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Crystal orientation control of single crystal Si strip formed by micro chevron laser beam scanning method to (100)

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Abstract

It was shown complete (100) single crystal Si strip cannot be formed at threshold power density of lateral growth in μCLBS method. Instead, it was achieved with a probability of 91% by using SiO_2 capping film combined with decreasing laser scanning speed *v* to 0.4 mm/s.

1. Introduction

Growth of high quality crystalline silicon (c-Si) thin film on amorphous materials such as quartz or glass substrate has long been a challenge for achieving both fully-depleted semiconductor on insulator (FD-SOI) transistors in integrated circuits (ICs)[1,2] and thin-film transistors (TFTs) for pixel driving circuit in active-matrix flat panel displays.[3] Continuous wave (cw) laser crystallization (CLC) of amorphous Si (a-Si) thin films using UV laser diode (LD) is a promising candidate for forming crystal Si film on SiO_2 substrate, because CLC have enabled continuous lateral grain growth and UV-LD have enabled low-cost laser annealing process for large area electronics. The problems of CLC was existence of linear grain boundaries in parallel to laser scanning direction that will deteriorate off characteristics of transistors and random crystal orientations that will increase characteristic variation of transistors. To meet the first problem, we have proposed micro-chevron laser beam scanning (μCLBS) method[4] by which random grain boundary free single crystal Si strip was formed, and TFTs with small characteristic deviation and high maximum field effect mobility (>500 cm^2/Vs) was achieved.[5] However, because of its random crystal orientations, variability of field effect mobility was still as large as 34%. As for the crystal orientation control, Sasaki and Kuroki have found CLC at near threshold power density of completely melting result in (100) preferential orientation of Si film[67]. But precise control of laser power density at threshold of Si film melting is not easy, because drop of laser power density will cause occurrence of new grain and rise of laser power density will cause appearance of unwanted orientation. In μCLBS method, there is only one lateral growth in the melt, so there is no race for survival of lateral grains which always seen in conventional line beam CLC. Instead, the crystal orientation spontaneously gradually turned to the most appropriate orientation when orientation rota-tion in lateral growth direction caused by expansion rate difference between Si film surface and bottom can be suppressed by SiO_2 capping layer. In this study, crystal orientation in normal direction will be controlled to (100) by optimization of laser annealing conditions.

2. Experimental method

60nm-thick a-Si film deposited by low pressure chemical vapor deposition (LPCVD) method on quartz glass was used as a sample. In some samples 300nm-thick SiO_2 film was capped on the a-Si film by DC reactive sputtering method to suppress crystal orientation rotation in lateral growth direction and to enable spontaneous crystal orientation rotation to (100). Output of 405nm-wavelength multimode LD was successively passed through collimating lens, one-sided Dove prism, focusing lens, to form chevron-figured laser spot on Si film. The μCLB was scanned over Si film to form single crystal Si strip over the scanning path. The scanning speed *v* was varied among 0.04 mm/s to 45 mm/s. The Si strips were then evaluated by electron beam back scattering diffraction (EBSD) method after removal of surface SiO_2 capping film.

3. Experimental results

Figure 1 (a) and (b) shows EBSD crystal orientation map of Si strip in respectively normal direction (ND) and laser scanning direction (SD) with different laser power *I* among 184 mW to 217 mW. Figure 1(c) shows boundary map of the Si strip in which black line was random angle grain boundary (RGB) and red line was Σ3-CSL twin boundary (TB). *v* was 10 mm/s here. At *I* = 201 mW, the Si strip was preferentially (100) surface texture but RGB existed at high density. Inverse pole figure (IPF) of 1mm-long Si strip in this condition in ND,

