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Dielectric breakdown of SiAlON insulating thin films prepared by rf magnetron sputtering

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The preparation and dielectric breakdown of SiAlON insulating thin film applied to ac electroluminescent devices were studied. The optimum preparation conditions of the film for electroluminescent device were obtained and the effects of the electrode geometry and the polarity of applied voltage on the dielectric breakdown were examined.

1. INTRODUCTION

Intensive attention has been paid to thin film electroluminescent (TFEL) devices because they have a number of attractive features such as high quality emissive display, flat and solid structure, lightness, and so on.[1] In general, the ac TFEL device has a structure in which an active layer is sandwiched between insulating films which play a very important role for stable and reliable operation of the devices. Although many investigations have been made on improving the active layer, seeking the higher brightness, the multicolor and the mechanism of the luminescence, few systematic works have been done on the insulating films. Many kinds of insulating materials such as SiO_2, Ta_2O_5, $SrTiO_3$ have been used for the ac TFEL devices, however there is no detailed report on SiAlON insulating film which has the excellently high breakdown strength.[2-3] The insulating films play a very important role in an ac TFEL device for the stable operation. The clamped field in the active layer is as high as $2 \sim 3 \times 10^6$ V/cm under the operation condition.[4] Therefore, it is required that the insulating films endure the applied voltage until the clamp occurs. In order to decrease the threshold voltage of the device, insulating films should have high dielectric constant. As the maximum luminance of the device is determined by the charges on the insulating films which can be transported through the active layer resulting in the excitation of the luminescent centers. The figure of merit of the insulating film is the maximum available charge density $Q_{max} = \varepsilon_r \varepsilon_0 E_b$ at its breakdown strength E_b.

The insulating films prepared by rf magnetron sputtering method were subjected to the dielectric breakdown test and the measurement of dielectric constant and the figure of merit was estimated to acquire the optimum preparation conditions.

2.EXPERIMENTAL

2.1. Preparation of SiAlON insulating films

SiAlON films were prepared from Si_3N_4 and Al_2O_3 mixed powder target with nitrogen and argon mixture gas by rf magnetron sputtering method (Tokki Co., Ltd. Model SPK-301) under the conditions shown in Table 1. In order to determine the optimum mixing ratio of the powders, films were prepared at the various mixing ratios.

Table 1
Preparation conditions of SiAlON insulating films

Target	Si_3N_4 Powder + Al_2O_3 Powder
Sputtering gas	Ar 75% + N_2 25%
Substrate temperature	260 ℃
Deposition rate	110 ~160 Å/min
Power density	2.76 W/cm^2

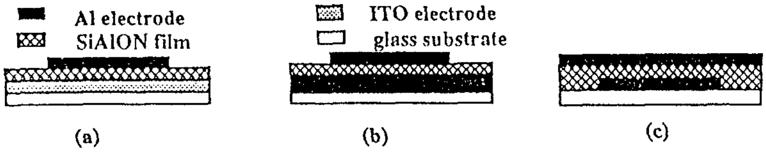

Figure 1.Schematic structure of the samples

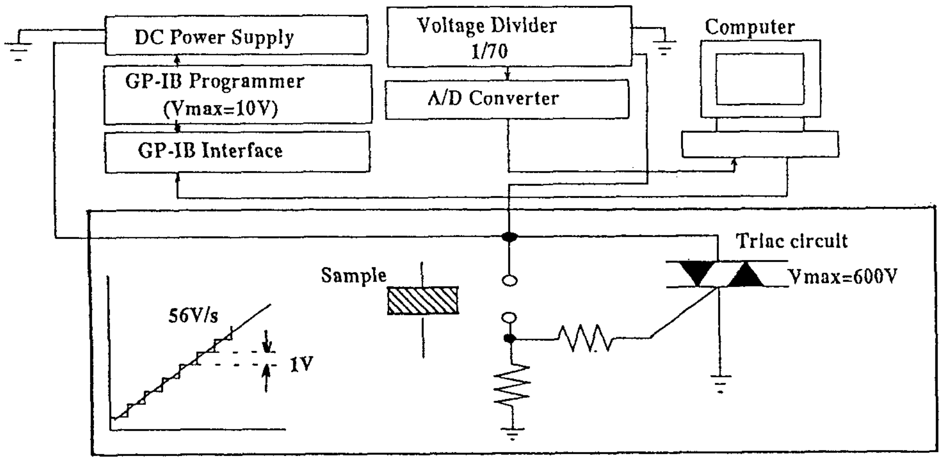

Figure 2. Schematic diagram of the dielectric breakdown test system.

2.2. Fabrication of samples for dielectric breakdown test

Figure 1 shows the schematic structure of the samples. They are all the same in that the SiAlON film is sandwiched between upper and lower electrodes. However the materials and/or the geometry of the electrodes are different from each other.

