Effect of Mechanical Strain on the Electrical Performance of Flexible LTPS Thin-Film Transistors

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ABSTRACT

In this work, the effects of external mechanical strain on the device performance and instability of flexible LTPS TFTs were studied. The field effect mobility increases by 10% due to an increases compressive strain to -0.38%, while mobility decreases by -1.7% with the increases in tensile strain of 0.67%. The reasonable arrangement of the strain direction and channel shape of drive TFT can be used to build robust LTPS backplane for flexible displays.

1. INTRODUCTION

Flexible active-matrix organic light-emitting diode (AMOLED) displays have gained much attention due to their thinness, lightness, and durability, along with their adaptability to arbitrarily shaped surfaces compared to the conventional rigid displays. Flexible displays experience external mechanical strain with a small radius of curvature, especially curved and foldable displays, and therefore a great deal of research has been devoted to the characteristics and reliability of the strained thin film transistors (TFTs). When compared to amorphous silicon, oxide-based, or organic TFTs, Low Temperature Poly-Silicon (LTPS) TFTs have attracted much attention, since they combine the beneficial characteristics such as high carrier mobility, good stability, and easy implementation into CMOS architectures and virtual reality applications [1-3].

In this paper, the electrical performance and stability of flexible substrate based LTPS TFTs under various strain conditions were studied. By measuring and analyzing the impact of strain direction and channel shape on the TFT characteristics, we suggested the optimum flexible TFT array design rule.

2. EXPERIMENT

Polymer film was prepared on glass with coating and thermal curing. Then, a conventional LTPS process sequence was performed to fabricate TFT backplane. First, a stack buffer layer SiN_x and SiO_2 was deposited by plasma-enhanced chemical vapor deposition (PECVD), followed by 45 nm thickness a-Si deposition. The a-Si was crystallized by XeCl excimer laser beam (λ = 308 nm). A gate insulator (GI) was deposited using the PECVD. Gate metal was sputtered, patterned, and then followed by the p+ implantation through a self-aligned doping process. After a dielectric material deposition, contact holes were patterned, the deposition of source/drain metal and subsequent patterning to form electrodes followed. Finally, the PI film were detached from the carrier glass substrate.

Flexible TFT stack was placed and fastened on inner or outer bending jigs with 1, 3, 5, 10 and 15 mm radii, the corresponding strain value was obtained through simulation shown in Figure 1(d) and 1(e). The electrical properties of the TFTs were evaluated under dark conditions using an Agilent B1500A semiconductor parameter analyzer.

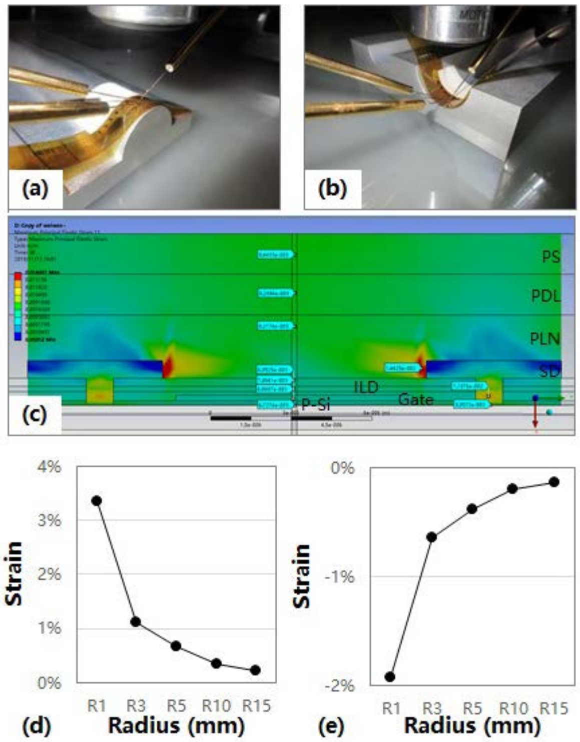

Fig. 1 Bending jigs with 1, 3, 5, 10, and 15 mm radii of curvature for the application of different degrees of compressive/tensile strain to the TFTs.

3. RESULT AND DISCUSSION

3.1 IV characteristics under mechanical strain

Figure 2(a) and (b) show the transfer and output characteristics of the LTPS TFTs under flat and 0.26%, 0.72% external tensile mechanical strain, respectively. It is obviously seen that the transfer characteristics and output current of the TFT are degrading rapidly along with the tensile strain. The drain current was degraded −56% for the 0.72% tensile strain. The electrical characteristics degradation of drive TFTs may cause poor display performance.

