

## 3.3. TWINNING OF CRYSTALS

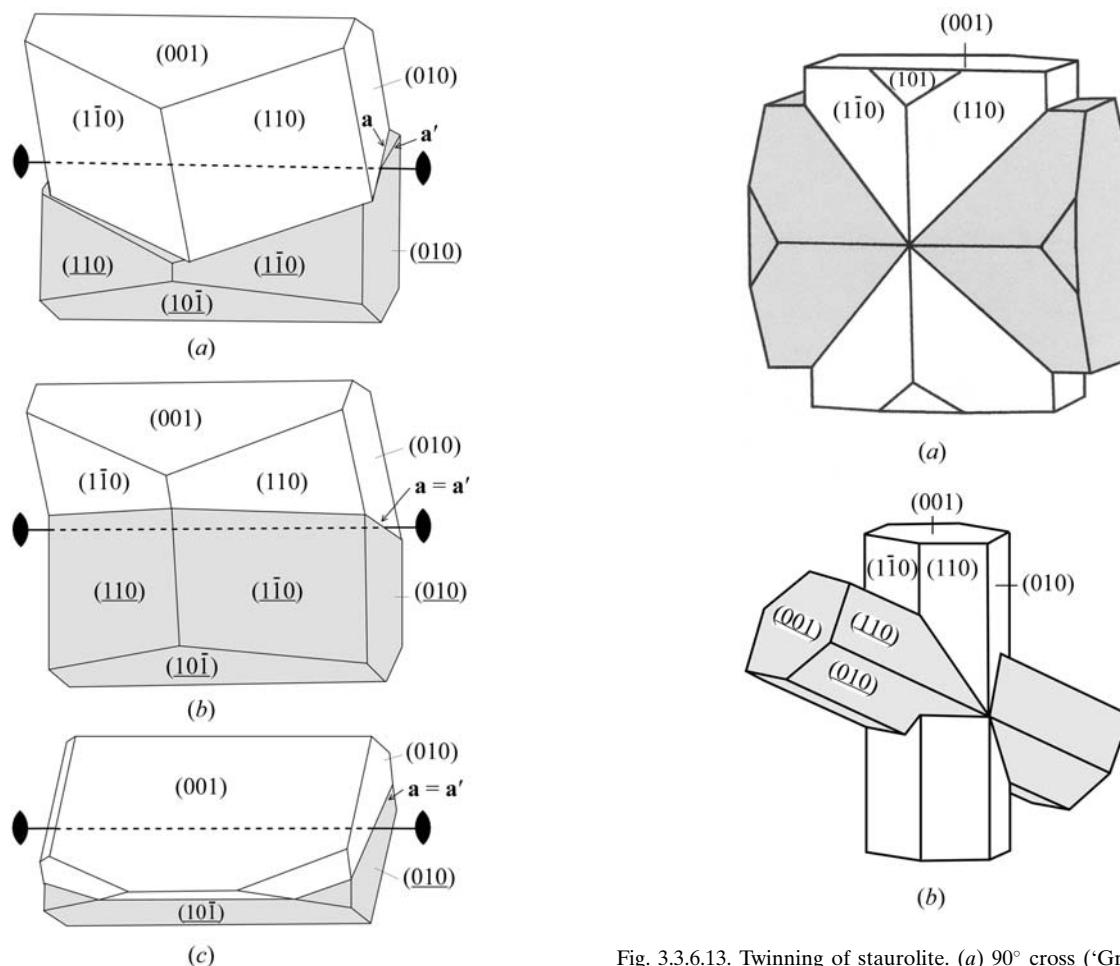


Fig. 3.3.6.12. Pericline twin of triclinic feldspar. Twofold twin axis [010]. (a) Twin with rational composition plane (001), exhibiting clearly the misfit (exaggerated) of the two adjacent (001) contact planes, as indicated by the crossing of lines  $a$  and  $a'$ . (b) The same (exaggerated) twin as in (a) but with irrational boundary along the 'rhombic section': fitting of contact planes from both sides ( $a$  and  $a'$  coincide and form a flat ridge). (c) Sketch of a real pericline twin with irrational interface ('rhombic section') containing the twin axis.

