International Journal of Engineering Innovation & Research
Volume 3, Issue 3, ISSN: 2277 – 5668

Tunneling Behavior and Transfer Characteristics of Organic Pentacene Thin Film Transistor

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***Abstract* – The organic thin film transistor was prepared by using pentacene on SiOC film, which was prepared by the plasma enhanced chemical vapor deposition and annealed in a vacuum. It was analyzed the dielectric constant, thickness, refractive indexes and O 1s electron orbital spectra by X-ray photoelectron spectroscopyof SiOC films, to obtain the correlation between the characteristic of SiOC and high performance of thin film transistor. The tunneling behavior of organic thin film transistor (OTFT) depended on the characteristic of the surface of gate insulator. Low polarization SiOC enhanced the mobility of TFT because of the possibility of perpendicular growth of pentacene molecule on substrate with low surface energy. The dielectric constant was decreased by the reduction of polarities, which contribute to produces low surface energies achieved from the more stable SiOC with increasing the oxygen related bonding strength in O 1s electron orbital spectra.**

***Keywords* – Pentacene, SiOC, Polarity, Transfer characteristic, OTFT.**

INTRODUCTION

The multi-level interconnect technology has become attractive to the semiconductor industry, as silicon devices keep shrinking in size while the circuits become more complex. A silicon device minimizes and their density increases, it requires that new materials can be replaced the silicon dioxide thin film.[1-2]Moreover, performance such as transparent conducting oxide or oxide semiconductor depended on the interface characteristic between dielectric materials and active layer.[3-5]The semiconductor requires a low temperaturedeposition process while maintaining good material quality and electrical characteristics. SiOC film measured by high density deposition as the low dielectric constant (low-k) material has been focused on the promising insulator, which can be replaced the silicon dioxide film. The HDP reactor such as inductively coupled plasma (ICP) or capacitively coupled plasma (CCP), have been used for SiOC film deposition. High density plasma (HDP) dielectric deposition becomes attractive due to its capability of producing good quality material with excellent mechanical properties.[6-7] The most important feature of HDP systems is its capability to generate high density plasma at low pressure. The ion density can reach 10^{11}~10^{12} cm^{-3} in the plasma chamber by using microwave to generate ECR (electron cyclotron resonance). A separate RF (13.56 MHz) bias applied to the substrate can modify the ion energy. For low deposition temperature, the PECVD method is widely used. During the deposition, the high density ion bombardment of the substrate with high energy provides a flat surface that these processes can be modified to reduce the chance of void in surfaces. The pore gives serious problems in semiconductor device, though the high porosity decreased the dielectric constant in low-k materials. The SiOC film by HDP system can be used the inter layer dielectric materials or gate insulator. Especially, the superior for high speed pentacene-channel organic thin film transistor (OTFTs) was latent in SiOC of organic-inorganic hybrid type film to realize the flexibility of semiconductor device. In this study, it was investigated the effect of mobility on OTFT (organic thin film transistor) device involved the SiOC film. The mobility of OTFT's device generally depends on the characteristic of surfaces. The surface propertiesare an important parameter in surface science to obtain the perpendicular growth. It is believed that the polarity of substrates provides a simple and reliable technique for interpretation of surface energetic, which is defined the hydrophobic or hydrophilic surfaces.[8]Surface modification and functionalization are essential for many application, organic semiconductors and nanoparticle synthesis. Among the various surface modification techniques, self-assembled monolayer has demonstrated their superiority over others.[9-10]

It is the purpose of this study to further explore the characteristic of OTFT-SiOC films from results of the physical and chemical properties. The optical and chemical characteristic properties were measured by the refractive index, thickness and XPS spectroscopy. To measure the TFT device, the active layer was the organic material of pentacene and produced the OTFT (organic thin film transistor) on SiOC film as a gate insulator. It was also researched the deposition profile related to the ion effects, radicals effects and the substrate bias effects.

