Effects of One-Time Post-Annealing(OPTA) Process on the Electrical Properties of Metal-Insulator-Metal Type Thin-Film

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Abstract

The origin of image-sticking in metal-insulator-metal type thin-film-diode(TFD) LCDs is the asymmetric current-voltage(I-V) characteristic of TFD element. we developed that MIM-LCDs have reduced-image-sticking and perfect symmetry characteristic. One-Time Post-Annealing(OPTA) heat treatment process was introduced to reduce the asymmetry and shift of the I-V characteristics, respectively. OPTA means that the whole layers of lower metal, insulator, and upper metal are annealed at one time. The treatment temperatures and fabricated process of TFD element were under 200℃. Also, this low temperature fabricated process allows the application of plastic substrates.

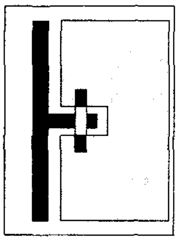
I. INTRODUCTION

In recent years, Active-matrix addressing liquid-crystal displays (AM-LCDs) are widely used in a variety of applications. In comparison to thin-film transistor liquid-crystal displays(TFT-LCDs), thin-film diode liquid-crystal displays(TFD-LCDs) have a lot of advantages such as their simple fabrication process leading to higher production yields, lower cost, lower power consumption. A TFD-LCD with MIM diodes has a larger aperture ratio than a TFT-LCD because its switching element is smaller. They have, however, the most serious problem of the image-sticking phenomena(long time image-retention) which caused by the asymmetry and shift of the current-voltage(I-V) characteristics of the MIM diodes. There are several methods to reduce the image-sticking such as the improvement of driving method, and adoption of symmetric tandem structure for MIM elements.

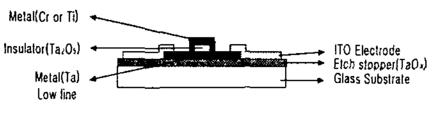
Effects of one-time post-annealing(OPTA) on the electrical properties of MIM device was investigated.

II. EXPERIMENTAL

For investigation, metal and insulator of the MIM device were fabricated by sputtering and anodization process, respectively. The MIM device is composed of Ta bottom electrode, Ta_2O_5 insulator, and Cr or Ti Top electrode, respectively. Anodized Ta_2O_5 was made between 200Å and 700Å thickness from ~2000Å tantalum films sputter deposited on glass substrates. The fabricated MIM device was annealed according to OPTA process, and current-voltage characteristics were observed. The results showed that OPTA was strongly effective to improve the electrical properties of the MIM device such as threshold voltage, symmetry, etc. Physical and electrical measurements revel that the as-deposited amorphous films have excellent properties: refractive indices ~2.15, dielectric constants ~25, and leakage currents $<10^{-6}$ A/cm^2 at 2.5V(1MV /cm). Ti Top-electrode shows current-voltage(I-V) characteristics having a good symmetry. The structure of a TFD element is shown in Fig. 1. The element consisted of a pair of Ta and Ti or Cr metal films with a Ta_2O_5 film inserted between the metal films.



(a) Pixel structure



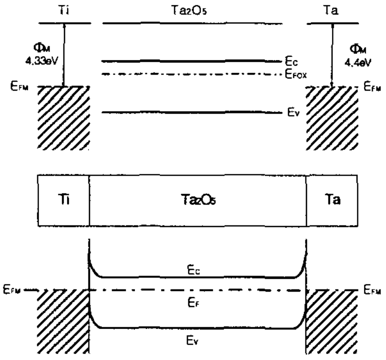
(b) Cross-sectional view of a TFD element

Fig. 1. TFD configuration. (a) Pixel structure, (b) Cross-sectional view of the TFD element.

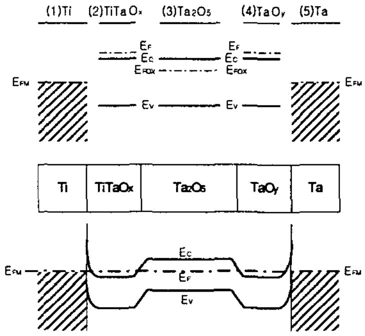
III.RESULTS AND DISCUSSION

III.1 Effects of postannealing on Current-Voltage Characteristics

Fabricated MIM element was annealed at 150~450℃ for 2h in a vacuum. The electrode annealing seems to be one of the key processes that affects the electrical properties, since the interface states between Ta_2O_5 and the both electrode constitute a portion of the leakage current. The reasons for increasing current density with increasing the annealing temperature are thought to reduce barrier heights of interfaces between the Ta_2O_5 layer and two electrodes. Fig. 2 shows energy band diagram of TFD element before and after annealing. In regions (2) and (4) of Fig. 2 (b), the metal which excessively exists in the oxide film behaves as the dopant and career density is probably very high. In this situation, the Fermi level is located within the conduction band, and regions (2) and (4) are considered to be degenerate. Fig. 2 also, suggests that the thickness of the interface layer increase with increasing the annealing temperature. As shown in TEM image of Fig. 3, after 350℃ annealing of whole TFD element for 2h in a vacuum, new layers of regions (2) and (4) was shown. Leakage current increases with increasing annealing temperature is shown in Fig. 5. In order to improve current-voltage symmetry characteristics of MIM device, we suggested the postannealing of whole TFD element. As shown in Fig. 5, high performance MIM device with perfect symmetry could be achieved by using novel process technologies and the TFD element with a $Ti/Ta_2O_5/Ta$ at 350℃ for 2h in a vacuum.

