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A – 4 – 6 Laser-Induced Lateral, Vertically-Seeded Epitaxial Regrowth of Deposited Si Films over Various SiO_2 Patterns

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Silicon on an insulating substrate (SOI) is a very attractive material structure for high speed and high density LSI application. Moreover, this SOI technology opens new possibilities for fabricating three dimentional LSIs. Recent laser and electron beam experiments have demonstrated the feasibility growing thin single-crystalline Si films on SiO_2 or Si_3N_4. Successful growth of single-crystallized (100) Si films over SiO_2 stripe patterns by ruby laser pulse irradiation has already been reported[1]. The basic idea is that crystal growth can be propagated laterally over the SiO_2, if it is nucleated on the substrate Si adjacent to the SiO_2(bridging epitaxy).

This paper first describes the characteristics and limitations of lateral growth of deposited Si films over the SiO_2 by a pulse laser shot. Then, this method is extended to eliminate the limitations introduced by pulse laser recrystallization over the SiO_2 using a cw-scanned laser beam.

Experiments: To obtain oxide films 50 - 600 nm thick, (100) and (111) Si wafers were oxidized in a wet O_2 ambient at 1000°C. The oxides were subsequently etched to produce various patterns such as stripes, circles, ovals and rectangles of several micrometer size. Using a LPCVD system poly-Si films were deposited 100 - 600 nm thick on these samples at 630°C. Samples were irradiated in air with a Q-switched ruby laser pulse (pulse duration: 25 ns, beam diameter: 10 mm). In addition, deposited films were recrystallized with a cw-scanned Ar laser. Scan conditions were varied as follows: output power: 8 - 15 W, spot size: 20 - 100 μm, and scan speed: 10 - 100 cm/s. Overlapping between beam lines and the substrate temperature during laser scan were chosen to be 50 % and 400°C, respectively.

Pulse laser results: Single crystal transformation of poly-Si on SiO_2 was always observed when poly-Si on Si was changed into single crystals under 1.0 - 2.5 J/cm^2 irradiation energies, irrespective of deposited poly-Si thickness, SiO_2 thickness and substrate orientations within present experimental conditions. The results showed little difference even if poly-Si films were amorphized by high dose phosphorus implantations (dose: $\geq 3 \times 10^{16}$ $ions/cm^2$, energy: 200 keV). However, no preferential lateral regrowth of Si over SiO_2 was observed by this irradiation. A typical example clearly indicating this phenomenon is shown in Fig. 1. In the figure, a 1.5 J/cm^2 laser was irradiated on poly-Si deposited on a sample having circular oxide window areas. It is clear from the figure that the poly-Si grains on SiO_2 grow spokewise from each oxide window edge, in contrast to a moderate increase in grain size of poly-Si on Si. This result was similarly observed for samples with ovals and rectangles. This suggests that lateral crystal growth during resolidification of laser-melted poly-Si films is governed only by the heat flowing evenly from the window edges to the center of the SiO_2 region. Actually, at higher energy irradiation between 1.7 and 2.0 J/cm^2, grains on both SiO_2 and Si were completely transformed into single crystals. However, lateral grain growth was restricted at region A in the figure by random nucleation and growth of poly-Si in this area during resolidification.

For optimum single crystallization conditions, it is characteristic of pulse laser irradiation that bridging epitaxy occurs equally in the large irradiated area as shown in Fig. 2. However, there are two major problems with films regrown on SiO_2 by this method from the standpoint of device application. One is the formation of a straight crystal boundary at the central portion of SiO_2 stripe patterns as seen in Fig. 2. The other is the limitation of the lateral growth distance of Si films over SiO_2 patterns. In particular, the oriented crystallization distance of Si over SiO_2 was not extended more than 3 μm from the Si/SiO_2 edge, although some attempts were made to improve this point.

