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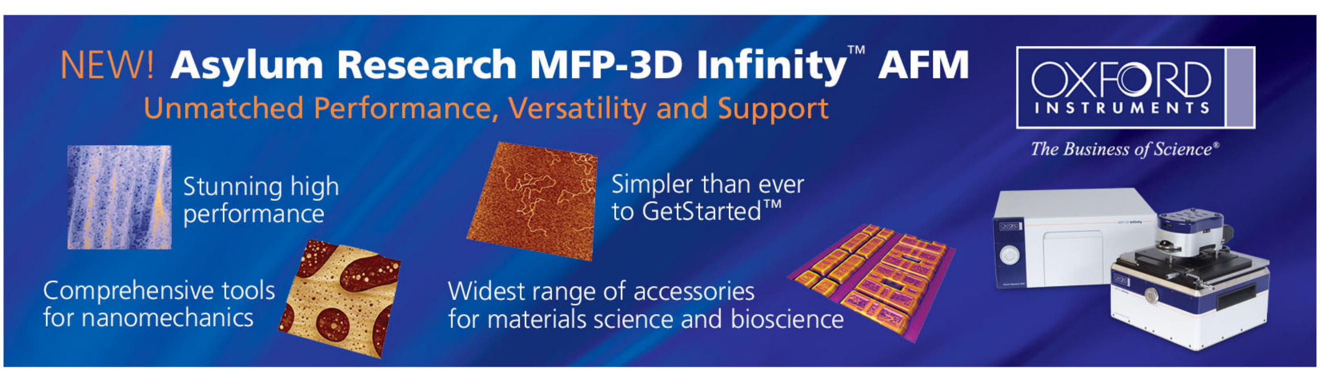

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Photo-leakage-current characteristic of F incorporated hydrogenated amorphous silicon thin film transistor

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The photo-leakage-current (I_{PLC}) characteristic of F incorporated *a*-Si:H thin film transistor (TFT) has been studied. The device activation energy (E_a) of *a*-Si:H(:F) TFTs is higher than those of typical *a*-Si:H TFTs, and resulted in the shift down of Fermi level in *a*-Si:H(:F). Experimental results show that the I_{PLC} of *a*-Si:H(:F) TFTs is smaller than that of conventional *a*-Si:H TFTs in the density of states limited region, stemmed from the higher recombination centers present in *a*-Si:H(:F) material. However, the higher I_{PLC} is observed in the hole conduction region, resulted from the larger E_a in the *a*-Si:H(:F) TFTs. © *2007 American Institute of Physics*.
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Amorphous Si hydrogenated thin film transistors (*a*-Si:H TFTs) have been widely used as switching devices for active matrix liquid crystal displays (LCDs). The *a*-Si:H TFT is particularly advantageous to the production of large flat panel displays and facilitates mass production.[1,2] Because *a*-Si:H is a photosensitive material, the main objectives for flat panel display application are to enhance the field effect mobility and to reduce the off-state leakage current under backlight illumination.[3] The off-state leakage current under light illumination is, in particular, a serious problem in the projection and/or multimedia displays that require high intensity backlight illumination. In order to reduce the parasitic capacitance between the gate and source/drain electrodes, a self-aligned *a*-Si:H TFT structure has been proposed. However, the higher off-state leakage current under light illumination compared to a conventional TFT has been observed.[4] As a result, the reduction of off-state photo-leakage-current in *a*-Si:H TFT is very important for TFT-LCDs technology.

