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Seeded oscillatory growth of Si over SiO_2 by cw laser irradiation

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Extensive seeded epitaxial growth of crystalline Si over SiO_2 was achieved by an oscillatory regrowth method applied to rectangular Si pads recessed into a thick SiO_2 film. Narrow ($\simeq 5\ \mu m$) via holes linked the pads with the bulk (100) Si substrate. Oriented single crystals propagated as far as $500\ \mu m$ from the seeding area, following the long term advance of a scanned focused laser beam.

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Fabrication of crystalline Si on amorphous insulating substrates by localized melting techniques[1,2] promises considerable improvement in metal-oxide-semiconductor (MOS) device performance.[3,4] In this letter we describe a new method for obtaining oriented single crystalline Si films on SiO_2. It combines the benefits of the oscillatory regrowth approach, which we applied recently to thin films,[5] with advantages of a patterned Si structure designed for best utilization of temperature gradients induced by the incident laser beam.[6] The structure includes narrow "via" holes linking the deposited polycrystalline Si film with the bulk (100) Si substrate.

As the first step in sample preparation, continuous 1-μm-thick sheets of SiO_2 with $\simeq 5$-μm-wide via holes filled with crystalline Si were fabricated by local oxidation of (100) Si wafers. Polycrystalline Si films of 0.6-μm thickness were then obtained by low pressure chemical vapor deposition (LPCVD) and patterned into rectangular pads by a second local oxidation process. The two patterns were matched so that the vias were within the rectangular Si islands and near one of their edges. A schematic cross section of the islands is shown in Fig. 1. The first local oxidation process ensured that there was no topological or thermal discontinuity of the deposited Si film in the via region. The second local oxidation sequence effectively provided SiO_2 crucibles or tubs surrounding Si islands from all but one (top) side.

The crystallization and epitaxial overgrowth of the deposited Si films were performed with a multiline cw Ar^+ laser. An intense, 10–20-W laser beam was usually focused to ≈ 50-μm spot on the Si samples. The samples were vacuum clamped to a resistively heated stage at 400 °C, which was moved in a desired fashion by a computer controlled x-y table. In some cases scanning mirrors were used to superimpose motion of the beam over the table movement.

Typical crystallization results after a single sweep of the laser beam from left to right are shown in Fig. 2. This sample, as well as those shown in subsequent figures, was Schimmel etched[7] to delineate the grain boundaries. The significance of the vias in laser crystallization is evident from the comparison of the two crystallized Si islands. On the left side, Si over the via was melted first and the moving beam produced single crystalline film in its wake. On the other island, the via is melted last and does not contribute to crystallization of Si over SiO_2. The resultant Si pad is crossed by several grain boundaries.

The recessed island structures with vias offer close to ideal temperature distribution under laser irradiation, with edges hotter than the center and the via heat sunk sufficiently to initiate crystallization there, but not so much as to prevent melting of this region.[6] Nevertheless, single crystalline overgrowth after uniform velocity laser scans in the direction of growth would extend only for $\approx 30\ \mu m$ from the seeding point. Others have reported similar problems in different lateral overgrowth structures. The nature of this limitation of the seeded overgrowth is not fully understood. It was suggested by Lam *et al.*[8] that the stress buildup in the recrystallizing film, caused by the differing thermal expansion coefficients of Si and SiO_2, produces a progressively increasing defect density and the breakup of the crystalline lattice into a feather-shaped mosaic structure and eventual formation of grain boundaries. They have also noticed that the extent of a successful overgrowth increases with increasing substrate temperature, which is compatible with the excessive stress hypothesis.

Recently, however, the Lincoln Laboratories group[9] has reported sub-boundary formation in material solidified

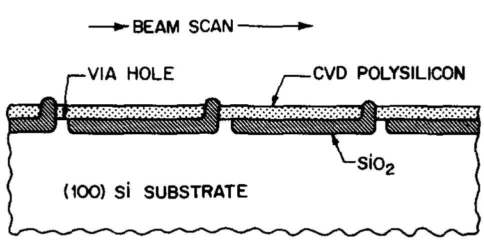

FIG. 1. Schematic cross section of Si islands recessed into SiO_2 "crucibles," with via links to the substrate.

