The Effects of Nanocrystalline Silicon Thin Film Thickness on Top Gate Nanocrystalline Silicon Thin Film Transistor Fabricated at 180℃

Dong-Won Kang*, Joong-Hyun Park, Sang-Myeon Han**, and Min-Koo Han***

***Abstract*—We studied the influence of nanocrystalline silicon (nc-Si) thin film thickness on top gate nc-Si thin film transistor (TFT) fabricated at 180 °C. The nc-Si thickness affects the characteristics of nc-Si TFT due to the nc-Si growth similar to a columnar. As the thickness of nc-Si increases from 40 nm to 200 nm, the grain size was increased from 20 nm to 40 nm. Having a large grain size, the thick nc-Si TFT surpasses the thin nc-Si TFT in terms of electrical characteristics such as field effect mobility. The channel resistance was decreased due to growth of the grain. We obtained the experimental results that the field effect mobility of the fabricated devices of which nc-Si thickness is 60, 90 and 130 nm are 26, 77 and 119 cm^2/Vsec, respectively. The leakage current, however, is increased from 7.2×10^{-10} to 1.9×10^{-8} A at V_{GS}=-4.4 V when the nc-Si thickness increases. It is originated from the decrease of the channel resistance.**

***Index Terms*—Nanocrystalline silicon, TFT, field effect mobility, leakage current, columnar**

I. INTRODUCTION

The nanocrystalline silicon (nc-Si) thin film transistor (TFT) is remarkable in terms of high field effect mobility and uniformity in active matrix liquid crystal display (AMLCD) or active matrix organic light emitting diode (AMOLED). Many studies related to the nc-Si TFT has been investigated to improve the field effect mobility. A staggered n-type nc-Si TFT which has the field effect mobility higher than 100 cm^2/Vsec is reported [1]. But, the leakage current of the nc-Si TFT has not been reported adequately. The nc-Si TFT has higher leakage current than hydrogenated amorphous silicon TFT due to many grain boundaries and dangling bonds [2]. The leakage current of the nc-Si TFT should be reduced for having application to active matrix displays.

In this paper, the effects of the nc-Si thin film thickness on the top gate nc-Si TFT were investigated in consideration of the electrical characteristics of the nc-Si TFT. Because the structure of the nc-Si grain growth is similar to columnar, the variation of the electrical characteristics of the nc-Si TFT depends on the nc-Si thin film thickness [3]. The nc-Si TFT which has the thick nc-Si film showed the better electrical characteristics due to the large grains, but the surface roughness was increased when the film thickness was increased. As the nc-Si film thickness was increased from 40 nm to 200 nm, the grain size was increased from 20 nm to 45 nm. The field effect mobility was increased from 26 to 119 cm^2/Vsec due to an increase of the grain size. At V_{GS}=-4.4 V, however, the leakage current according to the variation of the nc-Si film thickness was increased from 7.2×10^{-10} to 1.0×10^{-8} A. It is attributed to the reduction of off-state resistance induced by an increase of grain size.

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II. EXPERIMENT

1. Device Fabrication

For the application on plastic substrates, the nc-Si thin film and SiO_2 as an gate insulator were deposited at low temperature (<200 °C) employing inductively coupled plasma chemical vapor deposition (ICP-CVD). We fabricated typical the top gate nc-Si TFT as the nc-Si film thickness was varied 60, 90, 130 nm. The incubation layer thickness was reduced and the crystallinity of the nc-Si film was improved by using SiH_4 as a reaction gas and He gas instead of H_2 gas as a dilution gas [4]. The dilution ratio of SiH_4:He was 3:40 and RF power was 400 W which led to high deposition rate of 2.43 Å/sec. The gate insulator of 150nm was deposited when dilution ratio was $SiH_4:N_2O:He = 5:30:100$. Then, the gate metal (aluminum) of 300 nm was deposited. Ion implantation was performed at the ion density of 5×10^{15} #/cm^2 and the ion energy of 5 keV. The dopant activation of source and drain was performed by using an excimer laser. In this process, the nc-Si channel layer was kept uniformly because the excimer laser toward the channel region was reflected by the gate metal. The energy of the excimer laser annealing (ELA) was varied from 80 to 140 mJ/cm^2, increasing step of 20 mJ/cm^2. The sheet resistance of the doped nc-Si thin film was measured, smaller than 1 kΩ/□. The whole process was performed under 200 °C and no additional masks were used to make the structures of lightly doped drain or offset. Fig.1 shows the cross section view of the fabricated nc-Si TFT.