The most widely adopted method to lower the off-state photo-leakage-current is to reduce the thickness of undoped *a*-Si:H layer. However, the reduced undoped *a*-Si:H thickness would decrease the production yield of large size TFT-LCDs and also decrease the field effect mobility of the TFT devices.[5] The off-state dark leakage current of *a*-Si:H TFT mainly originates from the photoinduced hole current at the interface between *a*-Si:H and gate SiN layers. In contrast, electrons are the majority carriers of off-state current for the *a*-Si:H TFT under light illumination, since electron mobility is much higher than that of hole.[6] Recently, Cl incorporated hydrogenated amorphous silicon *a*-Si:H(Cl) has been prepared by various deposition methods using SiH_2Cl_2 mixtures to improve film quality,[7] stability[8] and deposition rate.[9] Furthermore, the off-state photo-leakage-current of *a*-Si:H TFT is also suppressed by the addition of Cl.[10,11] The photo-leakage-current of *a*-Si:H(Cl) TFTs is at least two orders of magnitude lower than that of conventional *a*-Si:H TFTs,[12] stemmed from the exhibited *p*-type-like behavior of *a*-Si:H(:Cl) channel. Although the lower density of states (DOS) by the addition of moderate F in *a*-Si:H was reported by Hyun *et al.*,[13] the different results were observed in this letter. In this study, the *a*-Si:H(F) TFT with F incorporated active layer has been fabricated by using 6% SiF_4 into silane plasma. The concentration of fluorine in the *a*-Si:H(F) active layer is about 4.970×10^{18} at./cm^3 via the secondary ion mass spectrometer analysis. The off-state leakage current characteristics of *a*-Si:H(:F) TFTs under light illumination was also investigated.

Inverted-staggered *a*-Si:H TFTs with back-channel-etched (BCE) process were fabricated on glass substrate for the study of electrical characteristics, as shown in the inset of Fig. 1. The device fabrication process was described as follows. After a 3000 Å thick Cr gate electrode was patterned on the glass substrate, a 3000 Å thick silicon nitride (SiN_x) layer, a 2000 Å thick *a*-Si:H(:F) active layer, and a 500 Å thick n^+-*a*-Si:H were continuously deposited by plasma enhanced chemical vapor deposition method. The undoped *a*-Si:H(:F) was deposited with a gas mixture of 3 SCCM (SCCM denotes cubic centimeter per minute at STP) SiF_4 and 50 SCCM SiH_4 at 200 °C. The n^+-*a*-Si:H layer in the

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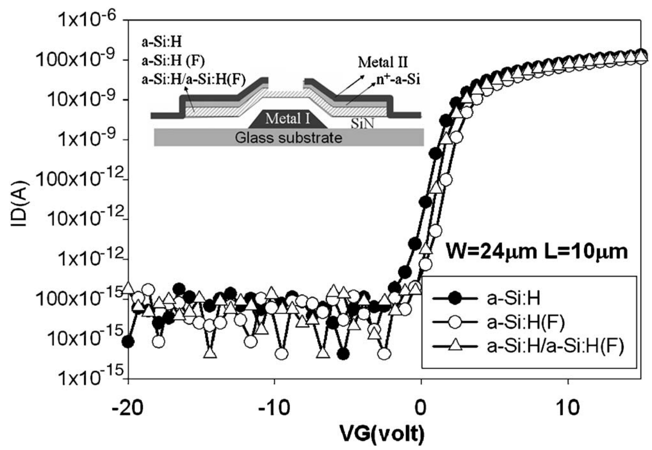

FIG. 1. Dark transfer characteristics of a-Si:H, a-Si:H(F) TFTs, and double channel layer structure TFTs. The inset shows the structure of BCE inverted-staggered TFT devices with a-Si:H, a-Si:H(F), and double channel layer.

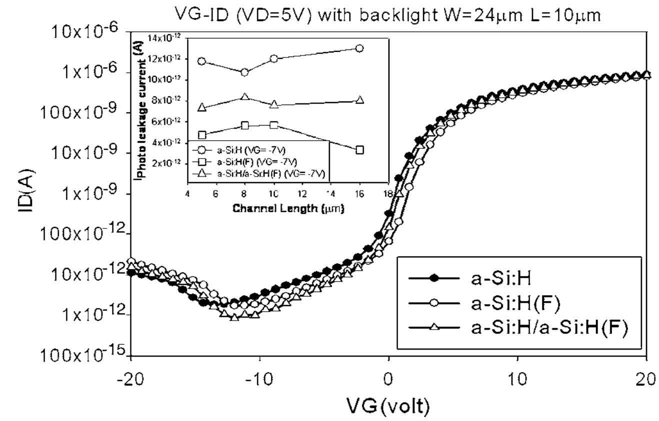

FIG. 2. Comparison of transfer characteristics between a-Si:H, a-Si:H(:F) TFTs, and double channel layer TFTs under light illumination. The inset shows the magnitude of photo-leakage-current at V_G=−7 V with different channel lengths.

