Single Crystallization Technology for Silicon Thin Films Transistor by Optical Fiber and Blue Laser Diode

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ABSTRACT

We propose the single crystallization technology using optical fiber and blue laser diode. This simple optical system which forms top-hat-shaped beam irradiated from the optical fiber with the rectangle core can perform single crystallization of Si film by choosing appropriate core shape, optical power and exposure time.

1 INTRODUCTION

Low temperature polycrystalline silicon (LTPS) by excimer laser annealing (ELA) is commonly used for thin film transistor (TFT) of liquid crystal display (LCD) and organic light emitting diode (OLED) because of its high carrier mobility and stability [1]. However, there is a problem that excimer laser system and optical lens system are impractical for over G6 substrate at a view of the cost. What is more, if the grain sizes become larger than the wavelength of the irradiated laser, the dispersion of grain sizes cannot easily be reduced.

As for CW laser crystallization, technologies of lateral crystallization and single crystallization as well as poly-crystallization have been developed in a laboratory scale by using second-harmonic generation of solid-state laser or violet laser diode [2, 3]. But these studies have not been applied for mass production devices in an industrial scale, because it is difficult to irradiate multiple beams with the same condition of power and shape.

On the other hand, blue laser diode annealing (BLDA) has been considered as next LTPS technologies because it has lower cost than excimer laser and solid-state laser, it is relatively easy to uniform laser power and beam size on the panel substrate and it is available for over G6 panel substrate by using multiple laser diode sources and optical fibers [4, 5]. In addition, as the crystallization device for Mini / Micro LED which requires grain boundary free TFT with high speed current response was required by panel manufacturers, we began to engage in the development of single crystallization technology by using optical fiber and blue laser diode to realize the crystallization device.

In this paper, we introduce a novel single crystallization technology by using optical fiber and blue laser diode. We define the term single crystallization where the rotation angle of crystal orientation is smaller than 15° [2, 6-8].

If optical fibers with the core which is larger than TFT width are lined up corresponding to TFT interval on panel substrate by using V-groove fiber array device, the problems against existing single crystallization technologies by CW laser could be solved.

2 EXPERIMENT

In the BLDA system, laser beam at the wavelength of 448nm was guided into the optical fiber which has the rectangle core shape using aspheric lens. The beam emitted from the output face of the fiber was projected onto a-Si film using imaging lenses (Fig. 1). The beam shape on the substrate was about 50 μm × 16.5 μm with top-hat intensity profile. Temperature of laser diode was controlled at 23 ± 0.2 °C by peltier cooling system and the stability of driving current of laser diode was within ±0.2%. The moving direction of the substrate was parallel to the short axis of the beam focused on a-Si surface. The servomotor was used for the scan stage control and the substrate moved at constant speed while laser annealing. We confirmed that the height variation of the surface of a-Si film in the annealing region using laser displacement sensor (Keyence LG-85), and it was in depth of focus determined by projection system. The laser power was measured by thermal power meter (Ophir 50 (150) A-BB-SH-26) and we calculated the power density from the top-hat beam shape and the laser power.

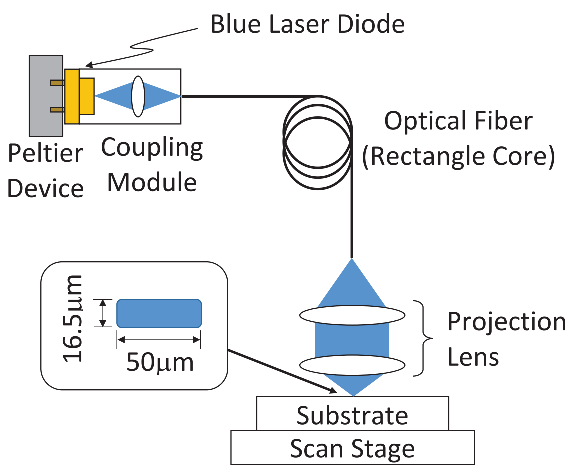

Figure 1. Optical diagram of the BLDA system.