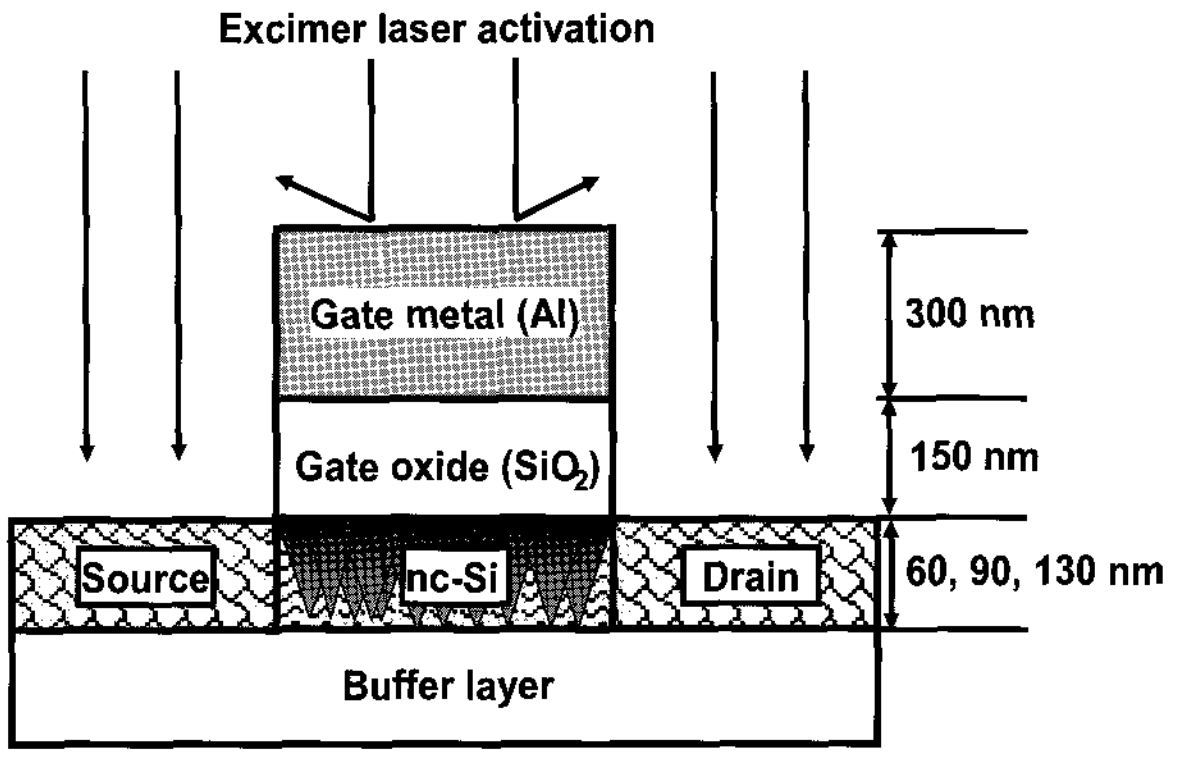

Fig. 1. The cross section of the fabricated nc-Si TFT. The intrinsic nc-Si channel layer was kept uniformly because the excimer laser toward the channel was reflected by the gate metal.

