LTPS technology for improving the performance of AMOLEDs

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ABSTRACT

The increase of repetition rate, the dithering of laser optics, and the extension of pulse duration time are major approaches in improving the picture quality of AMOLEDs fabricated by excimer laser crystallization (ELC). Advanced solid phase crystallization (ASPC) has been developed to improve the uniformity and the process cost. Even though the mobility of ASPC-TFT is lower than that of ELC-TFT, it is high enough to drive AMOLED pixels.

1. Introduction

Active-matrix organic light emitting diode display (AMOLED) is considered as a strong candidate for the next generation flat panel display due to its superiority in the performance, such as fast response time, higher contrast ratio, better color gamut, wide viewing angle, and so on. Many companies have been paid efforts to launch AMLOLED products to the market. However, volume productions are much slower than expected. The short lifetime of OLED was a critical barrier in going forward to volume productions. Even though the lifetime has been improved to be adaptable for some mobile applications, it needs to be improved much more for the adoption to various applications. Furthermore, since the applications are overlapped with those of AMLCDs, system makers tend to compare the performance and the cost between two technologies. If AMOLED manufacturers cannot meet the requirements in terms of both performance and the cost, it would be difficult to expand market volume in large scale. AMOLED makers are struggling to enhance the lifetime of OLEDs and to increase the manufacturing yield that affects the cost seriously.

Excimer laser crystallization (ELC) has been used for the mass production of AMLCDs since 1996, and poly-Si TFT device based on ELC is fully improved and optimized for mass-production of AMLCDs[1]. We have also stabilized low temperature poly-silicon TFT technology based on ELC for manufacturing AMLCDs with forth-generation glass size and have been using the same facility to develop and manufacture AMOLEDs. Even though we have achieved high yield in manufacturing the AMLCDs of high pixel densities, the yield for AMOLED was much lower. In addition, there were some quality issues caused by the characteristics of LTPS TFTs.

In this paper, the back plane technology will be discussed for the improvement of quality and cost. The uniformity of excimer laser-crystallized poly-Si TFTs is one of the most critical issues in achieving high yield because the system makers will not allow unevenness of displays. We have improved the performance of ELC LTPS TFTs through the optimization of laser equipment and TFT process. In addition, advanced solid phase crystallization (ASPC) process has been developed to solve the uniformity problem and improve the cost competitiveness.

2. ELC Technology

Differently from AMLCD pixels, the light intensity of each pixel in an AMOLED is very sensitive to the characteristics of driving transistors and bias conditions in the pixel circuits[2]. Therefore, various problems occur due to the fabrication process and the device performance. Among the problems, the periodic line dim is a very serous issue when ELC is used for the fabrication of TFTs in the pixels. Two typical patterns can be observed in AMOLEDs of which pixels consist of two transistors and one capacitor as shown in figure 1. One pattern is parallel with laser beam (laser beam direction) and the other is vertical with laser beam (laser scanning direction). TFTs are measured along the laser beam direction and the laser scanning direction to analyze the relationship between line dim and the device characteristics. The variations of the threshold voltage and the mobility are so large that they could provoke the line dims.

Figure 2 (a) and figure 2 (b) show the variations of the drain source current of TFTs along the direction of laser beam and along the direction of laser scan, respectively. Since the patterns match precisely with the directions of the laser beam and the laser scan, we can conclude that the variations are originated from laser. It can be also concluded that the variation along the laser scan comes from the fluctuation of excimer laser energy during the exposure and scan. The variation of TFTs along the laser scan can be explained as the laser energy variation along the long axis of a laser beam. The energy variation is caused by the defects in the homogenizer that makes uniform square beam profile from Gaussian or circular laser source.

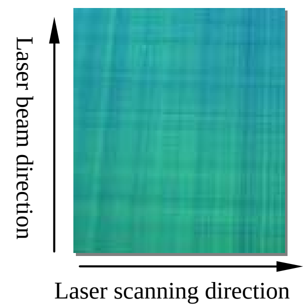

Figure 1. Typical patterns of laser beam direction and scanning direction.