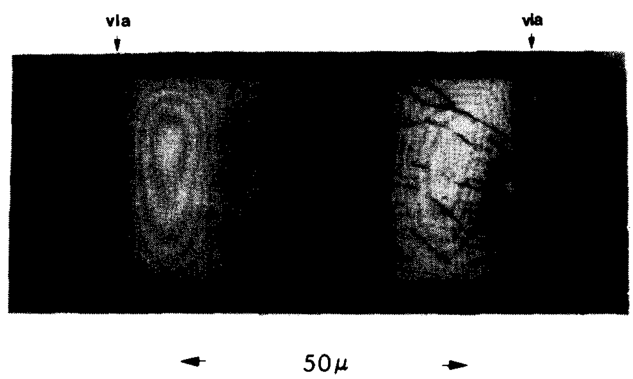

FIG. 2. Optical micrograph of laser recrystallized via islands. Laser beam was swept from left to right.

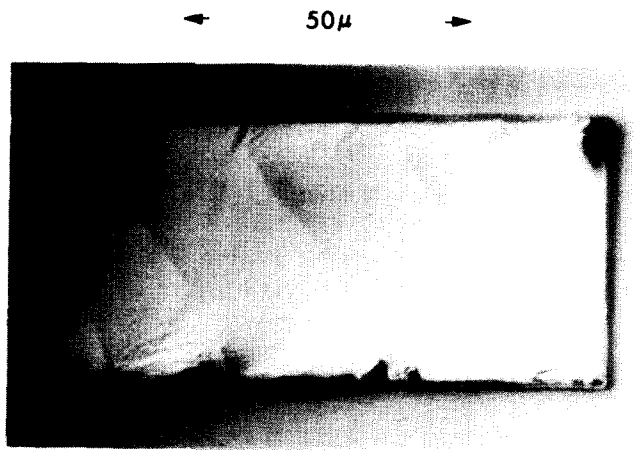

FIG. 3. Optical micrograph of a single crystalline via island produced by rapidly oscillating laser beam.

by a scanned molten zone at very high ambient temperatures, ~1200 °C. Leamy *et al.*[10] have shown that this defect structure is formed by cellular solidification of an impure liquid. In this instance, the high-temperature ambient and long liquid duration (~2 s) allow contamination of the polycrystalline precursor. In our experiments and those of Lam,[8] the liquid duration is shorter by a factor of 10^{-3}, the ambient is cooler, and lateral gradients are far larger. On this basis, therefore, we believe that the defect structures shown in Fig. 2 form in order to accommodate the temperature-gradient-imposed strain in the solidified material. Our purpose here is to show that they may be removed by repeated melting and resolidification of the material.

The first successful modification of the crystallization process involved rapidly scanning the laser beam in two orthogonal directions such that a crescent-shaped Lissajous figure resulted instead of a conventional circular molten zone. Sweeping the altered molten zone along the longitudinal axis of the rectangular islands produced seeded single crystalline regions as large as $50\times 100\,\mu$m, shown in Fig. 3.

In Fig. 4(a), another crystallization procedure is shown schematically. The laser beam was scanned across the islands with the incremental motion in the overgrowth direction of only 10 μm per scan. Each time the beam crossed the island, it remelted most of the Si recrystallized in the preceding scan. Since the center of the island is cooler then the edges, new crystallization always starts there. There is of course competing crystal growth from the side of the molten zone remote from the vias. This random growth is eliminated, however, by the subsequent scans. In Fig. 4(b), results of transverse laser scans are presented. Single crystalline areas as large as $50\times 500\,\mu$m have been obtained. The length of the seeded overgrowth was limited primarily by the dimensions of the lithographically defined patterns, or occasionally by damage induced in the sample, caused by an instability in the laser output.

