플라즈마 중합된 ppMMA 유기 박막을 절연층으로 한 유기박막 트랜지스터의 제작

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Fabrication of OTFT with plasma polymerized methylmethacrylate organic thin film

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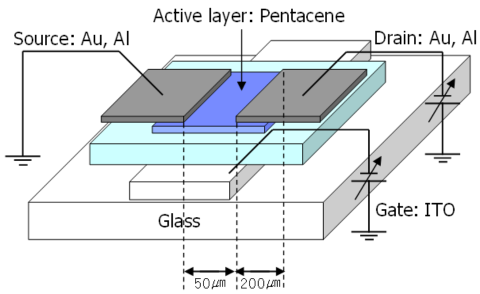
Abstract - In this paper, ITO gate electrode surface was modified using O_2 plasma and organic gate insulating layers were deposited on the ITO surface using plasma polymerization technique. In order to investigate the influence of the plasma coupling method and plasma conditions on the plasma polymerized methyl methacrylate (ppMMA) thin film properties, inductively coupled (ICP) and capacitively coupled plasma (CCP) were used to generate the plasma and the plasma parameters were varied. The ppMMAs were investigated using atomic force microscopy (AFM) and a Fourier Transform Infrared (FT-IR) spectroscopy. Dielectric constants of the ppMMA thin films were investigated using a impedance analyzer (HP4192A, LF Impedance Analyzer). Current-Voltage (I-V) characteristics of the organic thin film transistors (OTFTs) were investigated using a source measurement unit (SMU: Keithley 2612). Proposed method can be applied to dry-process to fabricate OTFTs during overall fabricating steps.

1. INTRODUCTION

The use of organic materials has a number of important advantages over conventional techniques using mainly inorganic materials, like amorphous silicon. The low process temperature, typically less than 200℃, creates the possibility to use a wide range of plastic substrates instead of glass. Furthermore, the (thermo) mechanical properties of organic semiconductors are compatible with plastic substrates. The possibility to use flexible plastic substrates to obtain thin, flexible organic electronics has been shown by several groups. In recent years charge carrier mobilities comparable to that of amorphous silicon have been reported using a variety of organic semiconductors. Some of the envisioned applications include RF-ID, electronic paper, flexible display, and solar cells. The prospect of inexpensive processing and flexible devices makes organic semiconductors especially attractive for use in all organic flat panel display. Specifically, organic semiconductors are of interest as the active electronic element in organic light-emitting diodes (OLEDs) and organic thin film transistors (OTFTs)[1].

Figure 1 illustrates the geometry of the common OTFT design, the inverted staggered structure. This leads to interpenetration between the metal electrodes and organic semiconductor, and improves the contact resistance. Besides, because no previous fabrication has been done to the insulator layer the organic semiconductor film grows with fewer defects, and thus improves device yield. Most of the gate dielectric materials require characteristics including high-permittivity or dielectric constant, barrier properties to prevent tunneling, stability in direct contact with silicon, good interface quality and good film morphology.

In the work reported here, ITO gate electrode surface was modified using O_2 plasma and organic gate insulating layers were deposited on the ITO surface using plasma polymerization technique. We investigated the effect of the RF plasma surface treatment and role of plasma polymerized gate insulating layer on the new dry processing method of OTFTs. The plasma polymerization of the organic gate insulating layers was carried out using a homemade inductively coupled and capacitively coupled RF plasma equipment. Effects of the plasma surface treatment of ITO and plasma polymerized gate insulating layer on the OTFT performance were discussed.



<Fig. 1> Schematic diagram of the plasma polymerization apparatus.

2. EXPERIMENTAL

2.1 Plasma polymerization

The substrates used in this study were ITO-coated glasses with the ITO film thickness of 200 nm and a sheet resistance of 12 Ω/□. The as-received substrates were chemically cleaned by using acetone, ethanol and DI-water with ultrasonic wave, which removed most of the ITO surface organic contaminants. After N_2 gas blow-drying, the cleaned ITO substrate was moved into a vacuum. A homemade plasma polymerization equipment was used for the plasma surface treatment. 13.56 MHz RF plasma generator (AUTO ELEC. ST-500m 600W) was used for creating plasma and matching box (Load coupler LC-1000) was installed for impedance matching. Also, RF power meter (Collins 30K-3) was connected to measure electric discharge power. A vacuum gauge (PG-1S23593 Okano, $10{\sim}10^{-3}$Torr) was used to detect the vacuum. Also, cold trap with liquid nitrogen was installed to protect the rotary pump from the attack of methyl methacrylate (MMA) monomer. The ITO was treated for various period of time in an O_2 plasma before depositions of buffer layer. An inductively-coupled plasma (ICP) was used in the plasma polymerization apparatus for the surface treatment of the ITO. O_2 plasma treatment was carried out at the pressure of 0.1 Torr, Ar flow rate of 10 sccm, and the RF power of 50W, respectively. Without a vacuum break directly after the plasma surface treatment of ITO anode, the organic gate insulating layer was formed by plasma polymerization technique. Plasma polymerized methyl methacrylate (ppMMA) was deposited under the following experimental condition;100W power, 0.1 Torr system pressure, and a deposition time of 15 min with a MMA monomer vapor supply. The film thicknesses with the conditions were approximately 300 nm. While Ar gas was introduced into the reaction tube (5 sccm) to generate the capacitively-coupled plasma (CCP) and the inductively-coupled plasma (ICP), the MMA monomer was the introduced in the Ar plasma and the ppMMA layer was deposited.

2.2 Fabrication of devices

The OTFTs fabricated in this report had inverted staggered structure of ITO/ppMMA/pentacene/Al. Figure 1 shows a schematic diagram of the OTFTs. The device was fabricated by conventional process. Pentacene as a organic semiconductor was thermally deposited on ppMMA-coated ITO substrate at a rate of 1 Å/s.