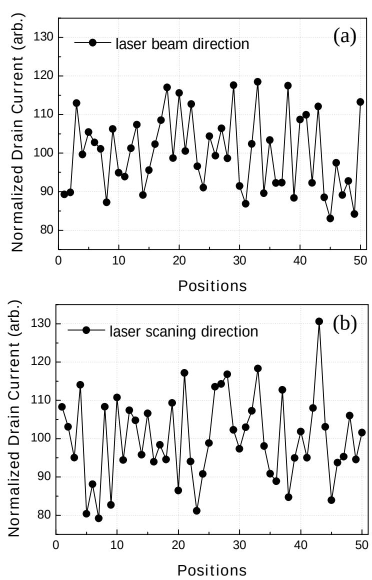

Figure 2. Local drain source current along the direction (a) laser beam direction, (b) laser scanning direction.

In order to solve the unevenness of TFTs, various compensation methods have been developed [3-7]. However, every method has pros and cons. Taking into account of the cost and the scalability of display size, a voltage driving method is most preferable. We have tried to improve the laser crystallization process and the laser equipment through the collaboration with equipment makers to improve the yield of AMOLEDs. The equipment companies also have made progress for past a few years. First of all, laser source has been improved so that the pulse energy has become more stable than before. In addition, laser optics has been also improved.

The extension of pulse duration is also helpful to improve the uniformity, because it can ensure the enough time for recrystallization[8]. The normal pulse duration time is 30nsec. Pulse duration time has been elongated by two and four times in this experiment. Figure 3 shows the results of crystallization according to pulse duration time of 1X, 2X, and 4X extension. Normal and 2X results are similar but the grain size has increased in case of 4X. While the optimal energy regions for TFTs are narrow in the case of in the case of 1X and 2X, the grain size and the acceptable energy margin for 4X have increased. It means that both device performance and uniformity can be improved by the adoption of 4X laser source. In case that there are some fluctuations in the energy density, the variation of TFT characteristics can be smaller by the 4X system. Figure 4 shows the comparison of AMOLED images between normal pulse duration and four times pulse extension. The line dim is much weeker in the panel fabricated with four times extension.

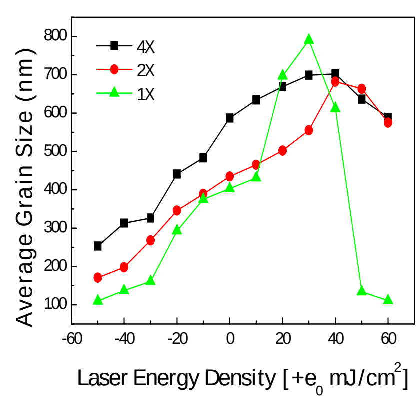

Figure 3. Grain size according to energy density.

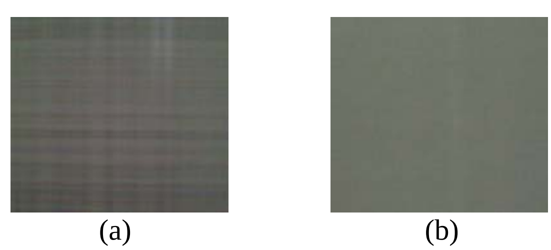

Figure 4. AMOLED display images with the pulse extension of (a) 1X (b) 4X.

The next approach is to increase of the pulse-to-pulse overlapping ratio. The uniformity can be improved by the averaging effect that the current variation can be decreased if more pulses are exposed in the channel of a TFT[9]. The drain source current variations are measured according to the overlapping ratio as shown in figure 5. As increasing the overlapping ratio, the uniformity has been improved very much along the laser scanning direction as expected. In addition, there is the improvement along the direction of laser beam. The four-time pulse duration was used for this evaluation.

