Modeling of pentacene MIS capacitors with admittance measurements and the effects of dispersive charge transport

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Abstract

Capacitance and loss values of pentacene MIS capacitors with different thicknesses are measured as a function of frequency for the modeling of the devices. The equivalent circuit for the ideal MIS capacitor is adopted to model the obtained admittance, so the values of C_i, C_d, C_b, and R_b are determined for each pentacene thickness. In the loss curve, broader loss peaks are observed in measurement than the modeling results regardless of the pentacene thickness. By considering the effects of dispersive charge transport in bulk semiconductor, more accurate modeling results are obtained.

1. Introduction

Recently much attention is paid to the admittance measurements on organic MIS structures[1-2] because intrinsic properties of the organic semiconductors such as acceptor concentration, relaxation time, or interface trap density can be obtained. The admittance analysis can be also used to model the MIS capacitors, which is one of the essential parts to make a good SPICE model of organic field effect transistors(OFETs). However, there has been no report on the admittance measurement on pentacene MIS capacitors, although pentacene is one of the most popular organic semiconductor materials, presumably because it is hard to remove the effects of peripheral pentacene region[3] to get the reliable admittance values. In this paper, the admittance of pentacene MIS capacitors with different pentacene thicknesses are obtained, and the characteristics of the admittance values are discussed using appropriate circuit models. In addition, simple circuit model is modified to reflect the effects of dispersive charge transport characteristics in bulk semiconductor.

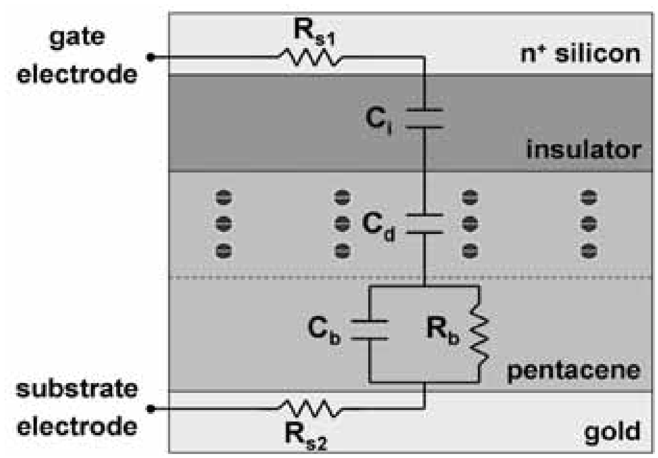

Figure 1. Cross-sectional view of the fabricated MIS structure. Each part is represented by an appropriate circuit model.

2. Results

Figure 1 shows the cross-sectional view of the fabricated MIS structure, and each part is represented by an appropriate circuit model. In these experiments, n^+ silicon is used as the gate electrode, 35 nm-thick oxide with dilute PMMA treatment[4] as the gate insulator, pentacene of 24, 37, 56 and 77 nm as the organic semiconductor, and gold of 100 nm as the substrate electrode. The morphology of pentacene surface does not change significantly by the pentacene thickness according to the atomic force microscope(AFM) measurements. In the figure, C_i represents the insulator capacitance, C_d the depletion capacitance, C_b the bulk capacitance, R_b the bulk resistance, and R_{s1}, R_{s2} the series resistances. For different dc gate voltages, the depletion width W_d of the bulk semiconductor changes, so do C_d, C_b, and R_b. If negative bias is applied to accumulate holes, C_d