Fig. 2 shows the cross-sectional scheme of the substrate structure. This structure was a 200 nm SiO_2 / 60 nm a-Si / 150 nm SiO_2 / 50 nm Si_3N_4 / 0.5 mm glass substrate. After these films were deposited by plasma-enhanced chemical vapor deposition (PECVD), dehydrogenation was carried out at 450 °C for 150min in the furnace.

In this BLDA process, before laser crystallization, additional laser dehydrogenation was carried out with the same beam size. The power densities of laser dehydrogenation and laser crystallization were about 23 kW/cm^2 and 35 kW/cm^2 respectively. The moving speed of the substrate while both annealing was 5 mm/sec.

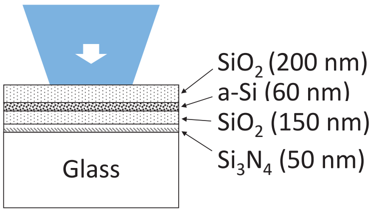

Figure 2. Cross-sectional view of the substrate.

3 RESULTS

We took the optical microscope images and laser confocal images (Fig. 3) using laser scanning microscopy (LSM; Keyence VK9700). Furthermore, the crystallization state was observed by electron backscatter diffraction (EBSD; Hitachi SU6600) after dissolving the protection SiO_2 layer by wet-chemical etching solution. Fig. 4 shows the inverse pole figure (IPF) map and grain-boundaries (GB) having rotation angle above 15 degree. ND, SD and TD mean normal surface direction, laser scanning direction and transverse direction respectively.

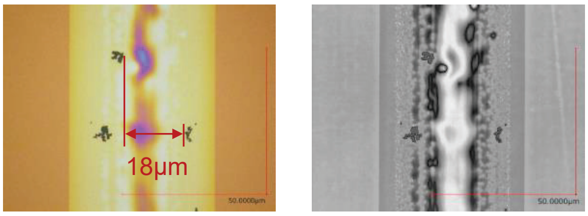

Figure 3. The optical microscope image (left) and the laser confocal image (right).

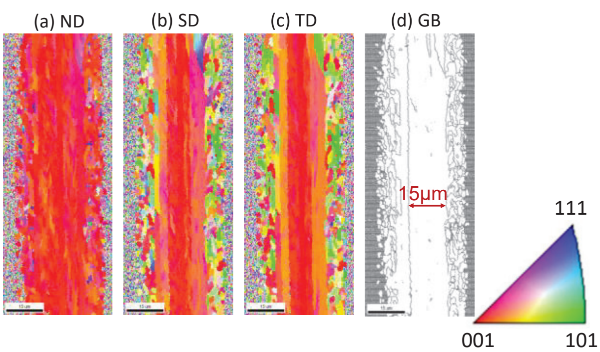

Figure 4. The inverse pole figure map (a-c) and the grain-boundaries (d).

The crystal orientation around the beam center was almost in accordance with {100} texture. The width of grain-boundary well-nigh corresponded to the distance between the both side's agglomerations.

4 DISCUSSION

To our knowledge, we performed single crystallization using rectangle core fiber and laser diode for the first time. In the conventional technologies, donuts beam, chevron beam or top-hat line beam were projected on the substrate using solid-state laser and laser diode. Because these optical transmission systems needed a large footprint, it was difficult to realize a mass production device for large glass substrate.

On the other hand, our BLDA technique makes it facilitate to downsize the optical systems and uniform the top-hat beam shapes. The optical fibers can be disposed at equally spaced intervals using V-groove fiber array structure which has been frequently utilized in the field of optical communication systems. In addition, it is easy to stabilize crystallization state, as the optical power density can be controlled by LD current. For these reasons, our single-crystallization technique has the possibility to be a low-cost mass production device for over G6 substrate.

5 CONCLUSIONS

We demonstrated the single-crystallization technique with rectangle core fiber and blue laser diode. We believe that our technology can be a solution for Mini / Micro LED which requires boundary free TFT.

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