

Enlargement of Location-Controlled Grains Grown from μ -Czochroski (Grain Filter) process with Excimer Laser by capping Layer

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Abstract—Effects of the SiO_2 capping layer on location-controlled Si grains by μ -Czochroski process (grain filter) with excimer-laser are investigated by experiments and simulation. Thin capping layer (less than 400nm) can function as a heat reservoir for 250nm thick α -Si. Without the capping layer, the location-controlled grain can grow up to $7\mu\text{m}$ from the grain filter. With 200nm capping layer the grains reaches $9\mu\text{m}$. When the capping layer thicker than 400nm, the capping layer acts as a heat sink and the grain size decreases.

Keywords— Location controlled Si, thin film transistor, Excimer laser crystallization, grain filter, capping layer

I. INTRODUCTION

Excimer laser crystallization is a well-established method to fabricate the poly-Si thin film transistor (TFT) on glass from α -Si precursor without thermal damage. Due to a large quantity of traps in the grain boundaries, the poly-Si TFT has a low field-effect mobility and high off current. By location-controlled grain boundaries and enlargement of the grain size, TFT can be built up in a single gain: single grain (c-Si) TFT [1]. The c-Si TFT should have a superior performance. To realize the large location-controlled grains, grain filter is a promising structure, in which the grain vertically grows through a narrow cavity (called grain filter), followed by lateral growth along the interface. The TFTs built on these grains have a high mobility ($430\text{cm}^2/\text{Vs}$) and a low off current (0.1pA) [2]. Further enlargement of the grain size will improve the device uniformity and provides a more flexible the circuit design.

SiO_2 capping layer (CL) on top of α -Si has been

reported to be effective for enlargement of the grains in excimer-laser crystallization [3, 4]. In this report, the CL was applied to increase the grain size in μ -Czochroski (grain filter) process. The influences of the CL on the location-controlled grains are investigated by the grain size, calculated from the SEM pictures. One-dimensional simulation about the heat conduction and phase transformation is performed to investigate the effects of the capping layer. Synergism between experiments and numerical simulations improves our understanding of the effects of CL on the grain growth from molten silicon.

II. EXPERIMENTS

Experimentally, the SiO_2 CL is deposited by Plasma Enhanced Chemical Vapor Deposition (PECVD) from TEOS precursor with various thicknesses on the top of 250nm α -Si. The α -Si is deposited by the Low-Pressure Chemical Vapor Deposition (LPCVD) on the surface of SiO_2 and in a narrow cavity (grain filter), made inside the underlying SiO_2 . The α -Si is crystallized by a single pulse (50ns) of XeCl excimer laser (308nm) with a substrate temperature heated up to 450°C and with the energy densities varied from $900\text{mJ}/\text{cm}^2$ to $1600\text{mJ}/\text{cm}^2$ with a step of $100\text{mJ}/\text{cm}^2$. Similar structure without the CL is used for a comparison. The crystallized samples are analyzed by SEM and Electron Backscattered Diffraction (EBSD) after Secco Etching. In the EBSD setup, the sample is tilted to 70°C and the voltage of the gun is 20KV. The average grain size is calculated from the SEM pictures.

III. RESULTS AND DISCUSSION

Fig. 1 shows the average grain size as a function of energy density E and various thicknesses (T_{ox}) of the capping SiO_2 . Without capping layer, the grain size gets the maximum of $7\mu\text{m}$ at E of 1300 mJ/cm^2 . When E is larger than 1400mJ/cm^2 , agglomeration of the molten Si happens. With a 200nm -thick capping SiO_2 layer, the maximum grain size is increased to $9\mu\text{m}$ at E of 1600 mJ/cm^2 . For a 300nm -thick capping layer, the grain size doesn't reach the maximum, since the agglomeration takes place at E of 1600mJ/cm^2 . With a 500nm -thick capping layer, the grain size is substantially decreased. From these results, it can be concluded that CL less than 400nm acts as heat capacitor, increasing the grain size. The CL thicker than 400nm functions as a heat sink, decreasing the grain size.

With the capping layer, the threshold energy for the agglomeration of the molten silicon is increased. In Fig. 1, it should be noticed that with the capping layer, the α -Si layer can withstand higher energy density up to 1600mJ/cm^2 without the agglomeration than the uncapped one (up to 1400mJ/cm^2).

