

Development of World's Largest 21.3" LTPS LCD Using Sequential Lateral Solidification (SLS) Technology

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Abstract

The world largest 21.3" LTPS LCD has been successfully developed using SLS crystallization technology. Successful integration of gate circuit, transmission gate and level shifter was performed in a large area uniformly. Uniformity and high performance from high quality grains of SLS technology make it possible to come true a uniform large size LTPS TFT-LCD with half number of data driver IC's used in typical a-Si LCD. High aperture ratio of 65% was obtained using an organic inter insulating method, which lead a high brightness of 500cd/cm².

Introduction

Polycrystalline-silicon (p-Si) thin-film transistors (TFTs) are used in a variety of applications, including large-area electronics [1] and vertically stackable components for three-dimensional integration [2]. P-Si is typically fabricated from amorphous Si (a-Si) thin-film deposited on an inexpensive glass, such as Corning 1737, which has a quoted working range below 600°C. Various recrystallization technologies of a-Si film have been developed to meet this temperature limitation of glass. Among various recrystallization technologies, the excimer laser annealing (ELA) has been commonly adopted in commercial fields. In this method, a pulsed laser is used for irradiating on an a-Si precursor film. It is absorbed by a film surface and induces instant melting and solidification. The short pulse duration of the laser beam prevents

sustained heating of the underlying substrate, and makes the process compatible with glass substrate [3]. The crystallinity is superior to that of other crystallization techniques such as SPC (Solid Phase Crystallization) because the transformation from a-Si to p-Si is occurred via melting and re-solidification process.

In the mean time, typical ELA method has a limitation on uniformity over large area. The crystallinity that is mainly determined by p-Si grain size varies with the laser energy density. With an optimum energy density window, the grain size is quite small but the uniformity is acceptable in fabricating a typical small area LTPS LCD devices. If the laser energy density is over that window, the grain size increases significantly but the uniformity becomes bad. Small fluctuation of laser energy density can induce fine grains among large grains because of homogeneous nucleation and growth from the completely molten Si region. So a typical energy density margin for ELA is about 30 ~ 40 mJ/cm². It is difficult to get a high performance p-Si TFT's from conventional ELA technique due to this small and narrow energy density window.

By the way, sequential lateral solidification (SLS) [4] technology has been developed to get large grains with wide processing window. Because it facilitates complete melting regime, the energy density window is the range of 200mJ/cm². The TFT performance is much better than that of ELA TFT's because of large lateral grains. Using this advantage of SLS technology, world's largest LTPS LCD could be successfully developed.

Crystallization Process

One of the most important processes in LTPS technology is a recrystallization process of a-Si film. For a development of 21.3" LTPS LCD, wider recrystallization process window than conventional method was essential for defect free device. Fig. 1 shows the universal dependence of p-Si grain size on laser energy density in case of conventional ELA crystallization.

