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Short Communication

Mechanical bending effect on the photo leakage currents characteristic of amorphous silicon thin film transistors

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ABSTRACT

The photo leakage current (I_{PLC}) characteristic of a-Si:H TFTs under different bending strains has been studied. The larger I_{PLC} of a-Si:H TFTs under the outward bending strain is due to larger conductivity of a-Si:H, stemmed from the shift up of Fermi level (E_F). Experimental results show the I_{PLC} of a-Si:H TFTs under the outward bending strain is larger than that of flattened and inward bending a-Si:H TFTs in the density of states (DOS) limited region, stemmed from the lower recombination centers present in outward bending a-Si:H material. Furthermore, the extracted smaller activity energy (E_a) of a-Si:H TFTs under the outward bending strain also confirmed the shift of E_F.

1. Introduction

a-Si:H TFTs have been widely used as switching device of AMLCD. Recently, a portable communication system is spotlighted such as electronic paper, smart labels [1]. For these applications, the traditional glass substrate of large-area electronics must be replaced with flexible and light-weighted substrates [2]. Except for the substrates, the electrical characteristic is also a critical issue for a-Si:H TFTs. The main objectives for flat panel display application are to enhance the field-effect mobility and to reduce the off-state leakage current under back light illumination [3]. Furthermore, for flexible display application, display panels are required to sustain a certain degree of bending. Bending effect would induce strain in the electronic circuits and may affect TFT device characteristics. According to previous studies [4,5], the change in the resistance of a-Si:H was found as a function of strains. However, the lack of long-range order should attenuate any piezoresistive effect. As a result, the transport mechanisms specific to a-Si:H would not apply to single crystal silicon [6,7]. The electrical characteristic of mechanical bending effect has been reported by Gleskova and Won et al. [8,9]. Won et al. reported that both the threshold voltage (V_{th}) and the mobility increase under the tensile stress, while V_{th} increases and mobility decreases under the compressive stress [8]. The I_{PLC} characteristic of a-Si:H TFTs under different bending strains, however, has not been reported yet. In this paper, the I_{PLC} characteristic of a-Si:H TFTs under different bending strains was investigated.

2. Experimental

Inverted–staggered a-Si:H TFTs with back-channel-etched structure were fabricated on a 50 μm thick polyether-sulphone (PES) plastic substrate at the maximum process temperature of 150 °C, as shown in Fig. 1. The device fabrication process was as follows. After a 200 nm-thick Cr gate electrode was deposited and patterned on the plastic substrate, a 300 nm-thick silicon–nitride, a 200 nm-thick a-Si:H active layer, and a 50 nm-thick n^+-a-Si:H layer were subsequently deposited by plasma enhanced chemical vapor deposition (PECVD) method. Finally, a 300 nm-thick Al source/drain electrode was deposited and patterned. The n^+-a-Si:H layer in the TFT channel region was etched with the source/drain pattern electrodes as the mask. The channel length of TFT devices was fixed at 5 μm and the channel width was fixed at 50 μm. The a-Si:H TFTs demonstrated the field-effect mobility with 0.1 cm^2/V s, the subthreshold slope with 0.93 V/dec, the

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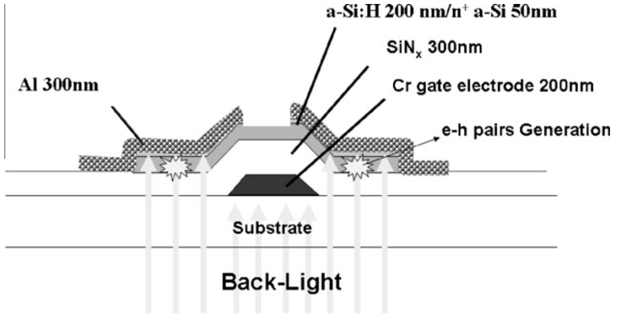

Fig. 1. The illustration of the e–h pairs generation region and the inverted–staggered bottom gate TFT structure.

threshold voltage (V_{th}) with 5.52 V (extracted from the linear I_D–V_G plot, where the V_{DS} = 0.1 V), and the I_{ON}/I_{OFF} ratio of $\sim 10^6$ at V_{DS} = 10 V. The leakage current through the gate insulator is less than 10^{-13} A. The four devices were measured and reversible changes in the TFT transfer characteristics were observed in this study.

