Improvement of Hydrogenated Amorphous-Silicon TFT Performances With Low-k Siloxane-Based Hydrogen Silsesquioxane (HSQ) Passivation Layer

Ta-Shan Chang, Ting-Chang Chang, Po-Tsun Liu, Tien-Shan Chang, Chun-Hao Tu, and Feng-Sheng Yeh

***Abstract*—A low-dielectric-constant (low-k)-material siloxane-based hydrogen silsesquioxane (HSQ) is investigated as a passivation layer in bottom-gate hydrogenated amorphous-silicon thin-film transistors (a-Si : H TFTs). The low-k HSQ film passivated on TFT promotes the brightness and aperture ratio of TFT liquid-crystal display due to its high light transmittance and good planarization. In addition, the performance of a-Si : H TFT with HSQ passivation has been improved, compared to a conventional silicon nitride (SiN_x)-passivated TFT because the hydrogen bonds of HSQ assist the hydrogen incorporation to eliminate the density of states between the back channel and passivation layer. Experimental results exhibit an improved field-effect mobility of 0.57 $\mathrm{cm}^2/\mathrm{V}\cdot\mathrm{s}$ and a subthreshold swing of 0.68 V.**

***Index Terms*—Low-dielectric constant, passivation, thin-film transistor (TFT).**

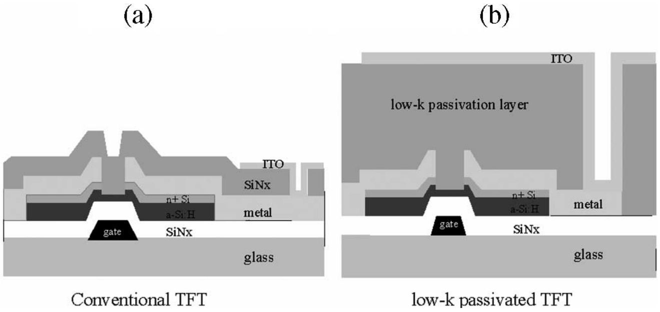

Fig. 1. (a) Cross section of the inverted-staggered a-Si : H TFT with SiN_x passivation. (b) Cross section of the inverted-staggered a-Si : H TFT with HSQ passivation.

I. INTRODUCTION

THE inverted-staggered back-channel-etched (BCE) hydrogenated amorphous-silicon (a-Si : H) thin-film transistor (TFT) has been widely used as a switching element in active-matrix liquid-crystal displays (AM-LCDs) [1], [2]. The issues of transmittance and RC time delay become more and more critical as the panel size becomes larger, and the resolution and brightness requirements of TFT-LCDs become higher [3]–[5]. Recently, low-dielectric (low-k) materials that have high transmittance are investigated for high-resolution and high-aperture-ratio TFT-LCD panels [6], [7]. In conventional BCE a-Si : H TFT, silicon nitride (SiN_x) has been used as a passivation layer on the device to protect the back channel from damage and contaminations, as shown in Fig. 1(a). It is difficult to expand the indium–tin–oxide pixel electrodes to increase the aperture ratio in the conventional structure because of its proximity and capacitive coupling to the gate and source bus (control) lines. These considerations limit the transmittance and resolution of the TFT panel. Thus, the adaptation of a thick low-k passivation layer on a TFT device for its superior planarization, as shown in Fig. 1(b), can extend the pixel electrode over the gate and data line with decreased RC time delay and increased aperture ratio. A conventional silicon nitride passivation layer on BCE a-Si TFTs is limited due to its relatively high dielectric constant ($k \sim 7$), low transmittance, high stress, and slow process rate.

A spin-on low-k-material ($k \sim 2.8$) siloxane-based hydrogen silsesquioxane (HSQ) was first proposed in this letter to replace the conventional nitride passivation layer. High transmittance in the range of visible light, good planarization properties, and good electrical properties make it a more potential candidate for passivation-layer application on BCE a-Si TFTs [8], [9]. In addition, higher process efficiency is another process advantage for using HSQ as a TFT passivation layer. The thickness of HSQ could be controlled by tuning the speed of the spin coater. Compared with conventional SiN_x that are deposited on devices in a vacuum environment by plasma-enhanced chemical vapor deposition (PECVD), HSQ spun-on devices has a higher and more effective deposition rate. Thus, the throughput will be more increased than previous ones. The HSQ film potentially combines the desired features of good adhesion, gap filling, high Young's modulus, low coefficient of thermal expansion, and nonetchback process [8]–[10]. The relative dielectric constant, thickness, and breakdown voltage of the HSQ used in the experiment are 2.8, 5000 A, and 5.0 MV/cm, respectively, whereas those of the conventional SiN_x are 7.0, 1000 A, and 9 MV/cm, respectively. In this letter, the characteristics of a-Si : H TFT with HSQ passivation layer would be discussed.

