Extended Defects in c-Si
(Claverie etc, MSSP 3, 269 (2000)

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General Perspective

- Materials Science in Semiconductor Processing (MSSP)
- Exact type of the predominant defects dependent on ion dose, energy and annealing conditions
- Evolution (nucleation, growing, transforming, dissolving) upon annealing

In the case of Non-amorphizing Implants

- {113} rod-like defects; {113} planes elongated along the <110> directions
- Formation energy; 1-1.3 eV and slowly decreasing as the size of the defect increases
- Defects growing in size and decrease in density upon annealing
- Activation energy (3.7 eV) = binding energy + migration energy

Terms

- Weak Beam Dark Field (WBDF) image
- High-Resolution TEM (HREM)
- Bravais lattices: 14 different point lattices
- Point lattice + atom group = periodic atom array
- Burgers vector: the shortest lattice translation vector of the crystalline structure

{113} Defects

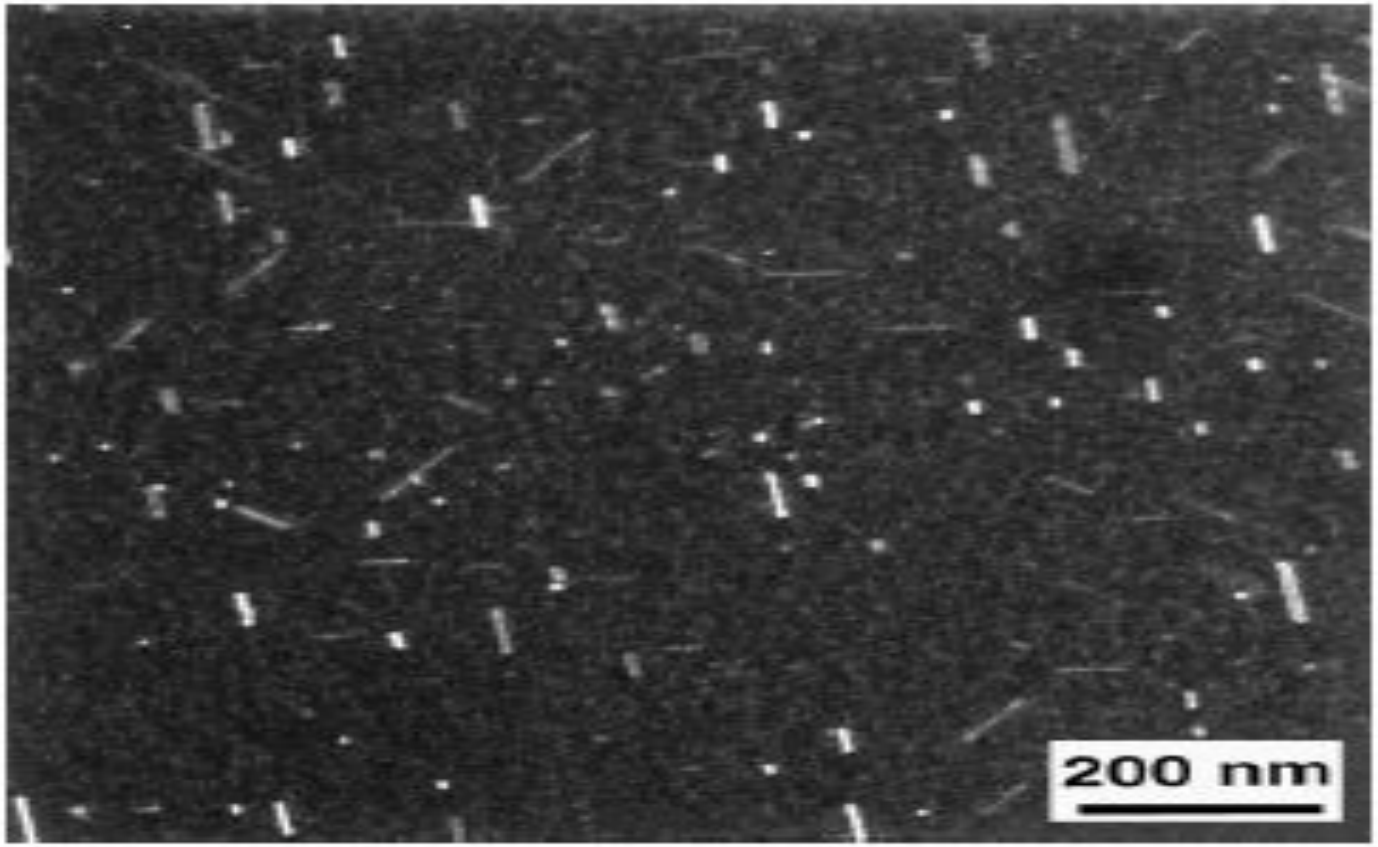


Fig. 1. Typical WBDF TEM image of a population of {113} defects seen after "moderate" annealing of B-implanted Si.

