Fabrication of Novel Thin Film Diode with Multi-step Anodic Oxidation and Post Heat-treatment

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Thin film diode with reliable interfacial structure was fabricated by using multi-step anodic oxidation. The thickness of the oxide layer was preciously controlled with anodic voltage. Also, interfacial structure between oxide layer and top electrode was improved by applying post heat-treatment. The thin film diode showed symmetric and stable I-V characteristics after the post heat-treatment.

Keywords : Thin-film diode, Multi-step, Anodic oxidation, Top electrode, Heat-treatment

1. INTRODUCTION

Recently, a remarkable progress has appeared in mobile communication industry. The mobile devices require the display with high performance such as fast speed, low power consumption, and full color, etc[1,2]. Especially, a switching device is absolutely necessary for moving pictures in IMT-2000. But, thin-film transistor liquid-crystal display (TFT-LCD) is not suitable for the purpose because of high power consumption and high cost. As an alternative, active-matrix (AM) LCD with thin-film diode (TFD) is being spotlighted[3,4]. It has many advantages, for example, low power consumption and low cost, etc. So, it is expected to be one of the best candidates for displays of IMT-2000. In order to apply the TFD-LCD to the mobile devices, both high quality and lower power consumption for display should be satisfied. For the high quality, it is required that the TFD devices have a perfect symmetrical curve of a I-V characteristic while a positive voltage and a negative voltage are applied. Also, for the low power consumption, display should be turned on at lower threshold voltage. TFD has an oxide layer between top and bottom metal electrodes. The quality of the oxide is one of the important factors to determine the performance and power consumption of display. As the oxide layer, generally, Ta_2O_5 is fabricated by anodic oxidation, sputtering, CVD, etc. Among these methods, anodic oxidation is preferred because the anodized Ta_2O_5 has a lot of advantages such as low cost and high throughput. However, the quality of the anodic oxide may cause problems such as reliability and lifetime[5,6].

In this work, we attempted new processes of our unique multi-step anodic oxidation and post annealing treatment. The new processes were applied to the fabrication of high performance TFD device with simple structure, low threshold voltage and perfect symmetry. The fabricated TFD device was investigated and characterized by TEM, RBS, and electrical measurements, respectively.

2. EXPERIMENTAL

A simple structure with one TFD and one electrical path was designed. As a substrate, the glass for high temperature was used, which size was 7 × 7 cm. An etch stopper was formed on the glass substrate to prevent the damage of the glass by etching solutions applied when patterning the metal electrode. As a bottom electrode, Ta was coated by a sputtering method. The thickness of Ta was 200nm. The Ta was patterned by photolithography and wet etching to form a bottom electrode of test pattern. Then, multi-step anodic oxidation was performed at room temperature in dilute ammonium tartrate aqueous solution as an electrolyte. The profile of the anodic current step was shown in Fig. 1. The first step is to increase the current density step by step. The second step is to keep the current density constant in order for linear growth. The thickness was monitored by anodic voltage. In this work, the maximum voltage was 23V to control the thickness to 26nm. The last step is to decrease the current density exponentially.

After the oxidation, Cr was coated on the oxide layer and patterned as a to electrode Thickness of the Cr was 350nm. Finally, the TFD device was heat-treated at one time to improve the interfacial structure between metal and oxide layers. The surface and the cross-section of the fabricated device was observed and analyzed by optical microscope, Transmission Electron Microscope (TEM), and Rutherford Back Scattering (RBS) spectroscopy, respectively.

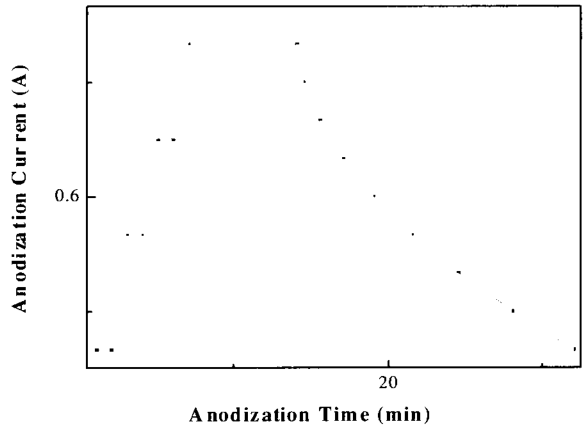

Fig. 1. Multi-step anodic oxidation.

