Effects of Stress Mismatch on the Electrical Characteristics of Amorphous Silicon TFTs for Active-Matrix LCDs

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Abstract

The effect of stress match between silicon nitride (SiN_x) and hydrogenated amorphous silicon (a-Si:H) layers on the electrical characteristics of thin-film transistors (TFTs) has been investigated. The result shows that modifying the deposition conditions of a-Si:H and SiN_x thin films can reduce the stress mismatch at a-Si:H/SiNx interface. Moreover, for best a-Si:H TFT characteristics, the internal stress of gate SiN_x layer with slightly nitrogen-rich should be matched with that of a-Si:H channel layer. The ON current, field-effect mobility, and stability of TFTs can be enhanced by controlling the stress match between a-Si:H and gate insulator. The improvement of these characteristics appears to be due to both the decrease of the interface state density between the a-Si:H and SiNx layer, and the good dielectric quality of the bottom nitride layer.

1. Introduction

Silicon nitride (a-SiN_x:H) thin films have been deposited by a variety of chemical-vapor-deposition (CVD) techniques, including plasma-enhanced CVD (PECVD), and have been widely used in the semiconductor industry as passivation layers, diffusion barriers, inter-level dielectrics, and insulators [1]. In addition, PECVD silicon nitride films have been used as gate dielectrics in applications of those requiring low deposition temperatures, such as hydrogenated amorphous silicon thin-film transistors (a-Si:H TFTs) [2]. SiN_x is the preferred gate dielectric material for a-Si:H TFTs because it gives better device performance than other dielectrics, such as silicon oxide and tantalum oxide [3,4]. The a-Si:H TFTs have been widely adopted as switching elements for high-quality flat-panel display, as driving circuits for image sensors and as basic logic functions. Therefore, it is important to understand in detail the electrical behavior of this material and its relationship to deposition conditions. To improve the performance and reliability of a-Si:H TFTs, however, the gate insulator, the interface between the active layer and gate insulator, and the a-Si:H active layer all must be improved. In thin-film device manufacturing, the internal stress of the thin film is a highly important factor because an excessive tensile stress may cause cracking in the device while an excessive compressive stress may invite peeling of the deposited thin film.

The high density of trap states in the SiN_x, however, causes the devices to suffer from charge-trapping phenomena as the threshold voltage shifts. This indicates the importance of optimizing the SiN_x gate insulator and the a-Si:H near the a-Si:H/SiN_x interface. Moreover, the performance and reliability of TFT using a-SiN_x:H gate insulator film are governed largely by its chemical composition. By operating the plasma under high power to activate the NH_3 or N_2 and under low SiH_4 flow to ensure that all of the SiH_4 reacts with N atoms, it is possible to deposit N-rich nitride that has no detectable Si-H bonding, which bonding others have corrected with charge trapping.

In this paper, we report how the stress mismatch between a-SiN_x:H and a-Si:H layers affects the performance and stability of a-Si:H TFT, focusing on the improvement in the electrical characteristics of a-Si:H TFTs for different a-SiN_x:H layers with different internal stress from tensile to compressive. We then discuss our findings in relation to the a-SiN_x:H and near-interface properties for a-Si:H and a-SiN_x:H.

2. Experiment

The fabrication process is similar to that of a conventional inverted-staggered a-Si:H TFTs, in which all of thin films were deposited under identical conditions, except for the deposition conditions of gate SiN_x layer with different flow rate ratio of NH_3 to SiH_4 gases from 6 to 20. These a-SiN_x:H films were also deposited under the conditions of higher power and lower pressure to possess the good quality as the gate insulator of TFTs [5]. The nominal channel width (*W*) for the completed TFT devices is 20 µm, while the nominal channel length (*L*) is 4 µm. The electrical characteristics and stability of the completed devices were measured by an HP4145B semiconductor parameter measurement system. The FTIR spectrum, refractive index (*N*), dielectric constant (*K*) and mechanical stress have been investigated for a series of hydrogenated amorphous silicon nitride (a-SiN_x:H) films for varying [NH_3]/[SiH_4] ratios R deposited at 350°C via PECVD employing a 13.56 MHz RF power source.

The mechanical (internal) stress in a-SiN_x:H layers is determined from room temperature through 410°C then cooled down by measuring the curvature of a-SiN_x:H-coated Si <100> crystal planes with the use of the Newtonian interference technique at a wavelength of 546 nm. Fourier-transform infrared (FTIR) absorption measurements have been carried out on a large number of a-SiN_x:H films to identify various possible bonding modes in the films. Infrared measurements were carried out using a DigiLab 3200 Fourier transform infrared spectrophotometer in the range from 400 to 4000 cm^{-1}, with a resolution of 4 cm^{-1}. Absorbances for the various absorption mode [N-H(stretching), Si-N(stretching), etc.] have been obtained from the measured film absorbance by subtracting a fitted baseline to account for the interference effects in the film itself.

