Extended Abstracts of the 1991 International Conference on Solid State Devices and Materials, Yokohama, 1991, pp. 650-652

Display Performance Improvement of TFD-LCD by Low Temperature Anodizing Method

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The TFD-LCD with low temperature anodic oxidation film (LTAOF) appears to achieve display performance improvement. From the experimental results, for the TFD element with LTAOF, its current-voltage characteristics steepness (beta) is larger and its capacitance is smaller than that for conventional TFD fabricated by room temperature anodic oxidation. The authors have paid special attention to the oxide layer state. Based on the results of several measurements and analyses, this paper indicates the reason why TFD-LCD with LTAOF shows good display performance.

1. Introduction

Active-matrix LCDs are now widely used in many applications. The authors have adopted Metal-Insulator-Metal (MIM)[1] type Thin-Film-Diode (TFD) as the switching element in LCDs for lap-top EWS[2] on the market. Now, in order to grade up the system, the TFD-LCD performance improvement has been required. This paper presents the results of the TFD-LCD characteristics improvement efforts and discusses the estimated mechanism.

2. Experiments

The TFD array was fabricated by anodic oxidation of patterned Ta and setting patterned Ti as the counter electrode of MIM. The anodic oxidation parameters were as follows; the electrolyte solution was 0.01% citric acid solution, anodizing time was 1 hour, anodizing voltage was 42 volts and counter electrode was Pt plate. The electrolyte solution temperature was changed between 2℃ and 60℃. The patterned ITO as the pixel electrode was connected with Ti. So, the array substrate was completed. Additionally, another substrate with ITO stripe pattern was prepared. The TFD-LCD was constructed by putting these substrates together. Its cell gap was 5 μm and the display mode was normally opened twisted-nematic (TN).

Various device characteristics were measured. For contrast ratio, the cell transmittance ratio at on and off-states was measured. Applied driving wave form was reversed every 2lines and every second frame. Current-voltage characteristics measurement were carried out for the TFD element. The oxide layer property was investigated by Ellipsometry, SEM, AES, XRD, ESCA and so on.

3. Results

3.1 Display performance

Figure 1 shows the device contrast ratio dependence on the electrolyte solution temperature. Note that the TFD fabricated with LTAOF has an extremely high contrast ratio, which is about twice that for conventional TFDs made by room temperature anodization. The display performance can be markedly improved.

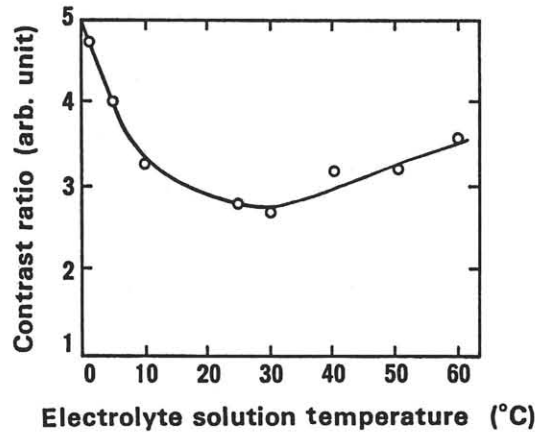


Fig.1 Contrast ratio dependence on the electrolyte solution temperature.

3.2 Current-voltage characteristics

The TFD current-voltage(I-V) characteristics follow the Poole-Frenkel effect[3]. That is, $I = \alpha \exp(\beta V)$.
Figure 2 shows that the beta-value is extremely large at low temperature, in comparison with the value at high temperature. As mentioned later, LTAOF is thinner than the oxide film fabricated in higher temperature under constant anodizing voltage. In general, beta-values become larger with decreasing oxide thickness. So, the TFD element, fabricated by room temperature oxidation with the same thickness as LTAOF, was prepared and beta-values compared. Still, the beta-value for the TFD with LTAOF is larger than that for the TFD with oxide fabricated in room temperature.

3.3 TFD element capacitance

The effective dielectric constant was obtained as the value dividing the capacitance by the ellipsometrically measured oxide thickness. The dielectric constant dependence on electrolyte solution temperature is shown in Fig.3. The LTAOF dielectric constant is relatively small. The small capacitance TFD element is preferable, in comparison with the LC capacitance, so that the sufficient driving voltage can be applied on the TFD element.

