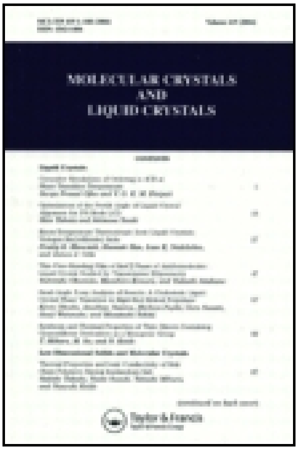

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Hun-Chul Jung [a], Kwang-Mook Park [a], Kyo-Ho Moon [a], Tae-Yong Lee [a] & Sie-Young Choi [a]
[a] School of Sensor and Display Engineering, Kyungpook National University, Daegu, Korea

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Hun-Chul Jung, Kwang-Mook Park, Kyo-Ho Moon, Tae-Yong Lee, and Sie-Young Choi
School of Sensor and Display Engineering, Kyungpook National University, Daegu, Korea

Amorphous silicon modulation-doped field effect transistors using the heterostructure of phosphorous-contained a-SiN:H and intrinsic a-Si:H films have been fabricated by plasma enhanced chemical vapor deposition of SiH_4, PH_3, Ar and NH_3 gases. The characteristics of the devices have been investigated and compared with conventional amorphous silicon thin film transistors. Various studies have been carried out on the properties of the materials of a-SiN:H films that were deposited with a varied delta-doping thickness and it was found that the V_{th} shifted from 2.5 to 4.5 V with an increase in the delta-doping thickness from 0 to 200 Å. The μ_n changed also from 0.19 to 0.38 $cm^2/V \cdot sec$.

Keywords: a-Si:H thin film transistor; delta doping; modulation-doped

INTRODUCTION

Nowadays, the amorphous silicon thin film transistor is being used for simple gate driver circuits eliminating gate driver IC's as well as active matrix devices for LCD's. Also active matrix organic light emitting displays are another probable application of a-Si:H TFT due to its excellent uniformity. Recently, a portable communication system was spot-lighted and thus there is increasing interest in display devices on a plastic substrate, which is flexible, unbreakable, foldable and

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Address correspondence to Prof. Sie-Young Choi, School of Sensor and Display Engineering, Kyungpook National University, Sankyuk-dong, Buk-gu, Daegu 702-701, Korea (ROK). E-mail: sychoi@ee.knu.ac.kr

light-weight [1–3]. Although the a-Si:H TFT has many advantages, its transfer characteristics are unstable for the applied voltage to a gate electrode. Two important parameters of TFTs are the carrier mobility μ_n and the threshold voltage V_{th}. In a-Si:H TFTs, the main carriers are electrons whose room-temperature mobility is typically 0.3–0.6 $cm^2/V \cdot s$ [4]. According to the research on a-Si:H TFT, the mobility of electrons depends on the carrier concentration in the channel [5]. Obviously, the conductivity can be increased by increasing the doping in the channel and thus the carrier concentration. However, increased doping also causes increased scattering by the ionized impurities which leads to a degradation of mobility. Therefore, this study focused on the function of delta doping in a-SiN:H thin film near the hetero junction to improve the mobility [6].

In this paper, the delta doping within the a-SiN:H thin film deposited with a variation of delta-doping thickness by PECVD has been investigated. Using these a-SiN:H thin films, the a-Si:H TFT was fabricated. The mobility shifts of a-Si TFTs that were deposited with various thickness of delta-doping layer have been studied. By measuring C-V characteristic, the changes of μ_n in the channel between the source and drain have also been obtained.

EXPERIMENTAL & MEASURMENTS

Figure 1 shows the two different a-Si:H TFT process that were fabricated. As a standard device, ordinary a-Si:H TFT was fabricated. Figure 1(a) shows the process for the fabrication of a-Si:H TFT. NiCr was used as the gate metal and 1500 Å was deposited on 1737 Corning glass using a thermal evaporator.

