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A Study on the Leakage Current Voltage of Hybrid Type Thin Films Using a Dilute OTS Solution

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ABSTRACT

To improve the performance of organic thin film transistor, we investigated the properties of gate insulator's surface according to the leakage current by I-V measurement. The surface was treated by the dilute n-octadecyltrichlorosilane solution. The alkyl group of n-octadecyltrichlorosilane induced the electron tunneling and the electron tunneling current caused the breakdown at high electric field, consequently shifting the breakdown voltage. The 0.5% sample with an electron-rich group was found to have a large leakage current and a low barrier height because of the effect of an energy barrier lowered by thermionic current, which is called the Schottky contact. The surface properties of the insulator were analyzed by I-V measurement using the effect of Poole-Frankel emission.

Key Words : FN tunneling current, Schottky contact, Pools-Frankel effect, OTS, leakage current

1. INTRODUCTION

In recent years, organic semiconductors have been attracting considerable in attention in an attempt to improve the electric properties for ultralarge-scale integration (ULSI) devices. Nontraditional materials such as conjugated organic molecules or organic-inorganic composites are being developed as semiconductors, because the ability of these materials attributed to the π-orbital overlap of neighboring molecules provides their semiconducting properties[1-2]. Among organic materials, organic-inorganic hybrid type n-octadecyltrichlorosilane (OTS, $CH_3(Cl_2)_{17}SiCl_3$) composition has been extensively investigated by researchers[3, 4]. The mobility of ptentacene OTFT's device also improved hybrid type SiOC films with the dielectric constant of 2.1, which shows the red shift caused by the C-H bond elongation effect[5]. In view of pentacene OTFT, the conductivity of organic materials depends on properties of the surface of the substrate on the gate insulator. Therefore, the improvement of the mobility of organic thin film transistor made from organic materials pentacene was achieved by treating the gate insulator materials or different gate insulator[6]. The mechanisms of electric properties may be explained from the observation of such characteristics as ionic flow, space-charge limited flow or tunneling[7-10]. The electric properties of insulators have been researched by examining the effect of Poole-Frankel emission caused by the metal-insulator barrier. The Poole-Frankel effect is similar to the Schottky effect[11]. Schottky effect is the attenuation of a metal-insulator barrier arising from electrod image-force interaction with the field at the metal-insulator interface, and Poole-Frankel effect is the lowering of a Columbic potential barrier associated with the lowering of a trap barrier in the bulk of an insulator. Especially, Poole-Frankel effect is well shown in field assisted thermal ionization[12]. In order to gain an understanding of the current flow process, we made thin insulating films through the various interfacial contacts, and measured the I-V of specimens. The conduction mechanisms in various types of film were studied by analyzing the current-voltage (I-V) curve dependence on the various inter-

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facial contacts. We report on the electrical properties of the hybrid type surface of the sample as a function of OTS content.

2. EXPERIMENT

n-octadecyltrichlorosilane (OTS) was purchased from Aldrich, and chloroform and hexane were obtained from Fluka. The SiO_2 gate dielectric on p-type Si wafer was grown to the thickness of 100 nm, and these wafers were soaked in OTS dilute solution to treat the surface. The rate of the mixed solution of chloroform ($CHCl_3$) and hexane was 300:700, and OTS was injected using the mucro-pipet as shown in Fig. 1.

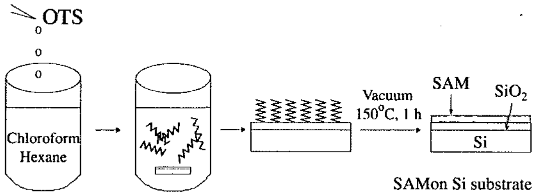

Fig. 1. Surface treatment using a dilute OTS solution on SiO_2 dielectrics.