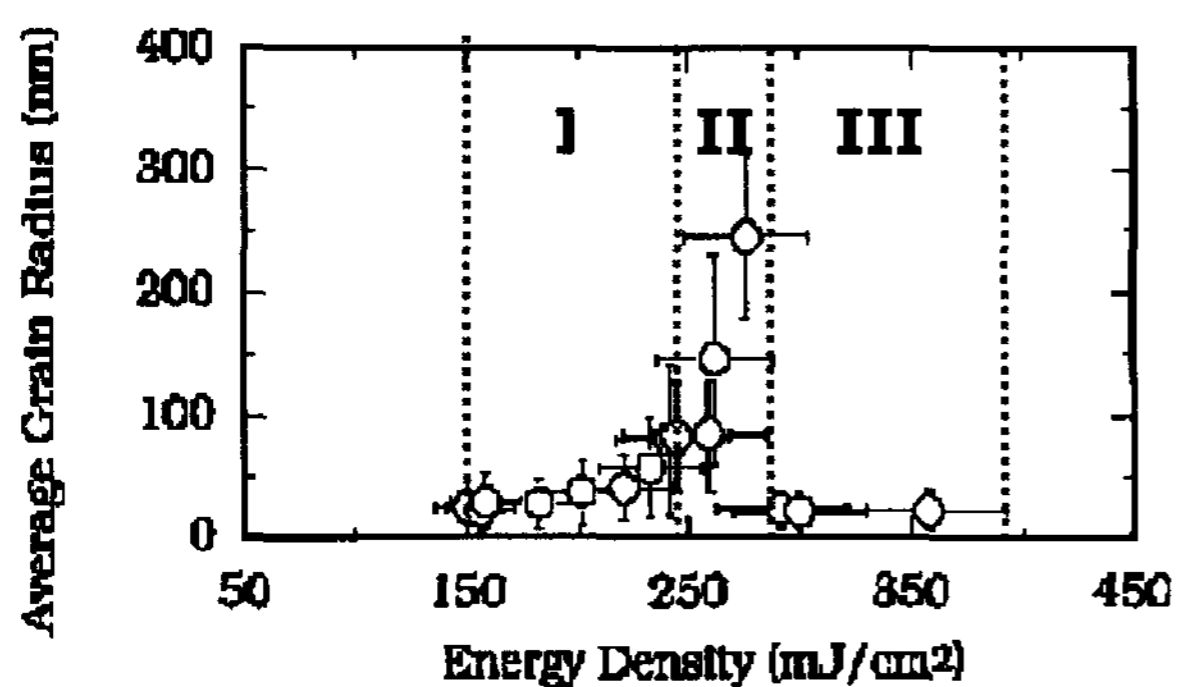


Fig. 1. Relationship between p-Si grain size and laser energy density. [5]

When energy density is in partial melting regime (regime I), the grain size is quite small ($\sim 0.2\mu\text{m}$) and the size increases with energy density. In this regime, the grain size is small but the size distribution is quite good. The grain size becomes maximum value when the laser energy density reaches critical value, which is called as SLG (Super Lateral Growth) regime (regime II). Above that energy, the grain size dropped abruptly and maintained constant with energy density because of homogenous nucleation and growth caused by complete melting (regime III). Because of this non-uniformity and grain size, only a partial melting regime should be chosen for an ELA technology. The typical laser energy density window is about $30\sim 40\text{mJ}/\text{cm}^2$. With this narrow processing window, large area LTPS LCD is hard to be developed due to laser energy density fluctuation. The laser energy density

fluctuation is typically known for 10%.

On the other hand, SLS technology uses complete melting regime. It masks laser beam and completely melts selective area of a-Si film. A lateral growth from unmelted region to molten center is occurred. There are three main advantages in SLS technology. One is that it can make large p-Si grains with only one shot. The lateral growth distance is typically over $1.5\mu\text{m}$ that is almost 1 order larger than that of p-Si crystallized by conventional ELA technology. Second advantage from SLS technology is its wide processing window. Fig. 2 shows the microstructures of p-Si crystallized by SLS technology with various energy densities.

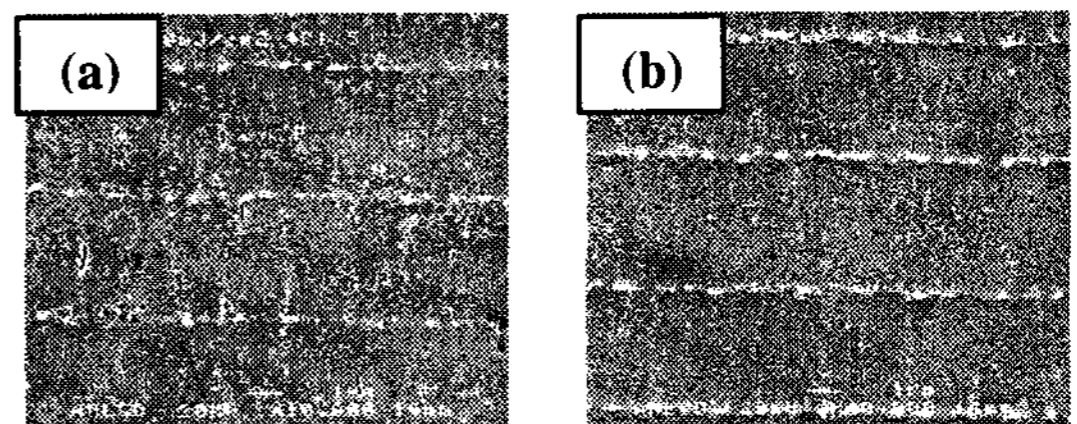


Fig. 2. SEM microstructures of p-Si crystallized by SLS technology at; (a) $750\text{mJ}/\text{cm}^2$ and (b) $950\text{mJ}/\text{cm}^2$.

The grain sizes are almost same within about $200\text{mJ}/\text{cm}^2$ energy density range. Note that the grain size reaches $3\mu\text{m}$ that is much larger than that of ELA grains. The TFT characteristics are also almost the same within this process window.