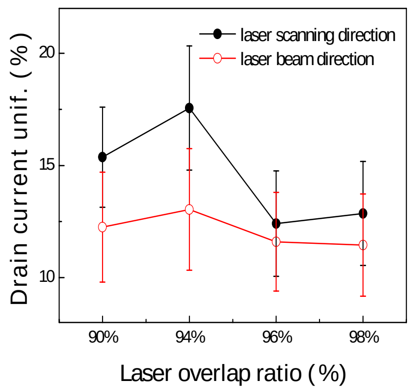

Figure 5. Local drain source current uniformity on various laser overlap ratio using four-time pulse duration time.

3. SPC Technology

We have found that ELC and voltage compensation technology can acceptable for the mass production due to the improvement of laser crystallization process and equipment. The uniformity of TFTs has been improved, which results in higher yield to meet the requirement of screen performance. However, the increase of laser overlapping ratio increases the cost for laser crystallization process. Therefore, non-laser crystallization has been endeavored to solve the unevenness of ELC TFTs and to reduce the fabrication cost.

A field enhance rapid thermal annealing (FERTA) system has been installed to crystallize a-Si precursor films. The basic concept of this system is utilizing uniform heating and cooling of substrate in combination with rapid thermal annealing and magnetic field to accelerate the crystallization[10]. Figure 6 shows the schematic diagram of FERTA system which consists of multiple RF heating module and one central rapid heating module. Since the temperature is very uniform and glasses pass through RTA zone in short time, the crystallization can be occurred in short time and at high temperature without the glass deformation. Figure 7 (a) and (b) show SEM and TEM images after solid phase crystallization, where the process conditions of FERTA zone are 750℃ of substrate temperature and 5minutes of heating. The grain size is around 500nm and a lot of micro defects intra grains such as twins and residual amorphous phase. The amount and distribution of the micro defects affect the electrical characteristics of TFTs such as mobility, subthreshold slope, threshold voltage, hysteresis, bias stability, and so on.

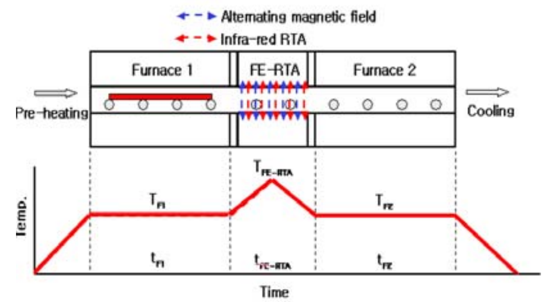

Figure 6. Schematic of FERTA system and temperature profile.

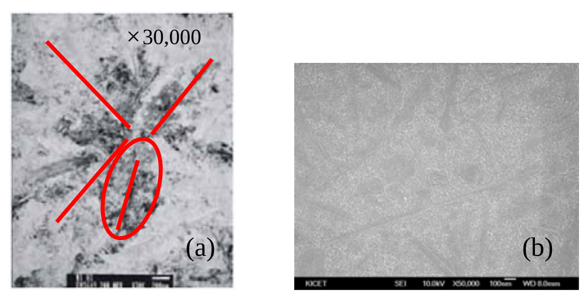

Figure 7. (a) TEM image (b) SEM image of ASPC.

It has been known that the deposition condition of precursor film and the pretreatment before deposition affect crystallinity[11]. Figure 8 shows the results of carrier lifetime analysis and the mobility of ASPC TFTs according to the deposition temperature of the precursor films. Maximum mobility is achieved at the deposition temperature of 270℃.

