Laser Thermal Processing System for Creation of Low Temperature Polycrystalline Silicon using High Power DPSS Laser and Excimer Laser

Doh-Hoon Kim*, Dae-Jin Kim

Advanced Optical Equipment Division, Kornic Systems Co., Ltd.
605 Jung-Ri, Dongtan-Myun, Hwaseoung-Si, Gyeonggi-Do, 445-813 Korea
Phone: +82-31-379-2831, Fax: +82-31-379-2800, E-mail: dhkim@kornic.co.kr

Abstract

Low temperature polycrystalline silicon (LTPS) technology using a high power laser have been widely applied to thin film transistors (TFTs) for liquid crystal, organic light emitting diode (OLED) display, driver circuit for system on glass (SOG) and static random access memory (SRAM). Recently, the semiconductor industry is continuing its quest to create even more powerful CPU and memory chips. This requires increasing of individual device speed through the continual reduction of the minimum size of device features and increasing of device density on the chip. Moreover, the flat panel display industry also need to be brighter, with richer more vivid color, wider viewing angle, have faster video capability and be more durable at lower cost.

Kornic Systems Co., Ltd. developed the KORONA^{TM} LTP/GLTP series – an innovative production tool for fabricating flat panel displays and semiconductor devices – to meet these growing market demands and advance the volume production capabilities of flat panel displays and semiconductor industry. The KORONA^{TM} GLTP/LTP series using DPSS laser and XeCl excimer laser is designed for the new generation of the wafer & FPD glass annealing processing equipment combining advanced low temperature poly-silicon (LTPS) crystallization technology and object-oriented software architecture with a semi-standard graphical user interface (GUI). These leading edge systems show the superior annealing ability to the conventional other method. The KORONA^{TM} GLTP/LTP series provides technical and economical benefits of advanced annealing solution to semiconductor and FPD production performance with an exceptional level of productivity. High throughput, low cost of ownership and optimized system efficiency brings the highest yield and lowest cost per wafer/glass on the annealing market.

1. Introduction

Polycrystalline silicon (poly-Si) thin films have been widely used as metal-oxide-silicon (MOS) gates [1], emitter contacts of bipolar transistors, load resistors in memory cell, solar cell and various other applications in semiconductor device technology. The high mobility of low-temperature poly-Si thin film transistor (TFT) enables external ICs to drive the pixels to be integrated on a panel. This yields a light and thin display with a reduction in the number of connection pins and also improves both the reliability of the panel and the resolution of displays. Further improvement of poly-Si TFT's performances enables the memory and controller to be integrated on a glass panel and an advanced ideal display, so called system on panel (SOP), can be realized [2, 3].

Poly-Si TFTs based on conventional excimer laser annealing (ELA) method allow a limited integration of circuits because of the relatively low field-effect mobility of 50–200 cm^2/V-s. For the ELA crystallization, non-uniformity of grain size and narrow process window make it difficult to achieve uniform TFT performance [2, 4]. Therefore, the key technology for achieving the system on panel (SOP) is to improve both the performance and uniformity of TFTs. To satisfy these needs, several crystallization methods based on lateral growth technique such as selectively enlarging laser X'tallization (SELAX) [5], diode pumped solid state (DPSS) CW laser lateral crystallization (CLC) [6–8] and sequential lateral solidification (SLS) [9–11] technologies have been proposed.

In recent, Kornic System has developed innovative laser annealing system to meet the requirement of FPD manufacturer for enlarging the grain size and for improving the TFT performance and uniformity. We introduce a line beam annealing system for low temperature poly silicon crystallization.

2. Laser Crystallization technologies

2.1 Excimer Laser Thermal Processing System

Kornic System has developed an excimer laser crystallization system named KORONA^{TM} LTP series, which is consist of high power excimer laser, beam delivery optics, process chamber, and transfer chamber and buffer station. KORONA^{TM} LTP series using an excimer laser is shown in Fig. 1.

For this laser crystallization system, high power XeCl excimer laser was used as a light generator with wavelength of 308 nm, maximum repetition rate of 300 Hz and stabilized maximum power of 315 W. The pulse stability of laser which used in this system is less than 1% at 1 sigma.

The laser beam generated from high power eximer laser was shaped and expanded using various optical components to 370 mm long line beam for easy scanning of the entire substrate, generation 3.5 glass. The initial laser beam which has Gaussian profiles was shaped into homogenized beam profile by homogenizer optics to realize uniform crystallization on the entire FPD glass. KORONA^{TM} LTP series with 370 mm long line beam can irradiate the whole area of G3.5 glass and applicable to larger substrate of G4 and G5 later.

