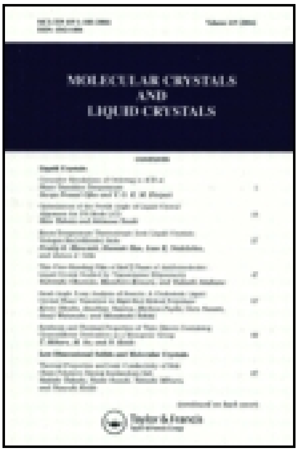

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Influence of Phosphorus Doping in the Active Layer with Deposition Time and Gas Flow Rate in a-Si:H Thin Film Transistor

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Influence of phosphorus doping in the a-Si:H layer with various deposition time and phosphine gas flow rate in hydrogenated amorphous silicon thin film transistor (a-Si:H TFT) has been investigated. The a-SiN:H layer, the phosphorus doped a-Si:H layer and the n^+ a-Si:H layer were deposited by plasma enhanced chemical vapor deposition (PECVD) using SiH_4, PH_3, Ar, H_2 and NH_3 gases. Proper phosphorus doping in the a-Si:H layer affected the channel of the a-Si:H TFT and improved the characteristics. Also, the field effect mobility was increased from 0.22 to 0.61 $cm^2/V{\cdot}s$. The characteristics of phosphorus doping in the a-Si:H TFT were investigated and compared with the conventional a-Si:H TFT.

Keywords phosphorus doping; channel; a-Si:H TFT; the field effect mobility

Introduction

Hydrogenated amorphous silicon (a-Si:H) has become the most widely used active material for making large area thin film devices. Of particular interest is the application of hydrogenated amorphous silicon thin film transistors (a-Si:H TFTs) as switching elements in liquid crystal display (LCD) panels [1–3]. LCD panels have been applied to many information tools such as notebook computers, video camcorders and TV applications. When employing the a-Si:H layer, the main issue is to increase the field effect mobility. According to the research on a-Si:H TFTs, the field effect mobility of electron depends on carrier concentration in the channel [4]. In a-Si:H TFTs, the main carriers are electrons which room-temperature mobility is typically 0.3-0.6 $cm^2/V{\cdot}s$. A-Si:H TFTs have the low drain current and the field effect mobility yet, because the a-Si:H layer has defects of the interface trap, deep states and tail states [5]. In order to improve the low characteristics, carrier doping in the a-Si:H layer was suggested. Carrier concentration in the channel can increase the conductivity. Also, carrier concentration in the channel increases ionized impurities which lead to a degradation of the field effect mobility. Improvement of the characteristics of a-Si:H TFTs through carrier doping in the channel can be expected. In other research, delta doping using phosphorus in the a-SiN:H layer improved the field effect mobility. The

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properly phosphorus doped layer affected the channel indirectly [6]. Therefore, we investigated direct influence of phosphorus doping in the a-Si:H layer with various deposition time and phosphine gas flow rate.

Experimental

Figure 1 shows two different types of the a-Si:H TFT process that were fabricated. Figure 1(a) shows the process of the conventional a-Si:H TFT. Figure 1(b) shows the process of the a-Si:H TFT with phosphorus doping in the a-Si:H layer. Both of them were fabricated with the inverted staggered a-Si:H TFT. The conventional a-Si:H TFT was fabricated following the process as shown in Figure 1(a). NiCr metal was deposited on the glass with a thickness of 1500 Å by a thermal evaporator and then patterned as the gate electrode. After that the a-SiN:H layer, the a-Si:H layer and the n^+ a-Si:H layer were deposited on the gate electrode by plasma enhanced chemical vapor deposition (PECVD) at a substrate temperature of 250°C and then patterned. The working pressure was 700 mTorr. The thickness of the a-SiN:H layer, the a-Si:H layer and the n^+ a-Si:H layer were 2500 Å, 2000 Å and 500 Å, respectively. The a-SiN:H layer was deposited by using a gas mixture of SiH_4, NH_3 and Ar, the a-Si:H layer using SiH_4 and H_2 and the n^+ a-Si:H layer using SiH_4 and PH_3. Al metal was deposited with a thickness of 2000 Å by a thermal evaporator and patterned to