After gate patterning, the hydrogenated amorphous silicon nitride (a-SiN:H) thin film was deposited to a thickness of 2500 Å. The plasma enhanced chemical vapor deposition (PECVD) was performed at 250°C and the total gas flow rate consisted of Ar of 100 sccm, NH_3 of 45 sccm and SiH_4 (in 89.5% He) of 30 sccm. The working pressure was 700 mTorr, and the plasma power was 200 W. The total gas flow of the a-Si:H layer was SiH_4 of 20 sccm and H_2 of 50 sccm. The thickness of a-Si:H was 2000 Å. The substrate temperature was 250°C, the working pressure was 700 mTorr and the plasma power was 150 W. Then, n^+ a-Si:H, as the top the triple layer, was deposited by PECVD. The total gas flow of the n^+ a-Si:H layer was SiH_4 of 30 sccm and PH_3 of 50 sccm. For the condition of PECVD, there was a substrate temperature of 250°C, a working pressure of 750 mTorr and a plasma power of 150 W. After deposition, thin triple films were patterned for an active area and etched by the reactive ion etching (RIE) method.

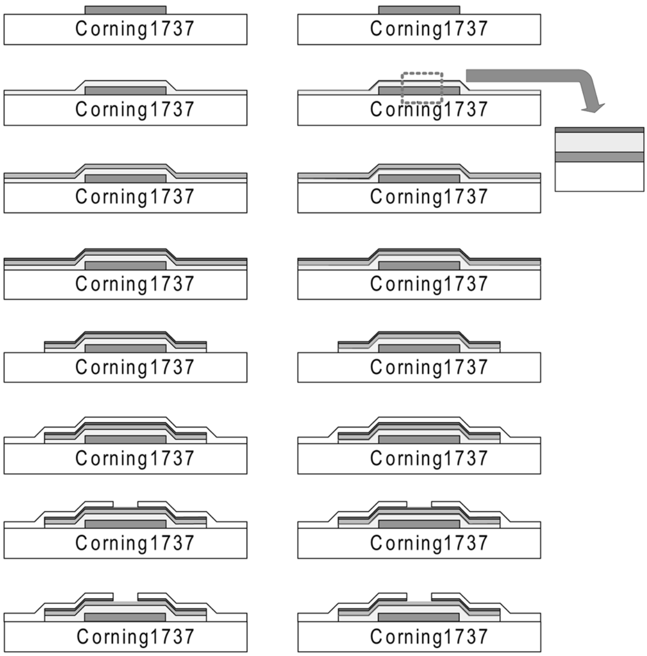

FIGURE 1 TFT process for experiments. (a) Standard TFT and (b) TFT with N-δ-I structure.

Plasma etching was executed for 17 minutes with an RF power of 40 W using 20 sccm of SF_6 gas, and the working pressure was 150 mTorr.

Al was used as a source-drain metal, and 2000 Å was deposited by a thermal evaporator. Source-drain contacts were defined by using photolithography. After Al patterning by Al etchant, the back channel between the source and drain electrodes was etched by a RIE. The conditions of back-channel etching were 45 seconds with an RF power of 20 W by using 20 sccm of SF_6 gas, and the working pressure was 150 mTorr.

The delta-doping structure was fabricated as illustrated in Figure 1(b). Delta-doping device (N-δ-i structure) has a delta-doping layer (δ) inside a-SiN:H layer with various buffer thickness of 20 Å to 200 Å at the interface of the gate dielectric (a-SiN:H) and a-Si:H layer. For a delta-doping device, the doping concentration was set at 3.0% PH_3/SiH_4 ratio. The thicknesses of the delta-doping layer (δ) were 20 Å, 50 Å, 100 Å, 150 Å and 200 Å respectively.