Source/Drain electrodes was thermally deposited on the pentacene layer with the channel width (*W*) of 2000 μm and the length (*L*) of 50 μm.

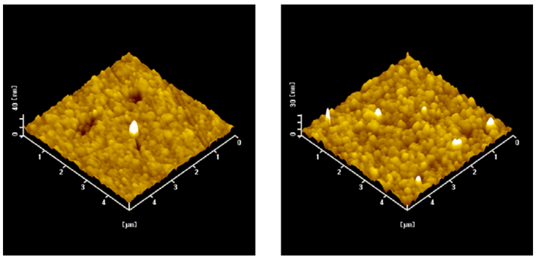
2.3 Characterization

Surface morphology/roughness, chemical composition, and electrical properties of the organic gate insulating layer were investigated using atomic force microscopy (AFM) and Fourier Transform Infrared (FT-IR) spectroscopy, respectively. For the purpose of investigating performance of the OTFTs, electrical properties were measured by a impedance analyzer measurement unit (HP 4192A) and a source measurement unit (SMU;Keithley 2612). Using a personal computer as a measurement process control system, the SMU controlled the supply of voltage through GP-IB interface and measured the current.

3. Results and discussion

3.1 Atomic force microscopy

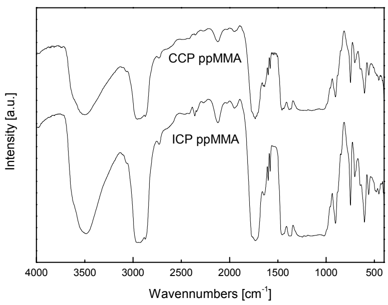
Figure 2 shows the AFM images of O_2 plasma treated ITO surface and ppMMA insulating layer. The ppMMA surface shows a relatively flat surface with a root mean square (RMS) surface roughness of about 1.6 nm compared to the bare ITO with an RMS of 2.8 nm. It is shown that RMS surface roughness of the ITO tends to decrease after the O_2 plasma treatment with a limited treatment time. Inaddition, the enhancement is attributed to the ppMMA layer giving a conformal coverage of the ITO spikes and pinhole, has a smooth morphology interface with good contact for the pentacenede position, resulting the field effect mobility is increased[2].



<Fig. 2> AFM 3D-images of ITO anode surface: (a) bare ITO anode surface (b) O_3 plasma treated and ppMMA insulating layer deposited ITO anode surface.

3.2 Fourier Transform Infrared spectroscopy

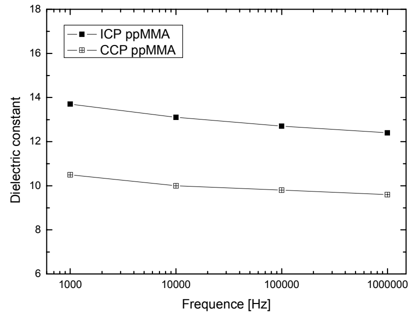
Figure 3 shows the FT-IR spectrum of CCP-ppMMA and ICP-ppMMA dielectric layer. In order to characterize the ppMMA films, ICP-ppMMA and CCP-ppMMA were deposited on a KBr substrate, and there FT-IR spectroscopy were analyzed. While there are differences in the strength and breadth of the absorption peaks between the conventional and corresponding plasma polymers, nearly all the sorption bands characteristic of PMMA are observed to some degree in the plasma polymer analog, ppMMA. The FT-IR spectra of the two films are consistent with similarly processed materials in the literature, which identifies the chemical similarities and dissimilarities of the two materials[3,4].



<Fig. 3> FT-IR spectrum of ppMMA films.

3.3 Permittivity

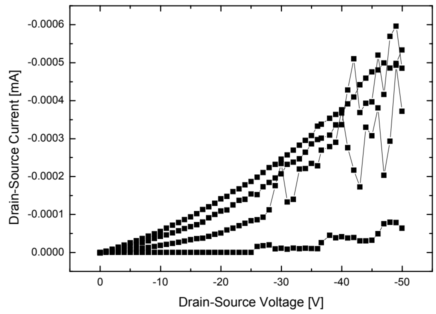
Figure 4 shows the variation of dielectric constant with frequency for ICP-ppMMA and CCP-ppMMA films. The ITO/ppMMA/Al structure was fabricated to analyze electrical characteristics. The dielectric spectra of ppMMA under AC electric fields as a function of frequency varied from 1 kHz to 1000 kHz. CCP-ppMMA and ICP-ppMMA films showed a relative dielectric constance value of 10.5 and 13.8, respectively. Most of the gate dielectric materials require characteristics including high-permittivity or dielectric constant, barrier properties to prevent tunneling, stability in direct contact with silicon, good interface quality and good film morphology[5].



<Fig. 4> Dielectric constant of ppMMA films.

3.4 OTFT characteristics

Figure 5 shows the electrical properties of the OTFTs of inverted staggered structure. New processing method of organic gate insulating layer in OTFTs was fabrication. Characteristics of devices with ICP-ppMMA insulator were measured as about $10^5$of the on/off current ratio, about 10^{11} of off-current, respectively. Even though the device characteristics were not much improved compared with other inorganic/organic gate insulator, ppMMA showed the possibility of application in the OTFTs.



<Fig. 5> Electrical characteristics of the OTFTs

4. SUMMARY AND CONCLUSION

We investigated the electric properties of OTFTs on the ppMMA layer used as a organic gate insulator. Proposed new method can be applied to dry-process to fabricate OTFTs during overall fabricating steps. Application of Flat panel displays has the advantages of shadow mask patterning (solution-free), large area deposition, and low-cost process.

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