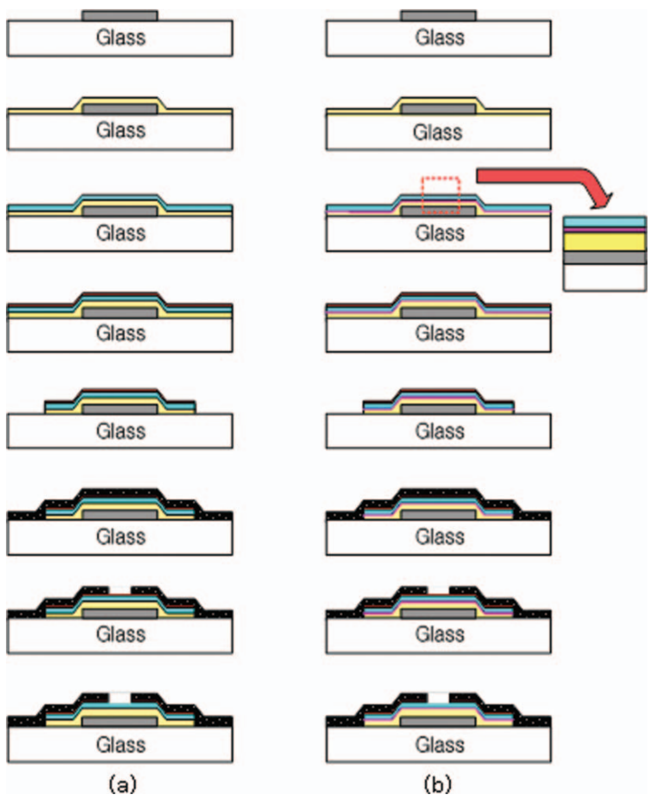

Figure 1. The Process flow of the inverted staggered a-Si:H TFT. (a) The conventional a-Si:H TFT and (b) the a-Si:H TFT with phosphorus doping in the a-Si:H layer.

Table 1. The deposition conditions of thin films

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	30/50/1∼9	30/50	30/50
r.f. power (*W*)	200	150	150	100
Substrate temperature (°C)	250	250	250	250
Working pressure (*mTorr*)	700	700	700	700
Deposition time	12 min	18 sec ∼ 1 min 29 sec	27 min	6 min

form the source and drain electrodes. Lastly, the n^+ a-Si:H region between the source and drain electrodes was etched for isolation by reactive ion etching (RIE). The a-Si:H TFT with phosphorus doping in the a-Si:H layer was fabricated as shown in Figure 1(b). This structure was doped by phosphorus with various deposition time and phosphine gas flow rate in the a-Si:H layer. Process conditions were the same as the conventional a-Si:H TFT process. The different process condition was phosphorus doping in the a-Si:H layer. At first, the phosphine (PH_3) gas flow rate of 3 sccm was fixed and changed the thickness of the phosphorus doped layer from 50 Å to 250 Å (50, 100, 150, 200, 250 Å) by controlled deposition time. When the thickness of the phosphorus doped layer was changed, the optimal thickness was 150 Å. Therefore, the optimal thickness was fixed at 150 Å and changed phosphine gas flow rate from 1 sccm to 9 sccm (1, 2, 3, 6, 9 sccm). Table 1 and 2 indicate the deposition conditions and etching conditions of thin films.

Results and Discussion

The characteristics of the fabricated a-Si:H TFT were measured using HP 4156C analyzer. Figure 2 shows the output characteristic of the conventional a-Si:H TFT and the a-Si:H TFT with various thicknesses of the phosphorus doped layer. At first, the phosphine gas flow rate was fixed at 3 sccm and the thickness of the phosphorus doped layer was changed from 50 Å to 250 Å by controlled deposition time. The drain current of the fabricated conventional a-Si:H TFT was 3.98 uA. When the thickness of the phosphorus doped layer was 50 Å, the drain current lower from 3.98 uA to 2.7 uA. The phosphine gas flow rate of 3 sccm was not little volume. When the thickness of the phosphorus doped layer was 50 Å,

