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Power dependence of orientation in low-temperature poly-Si lateral grains crystallized by a continuous-wave laser scan

Nobuo Sasaki [a,*], Yoshiaki Nieda [b], Daisuke Hishitani [b], Yukiharu Uraoka [b]

[a] *Sasaki Consulting, 3-16-4-2007, Nakasaiwaicho, Saiwaiku, Kawasaki 212-0012, Japan*
[b] *Nara Institute of Science and Technology, 8916-5, Takayamacho, Ikoma, Nara 630-0192, Japan*

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ABSTRACT

A low-temperature poly-Si film with 99.8% {100} texture in the surface normal direction within 10° is obtained by single-scan continuous-wave laser lateral crystallization of 60 nm-thick a-Si without a seed at room temperature in air. This texture extends over the entire melted width of 105 μm except for narrow edge regions and is maintained for the full scan length of 1.8 mm. Highly {100}-oriented films in the surface-normal direction are obtained at the low net laser power *P(1-R)* of 1–1.25 W above the threshold for the lateral grain growth, where *P* is the incident total power, and *R* is the reflectivity of the sample. A second power threshold exists where the degree of the {100} surface-normal texture begins to decrease above the first threshold for lateral grains. Above the second threshold, the percentage of the {100} surface-normal texture decreases linearly with the increasing *P(1-R)* at the same slope of 20% in 0.1 W change for all the samples with different cap thicknesses.

1. Introduction

Laser crystallization of a-Si has been widely used to produce low-temperature poly-Si (LTPS) films for fabrication of thin-film-transistors (TFTs) in liquid crystal displays or organic light-emitting diode displays. The Si film thickness is reduced to as little as ~50 nm to suppress the leakage currents of the TFTs. The substrate temperature during laser-crystallization is maintained at room temperature to avoid the deformation of the glass substrate. However, the uniformity of the electrical characteristics of the present commercially available 308 nm wavelength excimer laser annealed (ELA) TFTs is low [1]. A simple method to control the crystallographic orientation is required in the laser crystallization to improve the uniformity of the LTPS-TFT characteristics more, because the orientation affects not only the mobility [2,3] but also the threshold voltage of TFTs [4].

Even in ELA films, 96% {100} texture within 10° can be obtained in the surface normal direction, but a long processing time of 200 to 400 overlapping laser shots is required [5–7]. LTPS films can be also obtained by using a 532 nm wave-length continuous-wave (CW) laser crystallization of a-Si at room temperature substrate [8–14]. There are two kinds of LTPS films crystallized by using CW laser scanning; one comprises vertically-grown small polygonal grains crystallized at a lower power or a higher scanning velocity [11,12], and the other comprises laterally-grown laterally-elongated large grains crystallized by CW laser lateral crystallization (CLC) at a higher power or a lower scanning velocity [8–10]. CLC can be carried out even at an increased scanning velocity of 2 m/s by correspondingly increasing the laser power [8,9]. The cracking or warping of the glass substrate in CLC can be prevented by inserting a SiO_2 buffer layer thicker than 0.4 μm between the a-Si and the glass substrate [8–10]. In the vertically grown films by CW laser, 95% {100} normal texture of polygonal grains within 15° was obtained with 10 times overlapped scans [11,12], but it also took a long processing time. In the laterally grown films by using CLC, preferential {100} normal texture of elongated lateral grains was sometimes observed with a single scan [9], but it was not always obtained [9,13,14]. An occupancy of 83.5% {211} texture other than {100} was obtained in the surface-normal direction by a single scanning CLC with double line beam [13]. Surface-normal texture deviating from {100} was also obtained by using a single-scan CLC with a micro-lens array [14]. At a substrate temperature of 450 °C, by using CW Ar^+ laser recrystallization of a 0.6 μm-thick poly-Si with patterned antireflection caps, a single-crystalline stripe region extended to as long as 1.0 mm from a (100) textured seed, but the crystallized normal texture spontaneously rotated from (100) to (110) in a distance about 600 μm [15]. At a substrate temperature of 700 °C, by using a 808-nm wave-length CW laser crystallization of thick (10 μm), boron-doped (10^{16}–10^{17} cm^{-3}) nano-crystalline Si films, the degree of preferential {100} normal texture of the crystallized films was greater at the power near the threshold for lateral grain growth than that at the upper power limit of agglomeration, although

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* Corresponding author.
E-mail address: sassasaki@yahoo.co.jp (N. Sasaki).