{113} Defects
(800℃ of a 40 keV, $5x10^{13}$ Si^{+})

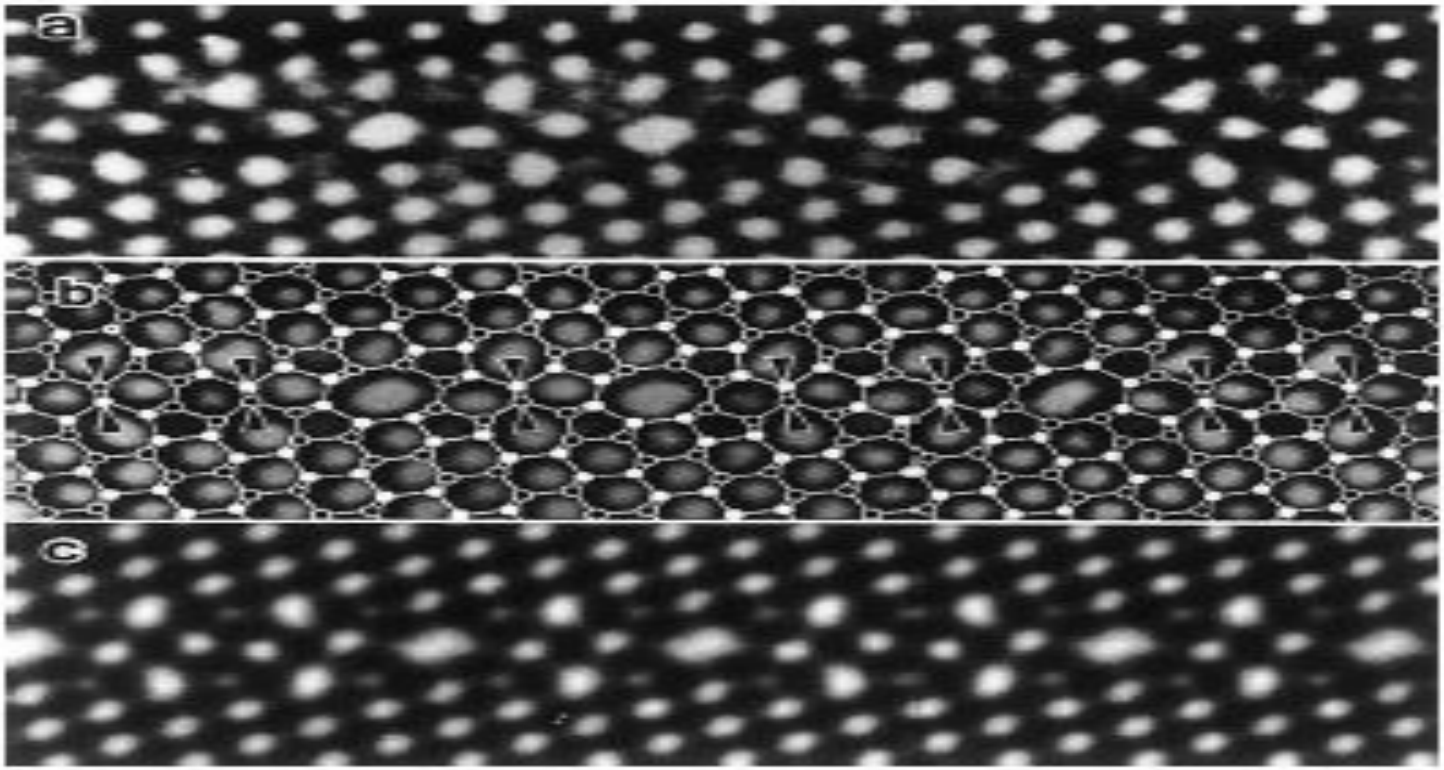


Fig. 2. HREM image of a section of a {1 1 3} defect. (a) direct image; (b) superposition of atomic model and simulated image; (c) simulated image (from Ref. [8]).