Figure 2 shows the C-V measurement system. The thicknesses of NiCr, a-SiN:H thin film and Al was 1500 Å, 2500 Å and 2000 Å

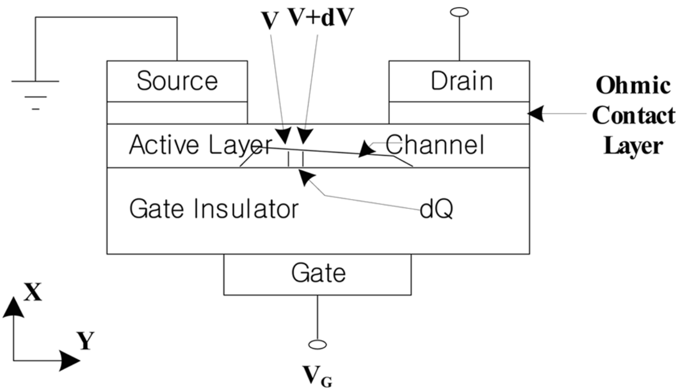

FIGURE 2 A schematic diagram of the inverted staggered a-Si:H TFT.

respectively. HP 4280A was used to measure the capacitance of a-SiN:H thin film. Alpha-Step was used to measure the deposition rate of the a-SiN:H thin film as variation of PH_3 flow. HP 4156C was used to measure I-V, on/off ratio and transfer characteristics of the fabricated thin film transistor [7].

RESULTS AND DISCUSSION

The operation of a-Si:H TFT is divided into two areas, the linear region and the saturation region. In a linear region, the basic current-voltage characteristics can apply to the gradual channel approximation. This condition shown in Figure 3 means that the transverse field forms the channel and the longitudinal field transfers the drain current (I_d) [6,7]. As the gate voltage (V_g) increases, more electron charge is induced in the channel and, therefore, the channel becomes more conductive. The I_D initially increases linearly with the drain bias (V_d). Once the V_D is increased to the point that $(V_g - V_d) = V_{th}$, the threshold is barely maintained near the drain end, and the channel is said to be pinched off. Now, the I_D is said to be in the saturation region because it does not increase with the drain bias significantly. Then I_D is given by [7]

$$I_d = C_i \mu_n W/(2L)(V_g - V_{th})^2 \tag{1}$$

Figure 4 shows the output characteristics of the inverted staggered a-Si:H TFT at the V_g of 20 V, in which the delta-doping layer was deposited with a variation of the thickness . The on-current of the

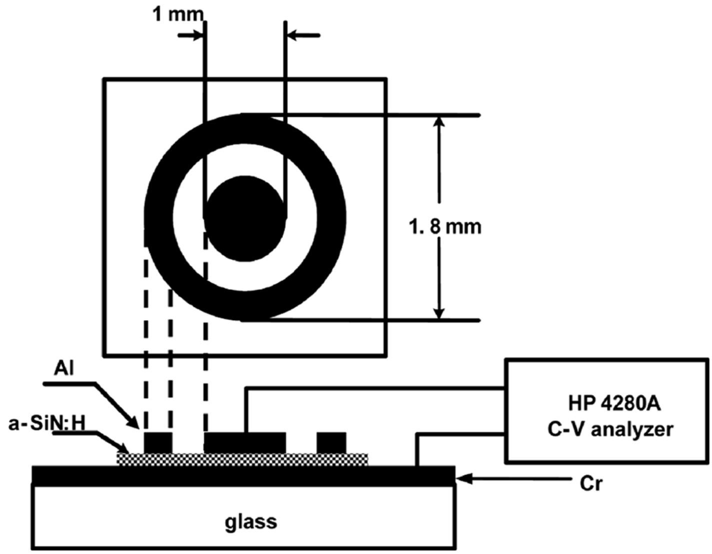

FIGURE 3 Schematic diagram of C-V measurement system.

