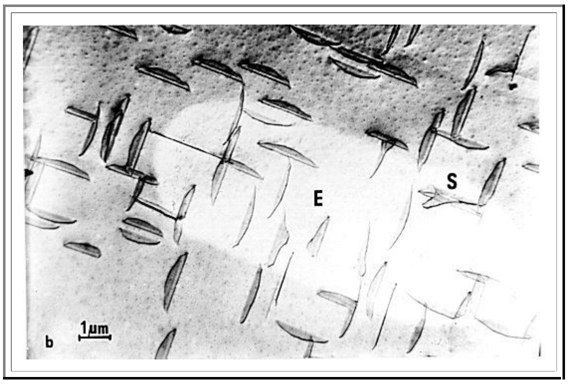
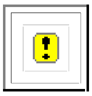
Oxidation Induced Stacking Faults in Silicon

Advanced

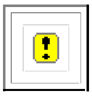
- Oxidation of Silicon produces interstitials in supersaturation. These surplus interstitials tend to agglomerate in discs - i.e. stacking fault loops. The difficult part is the nucleation; it determines what will happen. We have to consider two ways of oxidizing **Si**, we first consider
- *Surface oxidation*: The surface oxidizes homogeneously by exposing it to an oxidizing atmosphere at high temperatures. This is the normal oxidation process. The emission of interstitials occurs at the interface; the interstitials diffuse into the bulk; the supersaturation decreases with the distance from the surface.
  - There is no easy nucleation for an interstitial type dislocation loop as long as the interface is defect free. If defects are present, most prominent small precipitates of metal impurities as, e.g. **Fe**, **Ni**, **Cu**, they may serve as nucleation center for the interstitials; a stacking fault penetrating in a semicircular fashion into the bulk is formed. If many precipitates are available, a large density of small stacking faults may be observed:

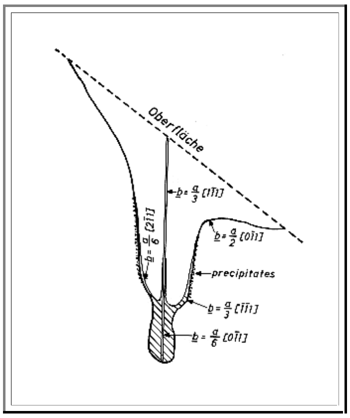


  - The oval shaped area with a lighter contrast is the emitter of a bipolar transistor. In preferential etching this would look similar to what was shown as an illustration for etching.
  - Some of these small stacking faults have a peculiar, "sailing-boat" like shape (marked by "**S**" in the picture above). Below, a detailed view of a "sailing boat stacking fault":

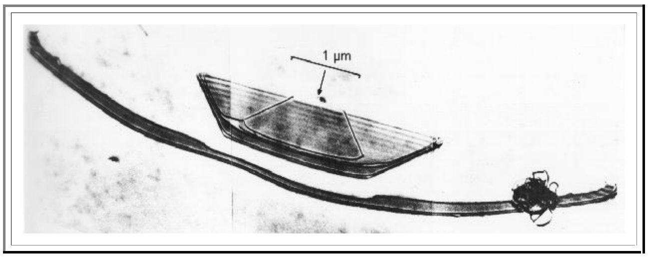


  - These "sailing boats" are formed whenever the nucleation produces two stacking faults on different planes (Connected by a pair of stair-rod dislocations). Obviously the diffusion of interstitial down the central dislocation dipole must be rather efficient. These stacking faults penetrate through the **pn**-junction and lead to a total loss of the transistor.
- In rare cases, "sailing boat" stacking faults started to unfault. For reasons still unknown, the unfaulting process stopped at a certain depth (maybe due to doping influence?); the resulting structure is remarkable, because it contains all types of dislocations that exist in an **fcc** lattice in one defect:

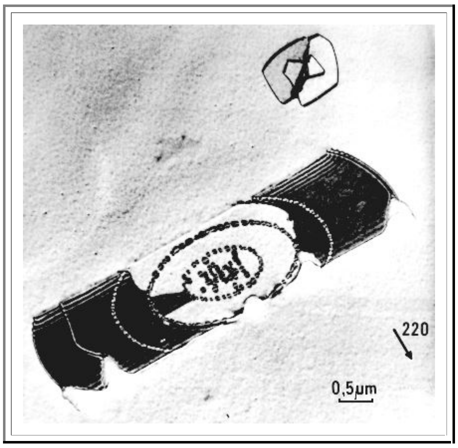




  - We have the perfect dislocation (**b = a/2<110>**), the Frank partial dislocation (**b = a/3<111>**); the Shockley partial dislocation (**b = a/6<112>**) and the stairrod dislocation (**b = a/6<110>**) in one defect.
- If there are only a few precipitates; they may nucleate a stacking fault many times. As soon as the first dislocation loop is too large, a new one will form. As a result, a whole system of overlapping stacking faults is seen (for every third one the contrast disappears because the sum of the displacement vectors is a lattice vector).
  - In this example the precipitate is still visible as a black dot in the center of the stacking fault system. This is usually not the case because the precipitate is incorporated into the oxide and etched off.



- If the **Si** contains some supersaturated oxygen (at high temperatures an equilibrium defect as an interstitial; "$\mathbf{O_i}$"), we may observe **internal oxidation**.
  - A $\mathbf{SiO_2}$ precipitate forms by the agglomeration of $\mathbf{O_i}$; but this may equally well be considered to be an internal oxidation of a small volume of **Si**. Again, interstitials are produced with the tendency for agglomeration.
  - In contrast to surface oxidation, nucleation is rather easy. The small $\mathbf{SiO_2}$ precipitate, especially if it is not spherical, has a stress field that helps to nucleate the stacking fault of the interstitials. We thus find oxide precipitates surrounded by large stacking faults.
- Both processes - the oxide precipitation and the stacking fault formation - occur simultaneously; new precipitates may be nucleated at the Frank dislocation and vice versa.
  - In the course of several high temperature treatments; the processes start all over again and complicated structures develop:



  - Several perfect stacking fault loops overlap (truncated by the sample surface, one of which has been preferentially etched; the etch pits at the dislocations are clearly visible). Some of the loops serves as nucleation sites for a second and third round of oxygen precipitation (shown as small coffee-bean like contrasts).