Thick single grain silicon formation with microsecond green laser crystallization

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The μ-Czochralski process which has been developed in TU Delft enables 2D location-control of single grain using pulsed-laser crystallization [1]. 6 μm Si grains have been obtained at predetermined positions with 250 nm thick a-Si crystallized with XeCl excimer laser with pulse duration of 25 ns and substrate heating of 450°C. Thin-film transistors and photo-diodes have been fabricated in the single-grain and been applied to different electrical components, SRAM, 3D-ICs, image sensor and solar cells [2]. However, in the applications of the image sensor and solar cells, thicker a-Si is needed to be crystallized in order to increase the light sensitivity of the photo-diode at longer wavelengths (>400 nm). We used a longer pulse of 250 ns and succeeded to crystallize 1μm a-Si [3]. Yet, the process window was narrow and there were some cracks in the layer. In general, longer pulse duration helps in crystallization of the thick Si layer; however use of millisecond laser will introduce severe thermal damage to underlying substrate or devices.

In this study, we used microsecond pulsed green laser (Yb:YAG Laser JenaRas Asama) [4] for crystallization of a 625 nm thick silicon layer. The laser has a wavelength and pulse-duration of 515 nm and 990 ns. The size of the beam was ~10 μm in x and several mm in y directions. No substrate heating was used and the substrate was kept at room temperature. Amorphous-Si was deposited at 545°C with LPCVD. The substrate has the grain-filters, which were placed with 6 μm pitch.

When using 300 ns pulse duration of green-laser, it was found that crystallization started at 2200 mJ/cm^2. Ablation threshold was found 3100 mJ/cm^2 (Figure 1). The thicker layers require higher energy density to fully melt the layer, however because of the short pulse the surface temperature increases drastically and results in ablation before full layer melting.

In case of the long-pulse green laser, even with 5200 mJ/cm^2, we did not have any ablation (Figure 2). There was no crack formed in the layer. With SEM it was confirmed that the grain was formed from pre-determined position of the grain-filter and the size reaches 6 μm (Figure 3). In the Figure 2, the beam shape is also illustrated. As seen in the figure, the laser pulse covered the grain filters in y direction but could not cover adjacent grain filters in x direction. Therefore, while the grain size reached 6 μm in y direction, it could only reach the half size in x. Grain shape in x direction will be improved using a wider pulse. Furthermore, a larger grain size is expected with using even higher energy density.

In summary, we proved that the microsecond green laser is powerful to crystallize the thick Si layer. We can apply more than 5200 mJ/cm^2 and thereby have larger grain size of 6 micron in thick silicon even without any substrate heating. Because of those the thermal stress was reduced and recrystallized thick silicon layer did not have cracks.

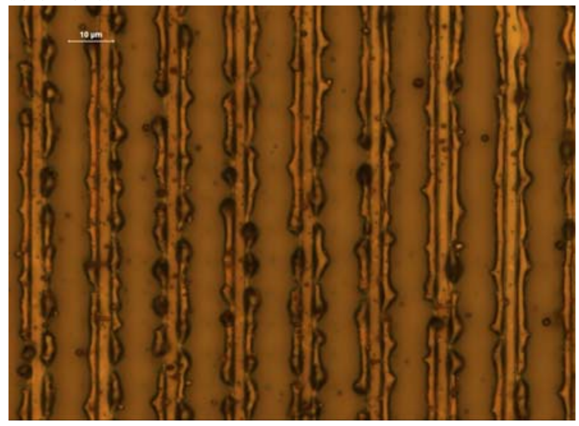

Figure 1. Ablation of 625 nm thick a-Si after irradiated with 300 ns green laser pulse at 3100 mJ/cm^2.

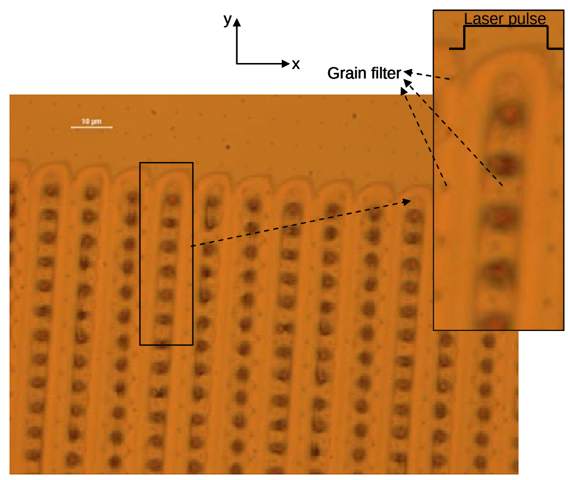

Figure 2. Optical microscopic image of crystallized 625 nm thick a-Si after irradiated with 990 ns green pulsed-laser at 5200 mJ/cm^2.

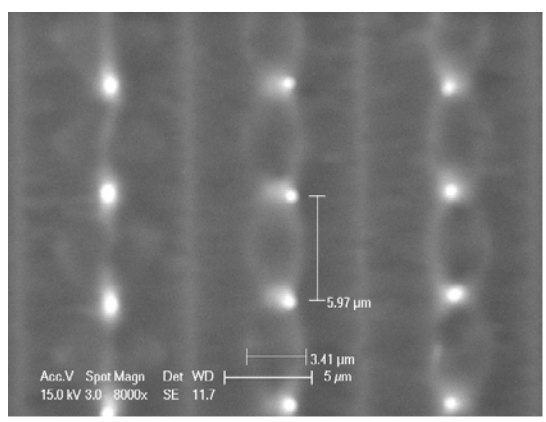

Figure 3. SEM picture of 6 μm size grain fabricated using 625 nm thick a-Si after irradiated with 990 ns laser pulse at 5200 mJ/cm^2.

Reference

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