{113} Defects upon Annealing

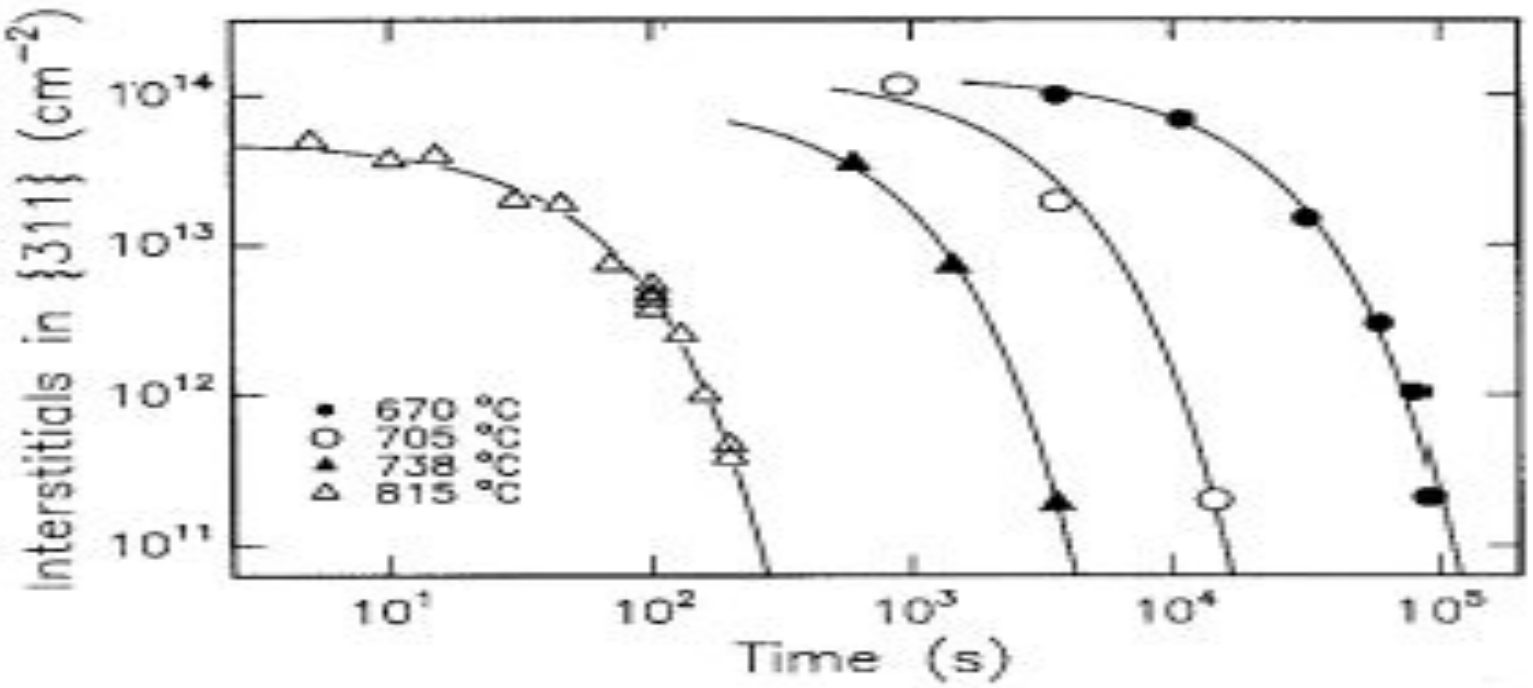


Fig. 3. Evolution of the total number of Si(int)'s bound to the {1 1 3} defects upon annealing at various temperatures (from Ref. [2]).

Energies

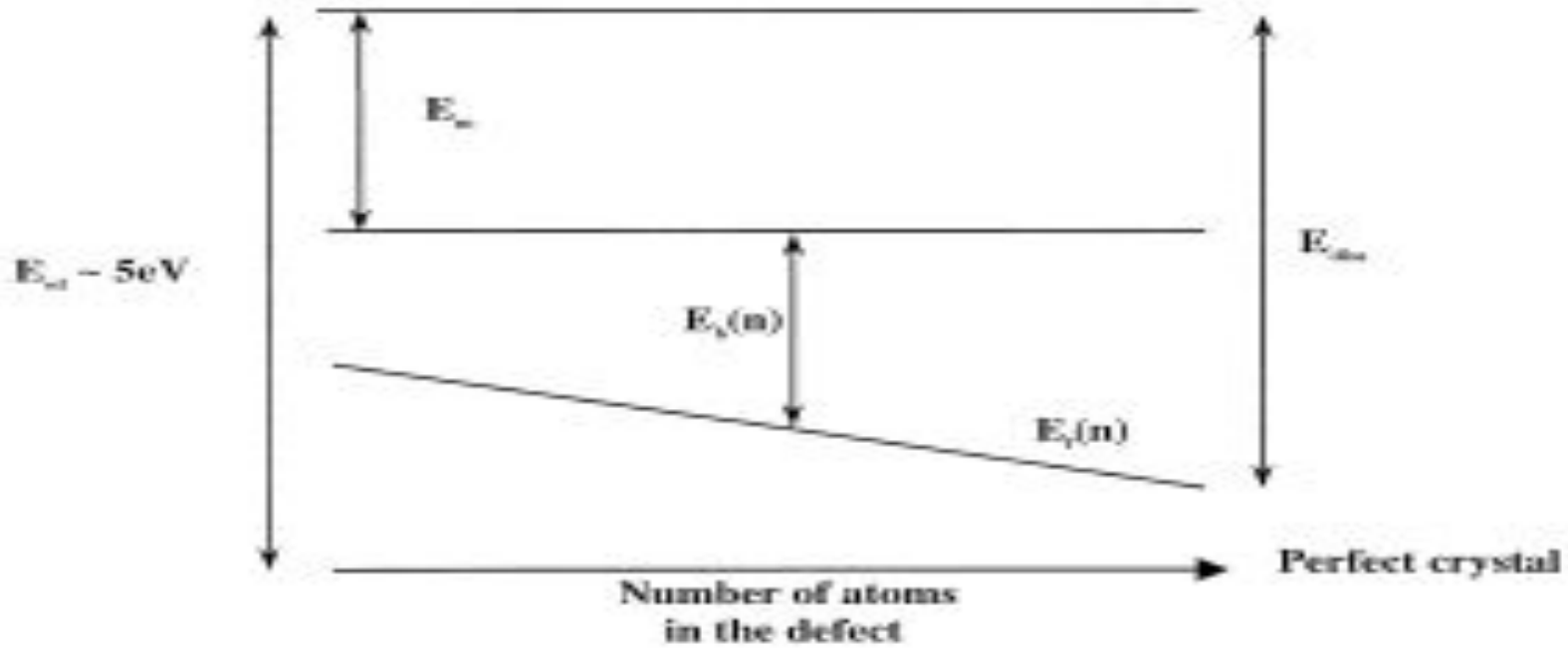


Fig. 4. The dissolution energy is the sum of the binding and of the migration energies. The formation energy depends on the size of the defect.