3. RESULTS AND DISCUSSION

3.1 Fabrication of the TFD device

The fabricated TFD device was shown in Fig. 2. The TFD device was well fabricated without damage of substrate. So, the etch stopper was turned out that to be effective for the protection of the glass substrate against the etching solutions. For detail investigation of tantalum oxide and two electrodes, cross-section of the TFD was observed with TEM. Shown in Fig. 3, the oxide layer was uniform and clean. The thickness of the oxide was 27nm.

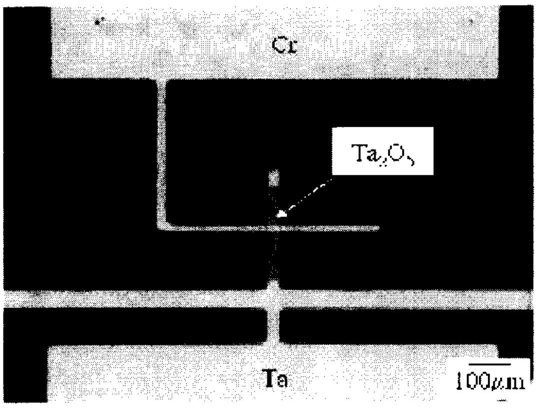

Fig. 2. Fabricated TFD device.

From this result, it was known that the quality and the thickness were preciously controlled by the new multi-step anodic oxidation method. Also, depth profile of the TFD without top electrode analyzed by RBS is shown in Fig. 4. The analysis of the depth profile was done with the direction of the incident ion beam was tilted as 10° to the parallel direction of the sample surface for more exact results. The straight and the serrated lines were corresponded to the results of the simulation and measurement, respectively. The simulation was based on the assumption that the tantalum oxide was Ta_2O_5. The two lines were exactly matched for Ta oxide layer. From the analysis, it is known that the anodized tantalum oxide is Ta_2O_5. So, Ta oxide with good quality could be fabricated by the new anodic oxidation method.

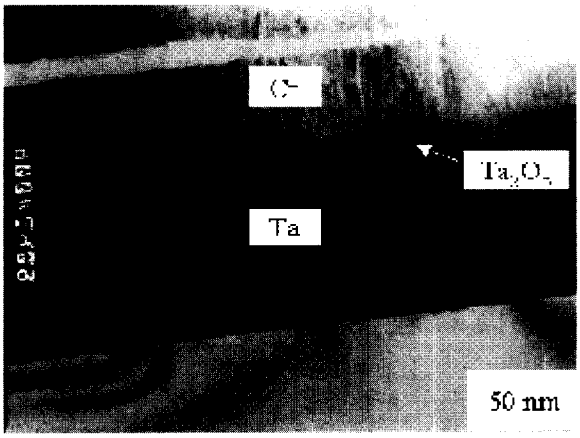

Fig. 3. Cross-section of TFD structure.

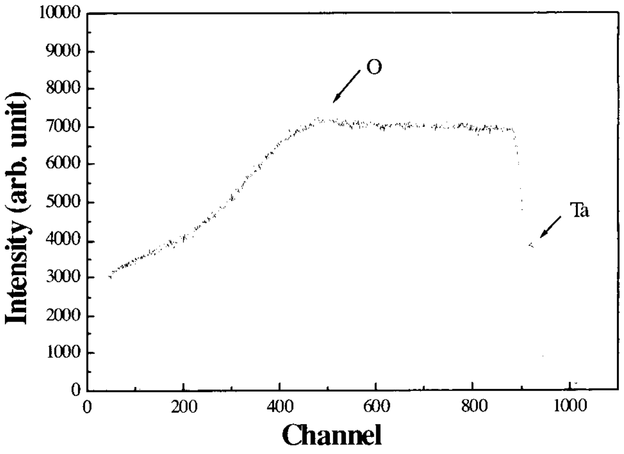

Fig. 4. Depth profiles of O and Ta in Ta_2O_5.

