TFD Device with Symmetrical Structure of Flexible Electrode Subject to Flexible Substrate

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In this work, we test electrode material of TFD (Thin Film Diode) device subject to flexible substrate. Al, that is ductile metal, was proper for flexible electrode to fabricate flexible display. The fabricated devices had symmetric electrode structure on both sides of insulation layer. The electrode was made of ductile Al so as to reduce the mismatch of properties between the electrode and substrate. The TFD device was successfully fabricated applying our own etch-free process. Electrical properties were improved by post-annealing.

Keywords : TFD, Flexible substrate, Symmetrical structure

1.INTRODUCTION

Recently, active matrix displays with thin film diode (TFD) switching device on flexible film substrate are becoming increasingly important because low power consumption and low weight are absolutely required for the mobile displays[1,2]. Conventional TFD device includes rigid electrodes such as Ta, Cr and Ti[3]. However, these electrodes cause distortion and crack on the flexible substrate owing to the great difference in stress and thermal expansion[4]. Consequently, the current technology cannot be applied to the TFD devices on the flexible substrate.

Therefore, in this work, new trials were done to solve this problem. Firstly, a new design including flexible and symmetrical electrode was introduced. That is, the instead of rigid materials, a flexible material was used as both bottom and top electrodes in the new TFD structure respectively. Secondly, for the successful fabrication of the TFD device, a new process was developed. The current fabrication process cannot be applied because bottom electrode is co-etched at the etching procedure of the top electrode, which is the same material as the bottom electrode. Accordingly, our own etch-free process was introduced in the process, and the fabrication of the flexible and symmetrical TFD device was attempted. The fabricated TFD device was analyzed and characterized to optimize the performance.

2. EXPERIMENTAL

As a substrate, flexible polycarbonate film was used. The size and thickness were 70×70mm and 200μm, respectively. Bottom electrode was made of Al, Ta, and bi-layer Ta/Al. Each metal layer, Al and Ta was deposited by sputtering with thickness of 150nm. Bi-layer was composed of 150nm thick Ta and very thin Al layer with 15nm. After formation of bottom electrode on the film substrate, Ta_2O_5 was formed by rf sputtering at room temperature using the Ta_2O_5 target. For patterning of Ta_2O_5 layer, lift-off process was adapted in order to avoid damage of film surface by etching solution including HF. Then, Al top electrode was formed on top of the oxide layer with sputtering and etch-free process, too. Finally, annealing treatment was done below 150°C under the various conditions. The fabricated TFD device was observed and analyzed with optical microscope, SEM and surface profiler. Also, the I-V characteristics of the TFD devices were evaluated using HP 4145B.

3. RESULTS AND DISCUSSION

A new type design of the TFD device in this work is illustrated in Fig. 1. The electrode for the flexible TFD device should be subject to polycarbonate film substrate. For subjecting to the flexible substrate, difference in both thermal and mechanical properties between the two materials should be as low as possible, because failure can arise from the difference in thermal expansion and mechanical stress between the film and the substrate.

Based on these parameters, we calculated to optimize the flexible design of new TFD structure using Stoney's equation[5]. Ta, currently used for bottom electrode of traditional TFD devices, has mechanically rigid properties.

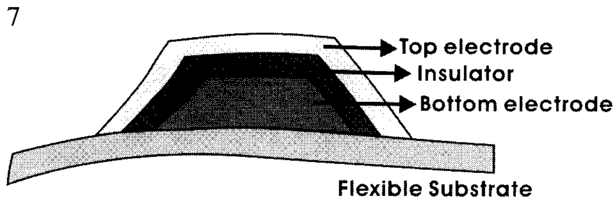


Fig. 1. Flexible TFD device.

So, it is not appropriate to the flexible substrate. However, Al has both values of coefficient in thermal expansion and Young's modulus closer than those of Ta as shown in table 1. Therefore, in order to minimize the stress, we selected Al thin film as electrode. The Al material has low specific-resistance satisfying requirements to TFD-LCD as well as the flexible properties[6].

Table 1. Thermal and Mechanical Properties.

	Ta	Al	Polycarbonate
C. T. E.*	6.5 ppm/°C	22.4 ppm/°C	37 ~ 43 ppm/°C
Y. M.**	140 Gpa	11.5 GPa	5.3 Gpa

* C.T.E. : Coefficient of Thermal Expansion
** Y. M. : Young's Modulus

For observing the surface state of the bottom electrode as the material, we deposited Al, Ta and their bi-layer on the polycarbonate film by sputtering. As shown in Figure 2 (a), many cracks were generated at Ta bottom electrode. It is considered to be owing to the thermal and mechanical mismatch between the flexible film substrate and the hard metallic film layer. That is, during the sputtering deposition, heat induced by collision of the Ta particles with polycarbonate film generates considerable thermal expansion of the polymer substrate. Therefore metal atoms were deposited on expanded film. As film reached room temperature, the difference in shrinkage between the two materials generates the distortion of the film substrate. Because these distortions happened frequently during process, it was difficult to make the device with Ta electrode. In case of bi-layer that was composed of 150nm thick Ta and very thin Al layer with 15nm, cracks were decreased remarkably, but a few cracks raised the serious problems of electrical properties (Fig. 2(b)).

