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The Improved Device Characteristics of MIM-LCD

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We have tried to improve characteristics of MIM device to establish the high contrast of liquid crystal display. It has been pointed out that the ON/OFF ratio of MIM device can create the wide range by using nitrogen(N_2)-doped tantalum(Ta) which is used as a substitution for pure tantalum film. This N_2-doped Ta is formed in the sputtering process by inducing the nitrogen gas into the sputtering chamber. However, it is difficult to make actual MIM devices on all over the large-sized substrate uniformly by ordinary N_2-doping method. Accordingly, we established improved device properties by employing the mixed gas of nitrogen and argon which kept the discharge condition stable in the sputtering chamber. In addition, the condition does not cause the lack of the contrast uniformity, which is realized by optimizing the gas flow ratio and the gas pressure.

INTRODUCTION

It is generally known as Baraff's study that there is the region where non-linearity of the device is drastically improved by using the nitrogen tantalum. …*1 This film is doped by N_2 gas in the sputtering process of fabricating MIM device. However, when we actually manufacture the MIM device by the method of inducing N_2 gas, Ta is not always patterned uniformly in the dry-etching process. In addition, this method sometimes causes unevenness of each characteristic of device and lacks uniformity of contrast all over the display area, which is proved by measuring the electric optical property of MIM-LCD. On the contrary, the contrast ratio is obviously improved. The possibility of existence of the region gives the MIM-LCD with N_2-doped Ta the uniform contrast and the stability of device.

EXPERIMENTAL METHOD

The DC Magnetron Sputtering Machine called In-Line type is used for the forming tantalum thin film. The detail of fabrication technology is the same as the conventional one's. …*2 In order to measure the device property easily, the experimental larger-sized MIM device was adopted in order to accumulate the data.

[Condition of Under Layer TaOx]

The tantalum oxide (TaOx) was used for as under layer on the conventional MIM device. This thin film is formed by heat oxidization or by reactive sputtering method. In this experiment, the reactive TaOx was employed to avoid the influence from the under layer.

RESULT

[Amount of N_2-Doping and Device Capacitance]

Fig. 1 shows the N_2 partial pressure vs. device capacitance and device resistance. The MIM device capacitance decreases in proportion to the increase of N_2 partial pressure, as shown in Fig. 1. In general, the ability of electrical charging to the MIM-LCD pixel is determined by the device time constant. Therefore, the practical electrical voltage addressed to the pixel is divided in the proportion of device capacitance to LC layer capacitance, because MIM device and LC layer are connected with each other in series in MIM-LC circuit. Accordingly, the MIM device capacitance has to be reduced by designing the small device dimension to get the effective charging ratio. Especially for the high resolution display such as the one of personal computer use, the MIM device dimension has to be fabricated as $4\times 4\ \mu m^2$, and this fabricating process causes the low yielding due to the lack of dimension uniformity. Consequently, it is a big merit that the N_2-doped device can decrease the device capacitance without exchanging the device dimensions, especially for the high resolution specification.

As for the specific resistance of MIM device, it is increasing according to the increase of N_2 partial pressure.

[Amount of N_2-Doping and I/V Characteristics]

The larger β is expected to realize large ON/OFF ratio of MIM-LCD. Fig. 2 shows the I/V characteristics of the conventional MIM and the N_2-doped MIM. The increasing ratio of the I/V steepness (shown as β) by N_2-doping is not so large. The β of the conventional MIM is about 4. On the other hand N_2-doped MIM indicates about 4.5. According to this result, β is not affected largely by N_2-doping. It seems that too much N_2-doping is not needed if that state of device causes other kinds of failure. On the Baraff's report, however, β is twice as non-doped one's. …*1 It is considered that β depends on the range of applied voltage to drive the LCD. The range of 6～8 (V) is used for our MIM, and the large β by N_2-doping could not be measured. It may be because the electrical conduction mechanism becomes similar to the Schottky Conduction in this range. The behavior about β at the Poole-Frenkel Conduction range was not investigated.

Fig. 2 also shows that the resistance of the N_2-doped device is higher than conventional device in the low voltage region. This phenomenon indicates that the leak current at low voltage is decreased about 1.5 figures, compared with conventional one. The efficiency of hold voltage is improved.