3.4 Film characterization

3.4.1 Atomic composition investigation

According to the AES in-depth profiles (Fig.4), it is clear that the LTAOF oxide layer, consisting of Ta and Oxygen and a little Ti, is thinner than that for higher temperature cases. Furthermore, the atomic composition ratio for the oxide film intermediate layer is the same. From the ESCA spectrum, the Ta valence values in oxide film are not only Ta(5+) and Ta(0), but also other sub-stoichiometric Tantalum oxides. In the XRD chart, there is a little difference, which indicates that LTAOF appears to be partially crystallized, but this is not definite. In LTAOF SEM sectional observation, the grain boundary shows clearer and its grain size is larger.

3.4.2 Film growth examination

The oxide thickness growth rate, measured by Ellipsometry, is shown in Fig.5. The anodized film thickness becomes thicker along with the temperature increase under constant applied voltages.

Current density changes, during anodic oxidation, were monitored.

The film growth rate difference is explained by the total electric charge flow amount during anodization. Thus, the charge amount is proportional to the thickness.

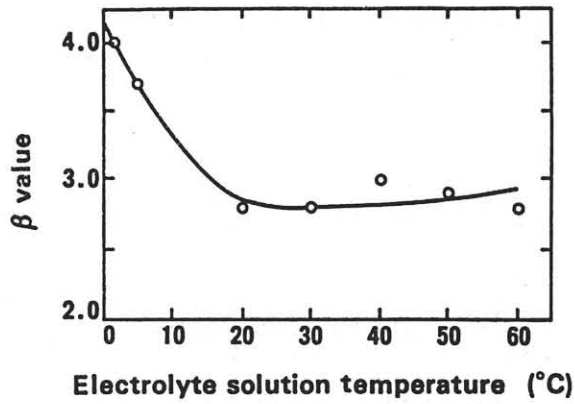


Fig.2 Beta-value in Poole-Frenkel plot dependence on the electrolyte solution temperature

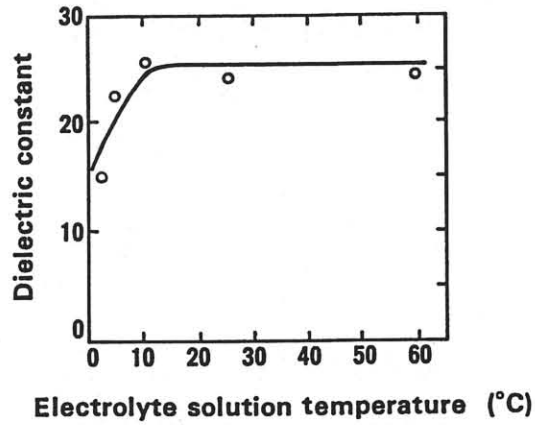


Fig.3 Dielectric constant for TFD element, fabricated at various anodizing temperatures under constant anodizing voltage (42V).

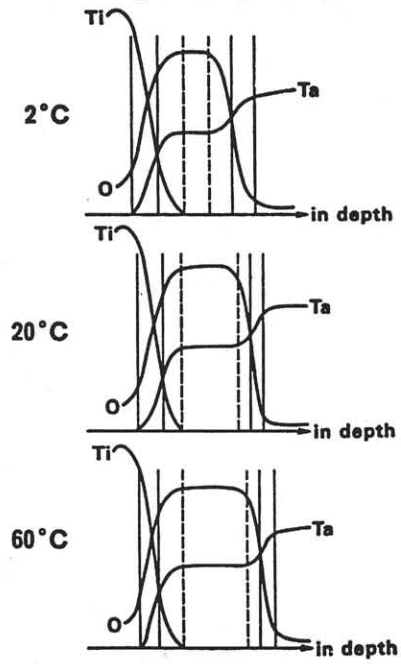


Fig.4 In-depth atomic profiles obtained by AES for TFDs formed at various anodizing temperatures.

