Advanced Low-Temperature Poly-Si Crystallization for AMOLED Displays

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Abstract: *An advanced Low-Temperature Poly-Si (LTPS) crystallization method for Active Matrix Organic Light Emitting Diode (AMOLED) displays has been developed. LTPS technologies have a lot of advantages such as high speed, high reliability, circuit integration, and so on. However, there is a weakness of non-uniformity due to laser crystallization process. We studied an advanced method of small grain crystallization using sequential lateral solidification to overcome the non-uniformity of LTPS.*

Keywords: LTPS; AMOLED; Crystallization

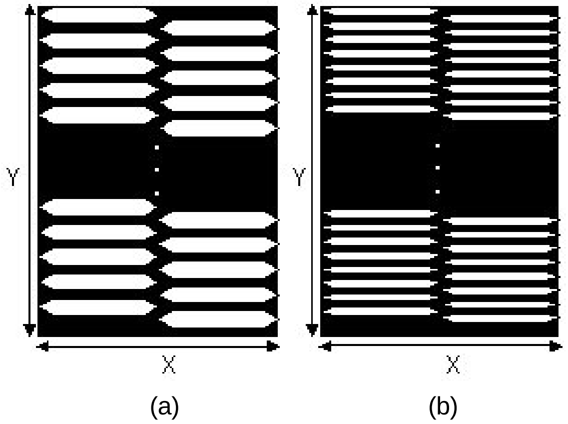
Introduction

Active Matrix Organic Light Emitting Diode (AMOLED) displays have attracted a considerable attention due to high brightness, high efficiency, fast response time, and wide viewing angle [1]. Recently, amorphous silicon (a-Si:H) based AMOLED displays are also reported, presenting the superiority of uniformity [2]. However, improving the poor reliability of a-Si:H TFT is well known as much more difficult problem than the uniformity of LTPS TFT. Although LTPS-TFT based AMOLED displays suffer from the non-uniformity problem, some compensation methods [3,4] and new crystallization methods are considered as promising techniques for the mass production [5].

In order to overcome the non-uniformity of LTPS, we have developed an advanced method of small grain crystallization using Sequential Lateral Solidification (SLS). The poly-Si film by the SLS crystallization method shows directionally large grains over several um resulting in high mobility, which enables very high density of circuit integration on the glass substrate [6]. In case of AMOLED displays, the uniformity of TFT is more important issue than high mobility for high quality displays. We found out that the uniformity of TFT is highly related to the surface roughness of the poly-Si film. The surface roughness of the poly-Si film in case of small grain crystallization has been reduced by 21% compared with that of the poly-Si film by conventional crystallization method. We successfully achieved the uniform TFT characteristics applicable to AMOLED with the small grain crystallization method.

Experimental

Conventional 2-shot SLS process has been known as a better method to get a high throughput. Unfortunately, mask overlapping and slit overlapping of 2-shot SLS cause irregular regions along the scan direction and the grain growth direction. TFT characteristics in the irregular regions, such as threshold voltage and s-factor, are quite different from those in other regions [7]. In this work, for the purpose of solving this problem caused by irregular characteristics between neighboring shot blocks shown by the 2-shot SLS, an advanced method of small grain crystallization using 2-shot based SLS has been studied comparing with conventional 2-shot SLS.



(a) (b)

Figure 1. Mask design of the 2-shot SLS for (a) conventional and (b) small grain crystallization. The mask has a dimension of 0.6 mm x 10 mm.

An a-Si layer was deposited from a reactant gas mixture of SiH_4 with H_2 as a carrier gas. After being dehydrogenated, the a-Si layer was crystallized by using the newly designed 2-shot SLS mask depicted in Fig. 1 with excimer laser (XeCl : 308 nm). Conventional 2-Shot SLS was carried out at laser energy density of 1300 mJ/cm^2 and small grain crystallization was performed at 1000 mJ/cm^2. The slit was defined as the beam width (BW) and the beam space (BS). In case of the small grain crystallization, each was designed with 1.0 μm and 0.2 μm, and 3.0 μm and 1.0 μm for the conventional 2-shot SLS, respectively (Fig. 2). The basic 2-shot SLS process was identical for the both cases. After the 1st irradiation, the stage was transferred by half of the mask size, 0.3 mm, along the scan direction and then the 2nd shot was irradiated. The following shots were irradiated with same pattern. After scanning one line, the mask was transferred to the next line spacing the Y dimension of the mask, 10 mm. For scanning the second line, the stage was transferred to the opposite direction to that of the first line. The beam space and the beam width of the mask used in this experiment are summarized in Table 1. Conventional TFT fabrication processes were followed to evaluate the electrical properties for each crystallization condition. The V_{th} uniformity of the small grain crystallization based LTPS TFTs and the conventional 2-shot SLS based LTPS TFTs were compared by evaluating TFTs. located away from 200 μm on the substrate both to the scan direction and the grain growth direction.

