IMAGEING BY MEANS OF CHANNELLED PARTICLES

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A positive particle is said to be channelled in a crystal when its trajectory is concentrated between two successive atomic planes (planar channelling) or along a few (three or four) neighbouring atomic rows (axial channelling). The velocity of a channelled particle is never far from being parallel to these planes (rows) so that its movement may be considered as due to a series of correlated glancing collisions on the successive atoms of a plane (row), gently repelling it to the neighbouring plane (row).

Classical mechanics apply quite well, at least for particles heavier than protons of, say, some keV's (a 1 MeV proton has a wavelength of $\simeq 2.5 \times 10^{-4}$ Å.). The repulsive potentials of planes (rows) have been calculated by Lindhard [1]. Two successive planes contribute to the formation of a potential valley along which the particles both propagate (longitudinal movement) and oscillate (transverse movement). A comprehensive review of channelling (theory, experiments and applications) has been given by Gemmel [2].

Obviously, channelling is a property of the perfect crystal. Inversely any type of lattice imperfection (phonons, defects..) is expected to dechannel particles. Defect-dechannelling was first observed for stacking faults [3] and afterwards for most types of defects like dislocations [4,5] or dislocation loops [6], interstitial atoms [7,8], gas bubbles [9], Guinier-Preston zones [11]...

Dechannelling by foreign atoms has been extensively used for locating atoms in a lattice. A recent and convincing example is the observation of octahedral and/or tetrahedral sites of hydrogen in f.c.c. metals [10].

Dechannelling by defects can also be used for the purpose of imageing. The principle is straightforward. Let us shoot channelled particles in a crystal and collect them when they emerge. The density of collected particles (i.e. the blackening of the collector) should depend, both

i/ on the local density (and nature) of defects in the crystal, giving a "defect contrast", and

ii/ on the orientation of the crystal, giving an "orientation contrast".

The simplest way to "shoot channelled particles" is just to shoot particles in a crystal thick enough so that only particles which have been channelled all the way through will emerge. This can be obtained either with sources of particles (Pu, Am, Cf ...) [11-14] or with accelerators [15]. Typical thicknesses will be ≃ 20μ (aluminium) or ≃ 8μ (gold) for 5 MeV α particles.

The "collector" is either a photographic device (generally plastic foils for α particles or protons; mica for fission fragments...) or a counter if more quantitative information is wished.

The following figures show some examples of this technique.

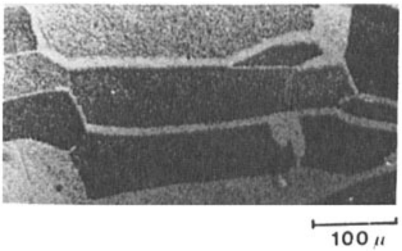

Figure 1
Grains and grain boundaries in a nickel foil. The white ribbons correspond to the projection on the plane of the foil, of boundaries which dechannel the particles. The defect-contrast (grain boundaries) and the orientation-contrast are visible. Particles are 1.9 MeV protons from a Van de Graaff [15].

Figure 2
Twins in copper (left) and silver (right). One will observe the defect-contrast, due to dechannelling on twin-boundaries, and the orientation-contrast between twin and matrix. Particles are α's from an americium source. Thickness of the samples: 12 μ.

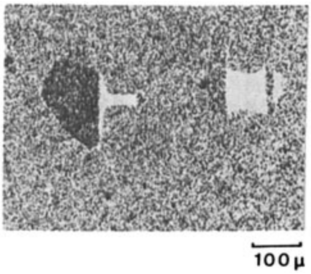

Figure 3
Insulary grains in a large single crystal of nickel showing a good example of orientation contrast. Particles are α's from an americium source.

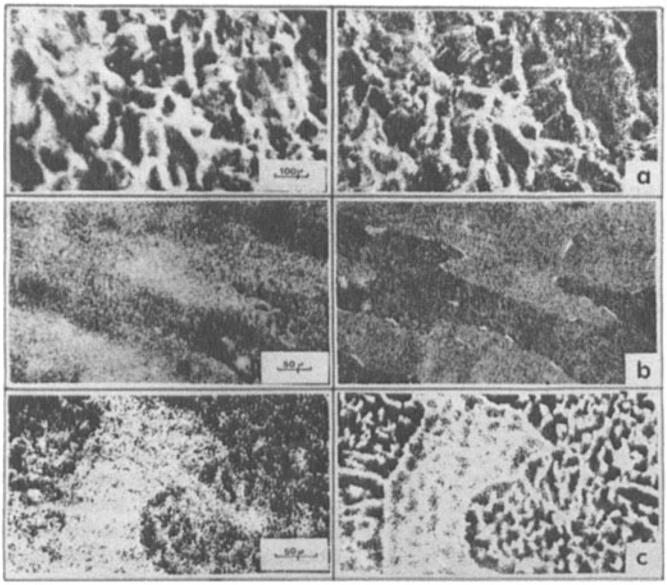

Figure 4
A comparison between contrasts obtained with two different types of particles. Left: α particles from an Am source. Right: fission fragments of uranium. The definition of the images is better for fission fragments, due to more restrictive conditions of channelling.
a : gold. b : molybdenum. c : tungsten. [14].