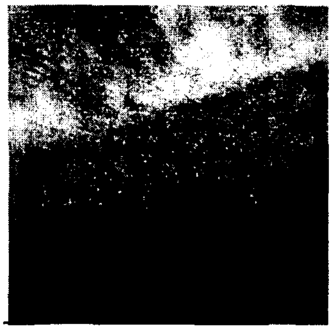


(a) Before annealing



(b) After annealing

Fig 2. Energy band diagram of TFD element



(a)not annealing

(b)350℃ annealing

Fig. 3. cross-sectional TEM image of Ta_2O_5

Ⅲ.2 Conduction mechanisms of TFD element with Ta_2O_5

The leakage current in a dielectric film can be due to several conduction mechanisms including Schottky emission, Poole-Frenkel emission, Fowler-Nordheim tunnelling and space charge limited current (SCLC)[1-3]. Electronic conduction in thin Ta_2O_5 film has been interpreted in terms of electronic conduction theories. A perennial problem is the question whether the dc conduction is controlled by a Schottky emission (SE electrode-limited conduction) or by a Poole-Frenkel (PF, bulk limited conduction) mechanism. Schottky emission is described by[4]

$$J_{SE} = AT^2 \exp\left[\frac{q\,(-\Phi_B + \sqrt{qE/4\pi\varepsilon_i}\,)}{kT}\right] \quad (1)$$

and the Poole-Frenkel emission can be written as[4]

$$J_{PE} = C\,E \exp\left[\frac{q\,(-\Phi_i + \sqrt{qE/\pi\varepsilon_i}\,)}{kT}\right] \quad (2)$$

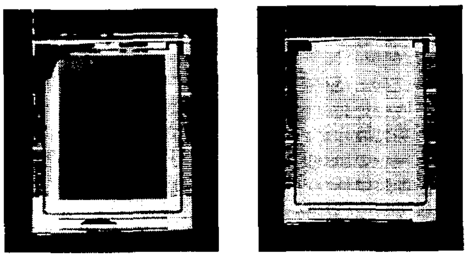
where, J is the current density (A/cm^2), A is the Richardson constant equal to 120A/cm^2-K^2, T denotes the absolute temperature, q is the elementary electric charge, k represents the Boltzmann constant, C is constant, E represents electric field, Φ_B is barrier height, Φ_i the depth of the donor level of oxide, and ε_i is the insulator dielectric constant of the oxide.

The interpretation of conduction mechanisms reliance for the experimental data has been placed on the measured slope of the log(J) vs E$^{1/2}$ and log(J/E) vs E$^{1/2}$ plot. If the measured value of log(J) vs E$^{1/2}$ is linear, the conduction mechanism is considered to SE process(electrode-limited). On the other hand, if the measured value of log(J/E) vs E$^{1/2}$ is linear, the conduction mechanism is considered to PF process(bulk-limited). Under a low electric field(<2.2 MV/cm), a straight line can be obtained. The dominant conduction mechanism at a low field is therefore determined to be Schottky emission.

The electrical conduction is governed by a different mechanism at higher electric field. The subsequence curve is a straight line at a high electric field(> 2.2 MV/cm^2). Therefore, the dominant conduction mechanism in this high field range is considered to be Poole-Frenkel conduction mechanism.

Ⅲ.3 Fabrication MIM-LCD

Using the MIM devices, we fabricated 2 inch MIM-LCD. As shown in Fig. 4, high performance MIM-LCD was fabricated. The switching operation of the MIM-LCD was very uniform. So, in this work, we could fabricated a high performance 2 inch MIM-LCD using our own developed processes.



(a) ON-State (b) OFF-State

Fig. 4. 2-inch MIM-LCD

Ⅳ. CONCLUSION

In this work we successfully fabricated Ta_2O_5 thin films by anodic oxidation and investigated the electrical and mechanical characteristics. In order to improve current-voltage symmetric characteristics of MIM device, we suggested the postannealing of whole TFD element. As shown in Fig. 5, high performance MIM device with perfect symmetry could be achieved by using novel process technologies. All the fabrication processes were developed below 150℃ so as to allow the application of plastic substrates. Using these new processes, the high performance 2 inch MIM-LCD with simple structure could be fabricated, and it can be applied to the AM-LCD for various applications.

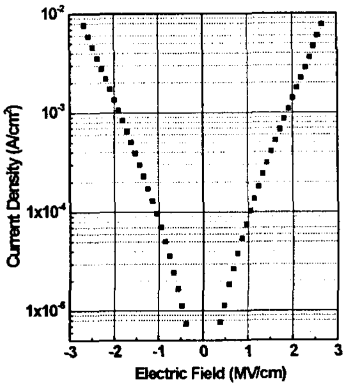


Fig. 5. Perfect symmetry of the I-V characteristics of MIM devices

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