4.Discussion

According to the in-depth atomic profiles obtained by AES, with the surface-sputtering method shown in Fig.4, it can be seen that the Ta, Oxygen and Ti mixing state depends on the anodizing temperature. The distinctive region thickness in the film can be calculated by FWHM of AES profiles.

The intermediate region, in which the O/Ta ratio is almost constant, is the electrically neutral (intrinsic) region[4]. The highly excess metal regions in contact with both electrode metals show metallic conductivity and can be considered to have the same property as the electrode. The inside regions for these electrode-like layers, have excess metal composition, in comparison with the intrinsic region, and are considered as an n-type, according to the structure model of anodic oxidized films[4]. The space charge region (d) thickness is estimated from several thickness relations mentioned above and listed in Table I. LTAOF has small d, which is almost half the values for the other higher temperature samples summarized in Table I. This is due to the large b, which means the transition region for the Ta and Oxygen mixing layer near the Ta electrode.

Concerning the potential distribution in the anodic oxidized films[5], in a case of thinner film, which means that film thickness is less than the Debye length, the potential is mostly applied on the space charge region d[5]. The thinner d is, the larger the electric field strength is. Hence, under the constant applied voltage, a strong electric field is induced in the d region for LTAOF, and large Poole-Frenkel current flows. This results in large beta value.

In Fig.3, the LTAOF dielectric constant is relatively small. This value was calculated by measured electric capacitances and oxide thicknesses t listed in the Table. In order to obtain a more appropriate dielectric constant value, d has to be employed instead of t. The decreasing LTAOF dielectric constant can be compensated by the d value.

A dominant factor in determining the d value, is b, which stands for the oxygen penetration depth into the base Ta. From several film characterization results, no conclusive explanation is possible. However, there are subtle indications that LTAOF has a special property in regard to the crystallographical structure and in mechanical structures. Especially, the oxide region grain size in the LTAOF is found to be larger. This fact coincides with the possibility of oxygen atom diffusion into Ta.

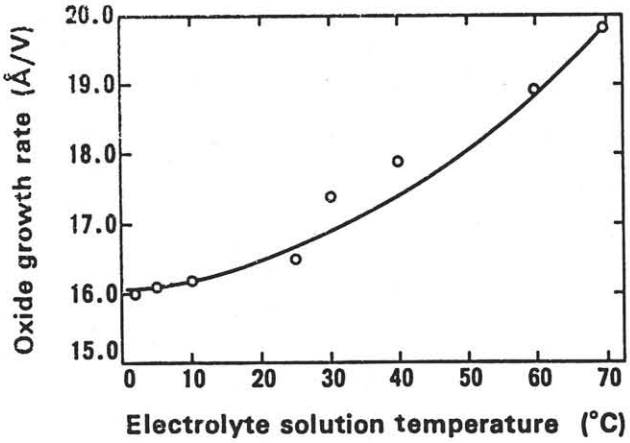
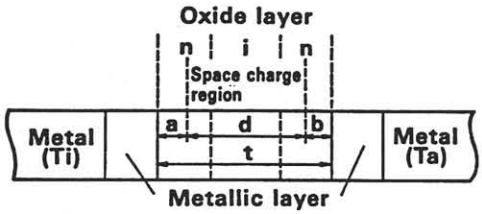


Fig.5 Growth rates comparison for anodic oxidation films by ellipsometric measurement.

Table.I TFD layer model constructed from AES in-depth profiles and thickness dependence on the electrolyte solution temperature.

	t	a	b	d
2°C	650Å	180Å	150Å	320Å
20°C	700Å	110Å	50Å	540Å
60°C	770Å	120Å	50Å	600Å



5.Conclusions

I-V characteristics for the MIM element, using LTAOF as an insulator, shows a great steepness (beta) value. Consequently, a large Ion/Ioff ratio can be attained and marked contrast ratio improvement is obtained by the two-terminal active matrix addressing LCD, utillizing switching arrays with loading LTAOF-MIM elements. From the consideration on potential distribution in the film, based on AES in-depth atomic profile etc., it was determined that LTAOF had thinner intrinsic region and the large electric field could be induced in the film, which caused suitable I-V characteristics and effective capacitance state.

References

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