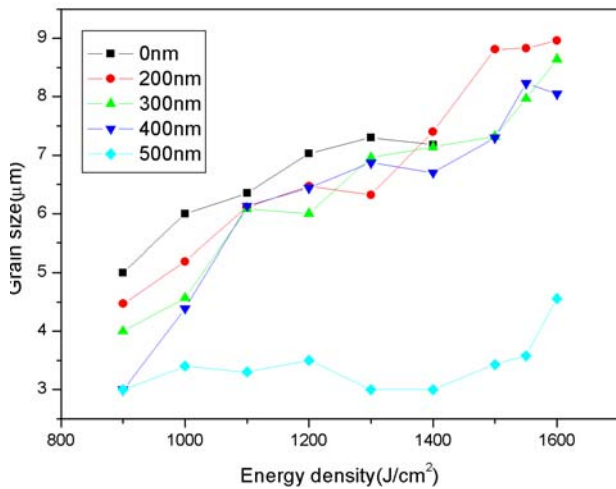
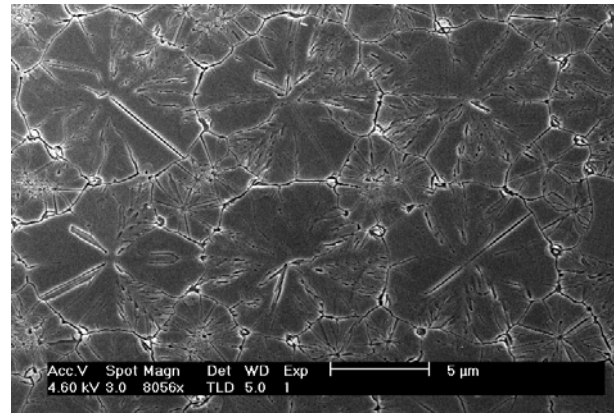
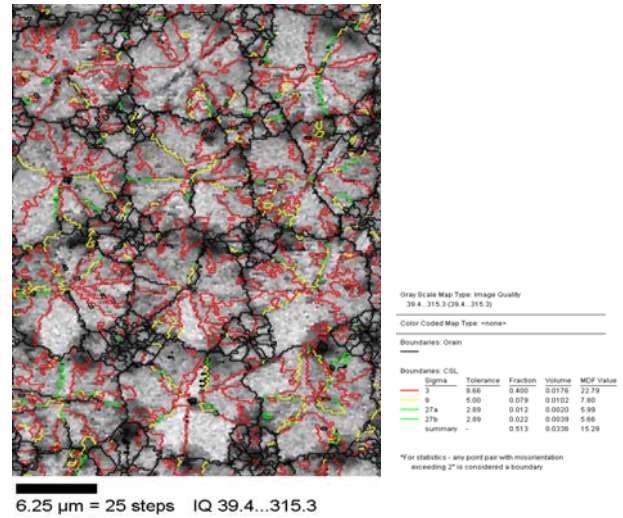


Fig. 1 Average size of the location-controlled grain changes as a function of energy density of laser for various thickness of the capping layer.



(a)



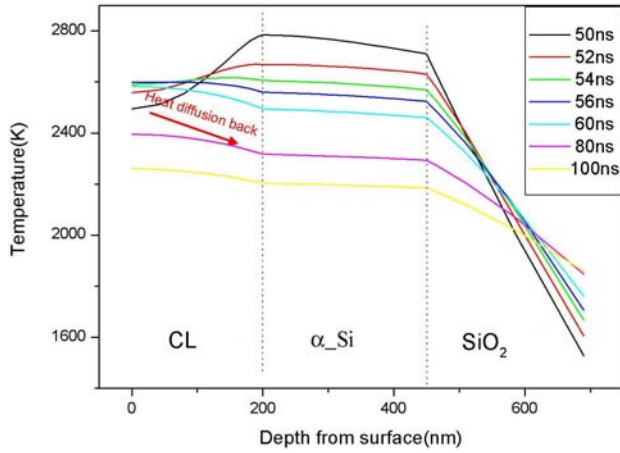
(b)

Fig 2: SEM picture after Secco etching (a) and map of grain boundary components measured by EBSD (b) of the crystallized silicon. Thickness of the SiO_2 CL and energy density is 200nm and 1400mJ/cm^2 , respectively.

