Orientation filtering by growth-velocity competition in zone-melting recrystallization of silicon on SiO_2

H. A. Atwater,[a] C. V. Thompson,[b] and Henry I. Smith[a]
Massachusetts Institute of Technology, Cambridge, Massachusetts 02139
M. W. Geis
Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, Massachusetts 02173

(Received 9 May 1983; accepted for publication 26 September 1983)

We describe a method of controlling the in-plane ⟨100⟩ directions of grains in (100)-textured silicon films produced by zone-melting recrystallization over amorphous SiO_2. Grains having in-plane orientation within a narrow range are able to grow through an orientation filter consisting of a pattern of crystallization barriers, while grains having other orientations are occluded. The results of experiments using an orientation filter, and the parameters which optimize filter performance, are reported.

PACS numbers: 68.55. + b, 81.10.Hs, 61.50.Jr, 81.10. – h

In zone-melting recrystallization (ZMR) of thin polycrystalline silicon films on SiO_2, solidification is seeded by small crystalline grains at the beginning of the recrystallized region, the so-called transition region.[1–9] These seeds have many different orientations but, after the molten zone has been scanned about 10 mm beyond the transition region, grains with (100) texture and in-plane ⟨100⟩ directions within approximately $\pm 25°$ of the zone-scanning direction predominate as a result of occlusion.[1,2] Occlusion occurs because the growth velocity at a given undercooling is orientation dependent, with maxima occurring in ⟨100⟩ directions. Films with a single in-plane orientation have been obtained by seeding from an underlying crystalline substrate,[10] by cross seeding,[1] or by zone melting through planar constrictions.[8] In the first case, film orientation is determined by the substrate orientation. In the latter two cases, a ⟨100⟩ direction is generally within $\pm 25°$ of the zone-scanning direction but its orientation within this range is otherwise unpredictable. Knowledge and control of the in-plane orientation are important in many applications.

In this letter we describe a technique, called orientation filtering, which produces a narrow, predetermined distribution of in-plane ⟨100⟩ orientations in silicon films recrystallized by zone melting. A schematic illustration of the operation of an orientation filter is given in Fig. 1(a). The filter consists of an array of rectangular voids which serve as barriers to solidification. In Fig. 1(a), two crystalline grains, *A* and *B*, which have different in-plane orientations and which are growing in the zone-scanning direction enter the apertures a and b at the same time. The grain which reaches aperture c first [depicted as grain *A* in Fig. 1(a)] will pass through, thereby occluding growth from the competing grain [depicted as *B* in Fig. 1(a)]. Thus, the filter pattern selects crystalline grains on the basis of growth-velocity competition. Beyond c, additional stages of the filter are depicted.

Experiments were performed on 0.5-μm-thick Si films deposited on oxidized silicon wafers by low-pressure chemical vapor deposition (LPCVD). The voids were formed by chemical etching through a photoresist mask. A composite encapsulation layer [1,2] of 2 μm SiO_2/30 nm Si_3N_4 was deposited by LPCVD and sputtering, respectively, after the voids were formed, thereby creating barriers. The dimensions d_1,d_2, and d_3 were varied as follows: $d_1 = 185$–1000 μm, $d_2 = 7$–50 μm, and $d_3 = 10$–50 μm. The voids etched in the silicon film were 7 μm wide, although they could have been much smaller.

Figure 1(b) is an optical micrograph showing grain occlusion by growth-velocity competition. The etch pit matrix[11] indicates that each of the several initial grains has (100) texture but a different in-plane ⟨100⟩ orientation. Single grains pass through the apertures on the left and the right of the barrier. The grain with the more favorable in-plane ori-

