Recent advances in excimer-laser-based crystallization for active-matrix displays

Brandon A. Turk,[1] Ludolf Herbst,[2] Frank Simon,[2] and Rainer Paetzel [2]
[1]Coherent, Inc, 5100 Patrick Henry Drive, Santa Clara, CA, 95070 USA
TEL:+1-408-764-4586, e-mail: brandon.turk@coherent.com
[2]Coherent, GmbH, Hans-Boeckler-Strasse 12, 37079, Goettingen, Germany

Keywords : ELA, SLS, AMLCD, AMOLED, TFT

Abstract

Excimer-laser-based crystallization is ideally-suited for forming crystalline Si films on glass substrates for use in active-matrix displays. In this paper, we will report on recent and significant technical advances in light sources and beam delivery systems targeted at enabling ultra-uniform mura-free low-temperature polycrystalline silicon active-matrix backplanes while simultaneously lowering production costs and increasing throughput.

1. Introduction

In recent years, Low Temperature Polycrystalline Silicon (LTPS) has demonstrated its advantages through successful implementation in the application spaces that include highly-integrated active-matrix liquid crystal displays (AMLCDs), cost competitive AMLCDs, and most recently, active-matrix organic light emitting diode displays (AMOLEDs). In the mobile display market segment, LTPS continues to displace a-Si technology, as consumers demand mobile devices with higher display performance, longer battery life and reduced form factor. LTPS-based mobile displays have clearly demonstrated significant advantages in this regard.

While the benefits of LTPS for mobile phones are well recognized, other mobile electronic applications such as portable multimedia players, tablet computers, ultra-mobile personal computers and notebook computers stand to benefit from the performance and potential cost advantages offered by LTPS.

With the advent of AMOLED displays, efforts to enable robust and cost-effective LTPS backplane manufacturing have gained significant attention. Current commercially available AMOLED displays are aimed at mobile applications, but it is expected that continued development of the technology will eventually lead to larger display sizes. Since LTPS is essentially required for AMOLED displays, LTPS technology should be ready to move beyond the small and medium displays sizes where it is found today.

With these technical advances and market opportunities for LTPS, it becomes extremely critical for the manufacturers of LTPS equipment to ensure widespread adoption of the technology by enabling robust manufacturing techniques, while reducing the cost of operation and increasing the production yield.

2. Background

In LTPS manufacturing, excimer lasers are used to transform as-deposited amorphous-Si into polycrystalline films. As laser light is efficiently coupled to the Si film in an extremely localized manner (within the first few nanometers of the Si film), the various laser-based production processes are entirely compatible with the glass and plastic substrates used for display manufacture.

Non-laser-based rapid thermal annealing (RTA) approaches are generally limited, in part because of the limited possibilities for solid transformation within a solid matrix. Efforts to enhance the process often lead to additional complexities. For example, when metal impurities are used to catalyze the transformation, additional and non-trivial process steps are needed to counteract the increased TFT leakage current. Considerable efforts must also be made to ensure a uniform energy distribution across a large substrate. Additional effects such as glass warping, compaction and breakage may also cause yield problems in a manufacturing environment.

In production, the vast majority of crystallization processes are excimer-laser-based. The two most noteworthy approaches being excimer laser annealing (ELA) and sequential lateral solidification (SLS).[1]

ELA is the mainstream LTPS crystallization technique, and has been proven in production over many years. SLS is a more recent and advanced approach that has now demonstrated itself to be a viable manufacturing option for LTPS.[2]

3. Recent Technical Advances

3.a. Excimer laser development

For LTPS to be successful, the crystallization techniques used in production must not be cost prohibitive, and must yield a material that affords sufficient performance and uniformity for the application. The performance characteristics of the laser used for crystallization have a direct and significant influence on the uniformity of the resulting polycrystalline Si material. For example in ELA, significant shot-to-shot pulse energy fluctuations are known to result in "shot mura" which can sometimes be visible directly on the processed display glass.

Excellent pulse energy stability at 308 nm has been achieved by developing a new laser platform, referred to as LAMBDA SX (LSX), which incorporates both improved laser discharge technology and higher computing power allowing for optimal feedback algorithms.