Process chamber which laser crystallization takes place in is mainly consists of precise X, Y and rotation stage, vacuum system and gas supply system that control the chamber pressure and ambient. Process chamber was evacuated using a mechanical dry pump attaining a base pressure of approximately 10^{-3} Torr. Transfer chamber and buffer station also are evacuated by mechanical pump and turbo molecular pump attaining a base pressure of about 10^{-4} Torr.

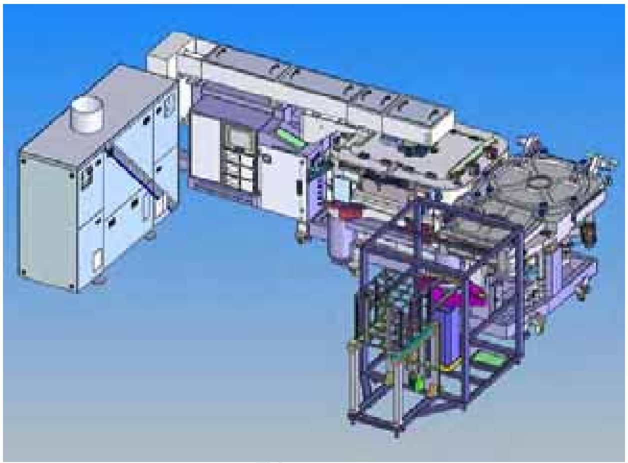

Figure 1. KORONA^{TM} LTP system using a high power excimer laser.

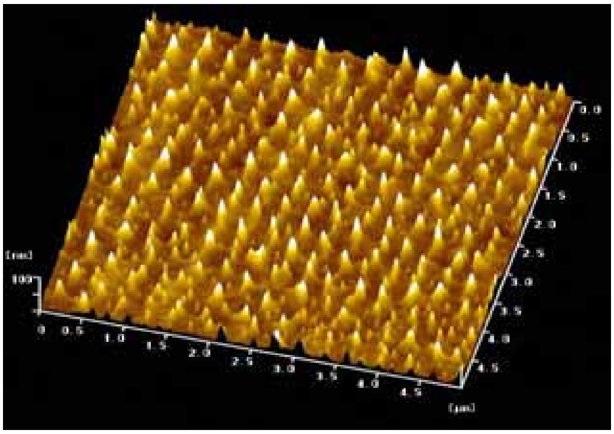

Figure 2. 3-dimensional AFM surface morphology of the laser irradiated crystallized poly-Si film at energy density 310 mJ/cm^2 with 95% overlap.

Surface roughness is very important characteristic of poly-Si film because it is related to the reliability of the gate SiO_2 [12]. The surface morphology of poly-Si films was observed by atomic force microscope (AFM), as shown in Fig. 2. The root-mean-square (RMS) roughness value is about 9.9 nm. Figure 2 shows the image obtained at laser irradiation of 310 mJ/cm^2 with laser beam overlap of 95% in N_2 atmosphere environment.

The average grain size values are plotted in Fig. 3 for energy densities in the range of 283–310 mJ/cm^2 with a various laser beam overlap, 95% and 97.5%. The average grain size progressively increases as the energy density and laser beam overlap increases as shown in Fig. 3.

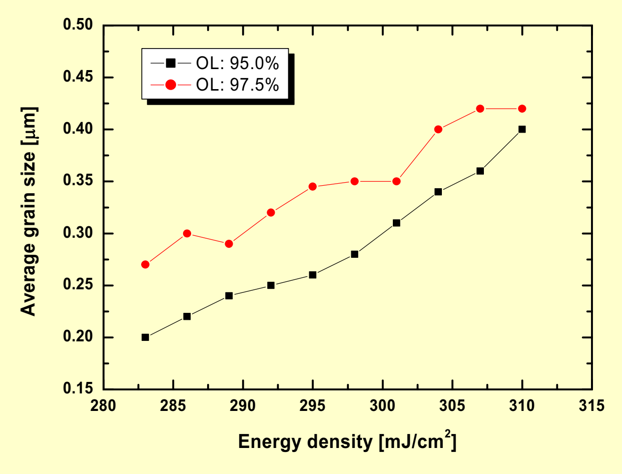

Figure 3. Results of average grain size value of poly-Si as a function of laser energy density with repetition rate of 300 Hz using KORONA^{TM} LTP series.