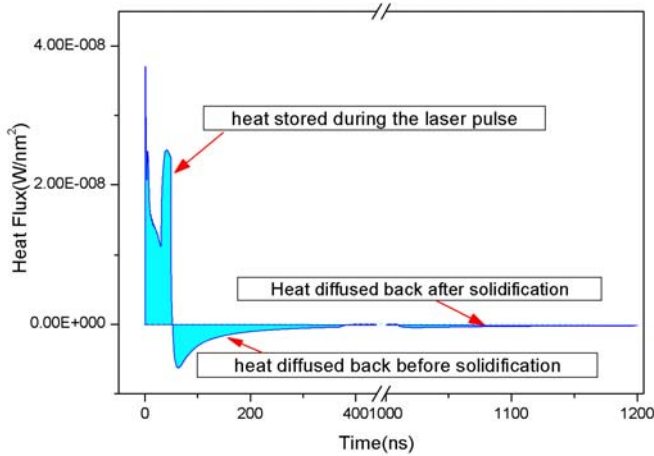
Fig 2 (a) shows the SEM image of 3×2 matrix of grains after Secco etching. The thickness of the SiO_2 CL (T_{ox}) and the E value is 200nm and 1400mJ/cm^2 , respectively. The location-controlled grains grow from the grain filter, interspaced with $8\mu\text{m}$, and parts are impinged with other grains grown from other grain filter. Fig 2 (b) shows a map of grain boundaries measured and analyzed by EBSD for the same process conditions. It can be seen that grain boundaries inside the large grain is mainly coincident site lattice (CSL) type, being predominantly $\Sigma 3$, followed by $\Sigma 9$ and $\Sigma 27$. It should be noted that random grain boundary presented with black lines is very minor inside the location-controlled grain.

To explain the experimentally obtained results, numerical simulation of transient heat transfer is performed. Heat transfer and phase transformation is

simulated by finite element method. For simplicity, only one-dimensional temperature profile in the sample depth is done assuming the sample structure outside the grain-filter area. Details about the model can be found in elsewhere [5]. The temperature dependent physical properties are taken from literatures [6,7,8].



(a)



(b)

Fig 3 1D heat transfer of 200nm CL at the energy density of 1400mJ/cm²: (a) the time dependent temperature profile in depth of the capping layer, α -Si and underlying thermal SiO₂; (b) heat flux of the bottom surface of CL (CL/SiO₂).

Fig 3 (a) shows the time dependent temperature profiles of CL, α -Si and underlying SiO₂ layers after laser pulse. The surface of α -Si reaches the maximum temperature at the end of laser pulse ($t=50$ ns). The temperature of liquid Si decreases during the cooling, owing to the heat transfer to the substrate and to the CL. At $t=54$ ns, the temperature of the surface of the liquid Si will become lower than that of capping layer; from that moment the heat stored in CL diffuses back into the molten pool of α -Si. Fig 3 (b) shows the heat flux of the bottom surface of the capping layer. During the steady-state solidification, there is negligible heat

diffused back into the melting pool from CL and the heat loss to the substrate is exactly balanced by the release of latent heat in the film. So the heat diffused back from CL can be divided into two parts: the heat diffused back before complete solidification and the heat diffused back after solidification (Fig 3(b)).