The OTS solution was made from OTS:chloroform :hexane=1:300:700 and 5:300:700. Finally, we prepared the OTS dilute solution of 1% and 5%. OTS ($CH_3(Cl_2)_{17}SiCl_3$) is the organic composition with many alkyl group, therefore the film treated to 0.1% OTS has more hybrid properties than that of 0.5% OTS. The SiO_2/Si prepared wafers were soaked in the prepared solution for 30 minutes, and the surface was cleaned for 5 seconds in a mixed solution of chloroform and hexane at the rate of 300:700 and annealed in a vacuum chamber at 150°C for 1 hour. After the surface state modifications of hybrid type by using dilute OTS solution, for the analysis of electric properties, the aluminum were evaporated using the mask pattern on the surface of the specimen, where the sputter-deposited aluminum with an area of $(0.1/2)^2 \times \pi$ cm was used on the top electrode. The leakage currents were measured by I-V characteristic at 1Mhz using the MIS (Al/ SiO_2 treated OTS/Si) structure.

3. RESULTS AND DISCUSSION

3.1. Fowler-Nordheim tunneling

Fig. 2 shows the leakage current density (J) versus root of electric Field E characteristic in view of the OTS content for surface treatments. The sample (a) without a treatment shows the breakdown near

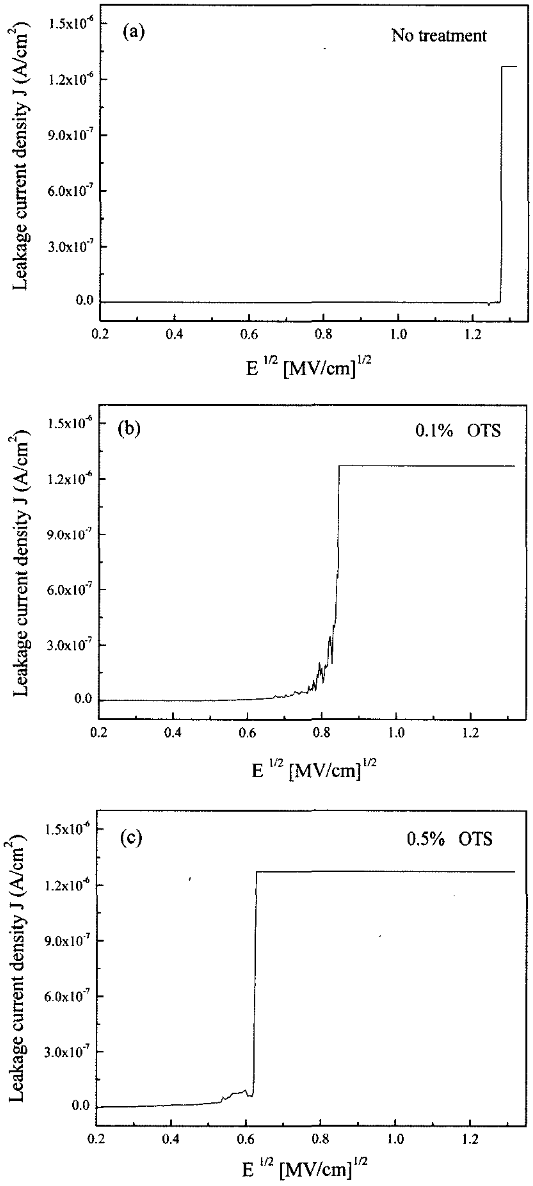

Fig. 2. Leakage current density (J) versus root of electric Field E characteristic of samples treated various dilute OTS solution.

$1.3\sqrt{E}(MV/cm)^{1/2}$ and the sample (b) with the treatment of 0.1% OTS is near $0.8\sqrt{E}(MV/cm)^{1/2}$ and the sample (c) with the treatment of 0.5% OTS is near $0.6\sqrt{E}(MV/cm)^{1/2}$.

The breakdown voltage decreased with the increasing content of OTS treatment as shown in Fig. 2(c), because the current increased owing to electron tunneling by the increasing electric field. In the case of thin insulators, when an electric field is applied across an insulator, electrons tunnel from the cathode to the conduction band of an insulator, therefore, the positive charged region occurs on the side of metal interface, and the negative charged region occurs on the side of the insulator interface. These charge separations generate the electric field and make the band bending in the energy diagram. Fig. 3 shows the band bending such as triangular energy barrier in the insulator. If the electric field is very high, electrons can easily flow across the insulator with a trangular energy barrier and the breakdown occurs. These tunneling currents cause the breakdown (VT) shifts and degrade the circuit performance. These mechanisms are called the effect of Fowler-Nordheim tunneling. The surface of sample (c) with the treatment of 0.5% OTS involves rich electrons owing to the alkyl group in composition. We learned that the tunneling current as the leakage current attributed to the breakdown originates from this electron-rich group.