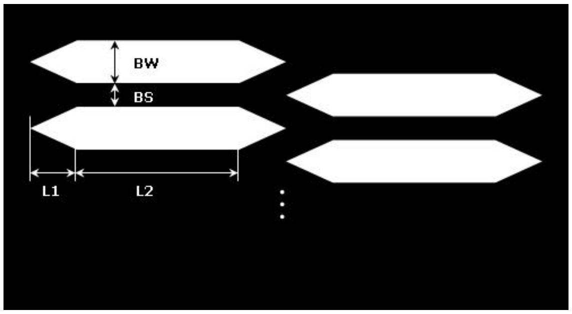


Figure 2. Description of open slits

Table 1. Details of open slits used in this experiment for small grain crystallization

	Conventional 2-shot SLS	Small grain crystallization
Beam width (um)	3.0	1.0
Beam space (um)	1.0	0.2
L1(um)	6.0	1.8
L2(um)	288	296.4

Results and discussion

Fig. 3 shows a basic concept of the 2-shot SLS process. Mask size X and Y is same as the horizontal and vertical dimension of the slit mask, respectively, and the beam length is a half of X in general. While laser is being irradiated on a-Si film through the slit mask, the irradiated region of a-Si is changed to a liquid phase. After the shot is transferred for the next region, a poly-silicon crystalline phase is formed in the previous region. There exist very poor crystalline Si grains in the first half region. When the 2^{nd} shot is irradiated after the stage is transferred to 1/2 X position to connect the non-irradiated region by the first shot, crystallization starts from the pre-crystallized region and grains grow to the perpendicular to the scan direction. Since the grain growth starts from the interface between the crystallized Si and liquid Si, which means that there is no potential barrier for nucleation, crystallization occurs very fast. The maximum grain size is constrained by the mask design and limited ideally to the half of "the beam space + the beam width", as shown in Fig.2.

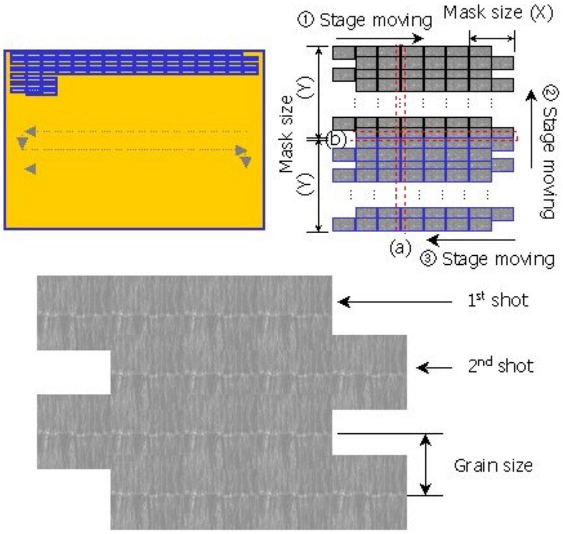


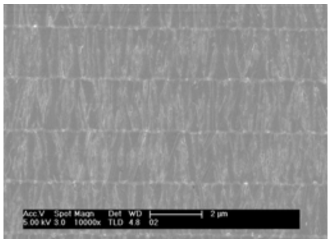
Figure 3. Schematic of the 2-shot SLS process

By moving 1/2 X per each laser shot, finally, the whole area can be crystallized. However, the 2-shot SLS makes irregular grain regions caused by two types of overlapping. One is produced by mask-to-mask overlap in Y direction (Fig. 3 (b)). In Y direction, there exist non-uniformities in laser intensity profile, occurred by limitation in mask size, producing a variation in TFT characteristics. This type of non-uniformity could not be perfectly solved by tuning laser process. The other is produced by slit-to-slit overlap in X direction (Fig. 3 (a)). The overlapped regions are generated at intervals of 0.3 mm to the scan direction (X) determined by the beam length. The grain size and crystallinity of Si in the overlapped regions are different from those of TFTs formed in the other regions, which make it difficult to adopt the conventional 2-shot SLS for AMOLED panels. In addition, the conventional 2-shot SLS makes regular grain boundary for its repeated and regular grain size. It causes the non-uniformity of devices because the number of the grain boundary in channel of TFTs is not equal exactly.