Another important point that can be obtained from SLS is that the grain boundary location is uniformly distributed and easily controlled by changing SLS mask design. This fact can make TFT characteristics very uniform over the whole panel area. To do so, the exact position control function is needed in SLS system. Fig. 3 shows the TFT performance (mobility and V_{th}) variation with and without position control function in SLS. As can be seen in fig 3(a), TFT performance is not so uniform

because of some bad TFT's of which grain boundaries are in some critical position. However, position controlled SLS TFT shows very uniform performance variation over the whole panel area because there are no grain boundaries in critical position, as is shown in fig. 3 (b).

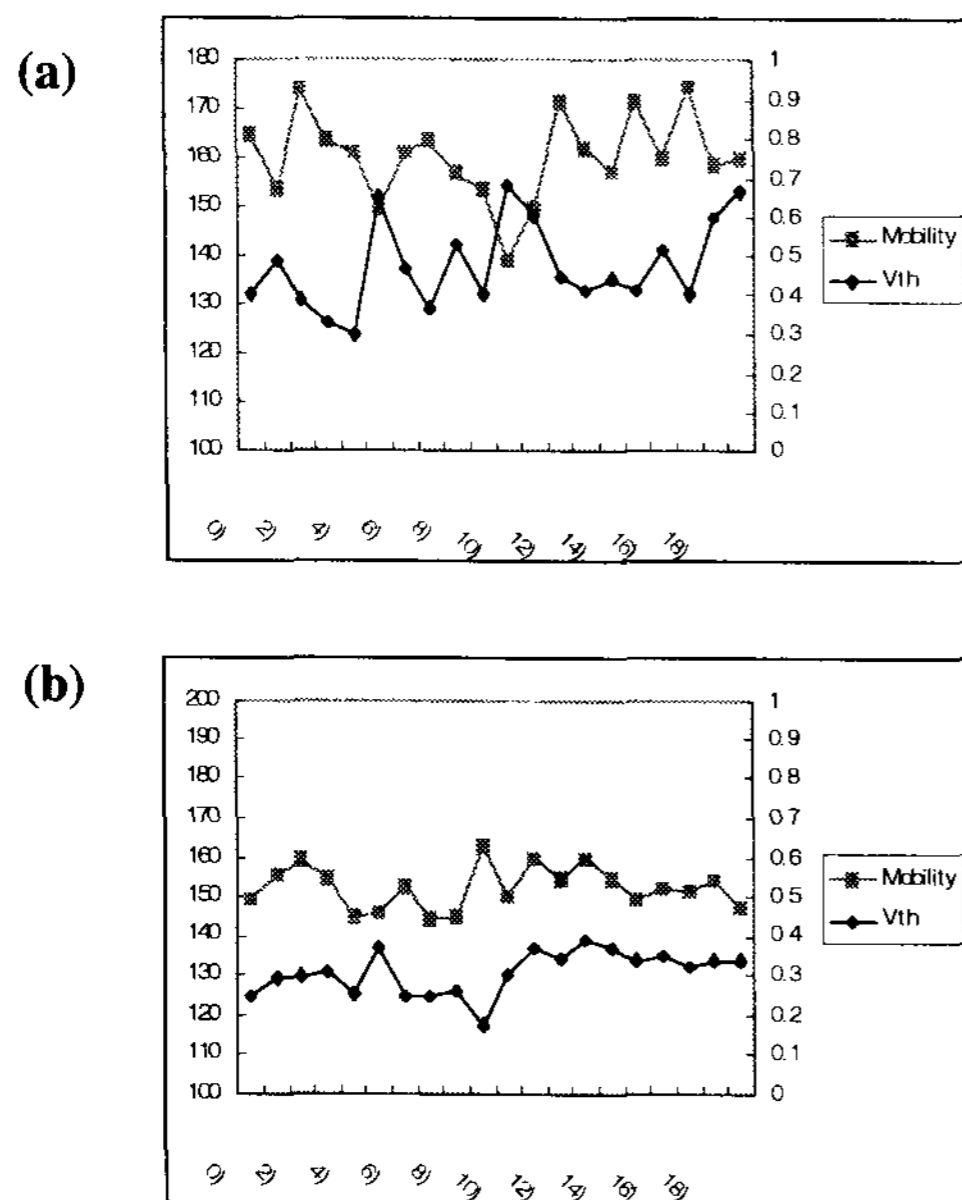


Fig. 3. TFT performance variation for (a) normal SLS TFT's and (b) position controlled SLS TFT's.

