(100) Textured Si Films with Controlled Microstructures Obtained via Hybrid SLS

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Abstract

Uniformity and performance characteristics of LTPS TFTs are important parameters for making advanced active-matrix displays. In this paper, we describe an SLS-based crystallization approach for producing orientation-controlled Si films with reduced concentrations of planar defects that stand to potentially deliver unprecedented levels of device uniformity and performance. Specifically, a 2-step process referred to as hybrid SLS has been developed that produces a variety of high-quality {100} surface-oriented Si films.

1. Introduction

Sequential lateral solidification (SLS) is a pulsed-laser-based thin-film crystallization technique [1]. The process is highly flexible and a particular version of the method, which is configured to produce a "2 shot" SLS material, has been successfully implemented in mass production of small AMLCDs [2]. Performed on an amorphous Si precursor, the SLS process typically results in crystallized materials with an apparently random to weakly textured surface crystal-orientation distribution, and which contain various planar structural defects such as sub-boundaries and twins.

In general, for low-temperature polycrystalline Si (LTPS) thin-film transistor (TFT) processes, the surface crystallographic orientation distribution of crystallized Si films needs to be considered as it can potentially affect both the uniformity and performance characteristics of the resulting devices. In the more established field of microelectronics, the significance of surface orientation has been long appreciated as it is known that it may influence the properties of field-effect devices through the orientation-dependency of the Si-SiO_2 interface-state density [3] and the field-effect carrier uniformity [4].

One recently discovered effect that further increases the significance of the need to control the orientation of single-crystal regions pertains to the correlation between the density of planar defects (that result from lateral solidification) and the surface orientation of the seed crystals [5]. In particular, it has been experimentally observed that what is considered to be the best surface orientation based on device properties and processing-related considerations (i.e., {100}) also leads to the least defective material; this specific finding has led to an additional motivation for pursuing the present investigation.

In this paper, we demonstrate one approach to control the surface orientation and decrease the defect density of SLS processed materials [6,7]. Specifically, we demonstrate that it is possible to produce the SLS-processed materials with a controlled {100} surface orientation and, in doing so, that the density of planar defects is reduced. We accomplish this in a simple manner by performing the process on (100) textured and large-grained polycrystalline Si precursor films that were, in turn, prepared using "mixed-phase" continuous-wave (CW) laser processing of as-deposited Si films. This hybrid approach is found to be possible and effective because the SLS techniques that are implemented in the present work allow for preserving the original texture of the "seed" crystals, while successfully manipulating the microstructure.

2. Experimental

In this work, we have implemented SLS on (100) textured films that were obtained via a "mixed-phase" zone-melting recrystallization (ZMR) technique performed using a frequency-doubled Nd:YVO_4 CW laser (532nm). The samples consisted of 100 nm Si films on quartz substrates. They were first scanned with the CW laser at 2.5 cm/s using a ~750 μm long line-beam that was shaped using a diffractive optical element. On the short axis, the beam was nearly Gaussian with a FWHM width of ~30 μm. To obtain highly (100) surface-textured material, the films were scanned multiple times with a ~90% overlapping scheme. An introduction and discussion on the mixed-phase ZMR technique and the details regarding the sample preparation can be found elsewhere [7].

SLS was performed using a projection-irradiation system capable of imaging chromium-on-quartz mask patterns with high resolution. The setup consisted of an excimer laser operating at 308nm (XeCl), a pulse duration extender for elongating the pulse to ~220ns (FWHM), a 5× demagnification imaging system, and a submicron-precision translation stage. Various SLS schemes were performed and tested for applicability