Table 2. The etching conditions of thin films

Parameter	a-SiN:H, a-Si:H, n^+ a-Si:H	Back side n^+ a-Si:H
Gas	SF_6	SF_6
Flow rate (*sccm*)	20	20
r.f. power (*W*)	40	20
Substrate temperature (°C)	25	25
Working pressure (*mTorr*)	150	150
Etching time	18 min	14 sec

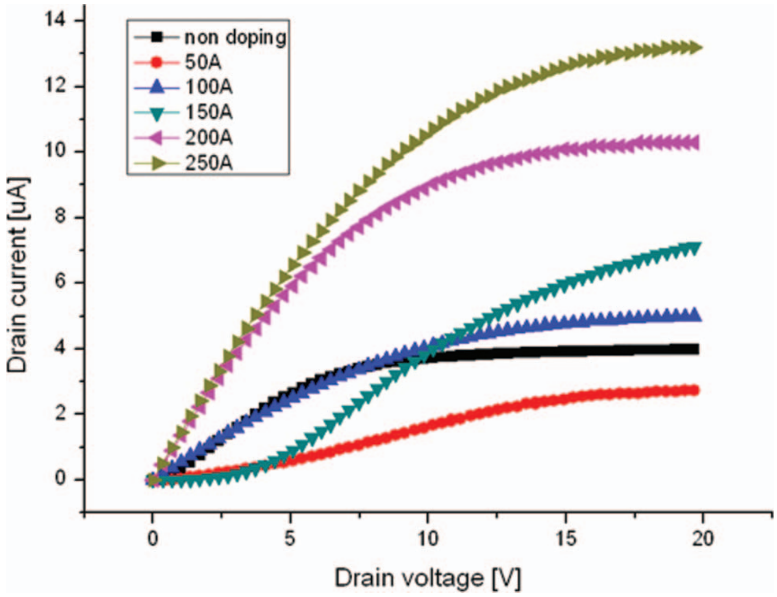

Figure 2. The output characteristic (V_D-I_D) of the conventional a-Si:H TFT and the a-Si:H TFT with various thicknesses of the phosphorus doped layer.

most of phosphorus impurities affected as surface scattering. The thickness of 50 Å was too low. So, the volume of surface scattering was bigger than contribution of electron flow in channel area. However, as the thickness of the phosphorus doped layer was increased from 100 Å to 250 Å, the drain current was increased up to 13.2 uA. Because as the thickness of the phosphorus doped layer was increased, the carrier affected area was increased too.

Figure 3 shows the transfer characteristic of the conventional a-Si:H TFT and the a-Si:H TFT with various thicknesses of the phosphorus doped layer. The range of on/off current ratio of the conventional a-Si:H TFT and the phosphorus doped a-Si:H TFT was between 1×10^3 and 1×10^6. On/off current ratio of the conventional a-Si:H TFT was 1×10^4. As the thickness of the phosphorus doped layer was increased from 50 Å to 150 Å, on/off current ratio was increased up to 1×10^6. However, on/off current ratio was decreased as the thickness of the phosphorus doped layer was over 150 Å, because off current was increased. And electrons were moved in to the phosphorus doped layer, when the a-Si:H TFT was turned off. So, the optimal thickness was fixed at 150 Å and changed the phosphine gas flow rate from 1 sccm to 9 sccm.

Figure 4 shows the output characteristic of the conventional a-Si:H TFT and the a-Si:H TFT with various phosphine gas flow rate. In this experiment, the optimal thickness of the phosphorus doped layer was fixed and controlled phosphine gas flow rate. From Figure 4, it could be confirmed that the drain current was the highest with the phosphine gas flow rate of 1 sccm. When the phosphine gas flow rate was over 1 sccm, the drain current was decreased from 15.9 uA to 4.4 uA. These results show that much phosphorus doping increased ionized impurities in the channel.