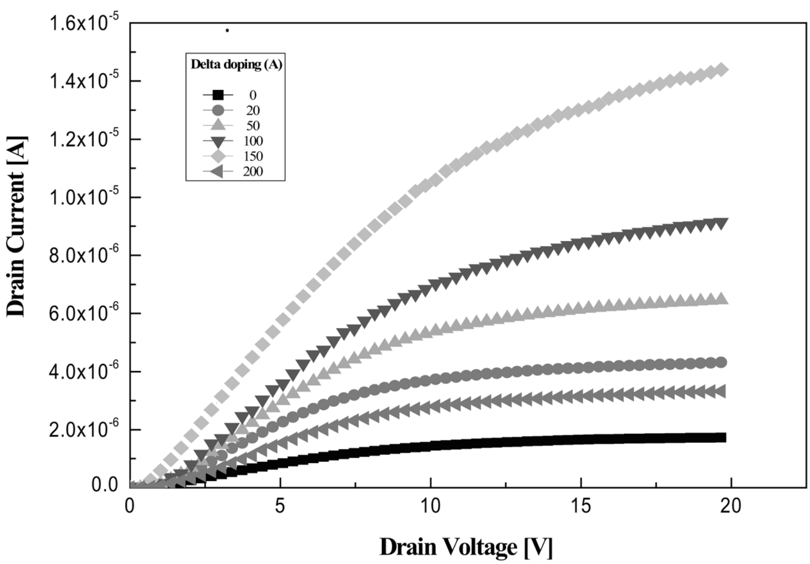

FIGURE 4 The output characteristics of TFT, where delta doping layers were deposited with a variation of the thickness.

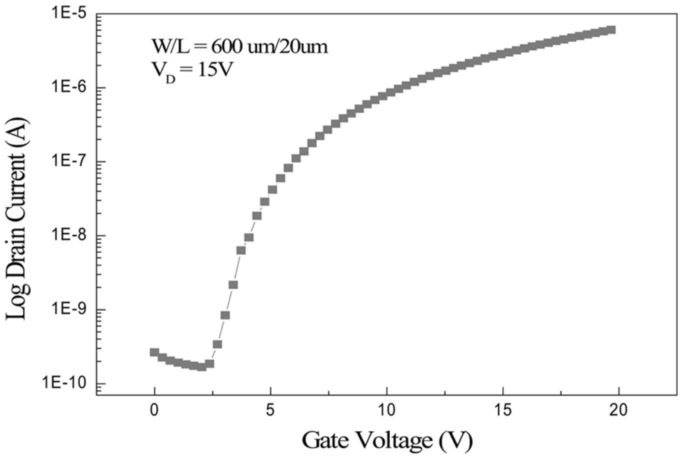

FIGURE 5 I_D-V_D characteristics for the an inverted staggered a-Si:H TFT.

fabricated device exhibited 12.9 μA at the delta-doping thickness of 150 Å. Figure 5 shows the transfer characteristics of the a-Si TFT in which the delta-doping layer was deposited. The sub threshold slope and the on/off current ratio obtained from the transfer curve at $V_D = 15\,V$ was 2.5 V/decade and $\sim 10^5$, respectively. The off-state

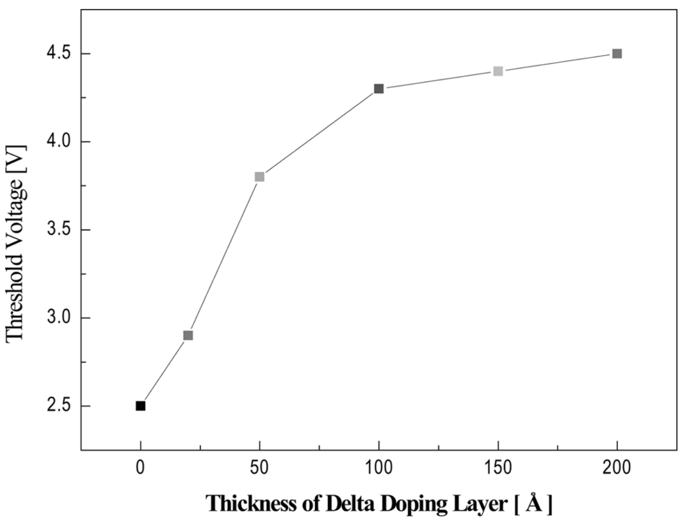

FIGURE 6 The V_{th} for the inverted staggered a-Si:H TFT, where delta doping layers were deposited using a varied thickness.

