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Oriented Crystal Growth of Si on SiO_2 Patterns by Pulse Ruby Laser Annealing

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Laser annealing technique has been successfully used to form single crystallized Si films on amorphous substrates or films$^{1-3)}$. The present authors previously demonstrated that poly-Si films deposited on Si substrates having SiO_2 stripe patterns were transformed by Q-switched ruby laser irradiation into single crystals on the SiO_2 patterns as well as on Si substrates (bridging epitaxy)$^{3)}$. In this paper, systematic observations were carried out, in more detail, on the Si oriented crystal formation conditions on SiO_2 patterns as a function of poly-Si film thickness, SiO_2 pattern width, irradiation laser energy, and laser pulse shot. The (100) Si wafers were first oxidized in a wet O_2 ambient for 40 min at 1000°C, resulting in the formation of a 0.25 µm thick SiO_2 film. Then, 1-5 µm striped patterns of SiO_2 with repeated 1-5 µm intervals were formed by standard photolithography as shown in Fig. 1. The 0.2-0.6 µm thick poly-Si film deposition was carried out on the above mentioned samples using SiH_4 at 630°C. Samples were annealed in air with a Q-switched ruby laser pulse (λ=0.69 µm, pulse duration 25 ns, beam diameter ∿10 mm) in the energy density range between 0.5 and 3.0 J/cm^2. The microstructure and crystallinity of the laser annealed poly-Si films were examined by TEM, and the recrystallized film morphology was observed by SEM.

<u>SEM observation results</u> The lateral growth phenomenon of poly-Si on SiO_2 patterns occurred from continuation just after or during the vertical growth of poly-Si on Si, when irradiation laser energy exceeded the threshold energy$^{3)}$. This threshold energy varied between 1.0 and 2.0 J/cm^2 in accordance with poly-Si thickness. In Fig. 2, a series of SEM micrographs shows the changes in morphology of 0.6 µm thick poly-Si growth on a SiO_2 pattern of 4 µm width as a function of irradiation laser energy density. As can be clearly seen from this figure, with the increase of laser energy density, recrystallized areas of poly-Si on SiO_2 proceed from Si window edges to central regions on a SiO_2 pattern. At the last stage of growth (2.0 J/cm^2 irradiation), just the central portion of poly-Si on SiO_2 rises up as a result of collision of the poly-Si growth from both window edges. However, in this case, it is evident from the figure that the whole area on SiO_2 having a 4 µm width is covered by recrystallized poly-Si. In Fig. 3, the SiO_2 pattern width dependence of the poly-Si lateral growth is shown under the conditions of fixed poly-Si thickness and laser energy density. The poly-Si is regrown completely on the whole SiO_2 area up to a 3 µm SiO_2 width, although the full coverage on SiO_2 by the regrown poly-Si is not achieved for the 5 µm width pattern. We note from the figure that the flatness of the poly-Si regrwon on both Si and SiO_2 ia as good as samples which have narrower SiO_2 width and window width. At the irradiation above the energy for inducing the lateral growth, partial diffusion of poly-Si on SiO_2 to Si substrate areas was observed for all the samples. The observed results of the lateral growth condition are summarized in Fig. 4 as a function of irradiation energy and SiO_2 pattern width.

<u>TEM observation results</u> Even if the lateral growth of poly-Si on SiO_2 occurs, the crystallinity of regrown poly-Si changed drastically according to irradiation energy in a limited region of lateral growth condition shown in Fig. 4. In Figs. 5 and 6, an example of TEM results, in which a slight difference of ir-

radiation energy results in the remarkable change of recrystallized poly-Si quality, is shown for the 0.3 µm poly-Si case. At 1.2 J/cm^2 irradiation, [110] oriented grain growth of poly-Si is observed on the SiO_2 pattern (Fig. 5). However, 1.5 J/cm^2 irradiation, (100) single crystal transformation of poly-Si on SiO_2 is clearly seen (Fig. 6). Surprisingly enough, in this case, little crystal defect formation is detected in this single crystallized Si film except for the straight boundary at the central portion of the SiO_2 pattern in spite of the existence of high density dislocations in the regrown poly-Si on Si. In other cases, the straight stacking fault formation along the < 311> directions was usually observed in the regrown poly-Si on SiO_2[3)]. This boundary corresponds to the rising growth observed by SEM in Figs. 2 and 3. The reason of no residual dislocations in the film on SiO_2 is considered as follows from the observations of inclined dislocations at the edge of SiO_2 patterns. Dislocations originated in the interface region of the poly-Si and Si substrates escape to the sample surface along the inclined plane of the SiO_2 edge during the lateral growth of poly-Si on SiO_2. This results in no residual dislocations in single crystallized Si film on SiO_2.