Energies

- Formation energy of a defect: energy incease due to the incorporation of an extra Si atom into a defect
- Activation energy for the dissolution of the defects = activation energy for self-diffusion – formation of the defect =binding energy + migration energy

In the case of Medium-dose Implants

- 100 keV Si^+-implanted Si at 800 ℃
- {113} and dislocation loops (DL) coexist after 5 min annealing at 800 ℃
- {113} defects are the source of DLs
- Perfect dislocation loops (PDLs) and faulted dislocation loops (FDLs)

Medium-dose Implants

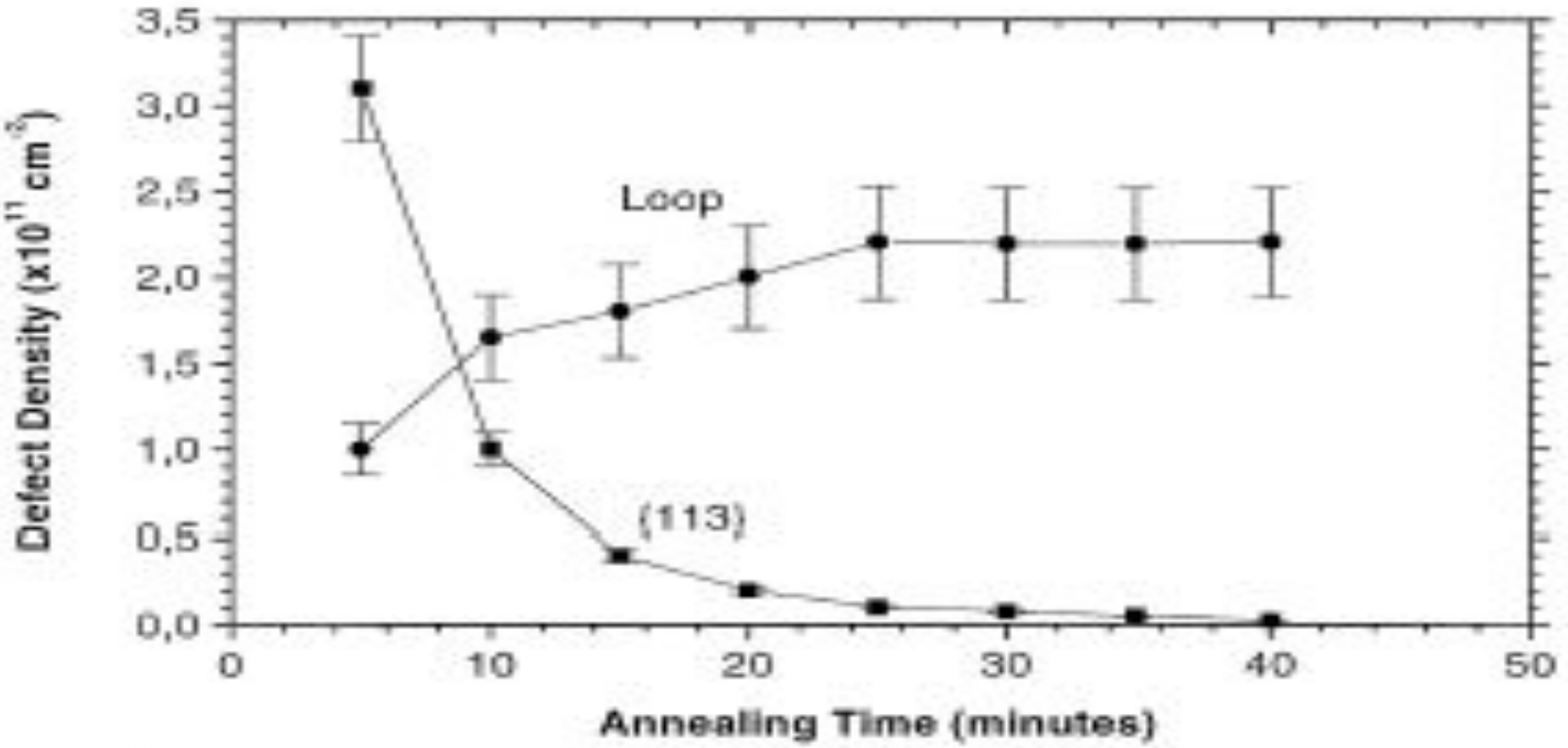


Fig. 5. Transformation of {1 1 3} defects into dislocation loops (from Ref. [14]).

In the case of Amorphizing Implants

- Oswald ripening process; formation energy decreases as its size increases and the supersaturation of Si's around a large defect is smaller than around a small defect
- Loop density varies with 1/t and the mean radius increases with $t^{1/2}$
- Wafer surface can be a better sink: when the free surface of the wafer is put closer a faster dissolution of PDL's is observed but the emitted Si's are not trapped by the FDL's.

Amorphizing Implants

- Formation energy of PDLs higher than FDLs
- For low-budget thermal annealings, clusters and {113} defects coexist and the latter become predominant when increasing the annealing time
- For higher thermal budgets, dislocation loops of two types are also found among the defects
- For the highest temperatures only faulted dislocation loops survive

