Impacts of N_2 and NH_3 Plasma Surface Treatments on High-Performance LTPS-TFT With High-κ Gate Dielectric

Ming-Wen Ma, Tien-Sheng Chao, Tsung-Yu Chiang, Woei-Cherng Wu, and Tan-Fu Lei

***Abstract*—Low-temperature polycrystalline-silicon thin-film transistors (LTPS-TFTs) with high-κ gate dielectrics and plasma surface treatments are demonstrated for the first time. Significant field-effect mobility $\mu_{\rm FE}$ improvements of $\sim$86.0% and 112.5% are observed for LTPS-TFTs with HfO_2 gate dielectric after N_2 and NH_3 plasma surface treatments, respectively. In addition, the N_2 and NH_3 plasma surface treatments can also reduce surface roughness scattering to enhance the field-effect mobility $\mu_{\rm FE}$ at high gate bias voltage V_G, resulting in 217.0% and 219.6% improvements in driving current, respectively. As a result, high-performance LTPS-TFT with low threshold voltage $V_{\rm TH} \sim 0.33$ V, excellent subthreshold swing S.S. $\sim$0.156 V/decade, and high field-effect mobility $\mu_{\rm FE} \sim 62.02\ {\rm cm^2/V \cdot s}$ would be suitable for the application of system-on-panel.**

***Index Terms*—High-κ, low-temperature polycrystalline-silicon thin-film transistors (LTPS-TFTs), NH_3 plasma, N_2 plasma.**

I. Introduction

HIGH-PERFORMANCE low-temperature polycrystalline-silicon thin-film transistors (LTPS-TFTs) with high-κ gate dielectrics have been studied in recent years [1]–[5]. High-κ gate dielectrics can provide higher gate capacitance density with the same physical thickness due to their high dielectric constant. A higher gate capacitance density can attract more carriers with a smaller gate voltage to fill up the traps that exist in the polycrystalline-silicon channel film. Therefore, the LTPS-TFT with high gate capacitance density could significantly reduce the operation voltage without any defect-passivation treatment [1]–[5]. The threshold voltage $V_{\rm TH}$ and the subthreshold swing (S.S.) can be significantly reduced by using high-κ gate dielectrics instead of conventional thick SiO_2 gate dielectrics [1]–[5]. However, the trap states still exist among the polycrystalline silicon in spite of the employment of high-κ gate dielectrics. The NH_3 plasma posttreatment is the most general method to passivate the trap states of the polycrystalline-silicon channel film for conventional TFTs [6], [7]. The impacts of NH_3 plasma treatment on the LTPS-TFT with high-κ gate dielectric have not been reported yet.

In this letter, the LTPS-TFT with HfO_2 gate dielectric and NH_3 plasma surface treatment is demonstrated for the first time. In addition, N_2 plasma surface treatment is also used to distinguish the impacts of nitrogen and hydrogen species.

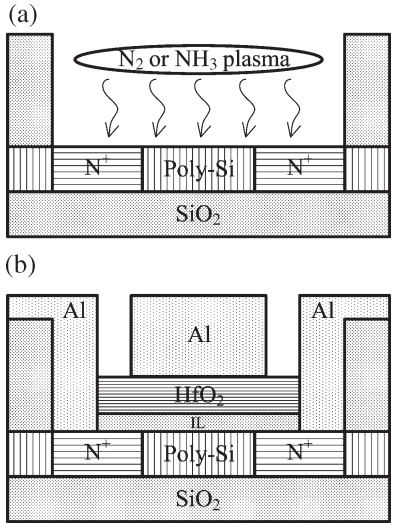

Fig. 1. Cross-sectional view of LTPS-TFT with plasma surface treatment and HfO_2 gate dielectric.