In conclusion, single crystal Si film formation is possible on whole SiO_2 patterns up to a width of 4 µm by selecting an appropriate combination of ruby laser power and poly-Si thickness.

References 1) J. F. Gibbons et al: Appl. Phys. Lett. 34 (1979) 831. 2) M. W. Geis et al: Appl. Phys. Lett. 35 (1979) 71. 3) M. Tamura et al: Japan J. Appl. Phys. 19 (1980) L23.

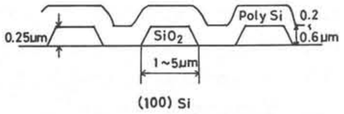

Fig. 1 Schematic representation of the sample structure.

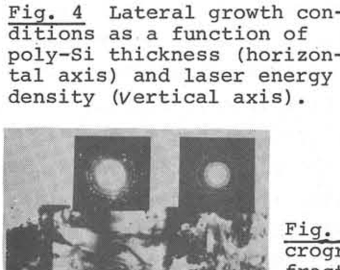

Fig. 4 Lateral growth conditions as a function of poly-Si thickness (horizontal axis) and laser energy density (vertical axis).

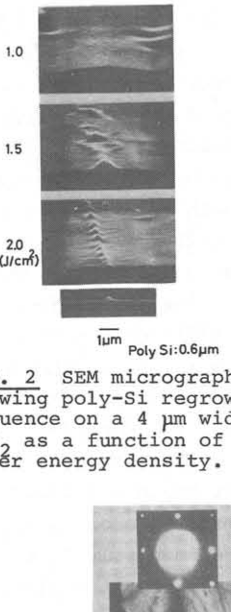

Fig. 2 SEM micrographs showing poly-Si regrowth sequence on a 4 µm width SiO_2 as a function of laser energy density.

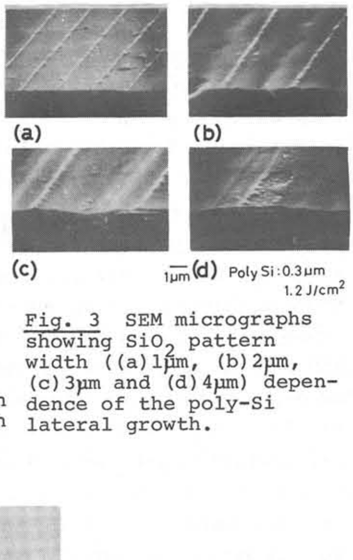

Fig. 3 SEM micrographs showing SiO_2 pattern width ((a) 1µm, (b) 2µm, (c) 3µm and (d) 4µm) dependence of the poly-Si lateral growth.

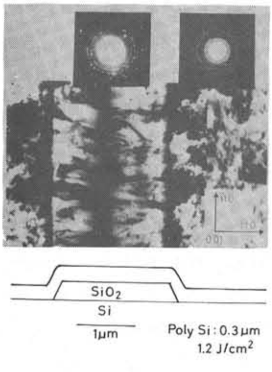

Fig. 5 TEM micrograph and diffraction patterns showing [110] oriented grain growth of poly-Si on SiO_2.

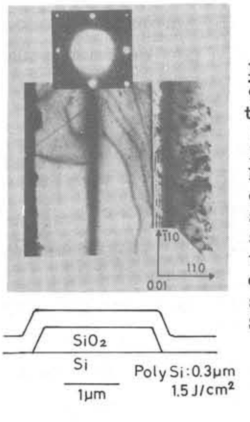

Fig. 6 TEM micrograph and diffraction pattern showing (100) single crystallized poly-Si on SiO_2. Note that defects except for one straight stacking fault and straight boundary at the central portion of SiO_2 are not observed in the film on SiO_2.