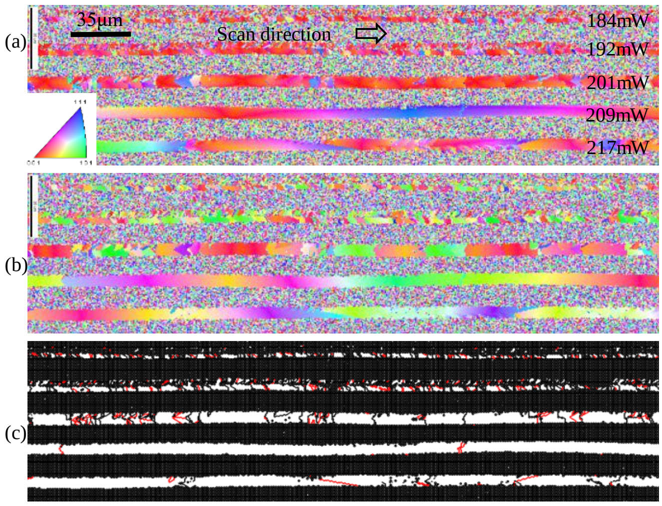

Fig 1. EBSD crystal orientation map of uncapped Si strip in (a) ND and (b) SD, (c) boundary map

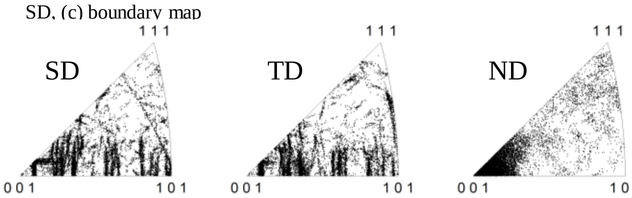

Fig.2 IPF of 1mm-long Si strip at threshold of the lateral growth in SD, TD, and ND

SD, and transverse direction(TD) were shown in Fig.2. As have been shown by others, Si film was (100) surface textured at I close to threshold power of the lateral growth. Schematic cross sectional image of Si film in this condition was shown in Fig.3. Solid Si remained at Si/SiO2 interface, so lateral growth originated from the solid interrupted the original lateral growth. The solid Si was preferentially (100) texture, but orientation in the plane perpendicular to ND was random at among <100> to <110>, as can be confirmed from IPF in SD and TD. The trajectory of poles extended vertically indicate there were orientation rotation with lateral growth in pitch and roll directions. Because of random orientation in plane vertical to ND and orientation rotation along with lateral growth, it is difficult to obtain single crystal strip in this condition. At $I = 209$ mW, the Si film was at completely melting condition, and single crystal Si strip free of RGB formed. The crystal orientation rotated at positive pitch direction because of expansion rate difference between Si film surface and bottom at solidification. At $I > 217$ mW, ablation of Si strip taken place at some portion of strip.

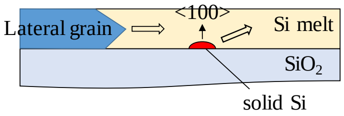

Fig.3 Schematic cross sectional image of melt/solid interface at threshold of lateral growth

300nm-thick SiO_2 was capped on Si to suppress pitch orientation rotation caused by volume expansion at solidification. Figure 4 (a), (b), and (c) show typical ND orientation map of Si strip with respectively $I \leq 93$ mW, 109 mW $\leq I \leq$ 142 mW, and $I \geq 159$ mW. RGB was shown by black line and TB by green line. Estimated length ratio of (100) strip R depending on I was shown in Fig.4(d). At $I \leq 93$ mW, the strip contained dense TBs, and R was only 10%. At 109 mA $\leq I \leq$ 142 mA, pitch orientation rotation have been suppressed by SiO2 capping film and the orientation spontaneously and gradually rotated to ND (100) with lateral growth. (100) strips become dominant and R increased to among 45% to 75%. Particles on Si film were main factor of continuous growth of (100) lateral grains, so decreasing of particles during sputtering deposition of capping film is essential. At $I \geq 159$ mW, R decreased to 24% and in most case the strip became polycrystalline which composed of short lateral grains.