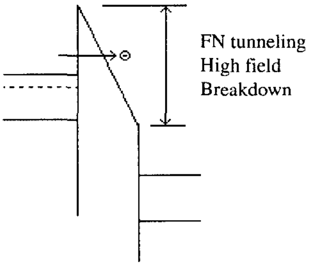

Fig. 3. Tunneling current due to Fowler-Nordheim effect in thin insulator with the high field.

3.2. Leakage current

Fig. 4 shows the breakdown occurs near $0.5\sqrt{E}$ $(MV/cm)^{1/2}$ when the current suddenly increases. The current increases an exponential function after the breakdown. For instance, the no-treatment sample shows good properties as insulator because there is no leakage current until $1.3\sqrt{E}(MV/cm)^{1/2}$ as shown in Fig. 4(a). The sample of Fig. 4(c) treated with 1% OTS also shows an exponential increase in the current after a breakdown near $0.5\sqrt{E}(MV/cm)^{1/2}$. In the case of Fig. 4(b), the first breakdown near $0.5\sqrt{E}(MV/cm)^{1/2}$ is caused by the interface of SiO_2/Si, and the second breakdown is attributed to the interface between 0.1% OTS treatment and SiO_2 thin film. These findings let us to believe that the increas-

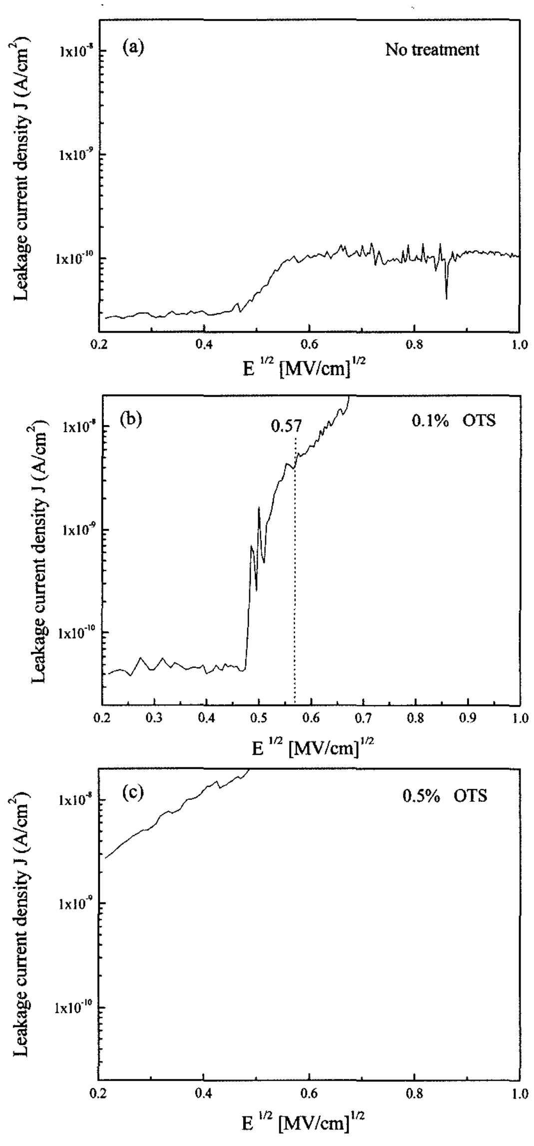

Fig. 4. Breakdown between an insulator and a silicon substrate near $0.5\sqrt{E}(MV/cm)^{1/2}$.

ing OTS content decreases the second breakdown (VT). Fig. 5(a) shows that the leakage currents near $0.5\sqrt{E}(MV/cm)^{1/2}$ occurred at interface of SiO_2/Si in MIS structure, and the sample in Fig. 5(c) treated with 5% OTS has the large exponentially increasing current, and there is no breakdown mechanism near $0.5\sqrt{E}(MV/cm)^{1/2}$. On the other hand, the sample of Fig. 5(a) without treatment does not have any exponential increasing current. Thus the leakage current between (a) sample and (b) or (c) samples originates from different reasons.