Amorphizing Implants

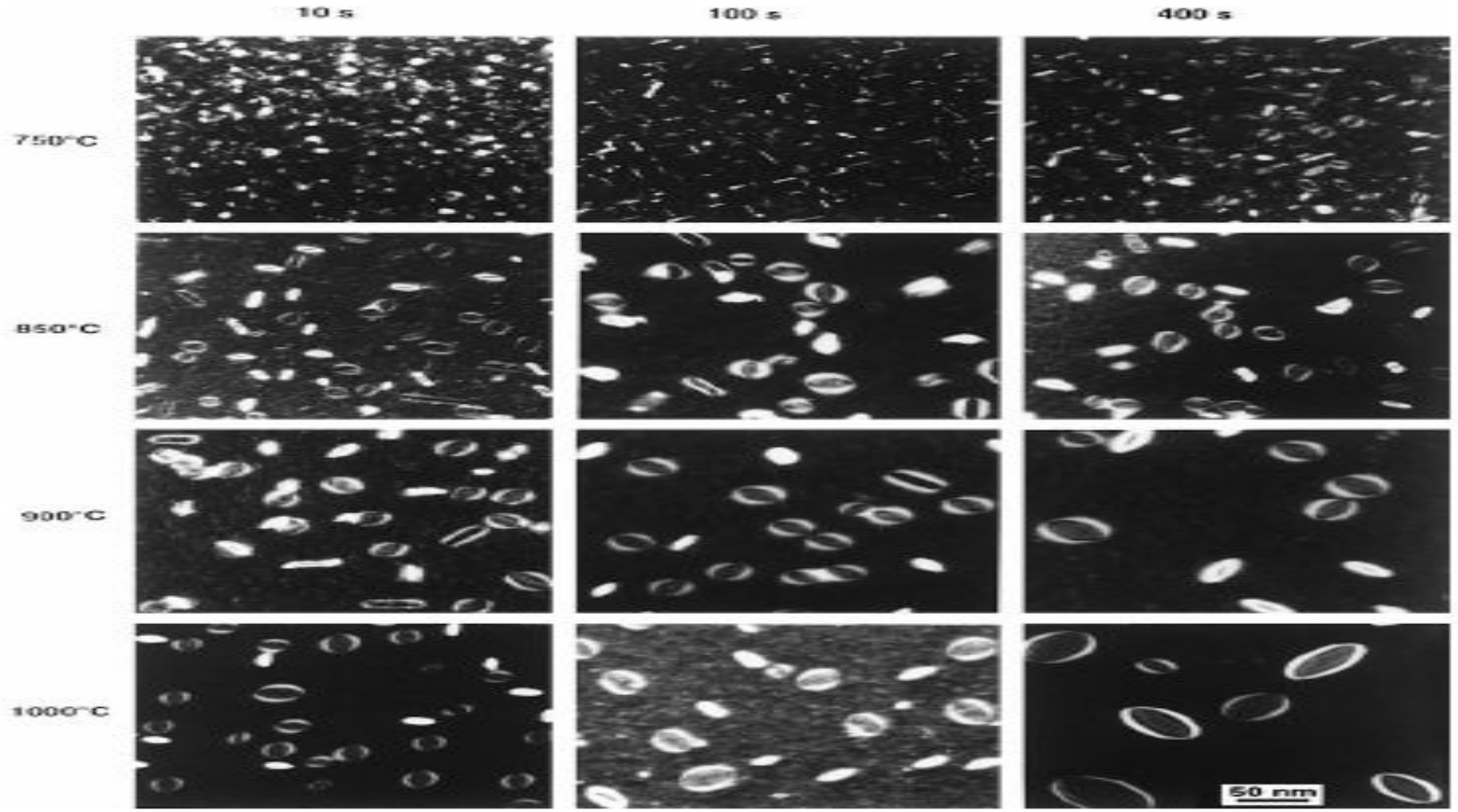


Fig. 6. Thermal evolution of EOR defects as a function of annealing conditions.