Figure 2 (c) represents the surface of the Al layer on the polycarbonate film substrate. The surface was very clean and no defect was found. It is assumed that

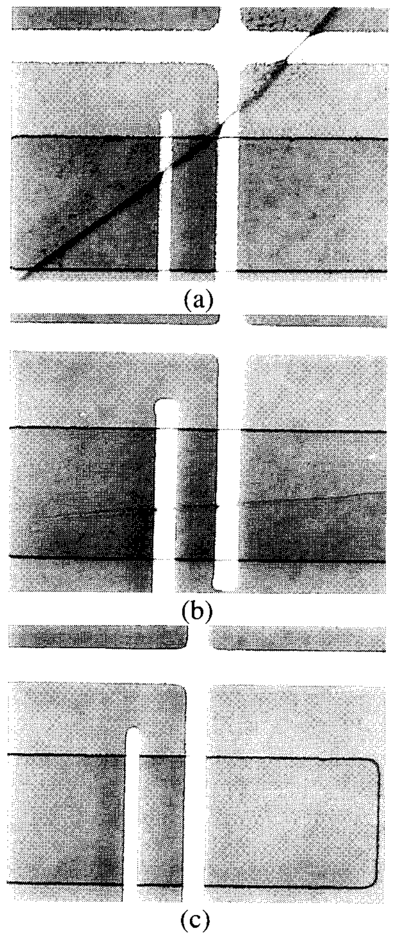


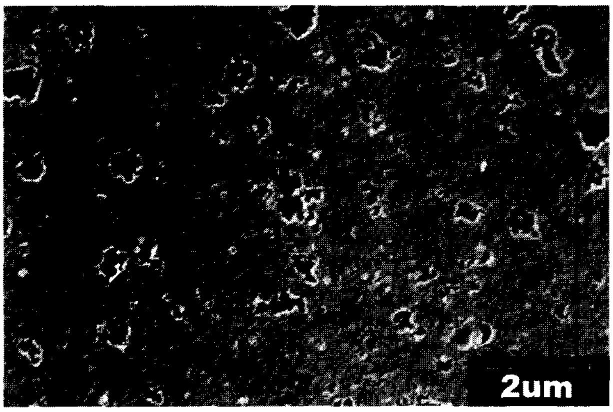
Fig. 2. After bending test, bottom electrode with various materials (a) Ta (b) Ta/Al bi-layer and (c) Al.

relatively lower difference of Young's modulus and coefficient in thermal expansion induced only small amount of stress and distortion of the polymeric film substrate. In addition, no crack was generated at the Al layer because it has mechanically ductile properties. Therefore the Al bottom electrode was turned out to be the very appropriate for the flexible film substrate.

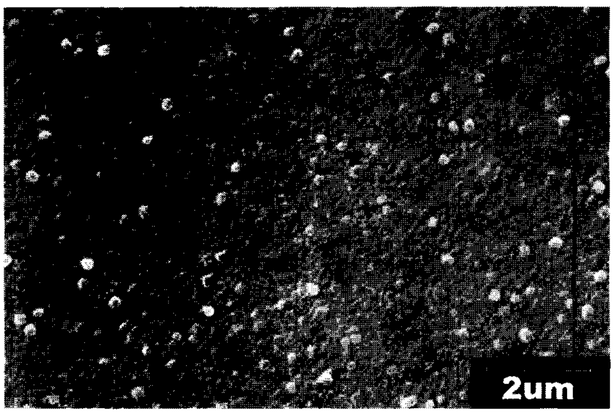
We selected ductile Al as an electrode material and designed a new structure. The bottom electrode and top electrode are the same flexible Al material, and they are located on both side of insulation layer. Since the electrode material is very ductile, the TFD device is expected to be subject to the flexible substrate. The device is composed of two flexible electrodes and an insulation layer between them. After the formation of Al bottom electrode, the Ta_2O_5 insulation layer and Al top electrode were deposited in sequence. The etch-free process was developed and applied to the fabrication of these two layers. The general process, wet etching or dry etching, cannot be applied because top and bottom electrode are same material, Al. If wet etching process is applied, the Al bottom electrode will be damaged severely during forming top electrode. For certifying this assumption, the current etching process and newly developed process were applied, respectively. As expected, extremely different results were appeared.

In Fig. 3(a), Al bottom electrode of TFD device fabricated by current process was seriously etched during the patterning of Al top electrode. The surface observed with SEM was very rough and partially sunk. The rough surface of the electrode should be improved because it induces the locally concentrated electron flow leading to the acceleration of failure[7]. The newly developed etch-free process solved the problem. As seen in Fig. 3 (b), the morphology of the top electrode was improved. The SEM observation of the surface also revealed that the Al bottom electrode was not damaged during the top electrode formation of the same material.

