SLS (Sequential Lateral Solidification) Technology for High End Mobile Applications

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Abstract

The new technologies in mobile display developed in SEC are briefly reviewed. For a differentiation, SEC's LTPS line is based on SLS (Sequential Lateral Solidification) technology. In this paper, the characteristics of SEC's SLS in recent and future mobile displays were discussed.

The microstructure produced by SLS crystallization is dependent on SLS process conditions such as mask design, laser energy density, and pulse duration time. The microstructure and TFT (Thin Film Transistor) performance are closely related. For an optimization of TFT performance, SLS process condition should be adjusted. Other fabrication processes except crystallization such as blocking layer, gate insulator deposition and cleaning also affect TFT performance.

Optimized process condition and tailoring mask design can make it possible to produce high quality AMOLED devices. The TFT non-uniformity caused by laser energy density fluctuation could be successfully diminished by mixing technology.

1. Introduction

Polycrystalline-silicon (p-Si) thin-film transistors (TFTs) are used in a variety of applications, including large-area electronics such as flat panel display [1] and vertically stackable components for three-dimensional integration [2] due to its ability in peripheral circuit integration and high reliability. P-Si is fabricated typically 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 have been developed to meet this temperature limitation of glass. Among those technologies, an excimer laser method has been commonly adopted in commercial fields. In this method, a pulsed laser is irradiated on an a-Si precursor film. It is absorbed by a film surface and induces rapid melting and solidification. The short pulse duration time (typically a few tens ns) of the laser beam prevents underlying glass from heating up to the melting point, and makes the process compatible with glass substrate [3]. The crystallinity is superior to that of other recrystallization techniques such as SPC (Solid Phase Crystallization) because the transformation from a-Si to p-Si is occurred via melting and re-solidification.

In the mean time, the property of p-Si TFTs is mainly dependent on grain boundaries within channel area because they can act as a charge trap states. Trap density in grain boundary increases Vth and decreases Ion. To minimize the number of grain boundaries within the channel area, a lot of recrystallization technologies have been developed in many research groups. SEC has been also developing unique SLS [4] technology, which can make uniformly-distributed large lateral grains.

SLS technology can make it possible to produce a few micrometers order of grains that are almost 10 times larger than conventional ELA grains. From the large grain size and controlled grain boundary locations, much higher TFT performance can be obtained. SEC has developed 21.3" world's largest Low Temperature Poly Si (LTPS) LCD using SLS technology. [5]

Even though the performance of SLS TFTs has been satisfactory to the conventional LTPS-LCD application, the performance level isn't acceptable to be applied to new advanced applications such as AMOLED Display or SOG (System on Glass). For example, the Vth variation should be less than 0.2V for these applications, which cannot be met in the typical SLS technology. Because the TFT performance is mainly dependent on microstructure, intensive study on tailoring microstructure was shown in this paper for high end LTPS TFT-LCD and AMOLED applications.

2. Experimental

Fabrication procedure of this paper followed normal top gate LTPS process. SiO_2 blocking layer (B/L) deposited glass was used as a substrate. The role of B/L is to protect impurities from a glass substrate during following high temperature processes. Upon the B/L, 500Å-thick a-Si precursor was deposited. Dehydrogenation was carried out at 430°C to decrease hydrogen content inside an a-Si film because residual hydrogen may explode during the laser recrystallization. ELA or SLS recrystallization with XeCl excimer laser that has a wavelength of 308nm was performed on this film. The microstructure of p-Si material was examined using optical microscopy and SEM. Various SLS mask patterns were used to optimize the microstructure.

After irradiation, TFTs were fabricated following typical LTPS fabrication sequences; active patterning, gate oxide deposition, gate patterning, ion implantation, inter insulating layer deposition, contact and data metal patterning. Ion implantations were carried out using an ion shower system with various doping conditions. TFT performances were measured using HP 4156 system. At least 24 consecutive TFTs were analyzed for ELA and SLS TFTs.

3. Results and discussion

Fig. 1 shows mask pattern design used in typical two shot (TS) SLS technology.