2. Results and Discussion

To measure grain size of the nc-Si thin film, scanning electron microscopy (SEM) is used. Fig. 2 shows SEM images of the nc-Si grain which is increased with the increase of the nc-Si thickness due to columnar growth structure. The nc-Si thickness of 40, 60, 120, 200 nm have grain sizes of 20, 30, 35, 45 nm, respectively. At early nc-Si growth stages, grains could grow individually. As the grains grow up, large grain could come in contact with other grains which interfere with formation of larger grains.

Fig. 3 shows current-voltage characteristics of doped nc-Si films. The driving current levels of the various nc-Si thickness were very high, which means contact resistance and sheet resistance of source/drain were sufficiently reduced by dopant activation employing the ELA. Therefore, the characteristics of nc-Si TFT were affected by the characteristics of nc-Si channel.

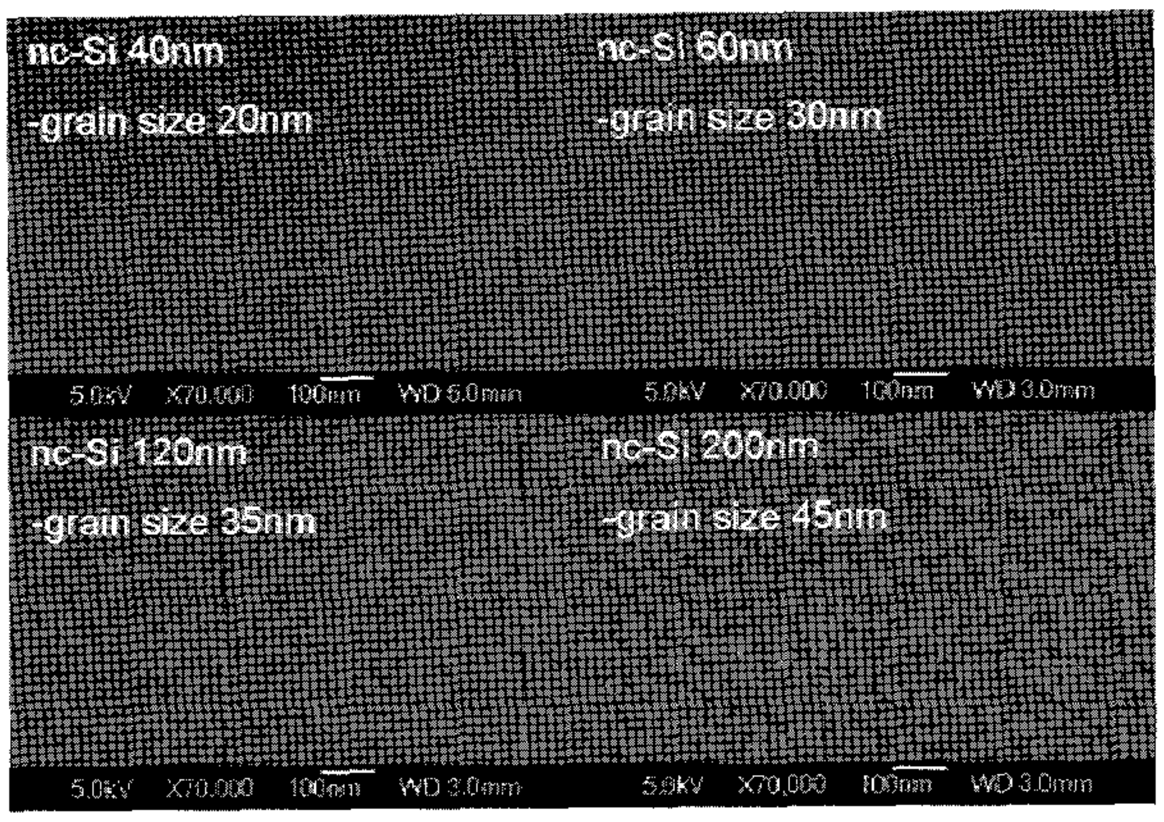

Fig. 2. SEM images of the various nc-Si thickness. The nc-Si grain increases with increase of the nc-Si thickness.

