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# EFFECT OF Cl INCORPORATION ON THE PERFORMANCE OF AMORPHOUS SILICON THIN FILM TRANSISTOR

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**Abstract** - We have studied the effect of Cl incorporation on the performance of amorphous silicon thin film transistors (a-Si:H(:Cl) TFTs). The off-state leakage currents of a-Si:H(:Cl) TFTs under light illuminations are much lower than those of a-Si:H TFT, caused by the fact that the photoconductivity of a-Si:H(:Cl) are much lower than those of conventional a-Si:H. The a-Si:H(:Cl) films deposited between  $[\text{SiH}_2\text{Cl}_2]/[\text{SiH}_4] = 0.04$  and  $[\text{SiH}_2\text{Cl}_2]/[\text{SiH}_4] = 0.12$  show a p-type conduction, leading to much lower photoconductivity. The TFT using a-Si:H(:Cl) deposited with  $[\text{SiH}_2\text{Cl}_2]/[\text{SiH}_4] = 0.04$  exhibited a field effect mobility of  $0.41 \text{ cm}^2/\text{Vs}$  and a threshold voltage of  $5.56 \text{ V}$ , but the off-state leakage current under light illumination is 2 orders of magnitude smaller than that of conventional a-Si:H TFT.

## I. INTRODUCTION

Thin-film transistors (TFTs) including an active layer of amorphous silicon or polycrystalline silicon have been widely employed as the pixel-driving elements of a liquid crystal display (LCD). Particularly, a-Si:H TFT is advantageous to the production of large screen displays and facilitates mass-production.<sup>1</sup> When employing a-Si:H layer, the main issues are to improve the production throughput and to reduce the off-state leakage currents under light illumination.

A-Si:H has high photoconductivity which results in high off-state leakage currents of a-Si:H TFT under light illumination.<sup>2</sup> Particularly, the off-state leakage current under light illumination is a serious problem in the projection and/or video displays which require high intensity backlight illumination. Recently, the fully self-aligned a-Si:H TFT has been developed to reduce the parasitic capacitance between source/drain and gate electrodes. However, it has high off-state leakage current under light illumination compared to conventional TFT.<sup>3</sup> Therefore, to reduce the off-state leakage current in a-Si:H TFT under illumination is very important to obtain a high quality TFT-LCD.

The off-state leakage current can be lowered by reducing the thickness of undoped a-Si:H, however, this also decreases the field effect mobility of the TFT.<sup>4</sup> The off-state leakage current of a-Si:H TFT is mainly due to the holes induced at the a-Si:H interfaced to a gate insulator. However, under light illumination, electrons are the majority carriers when a negative gate voltage is applied to the TFT because electron mobility is much higher than that of hole.<sup>5</sup>

Recently, Cl incorporated hydrogenated amorphous silicon (a-Si:H(:Cl)) has been prepared by various deposition methods using  $\text{SiH}_2\text{Cl}_2$  mixtures to improve film quality,<sup>6</sup> to improve the stability,<sup>7</sup> or to increase deposition rate.<sup>8</sup>

In our previous work we have studied the electrical and optical properties of a-Si:H(:Cl) films deposited by remote plasma chemical vapor deposition (RPCVD) using  $\text{SiH}_4/\text{SiH}_2\text{Cl}_2/\text{H}_2/\text{He}$  mixture with  $[\text{SiH}_2\text{Cl}_2]/[\text{SiH}_4] = 0.1$  and obtained the a-Si:H(:Cl) films with Cl concentration of  $7 \times 10^{18} \text{ cm}^{-3}$  and Urbach energy of  $55 \text{ meV}$  at the substrate temperature of  $240 \text{ }^\circ\text{C}$ .<sup>9</sup> The defect density and Urbach energy of a-Si:H are not much changed by addition of 10 %  $\text{SiH}_2\text{Cl}_2$  to silane plasma. Also we have fabricated the low off-state leakage current a-Si:H TFT using a-Si:H(:Cl) deposited at  $240 \text{ }^\circ\text{C}$ .<sup>10</sup> In the present work the a-Si:H(:Cl) TFTs have been fabricated using the a-Si:H(:Cl) films deposited at  $300 \text{ }^\circ\text{C}$  with  $[\text{SiH}_2\text{Cl}_2]/[\text{SiH}_4] = 0.04 \sim 0.12$  in order to study the effect of Cl incorporation on the performance of a-Si:H TFT.

