2.7. Topography

By A. R. Lang

2.7.1. Principles

The term diffraction topography covers techniques in which images of crystals are recorded by Bragg-diffracted rays issuing from them. It can be arranged at will for these rays to produce an image of a surface bounding the crystal, or of a thin slice cutting through the crystal, or of the projection of a selected volume of the crystal. The majority of present-day topographic techniques aim for as high a spatial resolution as possible in their point-by-point recording of intensity in the diffracted rays. In principle, any position-sensitive detector with adequate spatial resolution could be employed for recording the image. Photographic emulsions are most widely used in practice. In the following accounts of the various diffraction geometries developed for topographic experiments, the term 'film' will be used to stand for photographic emulsion coated on film or on glass plate, or for any other position-sensitive detector, either integrating or capable of real-time viewing, that could serve instead of photographic emulsion. (Position-sensitive detectors, TV cameras, and storage phosphors are described in Sections 7.1.6, 7.1.7, and 7.1.8.) All diffraction geometries described with reference to an X-ray source could in principle be used with neutron radiation of comparable wavelength (see Chapter 4.4).

Two factors, often largely independent and experimentally distinguishable, determine the intensity that reaches each point on the topograph image. The first is simply whether or not the corresponding point in the specimen is oriented so that some rays within the incident beam impinging upon it can satisfy the Bragg condition. The intensity of the Bragg-reflected rays will range between maximum and minimum values depending upon how well that condition is satisfied. The consequent intensity variation from point to point on the image is called *orientation contrast*, and it can be analysed to provide a map of lattice misorientations in the specimen. The sensitivity of misorientation measurement is controllable over a wide range by appropriate choice of diffraction geometry, as will be explained below. The second factor determining the diffracted intensity is the lattice perfection of the crystal. In this case, physical factors such as X-ray wavelength, specimen absorption, and structure factor of the active Bragg reflection fix the range within which the diffracted intensity can lie. One limit corresponds to the case of the *ideally perfect crystal*. This is a well defined entity, and its diffraction behaviour is well understood [see *IT* B (1996, Part 5)]. The other limit is that of the *ideally imperfect crystal*, a less precisely defined entity, but which, for practical purposes, may be taken as a crystal exhibiting negligible primary and secondary extinction. The magnitude, and sometimes also the sign, of the difference in intensity recorded from volume elements of ideally perfect as opposed to ideally imperfect crystals is to a large degree controllable by the choice of experimental parameters (in particular by choice of wavelength). Contrast on the topograph image arising from point-to-point differences in lattice perfection of the specimen crystal was called *extinction contrast* in earlier X-ray topographic work, but is now more usually called *diffraction contrast* to conform with terminology used in transmission electron microscopic observations of lattice defects, experiments which have many analogies with the X-ray case.

Figs. 2.7.1.1 and 2.7.1.2, respectively, show in plan view the simplest arrangements for taking a *reflection* topograph and a *transmission* topograph. The source of X-rays is shown as being point-like at *S*. If its wavelength spread is large then the Bragg condition may be satisfied over the whole length *CD* for Bragg planes oriented parallel to *BB*′, and an image of *CD* will be formed on *F* by the Bragg-diffracted rays falling on it. The specimen is mounted on a rotatable axis (the ω axis) perpendicular to the plane of the drawing, which represents the median plane of incidence, in order that the angle of incidence on the planes *BB*′ can be varied. The specimen is usually adjusted so that the diffraction vector, $\mathbf{h}$, of the Bragg reflection of principal interest is perpendicular to the ω axis. Let the mean source-to-specimen and specimen-to-film distances be a and b, respectively. Suppose the source *S* is extended a distance s in the axial direction (*i.e.* perpendicular to the plane of incidence). Then diffracted rays from any point on *CD* will be spread on *F* over a distance $s(b/a)$ in the axial direction. This is the simple expression for the axial resolution of the topograph given by ray optics. Transmission topographs have the value of showing defects within the interior of specimens, which may be optically opaque, but are in practice limited to a specimen thickness, t, such that μt is less than a few units (μ being the normal linear absorption coefficient) unless the specimen structure and the perfection are such as to allow strong anomalous transmission [the Borrmann effect, see *IT* B (1996, Part 5)]. If a reflection topograph specimen is a nearly perfect crystal then the volume of crystal contributing to the image is restricted to a depth below the surface given approximately by the X-ray extinction distance, ξ_h, of the active Bragg reflection, which may be only a few micrometres, rather than the penetration distance, μ^{-1}, of the radiation used.

Besides the ratio b/a, other important experimental parameters are the degree of collimation of the incident beam and its wavelength spread. The manner in which X-ray topographs exhibit *orientation contrast* and *diffraction contrast* under different choices of these parameters is illustrated schematically in Fig. 2.7.1.3. There, (*a*) represents a hypothetical specimen consisting of a matrix of perfect crystal *C* in which are embedded two islands *A* and *B* whose lattices differ from *C* in the following respects. *A* has the same mean orientation as *C* but is a region of

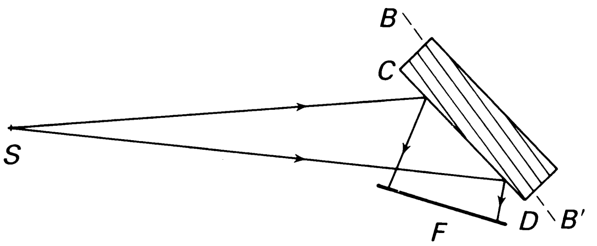

Fig. 2.7.1.1. Surface reflection topography with a point source of diverging continuous radiation.

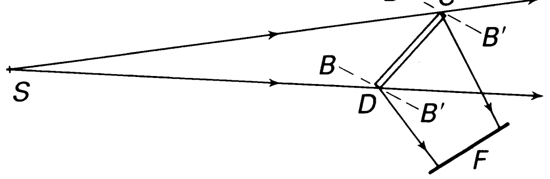

Fig. 2.7.1.2. Transmission topography with a point source of diverging continuous radiation.