3. Results and Discussion

The refractive index and dielectric constant of a-SiN_x:H films deposited at different NH_3/SiH_4 ratio are listed in Table 1. It shows that the increasing the ratio of NH_3/SiH_4 leads to a decrease in the refractive index of a-SiN_x:H films. The dielectric constant arrives the maximum of about 7.09 when the ratio of NH_3/SiH_4 increases to 15, while it falls to 6.96 when NH_3/SiH_4 ratio increases to 20.

Table 1. The refractive index and dielectric constant of a-SiN_x:H films deposited at different NH_3/SiH_4 flow rate ratio from 6 to 20.

[NH_3]/[SiH_4]	6	8	10	15	20
N	1.93	1.91	1.92	1.89	1.87
K	6.42	6.54	6.74	7.09	6.96

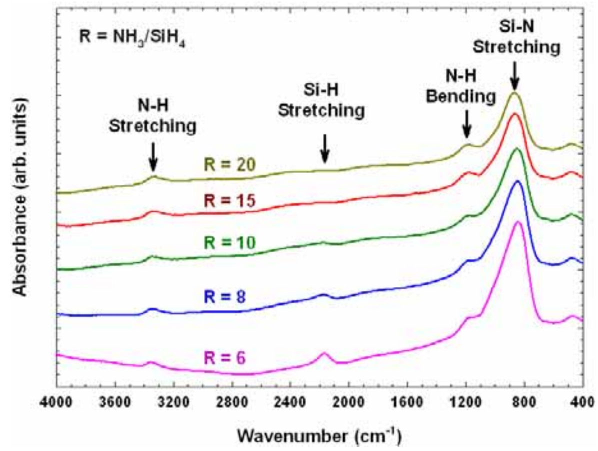

Figure 1. FTIR spectra of a-SiN_x:H films deposited at different NH_3/SiH_4 flow rate ratio.

From the paper which reported the general relationship between the threshold voltage of an inverted-staggered a-Si:H TFT and the refractive index of the SiN_x gate dielectric, the lowest threshold voltage falls into a small region of refractive indices, *i.e.*, between 1.85 and 1.90 [6]. In this study, it seems that the SiN_x films deposited at the NH_3/SiH_4 ratio from 14 to 20 could possess the refractive index for lowest threshold voltage of a-Si:H TFTs.

Figure 1 shows a series of infrared transmission spectra of about 300nm-thick a-SiN_x:H thin-films deposited at a varying ammonia-to-silane ratio (NH_3/SiH_4) from R=6 to R=20. It shows a dominant absorption peak and a weaker peak at around 897 cm^{-1} and 1168 cm^{-1}, which is characteristic of the Si-N asymmetric stretching bond and N-H bending bond, respectively [7-9].

Compared with a low pressure chemical vapor deposited Si_3N_4 film, the PECVD a-SiN_x:H film is slightly more nitrogen-rich and contains a large amount of hydrogen. The content of hydrogen in the a-SiN_x:H film can be determined by IR method, and the apportionment ratio between Si-H bonds and N-H bonds can be calibrated from the IR absorption of N-H and Si-H stretching frequencies at around 3350 cm^{-1} and 2190 cm^{-1}, respectively [10]. Since Si-H and N-H are usually electron and hole trapping centers, the N-H and Si-H peak area ratio should be minimized. Above the NH_3/SiH_4 ratio of about 10, the hydrogen content in the film is decreased and the number of hydrogen atoms bonded with silicon atoms decreases at the higher NH_3/SiH_4 ratio. Moreover, the

Si-H peak is almost not detectable above the NH_3/SiH_4 ratio of 15, as shown in Fig. 1.

Figure 2 shows that the internal stress of a-SiN_x:H at room temperature in the range of 2.8 x 10^9 dyne/cm^2 tensile to 3.8 x 10^9 dyne/cm^2 compressive is found to be controllable by changing the ratio of NH_3 to SiH_4 from R=6 to R=20 in the source gases.

The increase of NH_3/SiH_4 ratio results in the increase of compressive stress due to the increase of Si-N bonds and the decrease of Si-H and N-H bonds. It is found that the performance of a-Si:H TFTs is strongly dependent on the stress of a-SiN_x:H layers.