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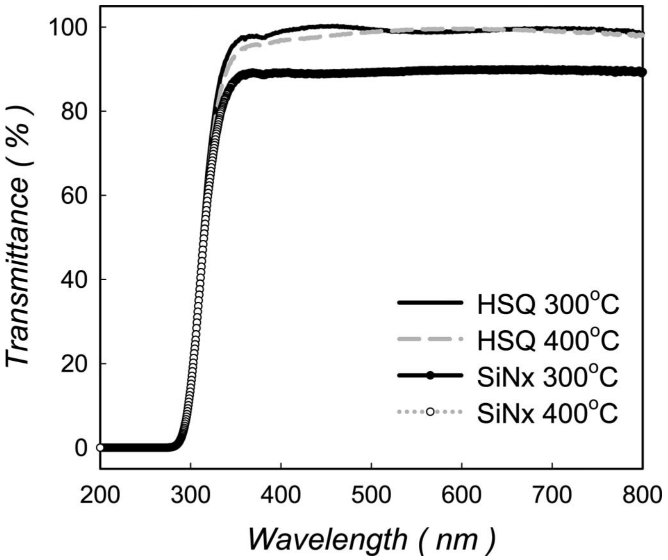

Fig. 2. Optical transmittance of the SiN_x and HSQ films with different process temperatures.

II. DEVICE STRUCTURE AND FABRICATION

Fig. 1(b) shows a schematic diagram of a gate-planarized BCE a-Si : H TFT, which used HSQ as the passivation layer. The fabrication process of the proposed TFT device is described in the following. First, metallic chromium was deposited on a 4-in substrate by sputtering and then was patterned to form gate electrodes. Sequentially, SiN_x, undoped a-Si : H, and phosphorous-doped a-Si : H (n^+a-Si : H) layers were deposited without breaking the vacuum at a PECVD chamber. The SiN_x layer was deposited with a mixture of SiH_4 (20 sccm), NH_3 (80 sccm), and N_2 (50 sccm) gases at a substrate temperature of 300 °C, the RF power was 50 W, and the pressure was 500 mtorr. The undoped a-Si : H layer was deposited from SiH_4 (100 sccm) at 300 °C, the RF power was 15 W, and the pressure was 300 mtorr. The thickness of the Cr, SiN_x, a-Si : H, and n^+ a-Si : H layers were 300, 350, 150, and 40 nm, respectively. The definition of a-Si : H active region was performed with lithography and etching processes. An aluminum film was evaporated to form the source/drain electrodes. The aluminum was deposited, and the source/drain metal contacts were defined by the third photolithography. Before the passivation formation, the 4-in substrate was divided into three groups: standard, HSQ, and SiN_x samples. The standard sample without any passivation layer was treated at 300 °C for 1 h in the furnace. The low-k film HSQ that is coated on the standard sample was baked sequentially on hotplates at 150 °C, 200 °C, and 250 °C for 1 min, respectively. Finally, the HSQ was cured in the furnace at 300 °C for 1 h under N_2 ambient. In this letter, the back-channel-passivated a-Si : H TFTs (SiN_x, HSQ) were treated in the same thermal condition as the standard.