Pulse-to-pulse energy stability data taken from an LSX 315C (308nm, 300Hz, 1050mJ/pulse) is shown in Figure 1. The data shows that over a continuous run lasting more than 2 days, the RMS energy fluctuation is about 0.5% sigma over 60 million pulses. By achieving a peak-to-peak energy fluctuation significantly lower than 5%, the effective probability of the laser inducing "shot mura" in production is essentially zero.[3]

The improved stability of the laser is attributed to three main design improvements. The solid state pulser that is used to switch the energy into the laser gas has been optimized and an improved steepness of the voltage pulse at the laser electrodes has been achieved. This steeper voltage pulse leads to increased efficiency and higher reproducibility from pulse to pulse. Secondly, the laser gas flow characteristics inside of the laser tube have been specifically optimized to yield higher energy stability and reduced maintenance. Lastly, the newly developed laser platform comes with a high resolution energy detection system and a fast energy control loop. This new laser control system allows active stabilization of the laser output and avoids drift effects and instabilities.

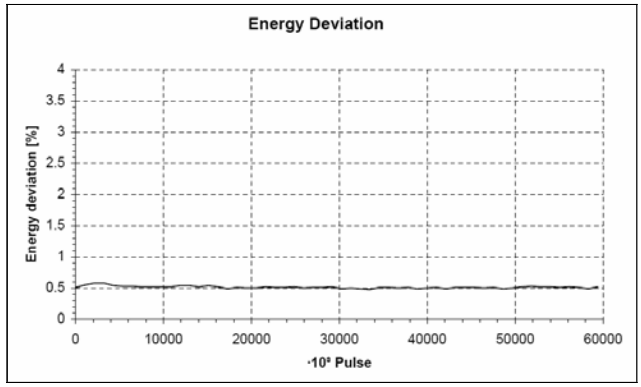

Figure 1: Energy stability as measured from the LSX315C, a 315 Watt XeCl excimer laser, over 60 million pulses. The high stability of about 0.5% (sigma) was maintained continuously over the entire run, which lasted more than 55 hours.

Other practical improvements in the laser's design have also been implemented in order to reduce the total cost-of-ownership. In particular, component lifetimes have been extended through enhanced predictive maintenance capabilities. For example, laser performance can be controlled online with the advanced e-diagnostic software tools.

We have also developed an active beam stabilization (ABS) system and control system that is designed to automatically compensate for pointing drifts from the laser. The system consists of photo-detectors that monitor the near- and far-field beam profiles. These signals are used to drive motorized folding mirrors that maintain the beam pointing and position while correcting for any long term system drifts. The ABS system is advantageous not only in preventing production run errors, but also in enabling the system to automatically recover following scheduled maintenance without the need for time consuming optical realignment.

Most recently, we have developed the LSX540C, a 540W XeCl laser operating at 600Hz, in an effort to increase the throughput of existing crystallization techniques. The higher repetition rate of the laser directly translates into a significant increase in the crystallization rates of both the ELA and SLS processes, which in turn enables more productive manufacturing tools.

3.b. ELA optical delivery systems

The performance characteristics of the laser used for crystallization are critical to the process, as is the performance of the optical delivery system used to homogenize, shape and deliver the radiation to the sample surface.

In an ELA optical delivery system, light is shaped into a high aspect ratio line beam, the longest commercially available offering currently being 465mm. Achieving sufficient uniformity over the entire length of the line, so as to create uniform polycrystalline material during the laser process, is a critical requirement. Through years of experience and refinement of optical design, we are able to achieve a peak to peak uniformity of better than 5% across the line. This level of uniformity is sufficient for most ELA applications.

However, AMOLED tends to demand extreme performance from the optical system, because the current driven AMOLED devices are susceptible to threshold voltage variations that are challenging to eliminate in polycrystalline material. Although the high performance of the laser can completely eliminate the “shot mura”, other visual artifacts can remain in the direction of the scan even when processed with a system having excellent beam uniformity.

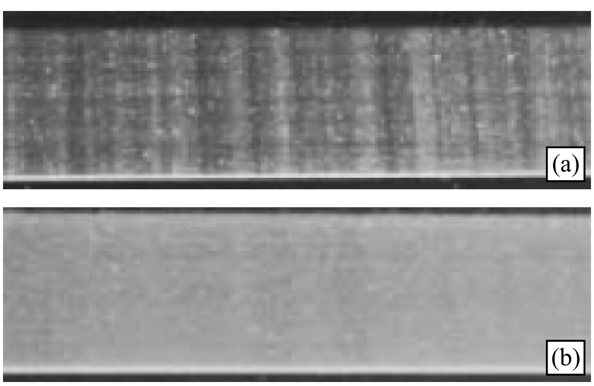

Figure 2: Optical microscope image of 50nm Si films crystallized by ELA. The films were processed at the same conditions a) without and b) with the micro-smoothing technology.

