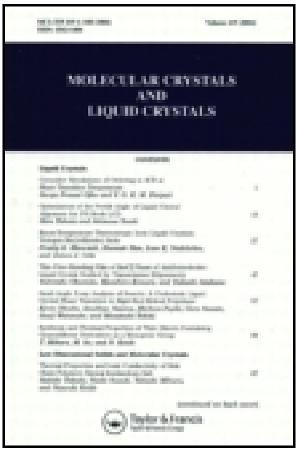


Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

The Effects of Phosphorus Doping in the a-Si:H and a-SiN:H on the Electrical Characteristics of a-Si:H TFT

Sang-Kwon Lee [a], Jung-Hwan Ji [a], Won-Ho Son [a] & Sie-Young Choi [a]
[a] School of Electrical Engineering and Computer Science, Kyungpook National University, Daegu, Korea
Version of record first published: 02 Aug 2012.

Mol. Cryst. Liq. Cryst., Vol. 563: pp. 26–35, 2012

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421406.2012.688547

The Effects of Phosphorus Doping in the a-Si:H and a-SiN:H on the Electrical Characteristics of a-Si:H TFT

SANG-KWON LEE, JUNG-HWAN JI, WON-HO SON, AND SIE-YOUNG CHOI*

School of Electrical Engineering and Computer Science, Kyungpook National University, Daegu, Korea

The effect of phosphorus doping in hydrogenated amorphous silicon (Si:H) and hydrogenated amorphous silicon nitride (a-SiN:H) for the electrical performances of hydrogenated amorphous silicon thin film transistors (a-Si:H TFTs) was studied. The phosphorus-doped layers in the a-Si:H and a-SiN:H with various concentrations were deposited by plasma-enhanced chemical vapor deposition (PECVD). We measured the electrical characteristics of a-Si:H TFTs fabricated by one or both phosphorus doping in a-Si:H and a-SiN:H, and then compared these results to conventional a-Si:H TFT. The sheet resistance and surface roughness of the a-SiN:H layers with various phosphorus doping concentrations were investigated to verify the effects of phosphorus doping on the electrical characteristics of the a-Si:H TFTs.

Keywords A-Si; H TFT; phosphorus doping; scattering effect

Introduction

Recently, hydrogenated amorphous silicon thin film transistors (a-Si:H TFTs) have been applied to liquid crystal displays (LCDs), organic light-emitting diodes (OLEDs), and other large area microelectronics and optoelectronics devices [1]. In particular, a-Si:H TFTs for active matrix OLEDs (AMOLEDs) have the advantages of low cost and good uniformity compared to low-temperature poly-silicon (LTPS) TFTs. However, it has some disadvantages such as low mobility, high off current, and gate swing. The degradation of the electrical characteristics of a-Si:H TFTs is caused by the a-Si:H layer of the active layer, which has defects of the interface trap, deep states, and tail states due to the amorphous material. The drive devices for large LCDs and OLEDs using a-Si:H TFT needs to have the characteristics of a high on current and a good on/off rate [2,3].

In investigating the electrical characteristics of a-Si:H TFTs, researchers have presented a method of phosphorus doping in a-Si:H and a-SiN:H [3]. In this study, we measured the electrical characteristics of a-Si:H TFTs fabricated by one or both phosphorus doping in a-Si:H and a-SiN:H to identify the optimal phosphorus doping condition. Also, we confirmed that the electrical characteristics of a-Si:H TFTs using phosphorus doping

*Address correspondence to Prof. Sie-Young Choi, School of Electrical Engineering & Computer Science, Kyungpook National University, 1370 Sangyuk-dong, Buk-gu, Daegu 702-701, Korea (ROK)(+82) 53-950-5518 (+82) 53-950-6837. E-mail: sychoi@ee.knu.ac.kr

