American Mineralogist, Volume 83, pages 811–822, 1998

Needle twins and right-angled twins in minerals: Comparison between experiment and theory

Ekhard K.H. Salje,[1,*] Andrew Buckley,[1] Gustaaf Van Tendeloo,[2] Yoshihiro Ishibashi,[3] and Gordon L. Nord Jr.[4]

[1]Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge CB2 3EQ, U.K.
[2]EMAT, University of Antwerp-RUCA, Groenenborgerlaau 171, Antwerp, Belgium
[3]Department of Applied Physics, School of Engineering, Nagoya University, Chikusa-ku, Nagoya 464-01, Japan
[4]956 National Center, U.S. Geological Survey, Reston, Virginia 20192, U.S.A.

Abstract

Transformation twinning in minerals forms isolated twin walls, intersecting twin walls with corner junctions, and wedge-shaped twins as elements of hierarchical patterns. When cut perpendicular to the twin walls, the twins have characteristic shapes, right-angled and needle-shaped wall traces, which can be observed by transmission electron microscopy or by optical microscopy. Theoretical geometries of wall shapes recently derived for strain-related systems should hold for most displacive and order-disorder type phase transitions: (1) right-angled twins show curved junctions; (2) needle-shaped twins contain flat wall segments near the needle tip if the elastic behavior of the mineral is dominated by its anisotropy; (3) additional bending forces and pinning effects lead to curved walls near the junction that make the needle tip appear more blunt. Experimental studies confirmed that these features occur in a wide range of materials. Bent right-angled twins were analyzed in $Gd_2(MoO_4)_3$. Linear needle tips were found in WO_3, $[N(CH_3)_4]_2 \cdot ZnBr_4$ CrAl, $BiVO_4$, $GdBa_2Cu_3O_7$, and $PbZrO_3$. Parabolic tips occur in $K_2Ba(NO_2)_4$, and GeTe whereas exponential curvatures appear in $BaTiO_3$, KSCN, $Pb_3(PO_4)_2$, $CaTiO_3$, alkali feldspars, $YBa_2Cu_3O_7$, and MnAl. The size and shape of the twin microstructure relates to its formation during the phase transition and the subsequent annealing history. The mobility of the twin walls after formation depends not only on the thermal activation but also on the structure of the wall, which may be pinned to impurities on a favorable structural site. Depinning energies are often large compared with thermal energies for diffusion. This leads to kinetic time scales for twin coarsening that are comparable to geological time scales. Therefore, transformation twins that exhibit needle domains not only indicate that the mineral underwent a structural phase transition but also contain information about its subsequent geological history.