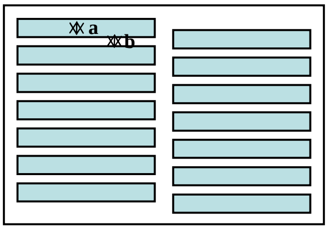

Fig.1. Schematic illustration of TS SLS mask pattern.

The shadowed area (slit) transmitts laser and the irradiated a-Si region can be fully melted. Laser is reflected for the rest area (space) so that a-Si can be remained as it is.

Fig. 2 shows the detailed description of TS SLS process that is used in mass production. Laterally grown grains can be obtained by using laser mask that defines irradiation area on the substrate as is shown in Fig. 2(a). A seed grains are initiated on the border between melted and un-melted region. Because of temperature gradient and thermal budget from phase transformation, grains grow to the center of melted region so that lateral grains could be obtained. As can be seen in SEM microstructure of Fig 2(a), the lateral growth distance is at least 1.5µm and this distance can be extended by increasing laser energy density or pulse duration time.

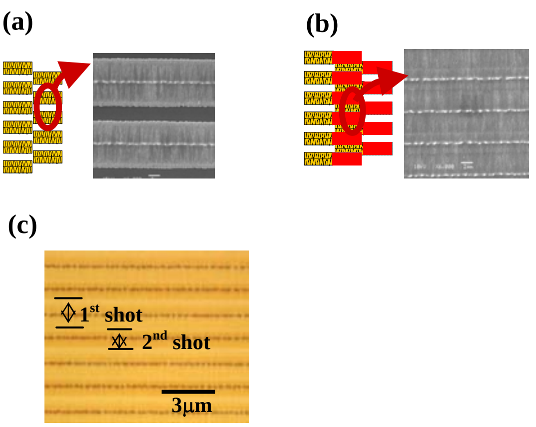

Fig.2. Schematics and SEM microstructure of TS SLS: (a) after 1 shot irradiation and (b) after two shot irradiation. (c) Optical microstructure after two shot.

To complete recrystallization over whole area, the rest of the a-Si region has to be crystallized by a translation of stage or laser mask as is shown in Fig. 1(b). In this time, the initially formed lateral grains grow again and form a uniform microstructure composed of grains of which sizes are over 3µm. Because melting region should be defined in SLS technology, the minimum number of laser shot to crystallize whole area is two. The orderly located lines in SEM microstructure of Fig. 1(a) and (b) are main grain boundaries formed in the center of melted region when lateral grains collide. Due to density difference between liquid Si and crystalline Si, protrusions are formed along the main grain boundaries so that the lines look brighter in SEM picture.

Based on Fig. 1 and Fig. 2, the grain size (*d*) and overlap distance (*l*) of melting region can be defined as equation 1 and 2.

$$d = (a+b)/2 \qquad (1)$$

$$l = (a-b)/2 \qquad (2)$$

From Eq. 1, it can be known that the grain size is maximized only by increasing slit width (a) and pitch (b). However, there should be limitation in increasing slit width because of lateral growth margin. Homogeneous nucleation can be initiated in the center of slit region if slit size is larger than lateral growth distance. To increase the lateral growth distance, process conditions such as film thickness, pulse duration time, blocking layer thickness and so on.

Increase of pitch will cause also a problem due to lower the overlap distance as is described in Eq. 2. The lack of overlap distance causes bad crytallinity.

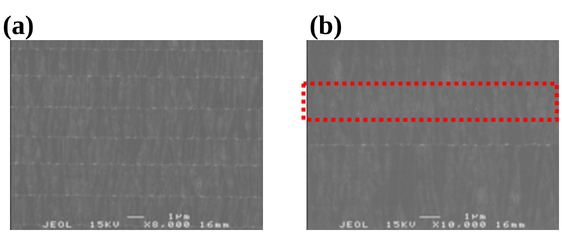

Fig.3. SEM microstructures of (a) large overlap and (b) small overlap distance

Even though the grain size is smaller in large overlap distance sample shown in Fig. 3(a), the width of each grain is quite uniform. However, the indicated area by rectangle in Fig. 3(b) shows narrowed width of grains that can act as a resistance in the channel area of TFTs. So the increased grain size effect cannot be seen after the fabrication of TFTs.