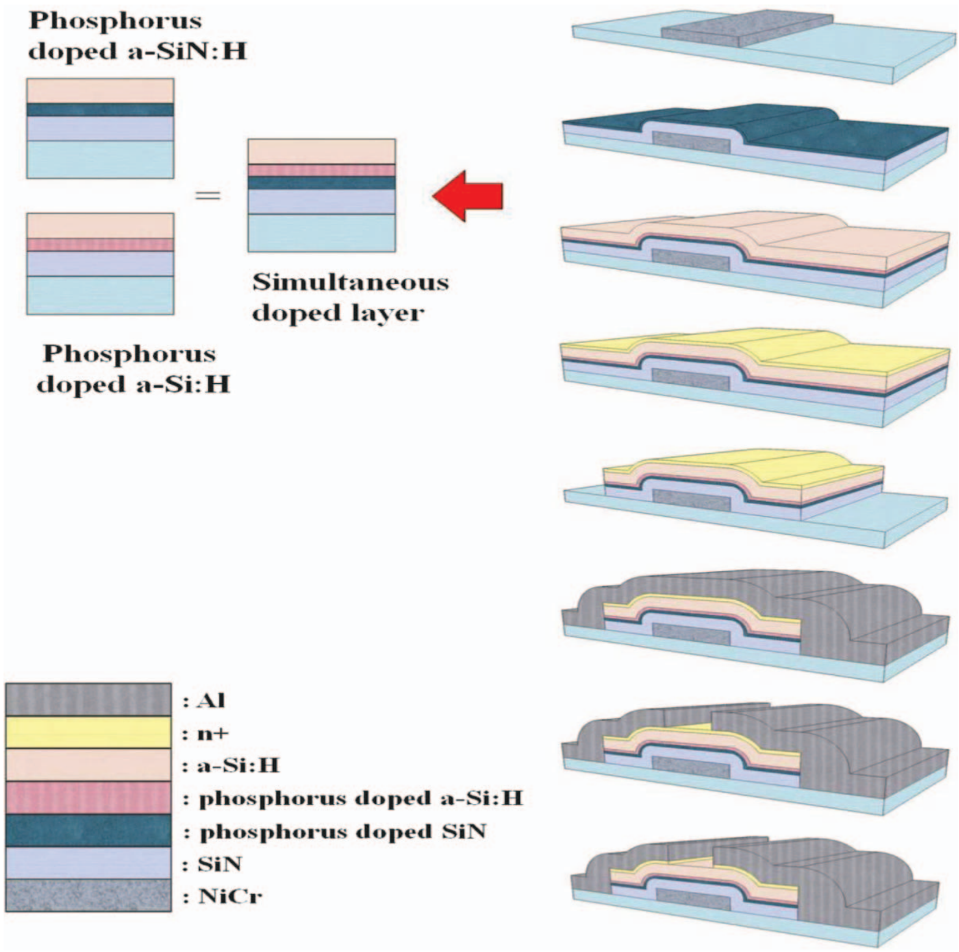


Figure 1. The fabrication process of a-Si:H TFTs with an inverted staggered structure as the method for phosphorus doping in a-Si:H and a-SiN:H.

depends on the various phosphorus concentrations during the doping of a-Si:H and a-SiN:H. In addition, we investigated the surface roughness of the phosphorus-doped layer in a-SiN:H with various concentrations by atomic force microscopy (AFM) and compared to the sheet resistance (Rs).

Experimental

Figure 1 describes the fabrication process of a-Si:H TFTs with an inverted staggered structure as the phosphorus doping method in a-Si:H and a-SiN:H. First, the nichrome (NiCr) with a thickness of 1500 Å for the bottom gate was deposited on glass by a thermal evaporator system. Afterward, it was patterned by the photolithography process. Next, a 2500 Å thick a-SiN_X, 2000 Å thick a-Si:H, and 500Å thick n^+ a-Si:H films were deposited consecutively in the plasma-enhanced chemical vapor deposition (PECVD). Each of the phosphorus-doped layers was deposited after forming the a-SiN:H and before forming the

Table 1. The deposition conditions of the thin films

Parameter	a-SiN:H	a-SiN:H (P-doping)	a-Si:H (P-doping)	a-Si:H	n^+ a-Si:H
Gas	$SiH_4/NH_3/Ar$	$SiH_4/NH_3/Ar/PH_3$	$SiH_4/H_2/PH_3$	SiH_4/H_2	SiH_4/PH_3
Flow rate (sccm)	30/45/100	30/45/100/3∼15	30/50/0.5∼4	30/50	30/50
Radio frequency power (W)	200	200	150	150	100
Substrate temperature (°C)	250	250	250	250	250
Working pressure (mTorr)	700	700	700	700	700
Deposition time	12 min	15∼22 sec	18 sec ∼ 1 min 29 sec	27 min	6 min

a-Si:H. The thickness of the phosphorus-doped layers in a-Si:H and a-SiN:H were 150 Å and 100 Å, respectively. The working pressure was 700 mTorr and the substrate temperature was 250°C. The a-SiN:H layer was deposited using a gas mixture of SiH_4, NH_3, and Ar, the a-Si:H layer used a gas mixture of SiH_4 and H_2, and the n^+ a-Si:H layer used SiH_4 and PH_3. The one or both phosphorus doping in a-Si:H and a-SiN:H were controlled by varying the deposition time and the flow rate of the phosphine gas for the doped layers. Table 1 presents the deposition conditions. Then, the layers were patterned. An aluminum (Al) metal with a thickness of 2000 Å was deposited subsequently by a thermal evaporation system and patterned to form the source and drain electrodes. Lastly, the n^+ a-Si:H layer was etched for