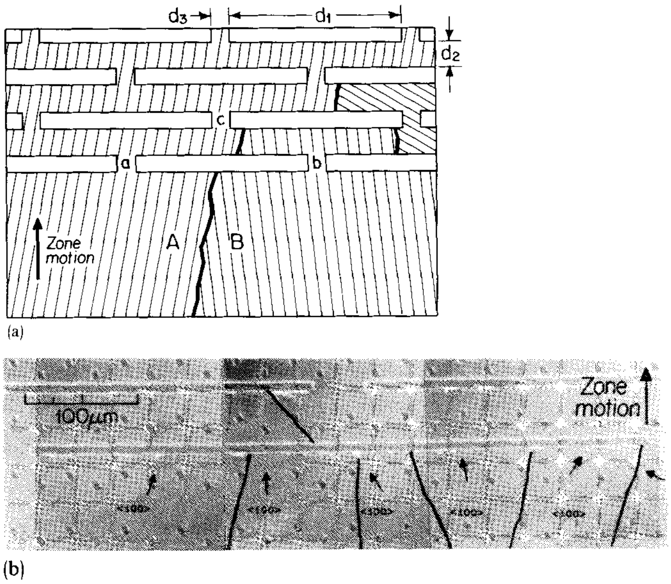

FIG. 1. (a) Orientation filtering. In the clear areas the Si is removed and replaced with SiO_2. Two grains, *A* and *B*, are shown growing into the filter through constrictions a and b, respectively. Both grains grow laterally, but *A* arrives first at the constriction c, thereby occluding grain *B*. Three stages of filtering are depicted. (b) Optical micrograph of a stage of an orientation filter showing occlusion of the less favorably oriented grain. Etch pits indicate the in-plane ⟨100⟩ orientations of grains.

---

[a] Department of Electrical Engineering and Computer Science.
[b] Department of Materials Science and Engineering.

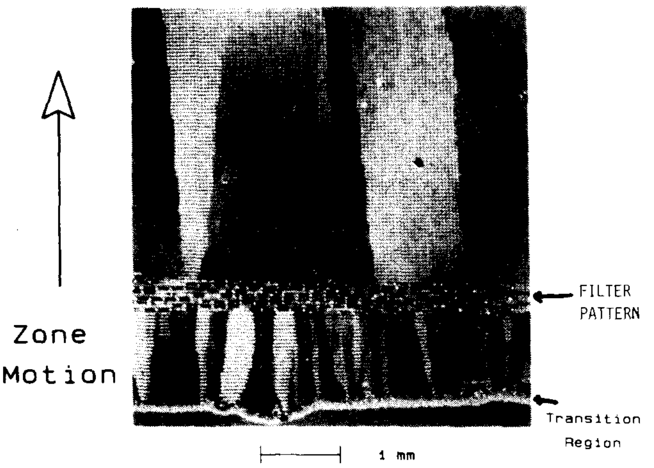

FIG. 2. Optical micrograph of region surrounding an orientation filter. Oblique illumination of the matrix of etch pits indicates large grain size beyond the orientation filter.

entation passes through the aperture in the second row of barriers.

In Fig. 2, an optical micrograph of the region surrounding an orientation filter shows the character of grains before and after the filter, as revealed by oblique illumination of the etch-pit array. The increase in the average grain size is apparent. Beyond the filter, the grain boundaries that remain tend to extend the full length of the region scanned. Subboundaries within grains have the normal morphology and spacing.[9] The grains which pass through the filter have a statistical preference for in-plane orientations in which ⟨100⟩ directions are parallel to the shortest distance between apertures a and c, and apertures b and c. This is consistent with ⟨100⟩ being the direction of fastest growth. Figure 3(a) gives a typical distribution of in-plane orientations for the (100)-textured grains about 1 mm in front of the transition region and before (i.e., prior to entering) an orientation filter. Figure 3(b) shows a typical distribution after passage through a filter in which $d_1 = 185$ μm, $d_2 = 15$ μm and $d_3 = 20\,\mu$m, and in which there were 14 stages (i.e., 15 rows of solidification barriers). Each vertical bar of the histogram represents a single grain, and the height of a bar indicates the grain width. Most grains are wider than 1 mm. The inset to Fig. 3(b) illustrates that the shortest path from an aperture in one row of barriers to an aperture in the next row of barriers corresponds to a ⟨100⟩ direction at an angle of $+\phi$ or $-\phi$ relative to the zone-scanning direction. For the particular filter pattern geometry used in this experiment, $\phi = 9.5°$, which is close to the observed mean angle of 8.2°. The distribution is bimodal, that is, both positive and negative angles are observed. The calculated standard deviation is 2.5°. The in-plane orientation measurements were made using the grid of etch pits; accuracy was limited to $\sim \pm 1.5°$. The distributions observed are generally skewed towards 0°.

For a filter of the design shown in Fig. 1, the mean orientation ϕ can be reduced by decreasing d_2/d_1. The spread in orientation can be reduced by decreasing d_3/d_1 and /or by increasing the number of filter stages. A practical limit to increasing d_1 is the zone velocity v_z. For large d_1 and v_z, spontaneous nucleation and subsequent dendritic growth become more likely.[8] Our current strip heater has a minimum velocity of 100 μm/s. With this limit, the maximum value of d_1/d_2 for which orientation filtering was successful was approximately 30 (where $d_1 = 600$ μm). Also, if d_1 is very large, the number of apertures will be small, limiting the number of grains available for competition. We are currently investigating the optimization of filters of the design shown in Fig. 1, and are also investigating filters which operate on the same general principle but which eliminate the direct line-of-sight from one aperture to the aperture in the next row of barriers.