3.3. Poole-Frenkel conduction

Poole-Frenkel conduction defines the leakage mechanism of insulator with thin film. The current density is based on Poole-Frenkel conduction as

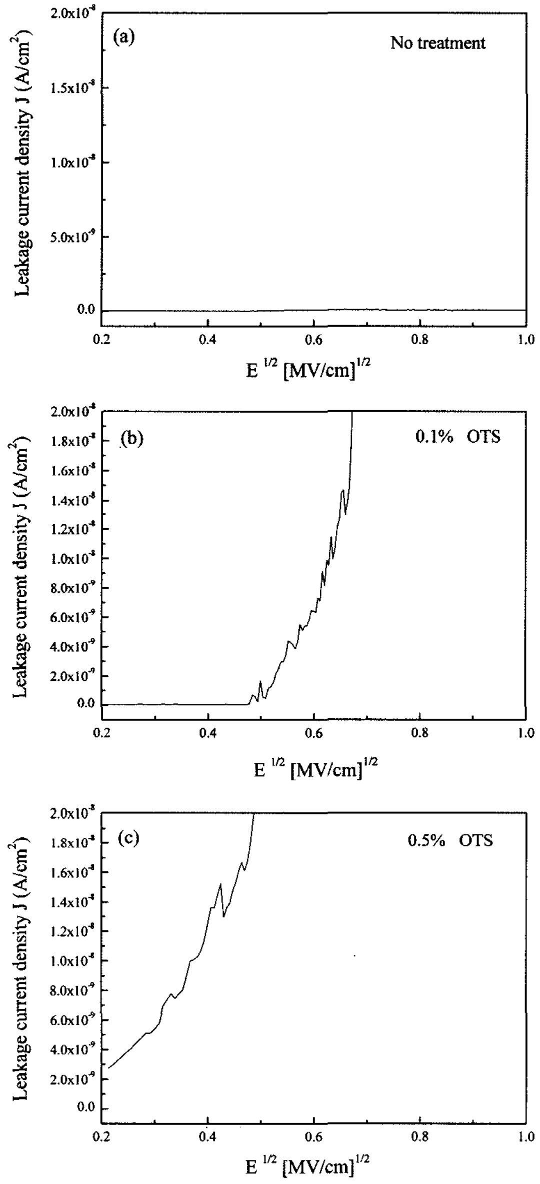

Fig. 5. Leakage current with exponentially increasing on the surface treated dilute OTS solution.

