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High Mobility and High Stability a-Si:H TFTs with Smooth MIS Interface

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The surface morphology for SiNx and an initial growth layer for a-Si:H have been observed, using the AFM method for the first time. By realizing a smooth surface for SiNx and a-Si, high mobility and high stability a-Si TFT has been obtained at the same time. This high performance TFT will have an important impact in application to high pixel density LCDs, such as for use in WS and HDTV.

1. Introduction

Amorphous silicon thin film transistors currently represent the leading technologies for active matrix-addressed LCDs. There are great demands for improving mobility and stability for a-Si:H TFTs in application to high resolution LCDs.

When the number of scanning line increases, the line charging time becomes very short. Therefore, high mobility is required to obtain high charging currents, without increasing a TFT channel width.

TFT instability is also a very important issue, because this instability defines the TFT-LCD life. The most important instability is the threshold voltage shift, that is observed after prolonged gate voltage application. High temperature deposition of amorphous silicon films is very effective to restrain this threshold voltage shift. However, the mobility decreases.[1]

This paper reports fabrication of a smooth SiNx/a-Si:H interface for realizing both high mobility and high stability TFTs at the same time.

2. Experiment

A-Si:H and SiNx films were deposited at 300°C by plasma enhanced CVD. A-Si:H films were made from SiH_4 gas. SiNx films, used as the gate insulator, were also made from SiH_4, NH_3, N_2 and H_2 mixture.

Surface roughness for SiNx and a-Si:H was evaluated by Atomic Force Microscope (AFM) measurement for the first time. The AFM measurement has an atomic scale resolution and is a suitable method for investigating an insulator sample without being coated with a conductive layer. 200nm thick SiNx, deposited on a flat quartz substrate, was measured. For a-Si:H films, 6nm thick a-Si deposited on 200nm thick SiNx was used.

TFT configuration used in this experiment has an inverted staggered structure as shown in Fig. 1. Various SiNx roughness values were used for gate insulators. The a-Si:H was deposited on the SiNx under various deposition power values.

The field effect mobility and threshold voltage are determined form these characteristics in the saturation region by plotting $(Id)^{1/2}$ versus Vg. Vt shift is measured as the difference of Vt in before and after applying the stress voltage at 30°C. The stress gate voltage is +25V and the drain voltage is 1V.

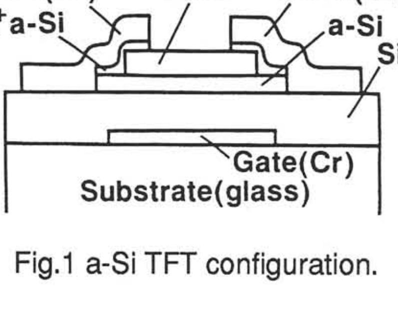
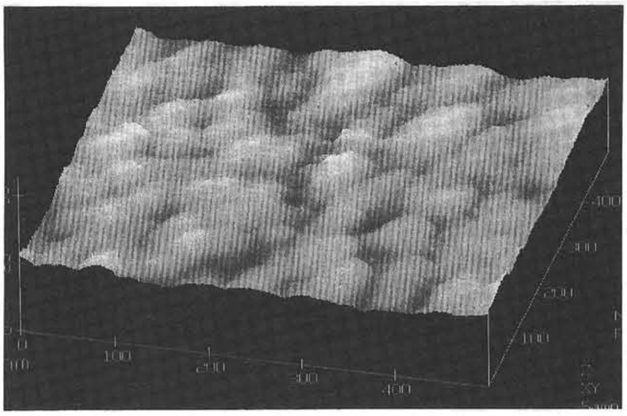
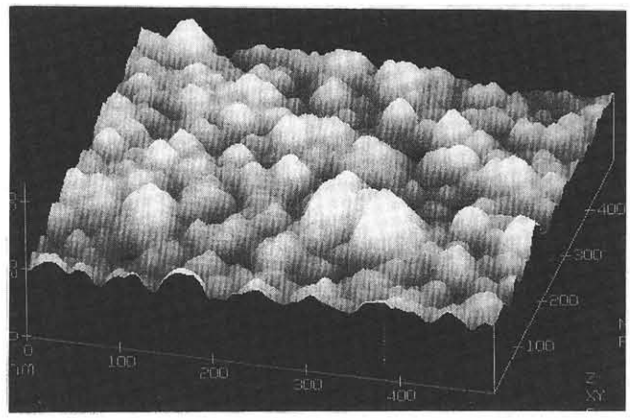


