Development of Highly Heat-Resistant, Dry-Etchable Blackening Film for TFT Wiring

Daisuke Kaneko[1], Keita Umemoto[1], Hiromi Nakazawa[2], Shin Okano[1], Yukiya Sugiuchi[1], Takeshi Ohtomo[1]

dakaneko@mmc.co.jp
[1]Mitsubishi Materials Corporation Sanda Plant, Sanda-shi, Hyogoken, 669-1339, Japan,
[2]Mitsubishi Materials Corporation Central Research Institute, Naka-shi, Ibaraki-ken, 311-0102, Japan,
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ABSTRACT

In the LTPS gate wiring, the requirements of heat-resistance and dry-etchability are getting higher quality because of the demand of higher resolution display. In this paper, we developed blackening material to enhance the heat resistance targeting to LTPS TFTs wiring. Moreover, we investigated the influence of deposition conditions for film properties from the viewpoint of film composition. Lastly, we also discussed properties of TFT when the blackening material applied to not only the gate electrode but also source/drain electrode.

1 Introduction

In recent years, many techniques related to high-resolution have been researched for high-end display[1][2]. In those research, we've been focusing on TFT wire blackening technique such as for enlarging the aperture area of pixel[3][4], and for bottom side blackening to realize the borderless LCD[5]. On the other hand, regarding the LTPS gate wiring, the requirements of heat-resistance and dry-etchability are getting higher quality because the demand of higher resolution display[6][7]. Molybdenum is commonly used as gate electrode of LTPS because of its process applicability than copper and aluminum. In this paper, we developed blackening material for Mo gate electrode, which has dry-etchability, high heat-resistance (up to 600 ° C). Moreover, we investigated the influences of deposition conditions for film properties from the viewpoint of film composition. Lastly, we also discussed properties of TFT when the blackening material applied to not only the gate electrode but also source/drain electrode.

2 Experiment

2.1 Deposition Condition

In this research, DIABLA35-1 sputtering target was designed to be optimal optical constant for blackening Mo[4] with high heat-resistance and made by sintering of highly durable metal and oxide powder mixture. The size of sputtering target was machined to 125 mm in diameter. The film deposition was performed by DC magnetron sputtering without reactive gas such as oxygen and nitrogen. The single blackening film deposited on Si substrate for analyzing optical constant. The EAGLE XG (Corning inc.) glass substrate was used for the electrical resistivity measurement to avoid the resistivity of substrate. The reflectivity was evaluated by DIABLA35-1/Mo/glass structure because Mo is often used for gate wiring of LTPS-TFTs.

2.2 Analysis

The refractive index and the extinction coefficient of DIABLA35-1 were obtained by spectroellipsometer UVISEL (HORIBA, Ltd.). The sheet resistivity was measured with DIABLA35-1 50 nm in thickness by loresta-GP (Nittoseiko Analytech Co., Ltd.). The reflectivity was measured by spectrophotometer UH-4150 (Hitachi High-Tech Corporation). In order to evaluate the durability, the reflectivity was measured before and after the heat treatment in nitrogen gas at 600 °C in 20 minutes by Au image furnace. For dry-etching experiment, RIE-101iPH (Samco Inc.) was used, and then the cross-section was observed by FE-SEM SU-70 (JEOL Ltd.). The film composition was analyzed by EPMA, JXA-8500F (JEOL Ltd.). The film density was obtained by XRR Smartlab SE (Rigaku Corporation). The plasma spectrum during sputtering was observed by HR4000CG-UV-NIR (Ocean photonics). The TFT with and without DIABLA were fabricated as shown in Fig.1 (W/L=100/40μm). The I_d-V_g curves were obtained by Model 4200A-SCS Parameter Analyzer (Keithley Instruments).

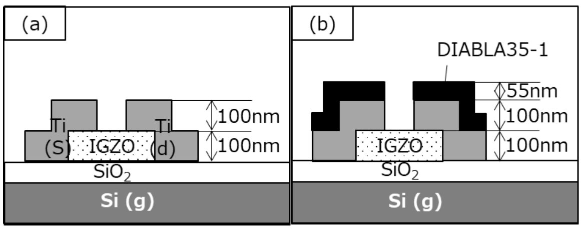

Fig. 1 The structure of I_d-V_g curve measurement samples (a) Ti/IGZO/SiO_2/Si, (b) DIABLA35-1/Ti/ IGZO/SiO_2/Si

3 Results

3.1 Evaluation of reflectivity and heat resistance

Fig.2 shows the results of reflectivity measurement in before and after heat-treatment. In the general top-gate LTPS-TFT, the blackening film should mount on the gate. In this paper we discuss the blackening film deposited on the upper side of wiring. The deposition condition for DIABLA35-1 was 4.1 W/cm^2 and 2.0 Pa. The average reflectivity of the DIABLA35-1 deposited sample in visible light (λ: 380nm-780nm) was 5.9 % before heat-treatment. That means the DIABLA35-1 reduced the reflectivity from 50.5 % without DIABLA to 5.9 %. The reflectivity did not change before and after the heat-treatment at 600 °C, indicating that DIABLA35-1 has high heat resistance.