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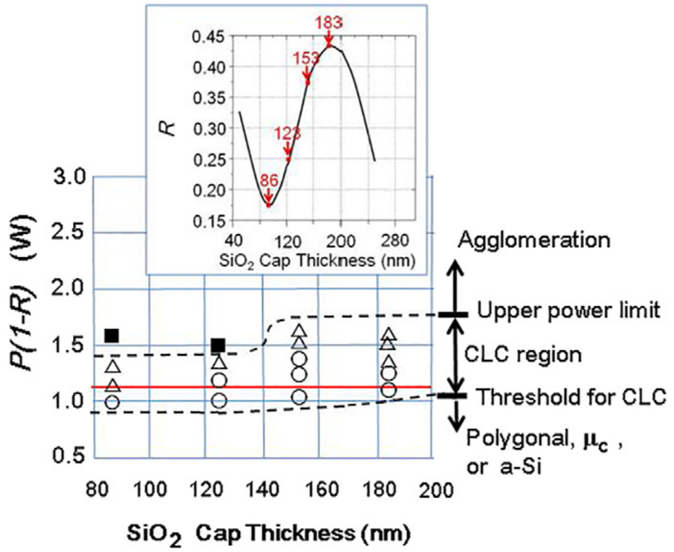

Fig. 1. Diagram of surface-normal texture for an area of 35 × 47 μm^2 randomly selected at the center of the melted width in CLC films as a function of the cap thickness and the net laser power *P(1-R)*. Open circles: CLC with nearly 100% {100} texture, open triangles: CLC with mixed texture of {100} and other orientations, and solid square: agglomeration. The inset shows calculated reflectivity *R* from the sample as a function of the cap thickness. The red line shows the mean of the nearly 100% {100} textures (open circle).

the texture in the scan direction varied between {100} and {110} [16]. However, in the similar 808 nm wave-length CW laser crystallization at a substrate temperature of 650 °C, {110} normal texture other than {100} was predominantly obtained [17]. It is currently difficult to control the surface texture in a single scan. It is also well known that, when the substrate is pre-heated to near the melting temperature (1100–1300 °C), {100} texture of Si on insulator can be obtained by using strip-heater [18,19], hot-wire [20], arc lamp [21], or RF heater [22] zone-melting recrystallization (ZMR) of poly-Si or a-Si [18,19]. However, ZMR cannot be applied to LTPS because the substrate temperature must be kept too high. Recently highly {100} oriented LTPS thin films have been obtained by a single-scan CLC with a highly-uniform top flat line beam at a low power condition for lateral grains at room temperature [23].

In this paper, we have studied the effect of laser power on the texture of LTPS thin films fabricated by a simple single-scan unseeded CLC of a-Si with a highly-uniform top-flat line beam at room temperature in air. A degree of 99.8% {100} surface normal texture of elongated lateral grains is obtained for the laser power close to the threshold for lateral grain growth. This film shows the same {100} textures in the scan and transverse as well as the surface normal directions over the entire melted width except narrow edge regions for the full scan length of 1.8 mm.

