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. Integration of gate circuit, transmission gate and level shifter was successfully performed in a large area display. Uniform and high performance of high quality grains of SLS technology make it possible to realize a uniform large size LTPS TFT-LCD with half the number of data driver IC's that is typically used in a-Si LCD. High aperture ratio of 65 % was achieved using an organic inter insulating method which lead to a high brightness of 500 cd/cm^2.

Keywords : LTPS, SLS crystallization, Integration, Large area display

1. Introduction

Polycrystalline-silicon (p-Si) thin-film transistors (TFTs) are used in various 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 of below 600 °C. Various recrystallization technologies of a-Si film have been developed to resolve this temperature limitation of glass. Among the various recrystallization technologies, the excimer laser annealing (ELA) has so far been the most 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 to be 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 occurs via a melting and re-solidification process.

Meanwhile, a typical ELA method has a limitation in terms of uniformity over a large area. The crystallinity that is mainly determined by p-Si grain size varies with laser energy density. At an optimum energy density window, the grain size is quite small but the uniformity is acceptable enough in fabricating a typical small area LTPS LCD devices. If the laser energy density exceeds this optimum window, the grain size increases significantly but the uniformity will worsen. A small fluctuation of the 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/cm^2. 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.

Manuscript received June 24, 2003; accepted for publication December 1, 2003.
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By the way, sequential lateral solidification (SLS) [4] technology has been developed to achieve large grains with wide processing window. As a complete melting regime is facilitated, the energy density window ranges 200 mJ/cm^2. The TFT performance is much better than that of ELA TFT's because of the large lateral grains. Using this merit of SLS technology, we were able to successfully build the world's largest LTPS LCD.

2. Crystallization Process

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

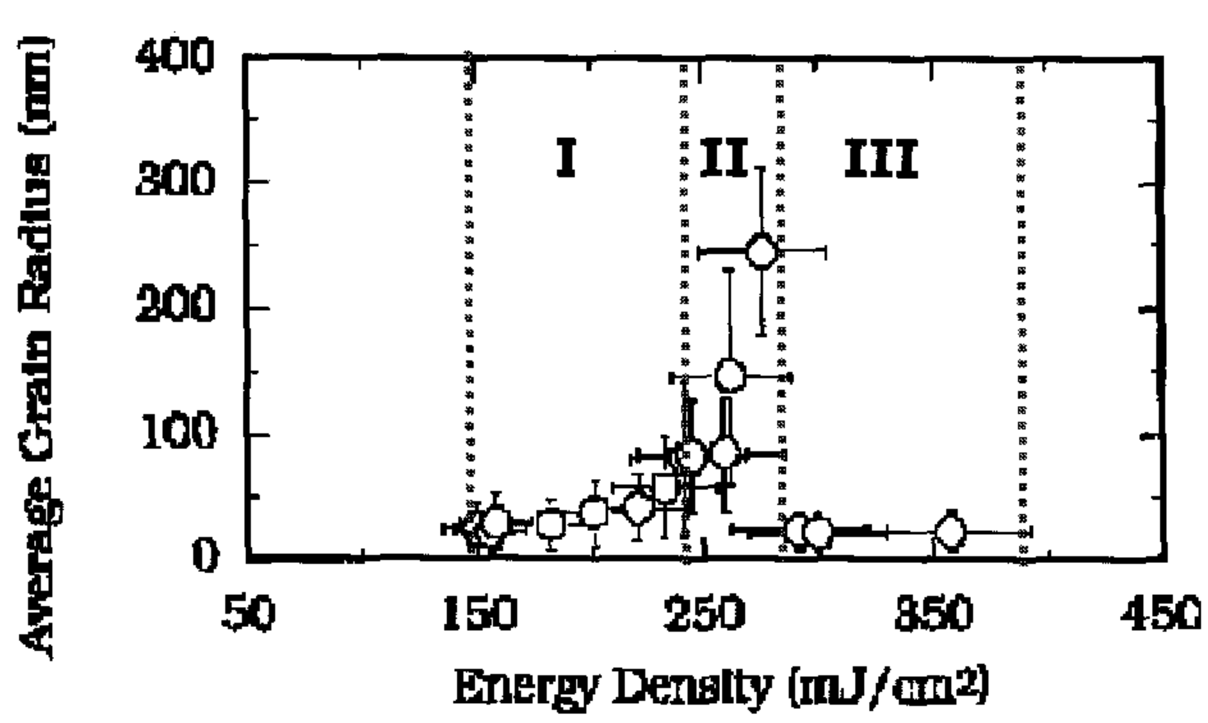
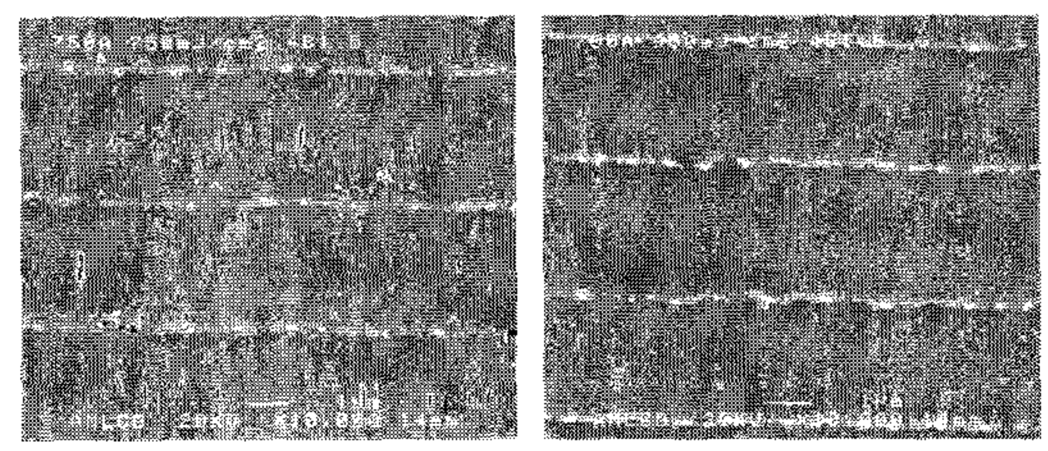