## II. EXPERIMENTS

The a-Si:H(:Cl) films were deposited by RPCVD using  $\text{SiH}_4/\text{SiH}_2\text{Cl}_2/\text{H}_2/\text{He}$  mixtures, in which the substrate temperature as well as  $[\text{SiH}_2\text{Cl}_2]/[\text{SiH}_4]$  ratio have been changed. We used He as a non-depositing, exciting species. Helium was passed through the plasma generating region contained inside a cylindrical quartz tube of a diameter of  $3.8 \text{ cm}$ . The distance between the

bottom of the quartz tube and substrate holder in the deposition reactor was  $\sim 10$  cm. Downstream from the plasma, in the deposition area,  $\text{SiH}_4/\text{SiH}_2\text{Cl}_2/\text{H}_2/\text{He}$  was added for deposition of a-Si:H(:Cl) films. The flow rates of He,  $\text{H}_2$ , and  $\text{SiH}_4$  were fixed at 100 sccm, 2 sccm and 1 sccm, respectively. The plasma was generated by applying rf power of 10 W at 13.56 MHz to an induction coil, wrapped around the outside of quartz tube.

The transistor used in this study is a conventional inverted staggered structure. Cr metal was deposited on the glass substrates by sputtering and patterned by standard photolithography to act as the gate electrodes. Three layers of 350 nm thick  $\text{SiN}_x$ , 150 nm thick a-Si:H(:Cl), and 50 nm thick  $n^+$  a-Si:H were consecutively deposited in an RPCVD reactor. The  $\text{SiN}_x$  layer was deposited by  $\text{SiH}_4$  and  $\text{NH}_3$  gas mixture with 1.8 %  $\text{SiH}_4$  in  $\text{NH}_3$  at 300 °C and the undoped a-Si:H(:Cl) was deposited from a gas mixture of  $\text{SiH}_2\text{Cl}_2$  and  $\text{SiH}_4$ . The  $n^+$  a-Si:H, of resistivity  $\sim 100$  ohm cm, was used to ensure an ohmic contact with the source/drain metals. The Al was evaporated on the  $n^+$  a-Si:H and then patterned to be used as source/drain contacts. The  $n^+$  layer in the channel was etched by  $\text{CF}_4$  plasma. The ratio of width to length of a TFT was  $60 \mu\text{m}/30 \mu\text{m}$ . The light was illuminated from the back or front side to compare the difference in the off-state leakage currents under light illumination between a-Si:H(:Cl) TFT and conventional one.

### III. RESULTS AND DISCUSSION

Figure 1 shows the comparison of the  $I_D$ - $V_G$  characteristics between a-Si:H TFT and a-Si:H(:Cl) TFT under backlight illumination. The off-state drain currents under light illumination of a-Si:H(:Cl) TFTs using a-Si:H(:Cl) films deposited with  $[\text{SiH}_2\text{Cl}_2]/[\text{SiH}_4] = 0.04, 0.08, 0.12$  are much lower than that of a-Si:H TFT, caused by the fact that the photoconductivity of a-Si:H(:Cl) is much lower than those of the conventional a-Si:H. The a-Si:H(:Cl) films deposited between  $[\text{SiH}_2\text{Cl}_2]/[\text{SiH}_4] = 0.04$  and  $[\text{SiH}_2\text{Cl}_2]/[\text{SiH}_4] = 0.12$  show a p-type conduction, leading to lower photoconductivity. From Fig. 1, it can be seen that the off-state dark leakage currents of a-Si:H(:Cl) TFT are much higher than those of conventional a-Si:H TFT at high negative gate bias, which is presumably due to the less density of states in the gap below the midgap of a-Si:H(:Cl). The density of states below the midgap of p-type a-Si:H is lower than that of n-type a-Si:H by defect pool model.<sup>11</sup>

Figure 2 shows the comparison of the  $I_D$ - $V_G$  characteristics between a-Si:H TFT and a-Si:H(:Cl) TFT under front light illumination of 6600 Lux. By using a-Si:H(:Cl) as an active layer of the TFT, the off-state leakage current can be reduced by at least 2 orders of magnitude, which is also due to lower photoconductivity of a-Si:H(:Cl).