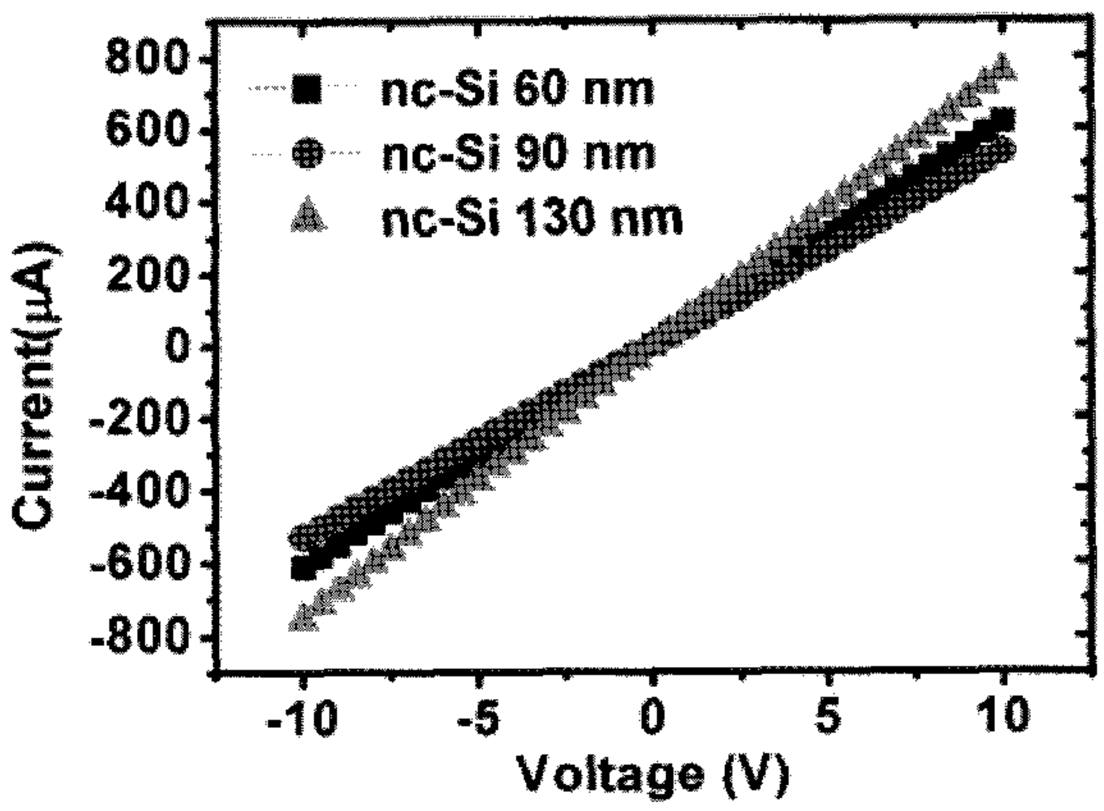

Fig. 3. The current-voltage characteristics of doped nc-Si films with various thickness.