Fig. 1. Relationship between p-Si grain size and laser energy density. [5]

When energy density is within partial melting regime (regime I), the grain size is quite small (~0.2 um) 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 reaches its maximum value when the laser energy density reaches a critical value, which is called the SLG (Super Lateral Growth) regime (regime II). Beyond that point, the grain size drops abruptly and maintains a constant size with energy density because of the 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 30~40 mJ/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 um 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.

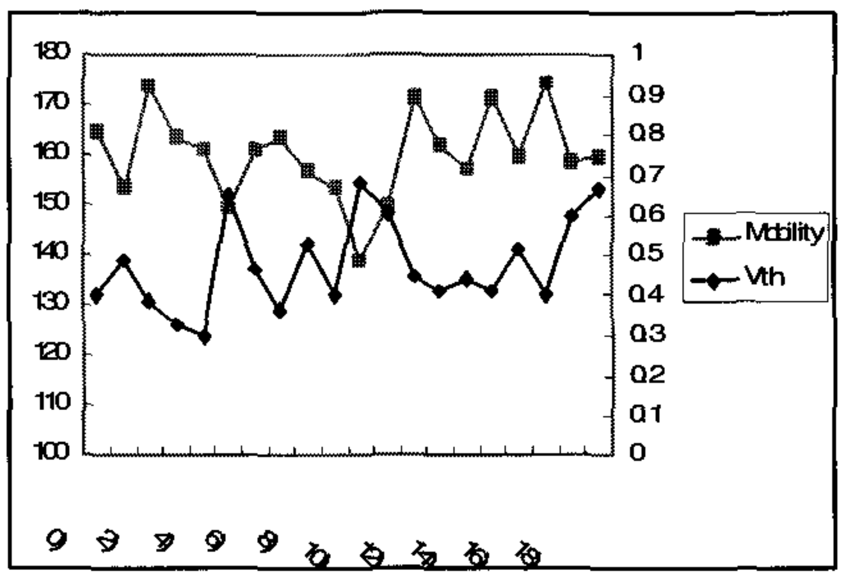


(a) (b)