2.2 Green Laser Thermal Processing System

The annealing technology utilizing a high-power diode pumped solid state laser beam is introduced to crystallize the amorphous silicon film deposited onto the LCD glass by low pressure chemical vapor deposition (LPCVD) with a thickness of 50 nm. The laser used in this system is a pulsed diode pumped solid state (DPSS) laser with wavelength of 532 nm. This laser has a maximum repetition rate of 50 kHz pulse and pulse duration of approximately 150 ns. Annealing and crystallization process were performed at a repetition rate of 10 kHz. The features of DPSS laser annealing system is shown in Fig. 4. The laser annealing system, which is installed in semiconductor production line, consisted of a DPSS laser, beam delivery optics system and X, Y air-bearing translation stage. Beam delivery optics system included a variable attenuator, telescope lenses, homogenizer array, focus lens and imaging lens.

The output laser beam, which is diameter of 2 mm, is expanded and shaped to a line beam by using a homogenizer for the easy scanning of the entire substrate surface. The final focused laser beam had an inhomogeneous distribution of less than ± 5% in long axis, but the beam profile of the short axis shows the Gaussian beam shape. The expanded beam is focused by projection lens and the final focused laser beam on the top of the substrate has the beam length of 5 mm with a variable beam width, which depends on required laser energy density. The laser energy density of the incident line beam was controlled by adjusting the beam width by moving the projection lens that was positioned on a linear translation stage. Changing either the laser beam width or the output laser beam energy can vary the irradiated laser energy density of the incident line beam. The applied laser energy density was varied 850 – 1,700 mJ/cm^2.

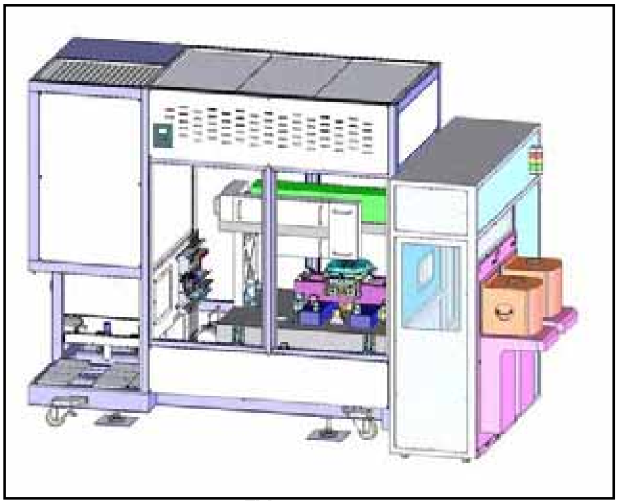

Figure 4. KORONA^{TM} GLTP system using a high power DPSS laser.

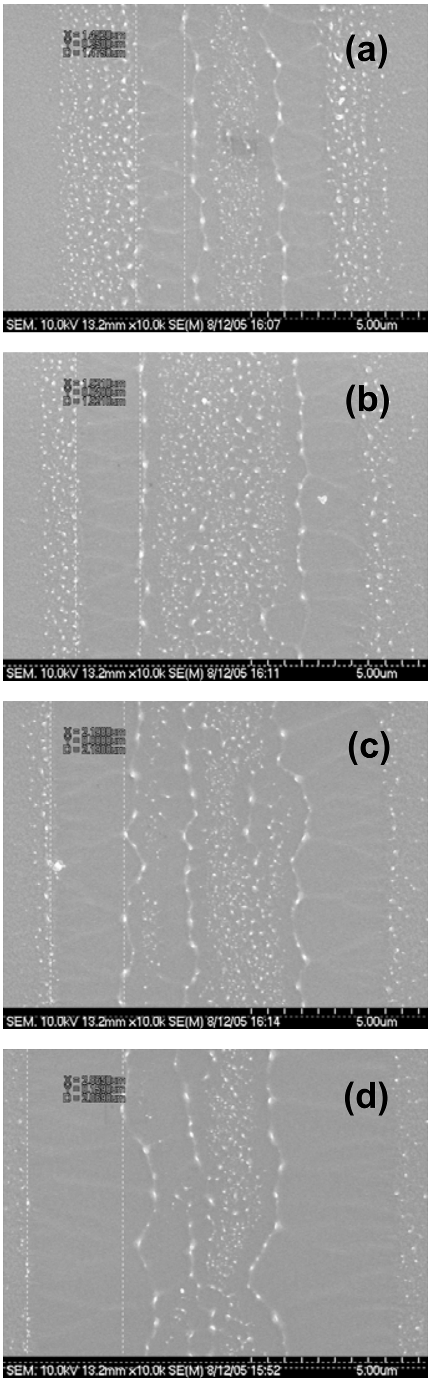

Figure 5. SEM images of single pulse irradiated Si films after irradiation at the laser energy density of 850 mJ/cm^2 (a), 1,000 mJ/cm^2 (b), 1,150 mJ/cm^2 (c) and 1,315 mJ/cm^2 (d) with 8 μm beam width.