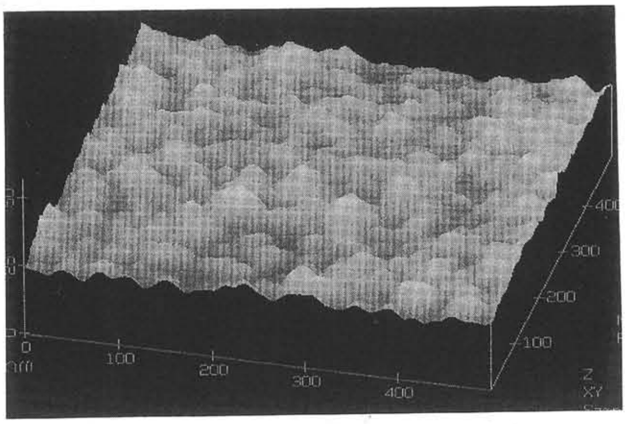
Fig.1 a-Si TFT configuration.



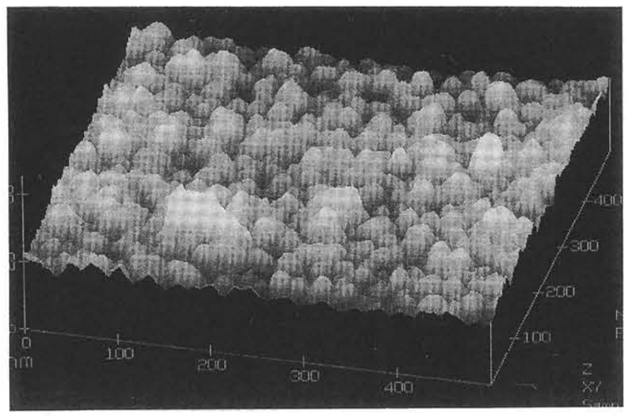
(a) SiNx deposited under smooth conditions.



(b) SiNx deposited under rough conditions.



(c) 6nm thick a-Si deposited under low power conditions on smooth SiNx.



(d) 6nm thick a-Si deposited under high power conditions on smooth SiNx.

Fig.2 AFM images for SiNx and a-Si on smooth SiNx.

3.Results and Discussion

SiNx films are deposited under the different source gas ratio. All other deposition conditions keep constant. These films have the same optical band gap (5.4eV) and the same BHF etching rate (24-30nm/min.). Nevertheless, surface roughness is quite different, as shown in Fig. 2. Under conventional conditions, SiNx film with a rough surface, whose average surface roughness was 1.6nm, was obtained. By controlling deposition source gas ratio, very smooth surface for the SiNx film has been obtained. The average surface roughness is 0.57nm.

Figures 1 (c) and (d) show the AFM image of the surface of 6 nm thick a-Si:H film deposited on a smooth SiNx film. Average surface roughness for the a-Si:H film, deposited under a high power condition ($32mW/cm^2$), is 1.43nm. Nevertheless, the roughness for a film deposited under low power conditions ($10mW/cm^2$), is 0.68nm. The surface roughness was also checked for films deposited directly on flat quartz substrate. The same results have been obtained.

From the standpoint of hydrogen content and optical band gap, these a-Si:H films have a different value. Hydrogen contents for the smooth a-Si:H film and the rough-surface a-Si:H film are $6x10^{21}cm^{-3}$ and $1.2x10^{22}cm^{-3}$, respectively. The optical gap is 1.62eV and 1.72eV, respectively.

The subject to be discussed now is the correlation between MIS interface roughness and TFT performance. As shown in Fig. 3, four different roughness combinations were fabricated. A is smooth a-Si:H on smooth SiNx, B is rough a-Si:H on smooth SiNx, C is smooth a-Si:H on rough SiNx, and D is rough a-Si on rough SiNx. So, A is called smooth MIS interface and C is called rough MIS interface. Transfer characteristics for the four TFTs are shown in Fig. 3. TFTs with smooth a-Si:H (A and C) have lower threshold voltage (1.2V) and higher field effect mobility than TFTs with rough a-Si:H. On the other hand, surface roughness for SiNx film mainly affects mobility. As shown in Fig. 4, the field effect mobility greatly increases along with decreasing a-Si average surface roughness for a smooth SiNx film. The smooth a-Si:H on smooth SiNx TFT shows the best performance, i.e. field effect mobility is 1.0 cm^2/V sec, Vt is 1.2V.

