Thin-Beam Directional X'tallization Technology for Fabrication of Low Temperature Poly-Si Transistors

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Abstract

We propose an improved laser crystallization method based on a directional lateral growth technique. To assess the feasibility of this technique, we have developed an experimental prototype using a 351 nm XeF excimer laser and special optics to produce a long and extremely sharp, narrow beam without need for a photo type mask pattern. Using this system, we have demonstrated very uniform directional laterally grown poly-Si films without any grain boundary protrusions. We believe this method can meet the high performance and uniformity requirements needed for future TFTs in System On Panel (SOP) and OLED applications, as well as providing high process throughput for mass production.

1. Introduction

It is well known that the high mobility of poly-Si TFTs enables the integration of driver ICs on a display panel. As the performance of the poly-Si TFTs improves, it is expected that integration of more sophisticated circuits on a glass panel will increase, leading to the System on Panel (SOP) technology [1]. Poly-Si TFTs are also well suited for OLED application due to the high mobility and reliability of the TFT characteristics. However, the brightness non-uniformity in the display image that comes from the non-uniformity of the TFT characteristics has been a key issue for OLED application.

The properties of poly-Si TFTs are closely related to the quality of the active channel material. The key for extending the performance of poly-Si TFTs is to develop a low cost, high quality and uniform poly-Si crystallization process. Excimer Laser Annealing (ELA) is the most common production method used for the crystallization process. However, polycrystalline Si films made using the conventional ELA method have relatively small, non-uniform grain size and large grain boundary protrusions. This crystal structure makes it difficult to apply to SOP and OLED applications.

Several crystallization technologies have been developed as alternatives to ELA, including Sequential Lateral Solidification (SLS) [2-8], Diode Pumped Solid State (DPSS) CW Laser Crystallization (CLC) [9], and Selectively Enlarging Laser X'tallization (SELAX) [10]. The mobility of poly-Si TFTs produced using these lateral growth techniques has been reported to be higher than 300cm2/V.sec. Despite supporting improvements in device performance, these techniques still struggle to produce the uniformity, throughput and yield that are needed for practical applications.

The Thin-beam Directional X'tallization (TDX) method described in this paper is an improved version of the line-scan SLS method [3,4] or ZMR method [11]. We believe it can satisfy both the high performance and uniformity requirements and high throughput needed for a practical poly-Si process. In this paper, we will discuss the details of the TDX method and experimental results from the prototype TDX equipment, as well as showing the advantages for both SOP and OLED applications

2. Details of TDX method and its requirements

The TDX process is based on a lateral growth technique where the panel is irradiated with a spatially controlled, very thin laser beam which melts the Si film completely. The narrow profile of the melt region then allows for crystallization by lateral growth of large poly-Si grains from seeds at the edge of the molten zone. After each laser pulse, the substrate is translated by approximately 2 microns, so that each subsequent pulse is seeded from the high quality poly-

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Si of the previous pulse. This allows the poly-Si to grow continuously to produce large directional laterally grown poly-Si grain as shown in Figure 1.

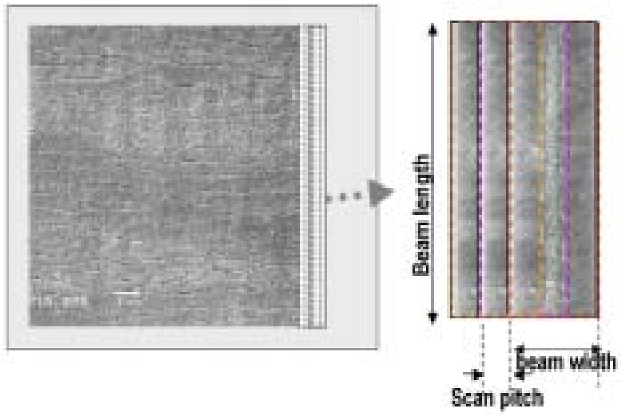


Figure 1. Details of TDX process

The TDX method places special requirements on the crystallization system. First, the laser source must produce high power with small pulse-to-pulse energy variation in order to produce uniform poly-Si films on a substrate with high process throughput. In these experiments we used a 351nm XeF excimer laser, based on the MOPA (Master Oscillator-Power Amplifier) configuration, which can operate up to 4 kHz to meet these requirements. Second, the process requires specially designed optics in order to produce the extremely asymmetrical long and narrow beam, with a steep edge slope, needed to maximize the process window. In addition, the beam profile on a substrate must be spatially uniform and insensitive to a change of focal position to achieve uniform TFT characteristics on a display panel. Using specially designed homogenization and focusing optics, we were able to produce a beam with a width that is adjustable between 5 and 10um. The intensity uniformity of the beam is better than 5%, and the sharp edge slope is less than 3um between the 10% and 90% of full intensity. Finally, a precisely controlled stage is needed for accurate translation of the substrate (Figure 2).

