Uniformity improvement of SLS poly-Si TFT AMOLED

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Abstract

In this work we attempted to find the origin of brightness non-uniformity in SLS poly-Si TFT AMOLED. By developing a suitable SLS process with a compensation circuit, we have successfully improved the non-uniformity from 40% to 1.7%. We could fabricate 2.2" AMOLED display using SLS poly-Si.

1. Objectives and Background

Sequential lateral solidification (SLS) is a crystallization technique using irradiation of laser beam shaped by a mask on a-Si film. It has been reported that large silicon grains were obtained using SLS method, resulting in high performance TFTs (Thin Film Transistors). [1,2,3,4] In addition, because of using a small laser beam of about tens of millimeters by about a millimeter, it is possible to make LTPS (Low Temperature Polycrystalline Silicon) on large substrates for fabrication of TFTs without any size limitation, compared to the conventional line-beam ELA (Excimer Laser Annealing) method. Due to such advantages, SLS may be one of the best crystallization methods for mass production of flat panel displays that require high performance and reduction of production cost by using large mother glasses.

However, there have been several issues regarding non-uniformity in brightness caused by using laser that has a fundamental limitation in improvement of beam uniformity. In particular, one of the serious brightness non-uniformity problems is that bright and dark regions appear on panel as bands at the same pitch as that of laser scan for SLS process (Figure 1). Such non-uniformity problem should be overcome to apply SLS method to fabrication of AMOLED (Active Matrix Organic Light Emitting Diode) displays that are sensitive to the uniformity of TFT substrate itself rather than that of electrolumiscent material.

Periodicity of non-uniformity in brightness is exactly the same as SLS scan pitch. The arrow indicates the direction and the range of the brightness measurements.

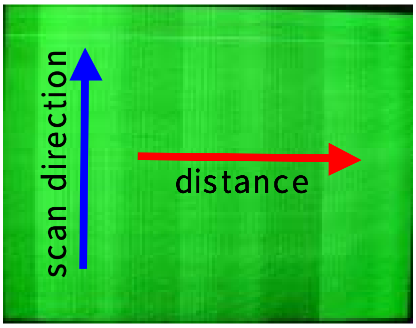

Figure 1. The mono-color image of 2.2" SLS poly-Si AMOLED.

In this work we studied to find the origins of non-uniformity and the solutions to improve the uniformity for AMOLED application. There may be two main factors that can possibly cause the non-uniformity in brightness of AMOLED display. One source for the non-uniformity may be an optical effect in that the same type of non-uniformity is observed on the poly-Si substrate immediately after crystallization using SLS method. One can assume that the 'shot marks' made on poly-Si film by repeating laser irradiation can directly affect the non-uniformity on the display image. To confirm such optical effect due to non-uniform crystallization, we evaluated the brightness distribution between top- and bottom-emission AMOLED displays (Figure 2).

In case the optical effect is the main origin, one can expect more severe brightness non-uniformity for the bottom-emission display in which the light comes out through the glass substrate on which SLS poly-Si is made.

The other factor may be related to the regular variation of SLS poly-Si TFT characteristics depending on position on display image. In that the TFT characteristics such as mobility and threshold voltage are directly affected by the crystallinity or the microstructure of the poly-Si itself, the non-uniformity of TFT output current, if there is any, can appear as non-uniformity in brightness due to the linear relationship between AMOLED brightness and TFT current. To find the origin of the non-uniformity on AMOLED display fabricated by using SLS poly-Si TFTs, we measured the output current of driving TFT for each pixel, and then compared with brightness distribution.

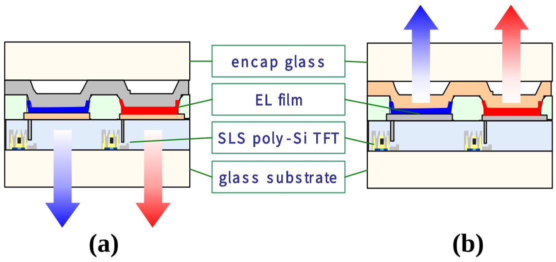

Figure 2. Schematics showing the relative position of SLS poly-Si TFT with respect to the bottom emission AMOLED (a) and the top emission AMOLED (b).

2. Results

Emission characteristics of SLS poly-Si TFT AMOLED were investigated for both bottom- and top-emission types using QCIF 2.2" display panels (Figure 2). The brightness was measured over a length of 30 mm at a pitch of 15mm (Figure 1). The brightness measurements as a function of distance showed very similar trend for both top and bottom emission AMOLED panels. This indicates that the emission type does not significantly affect the non-uniformity in brightness (Figure 3).

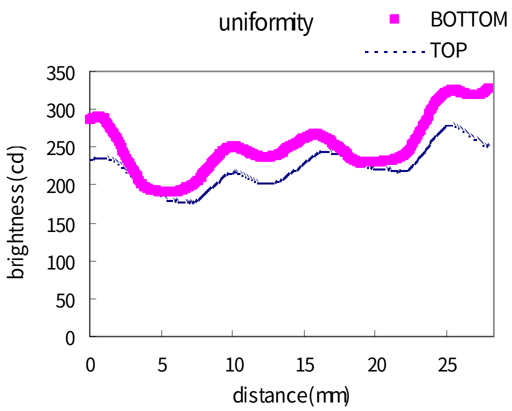

Figure 3. Comparison of brightness between the top- and the bottom-emission AMOLED displays as a function of brightness on the panels, which have been made using SLS poly-Si TFTs.