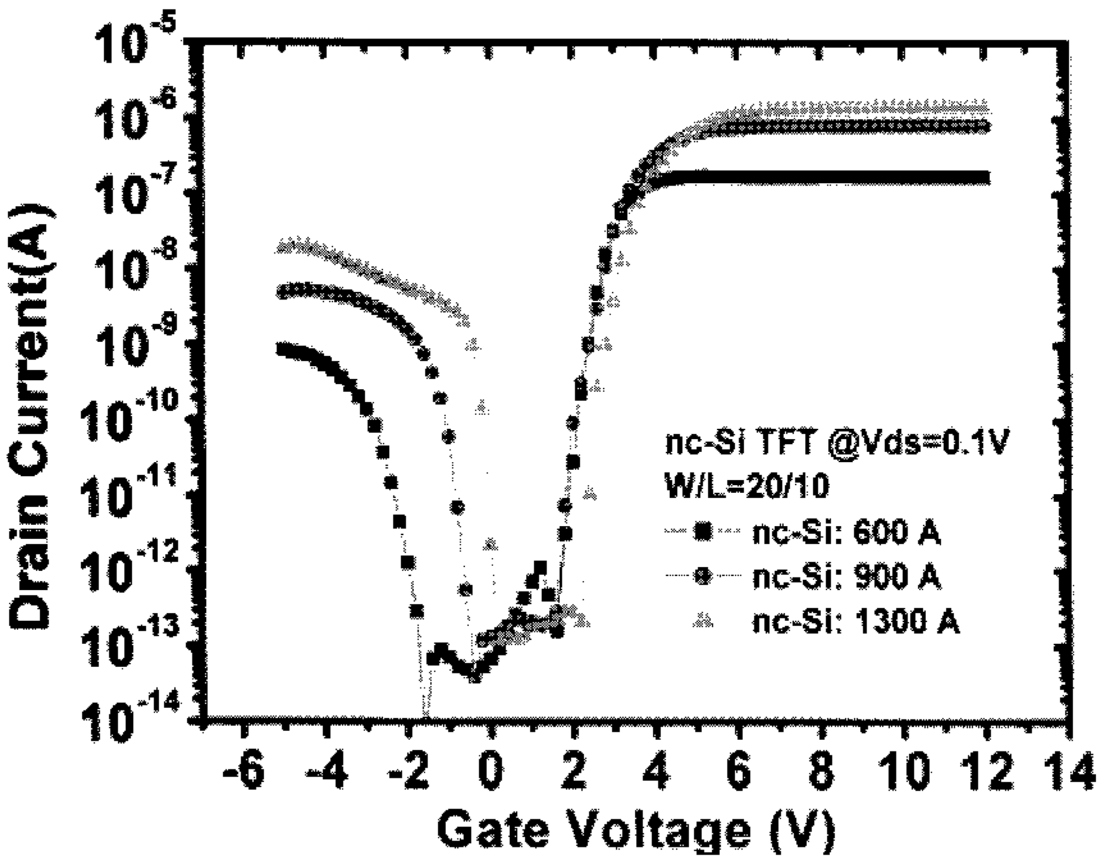

Fig. 4. The transfer characteristics of nc-Si TFT with various nc-Si thickness.

The top gate nc-Si TFTs with various nc-Si thickness of 60, 90, 130 nm were fabricated at 180 °C. The channel length and width of fabricated nc-Si TFTs are 10 μm and 20μm. Fig. 4 shows the transfer characteristics of nc-Si TFT. The field effect mobility of nc-Si TFT with nc-Si thickness of 60, 90, 130 nm were 26, 77, 119 $cm^2/Vsec$, respectively. The nc-Si TFT which has relatively thin active layer showed lower field effect mobility than that of nc-Si TFT with thick active layer due to insufficient grain growth.

The on/off ratio of nc-Si TFT was larger than 10^7 at drain voltage of 0.1 V. As the nc-Si thickness was increased, however, leakage current (at V_{GS}=-4.4 V) was increased from 7.2×10^{-10} to 1.0×10^{-8} A.

