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Effect of Laser Power on the Surface Texture Transition of the Thin Si-Films from Grain-Boundary Free (100) to Twinned (211) in CW Laser Lateral Crystallization

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Abstract

The surface texture transition from grain-boundary free (100) to twinned (211) is observed with laser power in the crystal growth of low-temperature silicon films by the CW Laser Lateral Crystallization of a-Si. This is explained by two step mechanism: the first rotation of the averaged solid-liquid interface keeping the surface (100) texture and the second successive deformation twinning in the solidified crystal by the induced stress during cooling down.

1. Introduction

Laser crystallization can be used to realize monolithic 3-dimensional integrations (3D IC) as well as flat panel display (FPD) back-planes, because crystallization of a-Si film on insulating substrates can be performed keeping the substrate at room temperature and the FETs fabricated in the crystallized thin film show high mobilities comparable to that on the bulk single crystalline Si. The mobilities from 200 to 1000 cm^2/Vs have been reported for NMOS TFTs [1-3]. However there exists a drawback of non uniformity in the electrical characteristics. The non uniformity results from existence of the grain-boundaries and variations in crystal orientations. Crystal orientation affects both the effective mass [4] and the Si-SiO_2 interface charge [5].

There are two kinds of laser crystallization methods; one uses pulse excimer-laser-anneal (ELA) and the other the cw-laser-lateral-crystallization (CLC). The ELA film usually used in commercial FPDs comprises small granular grains of about 0.3-0.4 μm in diameter. The CLC produces elongated large grains under the laser power-density above the threshold for lateral grain growth and shows higher TFT mobility than that of ELA TFTs [1,3].

In ELA, the increase in overlapped shot number to more than 100 times produces the (111) or (100) oriented film [6-8]. But the increase in shot number decreases the crystallization throughput. In addition, these numbers of multiple shots must be carried out in vacuum or nitrogen ambient, otherwise multiple shots in air increase the surface roughness of the crystallized film [9].

In CLC, an occupancy of 83.5% (211) surface texture was obtained by a single scan with a double line beam in air [10]. Recently we have found that a grain-boundary free 99.8% (100) surface texture is obtained within 10° by a single scan CLC even with a single line beam at room temperature in air, if the laser power density is close to the threshold of lateral growth [11,12]. However, a domain of (211) surface orientation is produced at a higher power-density by a single scan with single line beam. This paper presents mechanism of the transition of surface textures of the CLC film from the (100) to (211) with laser-power density.

2. Experimental

A 60 nm-thick a-Si film with a SiO_2 cap was deposited on fused-quartz by PECVD. The a-Si was crystallized by CLC with a DPSS Nd:YVO_4 CW laser at a wave length of 532 nm keeping the substrate at room temperature in air. A highly-uniform top-flat line beam was used [11,12]. The line beam consists of a single line. The spot size was 492 μm (long axis) × 8 μm (short axis) with a beam shape of top-flat for the long-axis and Gaussian for the short-axis. Scans were performed perpendicular to the long-axis. The crystal quality was investigated by the electron back-scatter diffraction (EBSD).

3. Results and Discussion

Fig. 1 shows the EBD maps throughout the melted width at a low laser power close to the threshold of the lateral grain growth. The effective laser power *P(1-R)* is 1.05 W, where *P* is the total power and *R* the reflectivity of the capped surface. Inverse Pole Figure (IPF) maps in the directions of surface normal (ND) and laser scan (SD) show (100) textures, as shown in Fig. 1 (a) and (b); in the result transverse direction (TD) also shows (100) texture. The degree of (100) surface texture is 99.8%. The melted area shows no grain-boundary except for the edges, as shown in Fig. 1 (c), where grain-boundary is defined as the boundary having the rotation angle larger than 15° as usual. Fig. 2 shows the EBSD maps at a high effective laser power; *P(1-R)* = 1.14 W. We can observe domains with different textures. For each domain, ND, SD, and TD orientations are labeled in the table inserted in Fig. 2.

The difference in the melted width between Fig. 1 and 2 means existence of the temperature distribution along the beam line due to thermal diffusion even for the top-flat laser beam. The mechanism of crystal growth in Fig.1 at room temperature substrate is similar to that of the strip-heater zone melting recrystallization (ZMR) at an elevated substrate temperature above 1100 °C [13]. The (100) texture in

ND is realized by the lowest Si-SiO_2 interface energy of (100) [12,13]. The in-plane (100) texture to the scan direction is realized due to the fastest growth direction of <100> [14]. A straight solid-liquid interface line averaging (111) facet chains exists along the isotherm and moves to the scan direction perpendicular to the isotherm [12]. In this growth, the growth rate R_g of the averaged solid-liquid interface to the scan direction agrees with the laser scan velocity V.