Cw-scanned laser results: A typical example of structural changes of regrown Si films on both Si and SiO_2 is shown in Fig. 3 as a function of laser energy (scan speed: 25 cm/s, spot size: 25 μm). Here, the laser beam was scanned perpendicularly on the SiO_2 stripe patterns. The poly-Si on SiO_2 in Fig. 3(a) has melted, producing large grains in contrast to the fine grained structure of poly-Si on Si (8 W laser energy). The large increase in grain size can be seen in Si grown on both Si and SiO_2 in Fig. 3 (b) (9 W laser energy), while continuous single crystal film formation is achieved on both Si and SiO_2 in Fig. 3 (c) (11 W laser energy). In all figures, straight boundary formation as shown in Fig. 2 is not formed in the recrystallized Si film on SiO_2. It should also be noted that grain growth of poly-Si is continuous from Si to SiO_2 as clearly seen in Figs. 3 (a) and (b). As a result, seeding from the substrate forms the single crystal Si over SiO_2 in Fig. 3 (c). These results strongly indicate that the lateral regrowth of deposited Si films over SiO_2 occurs by bridging epitaxy from one side of the oxide edge, although Magee et al.[2] have recently reported that bridging epitaxy is not necessary for Si layer growth over the SiO_2 stripes. To date, single crystal Si formation over the SiO_2 stripes has been restricted in a 5 μm wide SiO_2 pattern as seen in Fig. 3 (c). This method promises much wider coverage of SiO_2 stripes by regrown Si[3, 4].

It can be concluded that vertical seeding from the Si substrate is essential for single crystallized lateral regrowth of deposited films over the amorphous material, regardless of laser irradiation methods.

References: 1) M. Tamura et al: Jap. J. Appl. Phys. 19 (1980) L23 and Proc. 12th Conf. on Solid State Devices, Tokyo, 1980; Jap. J. Appl. Phys. 20 (1981) Suppl. 20-1, p.43. 2) T. J. Magee et al: Appl. Phys. Lett. 38 (1981) 248. 3) H. W. Lam: IEDM Tech. Digest, IEEE, Washington, D. C., Dec., p. 556, 1980. 4) J. Sakurai et al: Jap. J. Appl. Phys. 20 (1981) L176.

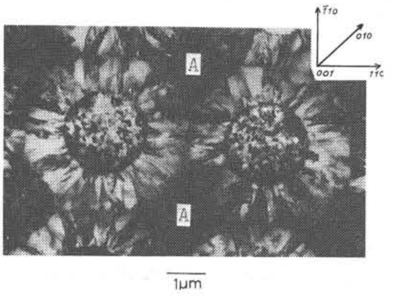


Fig. 1: TEM micrograph showing spokewise regrown poly-Si grains over SiO_2 from circular oxide window areas. Poly-Si: 0.4 μm, ruby laser energy: 1.5 J/cm².

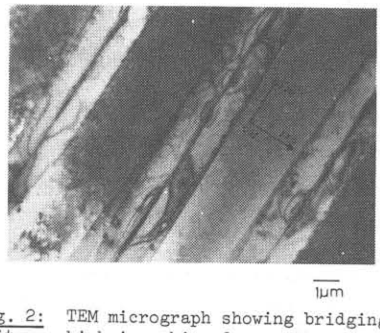
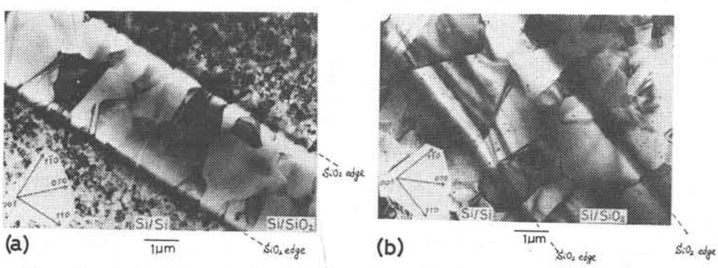


Fig. 2: TEM micrograph showing bridging epitaxy which is achieved over three adjacent stripe SiO_2 patterns. Poly Si: 0.35 μm, ruby laser energy: 1.5 J/cm².



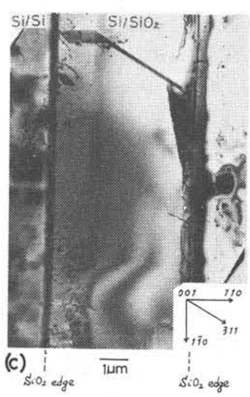


Fig. 3: TEM micrographs showing structural changes of regrown Si films on both Si and SiO_2 by cw-scanned Ar laser irradiation. Laser energy (a) 8 W, (b) 9 W, and (c) 11W.