However, as seen in Fig. 5, void defect was found at the interface between oxide and Cr top electrode. The main reason of the defect was suspected due to mismatch between two layers caused by surface roughness of the tantalum oxide. The surface roughness causes non-uniform distribution and local concentration of current. In consequence, it accelerates breakdown of TFD device [7]. This mismatch defect at the interface should be improved for high performance and reliability.

So, post heat-treatment process was extensively applied to remove the defect of the device. The heat-treatment was done at 350°C for 2 hours.

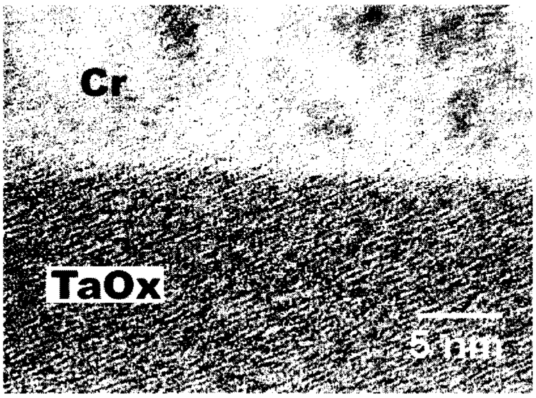

Fig. 5. Interface between Ta_2O_5 insulator and Cr top electrode as fabricated TFD device.

As a result, the defect was wiped out and the interface was improved as represented in Fig. 6. This is guessed to the two phenomena. First, inter-diffusion between the two layers fills out the void defect during the heat-treatment. Second, the surface roughness was decreased by the heat-treatment. Therefore, the post heat-treatment was proved to be a appropriate process for high quality TFD device.

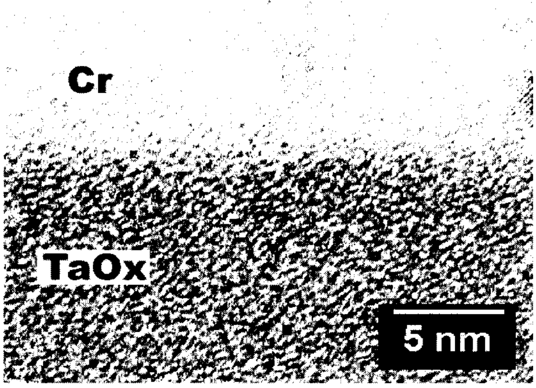

Fig. 6. Interface between Ta_2O_5 insulator and Cr top electrode after post heat-treatment.

3.2 I-V Characteristics of the TFD device

I-V characteristic of the fabricated TFD device was measured for evaluation of the performance. Fig. 7 shows the I-V curve according to the heat-treatment temperature. In case of non heat-treatment, the I-V characteristics exhibited unstable phenomena. At the first measurement, current could not penetrate the TFD despite of applying high voltage potential. However, at the second measurement, abrupt current penetration and breakdown of the TFD device occurred. The breakdown was caused by the defect at the interface between oxide and upper electrode. Owing to the mismatch, the anomalous distribution and local concentration of current occurred at the interface. Thus, the concentration of current caused abrupt breakdown of the device[7,8].