Amorphizing Implants

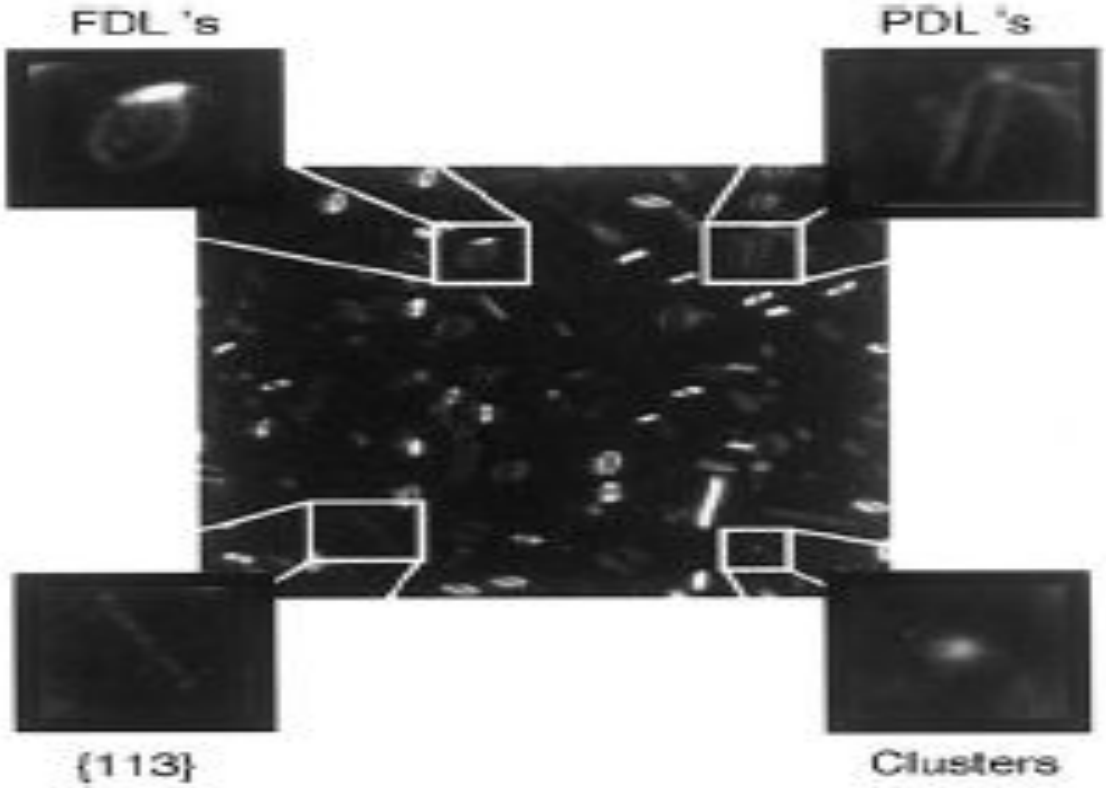


Fig. 7. After 400 s at 750°C, EOR defects can be four types: clusters, {1 1 3 }, FDLs or PDLs.

Thermal Evolution of FDLs

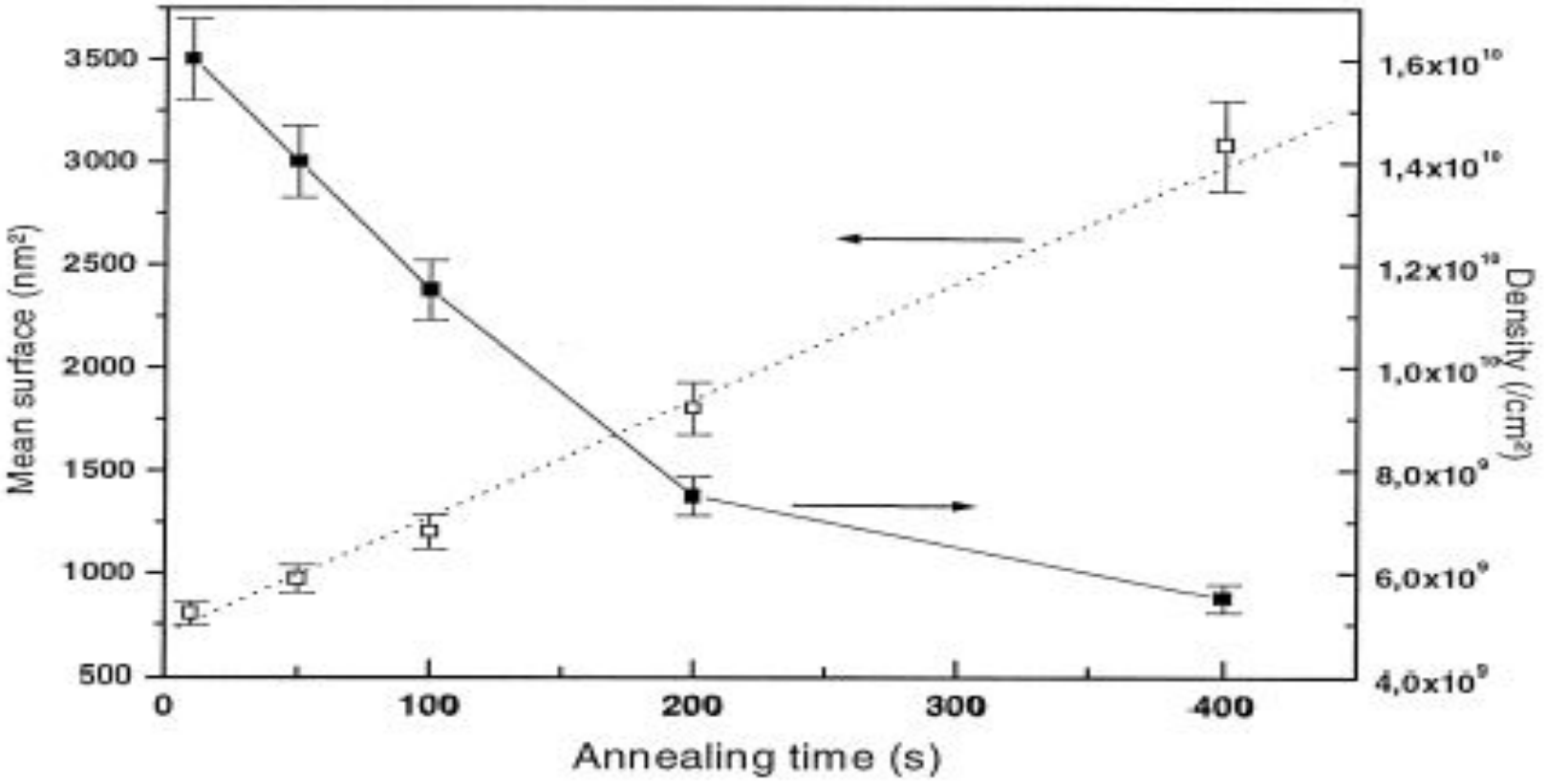


Fig. 9. Density and size evolutions of a population of EOR defects upon annealing at 1000°C.