To investigate whether the non-uniformity in brightness is related to the variation of TFT characteristics, we analyzed the image obtained from SLS poly-Si AMOLED in terms of both driving current and brightness as a function of distance on panel (Figure 4).

After the brightness was measured along the direction represented by an arrow in Figure 1, the measured brightness data were compared with the TFT pixel current in a driving range. One can see that both the brightness and the current vary with the measurement position on panel, having the same periodicity as the SLS scan pitch. The non-uniformity, NU, in brightness or pixel current can be defined as

$$NU = (L_{max}-L_{min})/L_{avg} \times 100\% \quad \text{--- (1)}$$

Where L_{max} = maximum luminance or pixel current
L_{min} = minimum luminance or pixel current
L_{avg} = average luminance or pixel current.

Before any attempt to improve the brightness non-uniformity of AMOLED fabricated by using SLS poly-Si TFTs, the maximum non-uniformity values calculated using equation 1 reached up to 42.6% and 40% for brightness and pixel current, respectively. Such high values in non-uniformity in both brightness and pixel current indicate that there is a strong relationship between the brightness and the TFT characteristics.

Based on our analyses, we have attempted to improve the uniformity of brightness, in particular, by eliminating the periodic non-uniformity caused by SLS poly-Si itself or TFTs made of it. We have found that there are several approaches to eliminate the brightness non-uniformity.

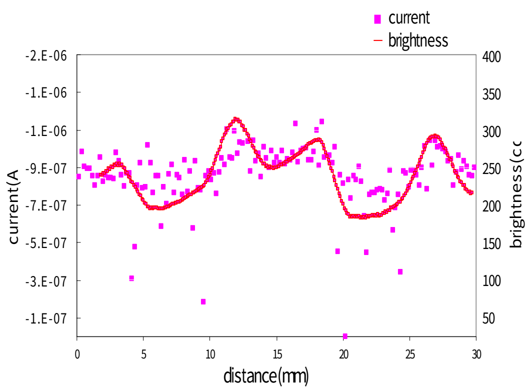

Figure 4. Pixel current and brightness as a function of measurement position on SLS poly-Si TFT AMOLED panel.

One approach is to improve the uniformity of laser beam used for SLS process, which is currently beyond our research scope. The other approach may be to use an extra circuit to compensate the non-uniform image caused by TFT characteristic variation, which is typically used to compensate the image of AMOLED fabricated using ELA (Excimer Laser Annealing) poly-Si. However, for SLS poly-Si TFT, the image non-uniformity was not sufficiently compensated by applying the compensation circuit because the TFT variation of SLS poly-Si TFTs was very large about 40%. Thus to improve the brightness non-uniformity, the TFT variation should be reduced by further optimizing TFT processes or developing optimum SLS process. We could improve the brightness uniformity by a combination of several approaches. In this work, among the approaches we propose one method regarding SLS process itself, assuming that the non-uniformity is caused mainly by the variation of TFT characteristics.

We have observed that the non-uniformity of solidification in the center region of laser beam was much higher than the outside region. And also the non-uniformity appeared to be conspicuous in long direction of the laser beam.

Thus the poly-Si region solidified after the first laser scan in short-direction was partially overlapped in long-direction by the second laser scan, using a specially designed SLS mask. After repeating the same process over the entire silicon film on glass substrate, we could achieve nearly uniform brightness without any laser shot marks on AMOLED panel. Therefore one can conclude that the shot mixing technique can be one excellent approach to eliminate the periodicity of electrical non-uniformity in TFTs.

Figure 5. 2.2" SLS poly-Si TFT AMOLED panel having a brightness non-uniformity of 1.7%.

Using the shot mixing technique, combined with a compensation circuit and optimized TFT processes, we could successfully fabricate 2.2" SLS poly-Si AMOLED panel without any non-uniformity in brightness that human eyes can perceive (Figure 5). On the panel, the measured maximum non-uniformity in brightness was significantly reduced from initially 42% to 1.7%.

3. Impact

In this work we have revealed that the brightness non-uniformity of SLS poly-Si TFT based AMOLED is mainly attributed to the non-uniformity of TFT characteristics.

The brightness non-uniformity could be successfully improved by applying a 'shot mixing' method that eliminated the periodic variation of TFT characteristics that averaged non-uniform distribution in solidification. We also confirmed that SLS technique would be applied to fabrication of high quality AMOLED displays through this work. In addition to further improvement of image quality of SLS poly-Si TFT AMOLED, a SLS apparatus equipped with uniform laser and accurate stage control for AMOLED should be developed for mass production. And also SLS technology should be developed to increase throughput when the shot mixing technique is applied.

4. Acknowledgements

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5. References

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