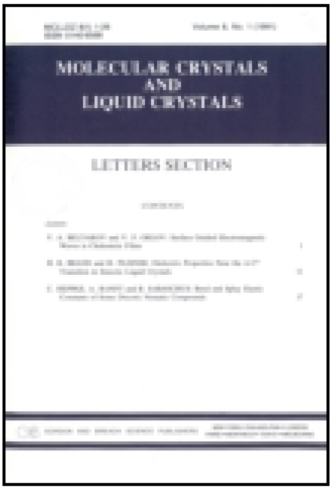

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

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Published online: 06 Dec 2014.

Mol. Cryst. Liq. Cryst., Vol. 601: pp. 71–78, 2014

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421406.2014.940507

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This paper suggests a method of phosphorus doping in the active layer to improve the electrical characteristics of hydrogenated amorphous silicon (a-Si:H) thin film transistor (TFT). Phosphorus doping in the active layer of a-Si:H was performed by the deposition of a-Si:H through the addition of phosphine gas by plasma enhanced chemical vapor deposition (PECVD). We confirmed that the electrical characteristics of phosphorus doped a-Si:H TFT were improved compared to those of conventional a-Si:H TFT to the extent that the field effect mobility and off current were 0.44 $cm^2/V\bullet s$ and 1.53×10^{-12} cm^2 when phosphorus was doped by 1 sccm. We investigated the sheet resistance (Rs), root-mean-square roughness (RMS) and density of state (DOS) to demonstrate the improved electrical characteristics. From the results, we confirmed that phosphorus doping in the active layer supplies the electron to use dopant in the channel as well as leads to an improvement of the DOS and higher quality in a-Si:H.

Keywords Thin film transistor (TFT); plasma enhanced chemical vapor deposition (PECVD); phosphorus doping

1. Introduction

Recently, a-Si:H TFT has been intensively researched for use in active-matrix organic light-emitting diodes (AMOLED). Because compared with crystalline silicon, a-Si:H possesses several major advantages: low cost process, large-area deposition, low deposition temperatures, and standard fabrication processes [1–3]. However, a fabricated a-Si:H TFT had poor electrical characteristics such as low field effect mobility and on/off ratio, because it has the defects of the interface trap, deep states and tail states in the active layer of a-Si:H [4, 5]. It is essentially improved as an applied drive device in large LCDs and OLEDs. The performance of the a-Si:H TFT depends on the characteristics of the a-Si:H such as the density of states, the conductivity, interface state between a-SiN:H and a-Si:H, and its device geometry. In other papers, research about the improvement of the interface state of a-SiN_X/Si:H and back surface states have been published in recent years [6, 7]. In this

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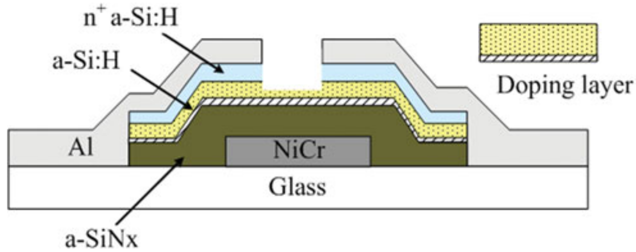

Figure 1. Schematic representation of the back channel etched inverted-staggered TFT with phosphorus doping in the a-Si:H layer.

paper, the phosphorus doing in the active layer was proposed to improve the electrical characteristics of a-Si:H TFT. In the case of dopant doping in crystalline silicon, it is well known that the variation of dopant concentrations in silicon material has effects on the electrical conductivity and Fermi level [1, 2]. Accordingly, when the phosphorus of dopant in the active layer at a-Si:H TFT is doped, the electrical characteristics of a-Si:H TFT are expected to be influenced as the variation of phosphorus doping concentration due to an increased conductivity in the channel [8]. For the fabrication of a-Si:H TFT, phosphorus in the active layer of a-Si:H can be doped through the deposition of a-Si:H by adding phosphine gas to the plasma enhanced chemical vapor deposition (PECVD) [9–11].

Therefore, we fabricated the a-Si:H TFT whose active layer was doped by the modified deposition method using PECVD. The electrical characteristics of a-Si:H TFT (drain current, on/off rate) were investigated to identify optimal conditions through the change of phosphorus doping concentration in the active layer. The sheet resistance (R_S) of a-Si:H layer with various phosphorus concentrations were measured and compared with the field effect mobility of a-Si:H TFT to demonstrate the influences of phosphorus doping in the active layer. The variation of interface quality between a-Si:H and a-SiN:H were investigated through D_{it} (interface trap density) which were then compared with the measured root-mean-square roughness (RMS) of a-Si:H layer. In addition, we observed the results of fourier transform infrared spectrometer (FT-IR), and ultraviolet visible (UV) spectroscopy in order to analysis the chemical composition, and density of state (DOS) of a-Si:H layer with various phosphorus concentrations.