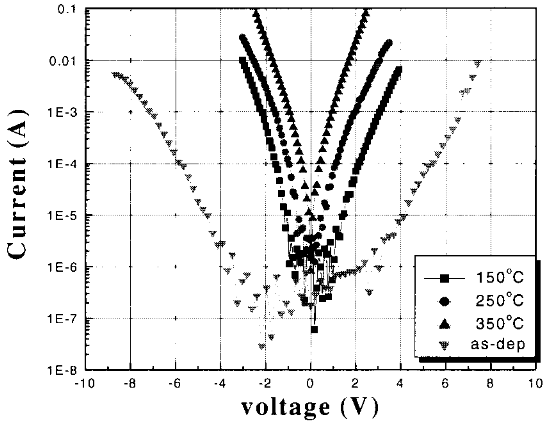

Fig. 7. I-V characteristics of the TFD device.

The mismatch should be removed for the reliable TFD device with low threshold voltage and symmetry. So, post heat-treatment was applied. As a result, the stability of the TFD was improved. It is thought that the mismatch of the interface was removed by the heat-treatment. As the temperature rises up to 350°C, the switching behavior was enhanced. But, above 450°C, the switching function of the TFD device was disappeared. So, the heat treatment was carried out below 350°C.

At the lower heating temperature, the I-V characteristic curve showed asymmetric phenomena. That is, Forward and reverse threshold voltages are not same. Threshold voltage is the voltage when current becomes 100nA [9,10]. When forward current flows, the threshold voltage was 5V. But, when reverse current flows the threshold voltage was 3.5V. So, for high quality display, this asymmetry should be improved[11]. Conduction mechanism of Ta_2O_5 is well explained with Poole-Frenkel equation[5]. One of the main factors affecting the conduction mechanism is donor density. When donor density is increased, conduction band approaches to Fermi energy level. Therefore, the energy level is dependent on the distribution of donor concentration. As the result, the threshold voltage can be controlled by the concentration profile.

So, post heat-treatment process was extensively applied to control the threshold voltage and symmetry of I-V characteristic curve. The result is shown in Fig. 8. The variation of the threshold voltage was apparent with the annealing temperature of the heat-treatment. As the temperature was increased, the threshold voltage was decreased. It is suspected that the phenomenon is due to the change of donor density according to depth of the TFD. That is, higher temperature enhanced the inter-diffusion at the interface, and the energy level difference was decreased. The threshold voltage at 350°C was 1.4 V, very low power consumption.

In order to evaluate symmetry, we defined the asymmetric ratio as $V_{th}(+)$ / $V_{th}(-)$. That is, as the asymmetric ratio approaches to 1, it means that the symmetry is improved. As presented in Fig. 9, the asymmetric ratio was decreased as the temperature was raised. It is considered that the post heat-treatment process reduced the difference in donor densities of two interfaces and the symmetry was improved. So, the multi-step anodic oxidation and post heat-treatment

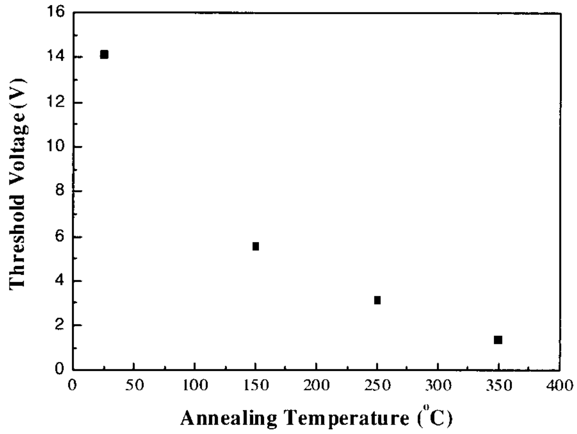

Fig. 8. The variation of threshold voltage with temperature in post heat-treatment process.

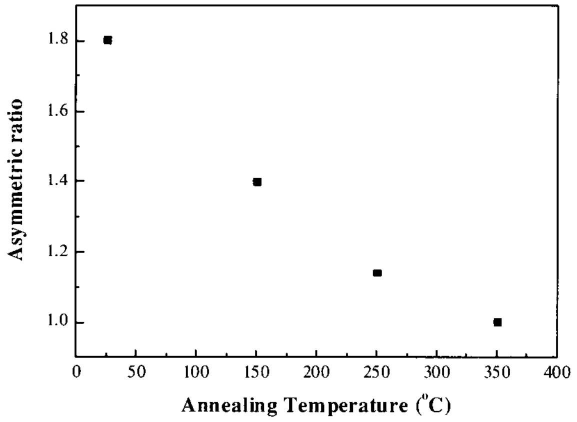

Fig. 9. The variation of asymmetric ratio with temperature in post heat-treatment process.