TFT channel region would to be etched off using the source/drain pattern as a mask, after the electrodes are formed for TFTs. In order to decrease the device degradation of a-Si:H(:F) layer, the a-Si:H/a-Si:H(F) double channel layer structure was also fabricated for this study. The thicknesses of a-Si:H and a-Si:H(F) in double layer structure were 40 and 160 nm, respectively. The channel length of TFT devices varied from 5 to 16 μm and the channel width was kept constant 24 μm. Similarly, the conventional a-Si:H TFTs without gas mixture of SiF_4 were also fabricated as a reference sample. The photo-leakage-current measurement was carried by light illumination from the back side of substrate to compare the difference in the off-state photo-leakage-currents between the a-Si:H(:F) TFT and the conventional one. The intensity of cold cathode fluorescent lamp backlight source was fixed at 3300 cd/m^2.

After a complete TFT manufacture process, the characteristics of the a-Si:H TFT demonstrated the field effect mobility ranging from 0.43 to 0.64 cm^2/V s, the minimum subthreshold swing from 0.58 to 0.59 V/decade, and the I_{on}/I_{off} ratio is 10^6 at V_D=10 V. The threshold voltage was distributed from 2.02 to 2.08 V, determined from turn-on current (I_{on}) extrapolation in the linear region of I_D-V_G curve at V_D =0.1 V. The a-Si:H(:F) TFT demonstrated the field effect mobility from 0.35 to 0.58 cm^2/V s, the minimum subthreshold swing from 0.65 to 0.67 V/decade, and the threshold voltage from 2.57 to 3.99 V. In contrast, the double channel layer TFT demonstrated the field effect mobility from 0.38 to 0.60 cm^2/V s, the minimum subthreshold swing from 0.59 to 0.62 V/decade, and the threshold voltage from 2.14 to 2.36 V. Figure 2 shows the comparison of the transfer characteristics between a-Si:H, a-Si:H(:F), and double channel layer TFTs under backlight illumination. As shown in the comparison, the off-state photo-leakage-currents of a-Si:H(:F) TFTs and double channel layer TFTs are smaller than those of conventional a-Si:H TFTs in the DOS limited region. It is also because the a-Si:H TFT under backlight illumination was in the nonequilibrium state ($pn > n_i^2$). As a result, the trap states played the role of recombination centers. The photo-leakage-current of a-Si:H(:F) TFT operated in the small negative gate voltage (V_G>−10 V) and 5 V drain voltage is less than 60% of conventional a-Si:H TFTs. Because the electric field is not large enough to separate the photoinduced electron-hole pairs, the increased density of states serving as recombination centers in a-Si:H(:F) channel material has resulted in the lower photo-leakage-current. However, with the hole conduction region (V_G<−10 V), the larger photo-leakage-current was observed. According to previous study,[6] the larger off-state photo-leakage-current is due to the faster hole channel accumulation in the larger negative gate voltage. The smaller hole accumulated voltage also indicated that the undoped a-Si:H(:F) shows near p-type-like behavior. Typical a-Si:H is n-type material even though the Fermi level lies near the midgap of undoped a-Si:H because the electron mobility is at least ten times higher than that of hole.[6] The undoped a-Si:H(:F) TFTs have shown larger threshold voltage and smaller field effect mobility. The double channel layer TFTs also indicated that the lower photo-leakage-current was not simply resulted from the shift of threshold voltage. A reasonable explanation is the shift of the Fermi level toward the valence band. The increase in the threshold voltage may originate from the increase of the defect density by F incorporation and lead to a resultant Fermi level shift toward the valence band edge.[6] The Fermi level of a-Si:H is determined from the charge neutrality condition. Some trap states within the band gap are charged positively and other states are negatively charged by the same amount. The a-Si:H(F) TFT with F incorporation has shown the larger threshold voltage and lower field mobility than conventional counterpart. In order to make sure the increase of acceptorlike state in a-Si:H(F) channel material, the activation energies (E_a) of a-Si:H(F) TFTs and conventional a-Si:H TFTs were extracted from varied temperature measurement in the temperature range from room temperature to 125 °C.[14,15] As shown in Fig. 3, the E_a of the a-Si:H(F) and double channel layer TFTs are larger than conventional a-Si:H TFTs. At V_G=0 V, the Fermi level E_F of a-Si:H TFT is situated below about 0.49 eV from the conduction band edge E_C. However, the Fermi level E_F of a-Si:H(F) TFT is situated below about 0.63 eV from the conduction band edge E_C. The Fermi level E_F of double channel layer structure TFT is situated below about 0.82 eV. This value indicates that in a-Si:H(F) channel, the density of the donorlike defect states is reduced than the density of the acceptorlike defect states. Also, the a-Si:H(F) TFT behaves as a similar p-type property com-