Through advanced engineering and hardware optimization, we have recently demonstrated that our proprietary “micro-smoothing” technology is able to produce highly-uniform and mura-free backplanes with existing ELA optical delivery systems.

Figure 2 shows two separately processed regions of a 50nm Si film on glass that has been crystallized with a 465mm linebeam optical delivery system combined with an LSX315C excimer laser. In the experiment, we have intentionally detuned the optics and set the energy density such that the line mura in the scanning direction is clearly visible in the optical image. Figure 2(a) illustrates the general features that are observable in this scenario. These undesirable features are effectively eliminated by implementing the micro-smoothing technology, as shown in Figure 2(b).

The combination of the LSX315C and micro-smoothing enables ELA to yield a highly-uniform LTPS backplane that meets the high demands of AMOLED applications.

3.c. SLS optical delivery systems

SLS, having recently been demonstrated as a viable manufacturing technique, can claim several advantages: 1) TFTs made in SLS-processed Si films can demonstrate high electron mobility and good uniformity, 2) SLS can be made to operate with high throughput rates and 3) the 2D mask-projection-based implementation of SLS is the only technique that directly enables formation of continuous polycrystalline Si films on any size substrate.[4]

The productivity of an SLS tool can be higher than that of any other crystallization technique. By utilizing our 600Hz LSX 540C Excimer laser, the crystallization rate is doubled when compared to existing SLS tools. In order to take full advantage of the high laser power, and to increase the performance of the optical delivery system, we have developed a new projection lens that is designed for high power operation. The lens not only has excellent thermal characteristics (by minimizing focal plane shifts due changes in optical power) but also improves image quality by reducing distortions. The result improves on an already robust manufacturing solution for LTPS; by combining the high power projection lens and LSX 540C, we are able to offer improvements in the productivity and yield of our existing and mass-production-proven SLS technology.

Another distinct advantage of the 2D-projection-based SLS approach is its inherent ability to scale to larger panel sizes without introducing any unwanted stitching lines or scan artifacts. With competitive approaches, for example thin-beam directional crystallization (TDX), the scanned area that can actually be used for a display is limited by the line length. While this may not be a significant problem for mobile displays (simply place the devices outside of the overlapped area), it will never provide a roadmap to larger AMOLED displays, for example, in the television-sized domain. Even in the small to medium display size regime, reducing the number of overlap lines (and effectively increasing the useable area on the panel) is desirable.

The 2D-projection implementation of SLS is the only approach that allows polycrystalline Si material to be uniformly generated across the entire substrate, with no discontinuities, regardless of substrate size. The introduction of our new LSX540C 600Hz laser and high power projection lens will enable very high productivity LTPS systems for Generation 5 and beyond.

4. Summary

ELA and SLS are two laser-based crystallization methods that are routinely used in industry to produce LTPS films for the fabrication of TFTs. We are enabling the manufacture of highly-uniform and mura-free LTPS backplanes for both AMLCD and AMOLED applications, by continuing to develop our core technologies.

Our highly reliable and robust industrial laser platform was designed with the specific intention of meeting and exceeding the pulse stability demands of the LTPS manufacturers. We have demonstrated a 600Hz version of our industrial standard laser, marking a significant breakthrough for productivity of LTPS crystallization systems. In addition, we have demonstrated our micro-smoothing technology for ELA and our high power projection lens for SLS, both of which enable display manufactures to realize high productivity and excellent yield in the LTPS crystallization process.

5. References

1. J. S. Im and R. S. Sposili, “Crystalline Si films for integrated active-matrix liquid-crystal displays” *MRS Bulletin* **21**, No. 3, p.39 (1996).

2. C.W. Kim, K.C. Moon, H.J. Kim, K.C. Park, C.H. Kim, I.G. Kim, C.M. Kim, S.Y. Joo, J.K. Kang, and U.J. Chung, “Development of SLS-based system on glass display”, *SID Int. Symp. Digest of Technical Papers*, **35**, pp. 868-71, 2004.

3. L. Herbst, B.A. Turk, R. Paetzel, “Excimer Laser Systems for LTPS Manufacturing”, *proceedings of the 2007 International Display Manufacturing Conference*, Taipei, Taiwan, (2007).

4. B.A. Turk, F. Simon, R. Paetzel, “2D-projection-based method for forming uniform and high-quality poly-Si films via Sequential Lateral Solidification”, *proceedings of the 2007 International Thin-film Transistor Conference* Rome, Italy (2007).