Thin-Beam Excimer Laser Annealing

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Abstract

Thin Beam Excimer Laser Annealing is investigated as one possible process enabled by the variable concept of Thin Beam LTPS processing. The structure of the resulting p-Si material is analyzed in terms of grain size distribution, scaling with energy density and overlap, as well as average surface roughness. This process provides similar control and latitude as conventional excimer laser annealing, but reduced average surface roughness and the potential to be scaled to significant productivity levels.

Introduction

As flat panel displays add increasing resolution and advanced capabilities, designers are pushing for smaller and faster high performance driver and support circuitry. This translates into a requirement for enhanced thin film transistor performance necessitating increased electron mobility and material uniformity in the p-Si back plane.

One promising technology for producing such advanced p-Si material is the Thin-beam Directional X-talization (TDX) process[1]. In TDX, light from a high repetition excimer laser is shaped into a high aspect ratio line beam with a very small short axis dimension of approximately 5 µm only; wide enough to cover the entire width of the glass substrate in the long axis dimension in a single pass scan.

The energy density in TDX processing is chosen so that each laser pulse completely melts the a-Si film within the irradiated zone. Because of the narrow dimension and profile of the beam, the resulting p-Si material crystallizes laterally. Each pulse overlaps with the previous crystallized region thus seeding the lateral growth of crystals from the previous pulse yielding long p-Si grains with a protrusion free smooth surface. As a result of the extended grain dimension, electron mobility results of up to 500 cm^2/Vs have been reported[2].

Besides, recent results[3] demonstrate that thin beam based LTPS processing provides the variability of not only being used for TDX and Thin Beam Sequential Lateral Solidification, (TB-SLS), but also for Thin Beam Excimer Laser Annealing (TB-ELA). All processes can, in principle, be supported as complimentary operational modes on the TCZ900C high volume production system.

While TDX and TB-SLS are being discussed elsewhere, results of an initial investigation of the TB-ELA process are presented in this paper. The focus is on process control and –latitude, surface roughness and throughput potential.

Experimental Set-up

This work was conducted using TCZ's Gen2 prototype system. It utilizes Cymer's XLX100

Xe-F excimer laser which operates at 351 nm wavelength and up to 4 kHz repetition rate. The optical system is provided by Carl Zeiss and generates the thin beam of 370 mm long axis length and a short axis of only 5 µm width. The resultant energy density is up to 1100 mJ/cm^2, allowing the TDX process that this system was originally specified for.

For investigating the TB-ELA process subject to this paper, the maximum energy density was lowered to a maximum of ED_{max} = 450 mJ/cm^2 which is just below the complete melt threshold of the a-Si films used in this experiment. This was achieved by re-aligning the optics to expand the short axis profile, and it allowed conserving the energy incident on the substrate for optimizing scan speed. The optics re-alignment also aimed at generating a top hat like profile which is expected to produce a more favorable p-Si grain structure. The resulting thin beam characteristics are shown in figure 1.

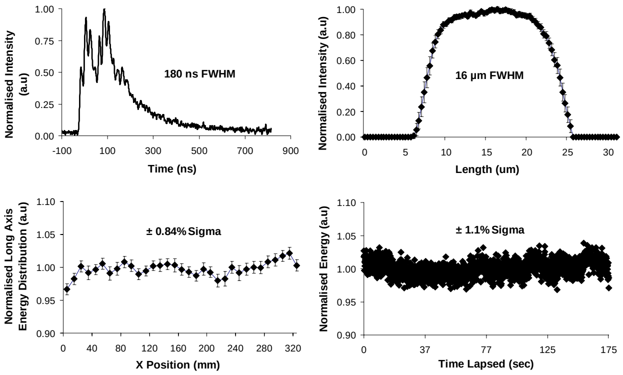

Figure 1: TB-ELA characteristics of TCZ's prototype system: (top left) laser pulse intensity versus time, (bottom left) normalized energy density as a function of long axis position, (top right) normalized energy density as a function of short axis position measured at the center position of the long axis, and (bottom right) normalized energy (energy density integrated over short axis profile) measured at the center position of the long axis as a function of time.