II. Experimental Procedure

The fabrication of devices started by depositing a 50-nm undoped amorphous-Si (α-Si) layer at 550 °C in a low-pressure chemical vapor deposition system on Si wafers capped with a 500-nm thermal oxide layer. Then, the 50-nm α-Si layer was recrystallized at 600 °C for 24 h. Then, a 500-nm silicon oxide was deposited by plasma-enhanced chemical vapor deposition at 300 °C for device isolation. The device active region was formed by patterning and etching the isolation oxide. The source and drain (S/D) regions in the active device region were implanted with phosphorus at 15 keV and $5 \times 10^{15}\ {\rm cm^{-2}}$. The S/D was activated at 600 °C for 24 h. Then, NH_3 or N_2 plasma surface treatment was performed for 0, 5, and 15 min at 300 °C with a power density of 1.6 mW/cm^2 in NH_3 or N_2 gas, as shown in Fig. 1(a). The flow rate was 100 sccm at pressure

Manuscript received July 23, 2008. First published September 16, 2008; current version published October 22, 2008. This work was supported by the National Science Council, Taiwan, under Contract NSC-96-2221-E-009-189. The review of this letter was arranged by Editor A. Nathan.

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Digital Object Identifier 10.1109/LED.2008.2004781

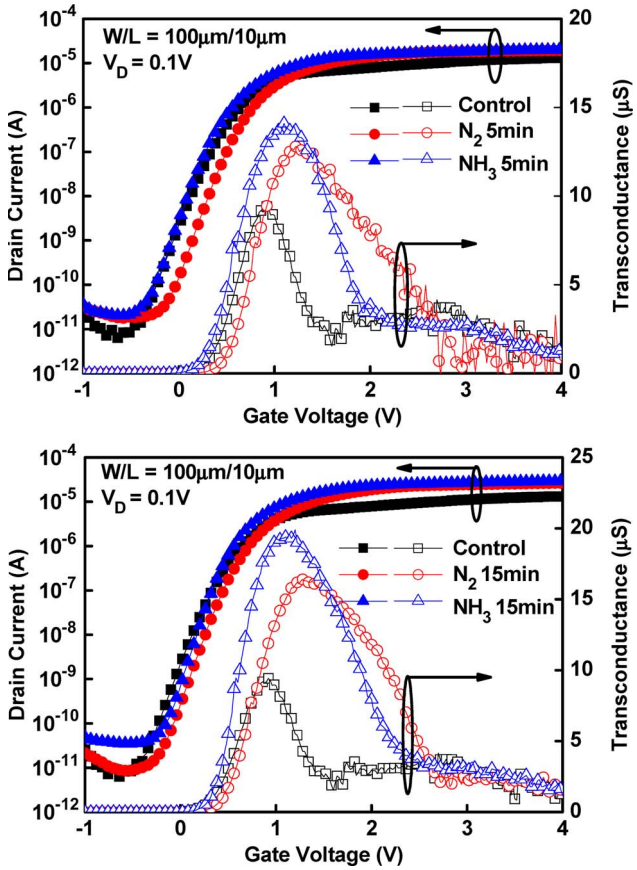

Fig. 2. Transfer characteristics (I_D–V_G and transconductance G_m) of LTPS-TFT with HfO_2 gate dielectric after N_2 and NH_3 plasma surface treatments for 5 and 15 min, respectively. The solid and hollow symbols represent the I_D and G_m, respectively.

of 67 Pa. A 50-nm HfO_2 with effective oxide thickness of $\sim$10.7 nm was deposited by an electron beam evaporation system at room temperature and pressure of 5×10^{-6} torr without gas flow. An O_2 treatment in furnace was applied to improve the HfO_2 quality at 400 °C for 30 min. The dielectric constant of HfO_2 is about 18.2. After the patterning of S/D contact holes, aluminum was deposited by thermal evaporation system as the gate electrode and S/D contact pad. Finally, the TFT devices were completed by the contact pad definition, as shown in Fig. 1(b). Devices with gate length (L) and width (W) of 10 and 100 μm, respectively, were measured. The threshold voltage $V_{\rm TH}$ is defined as the gate voltage at which the drain current reaches 10 nA $\times\, W/L$ and $V_D = 0.1$ V. The field-effect mobility $\mu_{\rm FE}$ is extracted from the maximum transconductance (G_m).