Figure 5 shows that on/off current ratio was decreased from 1×10^6 to 1×10^3 with the increasing phosphine gas flow rate of over 1 sccm. When the phosphine gas flow rate was over 3 sccm, on/off current ratio was lower than the conventional a-Si:H TFT. The threshold voltage of the phosphorus doped a-Si:H TFT was improved to compare with the

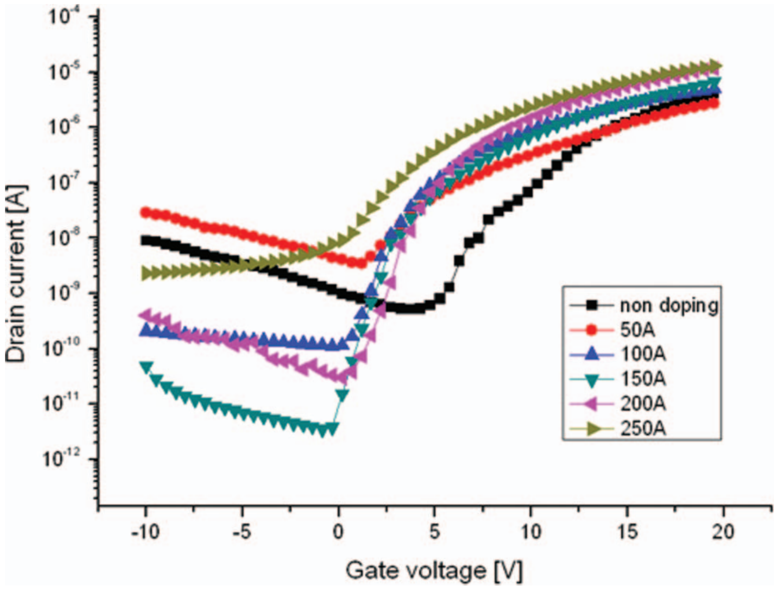

Figure 3. The transfer characteristic (V_G-I_D) of the conventional a-Si:H TFT and the a-Si:H TFT with various thicknesses of the phosphorus doped layer.

conventional a-Si:H TFT. Also, the field effect mobility of the conventional a-Si:H TFT was increased from 0.22 to 0.61 $cm^2/V{\cdot}s$ by phosphorus doping as shown in Figure 6. From these results, it could be confirmed that phosphorus doping in the a-Si:H layer affected the channel area directly.

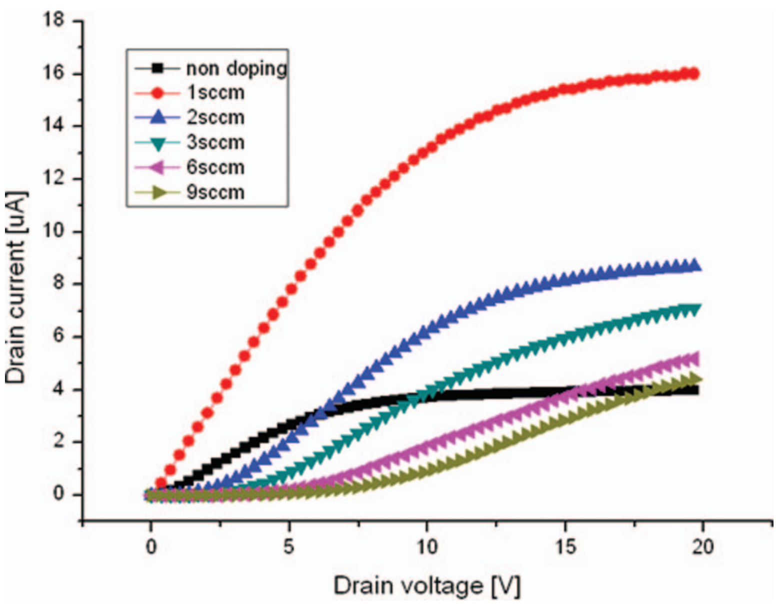

Figure 4. The output characteristic (V_D-I_D) of the conventional a-Si:H TFT and the a-Si:H TFT with various phosphine gas flow rate.