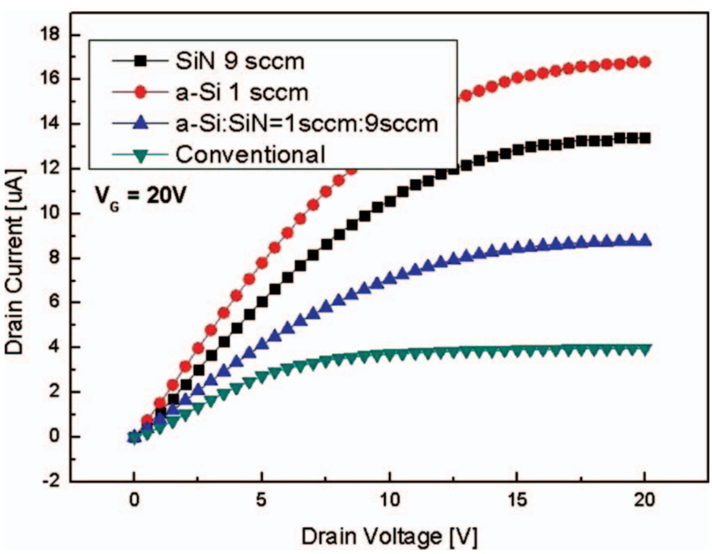


Figure 2. The drain current characteristics (V_D–I_D) of conventional a-Si:H TFTs and the phosphorus-doped a-Si:H TFT by one and both doping methods.