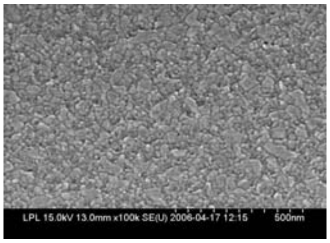
The proposed small grain crystallization is a kind of modified 2-shot SLS. The beam width is decreased to 1.0 ㎛. The small grain crystallization using 2-shot SLS process is carried out at the energy density of the near complete melting region (NCM) but the conventional 2-shot SLS process uses the energy density of the complete melting region (CM). Stage movement to the scan direction is the same as that of the 2-shot SLS process. The grain size of the small grain crystallization is much smaller than that of the conventional 2-shot SLS, there are no slit marks to the scan direction caused by slit-to-slit overlap. The small slit size makes the crystal growth pattern equivalent in every region on the substrate. This means that TFT uniformity in the scan direction could be improved greatly. Namely, the small grain crystallization with the very small grain is inferior to the conventional 2-shot SLS for the absolute value of the

TFT performance but it shows the good uniformity relatively.

Fig. 4 shows SEM images of Si crystallized by the conventional 2-shot SLS and the small grain crystallization, respectively. The microstructure by the small grain crystallization shows a great difference from that of the conventional 2-shot SLS. The grain boundaries of the small grain crystallization are randomly distributed and overlapped regions are not observed.



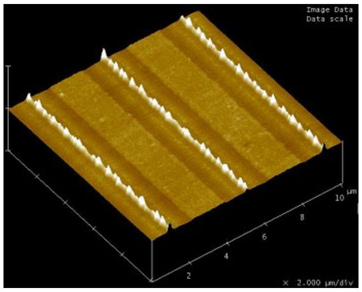
(a) Conventional 2-shot SLS grain



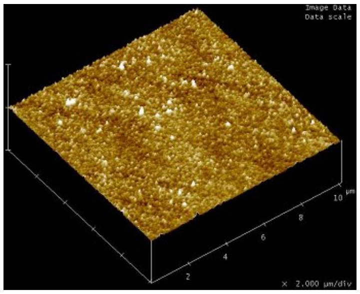
(b) Small grain crystallization grain

Figure 4. SEM images of the poly-Si film in a) conventional 2-shot SLS grains, b) small grain 2-shot SLS grains.

Fig.5 shows the surface images of the poly-Si film in both conventional 2-shot SLS and small grain crystallization. The surface roughness of the poly-Si film in case of the small grain crystallization has been reduced by 21% compared with that of the poly-Si film by conventional crystallization method.



(a) RMS roughness = 91Å



(b) RMS roughness = 19Å

Figure 5. Surface images of the poly-Si film in a) conventional 2-shot SLS grains, b) small grain crystallization grains.

In order to confirm the enhancement of local uniformity, we measured 15 TFTs formed along the scan direction for conventional 2-shot SLS and small grain crystallization. Fig. 6 shows the V_{th} of 15 points spaced at a distance of 200 μm. We observed that the V_{th} variation was greatly reduced by adopting the small grain crystallization. The transfer characteristic graph and the V_{th} characteristics of p-channel TFT are depicted in Fig.7 and summarized in Table 2, respectively.

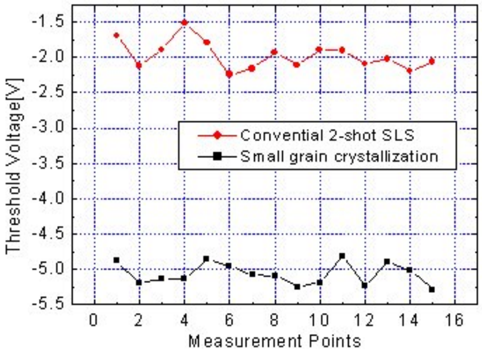


Figure 6. Comparison of variation of the threshold voltage in local region for conventional 2-shot SLS and small grain crystallization

Table 2. V_{th} characteristics of p-channel TFT

Process	Average ($\|V_{th}\|$)	V_{th}
Small grain crystallization	4.88V	0.45V
Conventional 2-shot SLS	1.97V	0.72V

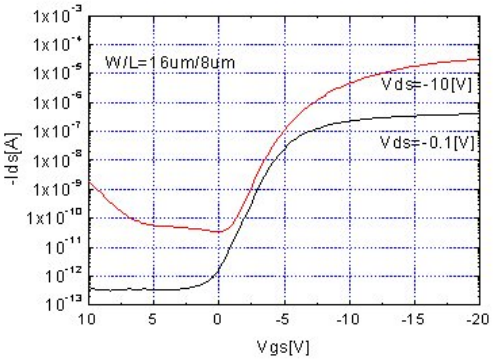


Figure 7. Transfer characteristics of p-channel TFT with small grain crystallization

Conclusion

For high quality AMOLED displays, the uniformity of TFT is more important issue than high mobility. We found out that the uniformity of TFT is related very closely to the surface roughness of the poly-Si film. The surface roughness of the poly-Si film in case of small grain crystallization has been reduced by 21% compared with that of the poly-Si film by conventional crystallization. We successfully achieved the uniform TFT characteristics applicable to AMOLED with the small grain crystallization method.

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