2. Experimental

2.1 Fabrication

A typical back channel etched inverted-staggered for a-Si:H TFT was designed [10]. The gate length and width of the TFT was 20 um and 1000 um. The schematic representation of the back channel etched inverted-staggered TFT with phosphorus doping in the active layer is represented in Fig. 1. First, the nichrome (NiCr) with a thickness of 1500 Å of bottom gate was deposited on glass by a thermal evaporator system. Then, it is patterned by the photolithography process. Second, the 2500 Å thick a-SiN:H, 2000 Å thick a-Si:H and 500 Å thick n^+ a-Si:H films were consecutively deposited in the PECVD. The phosphorus doping layer before forming the a-Si:H layer were deposited under process conditions which were controlled by varying the various flow rate (from 0.5 to 4 sccm) of phosphine gas. The deposition conditions of the PECVD system was presented in Table 1. Also,

Table 1. Deposition condition of PECVD system

Parameter	a-SiN:H	a-Si:H (P-doping)	a-Si:H	N+a-Si:H
Gas	$SiH_4/NH_3/Ar$	$SiH_4/H_2/PH_3$	SiH_4/H_2	SiH_4/PH_3
Flow rate [sccm]	30/45/100	30/50/0.5∼4	30/50	30/50
Sub temperature [°C]	250	250	250	250

the phosphorus concentration in a-Si:H layer was comprised in Table 2. Then, they were patterned. Third, Al metal was deposited with a thickness of 2000 Å by a thermal evaporator system and patterned to form the source and drain electrodes. Finally, the n^+ a-Si:H layer was etched for electrical isolation between the source and drain electrodes by reactive ion etching (RIE).

2.2 Measurements

In order to measure the electrical characteristics of fabricated a-Si:H TFT, we used a HP 4156C which is a semiconductor parameter analyzer system. The drain characteristics of a-Si:H TFTs were investigated from a drain voltage (V_D)-drain current (I_D), and the on/off current rate of those was investigated from the change of gate voltage (V_G) maintaining constant V_D. The Rs and RMS were measured by the four-point probe and AFM, respectively. Also, the characteristics of the chemical composition and the density of state were measured by FTIR, and UV spectroscopy. All the measurements were carried out at room temperature in a dark chamber to avoid any effects related to light.

Results and Discussion

3.1 Electrical Characteristics of Phosphorus Doped a-Si:H TFTs

Figure 2 shows the electrical characteristics of a-Si:H TFT (a) output curve (V_{DS}-I_{DS}), (b) transfer curve (V_{GS}-I_{DS}) with various phosphorus concentrations in the a-Si:H layer. The drain current of phosphorus doped a-Si:H TFT increased from 3.98 to 16.8 uA when an increase of the phosphorus doping in the active layer changed from 0 to 1 sccm, whereas when the phosphorus concentration increased from 1 to 4 sccm, the drain current dramatically decreased from 16.8 to 3.25 uA. The off current was decreased from 5.31×10^{-10} to 1.53×10^{-12} cm^2 when phosphorus doping increased from 0 to 1 sccm, while off current increased over 1 sccm. From the experimental results, we confirmed that the electrical characteristics of phosphorus doped a-Si:H TFTs were more improved than those of conventional a-Si:H TFT and the optimal condition of phosphorus doping concentration was 1 sccm. On other hand, the electrical characteristics of a-Si:H TFT deteriorated with an increase of phosphorus concentration with a doping ratio of over 1 sccm in the a-Si:H layer.

Table 2. Units of measure conversion of phosphorus concentration in a-Si:H layer

Doping condition [sccm]	0.5	1	2	3	4
Parts per million [ppm]	500	1000	2000	3000	4000