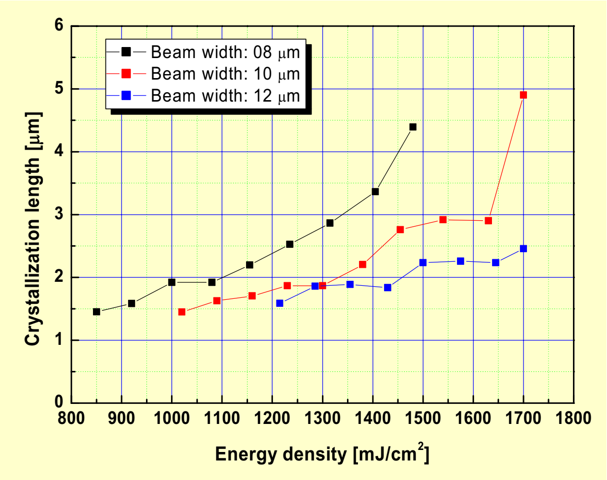

Figure 6. Results of crystallized length of 50 nm-thick poly-Si film as a function of energy density with various beam width using KORONA^{TM} GLTP series.

The surface morphology of poly-Si films was observed at various laser energy densities by SEM, as shown in Fig. 5. Figure 5 (a)–(d) show the images of the poly-Si film after laser irradiation for the laser energy densities of 850 mJ/cm^2, 1,000 mJ/cm^2, 1,150 mJ/cm^2 and 1,315 mJ/cm^2, respectively. As the laser energy density was increased, the crystallization length was observed to be larger. After laser crystallization, lateral crystallization length at 8 μm beam width of about 1.5 μm, 2 μm and 3 μm were obtained with laser energy density of 850 mJ/cm^2, 1,000 mJ/cm^2 and 1,315 mJ/cm^2, respectively. The lateral grain growth sizes were summarized as a function of laser energy density at various laser beam width in Fig. 6.

3. Summary

In summary, LTPS technologies based on high power excimer laser and DPSS laser are now widely established for use in AM-LCD and AM-OLED applications. These systems and technologies have been proven to fulfill the most significant design and manufacturing quality standards for current and next generation FPD manufacturing.

Kornic Systems developed the KORONA^{TM} LTP and GLTP series to meet these growing market demands and advance the volume production capabilities of FPD and semiconductor industry. The KORONA^{TM} LTP and GLTP series provides technical and economical benefits of advanced crystallization solution to semiconductor and FPD production performance with an exceptional level of productivity. High throughput, low cost of ownership and optimized system efficiency brings the highest yield and lowest cost per wafer/glass on the annealing market.

4. References

[1] F. Faggin and T. Klein: Solid State Electron. **13** (1970)1125.
[2] N. Ibaraki: SID '99 Dig., 1999, p. 172.
[3] T. Nishibe: Eurodisplay, 2002, p. 269.
[4] S. D. Brotherton, D. J. McCulloch, J. B. Clegg and J. P. Gowers: IEEE Trans. Electron Devices 40 (1993) 407.
[5] M. Hatano and T. Sjiba: SID'02 Dig., 2002, p. 158.
[6] F. Takeuch, M. Takei, K. Hotta, K. Yoshino, K. Suga, A. Hara and N. Sasaki: AM-LCD'01, 2001, p. 251.
[7] K. Yamazaki, T. Kudo, K. Seike, D. Ichishima and C. Jin: AMLCD' 02, 2002, p. 149.
[8] A. Hara, F. Takeuchi, M. Takei, K. Suga, M. Chida, Y. Sano and N. Sasaki: AMLCD'02, 2002, p. 227.
[9] R. S. Sposili and J. S. Im: Appl. Phys. Lett. 69 (1996) 2864.
[10] J. S. Im and R. S. Sposili: MRS Bulletin 21 (1996) 39.
[11] J. S. Im, M. A. Crowder, R. S. Sposili, J. P. Leonard, H. J. Kim, J. H. Yoon, V. V. Gupta, H. J. Song, H. S. Cho: Phys. Status Solidi 166 (1998) 603.
[12] Akito Hara, Michiko takei: Jpn. J. Appl. Phys. Vol43 (2004) p. 1269.