Competition between PDLs and FDLs

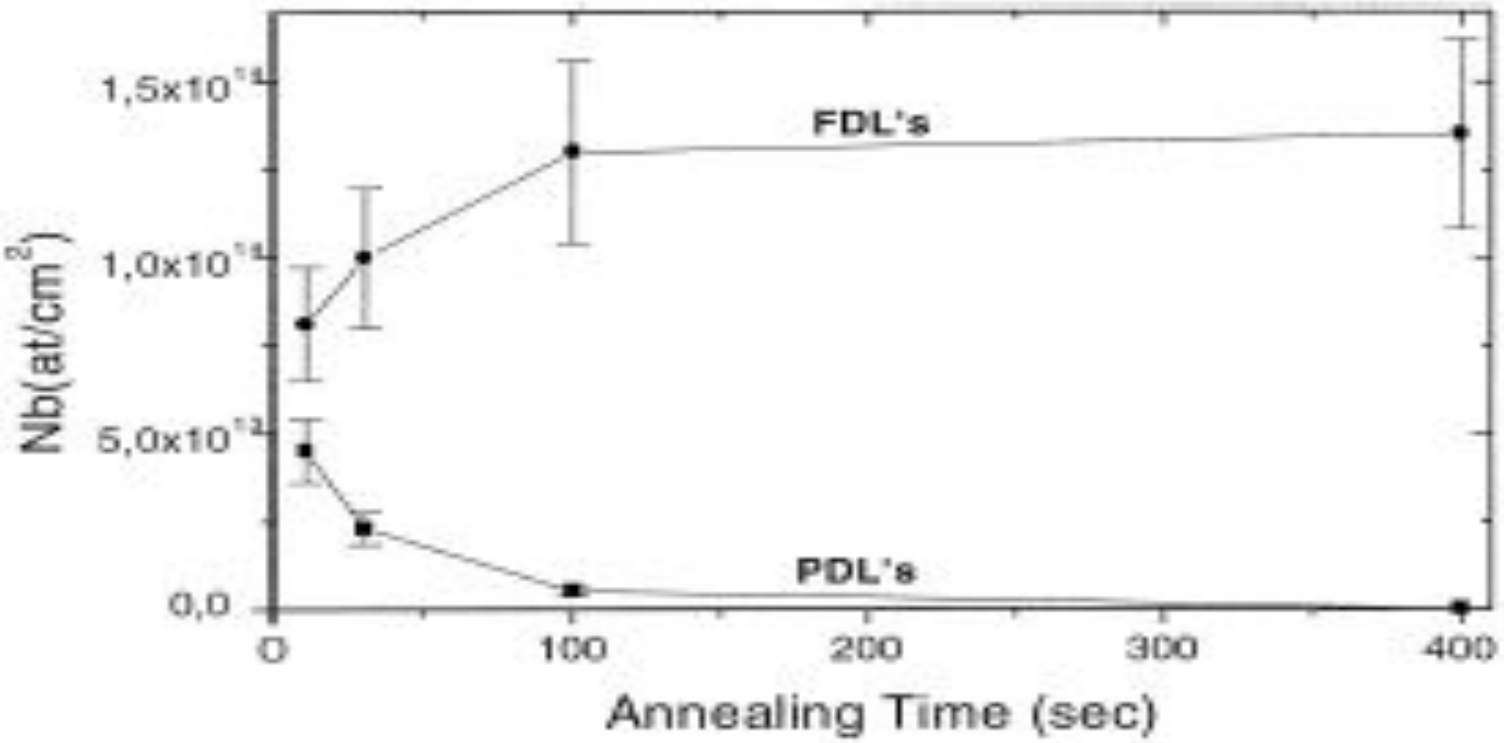
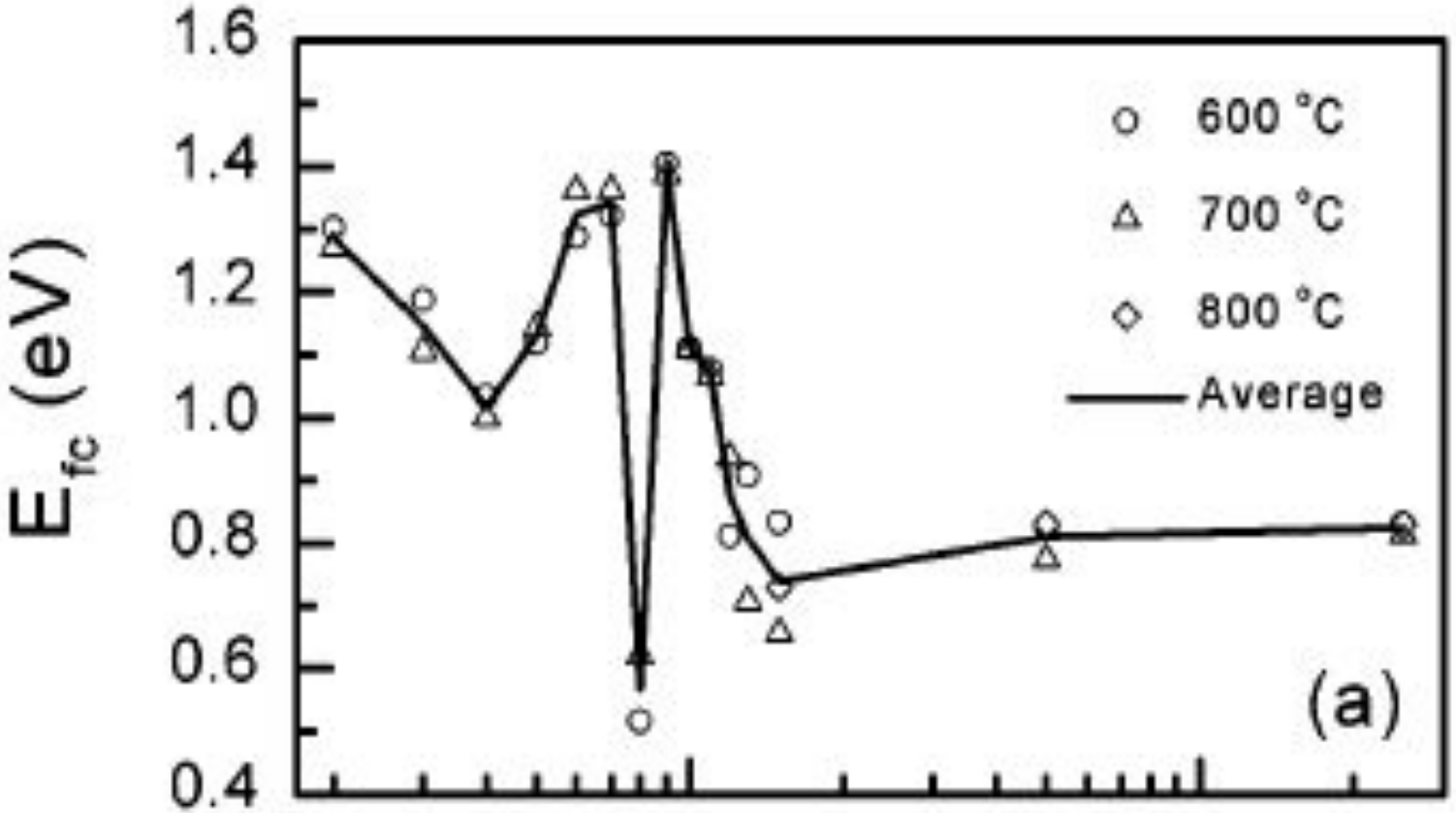