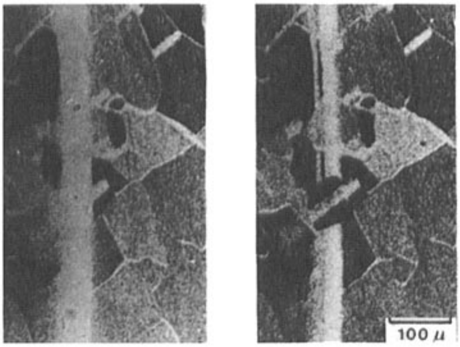

Figure 5
Dechannelling due to dislocations. Dislocations have been produced by a slight cold work in a polycrystal of nickel, along a vertical line (left). The result of a thermal anneal is visible on the right. Particles: 1.9 MeV protons [15].

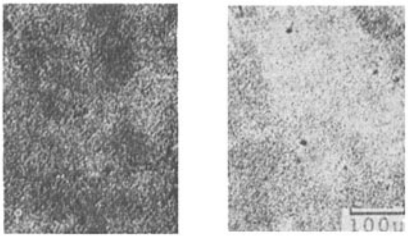

Figure 6
Dechannelling due to dislocation loops. Left: a crystal of well annealed aluminium. Right: the same crystal containing loops created by quenching and clustering of vacancies. 5 MeV α particles [12].

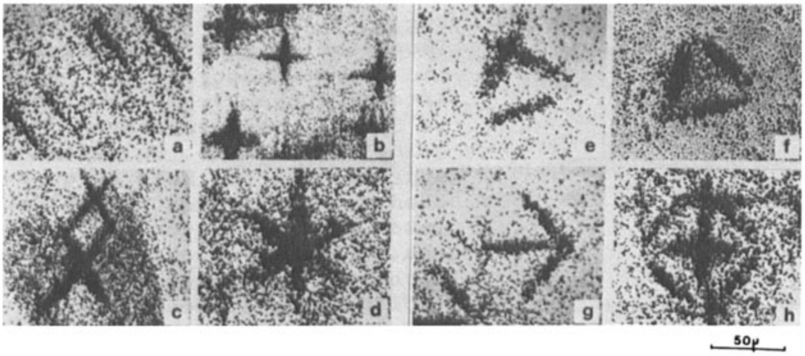

Figure 7
Some typical channelling patterns [14].
If the sources of particles are unhomogeneous, containing "points" of activity higher than the average, geometrical patterns appear on the collector which are images of these point-sources through the crystal. The straight lines of the patterns are the intersections of low-index atomic planes with the plane of the collector. These patterns thus allow a local orientation of the crystal. For example, the two lines of the cross in b/ indicate the $\langle 100 \rangle$ directions of a f.c.c. crystal; the three lines of the triangle in f/ indicate the three $\langle 110 \rangle$ directions of a $\{111\}$ plane of a f.c.c. etc. (These patterns are obtained with α americium sources). The principles of indexation will be found in [14].

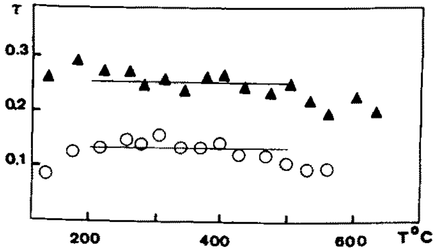

Figure 8
Evolution of gas bubbles in a solid.
If the channelled particles hit a counter instead of a collector like on figures 1-7, quantitative information on defects is easily obtained.

Here, the sample is an aluminium foil containing He bubbles. The crystal is annealed at temperature T, which allows the bubbles to migrate and coalesce, leading as a consequence to a large diffece in size between the initial bubbles and those after anneal at ≃600°C. The transmission τ (or dechannelling $1-\tau$) for two samples of different He concentration remains relatively constant. Here, $1-\tau$ is a measurement of the total surface of bubbles. This experiment illustrates the "law of surfaces" stating that if bubbles at thermal equilibrium coalesce, the surfaces — not the volumes — are additive [9].

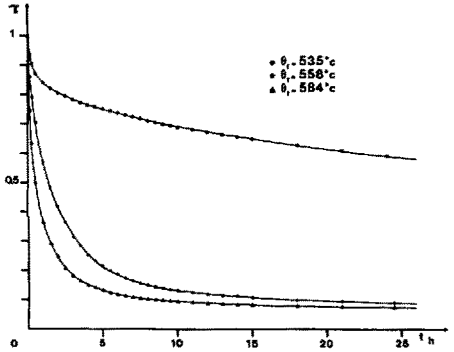

Figure 9

Isothermal ageing of an aluminium-copper alloy.
After a quench from temperature θ_T, a room-temperature "ageing" allows the Cu atoms to migrate with the help of quenched vacancies, and to coalesce into Guinier-Preston (G.P.) zones. These G.P. zones tend to dechannel particles (here α particles), thus decreasing the transmission τ (see Fig. 8) [11].

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