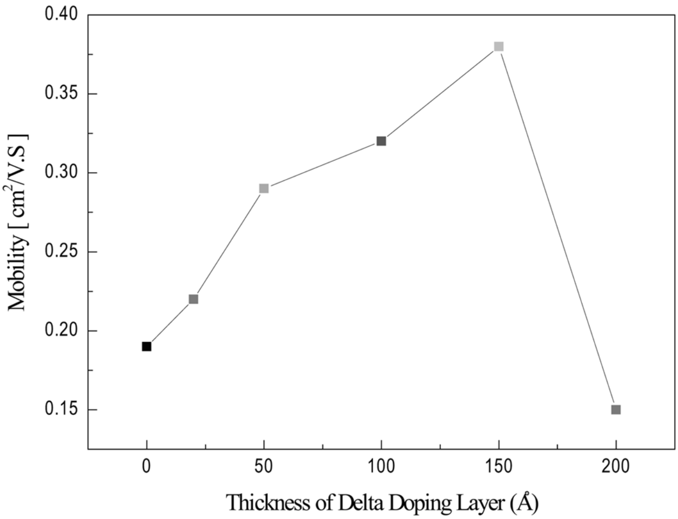

FIGURE 7 The μ_n for the inverted staggered a-Si:H TFT, where delta doping layers were deposited using a varied thickness.

leakage current is about 5×10^{-10} A at a drain voltage of 15 V and a gate voltage of -5 V. Figure 6 shows the V_{th} of the a-Si:H TFT as a function of the thickness for the delta-doping layer deposition. The threshold voltage increased from 2.5 to 4.5 V with an increase in the delta-doping thickness from 0 to 200 Å. Figure 7 shows the mobility of the a-Si:H TFT as a function of the thickness of the delta-doping layer deposition. The μ_n increased from 0.19 to 0.38 $cm^2/V \cdot s$ with an

TABLE 1 Deposition Conditions of a-SiN:H, a-Si:H, n^+ a-Si:H Thin Films

Parameter	a-SiN:H	a-Si:H	n^+ a-Si:H	Delta doping layer
Gas	SiH4 (+89.5%He)/ Ar/NH_3	SiH4 (+89.5% He)/H_2	SiH4 (+89.5%He)/ PH_3(+99%H_2)	SiH4 (+89.5%He)/Ar/ NH_3/PH_3
Flow rate (sccm)		20/18	20/50	
r.f. power (W)	200	150	100	200
Substrate temperature (°C)	250	250	250	250
Working pressure (mTorr)	700	700	700	700

TABLE 2 Etching Conditions of a-SiN:H, a-Si:H, n^+ a-Si:H and Back Side n^+ a-Si:H

Parameter	a-SiN:H, a-Si:H, n^+ a-Si:H	Back channel etch
Gas	SF6	SF6
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

increase in the delta-doping thickness from 0 to 150 Å. And then it was reduced to 0.15 $cm^2/V \cdot sec$ at the delta-doping thickness of 200 Å.

CONCLUSIONS

The material properties of the a-SiN:H films deposited via different delta-doping layers have been studied. It has been found that there is a change of mobility according to the various thicknesses of the delta-doping layer. As the delta-doping thickness increased within a-SiN:H thin film from 0 to 150 Å, the V_{th} of the a-Si:H TFT increased from 2.5 to 4.3 V and the μ_n increased from 0.19 to 0.38 $cm^2/V{\cdot}s$. Using this configuration, the high electron concentration in the channel can be achieved while retaining high mobility, since the a-Si:H channel region is spatially separated from the ionized impurities which provide the free carriers. But the mobility decreased from 0.38 to 0.15 $cm^2/V{\cdot}s$ with increasing delta-doping thickness from 150 to 200 Å. Because too much delta doping within a-SiN:H thin film have a bad effect to the dielectric properties of a-SiN:H thin film, it can be concluded that the therefore the V_{th} and μ_n at the delta-doping thickness of 200 Å are 4.5 V and 0.15 $cm^2/V{\cdot}s$, respectively.

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