The a-Si:H TFTs were mechanically strained at the radius of 10 mm. Inward (outward) cylindrical bending produces the compressive (tensile) strain, by definition negative radius Rn (positive radius Rp). The strain in the top surface was estimated about ±0.09% [8]. The I_{PLC} measurement was carried by light illumination from the back side of substrate to compare the difference in the off-state I_{PLC} between the different bending strains. The intensity of cold cathode fluorescent lamp (CCFL) back light source was fixed at 3300 cd/m^2.

3. Results and discussion

Fig. 2 shows the comparison of a-Si:H TFT transfer characteristics under different bending strains in the back light illumination. The off-state I_{PLC} of a-Si:H TFT with the inward bending strain is similar to the flattened a-Si:H TFT in the DOS limited region. However, the off-state I_{PLC} of a-Si:H TFTs with the outward bending strain has shown larger I_{PLC} characteristic than that with the flattened a-Si:H TFTs in the DOS limited region. According to our previous study [10], the channel sheet conductance has shown the variation under different mechanical bending strains. The variation under mechanical bending strains is originated from the evolution of defect state density in a-Si:H channel material. Because a-Si:H TFTs under the back light illumination were in the non-equilibrium state ($pn > n_i^2$), the trap states played the role of recombination centers. The similar I_{PLC} between the flattened and inward bending a-Si:H TFTs was resulted from the low fabrication process temperature (150 °C), and the larger DOS has been created during the low process temperature. As a result, the electric field is not large enough to separate the photo induced electron–hole pairs in the negative gate voltage region and V_{DS} = 10 V. However, the I_{PLC} of outward bending a-Si:H TFTs operated in the same condition is 50% larger than the I_{PLC} of the flattened and inward bending a-Si:H TFTs. Because the decrease of recombination centers in a-Si:H channel material, the larger I_{PLC} of outward bending a-Si:H TFTs has been observed in the DOS region. Furthermore, the V_{th} of different mechanical strains on a-Si:H TFTs has also observed in Fig. 2. The larger V_{th} of the inward bending a-Si:H TFT was also indicated that the larger DOS in the a-Si:H channel material. Oppositely, the smaller V_{th} of the outward bending a-Si:H TFT was due to the smaller DOS. Thus, a reasonable explanation is the shift of the E_F. The increase of V_{th} may originate from the increase of defect density by inward bending strain and lead to a E_F shift toward the valence band edge [11]. Because the E_F of a-Si:H is determined from the charge neutrality condition. Some trap states within the band gap are positively charged and other states are negatively charged by the same amount. a-Si:H TFTs under the inward bending strain have shown the larger V_{th} and decrease on current I_D than those of flattened and outward bending a-Si:H TFTs, as shown in Fig. 2. In order to make sure the increase of DOS in a-Si:H channel material, the E_a of a-Si:H TFTs under different bending strains was extracted from varied temperature measurement in the temperature range from room temperature to 125 °C [12]. As shown in the inset of Fig. 3, the E_a of flattened and outward bending a-Si:H TFTs are larger than inward bending a-Si:H TFTs. At V_G = 0 V, the E_F of flattened and inward bending a-Si:H TFT are situated below about 0.72 eV and 0.75 eV from the conduction band edge E_C, respectively. However, the E_F of outward bending a-Si:H TFT is situated below about 0.5 eV from the conduction band edge E_C. The small E_a of a-Si:H TFT under outward bending also resulted in the larger conductivity and increased the I_{PLC}.

The distribution of DOS $g(E_a)$ was estimated from the inset of Fig. 3 with the slope of E_a–V_G curve [13]. The DOS are nearly about 3.08×10^{16} cm^{-3} eV^{-1} and 3.51×10^{16} cm^{-3} eV^{-1} for both the flattened and the inward bending a-Si:H TFTs near the deep state region. Furthermore, the DOS is nearly about 2.81×10^{16} cm^{-3} eV^{-1} for the outward bending a-Si:H TFT near the deep state region. Thus, the smaller E_a of outward bending a-Si:H TFT also indicated the less DOS in the a-Si:H channel material. As a result, the larger I_{PLC} of outward bending a-Si:H TFTs has been observed in Fig. 2.