Device that was fabricated by general etching process was shown very poor electrical properties such as large leakage current and low breakdown voltage (Fig. 4). The rough surface of Al electrode caused the harmful influence of electron flow. However etch free process made to improve electrical properties of TFD devices.



(a)



(b)

Fig. 3. Bottom electrode after forming top electrode by (a) general wet etching and (b) own etch-free process.

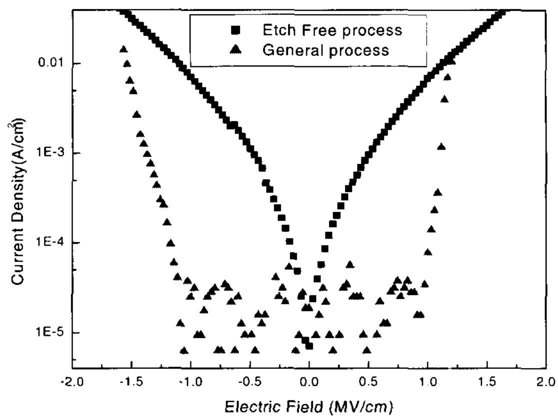
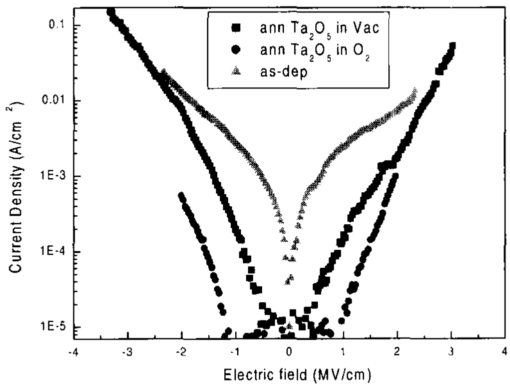
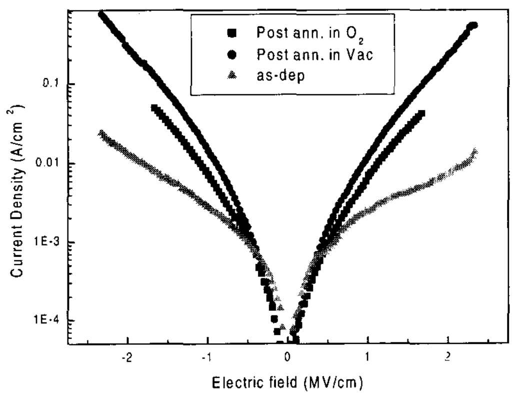


Fig. 4. I-V characteristics curves of the TFD Device as fabrication process general wet etching and own etch-free process.



(a)



(b)

Fig. 5. I-V curves of the TFD Device as annealing conditions (a) after deposition of Ta_2O_5 and (b) after fabrication of entire device.

In case of general wet etching process, bottom electrode was seriously damaged during top electrode patterning, and then their devices had very poor electrical properties. Therefore it is impossible to apply device with this bottom electrode to LCD panel. Our own etch-free process could reduce the damage of bottom electrode after forming top electrode.

Annealing treatment was performed in order to stabilize the characteristic of the TFD device. Four types of annealing treatment were done according to the atmosphere environment and annealing step, respectively. That is, the annealing was done after fabrication of Ta_2O_5 or whole device under the O_2 gas or vacuum environments, respectively. Annealing temperature and time was fixed 150°C and 2hrs.

In case of annealing after deposition Ta_2O_5, electrical properties were little improved. Current density was decreased than that of as-dep. device in –2.5~2.5MV region. Annealing in vacuum increased the asymmetry and non contentious. After annealing of O_2 atmosphere, threshold voltage was increased and breakdown voltage was lowered.

The I-V characteristic curves of the TFD devices are represented in Fig. 5(b). In case of the annealing treatment after fabrication of whole devices in vacuum and O_2, the curve shows nearly perfect symmetric properties. It is considered to due to the symmetrical electrode structure of the TFD device because the symmetric properties are strongly dependent upon the difference in work function value between the two materials[8]. Accordingly, the fabricated flexible TFD device was proved to have good properties as a switching device for plastic film AM-LCD.

4. CONCLUSION

In this work, we had the estimation of suitability of various electrode materials to apply flexible device for flexible display. Ductile material Al was suitable electrode of device on flexible substrate. The TFD devices subject to flexible substrate were attempted to fabricate by applying the newly developed flexible structure. As a result, flexible Al / Ta_2O_5 / Al TFD structure could be fabricated successfully by our own etch-free process, and the electrical properties were improved dramatically. Accordingly, the fabricated TFD device was certified to have good properties as a switching device for active matrix display on plastic.

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