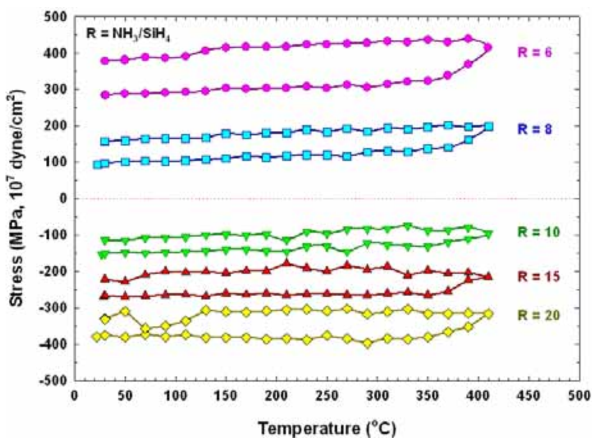

Figure 2. The mechanical stress of a-SiN_x:H films deposited at different NH_3/SiH_4 ratio as a function of temperature which varied from RT to 410°C then cooled to RT.

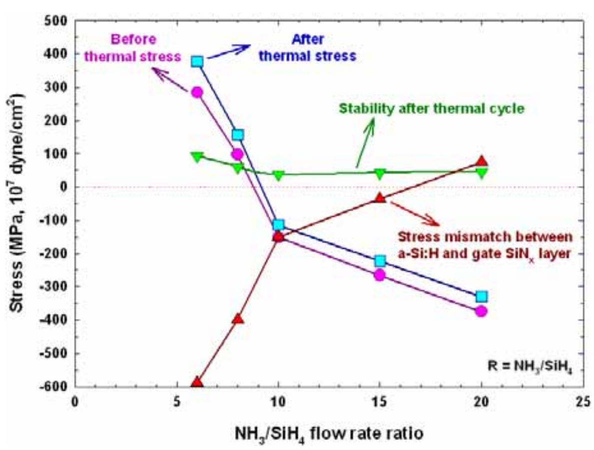

Figure 3. The internal stress of SiN_x films deposited at different NH_3/SiH_4 ratio and the stress mismatch between a-Si:H channel and SiN_x layers.

Figure 3 shows the internal stress of a-SiN_x:H films, which were deposited at different ratio of NH_3/SiH_4, before and after thermal stress. After a-SiN_x:H film suffered a thermal stress from room temperature (RT) to 410°C and then cooled to RT, the tensile stress slightly increased for all ratio of NH_3/SiH_4. Here, the difference of stress between after and before thermal cycle is defined as the thermal stability of stress. The thermal stability of a-SiN_x:H film with NH_3/SiH_4 ratio in the range from 10 to 15 is better than that of a-SiN_x:H film with other ratio due to a better quality of SiN_x film. The stress mismatch between a-Si:H channel layer and gate SiN_x layer with different NH_3/SiH_4 ratio is also shown in the Fig. 3. It shows that the stress mismatch is almost equal to zero when the ratio of NH_3/SiH_4 is about equal to 16.5, i.e., the stress of a-Si:H layer is almost equal to that of gate a-SiN_x:H layer.

As shown in Fig. 4, the I_{DS}-V_{GS} characteristics of a-Si:H TFTs with gate a-SiN_x:H layer deposited at different NH_3/SiH_4 ratio is strongly dependent on the stress match between a-Si:H channel layer and gate a-SiN_x:H layer. The ON current can arrive the maximum value when the ratio of NH_3/SiH_4 is equal to 15 in this study. We may imagine that the stress match between a-Si:H channel layer and gate a-SiN_x:H layer can strongly affect the performance of a-Si:H TFTs. In this case, it may gain the best performance of a-Si:H TFTs with a-SiN_x:H film deposited at the NH_3/SiH_4 ratio of about 16.5. The deposition condition of a-SiN_x:H layer should be modified to minimize the stress mismatch between channel and gate dielectric layers.

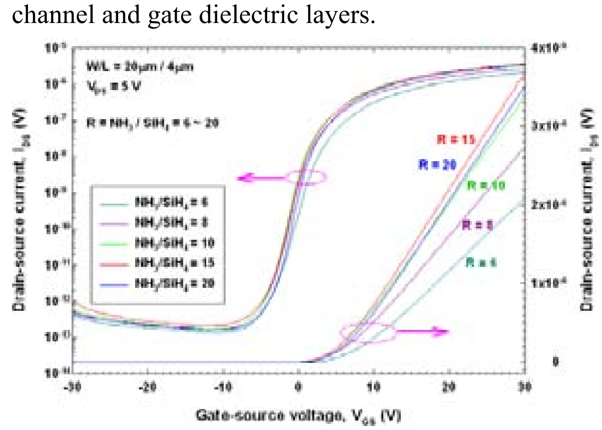

Figure 4. The effects of SiN_x films deposited at different NH_3/SiH_4 ratio on I_{on} improvement. The performance is strongly dependent on the stress match between channel and gate dielectric layers.