The two improved techniques differ primarily in the frequency of oscillation, one being of the same order as the inverse of the freezing time, the other frequency much lower, i.e., allowing sufficient time for recovery of the ambient temperature. In both cases, the seeded overgrowth front propagates in an oscillatory fashion, with part of the regrown film melted by a subsequent pass of the laser beam. The results may be interpreted on the basis of the periodic regrowth concept.[11] Recently Celler *et al.*[5] extended this work to laser crystallized thin Si films and demonstrated that conditions in which a quasi-planar crystalline front propagates in an oscillatory fashion result in extensive growth of single crystalline Si on SiO_2.

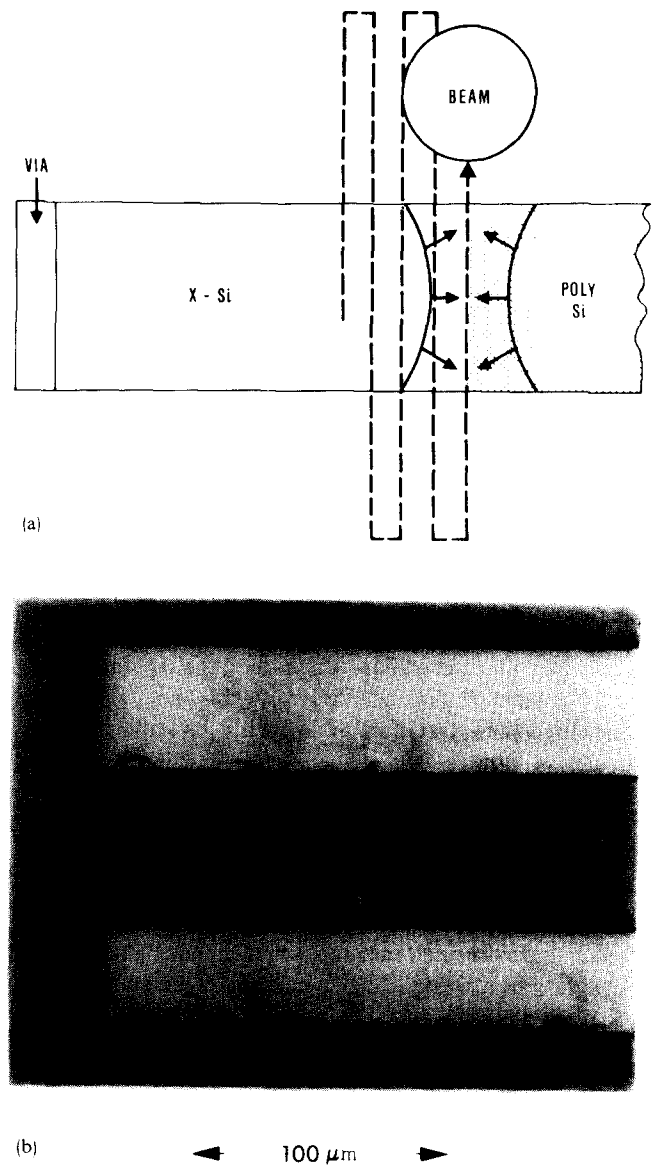

FIG. 4. Transverse scanning procedure. (a) Schematic, (b) optical micrograph of transversely scanned, single crystalline via islands.

An example of the crystalline structure obtained after oscillatory crystallization of a continuous Si film on the SiO_2 is shown in Fig. 5. A single crystalline region is obtained along the central portion of the recrystallized track, but its width is limited by simultaneous regrowth from the unprocessed small grained Si. In the present work, the narrow tub structure obviates the need for rapid oscillations as the whole width of the island is liquid during and immediately after the laser pass. During remelting of the previously crystallized