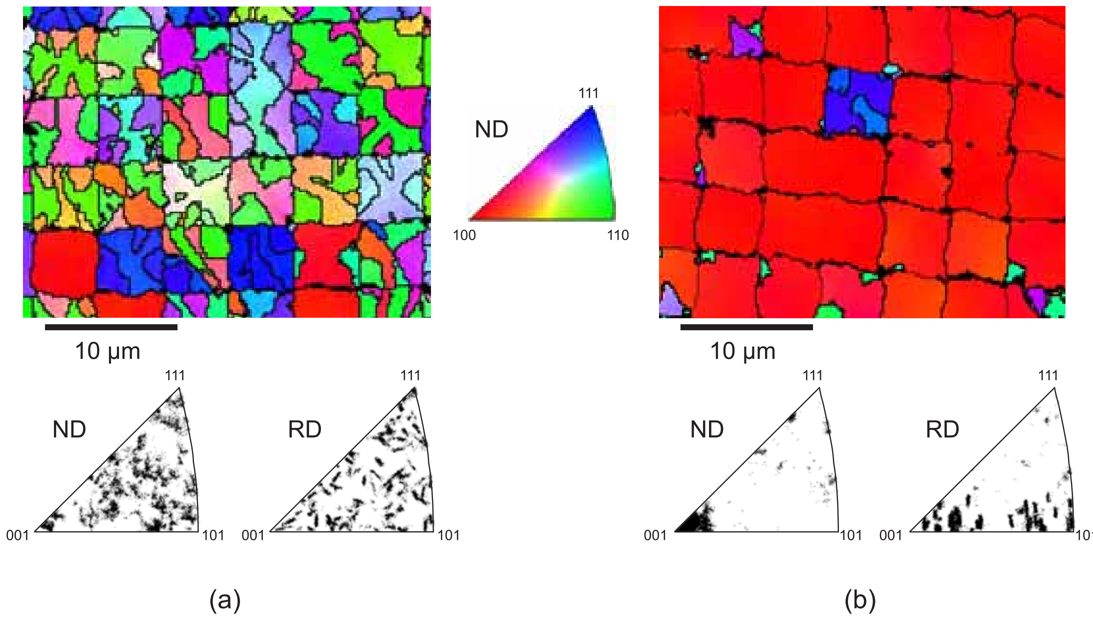

Figure 1: EBSD scans of Si films processed using a 4-shot dot-SLS process: (a) on an amorphous Si precursor and (b) on a (100) textured precursor obtained via mixed-phase ZMR. Colors show the orientation in a surface normal direction (ND) using a standard IPF coloring scheme. Thin and thick black lines indicate low-angle and high-angle grain boundaries, respectively.

to the hybrid approach. In this paper, we will focus on presenting a square-grained polycrystalline material obtained using dot-SLS, and a periodic polycrystalline microstructure with elongated grains obtained using 2-shot SLS.

Crystallographic orientation characterization was performed using a JEOL JSM-5600 scanning-electron microscope (SEM) equipped with an electron backscatter diffraction (EBSD) system from HKL. The analytical software from HKL was employed to clean up data by removing singular data points followed by minor interpolation to remove missing data points.

3. Results

An EBSD map of 4-shot dot-SLS processed Si obtained by using an "as-deposited" amorphous precursor is shown in Figure 1(a). The inverse-pole figures (IPFs) of the surface orientation ("normal direction" (ND)) and the vertical in-plane direction ("rolling direction" (RD)) of the mapped area are presented underneath. The surface-orientation distribution is found to be mostly random and the majority of square "islands" (each of which corresponds to a region processed by a single dot) are observed to contain predominantly, as was reported before, Σ=3 CSL grain boundaries (i.e., first-order twin boundaries) [5, 7].

Figure 1(b) shows a map of a 4-shot dot-SLS processed film obtained from implementing the process on a (100) textured precursor that was obtained using the mixed-phase ZMR technique for creating a strongly (100) textured film. As can be seen, the hybrid dot-SLS process can lead to the creation of highly {100} surface-oriented films consisting of an array of location-controlled single-crystal regions. It is found, furthermore, that the single-crystal regions are essentially free of planar defects, including geometrically special grain boundaries such as the Σ=3 CSL boundaries.

An additional example that further confirms the benefits and effectiveness of the hybrid-SLS technique presented in this paper is shown in Figure 2. Here the 2-shot SLS process has been performed using an amorphous precursor (Figure 1(a)) as well as a (100) textured precursor obtained via the mixed-phase ZMR technique (Figure 1(b)). The orientation distribution that is obtained after performing the 2-shot process on an amorphous precursor is not entirely random, as it apparently shows some removal of ⟨111⟩ RD-oriented growth (as was observed before [9, 10]). The surface orientation, however, appears to be mostly random.