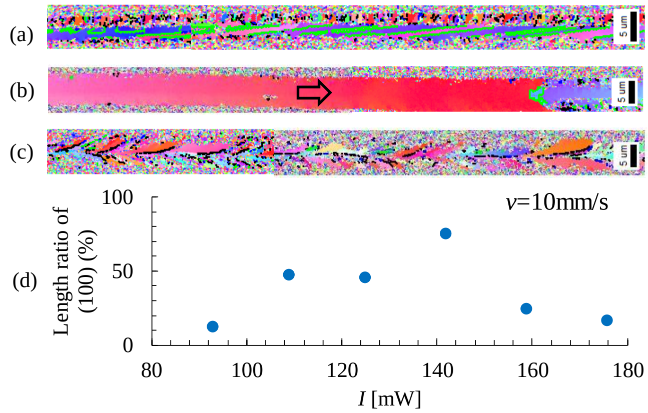

Fig. 4 Typical ND orientation map of Si strip with (a) $I \leq 93$ mW, (b) 109 mW $\leq I \leq$ 142 mW, (c) I $\geq$ 159 mW. (d) Estimated length ratio of (100) strip R depending on I

Figure 5 (a) - (d) shows ND orientation map of Si strip with scanning speed v of respectively 45mm/s, 10mm/s, 2mm/s, 0.4 mm/s, and Fig. 5 (e) shows R depending on v. As v decreased, R increased and become 91% at $v = 0.1$ mm/s. It can be interpreted that the effect on the lateral growth of particles was reduced by decreasing the speed. Figure 5(f) shows SD orientation map of Si strip in Fig.5(d). Many orientations in the film plane can exist stably in lateral growth. It will be a big challenge for control of crystal orientation in SD in CLC method.

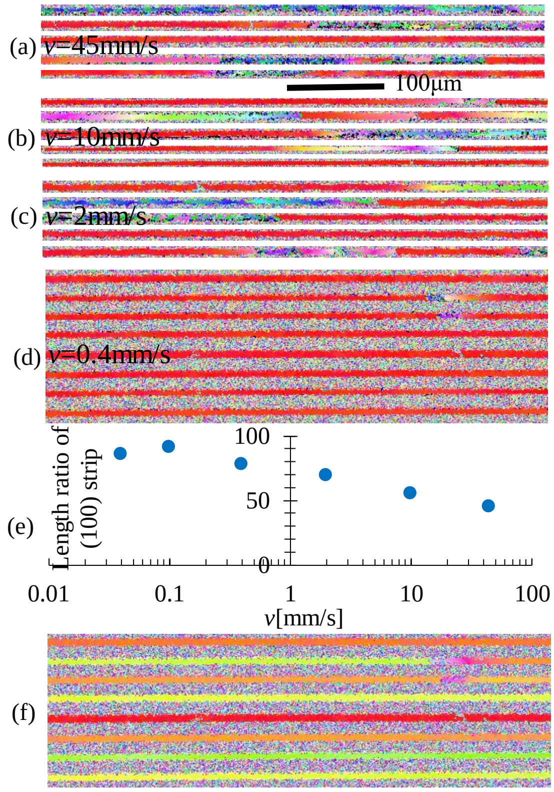

Fig. 5. ND orientation map of Si strip with v of (a) 45mm/s, (b) 10mm/s, (c) 2mm/s, (d) 0.4mm/s. (e) R depending on v. (f) SD orientation map of Si strip with v of 0.4 mm/s.

3. Conclusions

(100) single crystal Si strip cannot be formed at threshold power density of lateral growth in µCLBS method. Instead, it was achieved with a probability of 91% by using SiO2 capping film combined with decreasing laser scanning speed v to 0.4 mm/s.

[1] G. Celler et. al, J. Appl. Phys. **93**, 4955 (2003).
[2] A. Aipperspach, D. Allen, D. Cox, V. Nghia, and S. Storino, IEEE J. Solid-State Circuits **34**, 1430 (1999).
[3] T. Sameshima et. al., IEEE Electron Device Lett. **7**, 276 (1986).
[4] W. Yeh, S. Yamazaki, A. Ishimoto, S. Morito, APEX 9, 025503 (2016)
[5] W. Yeh et. al. Japanese Journal of Applied Physics 59, 071008 (2020)
[6] N. Sasaki et. al., SID digest of technical papers, 47, 1317 (2016).
[7] T. Nguyen, M. Hiraiwa, and S. Kuroki, APEX 10, 056501 (2017).