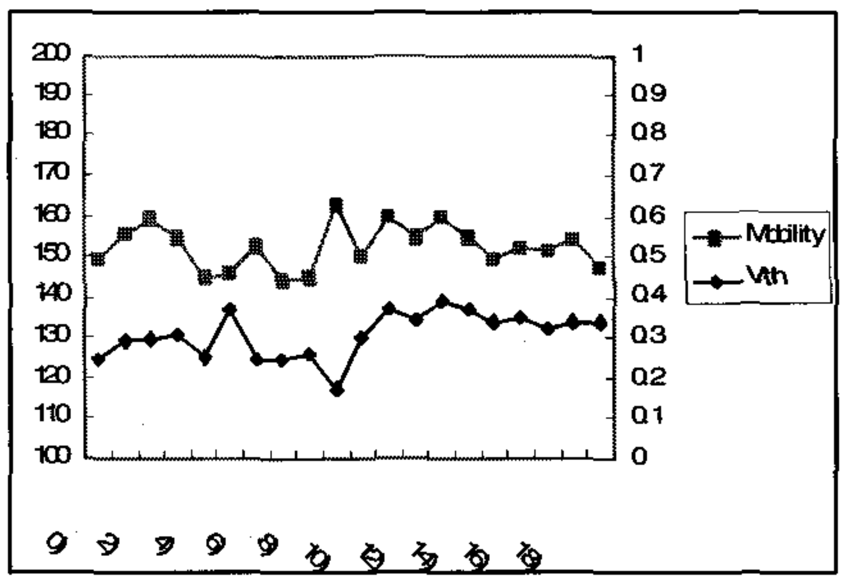
Fig. 2. SEM microstructures of p-Si crystallized by SLS technology at; (a) 750 mJ/cm^2 and (b) 950 mJ/cm^2.

The grain sizes are almost same within about 200 mJ/cm^2 energy density range. Note that the grain size reaches 3um 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 Vth) 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).



(a)



(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 ± 0.5 V but position controlled TFT's are about ±0.2 V. 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.

3. Process Architecture

Normal top gate LTPS process was used. As an inter-insulating layer, SiO_2/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.

4. 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 25 ms of response time. The gate diver 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 × RGB × 1200
Pixel Pitch	0.27×0.27 mm^2
Color Arrangement	RGB stripe
# of Colors	16M Colors
Brightness	500 nit
Contrast Ratio	500:1
Response Time	25 ms

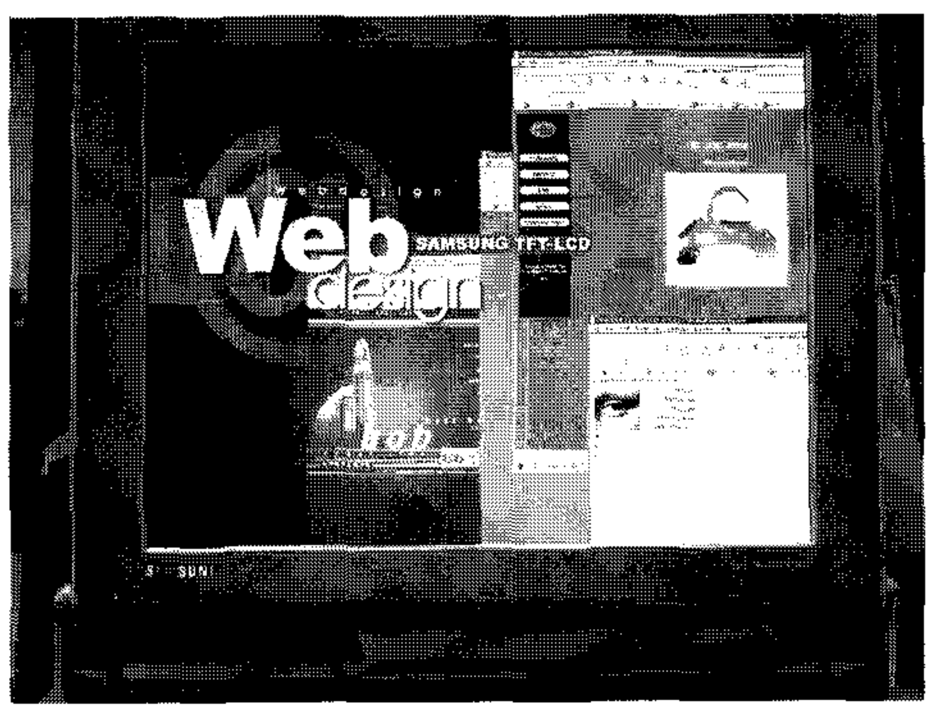


Fig. 4. Photograph of 21.3" LTPS LCD.

5. 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.

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