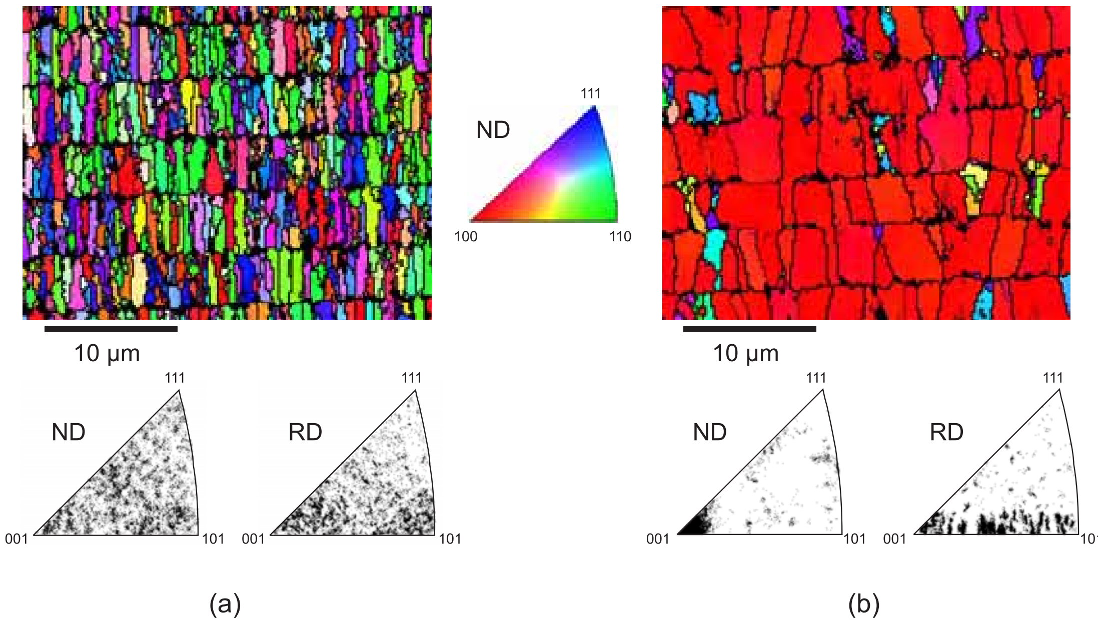

Figure 2: EBSD scans of Si films processed using 2-shot SLS: (a) on an amorphous Si precursor and (b) on a (100) textured precursor obtained via mixed-phase ZMR.

Performing the 2-shot process on the (100) textured and large-grained precursor, on the other hand, leads not only to well-oriented material with fewer grain boundaries but also to the "clean" grains that are essentially free of planar intragrain defects.

4. Discussion

We argue that the advent of advanced crystallization techniques that are capable of producing low-defect density Si films has resulted in the need to also control and optimize the surface-crystal orientation of the films. Furthermore, we have recently realized that for low-defect-density/large-grained Si films that are obtained via laser-induced lateral solidification, the need to accomplish this stems not only from well-known device and processing related factors but also from the dependence of defect density on the orientation of the material.

The work presented in this paper shows that a two-step hybrid approach that incorporates mixed-phase ZMR to induce (100) texture and subsequent SLS processing of the material to manipulate the microstructure can be a technically effective approach for addressing the above needs and optimizing the material. This has been clearly demonstrated for polycrystalline materials obtained via 2-shot SLS and dot-SLS. These (100) textured materials that are exceptionally free from the presence of intragrain defects are expected to lead to fabrication of high-performance TFTs with a high level of uniformity. Such devices should be particularly well suited for making advanced active-matrix displays such as complete system-on-glass products.

The CW-laser-crystallization technique has the additional advantage that it is conceivable to envision a single integrated system that is capable of performing the entire hybrid process in an efficient manner that may allow for high-throughput processing. One straightforward configuration corresponds to a system in which the integration areas of a display are processed via hybrid SLS while the pixel area is processed via 2-shot SLS only. Such a system will permit high throughput production of advanced 2-shot material (with (100) texture, low intragrain-defect density, and large grain size) for ultra-high-performance peripheral circuitry, while the regular process is implemented for providing the 2-shot material for the pixel TFTs.

Finally, we note that the idea behind the hybrid approach that is discussed in this paper is in fact a very general concept, which can be realized using alternative microstructure manipulation techniques (other than SLS), provided they allow for preservation of the orientation of textured grains.

5. Acknowledgements

The authors would like to acknowledge Coherent, Inc. (Santa Clara, CA) and Aerotech, Inc. (Pittsburgh, PA) for providing the CW-laser system that was utilized to perform mixed-phase ZMR. This work was in part supported by DARPA-funded, AFRL-managed Macroelectronics Program Contract FA8650-04-C-7101, by Sharp Labs of America, and by Samsung Electronics, Inc.

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