The substrates used in this experiment are Gen2 size glass sheets with a PECVD deposited a-Si film of 50 nm thickness. They were annealed under the conditions summarized in table 1. The energy density incident on the substrates was varied between 377mJ/cm^2 < ED < 428 mJ/cm^2 in order to investigate the process control offered by TB-ELA, the influence on surface roughness and the throughput potential.

Condition	Laser repetition rate (in kHz)	Step Size (in microns)	Overlap (in %)
A	2.5	0.50	97
B	2.5	1.25	92
C	2.5	1.75	88

Table 1: Annealing conditions chosen for characterizing the TB-ELA process.

Experimental Results

The produced p-Si material was characterized by SEM analysis using a JEOL FESEM system for each experimental condition and each applied energy density. Figure 2 shows a sample SEM image that demonstrates the capability of the TB-ELA process to yield highly homogenous p-Si material with general grain shape in cluster formations.

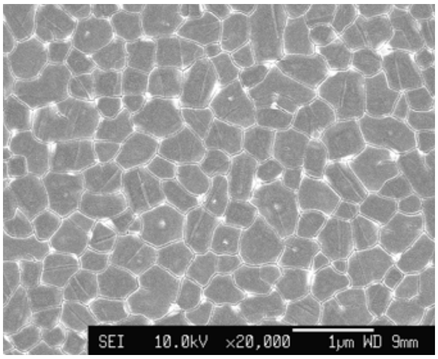

Figure 2: Homogenous TB-ELA p-Si material produced with 1.25µm step size.

Based on SEM images of 5 µm x 6 µm sample size, mean grain size and sigma grain size variation were quantified in both dimensions, i.e. parallel and perpendicular to the scan direction. The comparison of the mean grain size parallel and perpendicular to the scan direction reveals no significant difference at energy densities higher than ED = 390 mJ/cm^2 (Figure 3). TB-ELA p-Si material is therefore highly isotropic and, for the further analysis, the mean grain size is calculated as the average of the mean values measured parallel and perpendicular to the scan direction. Likewise, the sigma grain size variation is calculated as the average of the sigma variations parallel and perpendicular to the scan direction.

Figure 4 shows the mean grain size as a function of energy density for each step size with the sigma grain size variation presented as error bar to each data point. The following observations are made. Firstly, the mean grain size scales with energy density for all step sizes. TB-ELA thus provides control of grain size for all investigated experimental conditions, i.e. grain size can be distinctly selected by proper adjustments of energy density.

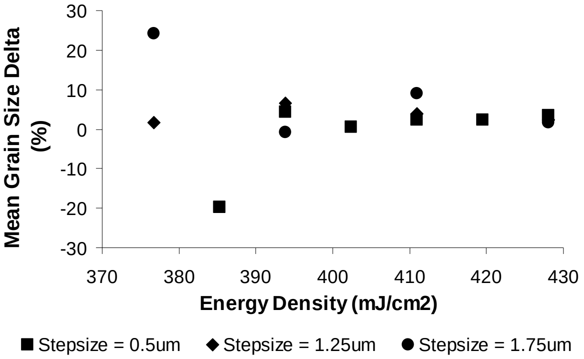

Figure 3: Percentage difference between mean grain size parallel and perpendicular to the scan direction as function of energy density and step size.

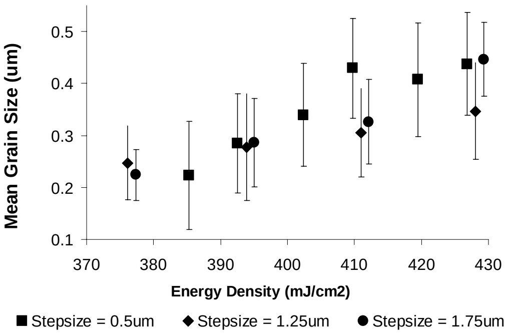

Figure 4: Mean grain size and sigma grain size variation (presented as error bars) as a function of energy density.