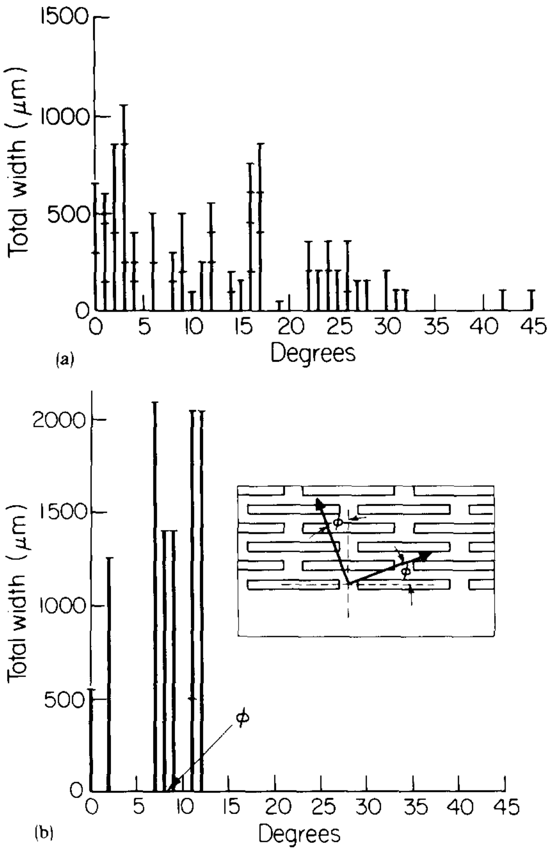

FIG. 3. (a) Distribution of in-plane ⟨100⟩ orientations approximately 1 mm after the transition region and before an orientation filter. (b) Distribution of in-plane orientations after orientation filtering. For this filter, $d_1 = 185\,\mu$m, $d_2 = 15\,\mu$m, and $d_3 = 20\,\mu$m and there are 14 stages. Inset shows shortest path between apertures. The angle ϕ is 9.5°; the measured mean $\phi_{\rm obs}$ of the distribution was 8.2°.

We have demonstrated a technique, called orientation filtering, which uses planar patterning to achieve a narrow, predetermined distribution of in-plane orientations in zone-melting recrystallization of silicon films on SiO_2. The technique should be useful in conjunction with subboundary entrainment[9] and other growth-modification methods[12,13] in achieving oriented films with controlled defect distributions.

This work was sponsored by the Office of Basic Energy Sciences, U.S. Department of Energy. The Lincoln Laboratory portion of the work was sponsored in part by the Defense Advanced Research Projects Agency. The authors are grateful to R. W. Mountain and C. L. Doherty who provided the substrates and P. Leach, who helped in the etch-pit analysis.

[1] M. W. Geis, H. I. Smith, B-Y. Tsaur, J. C. C. Fan, E. W. Maby, and D. A. Antoniadis, Appl. Phy. Lett. **40**, 158 (1982).

[2] M. W. Geis, H. I. Smith, B-Y. Tsaur, J. C. C. Fan, D. J. Silversmith, and R. W. Mountain, J. Electrochem. Soc. **129**, 2812 (1982).

[3] A. Kamgar and E. Labate, Mater. Lett. **1**, 91 (1982).

[4] H. J. Leamy, C. C. Chang, H. Baumgart, R. A. Lemons, and J. Cheng, Mater. Lett. **1**, 33 (1982).

[5] M. Haond, D. Bensahel, and M. Dupuy, J. Appl. Phys. **54**, 437 (1983).

[6] T. J. Stulz and J. F. Gibbons, Appl. Phys. Lett. **41**, 824 (1982).

[7] B-Y. Tsaur, J. C. C. Fan, M. W. Geis, D. J. Silversmith, and R. W. Mountain, Appl. Phy. Lett. **39**, 561 (1981).

[8] H. A. Atwater, H. I. Smith, and M. W. Geis, Appl. Phys. Lett. **41**, 747 (1982).

[9] M. W. Geis, H. I. Smith, D. J. Silversmith, R. W. Mountain, and C. V. Thompson, J. Electrochem. Soc. **130**, 1178 (1983).

[10] J. C. C. Fan, B-Y. Tsaur, R. L. Chapman, and M. W. Geis, Appl. Phys. Lett.**41**, 186 (1982).

[11] K. A. Bezjian, H. I. Smith, J. M. Carter, and M. W. Geis, J. Electrochem. Soc. **129**, 1848 (1982).

[12] H. A. Atwater, M.S. thesis, MIT, 1983; reprinted as VLSI memo #83-149.

[13] H. I. Smith, M. W. Geis, C. V. Thompson, and H. A. Atwater, J. Cryst. Growth (to be published 1983).