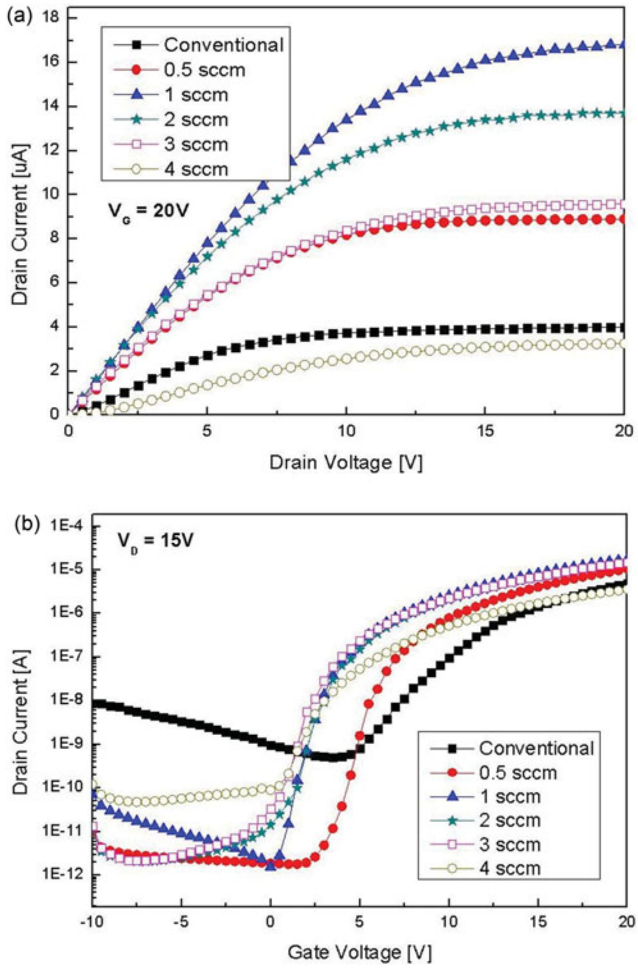

Figure 2. Electrical characteristics of a-Si:H TFT (a) output curve (V_{DS}-I_{DS}), (b) transfer curve (V_{GS}-I_{DS}) with various phosphorus concentration in a-Si:H layer.

This is related to the impurity scattering effect in channel for higher doping concentration. From the obtain results, we investigated the field effect mobility of a-Si:H TFTs from Eq. (1) [9].

$$\mu_{sat} = 2LI_D/C_iW(V_G - V_{TH})^2 \tag{1}$$

where C_i is gate insulator capacitance per unit area and L/W (1:50) is the channel length/width ratio. The field effect mobility of phosphorus doped a-Si:H TFT for 1 sccm (0.44 cm^2/V·s) increased more than conventional a-Si:H TFT (0.19 cm^2/V·s).

3.2 Sheet Resistance of a-Si:H Layer

We measured R_S to investigate the variation of electrical resistance with the various phosphorus doping concentrations in a-Si:H layer. It is comparable the measured mobility of phosphorus doped a-Si:H TFT, because the R_S of phosphorus doped layer related to

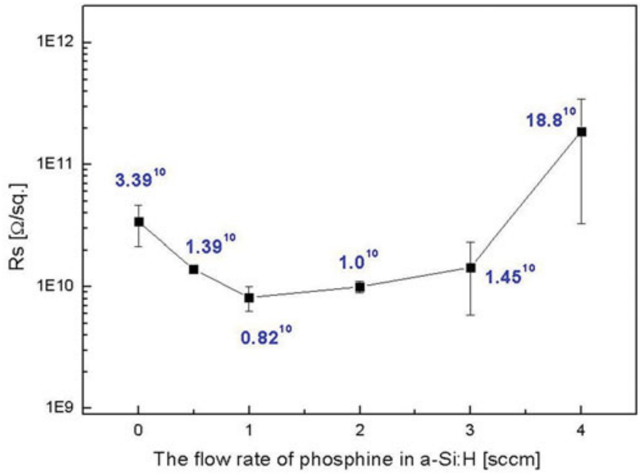

Figure 3. Rs of a-Si:H with the flow rate of phosphine.

the conductance dependent on the field effect mobility of phosphorus doped a-Si:H TFT. Figure 3 shows the Rs of a-Si:H with the flow rate of phosphine. The Rs was decreased from 3.39×10^{10} to 0.82×10^{10} Ω as a variation of a doping ratio from 0 to 1 sccm, while the R_S was increased from 0.82×10^{10} to 18.8×10^{10} Ω as with the variation of the doping ratio from 1 to 4 sccm. We ascertained that conductivity of the a-Si:H layer for the flow rate of 1 sccm is higher than that in other conditions. Figure 4 shows the variation of the field effect mobility and Rs with the flow rate of phosphine in a-Si:H layer. The Rs was decreased as the flow rate of phosphine gas increased from 0 to 1 sccm, and the result clearly shown that the field effect mobility was similarly increased. Also, the field effect mobility was decreased as much as the Rs was increased as the flow rate of phosphine gas increased from 1 to 4 sccm. From the experimental results, we confirmed that the field effect mobility of a-Si:H TFT can be efficiently improved, when phosphorus in a-Si:H layer is doped at 1