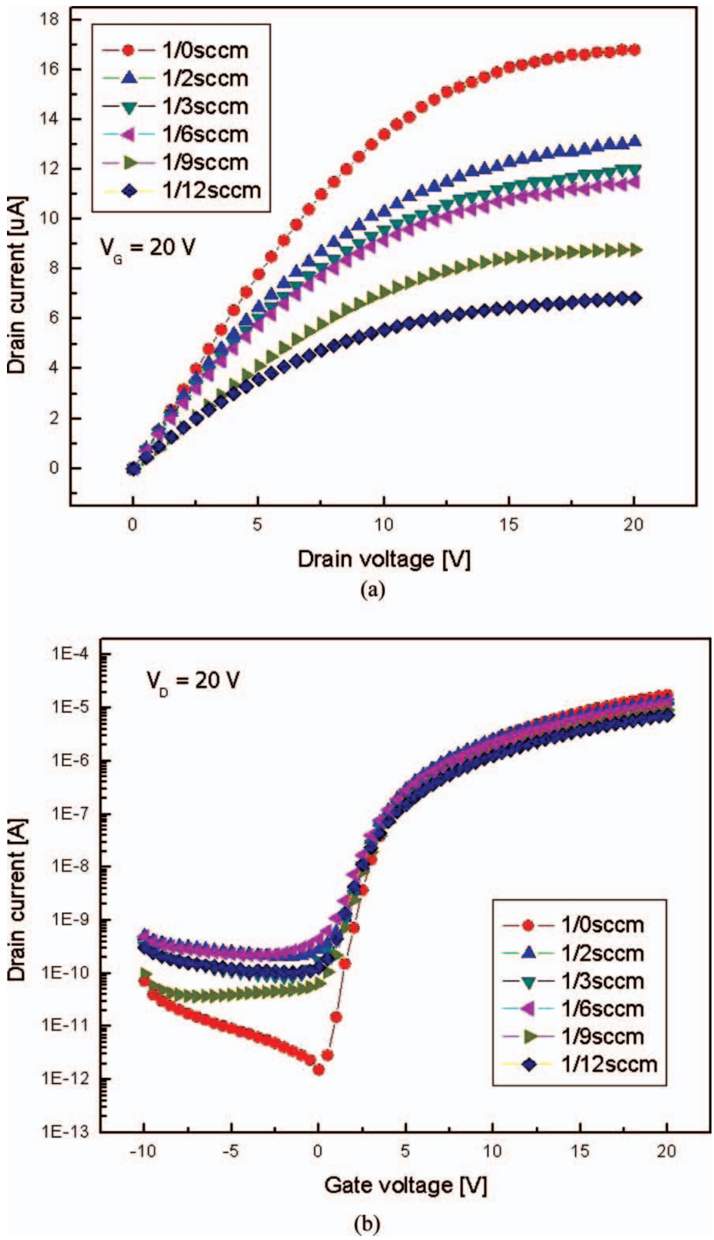


Figure 3. The output drain current (a) and the on/off current ratio (b) of the a-Si:H TFTs at the various concentrations of phosphorus with both phosphorus doping.

electrical isolation between the source and drain electrodes by reactive ion etching (RIE). In order to investigate the effect of phosphorus doping at the interface between a-Si:H and a-SiN:H, we measured the drain voltage (V_D), drain current (I_D), and the gate voltage (V_D)–drain current (I_D), respectively, using the HP 4155-6 semiconductor parameter. The measurements were performed in a dark chamber to avoid effects related to light [6].

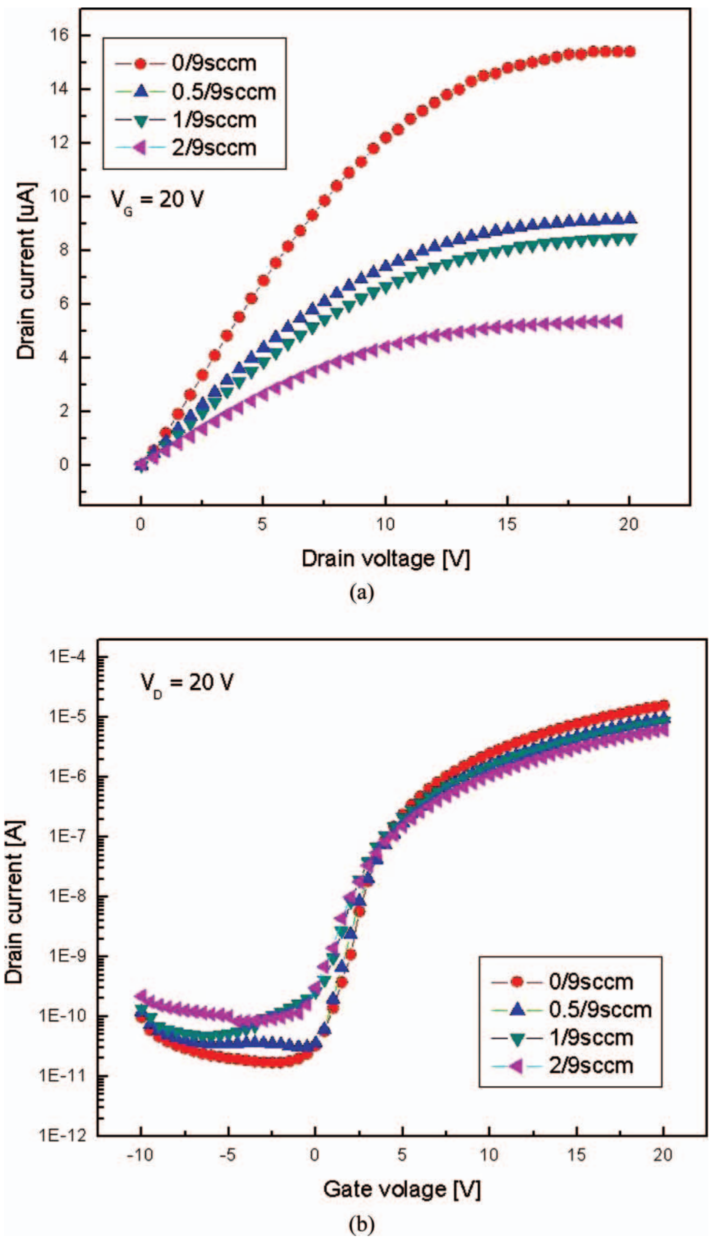


Figure 4. The output drain current (a) and the on/off current ratio (b) of the a-Si:H TFTs with respect to the various phosphorus concentrations in a-Si:H.