[N_2 Gas Flow Ratio and Device Characteristics]

We investigated the N_2 gas partial pressure vs. the amount of N_2-doping and the influences of the mixed gas flow ratio. Fig. 3 shows the relationship between the 15% partial gas flow ratio and the refractive index of anodized TaOx, and between the 15% partial gas flow ratio and the thickness of anodized TaOx. The refractive index is decreasing according to the increase of N_2 gas flow ratio. On the contrary, the thickness of N_2-doped TaOx is not affected by changing N_2 gas flow ratio.

β is changed by N_2-doping. As mentioned before, and we forecasted β by calculating, using the data of refractive index. The equation about β is as follows:

$$\beta=\frac{e}{2kT}\left(\frac{e}{\pi\varepsilon\varepsilon_0 d}\right)^{1/2} .$$

The relation $n=\sqrt{\varepsilon}$ is induced to this equation.

$$\beta=\frac{e}{2kTn}\left(\frac{e}{\pi\varepsilon_0 d}\right)^{1/2} .$$

Fig. 5 shows the increasing tendency about β by calculation. However, the result of experiment was different. It is because there were other many factors which determined β on in practice. It can be said that N_2-doped Ta did not efficiently affect β.

Fig. 4 shows the relationship between the gas flow ratio and the amount of N_2-doping in Ta. N_2 gas is doped into Ta in proportion to the N_2 gas flow ratio. We measured the amount of N_2 in Ta by ESCA. N_2 gas flow ratio had influence on the MIM device capacitance. The capacitance decreased according to the increase of gas flow ratio. It seems that strict control of gas flow ratio is required.

[Gas Pressure and Device Capacitance]

The device capacitance is getting larger according to the increase of mixed gas pressure. It can be said that the amount of N_2-doping at low pressure is larger than one at high pressure. As regards the capacitance, the low gas pressure is desirable, but the moderate gas pressure is required to keep electric discharge stable. Taking the discharge stability into account, we adopted 0.77 Pa condition.

[N_2-doping and Contrast Failure]

It is ascertained that there are two regions; one gives the good picture quality on the experiment samples and the other causes the lack of contrast uniformity, which is caused by excessive N_2-doping. The accuracy of Ta pattern formed in the etching process changes for the worse. It is considered that the lack of doping uniformity causes the etching condition mentioned above. Both of worse etching condition and lack of N_2-doping uniformity cause the contrast failure in the case of driving LCD. In order to investigate the adequate doping region, we searched the relationship between the statement of crystallization and actual sample LCDs. As a result, it is discovered that there is a stable region in the mixed crystallization state of α-Ta and Ta_2N. This region is limited, and it seems that the strict gas control on doping becomes important.

[X-ray Diffraction Method]

We used the X-ray diffraction analysis to examine the extent of N_2-doping in Ta.

Tantalum indicates β-Ta crystallization at non-doping state. This state is changed into the nitrogen Ta state by the sequence of N_2-doping. The device samples of several states were evaluated in LCD form. As a result, α-Ta state is not enough to realize contrast ratio improvement. It is ascertained that the non-uniformed contrast ratio is occurred when Ta becomes entirely nitrogen Ta state. It follows that the mixed crystallization state of α-Ta and nitrogen Ta indicates the most stable contrast uniformity. It is inevitable to employ those mixed crystallization region for fabricating uniform device on large sized glass substrate, otherwise the efficient β improvement and the decrease of capacitance is difficult to expect.

CONCLUSION

We have tried to improve the characteristics of MIM device for the purpose of producing better picture quality in LCD. As a result, the leak current is decreased about 1.5 figures and the device capacitance is reduced about 30% in comparison with conventional device by adopting N_2-doping method to Ta. In addition, it has been found that it is better for maintaining the stable fabricating condition to dope N_2 into Ta in the mixed state of α-Ta and Ta_2N.

