Preferential orientation effects in partial melt laser crystallization of silicon

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We report on progress toward controlling the crystalline orientation of laser-crystallized semiconductor films on an amorphous substrate. This is desirable for monolithic 3-dimensional integration of semiconductor devices[1], where each successive circuit layer is fabricated on top of pre-existing layers. This scheme has the potential to improve circuit density, power consumption and wire delay by reducing wire lengths. One of the challenges of this approach is obtaining device-quality single-crystalline silicon on top of an amorphous isolation layer, i.e. with controllable crystallite orientation. This must be done without exceeding the thermal budget of processed devices underneath in order to preserve device integrity. We have previously reported results[2] suggesting that a pulsed laser crystallization process can satisfy the temperature requirement, while also allowing the formation of a partial melt in a silicon film. There is evidence that a strong preferential orientation can result from partial melting[3], which we investigate here.

Our experimental apparatus has been previously reported[1]; the beam from a 10W frequency doubled Nd:YAG laser is used for melting, modulated and focused to a 25µm FWHM diameter spot. Fig. 1 shows electron backscatter diffraction (EBSD) data from a 2ms duration exposure of a 200nm thick amorphous silicon film on a quartz substrate. This shows a strong <001> out-of-plane texture in the individual grains within the exposed area. After nucleating from the partially molten solid-liquid interface at the edge of the melt zone, the grains compete for area as the melt cools toward the center. In this process, <001> grains appear to win over other orientations, obtaining a high fraction of the overall area. When reducing the exposure time to 200µs and 20µs, the resulting texture becomes random, indicating a kinetic process in the evolution of <001> grains. A similar experiment at 2ms was conducted on a 500nm thick film (Fig. 2). The sharp decrease in <001> texture likely results from the reduced dominance of film surface energy over the bulk[3]. Fig. 3 shows results from a 200nm thick film on 2.2µm of thermally-grown SiO_2, on an Si substrate. The increased heat flow from the film into the substrate, and the subsequent increase in probability of random nucleation, may be responsible for the reduced texturing. Further experiments are underway to investigate the kinetic processes involved in <001> grain growth.

[1] J. W. Joyner et al, IEEE Trans. On VLSI Sys. **9**, 922 (2001).
[2] D J Witte et al, Microelectronics Journal 38 no 4 (April 2007).
[3] D. K. Biegelsen, L. E. Fennell, and J. C. Zesch, Appl. Phys. Lett. **45**, 546 (1984).

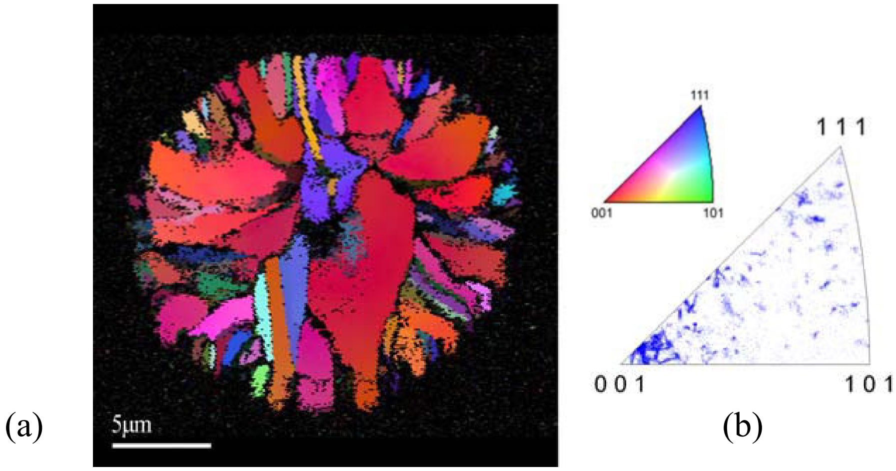

Fig. 1: (a) EBSD pattern showing grain orientations after a 2ms laser exposure of a 200nm thick Si film on a quartz substrate. (b) Distribution of grain orientations.

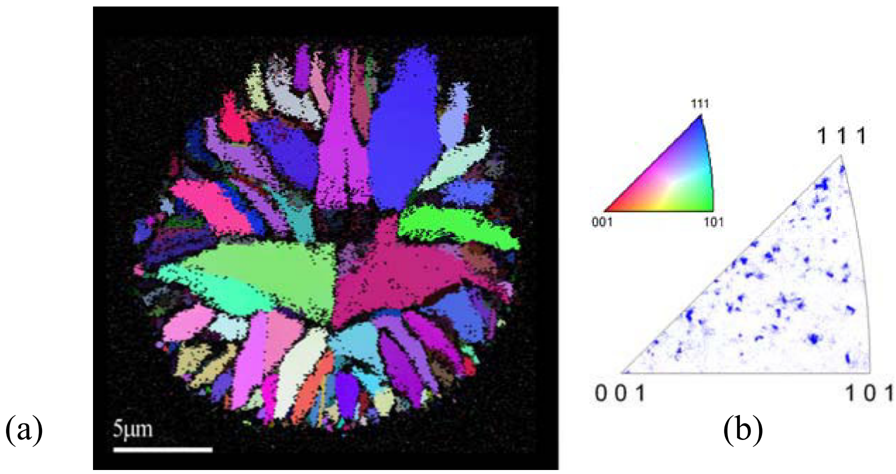

Fig. 2: Same as above, but with a 2ms laser exposure of a 500nm thick Si film on a quartz substrate.

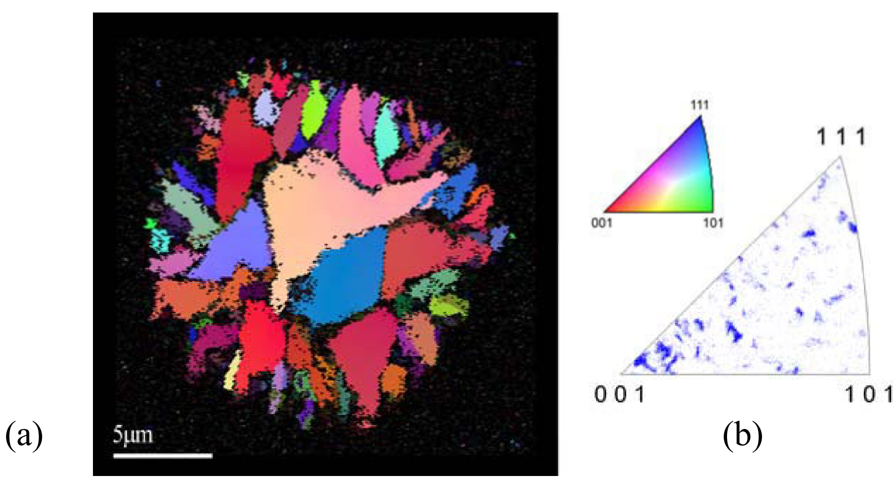

Fig. 3: Same as above, but with a 2ms laser exposure of a 200nm thick Si film on 2.2μm of thermally-grown SiO_2, on an Si substrate.