Results and Discussion

From previous experimental results, we found that the optimal phosphorus doping conditions (flow rate of the phosphine gas) in a-Si:H and a-SiN:H were 1 sccm and 9 sccm, respectively. In Fig. 2 with a fixed gate voltage (V_G) of 20 V, the drain current characteristics of a conventional a-Si:H TFT was compared with those of one and both phosphorus

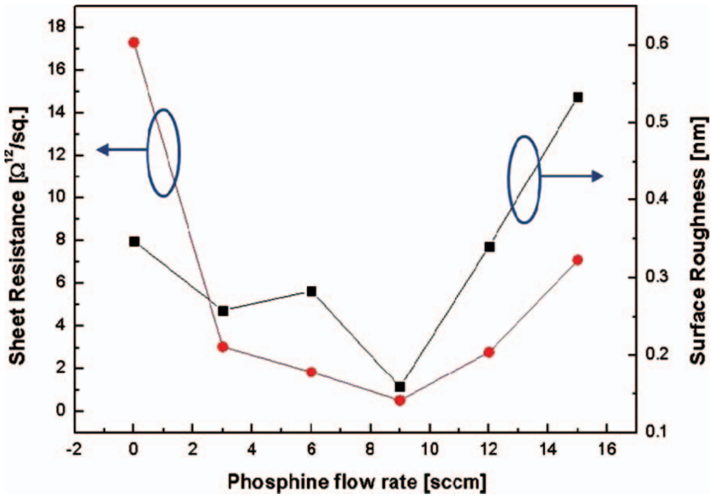
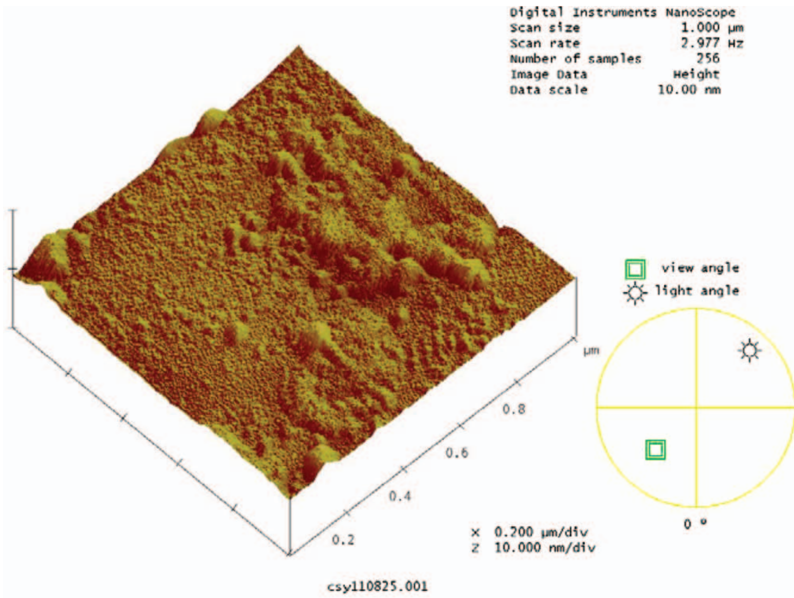


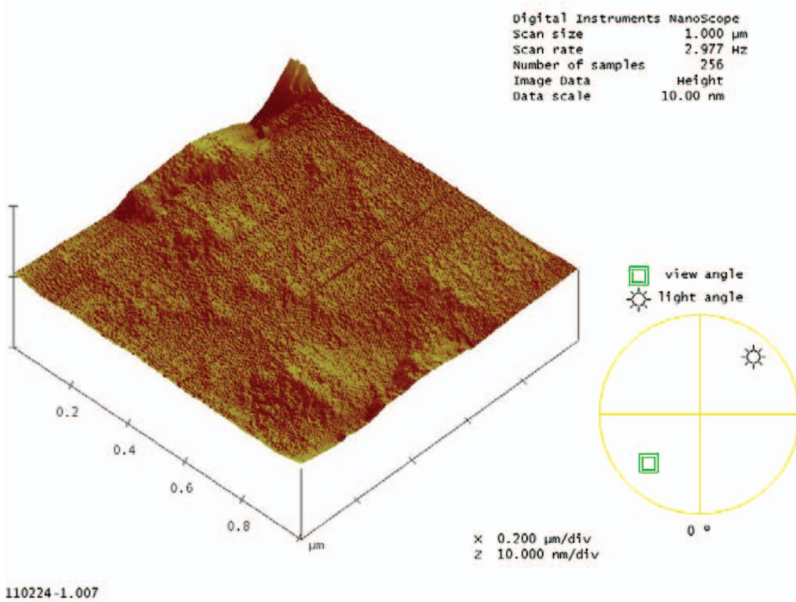
Figure 5. The RMS of surface roughness and the sheet resistance with respect to the flow rate of phosphine gas in a-SiN:H.