Figure 5 and 6 show the influence of a-SiN_x:H layer deposited at different NH_3/SiH_4 ratio on the electrical characteristics of a-Si:H TFTs. It also shows that the stress match between channel and gate dielectric layer can improve the ON current, mobility of TFTs. As shown in Fig. 6, the threshold voltage can be reduced to around zero due to the minimized interface state density. The result is consistent with the analysis from Fig. 3 and illustrates the importance of stress match between gate a-SiN_x:H layer and a-Si:H channel layer in the characteristics of a-Si:H TFTs.

4. Conclusion

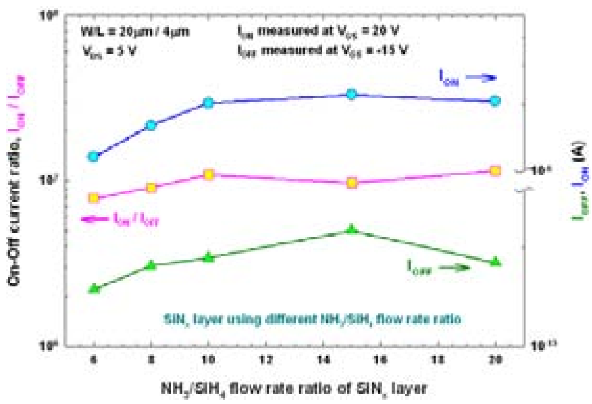

Figure 5. Influence of SiN_x layer deposited at different NH_3/SiH_4 flow rate ratio on I_{on}, I_{off} and I_{on}/I_{off} of TFTs.

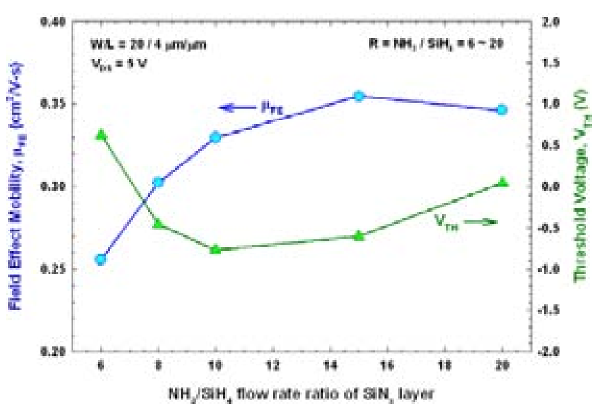

Figure 6. Influence of SiN_x layer deposited at different NH_3/SiH_4 flow rate ratio on mobility and threshold voltage shift of TFTs.

We have analyzed the bonding and internal stress properties of amorphous silicon nitride films made by plasma-enhanced CVD. Infrared transmission spectra of these films show characteristic absorption bands of Si-N, Si-H, and N-H bonds.

We have found that the performance of a-Si:H TFTs is strongly dependent on the composition of a-SiN_x:H layers. The stress mismatch at a-Si:H/SiN_x interface can be reduced by modifying deposition conditions of a-Si:H and a-SiN_x:H thin films. Moreover, for best a-Si:H TFT characteristics, the stress of gate SiN_x with slightly nitrogen-rich should be matched with that of a-Si:H channel layer. For different composition of a-Si:H channel layer resulting in a different internal stress, it is necessary to find a stress match a-SiN_x:H film as the gate dielectric of TFTs for gaining a good performance and stability.

5. Acknowledgements

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6. References

[1] C. E. Morosanu, *Thin Solid Films*, **65**, 171 (1980).

[2] K. D. Mackenzie, A. J. Snell, I. French, P. G. Lecomber, and W. E. Spear, *Appl. Phys. A*, **31**, 87 (1983).

[3] M. J. Powell, *Appl. Phys. Lett.*, **60**, 207 (1992).

[4] K. Suzuki, T. Aoki, M. Ikeda, Y. Okada, Y. Zohta and K. Ide, *SID'83 Dig.*, **00**, 146 (1983).

[5] Chien-Chien Tsai, Yeong-Shyang Lee, Ching-Chieh Shih, Chung-Yi Hsu, Chung-Yu Liang, Y. M. Lin and Feng-Yuan Gan, *IMID/IDMC 2006 Digest*, *ibid*, P-11 (2006).

[6] Y. Kuo, *Electrochem. Soc.*, **142**, 186 (1955).

[7] D. V. Tsu, G. Lucovsky and M. J. Mantini, *Phys. Rev. B*, **33**, 7069 (1986).

[8] E. A. Taft, *J. Electrochem. Soc.*, **118**, 1341 (1971).

[9] G. Lucovsky, J. Yang, S. S. Chao, J. E. Tyler and W. Czubatyi, *Phys. Rev. B*, **28**, 3234 (1983).

[10] W. A. Lanford and M. J. Rand, *J. Appl. Phys.*, **49**, 2473 (1978).