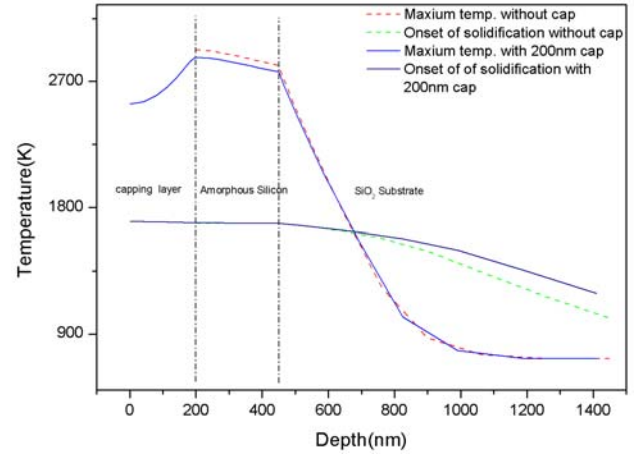


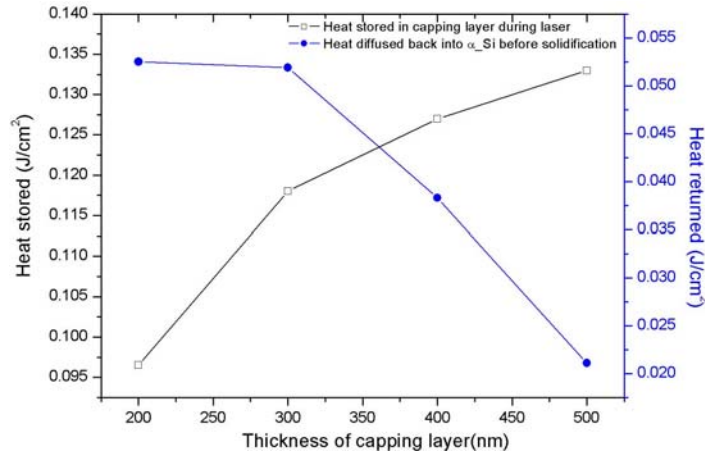
Fig 4 Temperature profiles in depth of the structure without the CL ($E=1067$ mJ/cm², dotted lines) and with a 200nm thick CL ($E=1400$ mJ/cm², solid lines) for the times at which the maximum temperature is reached ($t=50$ ns) and at solidification onset. The curves for the uncapped condition are shifted to 200nm in depth for comparison.

Figure 4 shows time dependent temperature depth profiles of the samples for the SiO₂ CL thickness of 0 and 200 nm. The energy density for the uncapped condition is adjusted so that it takes the same net input energy density for α -Si as the one with 200nm CL at 1400mJ/cm². The CL returns a fraction of the stored heat during the cooling down stage. The returned heat from the CL after the laser pulse effectively reduces temperature gradient (∇T) at bottom interface Si/SiO₂ and, as a result of that, solidification duration is elongated owing to the slow rate of heat extraction from the molten Si, which increases the grain size.

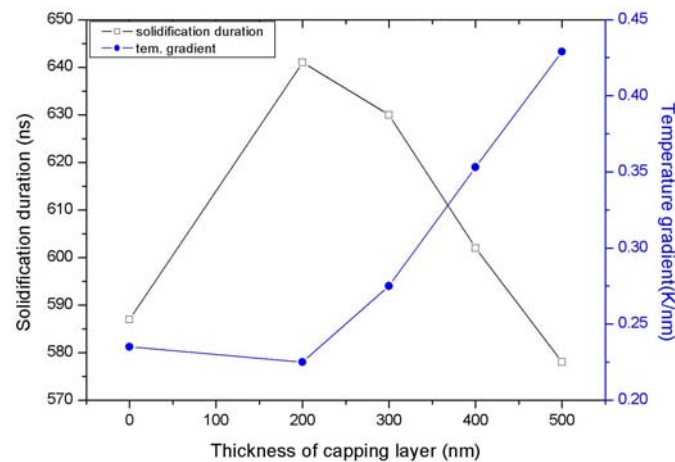
In Fig 3, the heat diffused back before complete solidification is helpful for the enlargement of the grain while the heat diffused back after solidification has no effect on the solidification.

Whether the CL functions as a heat reservoir or a heat sink depends on the heat amount stored in the capping layer, the heat amount diffused back and their effects on the solidification. As show in Fig 5(a), with the T_{ox} increase, more energy is stored in the capping layer; however, the heat diffused back into the melting pool before completely solidification decreased, that is, with the increase of T_{ox} , CL acts as a heat sink. In other word, more energy is lost with increase of T_{ox} .

Fig 5(b) shows the solidification duration and ∇T of bottom surface of liquid Si (L_{Si}/SiO_2) changes with T_{ox} . With T_{ox} increase from 0 to 200nm, ∇T decreased, and solidification duration increase. With the 200nm-capping layer, the solidification duration is the longest, as result of which the grain size is the largest. CL acts as the heat reservoir. With the T_{ox} from 200nm to 500nm, ∇T increase, so the solidification duration decreases, getting smaller grain. CL prefers to be the heat sink with increase of T_{ox} .



(a)



(b)

Fig 5: parameters changes with thickness of CL with energy density at 1400mJ/cm²: a) heat stored and the heat diffused back, b) the solidification duration and temperature gradient. E of 1400mJ/cm² is used for all thickness except for the 0nm at E of 1067mJ/cm².

IV. CONCLUSIONS

In this paper, effects of the SiO₂ CL on the location-controlled grains in the μ -Czochralski process with excimer-laser crystallization are investigated by both experiments and simulation. With increasing the thickness of the SiO₂ CL to 200 nm from 0, the maximum size of the grain is increased to 9 μ m from 7 μ m. When the

capping layer thicker than 400nm, the capping layer acts as a heat sink and the grain size decreases. Numerical simulation shows that the heat diffused back to Si is important to reduce the temperature gradient at Si/SiO₂ interface; thereby the grain size can be increased.

V. ACKNOWLEDGEMENT

This work was the research programs of the Dutch Foundational Research for Matters (FOM), Project No. 97TF05, which are financially supported by the Netherlands Organization for Scientific Research (NWO).

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