport mechanism may be caused by some structural changes. Fig.4 shows the I-V characteristics of the MIM device. Ion / Ioff is more than 4 orders of magnitude and symmetry (R) (ratio between forward and reverse current) is nearly 1.0.

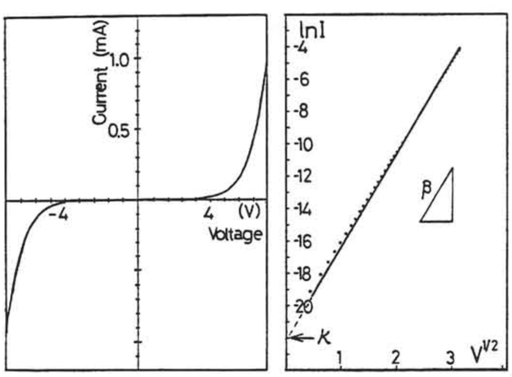

Fig.4 I-V characteristics of the MIM device. A solid line is forward current and a dotted line is reverse current.

Moreover, the I -V characteristics was expressed by the following equations,

$$I = \kappa \exp(\beta V^{1/2}) \qquad ---(1)$$

$$\kappa \propto 1/\rho d \qquad ---(2) \quad \text{and}$$

$$\beta \propto (1/\varepsilon d)^{1/2} \qquad ---(3).$$

Where ρ , ε and d is the resistivity, dielectric constant and thickness of DLC films, respectively. The coefficient κ and β denote the conductivity and the extent of nonlinearity. Both coefficients depend on the properties of DLC films and the geometry of MIM device. We considered that the mechanism of electrical conduction on this device was contact -limited phenomenon, or rather bulk -limited one,[4] because we found the extent of nonlinearity (β) and symmetry (R) were independent on the work function of upper electrode materials as shown in Fig.5. In addition, we investigated the dependence of κ, β on the film thickness and the deposition condition (rf power) to confirm the controllability of the I-V characteristics of our MIM devices. As illustrated in Fig.6, the experimental values agree quite well with the solid lines which are calculated from Eq. (2) and (3) . The remarkable decrease in κ as increasing rf power is shown in Fig.7. We consider that this change is due to the decrease in resistivity caused by the increase of the graphite portion.

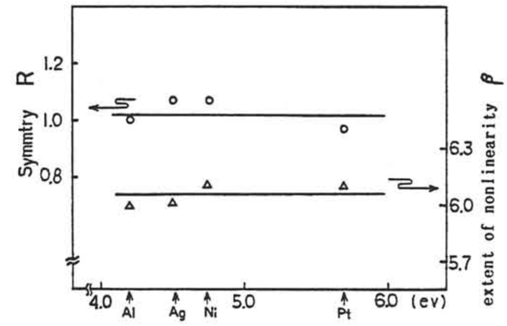

Fig.5 Dependence of the extent of nonlinearity (β) and symmerty (R) on work functions of upper electrode materials.

On the other hand, the β deceases with increasing rf power. We assume that the decrease in β is due to the decrease in the dielectric constant of the film caused by the increase of the graphite portion.

Moreover, we have developed the active matrix LCD[5] with 100X100 pixels by the photolithographic technology, using our MIM device which consisted of the ITO/Al/DLC film/ Ni layers. As shown in Fig.8, active area (10 μm X 10 μm) is formed by crossing to upper metal Ni with lower Al. As a result, the operation at 1 / 1024 duty ratio without flicker and close-talk was demonstrated. Thus it was confirmed that our MIM device had excellent performance as a switching element for LCD.

4. Conclusions

We have investigated the relationship between the properties and the structure of DLC films and have attempted to apply these DLC films as an insulator layer for Metal-Insulator-Metal(MIM)switching device.

(1) The resistivity decreased almost 4 orders of magnitude with increasing rf power in spite of undoped condition. We consider that the change is due to an increase of graphite portion in the films.

(2) The switching characteristics of our MIM device was satisfactory and controllable by the film thickness and the deposition condition(rf power). Ion/Ioff was more than 4 orders of magnitude and symmetry (R) was nearly 1.0. DLC films are very promising as an insulator layer for MIM device.

5. Acknowlegements

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6. References

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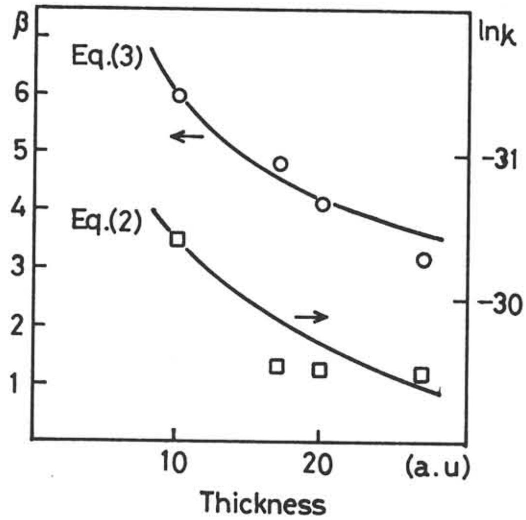

Fig.6 Dependence of β, κ on the film thickness.

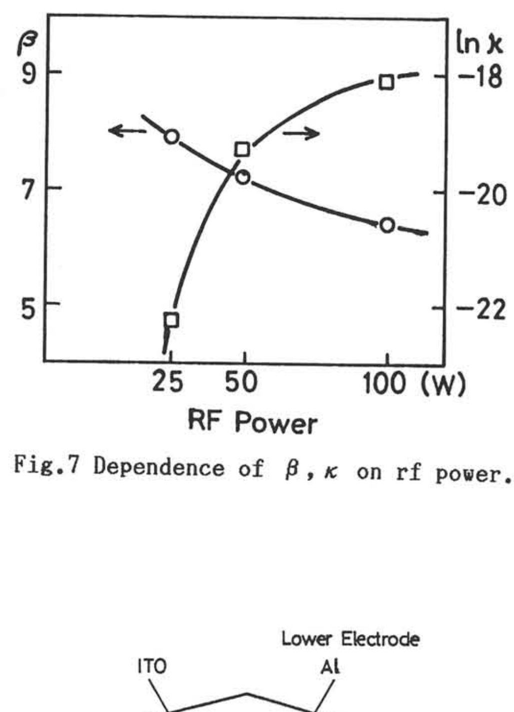

Fig.7 Dependence of β, κ on rf power.

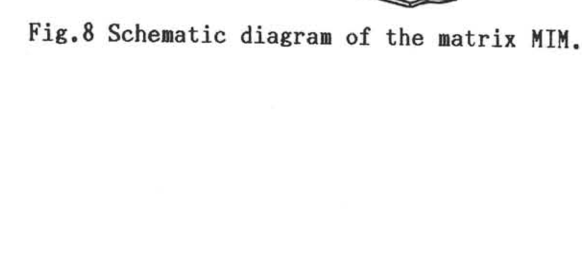

Fig.8 Schematic diagram of the matrix MIM.