Secondly, the process window can be estimated by the energy density variation that is necessary to increase the mean grain size by an amount equal to the sigma grain size variation. For 0.3 µm mean grain size, it is about ±20 mJ/cm^2 or 10% which is in good agreement with conventional ELA. Finally, the observed trend shows no significant dependency on step size within the investigated parameter range.

In order to determine the capability of the TB-ELA process to stably produce grain sizes within given specifications, the C_P capability indices[4] was calculated from the measured data for groups of grain sizes that fall within ±0.05 µm grain size intervals. The capability of a process increases with the value of C_P. Figure 5 shows that TB-ELA reaches a process capability of $10 < C_P(\text{TB-ELA}) < 20$ for 0.5 µm and 1.25 µm step size, which compares well with the typical capability of the conventional ELA process. However, at 1.75 µm step size, C_P increases desirably to a value of about $C_P = 40$ in this TB-ELA experiment. This result suggests the use of the larger investigated step size to the advantage of throughput.

The produced TB-ELA p-Si material was also characterized by tapping mode AFM analysis concluding the average roughness R_a as mean value of the measured surface topography data

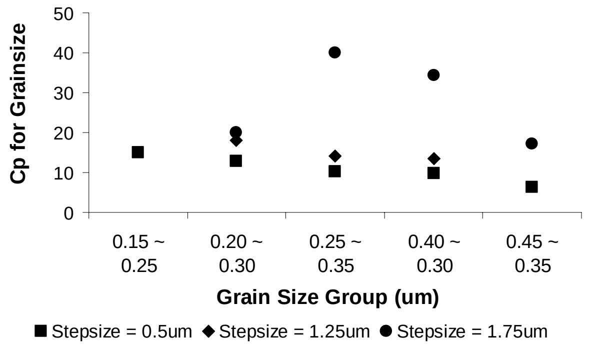

Figure 5: The C_P capability indices for TB-ELA as a function of grain size.

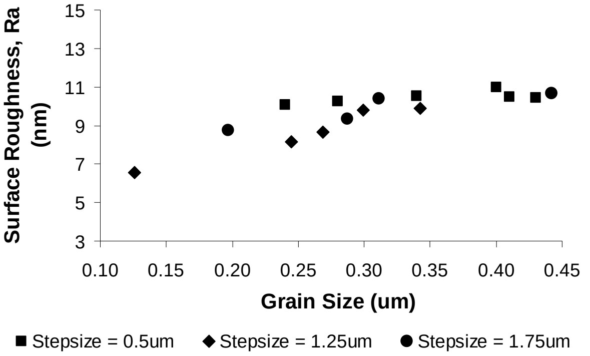

Figure 6: Surface roughness of the TB-ELA p-Si material as function of mean grain size and step size.

for all conditions and energy densities investigated in these experiments (Figure 6). R_a shows no dependence on step size and increases with grain size to reach saturation at R_a (TB-ELA) ≈ 10 nm. This presents an improvement compared to the typical surface roughness of conventional ELA p-Si material of R_a (ELA) ≈ 15 nm.

Conclusions and Outlook

We have investigated the potential of the recently proposed TB-ELA process. Our results confirm that the characteristics of the produced p-Si material compare well with the typical quality created by conventional ELA, including process control, -latitude and -capability indices. These results indicate an average surface roughness that is lower than the level obtainable with conventional ELA. This might allow reducing the insulating gate oxide layer thickness and, thereby, creating further room for improving TFT performance and ion doping control.

We also observe a low sensitivity to step size for the process window size and the average surface roughness. The process capability indices C_P even improves with step size for the investigated experimental conditions. This result suggests that the TB-ELA process quality could be maintained even for larger step sizes.

The TCZ900X Gen4 system is specified to operate at laser repetition rates of up to 6 kHz, and with a long axis beam length of 730 mm. With the largest step size reported in this paper, the projected scan speed is 76 cm^2/s. A Gen4 substrate of 73 x 92 cm^2 can therefore be scanned within about 90 seconds. Assuming 45 seconds overhead time for a single path scan process, the throughput potential of TB-ELA is expected to be 27 Gen4 substrates per hour.

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