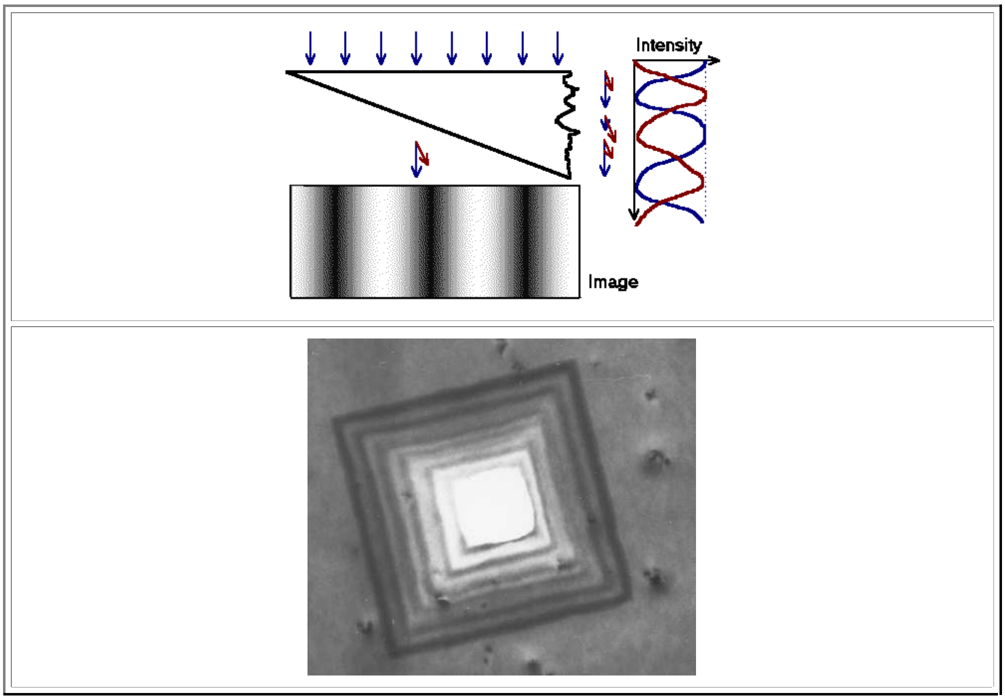
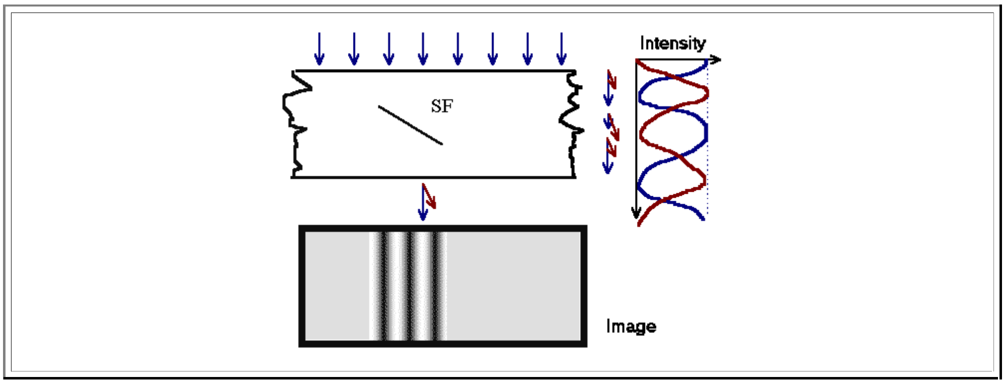
6.3.3 Stacking Faults and Other Two Dimensional Defects

Stacking faults

- Two-dimensional defects like stacking faults, but, to some extent also grain- and phase boundaries, give rise to some special contrast features.
  - Stacking faults are best seen and identified under dynamical two-beam condition; i.e. the Bragg condition is exactly met for one point in the reciprocal lattice.
  - This automatically implies that the diffracted beam, if seen as the primary beam, also meets the Bragg condition; it is diffracted back into the primary beam wave field.
  - This leads to an oscillation of the intensity between the primary and the diffracted beam as a function of depth in the sample; the "wave length" of this periodic intensity variations is called the **extinction length** ξ.
- For a wedge-shaped specimen, the intensity of the primary or diffracted wave thus changes with the local thickness; it goes through maxima and minima.
  - The illustration shows the resulting image: a system of black and white fringes, called thickness fringes or **thickness contours** is seen on the screen.On top a schematicdrawing, on the bottom the real thing. In this case it is an etch pit in a **Ge** sample which is the usual inverted pyramid with **{111}** planes.