Figure 9 shows electrical characteristics of TFT as functions of the process time and the temperature. We investigated field effect mobility, because it is considered to be most sensitive parameters to the degree of crystallization. Regarding temperature, there are significant difference between samples processed at 700℃ and 750℃. Higher temperature renders better mobility but the glass deformation occurs seriously above 750℃. The process time is very important in terms of productivity. While about 8,000 glasses can be produced in a month and with one machine with 5 minutes of the process time, only 4,000 glasses can be produced with 10 minutes of the process time. It is good results in terms of productivity that the performance of TFT is not sensitive to the FERTA process time

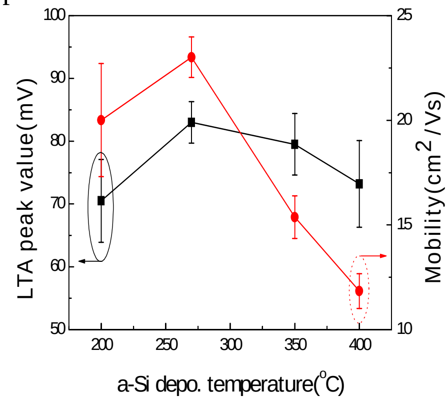

Figure 8. Carrier life time and mobility as a function of deposition temperature.

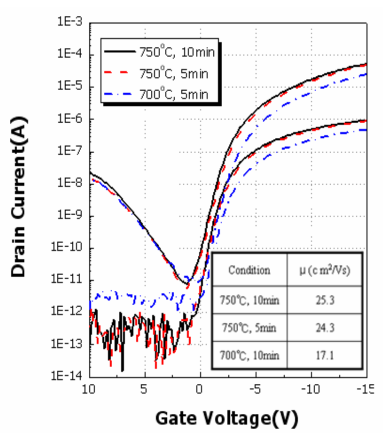

Figure 9. The transfer characteristics of p-TFTs.

4. Fabrication of AMOLED Panel

We have developed 2.4inch p-type AMOLED display employing the advanced SPC process. Ploy-Si TFTs based on ASPC method shows electrical characteristics enough to implement AMOLED panels. Gate driving circuitry and multiplexing circuits as well as pixel circuits can be implemented.

Diagonal Size	2.4 inch (166ppi)
Resolution	240×RGB×320
Luminance	200 nit
Contrast Ratio	> 10,000:1
Color Gamut	70%

(a) (b)

Figure 10. 2.4 inch QVGA AMOLED fabricated by employing ASPC (a) CCD image (b) Specification.

5. Conclusions

ELA method is matured and stable technology for low temperature poly-Si TFT device. Even though the progress in the equipment, the process, and compensation circuits have made it possible to start the production of commercial AMOLEDs, the production cost and the yield should be improved much more in order to compete with AMLCDs in markets.

We have developed an advanced solid phase crystallization technology which can eliminate laser process in the TFT lines. Uniformity of display and low fabrication can be achieved through this technology even though the design margins beccome narrow due to the low mobility and the high threshold voltage. The hysteresis and the bias stability of ASPC TFTs are worse than those of ELC TFTs. These disadvantages can be solved by the compensation technique. ASPC can be a good approach to improve the performance of AMOLEDs, especially for large-sized panels.

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7. Reference

[1] M. Kimura, et al, IEEE Trans.Electron Devices 46, 2282 (1999)

[2] B. K. Kim, et al, Japanese J. of Appl. Phys, 43(4A), L482(2004)

[3] R.M.A Dawson, et al, SID '98 Tech. Dig.,11(1998)

[4] S. H. Hung, W. J. Nam, M. K. Han, SID '02 Tech. Dig., 622(2002)

[5] J. C. Goh, H. J. Chung and C. H. Han, IDW '01 Tech. Dig., 319(2001)

[6] H. Kageyama, et al, SID '03 Tech. Dig., 96(2003)

[7] T. Ouchi, Y. Mikami, T. Satou and N. Kasai, IDW '02 Tech. Dig., 247(2002)

[8] J. Brune, B. Nikolaus, F. Simon, Thin Solid Films 487, 85 (2005)

[9] N. Matsuo, Y. AYA, T. Kanamori, T. Nouda, H. Hamada and T. Miyoshi: Jpn. J. Appl. Phys. 39,351 (2000)

[10] H. J. Kim, D. H. Shin, IMID 2005 665(2005)

[11] Kenji Nakazawa and Keiji Tanaka, J. Appl. Phys. 68(3), 1029 (1990)