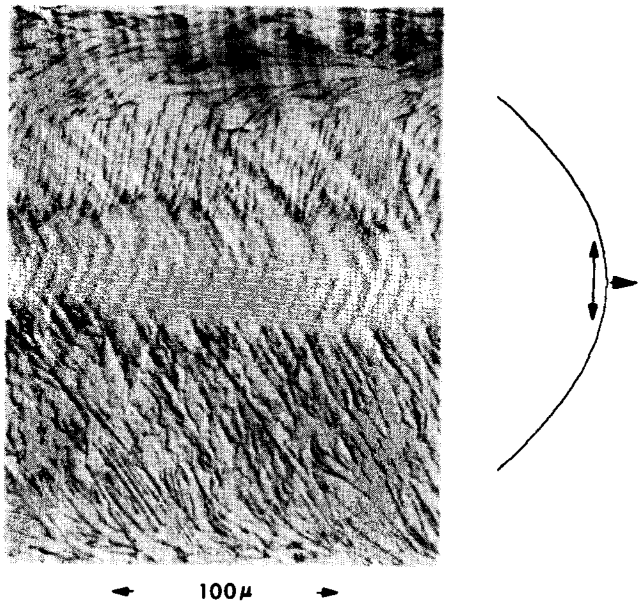

FIG. 5. Optical micrograph of a continuous Si film on SiO_2 recrystallized by a laser beam oscillating at 1400 Hz in the direction of the slow table motion and at 700 Hz in the other axis. The trace of the oscillation is shown at right.

material, the highly defective regions melt more rapidly, leaving depressions in the solid-liquid interface.[11] In early regrowth the growth into such depressions is faster, as it does not require the nucleation of new layers. Thus most extended defects, possibly left after the preceding laser scan, are eliminated. After repeated melting of previously crystallized segments of polysilicon film, few defects are left which could be precursors to grain boundary formation.

It should be stressed here that, although periodic remelting of the previously melted zone occurs in most cases where a raster scanned cw laser is used, this does not automatically lead to improved crystalline structure. When raster scanning, the melt and solidification fronts also move in a serpentine fashion and the thermal gradients are not in the direction of the long term advance of the crystalline sheet.

In summary, seeded epitaxial growth extending as much as 500 μm from the seed area was achieved from Si films contained in shallow SiO_2 crucibles, with narrow via links to the bulk crystal. Scanning procedures ensuring periodic motion of the crystallization front were instrumental in attaining long range overgrowth.

[1] A. Gat, L. Gerzberg, J. F. Gibbons, T. J. Magee, J. Peng, and J. D. Hong, Appl. Phys. Lett. **33**, 775 (1981).
[2] R. Fastow, H. J. Leamy, G. K. Celler, Y. H. Wong, and C. J. Doherty, in *Laser and Electron Beam Solid Interactions and Laser Processing*, edited by J. F. Gibbons, L. D.Hess, and T. W. Sigmon (North Holland, New York, 1981), p. 495.
[3] H. W. Lam, in *Laser and Electron Beam Interactions with Solids*, edited by B. R. Appleton and G. K. Celler (North Holland, New York, 1982).
[4] K. K. Ng, G. K. Celler, R. C. Frye, H. J. Leamy, E. I. Povilonis, and S. M. Sze, IEEE Electron. Devices Lett. **EDL-2**, 316 (1981).
[5] G. K. Celler, H. J. Leamy, and L. E. Trimble, Electron. Mater. Conf., Santa Barbara 1981.
[6] L. E. Trimble, G. K. Celler, K. K. Ng, H. Baumgart, and H. J. Leamy, see Ref. 3.
[7] D. G. Schimmel, J. Electrochem. Soc. **126**, 479 (1979).
[8] H. W. Lam, R. F. Pinizzotto, and A. F. Tasch, Jr., J. Electrochem. Soc. **128**, 1981 (1981).
[9] E. W. Maby, M. W. Geis, Y. L. LeCoz, D. J. Silversmith, R. W. Mountain, and D. A. Antoniadis, IEEE Electron. Devices Lett. **EDL-2**, 241 (1981).
[10] H. J. Leamy, R. A. Lemons, H. Baumgart, C. C. Chang, and J. Cheng, Mater. Lett. **1** (1982).
[11] K. A. Jackson and C. E. Miller, J. Cryst. Growth **42**, 364 (1977); and references therein.