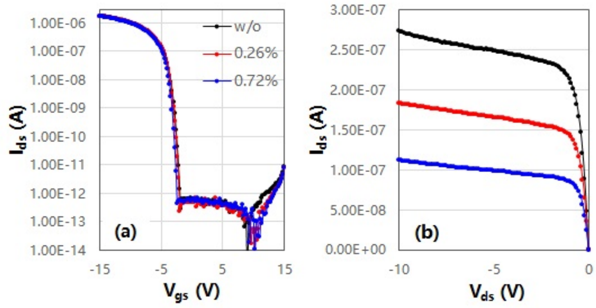

Fig.2 (a) Transfer characteristics, and (b) Output characteristics of the LTPS TFTs under various degree of tensile mechanical strain.

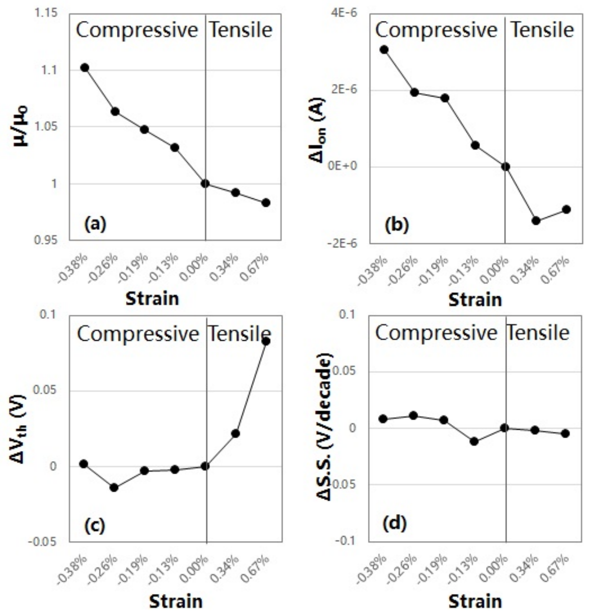

Fig.3 Device parameter variation of the (a) normalized field effect mobility, (b) on-state current, (c) threshold voltage, and (d) sub-threshold slope.

Figure 3 demonstrates the variances in the (a) normalized field effect mobility (μ) (b) on-state current (c) threshold voltage (Vth) and (d) sub-threshold swing of the TFTs as functions of bending strain， which mechanical strain direction is parallel to the I_{ds} current path. As shown in figure 3(a), the hole mobility increases by 10% due to an increased compressive strain of -0.38%, while it decreases by -1.7% with the increasing in tensile strain of 0.67%. The threshold voltage degrade through a positive V_{th} shift ~0.1V under the tensile strain, while being kept unchanged under compressive strain. The positive V_{th} shift under strain is usually due to the gate insulator (GI) defects induced by mechanical strain and followed by the electron trapping [4]. In addition, the sub-threshold swing degradation was not observed in our experiment both for compressive and tensile mechanical strain, which indicated that the interface state was kept unchanged and the effects of lattice torsion and carrier effective mass change caused the filed effect mobility varying through the mechanical strain [5].

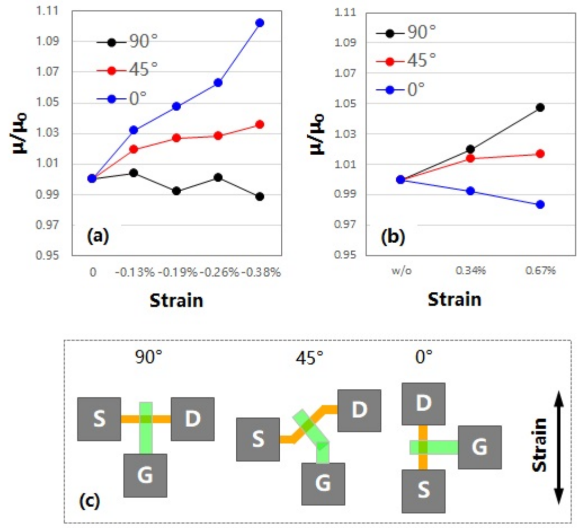

Fig.4 The direction dependence of the field effect mobility under (a) compressive strain, (b) tensile strain.

As shown in Figure.4(c), the strain direction was marked as that the 0 degree means parallel to the I_{ds} current path and the 90 degree means perpendicular to the I_{ds} current path. As seen in the figure 4, the normalization mobility change dramatically depending on the strain directions. Figure 4(a) shows that the mobility increasing with compressive strain at 0 degree, while it's suffer slightly decreasing with strain in the 90 degree direction, the TFT performance under 45 degree strain is in between. Contrary to the compressive strain, tensile strained-TFTs shows mobility increasing in 90 degree and decreasing in 0 degree situation. This results do add to accumulating evidence that the mobility enhance coming from the effects of lattice torsion and carrier effective mass change, which is known as depend on the orientation of silicon crystal [6]. The angle between the I_{ds} current path and the strain direction can be designed to ensure a consistent pixel current in the whole panel.