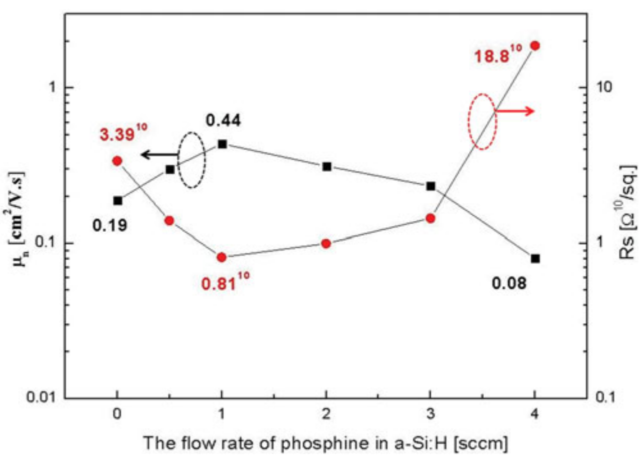

Figure 4. The variation of the field effect mobility and Rs with the flow rate of phosphine in a-Si:H layer.

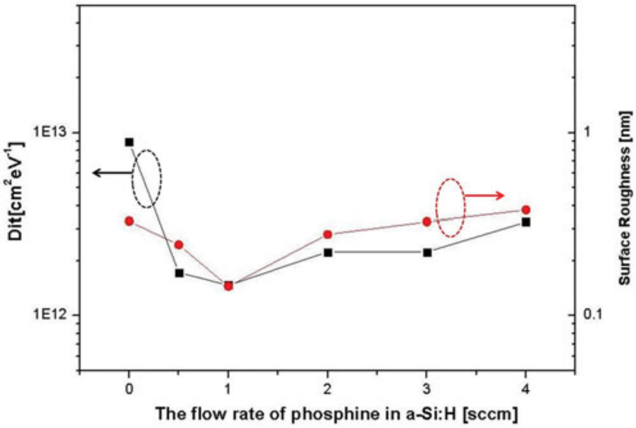

Figure 5. D_{it} and RMS with the flow rate of phosphine in a-Si:H layer.

sccm because the electrons to use dopant are supplied in the channel. However, we believe when the phosphorus doping ratio increased higher than 1sccm, the decrease of mobility in doped a-Si:H TFT is the cause of the impurity scattering effect and the increase of trap density in the channel.

3.3 Quality Between a-SiN:H and a-Si:H

The on/off ratio of a-Si:H TFT particularly depends on the difference in quality between a-SiN:H and a-Si:H among the dominate factors relative to the deposition conditions of PECVD. So, we investigated the characteristics of interface trapped density (D_{it}) with various phosphorus doping concentrations from Eq. (2) [13], those were compared with the measured results of the root-mean-square roughness (RMS) of a-Si:H by AFM.

$$S = 2.3kT(1 + qD_{it}/C_{SiN})/q \tag{2}$$

where q is the electron charge (C), k is the Boltzmann's constant (J/K,eV/K), T is temperature (K), C_{SiN} is depletion capacitance (F/cm^2) and S is subthreshold slope of a-Si:H TFT.

Figure 5 shows the D_{it} and RMS with the flow rate of phosphine in a-Si:H layer. The RMS in the a-Si:H layer was decreased by as much as the D_{it} of a-Si:H TFTs was similarly decreased as the flow rate of phosphine gas increased from 0 to 1 sccm. Also, the D_{it} and RMS was similarly increased as the doping ratio of phosphine increased over 4 sccm. With these results, we confirmed that the difference in the quality of the interface between a-SiN:H and a-Si:H layer can be improved through phosphorus doping in the a-Si:H layer, because the improved dominate factor was represented from the variation of the RMS a-Si:H layer with various phosphorus concentrations. Also, it is certain that the difference in the quality of the interface between a-SiN:H and a-Si:H layer lead to an improvement of the on/off ratio in the a-Si:H TFT.