Fig. 10. During annealing, FDLs capture the Si(int)'s atoms which are lost by the PDLs.

Origin of {113} Defects



Defect Evolution

- Di-interstitials
- {113} defects
- PDLs and FDLs
- FDLs
- Surface effect as a sink

Defect Evolution

- Driving force for the growth of a given type of defects is due to the decrease of the formation energy as its size increases
- The change from one type of defect to the next is driven by the reduction of the formation energy consecutive to the crystallographical reordering of the same number of Si atoms into the new defect
- Formation energy change due to the size increase or in their structural characteristics

Formation Energy

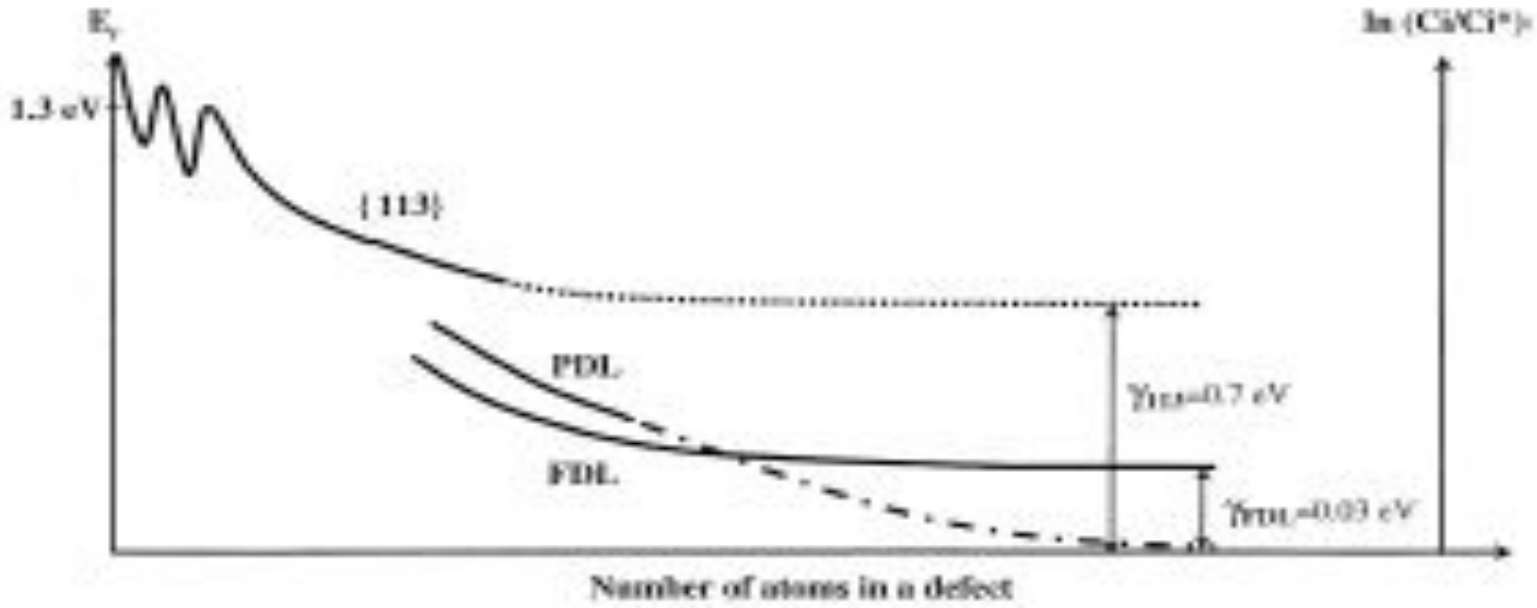


Fig. 11. Time and/or size evolution of the formation energy of the various extrinsic defects formed after annealing of ion implanted Si.