To make thick grains, various technologies can be possible. One of them is ELA + SLS technology. After ELA, the grain size is uniform and about 3000~6000A. SLS crystallization on this substrate can make uniformly thick lateral grains. Fig. 4 shows the difference between SLS only and ELA + SLS.

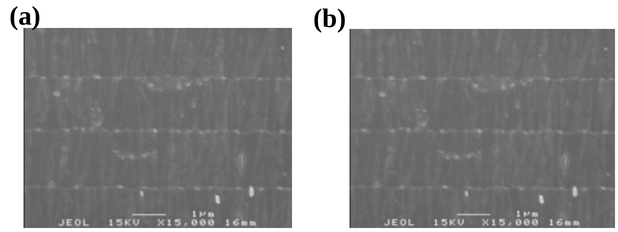

Fig.4. SEM microstructures of (a) SLS only and (b) ELA + SLS p-Si.

The overlap distance can be increased by film quality control. Even though the slit sizes of 1st shot and 2nd shot in the SLS mask pattern are the same, the melting distance is quite different as is shown in Fig. 2(c). Different from SEM image, optical microstructure shows surface morphology clearly via color difference. From this benefit, the melting distance could be verified. The melting distance of 1st shot is about twice larger than that of 2nd shot. This is because that 1st shot melts a-Si film and 2nd shot melts p-Si. Based on this result, thick a-Si precursor/higher laser energy density/longer pulse duration time and so on can make longer lateral grains.

The easy modification of microstructure for SLS technology can be used in deletion of non-uniformity of AMOLED devices. The p-Si structure can affect the display quality for AMOLED devices, because current driving concept is used compared to LCD that is using voltage driving. In current driving mode, TFT property variation is revealed directly in display quality. Fig. 4 shows AMOLED display quality when p-Si property isn't uniform.

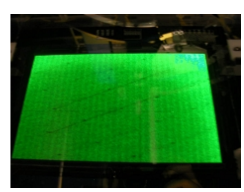

Fig.4. Stain from p-Si TFT non-uniformity in AMOLE Display.

As can be seen in Fig. 4, the display shows a lot of stains and non uniform lines that are brighter or darker than environment color. The origin of non-uniformity comes from laser energy density fluctuation which can affect TFT current driving performance.

To minimize this effect, SLS mixing technology was devised. In this technology, two or more laser shots can be mixed in one shot area.

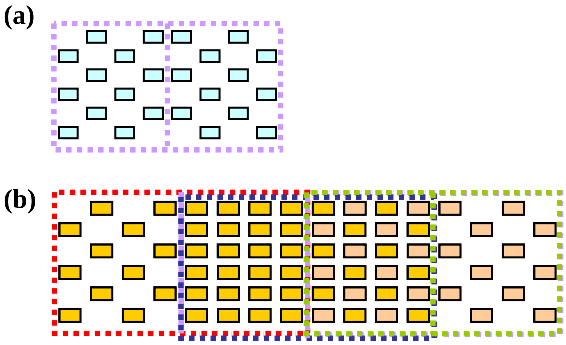

Fig.5. (a) SLS mask pattern for mixing technology and (b) schematic illustration of

Fig. 5(a) shows the TS SLS mask pattern for mixing technology. The mixing ratio and unit size can be controlled easily by pattern change. The mixing mechanism is shown in Fig. 5(b)

In this case, the 1st and 2nd shots are fine but 3rd shot shows different laser energy density. But the energy fluctuation is mixed by 2nd shot so that the non uniform area cannot be seen clearly.

Fig. 6 shows the AMOLED devices using SLS mixing technology. The display quality has successfully improved a lot due to mixing of non uniform area.

Fig.6. AMOLED display produced by SLS mixing technology.

4. Summary

Various parameters that affect SLS p-Si microstructure and TFT performance were intensively studied. Lateral growth distance and crystallinity of p-Si after SLS are dependent on slit and pitch design of mask. For larger lateral growth distance, process parameters such as film thickness, pulse duration time and laser energy density are to be optimized.

Mixing technology to diminish the difference between laser shots can be used to produce high quality uniform AMOLED devices. Mixing can be done by SLS mask pattern and easily modify the mixing ratio, shape and size.

5. References

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