The tendency of the leakage current increase with increase of nc-Si thickness can be accounted for resistive component of nc-Si TFT. The total resistance of nc-Si TFT was analyzed in the following equations.

$$R_{TOT} = 2R_C + 2R_S + R_{CH} \qquad (1)$$

$$R_{CH} = \rho \times L/(W \times t) \qquad (2)$$

R_{TOT} is the total resistance of nc-Si TFT. R_C is the contact resistance between source/drain and metal. R_S is the resistance of source/drain and the channel resistance is modeled to R_{CH}. ρ is the resistivity of nc-Si TFT channel and W,L are the width and length of nc-Si channel. t is the thickness of nc-Si active layer. The implanted dopants were appropriately activated by the ELA, as showed in Fig. 3, R_S and R_C is low. R_{CH} is dependent on the grain size and thickness variation of nc-Si channel. If the nc-Si thickness is increased, t and grain size are increased. Then, ρ is decreased and it results in reduction of R_{CH} resulting in reduction of R_{TOT}. In other words, the turn on (V_{GS}= 5 V) resistance of nc-Si TFT with channel thickness of 130 nm is smaller than that of nc-Si TFT with channel thickness of 60 nm. Therefore the field effect mobility of nc-Si TFT which has thicker channel increases. The turn off (V_{GS}= -4.4 V) resistance of nc-Si TFT is mainly dependent on R_{CH}. The reduced R_{CH} can influence on increase of field effect mobility and off-state current.

III. CONCLUSIONS

We fabricated the top gate nc-Si TFT with various nc-Si thickness to investigate the effect of nc-Si channel thickness on the characteristics of nc-Si TFT. As the nc-Si thickness was increased, the nc-Si grain size was increased from 20 nm to 45 nm. The field effect mobility of nc-Si TFT with the nc-Si channel thickness of 60, 90, 130 nm was 26, 77, 119 $cm^2/Vsec$, respectively. This enhancement of the field effect mobility is due to the increase of nc-Si grain size. However, at off-state bias condition (V_{GS}=-4.4V), the leakage current was increased from 7.2×10^{-10} to 1.0×10^{-8} A with the increase of nc-Si channel thickness. This phenomenon is originated from the reduction of off-state channel resistance caused by the increase of nc-Si grain size.

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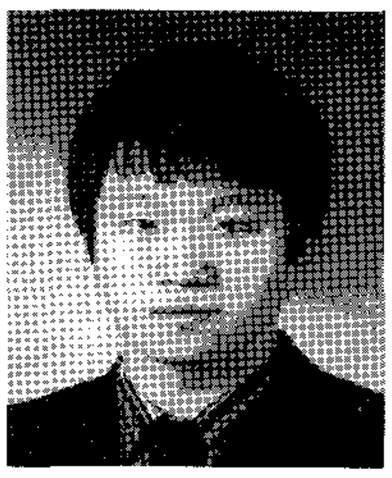

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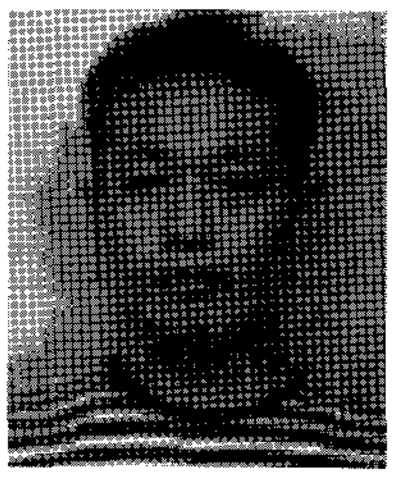

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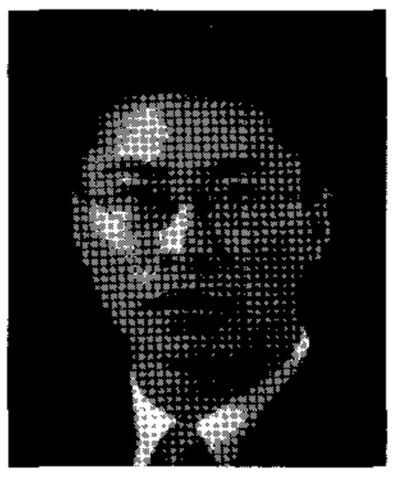

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