Bringhurst & Griffin, 1986, p. 1470) have failed to detect the submicroscopic twins.

(ii) Superimposed upon this first generation of microtwins very often occurs one or the other of *two spectacular 'macroscopic' growth penetration twins* in the shape of a cross, from which in 1792 the name 'stauros' of the mineral was given by Delamétherié. The first detailed analysis of these twins was provided by Friedel (1926, p. 461).

(a) The  $90^\circ$  cross (*Greek cross*) with twin reflection and composition plane (031) is illustrated in Fig. 3.3.6.13(a) [cf. also the figures on p. 151 of Hurst *et al.* (1956) for less idealized drawings]. Plane (031) generates two twin components with an angle of  $2 \arctan(b/3c) = 2 \arctan 0.9805 = 88.9^\circ$ , very close to  $90^\circ$ , between their  $c$  axes. The equivalent twin reflection plane (03̄1) leads to the same angle, and both twin planes intersect along the lattice row [100].

With eigensymmetry  $\mathcal{H} = 12/m1$ , the intersection symmetry of the domain pair is  $\mathcal{H}^* = \bar{1}$  and the reduced composite symmetry is  $\mathcal{K}^* = 2'/m' [m' = (031)]$ . Owing to the special axial ratio  $b/3c \approx 1$  mentioned above, the  $90^\circ$  cross is an excellent example of a pseudo-tetragonal twin. The extended composite symmetry of this twin is oriented along [100]:

$$\mathcal{K}(4) = 4(2)/m\ 2/m\ 2/m$$

Fig. 3.3.6.13. Twinning of staurolite. (a)  $90^\circ$  cross ('Greek cross') with twin reflection and composition planes (031) and (03̄1). (b)  $60^\circ$  cross ('St Andrew's cross') with twin reflection plane (231).

[cf. Section 3.3.4.2(iii)] with two domain states and all twin operations binary.

(b) The  $60^\circ$  cross (*St Andrew's cross*) with twin reflection plane (231) is illustrated in Fig. 3.3.6.13(b). It is the more abundant of the two crosses, with a ratio of  $60^\circ : 90^\circ$  twins  $\approx 9 : 1$  in one Georgia, USA, locality (cf. Hurst *et al.*, 1956, p. 152). Two equivalent twin mirror planes, (231) and (2̄31), intersecting in lattice row [10̄2] exist. They include an angle of  $60.4^\circ$ . The action of one of these twin reflection planes leads to the  $60^\circ$  cross with an angle of  $60^\circ$  between the two  $c$  axes. The reduced composite symmetry of this twin pair is  $\mathcal{K}^* = 2'/m' [m' = (231)]$ .

In rare cases, penetration trillings occur by the action of *both* equivalent mirror planes, (231) and (2̄31), leading to three interpenetrating twin components with angles of about  $60^\circ$  between neighbouring arms.

#### Notes

(1) In many books, the twin reflection planes for the  $90^\circ$  cross and the  $60^\circ$  cross are given as (032) and (232) instead of (031) and (231). The former Miller indices refer to the morphological cell, which has a double  $c$  axis compared with the structural X-ray cell, used here.

(2) Friedel (1926) and Hurst *et al.* (1956) have derived both twin laws (031) and (231), mentioned above, from a multiple cubic pseudo-cell, the 'Mallard pseudo-cube'. This derivation will be presented in Section 3.3.9.2.4 as a characteristic example of 'twinning by reticular pseudo-merohedry'.

#### 3.3.6.13. $\text{BaTiO}_3$ transformation twins

The perovskite family, represented by its well known member  $\text{BaTiO}_3$ , is one of the technically most important groups of dielectric materials, characterized by polar structures which