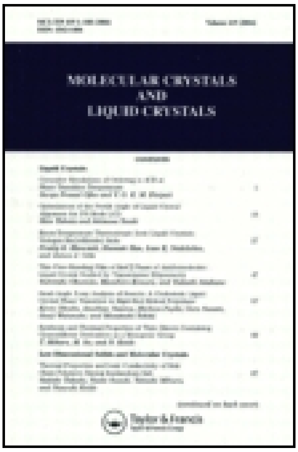

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Electrical Characterization of C_{60} Evaporated Films Using MOS Structure

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ELECTRICAL CHARACTERIZATION OF C_{60} EVAPORATED FILMS USING MOS STRUCTURE

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Abstract Field effect and capacitance–voltage characteristics of vacuum evaporated C_{60} films are studied using metal–oxide–semiconductor structures such as metal / C_{60} / SiO_2 / n^+–Si or C_{60} / source–drain electrodes / SiO_2 / n^+–Si. The electrical conductivity, carrier type, carrier concentration, and carrier mobility are estimated from these measurements. In particular, electrical characteristics during the deposition in vacuum and the influence of oxygen and nitrogen gases are investigated by the in–situ field effect measurement.

INTRODUCTION

Fullerenes (C_{60}, C_{70}, and so forth) are particularly interesting as new functional π–conjugated molecules. For example, C_{60} molecule shows superconductivity in alkali–metal–doped films[1] and ferromagnetics appears in C_{60} – tetrakis (dimethylamino) ethylene complex.[2] Although fundamental studies concerning electric conductivity[3,4] and photoconductivity[5,6] of C_{60} evaporated films have been reported, little is known about conduction mechanism in C_{60} films. In particular, the study on the effect of impurity, atmosphere and fabrication condition on the electrical properties is quite few. From this point of view, the in–situ field effect measurement during the deposition[7] is attractive because this method makes it possible to obtain the basic electrical parameters such as electrical conductivity, carrier type, carrier concentration, and carrier mobility without the influence of atmospheric gases.

In this paper, we report field effect and capacitance–volatage (C–V) characteristics using metal–oxide–semiconductor (MOS) structures with vacuum evaporated C_{60} films. Furthermore, we show the estimated electrical parameters of the C_{60} films as deposition and after the exposure to nitrogen and oxygen gases.

EXPERIMENTAL

I. Samples Preparation

We have prepared MOS structure samples as shown in Figure 1. In this case, highly doped n–type Si substrate (ρ = 0.005 – 0.02 Ω cm) was used as a gate electrode, that is, M, O, and S correspond to n^+–Si, SiO_2, and C_{60}, respectively. An SiO_2 layer of about 200 nm in thickness was thermally grown at 1100 °C in dry oxygen. C_{60} films (150 – 200 nm thick) were deposited onto the SiO_2 layer at a pressure of around 10^{-5} Torr and the substrate was kept at room temperature. Top electrodes for the C–V measurement were evaporated on the C_{60} film. On the other hand, source and drain electrodes were fabricated on the SiO_2 layer before the C_{60} film deposition for the purpose of in–situ field effec measurement. The length, L, and the width, W, of the channel region were 0.1 mm and 10 mm, respectively. As the metal electrodes, In, Al and Au which have different work functions were used to make good contacts with the C_{60} films in both accumulation and inversion layer formation.

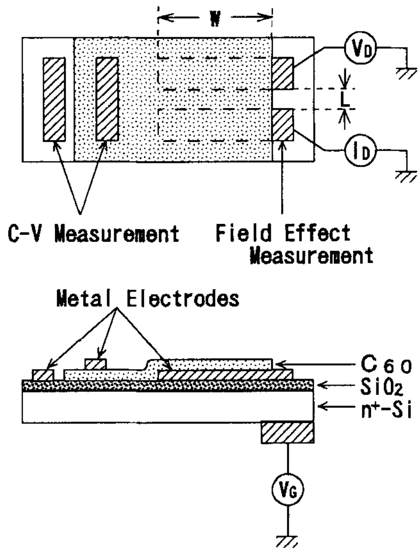

FIGURE 1 Schematic view of the C_{60} MOS sample.

II. C–V measurement

The measured capacitance, C, is that of the series combination of the oxide capacitance, C_{ox}, and the depletion capacitance of C_{60} film, C_d, and is given by $C = C_{ox} C_d / (C_{ox} + C_d)$. The capacitance C falls to a lower value as the thickness of depletion layer increases. On the other hand, C equals to the geometric capacitance of the SiO_2 layer when the accumulation or inversion layer is formed. The C–V measurement used here is based on a Lissajous' figure of the MOS displacement current using a triangular wave voltage source. When the leakage current through the SiO_2 layer is negligible compared with the displacement current, the measured current is directly proportional to the MOS capacitance, because the sweep rate of triangular wave voltage, dV/dt, is constant. Peak voltage of ± 8 V was applied to the gate electrode and the voltage sweep rate was varied from 0.32 to 16 V/s by changing the repetition frequency of the triangular wave voltage.

