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Effects of dislocation strain fields on Bragg lines in an $Al_{70}Co_{15}Ni_{15}$ decagonal quasicrystal studied by an improved LACBED technique

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Résumé. — Les effets induits par les champs de contraintes des dislocations sur les lignes de Bragg observées dans un quasicristal décagonal $Al_{70}Co_{15}Ni_{15}$, ont été étudiés par une technique améliorée de diffraction électronique en faisceau convergent à grand angle. Il est montré que ces effets sont semblables à ceux observés dans des cristaux conventionnels.

Abstract. — Effects of dislocation strain fields on Bragg lines in an $Al_{70}Co_{15}Ni_{15}$ decagonal quasicrystal have been studied by using an improved large-angle convergent-beam electron diffraction technique. It is found that the effects are the same as that in conventional crystals.

1. Introduction.

Large-angle convergent-beam electron diffraction (LACBED) has been well established as a powerful method in materials science to study defects such as dislocations and stacking faults [1-4]. LACBED combines real space and reciprocal space information. In principle, it is more informative compared with either the diffraction or the imaging technique alone in the study of defects in crystals. Recently Duan [5] described a method to minimize the spot size and obtained a LACBED pattern with sharp HOLZ lines superimposed by a shadow image with satisfactory resolution of a cross-sectional specimen of Ge_xSi_{1-x}/Si strained-layer superlattice. Xin and Duan [6] studied the effects of dislocation strain fields on Bragg lines in silicon single crystal by using this improved LACBED technique.

Since the discovery of quasicrystals (QCs), studies of defects in quasicrystals have drawn extensive attention, because of their importance not only for structure studies, but also for understanding of many their physical and mechanical properties. Details of dislocations are still unknown. In this present work we report an application of the improved LACBED technique to QCs to the study of effects of dislocation strain fields on Bragg lines in $Al_{70}Co_{15}Ni_{15}$ decagonal QC.

2. Experimental.

Small ingots with the composition of $Al_{70}Co_{15}Ni_{15}$ were obtained by melting under Ar atmosphere and cooling to room temperature, and then annealed at 900 K for 24 hours under Ar atmosphere. Thin foils for transmission electron microscopy were mechanically thinned to a thickness of nearly 30 μm and then ion-milled. All observations were conducted by using a Philips CM12 electron microscope operated at 100 kV. Both bright field (BF) and dark field (DF) LACBED patterns were obtained by using the improved LACBED technique described by Duan [5].

3. Results and discussions.

Figure 1 shows the selected-area electron diffraction patterns (SAEDPs) obtained from the $Al_{70}Co_{15}Ni_{15}$ decagonal QC. Figure 1a is the SAEDP taken along the tenfold axis A10. The diffraction spots are sharp and all of them are located at positions of the vertex of different sites of undistorted pentagons or decagons, implying that what we are examining is a decagonal quasicrystal rather than some crystalline approximant. From the symmetry of this diffraction pattern it is clear that there are 20 twofold axes at 18° intervals in the plane normal to the tenfold rotational axis. These twofold axes belong to two sets, which are denoted by A2D and A2P respectively. Figures 1b and c show the SAEDPs taken along two-fold axes A2D and A2P respectively. The extra spots (denoted by thick arrows) in figure 1b indicate that the periodicity of the $Al_{70}Co_{70}Ni_{70}$ decagonal QC along the tenfold axis is 0.8 nm. The quasiperiodic arrangement of the diffraction spots along the twofold axes and the periodic form of that along A10 (denoted by the thin arrow) show again the quasicrystal nature of the decagonal phase.

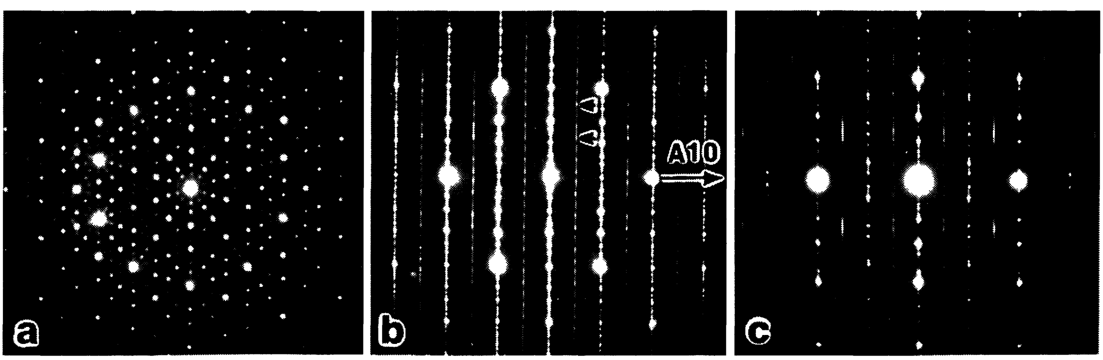

Fig. 1. — Selected-area diffraction patterns of decagonal quasicrystal in the $Al_{70}Co_{15}Ni_{15}$ alloy with the electron beam parallel to (a) the A10, (b) the A2D and (c) the A2P axes.