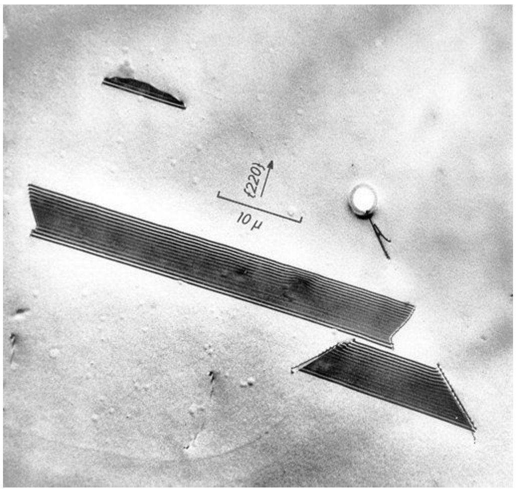


- A stacking fault can be seen as the boundary between two wedge shaped crystals which are in direct contact, but with a displacement ***R*** along the wedge.
  - As a result, the two fringe systems resulting from the two wedges do not fit together anymore. A new fringe system develops delineating the stacking fault; we see the typical **stacking fault fringes**

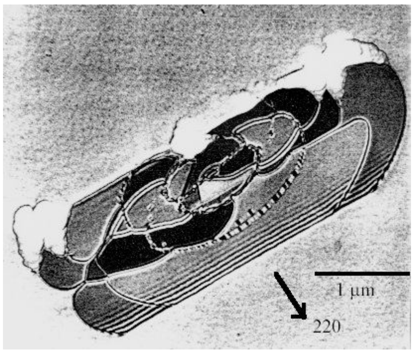


  - Again, getting all the signs right, the nature of the stacking fault can be determined. If intrinsic stacking faults under some imaging conditions would start with a white fringe, extrinsic stacking faults would start with a black one. Reversing the sign of the diffraction vector ***g*** or the displacement vector ***R*** changes white to black and vice versa.
- If more kinematical conditions are chosen, the amplitude of the intensity oscillation decreases; the stacking fault contrast assumes an average intensity that is usually different from the normal background intensity - stacking faults appear in grey.

- A few examples: The picture below shows three defects that behave as predicted and could be stacking faults. Indeed, the small defect in the top half and the very large defect are stacking faults. The smaller defect in the bottom part, however is a **micro twin**. This is not evident from one picture, but can be concluded from **contrast analysis**.



- The next picture shows a complicated arrangement of several stacking faults:



  - A whole system of overlapping **oxidation induced stacking faults** in **Si**. The biggest loop was truncated by the specimen preparation; the fringe system where the stacking fault intersects with one surface is clearly visible.
  - The other surface was preferentially etched; the etch pits down the (Frank) dislocation lines are clearly visible.
  - The overlap of several stacking faults leads to changing background contrasts **-** from black to no contrast (whenever multiples of three stacking faults overlap) to almost white.
  - Similar if less complicated contrast effects were already encountered in illustrations given before in the context of point defect agglomeration.
  - More examples of a typical **oxidation induced stacking faults** in **Si** (***OSF***) are given in the link

- But there are limits to **TEM** analysis: Sometimes defects are observed which resist analysis. One example is shown in the link; another one we will encounter in the next subchapter.

Other Defects

- The strain-induced contrast of dislocations due to local intensity variations in the primary and diffracted beams and the fringe contrast of stacking faults due to local phase shifts of the electron waves, if taken together, are sufficient to explain (quantitatively) the contrast of any defect.
  - It may get involved, and not everything seen in **TEM** micrographs will be easily explained, but in general, contrast analysis is possible and the detailed structure of the defect seen can be revealed within the limits of the resolution (you cannot, e.g., find a kink in a dislocation (size ca. **0,3 nm**) with a typical kinematical bright field resolution of **5 nm**).

- In the links a gallery of micrographs is provided with a wide spectrum of defects. Bear in mind that most examples are from single crystalline and relatively defect free Silicon. The images of regular poly-crystalline materials would be totally dominated by their grain boundaries (see the examples at the end of the list).
  - Small dislocation loops in Cobalt produced by ion-implantation.
  - Precipitates in Silicon with dislocation structures.
  - Needle shaped **$FeSi_2$** precipitates in **Si**; the bane of early IC technology.

- Helical dislocations resulting from the climb of screw dislocations.
- Bowed-out dislocations in a **TiAl** alloy; kept in place by point defects and small precipitates.
- A thin film of **PtSi** on **Si** as an example of the "real" world of fine-grained materials.
- Overview of **TiAl** as an example of a specimen with a high defect density.