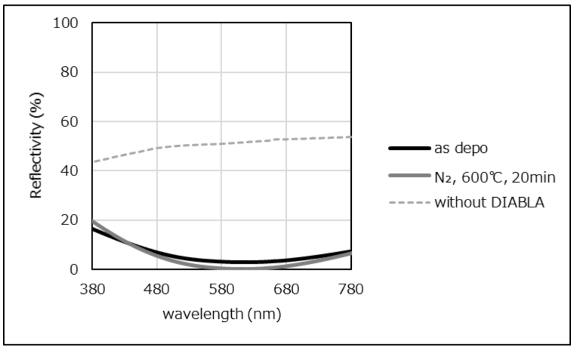

Fig. 2 The reflectivity before and after heat-treatment of DIABLA35-1(55 nm)/Mo(50 nm)/glass.

3.2 Evaluation of dry etching

Fig.3 shows the cross-sectional SEM image of DIABLA35-1(60 nm)/Mo(50 nm)/glass after dry etching. CF_4 and O_2 gas was used as the etching gas for dry etching process. It was possible to etch the wiring with DIABLA35-1 all at once.

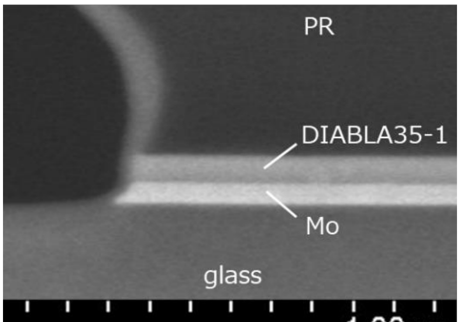

Fig. 3 Cross-sectional SEM image of DIABLA35-1(60 nm)/Mo(50 nm)/glass after dry etching.

3.3 Influences of deposition conditions for film properties

Firstly, the properties of the single film of DIABLA35-1 were investigated. The dependence of the refractive index (n) and the extinction coefficient (k) on the deposition power density is as shown in Fig.4(a). The higher the power density, the higher the refractive index and extinction coefficient respectively. As for the sheet resistance (Rs), higher value was shown in Fig.4(b) in lower power density. In addition to the power density, the sputter pressure dependence was also investigated (Fig.5). When the gas pressure was lower, the n and k were increased and Rs was decreased respectively and showed the opposite tendency to the power density. The relationship between film properties and deposition conditions will be discussed from the perspective of film composition and film density. Next, the blackening property of these films was investigated.

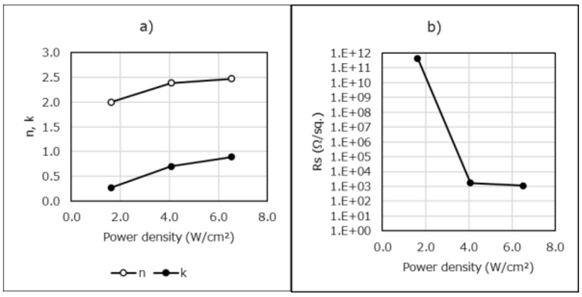

Fig. 4 The power density dependence of (a)refractive index (n) and extinction coefficient (k) (each value is average of 380 nm-780 nm) and (b)sheet resistivity at 50 nm. The deposition pressure was fixed to 0.67 Pa.

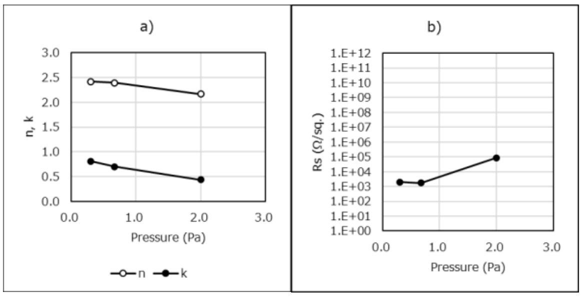

Fig.5 The sputter pressure dependence of (a)refractive index (n) and extinction coefficient (k) (each value is average of 380 nm-780 nm) and (b)sheet resistivity at 50 nm. The power density was fixed to 4.1 W/cm^2.