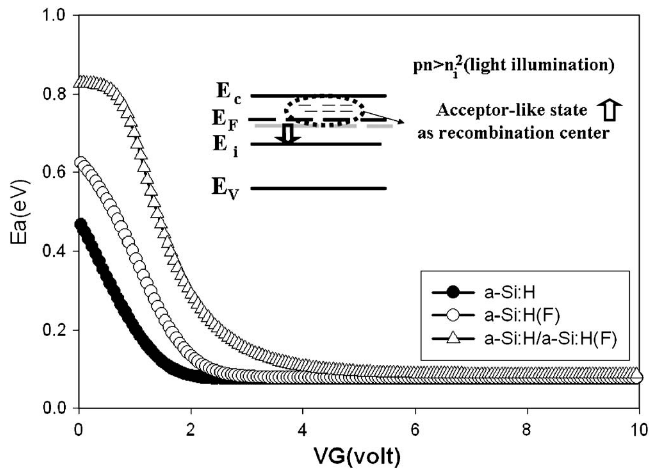

FIG. 3. Extracted activation energy E_a for the *a*-Si:H(F) TFT and conventional *a*-Si:H TFT. The inset shows the mechanism of DOS as recombination centers under backlight illumination.

pared with the *a*-Si:H TFT and results in the little electrical degradation with F incorporation. The correlation between the DOS and the gate voltage allows obtaining the distribution of the density of states by studying the dependence of E_a vs V_G. Globus *et al.*[16] proposed a method to evaluate DOS in *a*-Si:H TFTs through the dependence of E_a vs V_G.

The distribution of density of states $g(E_a)$ was estimated from Fig. 3 with the slope of E_a-V_G curve. The acceptorlike states are nearly about 5×10^{16} and 1×10^{17} cm^{-3} eV^{-1} for both the *a*-Si:H and the double channel layer TFT. Furthermore, the Fermi level is shifted through these states during the operation of TFT devices in the subthreshold region. The additional deep states have been found in the *a*-Si:H(F) TFT and the double channel layer TFTs. These additional deep states in *a*-Si:H(F) TFT thereby resulted in lower photo-leakage-current compared to the *a*-Si:H TFT, and illustrated by the inset of Fig. 3. The double channel layer TFTs have shown the less degradation on device characteristics. These results also indicated the slight degradation on *a*-Si:H(F) TFT. The increase of acceptorlike deep state in *a*-Si:H(F) material leads to slight electrical degradation on *a*-Si:H(F) TFTs and results in the shift down of Fermi level.

We have fabricated *a*-Si:H(F) and the double channel layer TFTs in which the *a*-Si:H(F) layer was deposited with the ratio of 6% SiF_4 into silane plasma. The *a*-Si:H(F) TFTs have shown the better characteristic against photoillumination, resulted from the increase of acceptorlike deep states in *a*-Si:H(F) material. The double channel layer TFTs have shown the less degradation on device characteristic and the lower photo-leakage-current. The incorporation of F in *a*-Si:H channel material, however, appears to shift the Fermi level toward the valence band edge due to the increase of acceptorlike deep states in *a*-Si:H(F) material. This makes the *a*-Si:H(F) TFT trend to *p*-type conduction. Since a smaller voltage is required for hole accumulation, the larger photo-leakage-current is observed with the increase of negative V_G. These results indicated that *a*-Si:H TFT with F doping could reduce the photo-leakage-current ($V_G > -10$ V) due to the increase of acceptorlike deep states as recombination centers in *a*-Si:H(F) material.

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