Figure 3 shows the plots of  $\sqrt{I_D}$  against  $V_G$  for a-Si:H(:Cl) TFTs to obtain field effect mobility and threshold voltage from  $I_D^{1/2} = (WC_i \mu_{fe}/2L)^{1/2}(V_G - V_T)$ , where  $I_D$ ,  $\mu_{fe}$ ,  $V_G$ ,  $V_T$ , and  $C_i$  are drain current, field effect mobility, gate voltage, threshold voltage, and the capacitance of silicon-nitride, respectively.<sup>12</sup>

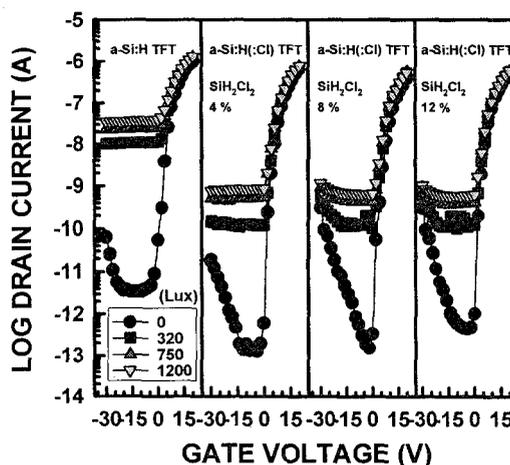


Fig. 1. Comparison of the  $I_D$ - $V_G$  characteristics between a-Si:H TFT and a-Si:H(:Cl) TFT under backlight illumination.

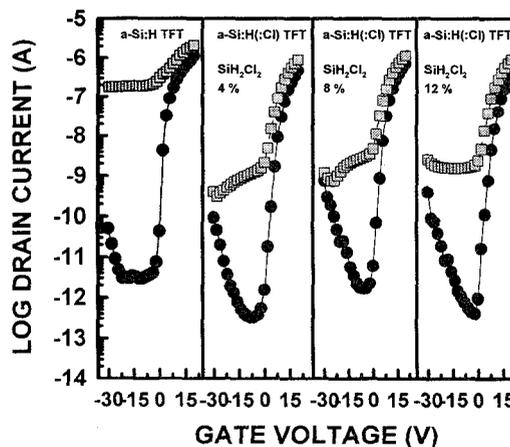


Fig. 2. Comparison of the  $I_D$ - $V_G$  characteristics between a-Si:H TFT and a-Si:H(:Cl) TFT under front light illumination of 6600 Lux.

The field effect mobility decreases and the threshold voltage increases with increasing  $\text{SiH}_2\text{Cl}_2$  flow rate. The threshold voltage and field effect mobility of the a-Si:H(:Cl) TFT using an a-Si:H(:Cl) layer deposited with  $[\text{SiH}_2\text{Cl}_2]/[\text{SiH}_4] = 0.04$  are 5.56 V and  $0.41 \text{ cm}^2/\text{Vs}$ , respectively. The field effect mobility decreases by 18 % and the threshold voltage increases by 46 % compared to

those of conventional a-Si:H TFT.

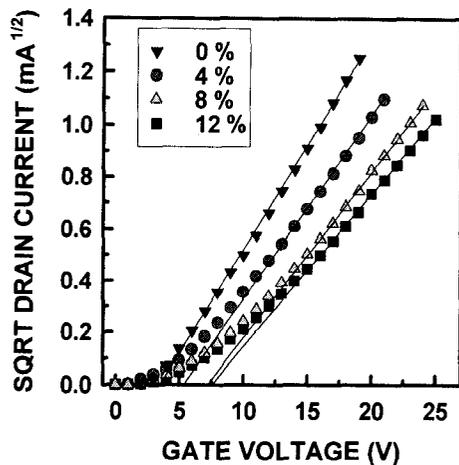


Fig. 3. Plots of  $\sqrt{I_D}$  against  $V_G$  for a-Si:H(Cl) TFTs to obtain field effect mobility and threshold voltage.

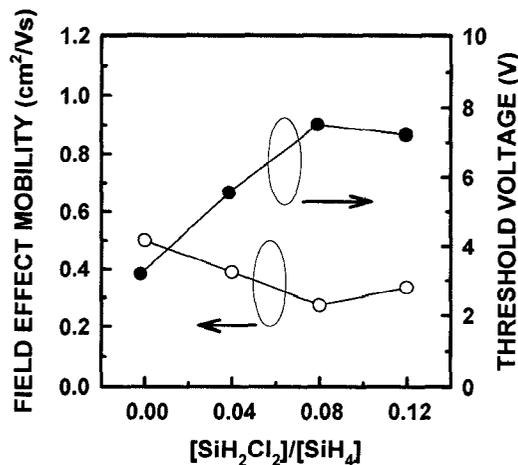


Fig. 4. The field effect mobility and threshold voltage for the a-Si:H(Cl) TFTs.