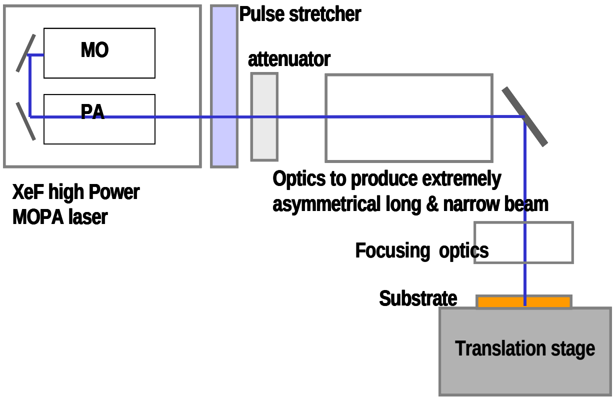


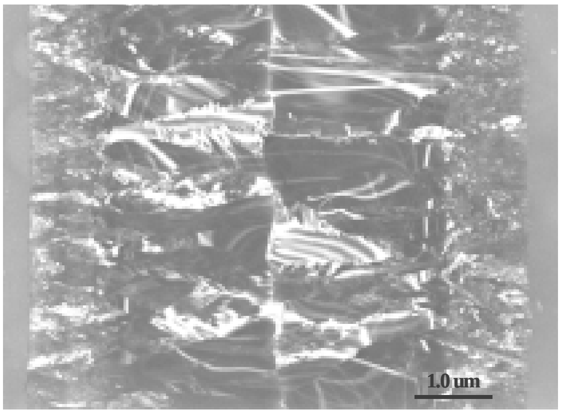
Figure 2. Schematics of TDX prototype system

3. Results and Discussion

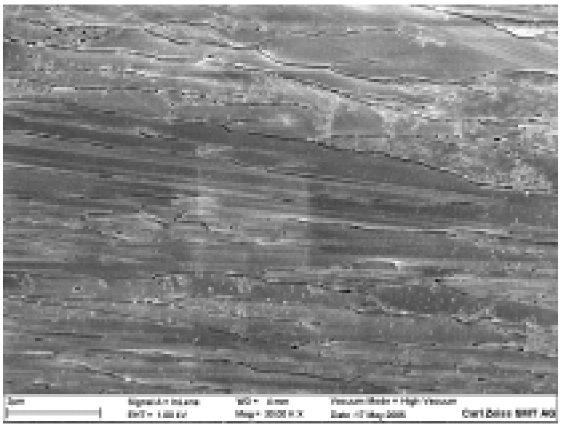
The microstructure produced by the TDX prototype for a 50nm thick Si film is shown in figure 3. Figure 3(a) shows the grain structure after a single laser pulse, which consists of approx. 2um long laterally grown poly-Si grains and smaller grains at both edge of the beam. After repeatedly exposing the substrate with a translation of ~1.5 microns between pulses, we can produce large and uniform crystal grains as shown in Figure 3(b). The surface of the poly-Si film was very flat (peak- to-peak value of ~15nm) because each pulse re-melts the grain boundary protrusions caused by the previous pulse.

It is well known that the field effect mobility of the poly-Si TFT strongly depends on the poly-Si grain boundaries crossing the direction of current flow. The mobility of poly-Si TFTs using directional laterally grown poly-Si films has been reported as more than 500cm2/V.s [9,10]. Moreover, the flat surface of the Si film should make it possible to successfully implement a thin gate oxide film. We have not yet measured device performance of this material, but expect the mobility for thin beam crystallized materials should be up to 500cm2/V.s, which is sufficient for the SOP applications [6].

The reliability of the crystallization process is important for a practical production process. We checked the process window of the TDX technique by investigation of the poly-Si microstructure after intentionally changing the energy density of the laser beam and focal position of the optics. The energy range for the lateral growth was quite wide (approx. 450mJ/cm^2 and 820mJ/cm^2) with the lateral growth length increasing proportionally with energy density (Figure 4).



2(a)



2(b)

Figure 3. Micrographs showing poly-Si microstructure after (a) single pulse irradiation and after (b) scanning with translation step of 1.5um using the TDX method.