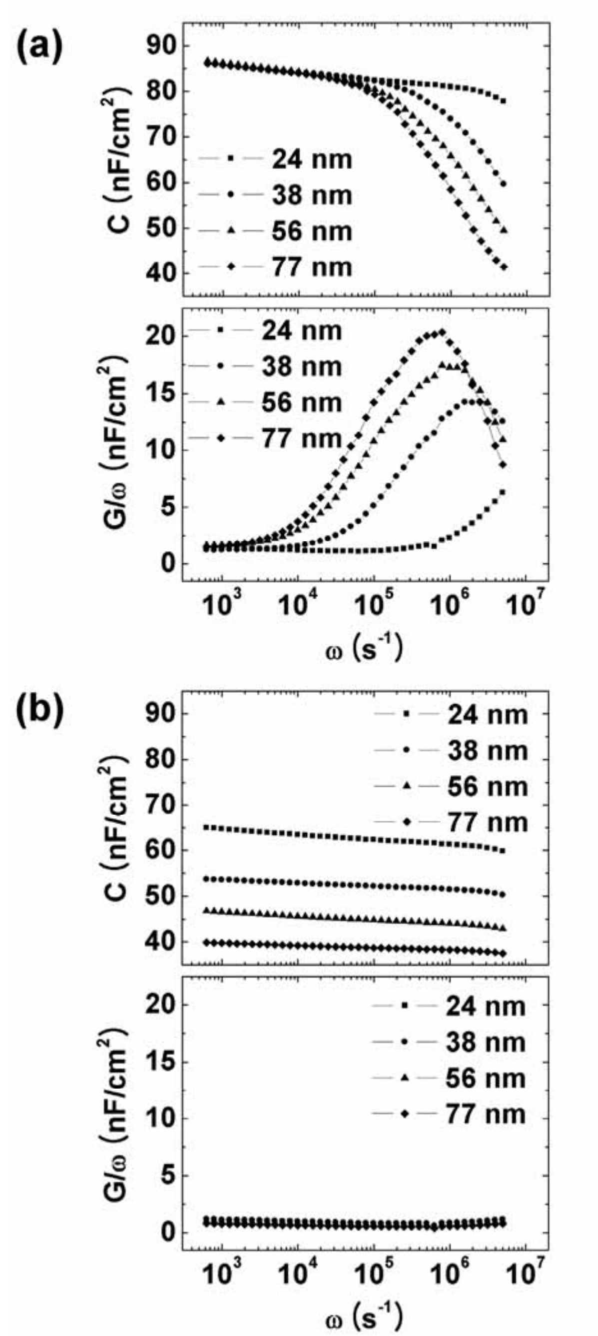

Figure 2. (a) C versus ω curve and G/ω versus ω curve when V_G=-10 V. When the gate bias is negative, peaks due to R_b are observed in the loss curve. (b) C versus ω curve and G/ω versus ω curve when V_G=10 V. C changes with pentacene thickness.

becomes very large, i.e., a short circuit. On the other hand, if positive bias is applied to fully deplete the bulk semiconductor, the effects of C_b and R_b disappear from the circuit and C_d prevails the characteristics of the semiconductor. Measurements on the capacitance(C) and the loss(G/ω) of the devices are done in air with HP4284A LCR meter with frequency of 100 Hz ~ 1 MHz. The dc gate voltages of -10 V and 10 V are applied to make the accumulation and full depletion regime, respectively.

The measured C and G/ω are shown in Figure 2 with different bias conditions. When the gate voltage is negative(V_G = -10 V), C is the same as with C_i at low frequency up to ω~10^5 because accumulated holes at the interface can fully respond to the small ac signal through R_b. But C decreases as the frequency increases, because holes can not respond to the fast change of ac signal through R_b so the ac signal should be transferred through C_b. The loss curve in this regime also shows a peak around a relaxation frequency which depends on the pentacene thickness. The relaxation frequency ω_R in this regime is given as $1/(C_i+C_b)R_b$, and the peak value of loss is given as $C_i^2/2(C_i+C_b)$. Using these equations, the values of C_b and R_b can be obtained with different pentacene thicknesses. For the depletion regime (V_G = 10 V), the total capacitance is almost constant and the loss is almost zero for all frequency because there is no hole in the semiconductor to respond. However, thicker pentacene gives small C which is the same as $C_iC_d/(C_i+C_d)$ because C_d is smaller when depletion width is larger. For both bias conditions, the loss peak due to the $R_{s1,2}$ is well above the measuring frequency and not observed in these experiments.

The obtained values are modeled with the equivalent circuit described in Figure 1. C_i which varies slightly with the measuring frequency due to the PMMA treatment is modeled with the empirical equation of $C_i = C_{i0}\omega^{-\alpha}$. C_d in full depletion regime is obtained from C at V_G = 10 V. This C_d is the same as C_b in the accumulation regime. From the peak in the loss curve, R_b is determined. However, the modeling results from

thickness (nm)	C_{i0} (nF/cm²)	α	C_b, C_d (nF/cm²)	R_{b0} (Ω)	β
24	91.0	0.0074	259.9	82.8	0.39
37	91.0	0.0074	142.2	630.5	0.39
56	91.0	0.0074	100.1	1270.0	0.39
77	91.0	0.0074	73.9	1909.2	0.39

Table 1. Extracted modeling parameters after R_b modification.

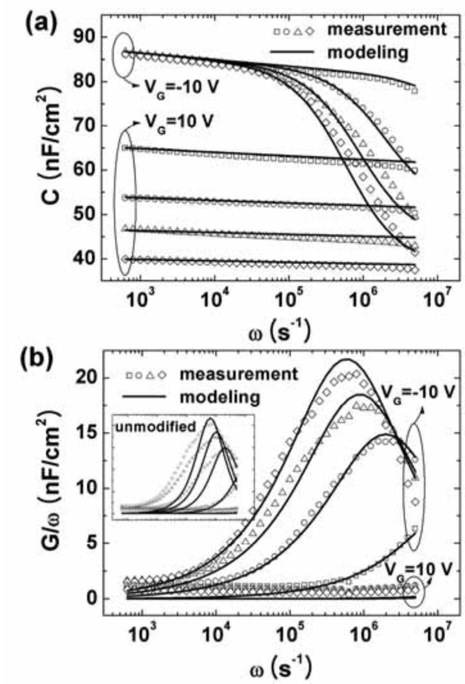

Figure 3. (a) Comparison of the measured C and the modeling results. (b) Comparison of G/ω. By modifying R_b to have frequency dependency, good fitting results are obtained.

this simple circuit model do not fit well with the measured values. Especially, the peak in the loss curve at V_G = -10 V is broader in measurement than in the modeling results. This is presumably due to the dispersive charge transport of the pentacene bulk semiconductor[5]. Therefore, R_b is modified to have frequency dependence, i.e., $R_b = R_{b0}\omega^{-\beta}$, and the relaxation frequency ω_R changes to $1/((C_i+C_b)R_b)^{1/(1-\beta)}$.

With this modification, all the parameters are extracted again and summarized in Table I. Figure 3 compares the measurement and modeling results, and in the inset of Figure 3(b), the modeling results without R_b modification is depicted for comparison. The modified model shows relatively good agreement with the experiments, and this confirms the effects of dispersive charge transport in bulk pentacene.

3. Conclusion

A modified circuit model for pentacene MIS capacitors including the effects of dispersive charge transport is suggested and the modeling results are shown. These results can be used for more general modeling of organic MIS capacitors or organic thin film transistors.

4. Acknowledgements

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5. References

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