Annealing of Isolated Amorphous Zones in Silicon

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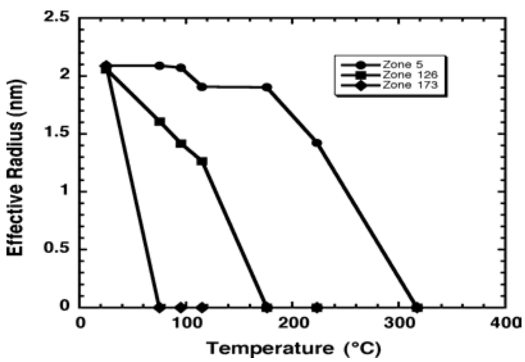
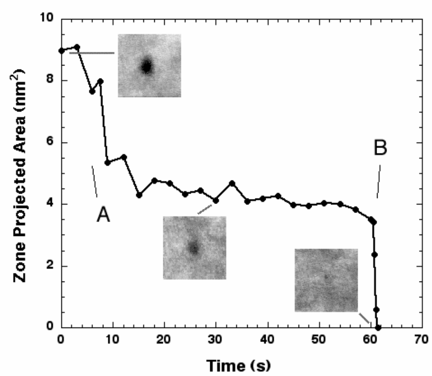
Ion implantation is a major technology for semiconductor device manufacture, but it unavoidably leads to radiation damage that must be minimized, controlled or removed. A single ion impact, with high energy deposition density, may create a sufficient local defect density to render a small region amorphous. As ion fluence further increases, these zones accumulate and form an amorphous layer. Thermal annealing can convert such amorphous layers to crystal by advancement of the interface with good crystal. This process exhibits Arrhenius-type behavior with a single activation energy of 2.7 eV for recrystallization rates varying over ten orders of magnitude and temperatures from 500–1400K.

The kinetics of thermal annealing of isolated amorphous zones in Si has not been fully investigated. To address this, we have used a TEM in which in-situ ion irradiation can be carried out and individual amorphous zones can be followed from creation to recrystallization.

Recrystallization of small amorphous zones differs from that of the planar amorphous/crystalline interface. The total amorphous volume fraction continuously decreases over a temperature range from room temperature to approximately 500°C. Volume-averaged information fails to reveal the erratic annealing of individual zones. Analysis of more than 400 isolated zones reveals little consistency in their behavior with no correlation between their size and recrystallization temperature. Zones with similar starting sizes crystallized at temperatures anywhere from 70°C to more than 400°C. On any temperature increase, zones of every size disappear. Frame-by-frame analysis of video recordings revealed that the recovery of individual zones is a two-step process with changes taking place over a few seconds separated by longer periods of stability.



Change in effective radius of three amorphous zones with similar initial radius following 10 minute anneals.



Recrystallization of a single amorphous zone as a function of time while the temperature rose from 302°C to 308°C.

This is the first demonstration of sporadic recrystallization of nanometer sized amorphous zones. Recrystallization involves at least two thermally activated processes: a triggering event and the recrystallization process itself. Triggering events are not unique but occur over a temperature range of more than 300 °C. The subsequent rapid recrystallization has an associated energy of about 1.2 eV. MD simulations show that when a single heavy ion impact results in an energy density sufficient for an amorphous zone to form, the surrounding region, where the energy density is lower, will have a high density of point defects. The precise atomic arrangement near the interface will vary from zone to zone and from point to point around the surface of each zone. The energy required to create a trigger defect may thus vary from zone to zone (as possibly will the migration energy).

Annealing of Isolated Amorphous Zones in Silicon, S. E. Donnelly, R. C. Birtcher, V. Vishnyakov and G. Carter, Appl. Phys. Lett. 82, 1860 (2003).

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