II. EXPERIMENTAL METHOD

The SiOC films were obtained using the mixed gases of oxygen and bistrimethylsilylmethane (BTMSM) by plasma enhanced chemical vapor deposition (PE-CVD). The SiOC films were prepared by various flow rate ratios of BTMSM precursors, but the oxygen gas flow rate was 70 sccm. The samples were named depending on the Ar gas flow rates. The substrate was sustained the temperature at 100℃ for 10 sec. The BTMSM was vaporized and carried by argon gas at 35 ℃ from a thermostatic bubbler. The base pressure was 3 Torr and the rf power was 450 W in each experiment. Then the samples were named 24~46 owing to the BTMSM flow rates. The dielectric constant was obtained by C-V measurement at 1MHz by using the structure of the Al/SiOC film/p-Si substrate. The thickness and refractive index were measured by the Ellipsometer (uvsel/fpd-12, Horiba JobinYvon) with a He lasersource of 632.8 nm. After the deposition of SiOC films, 250 μm circular patterns of high purity Al metal with a thickness of 250 nm were thermally evaporated by using a shadow mask. The chemical structure of SiOC films was analyzed by means of X-ray photoelectron spectroscopy (ESCALAB250, VG Scientifics, UK). The pressure of the analysis chamber was maintained at $5.0x10^{-8}$Torr during each measurement, by performing charge compensation with a flood gun. The X-ray source was an Al Ka line (1486.6 eV) operating at 150W. Pentacene was deposited on SiOC film, and the electrodes of the source, drain, and gate were made by thermally evaporating Al through a shadow mask. Pentacene was used as a source material for the channel of the TFT device. The substrates were held at 80 ℃ and the pentacene was deposited at 0.1~ 0.3 nm/s, with a final thickness of 50 nm. The thickness of the pentacene was taken on the basis of a thickness monitor during the deposition. The base pressure was 10 Torr in each experiment.

III. RESULTS AND DISCUSSION

To research the physical and chemical characteristic of SiOC, the films were fabricated by the mixed precursor of oxygen and Ar as carrier gas for BTMSM, and the sample was named as Ar gas flow rates. Moreover, the pentacene OTFT was made on SiOC as a gate insulator and then studied the correlation between the electrical properties and lowering the polarization of SiOC.

Figure 1 is the characteristic of SiOC film estimated by using various analyzers. The dielectric constant was obtained by the C-V measurement. Dielectric constant of Fig.1(a) decreased depending on the lowering of polarity by the recombination of electron-halls owing to the alkyl and hydroxyl properties in SiOC. Most samples, the dielectric constant were decreased after annealing process. The as-deposited film sample 32 was 2.5 and became 2.4 after annealing. The dielectric constant was changed depending on the difference of polarity by the oxygen and organic precursor.

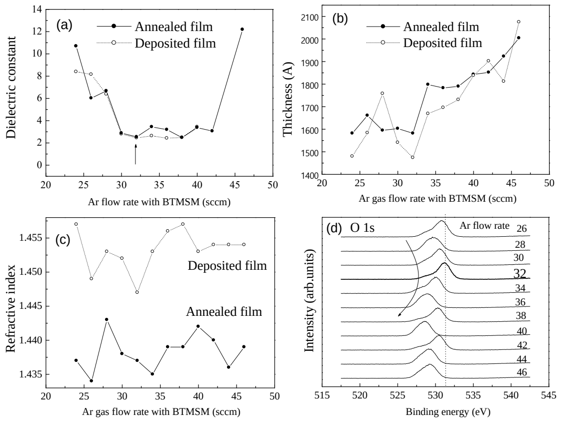

Fig.1. Physical and chemical characteristic of as deposited and annealed SiOC, (a) dielectric constant, (b) thickness, (c) refractive index, (d) binding energy of O 1s electron orbital in XPS spectra of as deposited SiOC.

Lowering the polarization decreased the dielectric constant in SiOC by the nucleation and recombination of electron-hall or the chemical reaction between different groups such as OH or CH group. Figure 1(b) is the thickness of SiOC with various gas flow rates and after annealing. The thickness was usually increased with increasing the Ar gas flow rates. The increment of alkyl group makes the pores in SiOC films by the aloof force between alkyl groups with high surface energy. Therefore, increasing of the aloof force and alkyl group increased the thickness in SiOC. However, the thickness was abruptly varied at the as-deposited SiOC 32 and this phenomenon was also shown at the annealed SiOC 32, because of lowering the polarization. The thickness increased with increasing the polarity, so it can be deducted that the sample 32 is the lowest polarity and then the lowest thickness. On the other hand, other samples have the polarity due to the hydroxyl or alkyl groups and this polarity increases the dielectric constant and thickness. The polarity in SiOC is made from the effect of localized ionic state from the defects, and these localized trap states play the part for the electron trapping phenomenon. However these trapping in a gate dielectric material are the leakage current as the prevention for source-drain current in TFTs. Non-polarity in SiOC as a gate insulator means a non-leakage current as well as an ideal amorphous structure. Figure 1(c) is the reflective index of SiOC with various gas flow rates and annealing. The reflective index was directly related to the thickness and the dielectric constant. The reflective index was decreasing after annealing process. The trend of refractive index of annealed samples was proportion to that of as deposited films. Figure 1(d) is the binding energy of O 1s electron orbital in XPS spectrum of as deposited SiOC. The binding energy of O 1s electron orbital was the highest at sample 32. Si-O-C bonding strength in SiOC became higher than other bonds and it means that the SiOC became more stable structure than others, because of the diminishment of terminal alkyl group. More stable Si-O-C bonding structure was made from the migration and recombination of the Si-O and Si-C bonds by high surface energy and then decreased the surface energy.