REFERENCES

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[2]H. Aruga et al., "A-10"-diagonal Full Color MIM Active Matrix LCD" Japan Display digest 1989

[3]N. Ono et al., "An MIM-LCD with Improved TV Performance" SID digest 1990

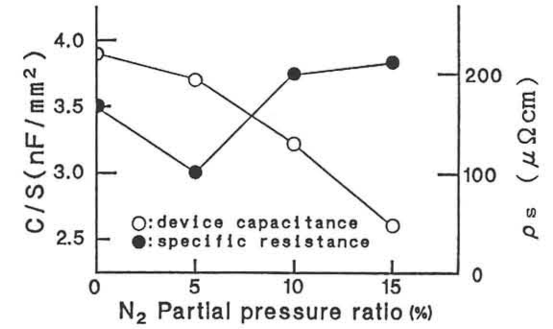


Fig.1 N_2 Partial Pressure Ratio vs. Device Capacitance and Device Specific Resistance

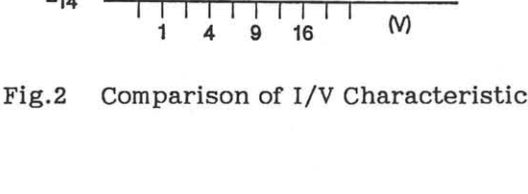


Fig.2 Comparison of I/V Characteristics

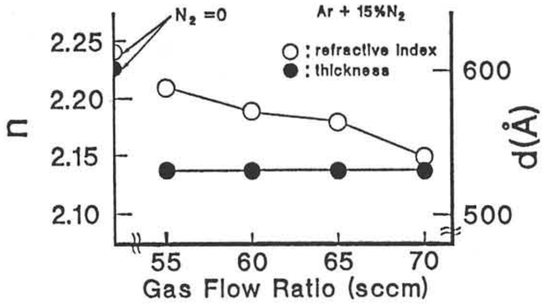


Fig.3 Gas Flow Ratio vs. Refractive Index and Thickness of Anodized TaOx Layer

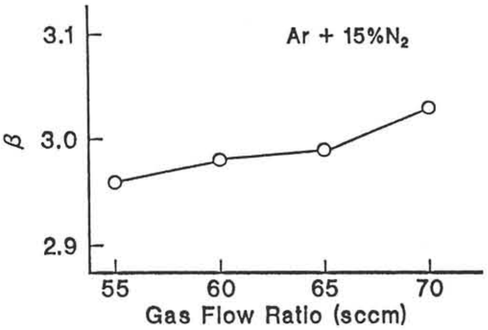


Fig.6 Mixed Gas Flow Ratio vs. Forecast of β.

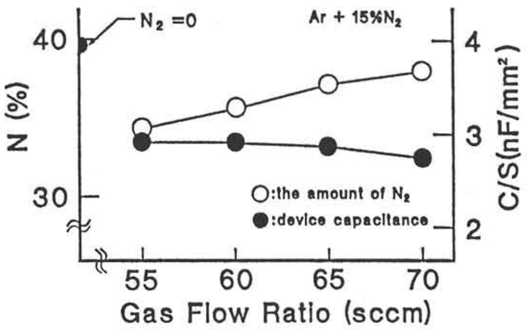
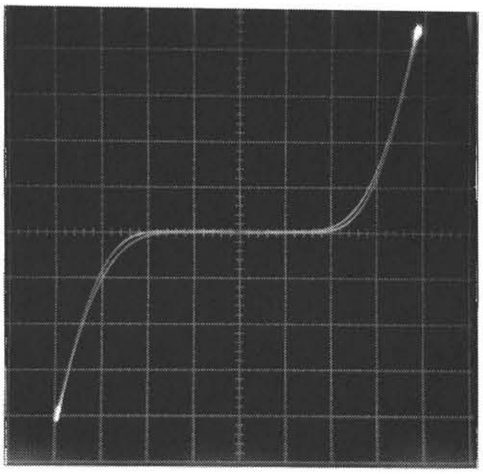


Fig.4 Gas Flow Ratio vs. Amount of N_2 Doping and Device Capacitance



1 div.
X:5V
Y:50μA

MIM size
200×100μm^2

Picture 1 I/V Characteristic

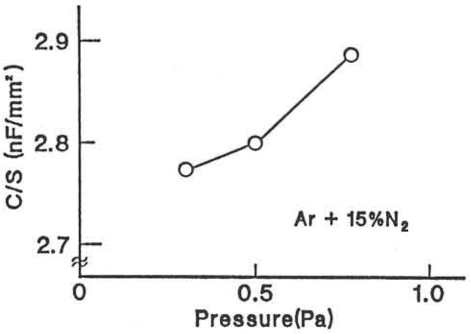


Fig.5 Mixed Gas Pressure vs. Device Capacitance