doping in a-Si:H and a-SiN:H, respectively. We confirmed that the output drain current of the phosphorus-doped a-Si:H TFTs improved better than that of conventional a-Si:H TFT. However, the output drain current of a-Si:H TFT using both phosphorus doping in a-Si:H and a-SiN:H was less than that of the a-Si:H TFTs using one doping in a-Si:H or a-SiN:H. Figure 3 shows the output drain current and the on/off current ratio of the a-Si:H TFTs at the various concentrations of phosphorus with both phosphorus doping in which a-Si:H was fixed at 1 sccm and a-SiN:H was changed from 0 sccm to 12 sccm. The electrical characteristics (drain current and on/off current) of the a-Si:H TFT fixed at 1 sccm in a-Si:H deteriorated as the phosphorus concentration in a-SiN:H increased from 0 sccm to 12 sccm. Figure 4 shows the output drain current (a) and the on/off current ratio (b) of the a-Si:H TFTs with respect to the various phosphorus concentrations in a-Si:H. As the phosphorus doping in a-SiN:H increased from 0 sccm to 2 sccm, the electrical characteristics of the a-Si:H TFT fixed at 9 sccm in a-SiN:H deteriorated, too. One explanation of these results is that the electrical characteristics of both phosphorus-doped a-Si:H TFTs have a greater deterioration than that of the one doped a-Si:H TFTs because of the ion-scattering effect in the channel [7].

To verify that the effects of high phosphorus doping on the ion scattering in the channel caused the low electrical characteristics of the a-Si:H TFTs, the surface roughness of the a-SiN:H layers with respect to the flow rates of the phosphine gas was investigated by AFM [6]. Moreover, the surface roughness was compared to the Rs of the a-SiN:H layers deposited with various flow rates of phosphine gas. Figure 5 shows that the root mean square (RMS) of the surface roughness was slowly decreased from 0.347 nm to 0.159 nm as the flow rate of phosphine gas increased from 0 sccm to 9 sccm, while the RMS of the surface roughness dramatically increased to 0.534 nm as the flow rate of phosphine gas increased up to 15 sccm. In case of the Rs versus the flow rate of phosphine gas in the a-SiN:H, when the flow rate of phosphine gas in the a-SiN:H increased from 0 sccm to 9 sccm, the Rs decreased from 17.3×10^{12} to 0.51×10^{12} Ω. The Rs then increased to 7.1×10^{12} Ω as the flow rate of phosphine gas increased to 15 sccm. Figure 6 shows the three-dimensional AFM images of the surfaces deposited with