2. Experimental

A 60 nm-thick undoped a-Si film was deposited on quartz with a size of 1.5 × 1.5 cm^2 by using inductively-coupled-plasma chemical-vapor-deposition (ICP-CVD) with SiH_4 at 250 °C and 6.8 Pa. Then the substrate was annealed at 500 °C for 1 h in N_2 for dehydrogenation. SiO_2 capping layers were deposited from 86 to 184 nm thickness by using ICP-CVD with tetraethoxysilane at 300 °C and 80 Pa. The CLC of a-Si was performed by using a frequency-doubled diode-pumped solid-state Nd:YVO_4 CW laser with a wave-length of 532 nm at a power from 1.2 to 2.8 W, and a scan velocity of 15 mm/s. All the laser scans were carried out without seed at room temperature in air. A highly-uniform top-flat line beam was generated by a diffractive optical element. The standard deviation of the power density along the long axis was 1.3%. The spot size was 492 μm (long axis, perpendicular to the scanning direction) × 8 μm (short axis, parallel to the scanning direction) with a beam shape of top-flat for the long axis and Gaussian for the short-axis. The crystal quality was investigated by using electron backscatter diffraction (EBSD) at an electron acceleration voltage of 15 kV and a tilt angle of 70° using a Hitachi SU6600 scanning-electron microscope equipped with an EBSD module from EDAX.

3. Results

Fig. 1 shows variations of the normal textures in the lateral-grained-film obtained by single scan CLC for different cap thicknesses. The textures are evaluated based on the EBSD measurements of a 35 × 47 μm^2 randomly selected area at the center of the melted width and the scanned length for each CLC condition. The net laser power *P(1-R)* [24] penetrating through the *Si*-SiO_2 interface is used instead of the total incident power *P* in order to compensate the antireflection effect of the SiO_2 cap, where *R* is the reflectivity of the sample calculated for the multi-layer stacked structure as a function of cap thickness, as shown in the inset of Fig. 1. Nearly 100% {100} surface-normal textures (open circle) are obtained at the low net laser power *P(1-R)* of 1–1.25 W above the laser power threshold for lateral grains. The grains change from lateral grains to polygonal below this threshold due to the change of growth direction from lateral to vertical. Mixed surface-normal textures (open triangle) of {100} and other orientations are obtained in the high laser power *P(1-R)* region of the CLC condition. The upper power limit for the lateral grains is determined by the agglomeration. The data for 86 nm cap thickness shift to lower *P(1-R)* values than

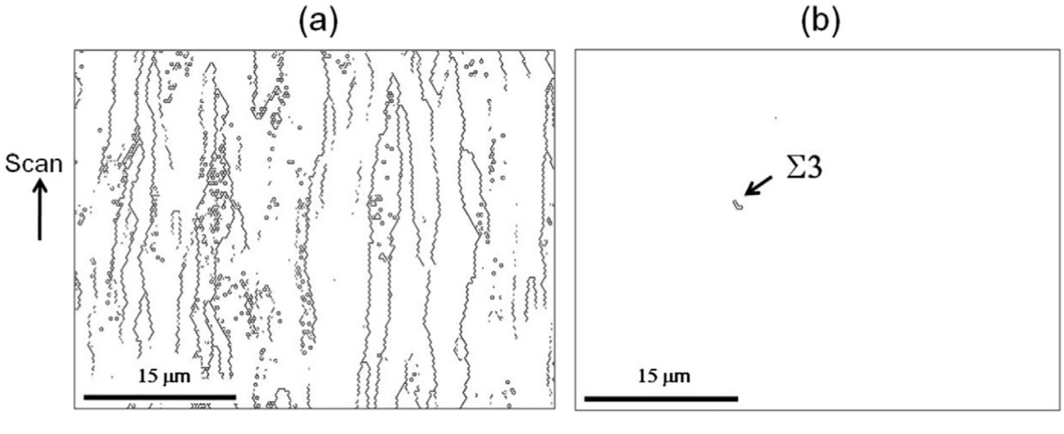

Fig. 2. Grain-boundary patterns obtained at the laser power close to the threshold for the lateral grain growth with a cap thickness of 123 nm and a *P(1-R)* of 1.05 W shown in Fig. 1. Grain boundaries with rotation angles of (a) 2–65° and (b) 15–65°. The contained grain boundaries are almost all low-angle grain boundaries with rotation angles less than 15°, because they are visible in (a) but not in (b) except for a tiny Σ3 CSL grain boundary.