2.3. Dielectric breakdown test

Figure 2 shows the schematic diagram of dielectric breakdown test system. A staircase voltage (1 V step, average rising speed 56 V/sec) is applied to a sample,until the dielectric breakdown occurs in the sample. The applied voltage can be removed by a triac circuit immediately after the breakdown occurs so that the self-healing breakdown occurs and the one sample can be subjected many times to the breakdown test. The breakdown strength increases with increasing the test number. In the earlier stage of the test, the breakdown strength increases considerably because of the elimination of the weak spots, and then the breakdown strength reaches to some constant value E_{bi}. We'll call the initial stage of the breakdown the weak spot breakdown and the following stage the intrinsic type breakdown.

2.4. Dielectric constant

The dielectric characteristics of SiAlON films were examined by a bridge (Ando Denki Co., Ltd, Model TR-1B Type) at a frequency of 1 kHz and room temperature in atmosphere. The thickness of the films was measured by Multiple Beam Interferometry (Olympus Optical Co., Ltd). The dielectric constant was estimated by

$$C = \varepsilon_r \varepsilon_0 \, S/d$$

where C represents capacitance of the film, ε_0 dielectric constant in vacuum, ε_r relative dielectric constant of the film, S the area of the electrode (fixed) and d the thickness of the film. From a lot of data pairs of C and d, we determined ε_r by the regression analysis.

2.5. Composition of SiAlON film

The composition of SiAlON films prepared by rf magnetron sputtering method was analyzed by ESCA (Shimadzu Work, Model ESCA-750). The depth analysis was performed by Ar ion etching in the analysis chamber of ESCA.

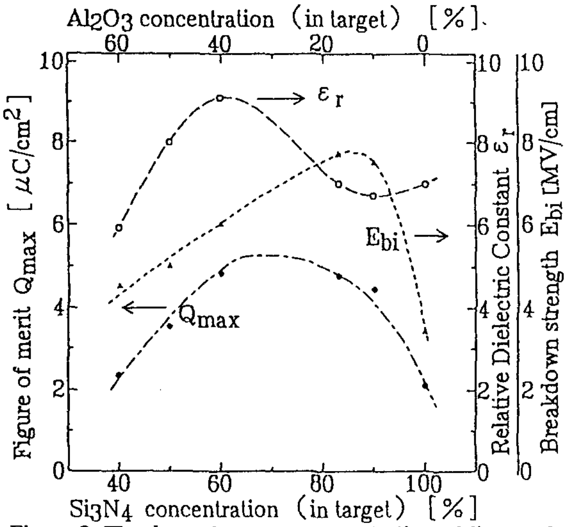

Figure 3. The dependence on concentration of figure of merit, relative dielectric constant, and breakdown strength. (Thickness: 160 380 nm)