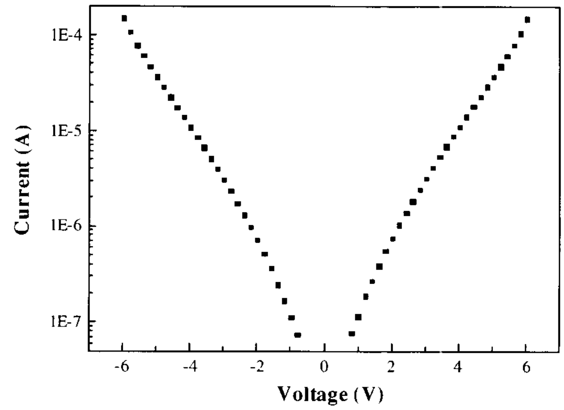

Fig. 10. I-V Characteristic curve of the TFD device with low threshold voltage and perfect symmetry.

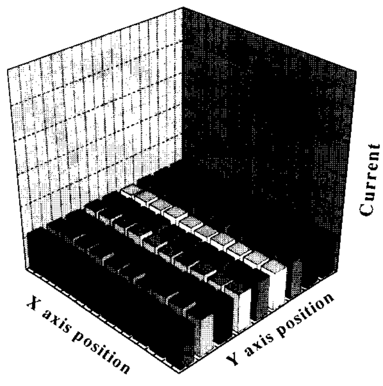

Fig. 11. Uniformity of the I-V Characteristic of the TFD devices.

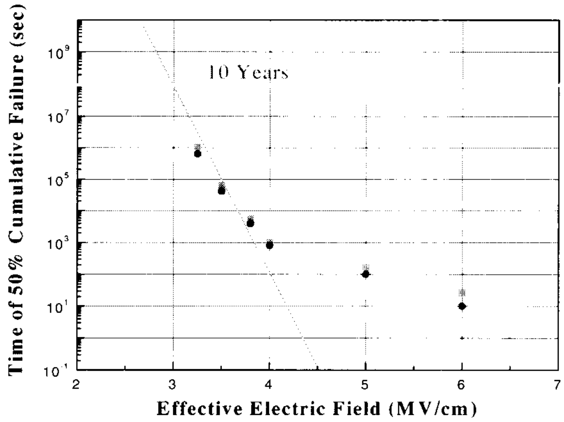

Fig. 12. Lifetime of the TFD devices.

process improved the quality of films and interface, and resulted in the improvements of electrical properties.

As shown in Fig. 10, high performance TFD device with very low threshold voltage down to 1.4 V and perfect symmetry could be achieved. The electrical properties were very uniform on the 7 × 7 cm sized glass substrate as shown in Fig. 11. The deviation of the current at 10V was less than 8.5%, and they were very stable all the position of the substrate.

Also, the TFD devices exhibited very good reliability. The available voltage range of the current TFD device is within 1 MV/cm. So, we extended the test range to 6 MV/cm for the accelerated lifetime test. As a result, as seen in Fig. 12, the TFD devices endured very long time, and it was expected that the lifetime of the TFD device was 10 years at 3 MV/cm.

4. CONCLUSION

In this work, highly reliable TFD could be fabricated by using multi-step anodic oxidation. The thickness of the oxide layer was preciously controlled with anodic voltage. Also, interfacial defect between oxide layer and top electrode was removed by applying post heat-treatment. The thin film diode showed symmetric and stable I-V characteristics after the post heat-treatment. the high performance TFD device could be fabricated with the newly developed processes based on our unique multi-step anodic oxidation and post heat-treatment.

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