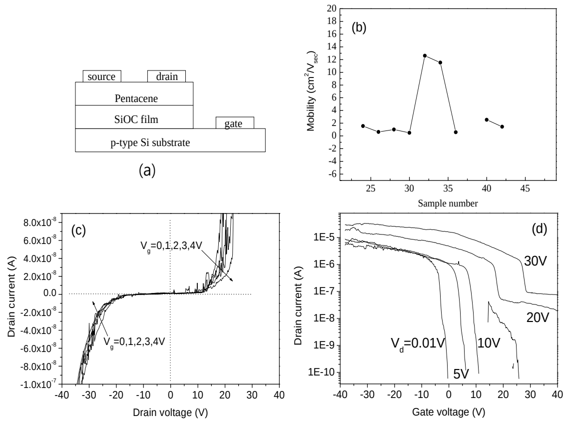

Fig.2. Electrical properties of pentacene OTFT on SiOC, (a) schematic diagram of pentacene OTFT, (b) mobility, (c) Id-Vd curve, (d) Id-Vg transfer characteristic.

Figure 2 is the electrical properties of pentacene OTFT prepared on SiOC with various gas flow rates. Figure 2(a) is the schematic diagram of OTFT on SiOC. Figure 2(b) shows the mobility obtained from aId-Vg curve at Vd=0.01 V. The highest mobility was 12.1 cm^2/Vs at annealed SiOC of sample 32 with the lowest dielectric constant. Figure 2(c) and (d) was the result of sample 32, and the mobility of others with high polarity SiOC it was lower than samples 32 and 34. The figure of Id-Vd curve was shown the ambipolaroutput characteristicsof pentacene OTFTswith the low polarity of SiOC. Figure 2(d) is the ambipolartransfer characteristicsof TFT with pentacene grown on SiOC 32 because of a tunneling behavior. The transfer curve improved with decreasing the drain voltage and increased the mobility. TheId-Vg curve was shifted to positive bias with a increment of drain voltages. Simultaneously with theId-Vg curve shift, it was attended with the reduction of mobility of OTFT. The polarity formed by the carrier localization effect also gives to increases the leakage currents, this leakage current as the carrier scattering interrupted the source-drain currents of TFT.[8] Moreover, it is prevented the growth of pentacene on a surface. Therefore, it was investigated that the electrical properties of Id-Vg curve shifts and mobility is strongly influenced by the polarity of gate insulator, and the non-polarity of SiOC has the effect of the reduction of leakage currents due to the electron deficiency group.

IV. CONCLUSIONS

To improve the performance of pentacene OTFT, non-polarity SiOC was used as a gate insulator and it was researched the dielectric constant, chemical properties of SiOC and the Id-Vg curves of OTFT prepared on SiOC with various gas flow rates. The mobility of OTFT strongly depended on the properties of gate insulator. The transfer characteristic of OTFT was showed the ambipolar properties, andthe mobility was the highest at the pentacene OTFT on SiOC with the non-polarity, whichcan be influenced to the leakage current at the interface between anactive channel layer and dielectric material. Lowering the polarization of SiOC with the lowest dielectric constant also decreased the thickness and refractive index. These properties such as low-k (low dielectric constant) materials, low thickness and refractive index were fit for the small size of semiconductors. The Id-Vg curve shift was related to the drain voltage, and the Id-Vg curveshifted depending on the increment of drain voltages. The SiOCsample 32 with the lowest dielectric constantbecame stable TFT as semiconductor because of the highest binding energy in the O 1s electron orbital spectra, and then these films increased the mobility of TFTs because of the perpendicular growth of pentacene on non-polar SiOC and protection of the electron scattering at surfaces without polar.

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