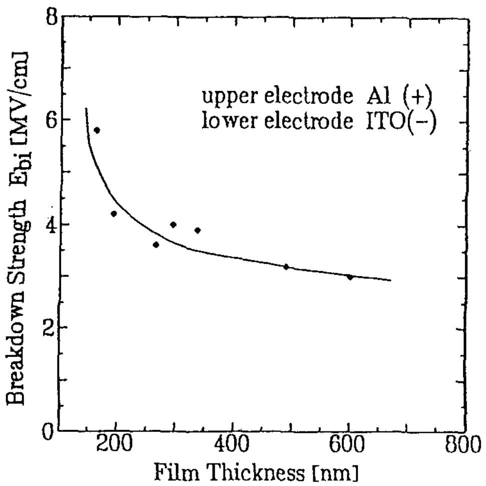

Figure 4. The dependence of breakdown strength on thickness

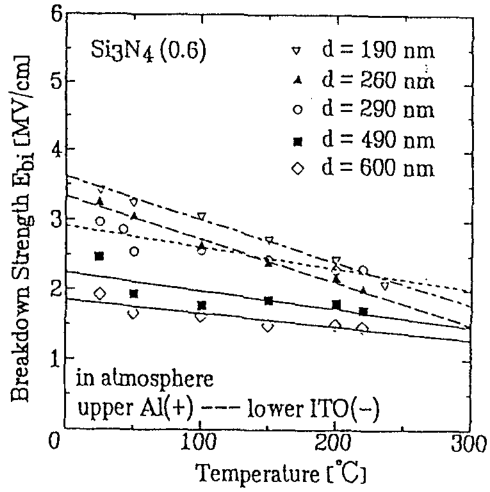

Figure 5. The dependence of breakdown strength on temperature

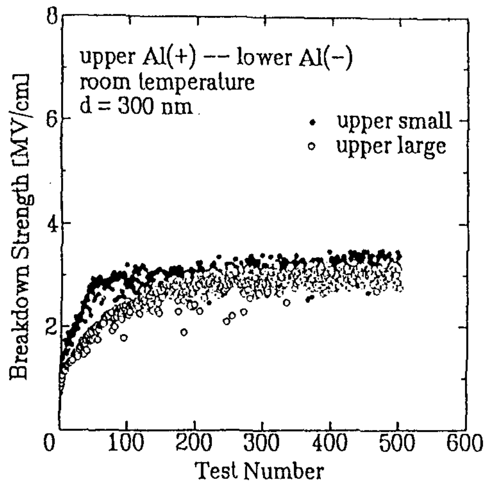

Figure 6. The dependence of breakdown strength on geometry of the electrode

3. RESULTS AND DISCUSSIONS

3.1. The dependence of ε_r ,E_{bi} and the figure of merit Q_{max} on the mixing ratio of Si_3N_4 and Al_2O_3 powder

The dielectric properties of the thin insulating films depend upon the concentration of the target. Figure 3 shows that the optimum Si_3N_4 concentration that makes Q_{max} the greatest lies in about 0.6~0.8.

3.2. The dependence of E_{bi} on the film thickness

Samples with various thicknesses were prepared by changing the sputtering time. The Si_3N_4 concentration in the target was kept constant at 0.6. Figure 4 shows the dependence of dielectric breakdown strength on the thickness of the SiAlON insulating films. It should be noted that with increasing the thickness, E_{bi} decreases drastically below 300 nm, and E_{bi} shows less dependence on the thickness above 300 nm. This suggests that the mechanisms of the dielectric breakdown of the thick and thin films are different from each other.

3.3. The dependence of E_{bi} on the environment temperature of the film

Figure 5 shows the temperature dependence of the dielectric breakdown strength of the films with different thickness. With increasing the environment

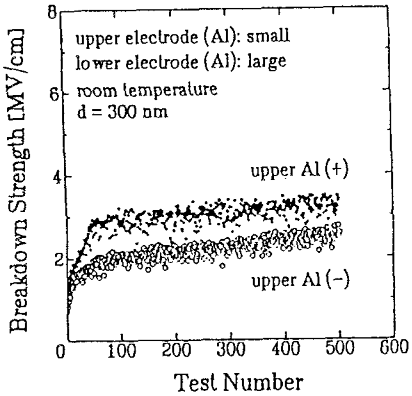

Figure 7. The dependence of breakdown strength on the polarity of the electrode

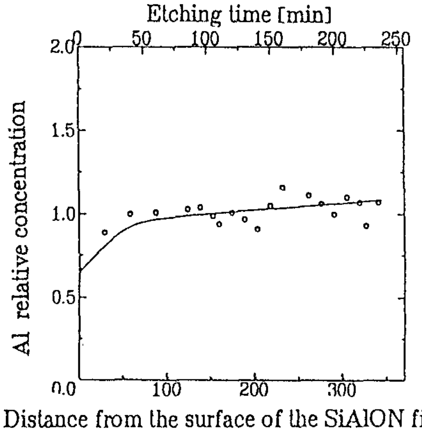

Figure 8. Depth profile of the relative Al concentration in SiAlON insulating film

temperature the dielectric breakdown strength decreases. The thinner the thickness of the film, the more rapidly the strength falls with increasing temperature.

With the results mentioned in 3.2., the thermal breakdown mechanism should be taken into account in the breakdown of the SiAlON insulating film.

3.4. The effects of electrode geometry and the polarity of the applied voltage

The geometrical effects of the electrode on the breakdown strength are shown in Figure 6. The breakdown strength of the sample with the larger upper electrode increases more slowly with the test number than that with the smaller electrode. This means that the sample with the larger upper electrode has the larger number of weak spots. The effects of the polarity of the applied voltage on the dielectric breakdown strength are shown in Figure 7. The higher strength can be obtained when the positive voltage is applied on the upper electrode although both the upper and the lower electrodes are the same Al.

3.5. Depth profile of the composition of Al and Si in SiAlON film

SiAlON film was subjected to the analysis by ESCA in order to clarify how Al and Si concentration changes with the depth from SiAlON top surface. The Al relative concentrations were plotted against the distance from the surface in Figure 8, where the concentration is normalized with respect to Si concentration. It is shown that the composition of the film is not uniform along the depth. Especially Al runs short of at the top surface of the film. Possibly that is why the breakdown strength depends on the polarity of the applied voltage although the upper and lower electrode are of the same material.

4. CONCLUSION

The optimum Si_3N_4 concentration in the sputtering target of Si_3N_4 and Al_2O_3 mixed powder for preparing SiAlON insulating films by rf magnetron sputtering method lies in about 0.6 ~ 0.8 When Si_3N_4 concentration was set at o.6, ε_r =9.11 and Q_{max}=4.83 μC/cm^2 were obtained respectively.

The thermal effect and the nonuniform concentration should be taken into account when discussing the breakdown mechanism in the SiAlON insulating film.

The nonuniformity of the concentration along the depth could be a reason why the breakdown strength depends on the polarity of the applied voltage.

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