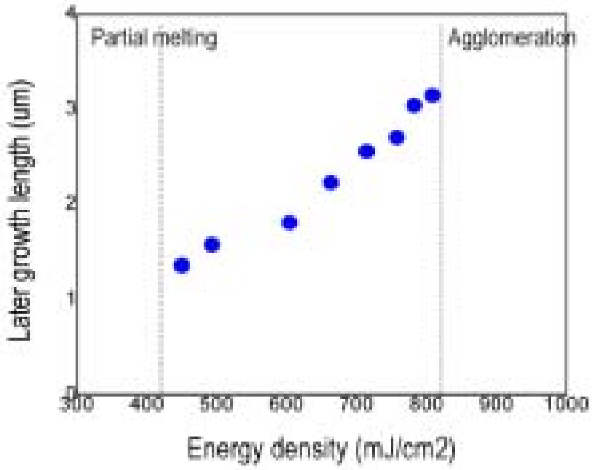


Figure 4. Effect of pulse energy density on the lateral growth.

The poly-Si crystal structure was very consistent over a large depth of focus. Figure 5 shows the lateral growth during single laser pulses, with the focus shifter by ±60μm. From this data, we believe that the TDX process offers a large process window, and should be promising method for stable production for poly-Si substrates.

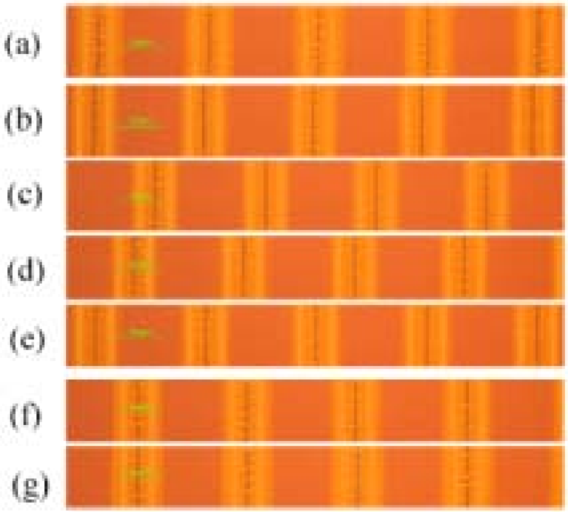


Figure 5. Poly-Si microstructures after changing the substrate position of (a) –60um, (b)-40um, (c) –20um, (d) 0um, (e) 20um, (f) 40um, and (g) 60um from the optical focal position.

In the conventional ELA process, the most common cause of the non-uniformity in poly-Si TFT characteristics is pulse energy variation and the narrow process window. Generally, the translation step of the ELA process is between 10 to 20um, which is close to the TFT dimension. An abrupt change of laser pulse energy can induce a significant change of the TFT properties, which then causes a significant non-uniformity in the OLED display image. Decreasing the translation step improves the uniformity of the poly-Si TFT properties, but this also causes a significant decrease in the throughput.

In comparison, the translation step for the TDX method is much smaller (~2 microns). Since the laser is operating at a much higher repetition rate (~4 kHz), many pulses are included in one TFT channel without sacrifice of process throughput. Since the process window of the TDX method is much larger than ELA (as shown in Figure 4 and 5), we expect the uniformity of TFT properties will be much better.

Another source for non-uniformity can be produced by multiple passes to expose the substrate. If the length of the laser beam is shorter than the width of the mother glass, the substrate must be scanned multiple times in order to completely cover the substrate. This causes an overlapped region where can have different mobility properties, so that the maximum display panel size could be limited depending on the beam length.

Finally, we have compared the throughput that would be expected for a possible production version of TDX system. The TDX process throughput depends on the laser repetition rate, the beam length and the step size:

Process time ≈ 1/(beam length × repetition rate × scan pitch).

To insure high throughput, and to avoid unusable stitching regions, we believe that the substrate should be exposed in a single pass. To increase the beam length, the laser must produce more energy per pulse. When combined with the desire for a high repetition rate, this means that the throughput is directly proportional to the available laser power. Another approach to higher throughput would be to increase the scan pitch, which requires an increase of lateral growth length. Using realistic values for a possible commercial tool, Table 1 shows the calculated process time for both a Gen 4 version using both the ELA and TDX process.

Table 1: comparison of thin beam and ELA throughput using typical process parameters.

	ELA	TDX
substrate size (mm)	730X920	730X920
laser rep. Rate (Hz)	300	6000
laser pulse energy (mJ)	1000	150
Beam dimension (mm)	465X0.4	720X0.005
Overalp (%)	95	60
Process time per panel (sec.)	~250	~75

In this example, a thin beam crystallization annealing tool with a 6 kHz, 900W laser would process an entire Gen 4 panel in approximately 75 seconds, compared to approximately 250 seconds for the ELA process.

4. Acknowledgements

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