Fig.6(a) shows the power density dependency of reflectivity in DIABLA35-1/Mo(50 nm)/glass sample and the simulation results of insulator(3 μm)/DIABLA35-1/Mo(50 nm)/glass sample where the ideal insulator (n=1.4, k=0) was used to simulate the actual TFT structure. The deposition pressure DIABLA35-1 was fixed at 0.67 Pa. From the rule of n×d and k value of blackening film[3], the film thickness of DIABLA35-1 was set 60, 50 and 50nm for 1.6, 4.1 and 6.5 W/cm^2 respectively to get the lowest reflectivity on Mo film. Similarly, the thickness of DIABLA35-1 with insulator structure was set to 65, 55 and 55 nm for 1.6, 4.1 and

6.5 W/cm^2 respectively. The reflectivity value is the average value of visible light (380 nm-780 nm). The DIABLA35-1 stacked films were significantly reducing the reflectivity of Mo. Generally, the average reflectivity of Mo is around 50 %, so that the reflectivity could be suppressed over 40 % by DIABLA35-1 deposition in both bare and insulator stacked structure. Without the insulator structure, the reflectance was minimal at 1.6 W/cm^2, but with the insulator structure, the reflectance was minimal at 4.1 W/cm^2. These data show the optimal optical constant of blackening film is changed by upper insulator.

Fig.6(b) shows sputter pressure dependency of reflectivity in DIABLA35-1/Mo(50 nm)/glass sample and the simulation results of insulator(3 μm)/DIABLA35-1/Mo(50 nm)/glass sample. The film thickness of DIABLA35-1 was set by the same procedure as Fig.6(a). The thickness was set 50, 50 and 60nm for 0.30, 0.67 and 2.0 Pa respectively in without insulator structure, and it was set 55, 55 and 65 nm for 0.30, 0.67 and 2.0 Pa respectively in with insulator structure. Where the deposition power density was fixed at 4.1 W/cm^2. In both cases with and without the insulator structure, the higher the sputter pressure, the lower the reflectivity. The lowest reflectance was 2.1 % with the insulator structure at 4.1 W/cm^2, 2.0 Pa condition.

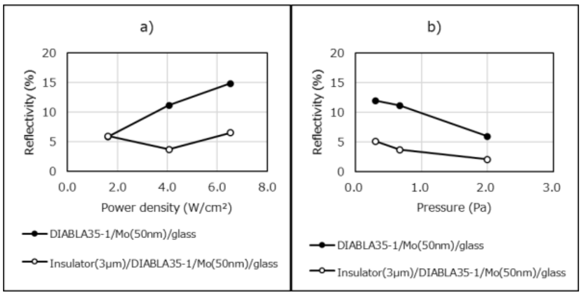

Fig. 6 The DIABLA35-1 stacked film reflectivity of (a)power density dependency and (b)sputter pressure dependency.

3.4 Evaluation of TFT electrical properties

When the blackening film deposited on the upper side of the gate, the electrical properties don't change because there is no additional layer between the gate and the semiconductor layers. Therefore, the blackening film deposited on the upper side of the source/drain was investigated. Fig.7 shows the I_d-V_g curves of TFT with and without DIABLA35-1. The deposition condition for DIABLA35-1 was 4.1 W/cm^2 and 2.0 Pa. In the sample without DIABLA35-1 prepared as a reference the threshold voltage (V_{th}) was -0.1 V, the subthreshold factor (SS) was 0.082 V/dec, and the field effect mobility (μ_{FE}) was 15.9 cm^2/V · s, respectively. In the sample with DIABLA35-1, the I_d-V_g curve was almost the same as the sample without DIABLA35-1, the V_{th} was -0.1 V, the SS was 0.101 V/dec, and the μ_{FE} was 14.1 cm^2/V · s, respectively. It revealed that DIABLA35-1 also can be used for blackening source/drain wiring.

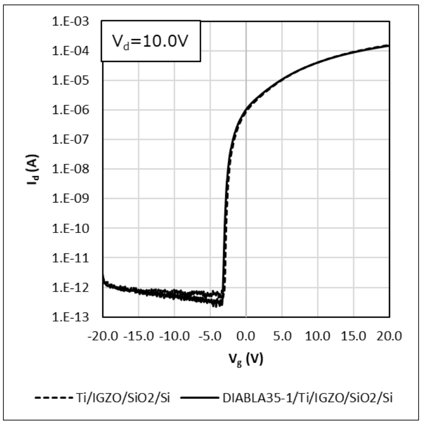

Fig. 7 The I_d-V_g curves of TFT with and without DIABLA35-1

4 Discussion

In order to investigate the cause of the change in DIABLA35-1 film properties depending on the deposition conditions, film compositions were analyzed by EPMA. The results are shown in Fig.8. The film compositions differed depending on the deposition conditions, the metal composition tendency was matches well that of the change in the film properties. From these results, it was considered that the change in the film properties was deeply related to the film compositions.