The Vth variations of normal SLS and ELA TFT's are about $\pm 0.5V$ but position controlled TFT's are about $\pm 0.2V$. The relationship between grain boundary location and performance variation will be discussed in detail in the next paper. Wider processing window, higher performance and good uniformity from SLS technology can make it possible to develop a 21.3" LTPS LCD.

Process Architecture

Normal top gate LTPS process was used. As an inter-insulating layer, SiO₂/SiNx dual layer was adopted to improve reliability. For a peripheral driver, CMOS was fabricated

and NMOS for pixel. P-Si material was fabricated from SLS crystallization technology that was covered in the previous session. Organic layer was used for a passivation, which can lead a high aperture structure due to its lower dielectric constant.

Device specification

Table 1 shows the specification of 21.3" LTPS LCD. It features a 16M colors, 500 nit of brightness and 500:1 contrast ratio. Display mode is transmissive type and it has 25ms of response time. The gate driver composed of level shifter and buffer was fully integrated. To reduce the number of data driver IC's, transmission gate was integrated. The number of data driver IC's could be reduced from 12 to 6, which can lead to a low cost, competitive LTPS products. The displayed picture of this device is shown in fig 4.

Table 1. Specification sheet of 21.3" LTPS LCD

| | |
|-------------------|-----------------------------|
| Display mode | Transmissive |
| # of Pixels | 1600 X RGB X 1200 |
| Pixel Pitch | 0.27 X 0.27 mm ² |
| Color Arrangement | RGB stripe |
| # of Colors | 16M Colors |
| Brightness | 500 nit |
| Contrast Ratio | 500:1 |
| Response Time | 25ms |

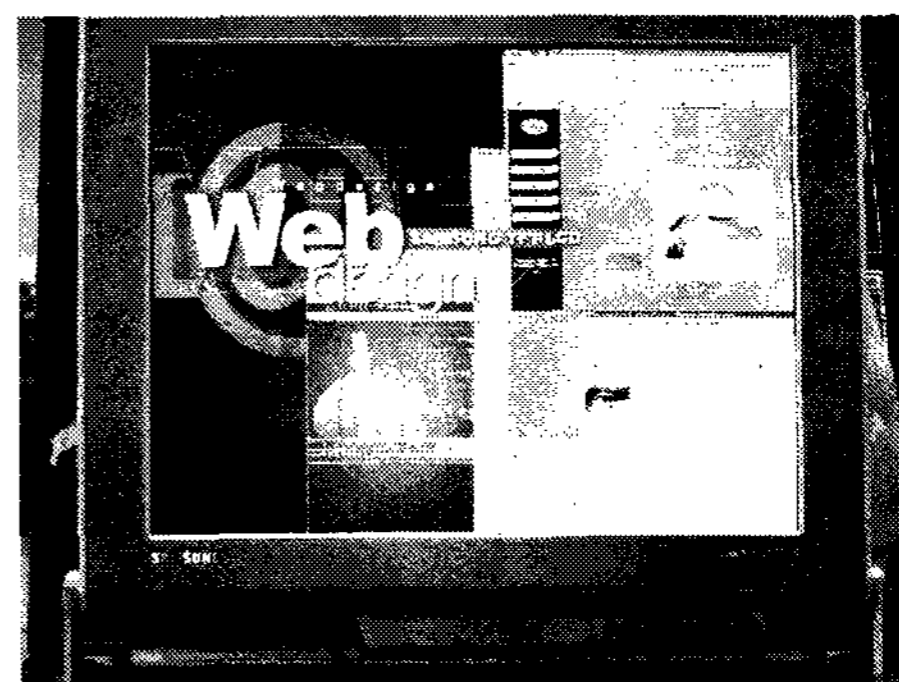


Fig. 4. Photograph of 21.3" LTPS LCD.

Summary

The world-largest LTPS LCD, 21.3" SLS LTPS, has been developed successfully. To cover the limitation of conventional crystallization technology of a-Si to p-Si, SLS technology was implemented to this device. SLS technology has wide processing window, high TFT performance, and good uniformity. This device has fully integrated gate driver containing level shifter and buffer. The number of data driver IC's could be reduced to the half by multiplexing scheme. SLS technology and the success of 21.3" LTPS LCD can enlarge the scope of LTPS technology from small to mid size to large size display.

References

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