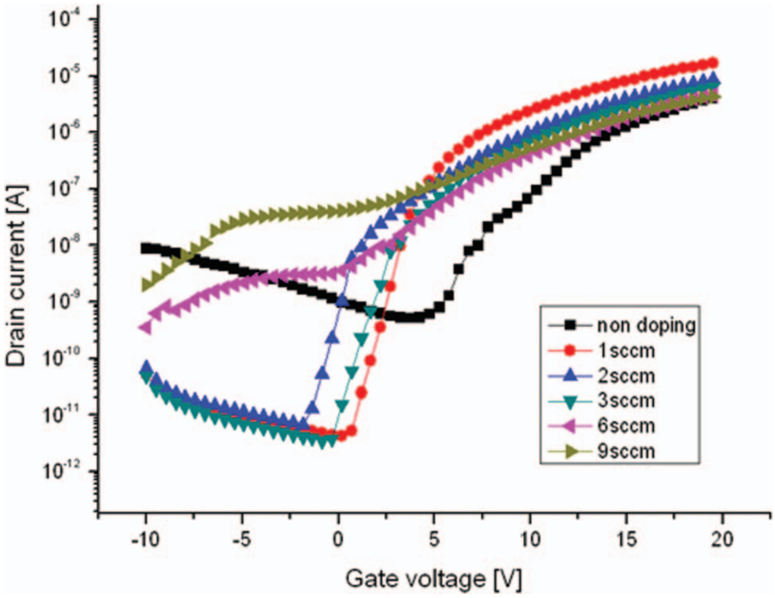

Figure 5. The transfer characteristic (V_G-I_D) of the conventional a-Si:H TFT and the a-Si:H TFT with various phosphine gas flow rate.

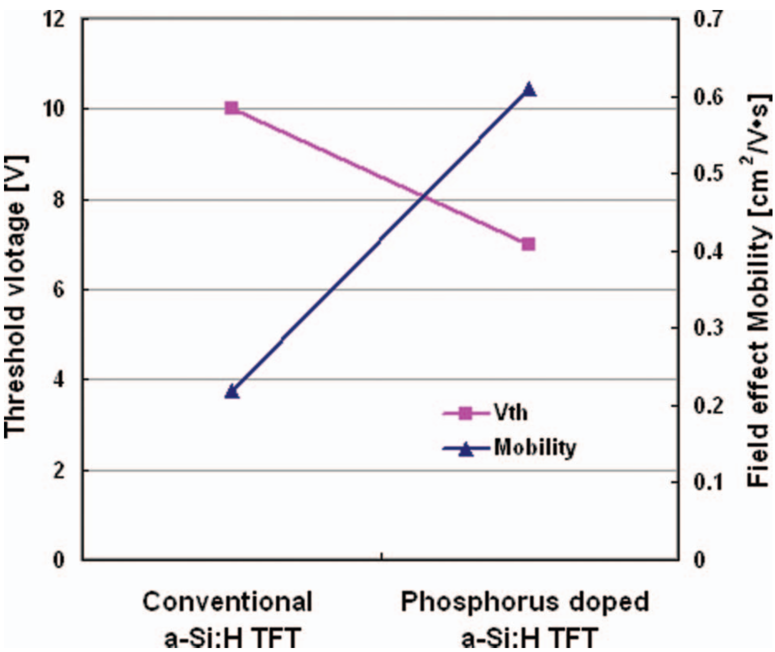

Figure 6. The threshold voltage and the field effect mobility.

Conclusions

In this study, influence of phosphorus doping in the a-Si:H layer with various deposition time and phosphine gas flow rate has been investigated. It was found that phosphorus doping in the a-Si:H layer affected the channel of the a-Si:H TFT directly. Carrier doping in the channel increased the conductivity and ionized impurities. At first, the phosphine gas flow rate was fixed at 3 sccm and changed the thickness of the phosphorus doped layer from 0 Å (the conventional a-Si:H TFT) to 250 Å by controlled deposition time. When the thickness of the phosphorus doped layer was 150 Å, the characteristics were the optimal conditions. So, the optimal thickness of 150 Å was fixed and changed the phosphine gas flow rate from 0 sccm (the conventional a-Si:H TFT) to 9 sccm. When the phosphine gas flow rate was 1 sccm, the drain current and on/off current ratio were the highest. Also, the field effect mobility of the conventional a-Si:H TFT was increased from 0.22 to 0.61 $cm^2/V{\cdot}s$. The threshold voltage was improved too. From these results, the optimal conditions of thickness and phosphine gas flow rate were 150 Å and 1 sccm. Optimal conditions of carrier doping can improve the characteristics and the field effect mobility of a-Si:H TFT.

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