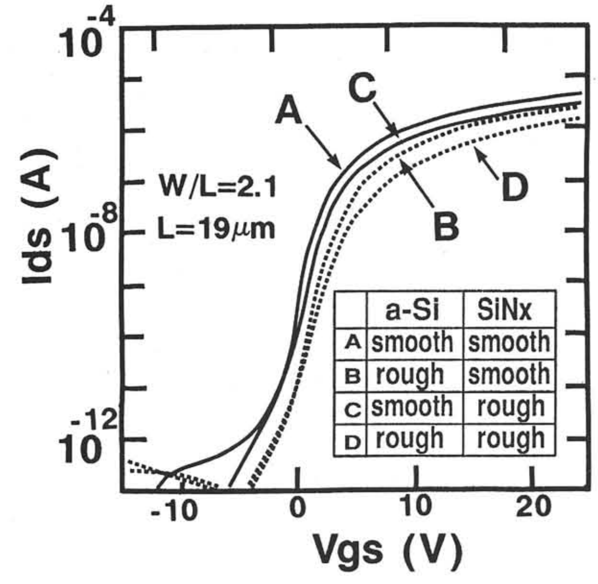


Fig.3 Transfer characteristics for TFTs.

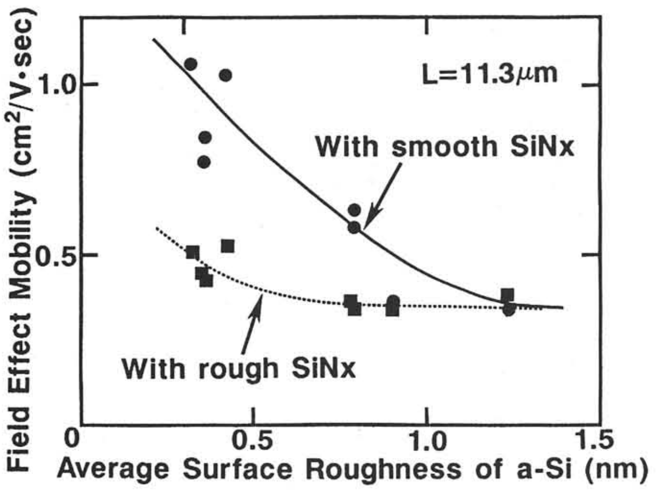


Fig.4 Field effect mobility as a function of average roughness for a-Si with smooth SiNx(0.57nm) and rough SiNx(1.62nm).

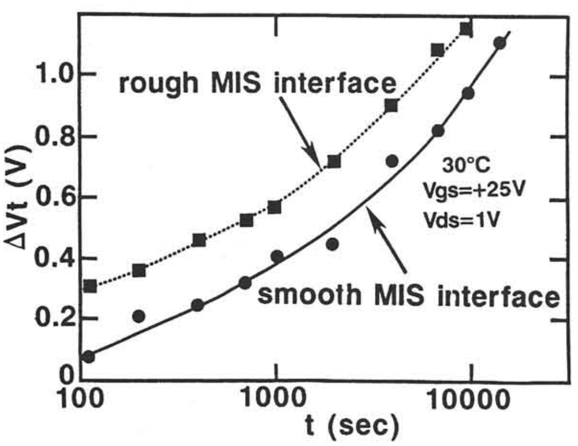


Fig.5 Threshold voltage shift as a function of time for smooth and rough MIS interfaces.

The transistor stability was also improved by using the smooth MIS interface, as shown in Fig. 5. For TFTs with the smooth MIS interface, very small Vt shift value, that is 0.4V after +25V gate voltage application for 1000sec, have been obtained. This Vt shift value is not larger than the value for TFTs fabricated by high temperature deposition.[1] The a-Si TFT with smooth MIS interface has both high mobility (1.0 cm^2/V sec) and high stability at the same time.

Now consider the simple interpretations of these results. The smooth initial growth layer for a-Si film may be due to unreactive deposition species with a sufficiently high surface mobility to bind at lower energy Si sites under low power deposition conditions. Therefore, surface roughness became small and the defect states could be eliminated. Therefore, initial growth layer quality for the a-Si:H film, which is an active layer for TFT, is improved and TFT mobility became high. Stability is also improved, because of decreasing weak Si-Si bonds.[2]

The SiNx surface morphology define the MIS interface roughness. In the case of Si-SiO_2 interface, the mobility reduction due to surface roughness scattering has been observed.[3] For a-Si/SiNX MIS interface, this effect is plausible. However, further work is needed to confirm these suggestions.

4.Conclusion

The surface morphology for SiNx and an initial growth layer for a-Si:H have been observed, using the AFM method for the first time. By realizing a smooth surface for SiNx and a-Si, high mobility and high stability a-Si TFT has been obtained at the same time. This high performance TFT will have an important impact in application to high pixel density LCDs, such as for use in WS and HDTV.

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