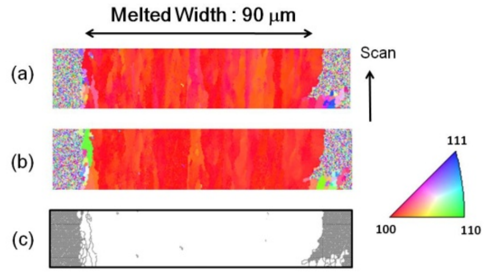

Fig. 1. EBSD maps at a low laser power close to the threshold of lateral grain growth. (a) IPF ND, (b) IPF SD, and (c) Grain boundary having rotation angle between 15-65°. The SiO_2 cap thickness was 123 nm and $P(1\text{-}R)$ = 1.05 W.

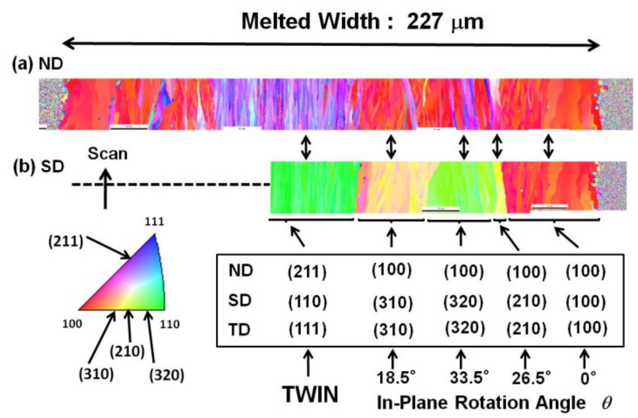

Fig. 2. EBSD maps at a high laser power. (a) IPF ND and (b) IPF SD. The crystal orientations are analyzed and shown in the inserted table. The SiO_2 cap thickness was 84 nm, $P(1\text{-}R)$ = 1.14 W.

In Fig. 2, a lot of domains are found in the melted width due to the temperature distribution along the long axis. Close to the edge at the low power-density, grain-boundary free (100) domain is observed. Next to this domain, rotated domains at angles from 18.5° to 33.5° exist keeping (100) surface normal direction. The rotation is explained by the deeper supercooling at the solid-liquid interface with the power density. The growth rate R_g becomes larger than V because of the deeper supercooling. Then the solid-liquid interface line tends to tilt at an angle θ to satisfy $V = R_g \cos(\theta)$ resulting in domains with different θ.

Around the center of the melted width, (211) ND domain is observed. The (211) ND domain contains narrow parallel grains linearly extended to the scan direction. This domain has (110) SD and (111) TD textures. This domain has similar crystallographic structures to the reported one with double line beams [10]. The (211) ND domain coincides with twin boundary detected by EBSD, as shown in Fig. 3. The twin boundaries make angles of 10° and 0° with the scan direction. These domains are formed by two steps; first the solid-liquid interface inclines at angles of 35° or 45° around <100> ND, and secondly twinning occurs in the solidified film by the rotation on the (111) twin plane due to the extension stress during cooling down, as shown in Fig.4. The initial rotation of the solid-liquid interface at 35° (left side) or 45° (right side) results in the twin boundaries having tilt angles of 10° and 0° to the scan direction in Fig. 3(d).

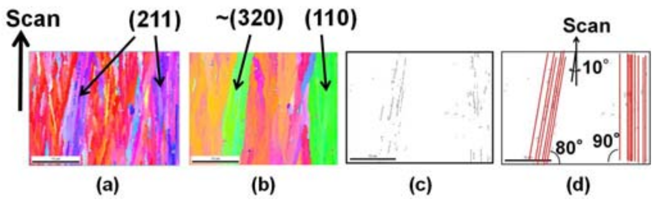

Fig.3. EBSD maps at the center of melted width crystallized at a high laser power. (a) IPF ND, (b) IPF SD, (c) twin boundaries and (d) lines to delineate the tilt angles of twin boundaries. The SiO_2 cap thickness was 183 nm and $P(1\text{-}R)$ = 1.47 W.

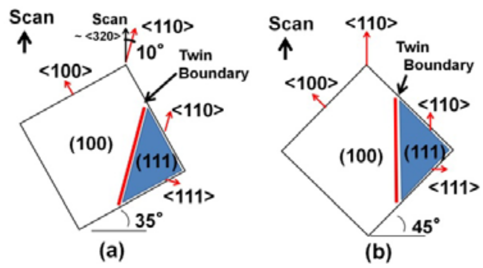

Fig. 4. Generation model of the (211) ND texture shown in Fig. 3. Firstly the rotated crystals are grown at rotation angles of (a) 35° or (b) 45° around the (100) ND and secondary twins are formed by the rotation of the solidified crystals on the (111) planes.

3. Conclusions

The transition of CLC films from the (100) to the (211) surface textures is induced with laser power in two steps: the in-plane rotation of the averaged solid-liquid interface and the generation of the deformation twinning.

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