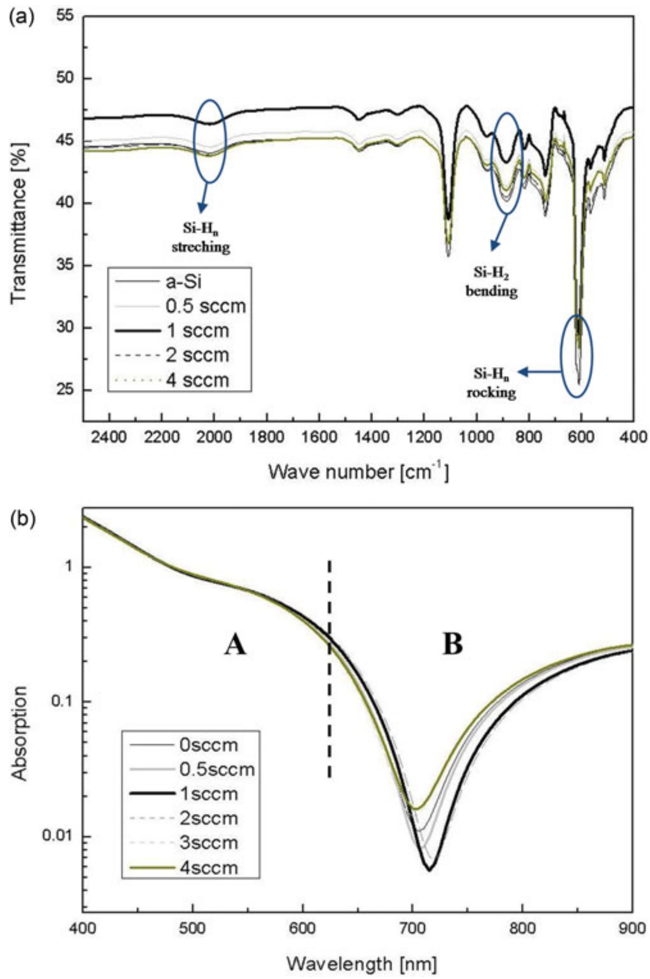

Figure 6. The optical analysis of a-Si:H with various phosphorus concentration (a) FT-IR results and (b) UV results.

3.4 Optical Analysis of a-Si:H

The chemical composition and density of state (DOS) in the gap of a-Si:H layer is significantly important for high performance of a-Si:H TFTs, dependent on the deposition condition in PECVD. So, we investigated the variation of the chemical composition and DOS of the a-Si:H layer with various phosphorus concentrations. Figure 6 shows the optical analysis of a-Si:H with various phosphorus concentrations (a) FT-IR results and (b) UV results. The FT-IR results shows that the Si-H_n stretching (2020 cm^{-1}), Si-H_2 bending (883 cm^{-1}), and Si-H_n rocking (636 cm^{-1}) modes [14] were observed and were fixed with phosphorus concentration. These peaks mean that the phosphorus doping in a-Si:H layer is not mainly attributed to the chemical bonding. UV spectroscopy results shows the absorption spectrum of a-Si:H classified according to wavelength. Region B is denoted as subband gap absorption since the absorption coefficient reflects transitions involving a structural defect within the band gap. The measured results clearly showed a decrease of absorption coefficient as the phosphorus concentration increase from 0 to 1 sccm. This means a decrease of DOS with the increase of phosphorus doping. However, we actually observed an increase of absorption coefficient in long wavelength region for phosphorus concentration over 1 sccm. It reveals that the field effect mobility of a-Si:H TFT is degraded for over 1 sccm, as caused by an increase of DOS in band gap with the increase of phosphorus doping [2]. From the two experimental results, we could derived the conclusion that the DOS in band gap in a-Si:H layer can be improved through the phosphorus doping method without a change in the chemical composition.

Conclusions

We have proposed a method of phosphorus doping in active layers to improve the electrical characteristics of a-Si:H TFT. We found that the optimal condition for phosphorus doping concentration were 1 sccm and we confirmed that the field effect mobility (0.44 $cm^2/V{\cdot}s$) and on/off ratio of phosphorus doped a-Si:H TFTs were more improved compared to those of conventional a-Si:H TFT. We confirmed that the field effect mobility of a-Si:H TFT can be efficiently improved through phosphorus doping in a-Si:H due to the electrons supplied to use dopant in the channel as was demonstrated by the results of field effect mobility and Rs. The dominate factor in the improved off current was demonstrated by the fact that the D_{it} and RMS are similarly varied with change of phosphorus doping concentrations. Therefore, the suggested method of phosphorus doping in active layer is able to improve the electrical characteristics of a-Si:H TFT. Also, phosphorus doping in active layer leads to an improvement of DOS in band gap in a-Si:H without a change in the chemical composition. This will be applied to the drive devices in large LCDs and OLEDs.

Funding

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (2012R1A1A2007685).

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