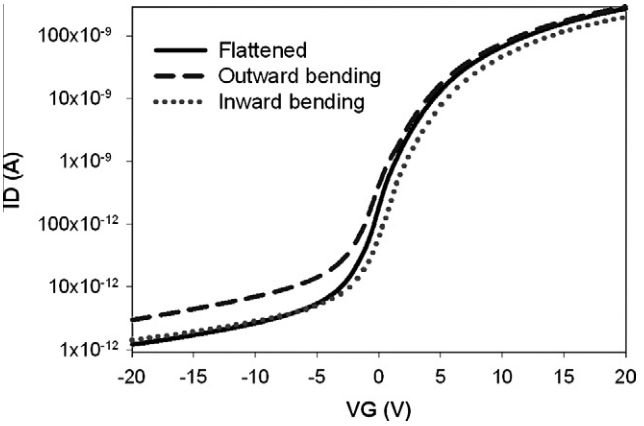

Fig. 2. The comparison of I_{PLC} characteristics between a-Si:H TFTs under different mechanical bending strains (W/L = 50 μm/5 μm).

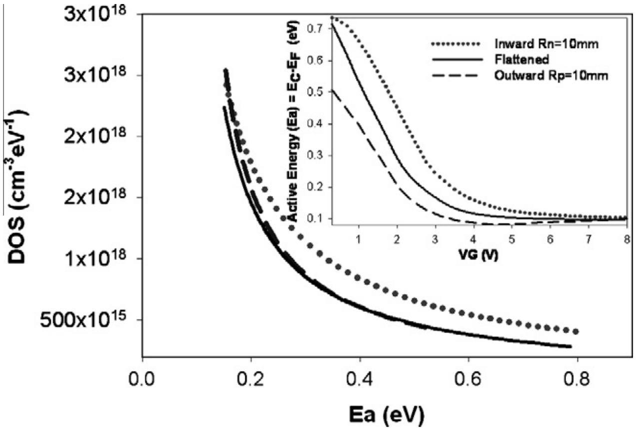

Fig. 3. The extracted distribution of DOS for the a-Si:H TFT under different strains and the inset showed the E_a in different strains.

Furthermore, the inward bending a-Si:H TFTs also demonstrated the higher DOS distribution from the E_C to $E_{F,}$ as shown in Fig. 3.

4. Conclusion

The larger I_{PLC} of a-Si:H TFTs under the outward bending strain is due to larger conductivity of a-Si:H, stemmed from the shift up of E_F. The outward bending strain in a-Si:H channel material, however, appears to shift the E_F towards the conduction band edge due to the decrease of DOS in a-Si:H material. Furthermore, the inward bending a-Si:H TFTs have shown the similar I_{PLC} characteristic to the flattened a-Si:H TFTs due to the large DOS created during the low temperature fabrication process. Although the decrease of DOS has resulted in the better device characteristic, it also resulted in the large off-state I_{PLC}.

Acknowledgements

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References

[1] Baeuerle R, Baumbach J, Lueder E, Siegordner J. SID'99 Dig 1999; 14–7.
[2] Gleskova H, Konenkamp R, Wagner S, Zhang Q, Shen DS. IEEE Electr Dev Lett 1996;17:264–6.
[3] Yoon JK, Jang YH, Kim BK, Choi HS, Ahn BC, Lee C. J Non-Cryst Solids 1993;164–166:747–50.
[4] Minomura S, Drickamer HG. J Phys Chem Solids 1962;23:451–6.
[5] Spear WE, Heintze M. Philos Mag B 1986;54:343–58.
[6] Menard E, Nuzzo RG, Rogers JA. Appl Phys Lett 2005;86(9):093507.
[7] Zhu ZT, Menard E, Hurley K, Nuzzo RG, Rogers JA. Appl Phys Lett 2005;86(13):133507.
[8] Won SH, Chung JK, Lee CB, Nam HC, Hur JH, Jang J. J Electrochem Soc 2004;151(3):G167–70.
[9] Gleskova H, Hsu PI, Xi Z, Sturm JC, Suo Z, Wagner S. J Non-Cryst Solids 2004;338–340:732–5.
[10] Wang MC, Chang TC, Liu PT, Tsao SW, Chen JR. Electrochem Solid-State Lett 2007;10:J49–51.
[11] Spear WE. J Non-Cryst Solids 1983;59–60:1–13.
[12] Schropp REI, Snijder J, Verwey JF. J Appl Phys 1986;60:643–9.
[13] Globus T, Slade HC, Shur MS, Hack M. Mat Res Soc Proc 1994;336:823.