III. Field effect measurement

Drain current (I_D) – drain voltage (V_D) characteristics under the various gate voltages (V_G) are measured during the C_{60} film deposition. In the conventional MOS-field effect transistor (FET), the drain current I_D in the lower V_G region before saturation of I_D is [8]

$$I_D = (1/2)(W \mu C_{OX}/L)(2(V_G - V_T)V_D - V_D^2), \quad (1)$$

where μ is the mobility of electrons, C_{OX} capacitance of SiO_2 per unit area, V_G gate voltage, V_D drain voltage, and V_T threshold voltage. At constant V_D, differences of I_D for varying V_G (transconductance g_m) become:

$$g_m = dI_D / dV_G = (W/L)\mu\, C_{OX} V_D . \quad (2)$$

The relation between carrier mobility, μ, conductivity, σ, and carrier concentration, n, is

$$n = \sigma / (e\mu). \quad (3)$$

From the field effect characteristics of the C_{60} MOS-FET, one can determine the basic electrical parameters of electric conductivity, carrier mobility, and carrier density.

RESULTS AND DISCUSSION

I. C-V Characteristics

The capacitance versus bias voltage curve for a C_{60} MOS capacitor is shown in Figure 2. As expected, for positive gate voltages the measured capacitance approaches to the value of C_{OX} and indicates the formation of an accumulation layer. On the other hand, the decrease in capacitance for negative voltages shows the formation of a depletion layer. Saturation of the capacitance for large negative biases seems to indicate the depletion layer extends to the C_{60} film (200 nm in thickness). This result supports that the C_{60} behaves as an n-type semiconductor.[9] In this experimental condition, however, there is no evidence for the formation of an inversion layer at higher negative gate voltages, even in a case of very low frequency of triangular voltage (0.01Hz : quasi-static condition[10]).

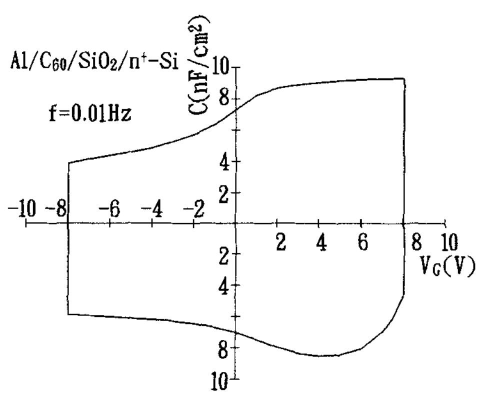

FIGURE 2 Capacitance – voltage characteristics of C_{60} MOS capacitor.

II. Field Effect Characteristics

Figure 3(a) shows typical drain current, I_D, versus drain voltage, V_D, characteristics for different gate voltages, V_G. The variation of the drain current as a function of the gate voltage is also shown in Figure 3(b). The I_D increases with positive V_G and slightly saturates for large V_D. This behavior also demonstrates that the C_{60} evaporated film essentially shows an n-type conduction without the influence of ambient gases. In the present experiments, however, an increase of the channel conduction due to the formation of an inversion layer is not observed in both samples having In and Au source-drain electrodes.

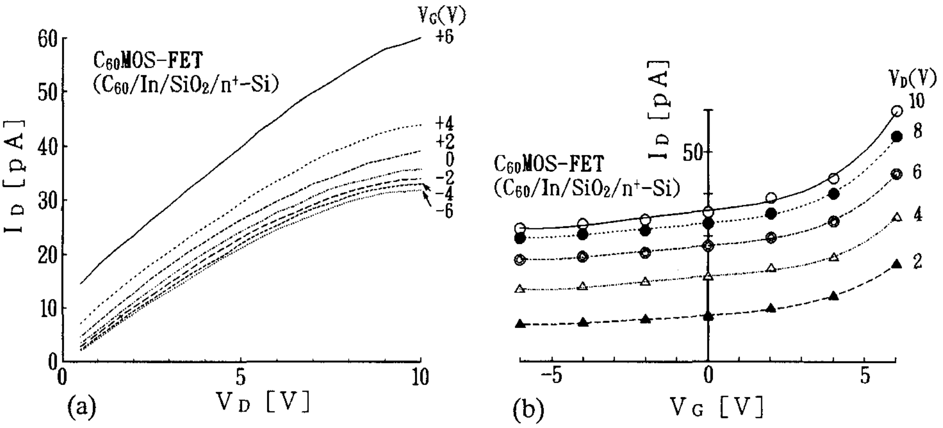

FIGURE 3 Field effect characteristics of C_{60} MOS-FET. (a)Drain current - drain voltage characteristics. (b)Drain current - gate voltage charcteristics.