III. Results and Discussion

Fig. 2 shows the transfer characteristics (I_D–V_G and transconductance G_m) of the LTPS-TFT with HfO_2 gate dielectric after N_2 and NH_3 plasma surface treatments for 5 and 15 min, respectively. The important device parameters of LTPS-TFTs are listed in Table I. The S.S.'s of devices show improvements of 8.6% and 9.6% with N_2 plasma surface treatment for 5 and 15 min, respectively. Moreover, the $\mu_{\rm FE}$'s of devices also show increases of 43.7% and 86.0% with N_2 plasma surface treatment for 5 and 15 min, respectively. It is known that S.S. and $\mu_{\rm FE}$ are related to the dangling-bond deep trap states and the strain-bond tail trap states of the polycrystalline-silicon channel [8], respectively. The significant increase on $\mu_{\rm FE}$ indicates that nitrogen has better passivation effect on strain-bond tail trap states than on dangling-bond deep trap states. On the other hand, devices show 9.1% and 21.2% S.S. improvements with NH_3 plasma surface treatment for 5 and 15 min, respectively. In addition, the 5- and 15-min NH_3 plasma surface treatments show 51.4% and 112.5% $\mu_{\rm FE}$ improvements, respectively. It is found that the improvement of S.S. is on the same level by either 5-min N_2 or NH_3 plasma treatment. This implies that hydrogen from NH_3 has less significant contribution to the improvement of S.S. for such a short 5-min treatment. On the contrary, devices with a longer 15-min NH_3 plasma treatment exhibit more S.S. improvement, indicating more passivation effect on the dangling-bond deep trap states due to the contribution of hydrogen. Devices with either 15-min N_2 or NH_3 plasma treatment show significant $\mu_{\rm FE}$ improvement, indicating that good passivation on strain-bond tail states can be achieved by both plasma treatments. Fig. 3 shows the output characteristics (I_D–V_D) of the LTPS-TFT with HfO_2 gate dielectrics after N_2 and NH_3 plasma surface treatments for 5 and 15 min, respectively. For 5 min, N_2 and NH_3 plasma surface treatments show 165.0% and 91.3% driving saturation current $I_{D\_\rm sat}$ enhancements at $V_G - V_{\rm TH} = 4$ V and $V_D = 5$ V, as shown in Table I and Fig. 3. The 5-min N_2 plasma surface treatment shows a smaller $\mu_{\rm FE}$ improvement and a higher $I_{D\_\rm sat}$ enhancement than the 5-min NH_3 plasma surface treatment. From Fig. 2, it is noted that the $\mu_{\rm EF}$ reduction rate after the peak is improved using plasma surface treatment at high V_G. This improvement is due to the reduced surface roughness scattering [9]. The N_2 plasma-treated device has more improvement on surface roughness scattering than the NH_3 plasma-treated device for 5-min treatment time, resulting in a higher driving saturation current $I_{D\_\rm sat}$ of the N_2 plasma-treated device. The surface roughness scattering is improved further, leading to 217.0% and 219.6% improvements in driving saturation current for the 15-min N_2 and NH_3 plasma surface treatments, respectively.

In addition to the performance improvement of the HfO_2 LTPS-TFT after plasma surface treatment, the gate capacitance density C_G also decreased due to the growth of interfacial layer (IL) during the plasma treatment. As shown in Table I, the HfO_2 LTPS-TFT after N_2 plasma surface treatment has lower C_G than after NH_3 plasma surface treatment, suggesting that the thickness of IL grown by N_2 plasma is thicker than the one grown by NH_3 plasma. The gate leakage current I_G of HfO_2 LTPS-TFTs after plasma surface treatment at $V_G - V_{\rm TH} = 2$ V and $V_{\rm DS} = 0.1$ V are also measured and listed in Table I. Much more I_G reduction of the N_2 plasma-treated device is observed to consist with the results of decreased C_G. The effective interface trap states $N_{\rm it}$'s and effective grain boundary trap states $N_{\rm trap}$'s of the poly-Si channel film were extracted from S.S. and I_D–V_G curve [10]–[12]. These values are all listed in the Table I. The $N_{\rm it}$'s of N_2 plasma-treated devices show a higher initial improvement due to the growth of IL by N_2

TABLE I
IMPORTANT DEVICE PARAMETERS OF LTPS-TFT WITH HfO_2 GATE DIELECTRIC AFTER N_2 AND NH_3 PLASMA SURFACE TREATMENTS FOR 5 AND 15 MIN, RESPECTIVELY

