International Tables for Crystallography (2013). Vol. D, Figure 3.4.1.3, p. 485.

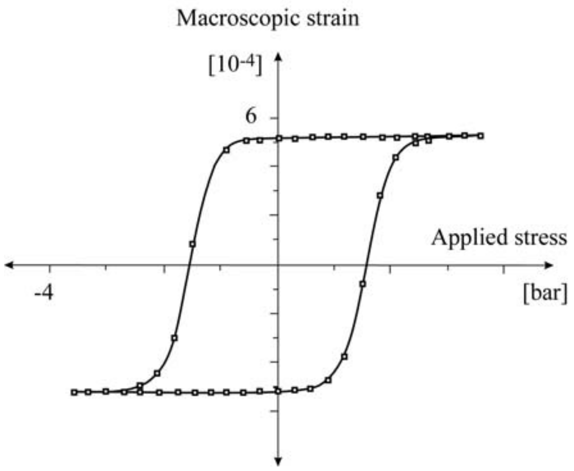

Fig. 3.4.1.3. Elastic hysteresis of ferroelastic lead phosphate $Pb_3(PO_4)_2$ (Salje, 1990). Courtesy of E. K. H. Salje, University of Cambridge. The dependence of strain on applied stress has the form of a loop. The states at the extreme left and right correspond to two ferroelastic domain states, steep parts of the loop represent switching of one state into the other by applied stress. The strain at zero stress corresponds to the last single-domain state formed in a field larger than the coercive stress defined by the stress at zero strain (the intersection of the loop with the axis of the applied stress). Similar dielectric hysteresis loops of polarization *versus* applied electric field are observed in ferroelectric phases (see *e.g.* Jona & Shirane, 1962).

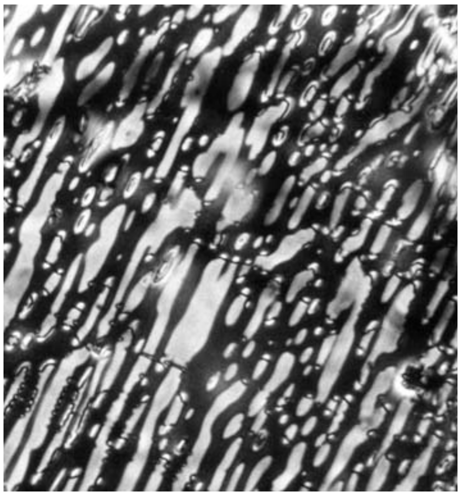

Fig. 3.4.1.5. Non-ferroelastic ferroelectric domains in triglycine sulfate (TGS) revealed by a liquid-crystal method. A thin layer of a nematic liquid crystal deposited on a crystal surface perpendicular to the spontaneous polarization is observed in a polarized-light microscope. Black and white areas correspond to ferroelectric domains with antiparallel spontaneous polarization. The typical size of the domains is of order of 1–10μm. Courtesy of M. Połomska, Institute of Molecular Physics, PAN, Poznań. Although one preferential direction of domain walls prevails, the rounded shapes of the domains indicate that all orientations of non-ferroelastic walls are possible.

spontaneous polarization. Such a domain structure is formed at ferroelectric phase transitions that are characterized by the appearance of a new polar direction in the ferroic phase. Ferroelectric domains can usually be switched by external electric fields. Two ferroelectric domains with different directions of spontaneous polarization can have different spontaneous strain [*e.g.* in dihydrogen phosphate (KDP) crystals, two ferroelectric domains with opposite directions of the spontaneous polarization have different spontaneous shear strain], or two ferroelectric domains with antiparallel spontaneous polarization can possess the same strain [*e.g.* in triglycine sulfate (TGS) crystals].

The physical properties of polydomain crystals are significantly influenced by their domain structure. The values of important material property tensor components, *e.g.* permittivity, piezoelectric and elastic coefficients, may be enhanced or diminished by the presence of a domain structure. Owing to switching and detwinning phenomena, polydomain materials exhibit hysteresis of material properties. These features have important practical implications, *e.g.* the production of anisotropic ceramic materials or ferroelectric memories.

Fig. 3.4.1.4. Transmission electron microscopy image of the ferroelastic domain structure in a $YBa_2Cu_3O_{7-y}$ crystal (Rosová, 1999). Courtesy of A. Rosová, Institute of Electrical Engineering, SAS, Bratislava. There are two systems (‘complexes’), each of which is formed by almost parallel ferroelastic domain walls with needle-like tips. The domain walls in one complex are nearly perpendicular to the domain walls in the other complex.

The domain structure resulting from a structural phase transition belongs to a special type of twinning referred to as *transformation twinning* (see Section 3.3.7.2). Despite this, the current terminology used in domain-structure studies is different. The main terms were coined during the first investigations of ferroelectric materials, where striking similarities with the behaviour of ferromagnetic materials led researchers to introduce terms analogous to those used in studies of ferromagnetic domain structures that had been examined well at that time.

Bicrystallography (see Section 3.2.2) provides another possible frame for discussing domain structures. Bicrystallography and domain-structure analysis have developed independently and almost simultaneously but different language has again precluded deeper confrontation. Nevertheless, there are common features in the methodology of both approaches, in particular, the principle of symmetry compensation (see Section 3.2.2), which plays a fundamental role in both theories.

In Chapter 3.1, it is shown that the anomalous behaviour near phase transitions can be explained in the framework of the Landau theory. In this theory, the formation of the domain structures follows from the existence of several equivalent solutions for the order parameter. This result is a direct consequence of a symmetry reduction at a ferroic phase transition. It is this dissymmetrization which is the genuine origin of the domain-structure formation and which determines the basic static features of all domain structures.

3.4.1.2. *Scope of this chapter*

This chapter is devoted to the crystallographic aspects of static domain structures, especially to the symmetry analysis of these structures. The main aim is to explain basic concepts, derive relations that govern the formation of domain structures and provide tables with useful ready-to-use data on domain structures of ferroic phases. The exposition uses algebraic tools that are

references