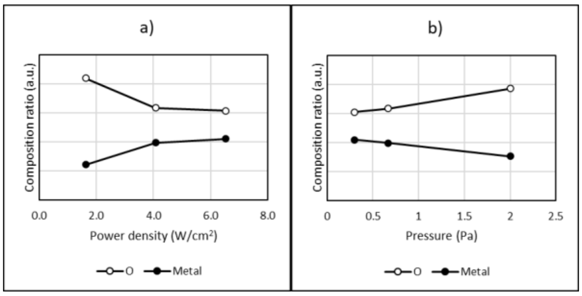

Fig. 8 The DIABLA35-1 film composition of (a)power density dependency and (b)sputter pressure dependency. The Y-axis shows the ratio of detected value per theoretical value.

Furthermore, the cause of the change in the film composition due to the deposition conditions was investigated. Especially in the sample deposited with low power density, oxygen ratio was much higher than the stoichiometric ratio. In addition, as a result of plasma analysis during DIABLA35-1 sputtering, no oxygen peak (777 nm) was observed not shown in figure. It was found that the sputtered particles existed not as dissociated oxygen but as neutral oxide particles. Therefore, excessive oxygen is considered to be an oxide produced by the reaction with oxygen in the atmosphere after the deposition. Fig.9 shows the film density of DIABLA35-1 obtained from XRR measurement. The film density was lower in the sample deposited with low power and high pressure. It is considered that these samples had a large surface area contact with oxygen in the atmosphere.

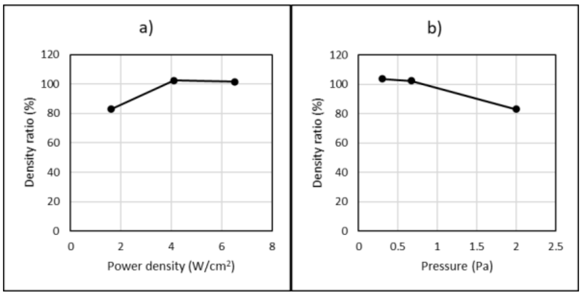

Fig. 9 The DIABLA35-1 film density obtained by XRR of (a)power density dependency and (b)sputter pressure dependency.

Lastly, the cause of the change in film density depending on the deposition conditions was considered. We hypothesized that the change in the kinetic energy of the sputtered particles related to the film density. To prove the hypothesis sputtering targets consist of heavier metal (M_H) and lighter metal (M_L) as substitute of the metal in DIBALA35-1 were prepared respectively. These film compositions were investigated by the same method as DIABLA35-1. The results of oxygen were shown in Fig.10. The weight of the element increases in the order of M_L, metal component of DIABLA35-1, and M_H. The atomic peening effect differs depending on the metal weight[8]. The relationship between the amount of oxygen and each metal during low-power deposition was in good agreement. The film density changes can be explained by the atomic peening effect.

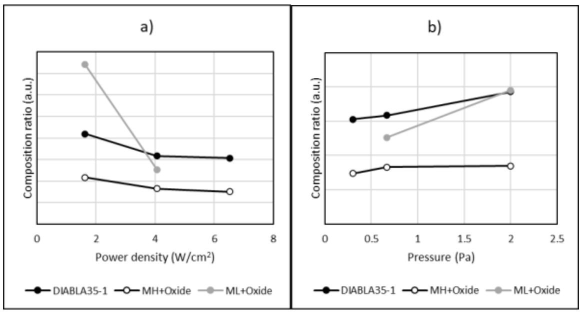

Fig. 10 The composition ratio of oxygen in DIABLA35-1, M_H+Oxide and M_L+Oxide of (a)power density dependency and (b)sputter pressure dependency.

5 Conclusions

It was possible to develop a dry-etchable blackening material with high heat resistance by combining a highly durable metal and oxide. The average reflectivity of Molybdenum was suppressed over 40% by deposition of DIABLA35-1 film. This kind of material can also be applied to source and drain electrodes and has almost no effect on TFT properties.

It was clarified that the cause of the change in film properties depending on the deposition conditions is the change in film composition. Furthermore, it was found that the cause of the change in the film composition depending on the deposition conditions is the change in the film density. The low density films obtained in lower power and higher gas power conditions were thought to be related to the magnitude of the atomic peening effect.

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