Table 1. Mobility and simulated OLED current change under 0.37% tensile strain.

Channel Shape	*Δμ/μ₀*	*Simulated ΔOLED Current*		
		Low Gray	**Medium Gray**	**High Gray**
Line	-1.42%	0.61%	0.28%	0.08%
Square	0.47%	-0.17%	-0.08%	-0.03%
Ring	-0.22%	0.09%	0.04%	0.02%
Omega	-0.40%	0.16%	0.07%	0.03%

For the purpose of the improvement of mobility instability of the mechanical stained-TFTs, we designed different shapes of poly silicon channel and tested its electrical characteristics, as shown in Figure 5. Compare to the 1.42% mobility decreasing of the line shaped TFTs, the omega shaped TFTs shows less mobility change, which is about -0.4% with 0.37% tensile stain. Moreover, the omega shaped TFTs has less mobility change under the compressive strain.

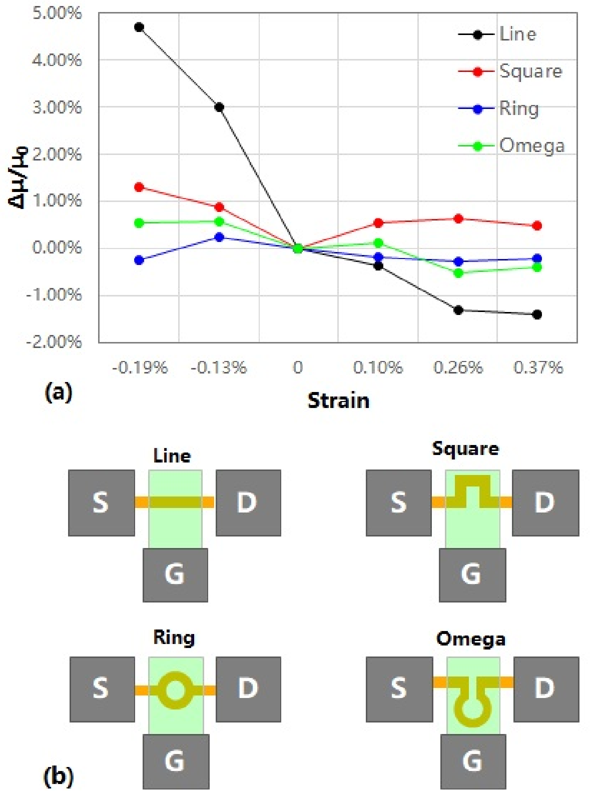

Fig.5 Normalized field effect mobility variation under the compressive and tensile strain on the line, square, ring, and omega channel shape TFTs.

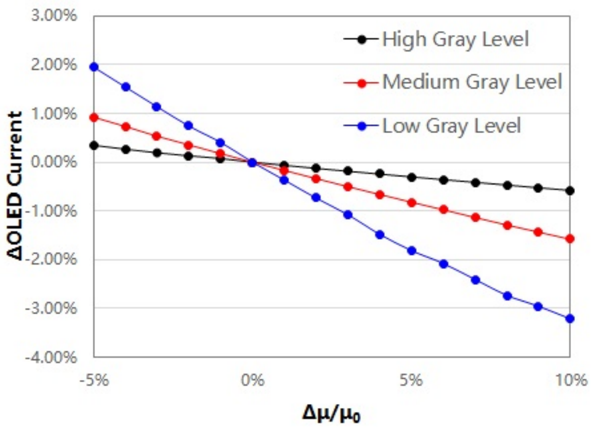

Fig.6 The variation of simulated OLED current versus mobility for high, medium, low gray level.

3.2 Organic light emitting diode (OLED) emission currents spice simulation

Figure 6 show the spice simulation of the OLED emission currents of stained TFTs for high, medium, low gray levels. Spice simulation was done based on the conventional 7T-1C LTPS pixel circuit. The biggest change is at the low gray level, where 4.76% decrease of the OLED current with the 10% increase of field effect mobility. At the low gray level, it is shown that the emission current of the proposed omega shaped TFTs is slightly increasing with an average value of 0.16% compared with that of the line shaped TFT with an average value of 0.61%, that induced by the mobility changes under the same 0.37% tensile strain. Therefore, the proposed omega shaped channel has high immunity to variation in LTPS TFT characteristics with external mechanical strain and to the degradation of OLED.

4. CONCLUSIONS

We investigated the performance of LTPS TFTs under the static mechanical strain with tensile and compressive directions. The field effect mobility increases or decreases depending on the strain direction and channel shape. Spice simulation results show that the Omega shaped TFTs can effectively reduce the OLED current variation, which can be adopted in the flexible display layout design.

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