III. RESULTS AND DISCUSSION

The solid and dashed lines in Fig. 2 indicate the optical transmittance of the SiN_x and HSQ films with different process temperatures, respectively. As shown in Fig. 2, the optical transmittance of HSQ is above 98% in visible light range (300–800 nm). The optical transmittance of SiN_x is below 90%, which is lower than that of HSQ. In addition, the optical transmittance does not have dramatic variation in different temperatures, which is an additional advantage of HSQ integrated on a-Si : H TFT devices. Fig. 3 exhibited the $I_d - V_g$ transfer characteristics of BCE a-Si : H TFTs with HSQ passivation, SiN_x passivation, and without any passivation (standard), respectively. Compared with the standard TFTs, it is found that the current operated in the "ON-state" of both back-channel-passivated a-Si : H TFTs are improved, especially for the HSQ-passivated a-Si : H TFTs. Furthermore, the HSQ passivation process does not lead to increased OFF-state current, which is observed in SiN_x-passivated TFTs. The increase of OFF-state current could be attributed to the defect states at the back-channel surface. The passivation at the HSQ/a-Si : H interface decreased the density of defect states, leading to the improved electrical characteristics of TFTs. The Fourier transform infrared spectra of HSQ and SiN_x films were shown in the inset of Fig. 3. The peak near 2250 cm^{-1} is identified as a Si-H stretching bond for HSQ films, and the peak near 890 cm^{-1} is identified as a Si-N stretching band for SiN_x films. This indicates a high concentration of hydrogen that is present in the HSQ film. The hydrogen content in HSQ film is beneficial to the passivation of Si dangling bonds at the back-channel surface [11]–[13]. The means and the standard deviations for the field-effect mobility μ_{FE}, the subthreshold swing (SS), the threshold voltage V_{TH}, and the ON/OFF current ratio $I_{\mathrm{ON}}/I_{\mathrm{OFF}}$ of the standard, SiN_x-passivated, and HSQ-passivated a-Si : H TFTs are shown in Table I. These electrical parameters are derived from the $I_d - V_g$ plot by operating the device in the linear region. It is observed that the HSQ passivation was relatively effective to improve the TFT device performances. From the previous knowledge [12], trap states at the back channel lead to worse electrical characteristics, such as I_{OFF} and SS. The I_{ON}, SS, and I_{OFF} of HSQ-passivated a-Si : H TFTs are improved by incorporating the hydrogen that originated from the HSQ film. Furthermore, from standard deviations, it is found that HSQ passivation improved the electrical characteristics of a-Si TFTs in the sample uniformly. The experiment results indicate that

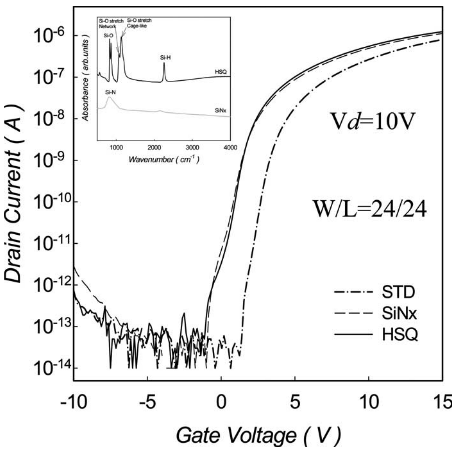

Fig. 3. $I_d - V_g$ transfer characteristics of BCE a-Si : H TFTs at $\mathrm{V}_d = 10$ V. The solid line, dashed line, and broken-dashed line represent the TFTs with HSQ passivation, the TFTs with SiN_x passivation, and the standard TFTs, respectively.

TABLE I
VALUES OF THE DEVICE PARAMETERS OF THE a-Si : H TFTs WITH HSQ PASSIVATION, THE a-Si : H TFTs WITH SiN_x PASSIVATION, AND THE STANDARD a-Si : H TFTs

		μ_{FE} (cm^2/Vs)	S.S. (V/dec)	V_{TH} (V)	I_{ON} / I_{OFF} (10^6)
Standard	Means	0.50	0.87	3.25	5.26
	Standard Deviation	0.009	0.033	0.087	1.327
SiN_x	Means	0.51	0.77	2.01	6.91
	Standard Deviation	0.005	0.019	0.041	0.603
HSQ	Means	0.57	0.68	1.88	7.16
	Standard Deviation	0.008	0.022	0.048	0.889

HSQ, instead of conventional SiN_x, is a promising candidate to be the passivation layer for the high-transmittance and high-aperture TFT-LCD array.

IV. CONCLUSION

The a-Si : H TFTs with low-k dielectric passivation was performed in this letter. The improved electrical characteristics of HSQ-passivated a-Si : H TFTs resulted from the incorporation of hydrogen. In addition, compared to the conventional silicon nitride film, the HSQ film is a more potential candidate on a-Si : H TFT fabrication for higher light transmission, lower stress, and superior planarization, which attributes to a higher aperture ratio. Furthermore, the process is not difficult and compatible with current a-Si : H TFT fabrication processes. HSQ is a viable candidate to replace conventional SiN_x as a passivation layer in the future.

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