The variation of the mobility and conductance of evaporated C_{60} films as a function of deposition time is shown in Figure 4. For this region plotted in this figure, the deposition rate is almost constant of about 1.25 nm/min. Small values of the conductance and mobility observed in very thin C_{60} films are mainly due to the effect of the carrier scattering at the C_{60}/SiO_2 interface. Similar phenomena are also observed in Si thin film transistor[8] and the lowering of the carrier mobility compared with that of the bulk region is explained by the interface effects such as surface roughness, localized charges and misfit dislocations.[8]

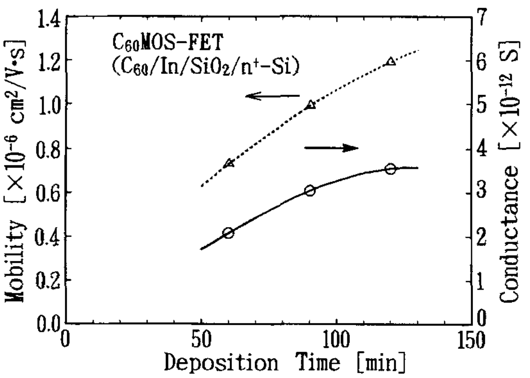

FIGURE 4 The carrier mobility and conductance as a function of deposition time.

In order to examine the effect of ambient gases on the electrical properties, the change of field effect characteristics is measured after the break of vacuum by N_2 and O_2 gases. Figure 5 shows the I_D $-V_D$ characteristics at zero bias of V_G as deposition and after the leak by N_2 or O_2. The drain current decreases after the leak of O_2 gas, but increases for N_2 gas. From the equations (1) - (3), we have estimated electric conductivity, carrier mobility, and carrier concentration. Table I shows the estimated σ, μ, and n of the C_{60} film as deposition and after the leak of N_2 and O_2 gases. The decrease of conductivity and carrier density by O_2 leak can be explained by the compensation effect of acceptor oxygen in the n-type C_{60} film.[6] In the present stage, however, precise mechanism is unknown for the increase of the conductivity by N_2 leak.

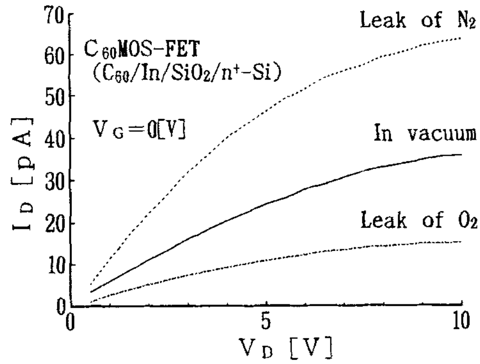

FIGURE 5 Drain current - drain voltage characteristics of C_{60} MOS sample as deposion and after O_2 and N_2 leak.

	In vacuum	Leak of N_2	Leak of O_2
Conductivity σ [$\times 10^{-9}$S/cm]	3.75	8.00	1.93
Mobility μ[$\times 10^{-6}$cm^2/V·s]	1.19	1.71	1.13
Carrier Concentration n [$\times 10^{16}$cm^{-3}]	1.97	2.92	1.07

TABLE I Estimated electric conductivity, carrier mobility, and carrier density of C_{60} evaporated films.

CONCLUSION

We have examined the capacitance-voltage and field effect characteristics of C_{60} evaporated films. The C_{60} evaporated films show an n-type semiconductor. The estimated field effect mobility and carrier concentration are about 10^{-6} cm^2/Vs and 2×10^{16} cm^{-3}, respectively. However, these values are strongly influenced by the exposure of atmospheric gases and the film thickness.

The results obtained here demonstrate that the in-situ field effect measurement during the film deposition is useful to obtain the real electrical parameters without the influence of ambient gases and the degradation of the films during device fabrication.

REFERENCES

1. A.F.Hebard, M.J.Rosseinsky, R.C.Haddon, D.W.Murphy, S.H.Glarum, T.T.M.Palstra, A.P.Ramirez and A.R.Kortan, Nature,350,600(1991).
2. P.–M.Allemand, K.C.Khemani, A.Koch, F.Wudl, K.Holczer, S.Donovan, G.Gruner and J.D.Thompson, Science,253,301(1991).
3. J.Mort, R.Ziolo, M.Machonkin, D.R.Huffman and M.I.Ferguson, Chem.Phys.Lett.,186,284(1991).
4. R.C.Haddon, A.F.Hebard, M.J.Rosseinsky, D.W.Murphy, S.J.Duclos, K.B.Lyons, B.Miller, J.M.Rosamilia, R.M.Fleming, A.R.Kortan, S.H.Glarum, A.V.Makhija, A.J.Muller, R.H.Eick, S.M.Zahurak, R.Tycko, G.Dabbagh and F.A.Thiel, Nature,350,320(1991).
5. J.Mort, K.Okumuara, M.Machonkin and R.Ziolo, Chem.Phys.Lett.,186,281(1991).
6. N.Minami and N.Saito, Synthetic Metals,55,3092(1993).
7. K.Kudo, M.Yamashina and T.Moriizumi, Jpn.J.Appl.Phys.,23,130(1984).
8. S.M.Sze, Physics of Semiconductor Devices (Wiley, New York, 1969) p.425–486.
9. B.Miller, J.M.Rosamilia, G.Dabbagh, R.Tycko, R.C.Haddon, A.J.Muller, W.Wilson, D.W.Murphy and A.F.Hebard, J.Am.Chem.Soc.,113,6291(1991).
10. M.Kuhn, Solid State Electron.,13,873(1970).