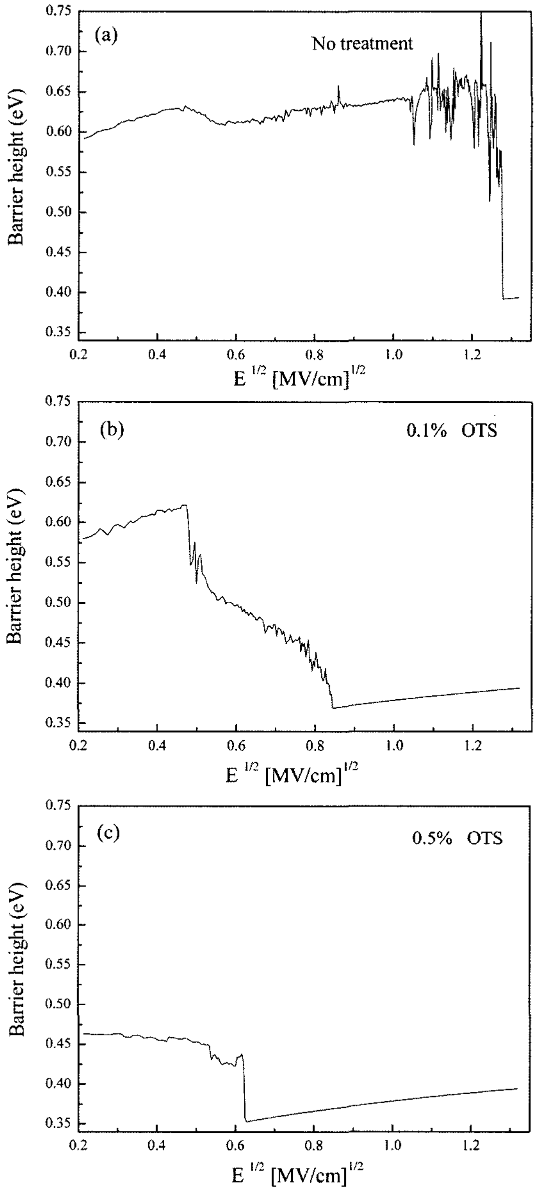

Fig. 6. Barrier height according to the electron energy at various surfaces treated with dilute OTS solution.

explained by the equation (1) below, and the barrier height is obtained.

$$J \propto E\exp(-q\Phi_B/kT)\exp[(q/kT)(qE/\pi\varepsilon_0\varepsilon_r)^{1/2}] \quad (1)$$

where Φ_B, T, q, E, k, ε_0 and ε_r are the barrier heights at the injected electrode, absolute temperature, electric charge, electric field strength in the insulator, Boltzmann's constant, the dielectric constant of free space and the relative dielectric constant at high frequency, respectively.

Fig. 6 shows the barrier height of electron energy obtained from I-V characteristic curves using equation (1). The barrier height of the sample without treatment is higher than any others as shown in Fig. 6(a). The sample of Fig. 6(c) with 0.1% OTS treatment clearly shows two kinds of breakdown. The barrier height of Fig. 6(a) is almost twice in comparison with that of Fig. 6(c). These findings let us to conclude that the sample without treatment generates Ohmic contact on the surface, and the high barrier height does not allow leakage currents. However, the sample with 0.5% OTS treatment shows the effect of Schottky contact between a metal and a SiO_2 film at the equilibrium, and the low barrier height causes leakage currents.

4. CONCLUSIONS

The surface properties under various treatments were analyzed from the leakage current by the I-V measurement. The direct tunneling of electrons across an insulator at high electric field causes the breakdown, which is known as the FN tunneling effect. The breakdown of silicondioxide as conventional low-dielectrics occurs at $1.3\sqrt{E}(MV/cm)^{1/2}$. The contact of samples attributed to increase the OTS content changed from Ohmic contact to Schottky contact. Ohmic contact caused by a high energy barrier, while Schottky contact was caused by the thermionic current. Therefore, the alkyl group of OTS makes the lowering energy barrier and then increases the leakage current.

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REFERENCES

1. Knipp, D., Street, R. A., J. Non-crystalline Solids, 338-340 (2004) 595.
2. Nathalie Vets, Mario Smet and Wim Dehaen, Tetrahedron Letters, Vol. 45, 7287 (2004) 7287.
3. Ashurst, W. R., Yanu, C., Carraro, C., Maboudian, R. and Dugger, M. T., Journal of Microelectromechanical systems, 10 (2001) 41.
4. Max Shtein, Jonathan Mapel, Jay B. Benziger and Stephen R. Forrest, Applied Physics Letters, 81(2) (2002) 268.
5. Oh, T. R. S., Jpn. J. Appl. Phys. 44, (2005) 1409.
6. Gundlach, D. J., Lin, Y. Y., Jackson, T. N., Nelson, S. F. and Schlom, D. G. IEEE ELECTRON DEVICE LETTERS, 18, (1997) 87.
7. Pernstich, K. P., Goldmann, C., Krellner, C., Oberhoff, D., Gundlach, D. J. and Batlogg, B., Synthetic Metals 146, (2004) 325.
8. Cheng, K. H. and Krishnamoorthy, A., Thin Solid Films, 462-463, (2004) 316. 75 (2002) 393.
9. Kalita, P. K., Sarma, B. K. and Das, H. L., Bull. Mater. Sci., 26, 613 (2003).
10. Mead, C. A., Phys. Rev. 128 (1962) 2088.
11. Emtage, P. R. and Tantraporn, W., Physcal Review, 8 (1962) 267.
12. Kellicutt, M. J., Suzuki, I. S., Burr, C. R. and Suzuki, M., Physical Review B, 47 (1993) 664.