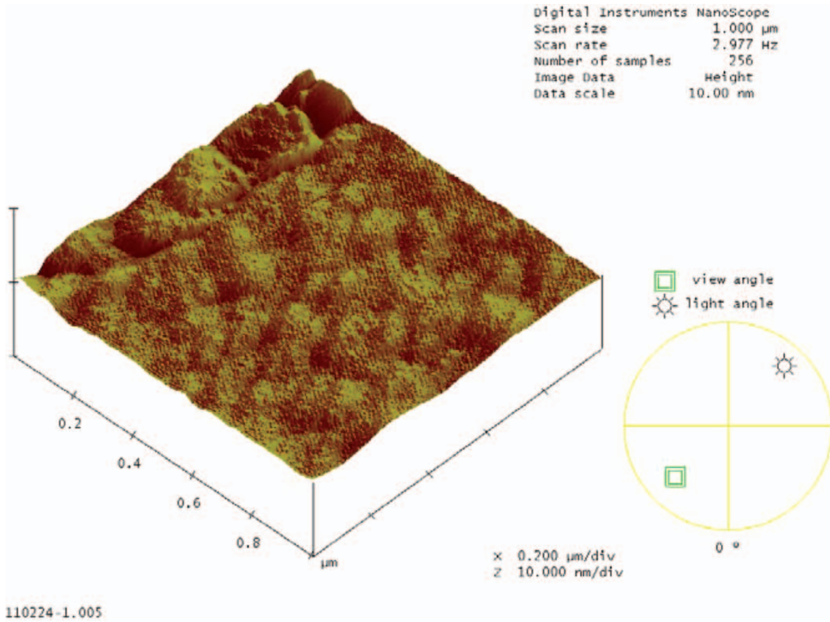


(a) Without doping

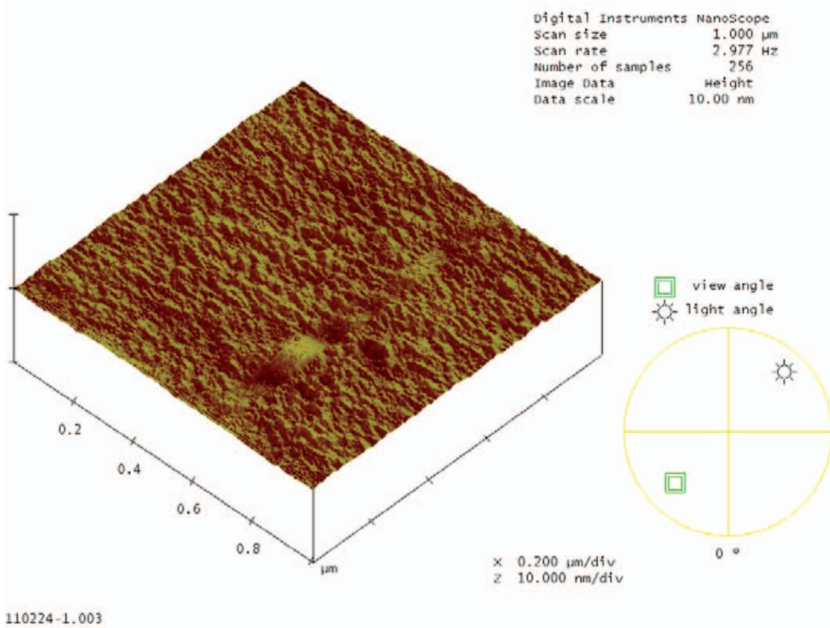


(b) 3 sccm

Figure 6. Three-dimensional (3D) AFM images of the a-SiN:H thin films. (*Continued*)