HfO_2-TFT	V_{TH} (V)	S.S. (V/dec.)	I_G (nA)	C_G (fF/μm^2)	μ_{FE} (cm^2/V-s)	N_{trap} (cm^{-2})	N_{it} (cm^{-2})	I_{D_sat} (mA)
Control	0.33	0.198	0.195	3.22	29.19	4.87×10^{12}	4.67×10^{12}	0.311
N_2 5min	0.5	0.181	0.0333	3.05	41.96	4.85×10^{12}	3.88×10^{12}	0.824
NH_3 5min	0.28	0.180	0.193	3.19	44.20	3.96×10^{12}	4.02×10^{12}	0.595
N_2 15min	0.45	0.179	0.0233	3.02	54.30	4.55×10^{12}	3.78×10^{12}	0.986
NH_3 15min	0.33	0.156	0.191	3.16	62.02	3.87×10^{12}	3.19×10^{12}	0.994

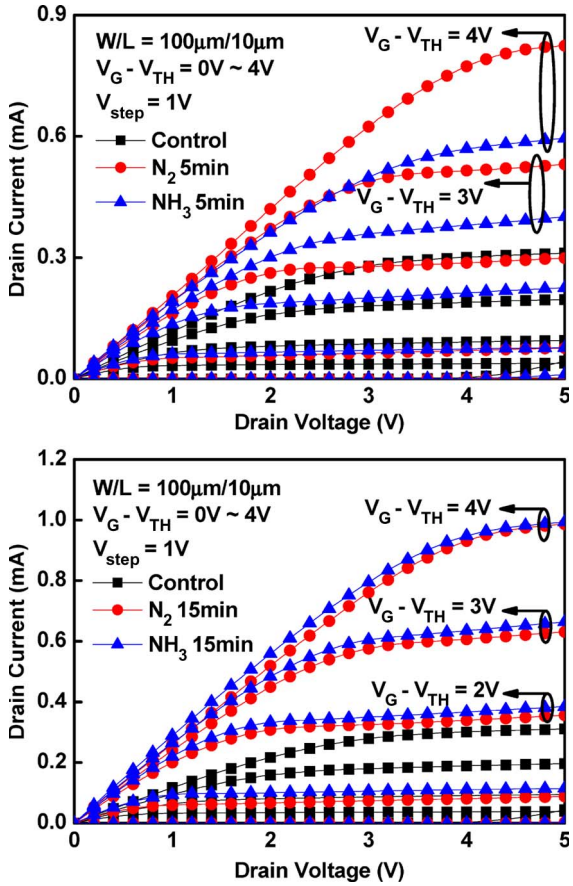

Fig. 3. Output characteristics (I_D–V_D) of LTPS-TFT with HfO_2 gate dielectric after N_2 and NH_3 plasma surface treatments for 5 and 15 min, respectively.

plasma treatment. However, for longer 15-min plasma treatment, the effect of NH_3 plasma on N_{it} is greater than that of N_2 plasma due to hydrogen incorporation. In addition, as shown in Table I, NH_3 plasma treatment shows greater passivation effect on grain boundary traps N_{trap}'s compared to N_2 plasma treatment.

High-performance LTPS-TFT with low threshold voltage $V_{TH} \sim 0.45$ V, excellent S.S. ~ 0.179 V/decade, and high field-effect mobility $\mu_{FE} \sim 54.30$ cm^2/V $\cdot$ s is obtained by using HfO_2 gate dielectric and 15-min N_2 plasma surface treatment. In addition, high-performance LTPS-TFT with low threshold voltage $V_{TH} \sim 0.33$ V, excellent S.S. ~ 0.156 V/decade, and high field-effect mobility $\mu_{FE} \sim 62.02$ cm^2/V $\cdot$ s is also obtained by using HfO_2 gate dielectric and 15-min NH_3 plasma surface treatment.

IV. CONCLUSION

In this letter, high-performance LTPS-TFT with HfO_2 gate dielectric has been fabricated. In order to enhance the performance of the LTPS-TFT with high-κ gate dielectric, two kinds of plasma, N_2 and NH_3, are employed. S.S., field-effect mobility μ_{FE}, and driving saturation current are all significantly improved after N_2 and NH_3 plasma surface treatments.

ACKNOWLEDGMENT

The authors would like to thank the process support from National Nano Device Laboratories and the Nano Facility Center, National Chiao Tung University, Hsinchu, Taiwan, R.O.C.

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