Figure 4 shows the field effect mobility and threshold voltage for the a-Si:H(Cl) TFTs, obtained from Fig. 1. With increasing  $[\text{SiH}_2\text{Cl}_2]/[\text{SiH}_4]$ , the field effect mobility decreases slightly and threshold voltage increases. The Fermi level of Cl incorporated a-Si:H is lower than conventional a-Si:H. The increase in the threshold voltage may be due to the increase in the defect density by Cl incorporation and/or due to the shift of the Fermi-level in the band gap toward the valence band edge.

The density of states in the gap of a-Si:H(Cl) will be modified by the introduction of Cl into a-Si:H, resulting

in the shift of the Fermi-level toward the valence band edge. The Fermi-level of a-Si:H is determined from the charge neutrality condition. The acceptor-like states are extended from the conduction band edge and the donor-like states from the valence band edge, and dangling bonds exit around the midgap. Among these, some states are charged positively and other states are negatively charged with the same amount. The position of the Fermi-level can be lowered by the reduction of donor-like states or by the increase of the acceptor-like states. The modification in the density of the states in the gap by the incorporation of Cl atoms in a-Si:H should be studied in the future in order to understand the origin of the shift of the Fermi-level toward the valence band edge by Cl incorporation. However, the density of states in the gap below the midgap appears to be reduced by Cl incorporation, which is consistent with the high leakage currents of a-Si:H(Cl) TFTs under dark condition at high negative bias region, as shown in Figs. 1 and 2.

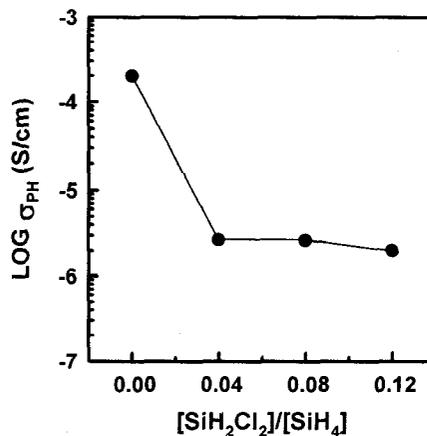


Fig. 5. The photoconductivity under AM-1(100mW/cm<sup>2</sup>) for a-Si:H(Cl) films.

The off-state leakage current of a-Si:H TFT under light illumination is related with its photoconductivity, so that the photoconductivity for the a-Si:H(Cl) films have been investigated. The results are shown in Fig. 5. With increasing  $[\text{SiH}_2\text{Cl}_2]/[\text{SiH}_4]$ , the photoconductivity decreases remarkably at first and then saturates. The photoconductivity of a-Si:H(Cl) is at least 2 orders of magnitude lower than that of undoped a-Si:H.

The photoconductivity of a-Si:H has a close relationship with the position of the Fermi-level. The position of the Fermi-level for a-Si:H(Cl) film exists below the midgap, so that the a-Si:H(Cl) shows a p-type behavior. It should be noted that the photoconductivity of p-type a-Si:H is much lower than that of n-type a-Si:H, because the mobility of electron is much higher than that of hole.<sup>5</sup>

#### IV. CONCLUSION

We have fabricated a-Si:H(:Cl) TFTs in which a-Si:H(:Cl) was deposited as function of  $[\text{SiH}_2\text{Cl}_2]/[\text{SiH}_4]$ . With increasing  $[\text{SiH}_2\text{Cl}_2]/[\text{SiH}_4]$ , the field effect mobility decreases and the threshold voltage increases. However, the off-state leakage current are remarkably decreased by incorporating Cl atoms in a-Si:H. The role of Cl in a-Si:H appears to shift the Fermi-level toward the valence band edge, resulting the a-Si:H(:Cl) being a p-type. Therefore, the photo-leakage current of a-Si:H(:Cl) TFT is at least 2 orders of magnitude lower than that of conventional a-Si:H TFT.

#### ACKNOWLEDGEMENT

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