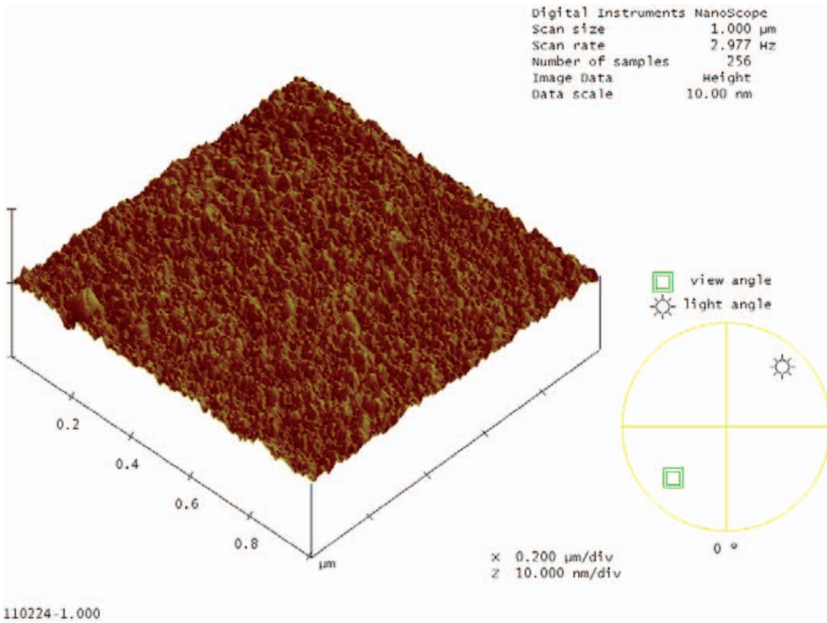


(c) 6sccm

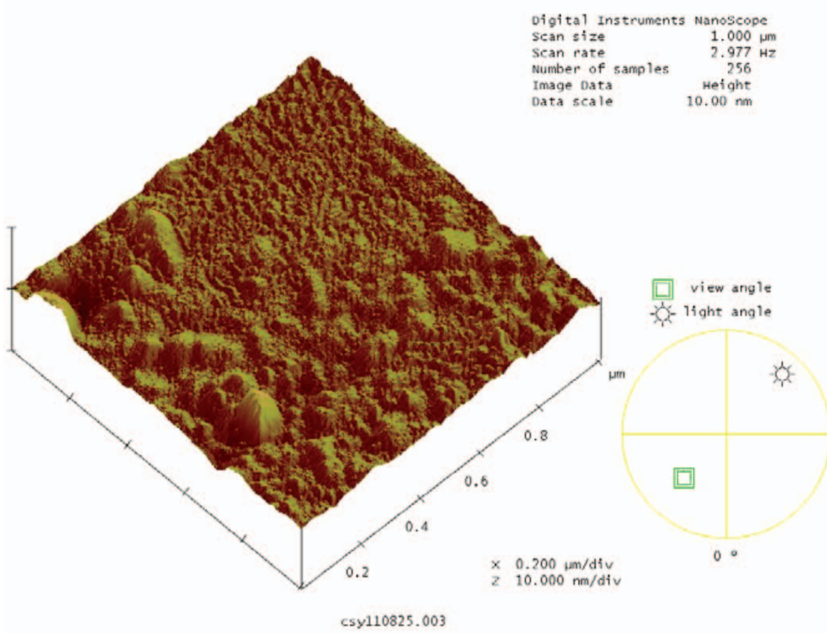


(d) 9 sccm

Figure 6. (*Continued*)



(e) 12 sccm



(f) 15 sccm

Figure 6. (*Continued*).

various flow rate of phosphine gas in the a-SiN:H. From these results, we confirmed that the phosphorus-doped layer deposited as the low flow rate of phosphine gas contributed to the increase of carrier concentrations in the channel of a-Si:H TFTs; however, high phosphorus doping in the channel of a-Si:H TFTs caused a higher ion-scattering effect and lower conductivity due to the increased surface roughness and Rs. It has been known that the scattering effects due to surface roughness scattering should be considered for variations of electrical characteristics [8].

Conclusions

In this paper, we investigated the effects of one or both phosphorus doping in a-Si:H and a-SiN:H on the electrical characteristics of a-Si:H TFTs and compared the results to the electrical characteristics of conventional a-Si:H TFT. We obtained the results that the electrical characteristics (drain current and on/off rate) of phosphorus-doped a-Si:H TFTs improved compared to the conventional a-Si:H TFT. Also, we confirmed the optimal conditions for the phosphorus-doped layer, which is 1sccm for a-Si:H doping and 9sccm for a-SiN:H doping. The electrical characteristics of phosphorus-doped a-Si:H TFTs by both phosphorus doping in a-Si:H and a-SiN:H were measured with increased doping concentration. The electrical characteristics of doped a-Si:H TFTs deteriorated as the phosphorus concentrations increased in a-Si:H as well as in a-SiN:H due to the ion-scattering effect in the channel. To confirm the ion-scattering effect, we investigated the Rs and surface roughness of phosphorus-doped layers in a-SiN:H, which indicated 0.159 nm and $0.51 \times 10^{12}\,\Omega$ at the phosphine gas flow rate of 9 sccm, respectively. However, the RMS of the surface roughness and the Rs increased as the flow rate of phosphine gas increased to 15 sccm. From our experimental results, we confirmed that the increase of phosphorus doping concentrations in the channel had effects on the electrical characteristics of a-Si:H TFTs due to the variation in Rs and the surface roughness of the phosphorus-doped layers.

Acknowledgment

This work was supported by the Regional Innovation Center program (ADMRC) of the Ministry of Knowledge Economy, Republic of Korea.

References

[1] Yamazaki, E. (2001). *Proc. International Display Workshop*, *01*, 659–.
[2] Jang, J. (2003). *Thin Film Transistors*, Marcel Dekker, Inc.
[3] Aoki, H. (1996). *IEEE Trans. Electron Devices*, *43*, 31.
[4] Moon, K. H., Cho, Y. S., Choi, H., Ha, C. K., Lee, C. G., & Choi, S. Y. (2009). *Jpn. J. Apl. Phys.*, *48*, 03B017.
[5] Jung, H. C., Park, K. M., Moon, K. H., Lee, T. Y., & Choi, S. Y. (2009). *Mol. Cryst. & Liq. Cryst.*, *514*, 274.
[6] Lee, S. K., Shin, S. H., Jung, H. J., & Choi, S. Y. (2010). *Mol. Cryst. & Liq. Cryst.*, *532*, 127.
[7] Smith, Z. E., & Wagner, S. (1987). *Phys. Rev. Lett.*, *59*, 688.
[8] Huang, J. J., Liu, C. J., Lin, H. C., Tsai, C. J., Chen, Y. P., Hu, G. R., & Lee, C. C. (2008). *J. Phys. D: Appl. Phys.*, *41*, 245502.