Figure 2 shows the BF images of an edge dislocation (a) and a screw dislocation (b) obtained in annealed $AL_{70}Co_{15}Ni_{15}$ decagonal QC under g = (400000) two-beam conditions. In the present work, the index system for decagonal QC given by Yan, Wang, Gui and Dai [7] is used where the first number corresponds to the tenfold axis A10 with a period of 0.8 nm. Contrast analysis indicates that the Burgers vector of the dislocations is along the tenfold axis A10.

Figure 3 shows the BF(left), (200000) DF (middle) and (400000) DF (right) improved LACBED patterns superimposed by shadow images of the edge dislocation (shown in Fig. 2a)

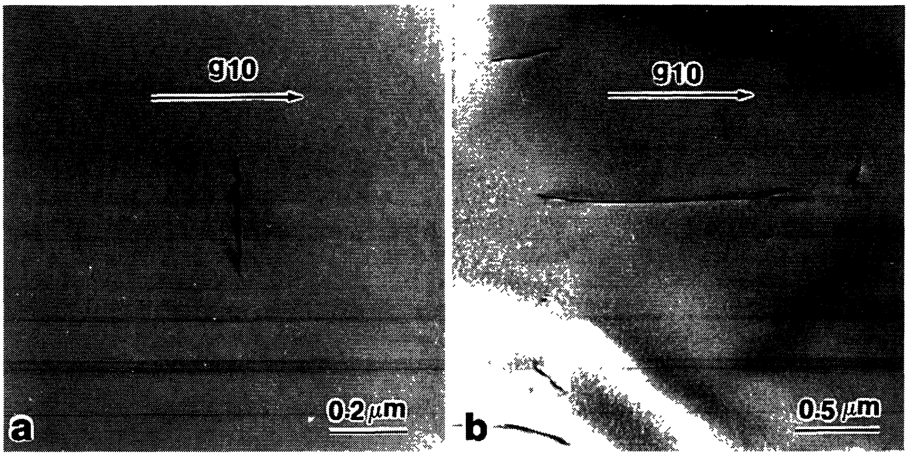

Fig. 2. — Bright-field images of the edge dislocation (a) and screw dislocation (b) studied in this letter.

close to the A2P orientation taken with the beam cross-over below the specimen. The indices of the main reflection lines in the LACBED patterns are marked in the figure. The shadow image of the dislocation is clearly seen in the improved LACBED patterns. In figure 3a, the dislocation is seen in the BF pattern lying close and parallel to the (200000) reflection fringe implying the two-beam conditions is approximately satisfied and the excitation error "s" is small for the dislocation line. Both (200000) and (400000) reflection fringes are affected by the existence of this edge dislocation, being slightly curved away from the dislocation, as shown in the BF and DF patterns in figure 3a. In crystals, the intensity of a dislocation image will oscillate with a period ξ_g, when the dislocation is inclined to the specimen surface (ξ_g is the extinction distance of g). The oscillation of the shadow image of the dislocation in the LACBED is also seen. When the dislocation is moved to the right side away from the (200000) reflection fringe as the middle in figure 3b, the oscillation period of the diffraction image becomes smaller. The (400000) reflection fringe curves more severely and at the same time splits. This is because the dislocation now is closer to this fringe. When the dislocation is moved even closer to the (400000) reflection fringe, the shadow image of the dislocation is formed by (400000) diffraction, as shown in figure 3c. Because the (400000) diffraction intensity is weak, the shadow image of the dislocation is weak. Now the (400000) diffraction fringe becomes severely curved and split because the dislocation lies closer to it. Comparing the figures 3a, b and c, it is found that the closer the dislocation lies to the (400000) fringe, the larger the strain field is, the more severely the reflection fringe curves. These characteristics are the same as in the Si crystal.

When a dislocation line is parallel to some reflection fringes, the contrast image of the dislocation and the shifting and splitting of the reflection fringes are caused by the displacement field of the edge component of the dislocation. For a screw dislocation in an isotropic material, there is no strain field perpendicular to it, hence the reflection fringe is not affected and there is no contrast image of the screw dislocation. Figures 4a and b are two LACBED patterns of the screw dislocation (shown in Fig. 2b) with the cross-over below the specimen. The Burgers vector of this dislocation is parallel to the tenfold axis A10. The dislocation line runs parallel to (0100 − 10) reflection fringes. For (011 − 1 − 10) and (0100 − 10) reflections $\mathbf{g} \cdot \mathbf{b} = 0$, so the dislocation is invisible. The diffraction fringes (011 − 1 − 10) and (0100 − 10) are not affected by the dislocation when it crosses or lies near these fringes. On the other hand, this screw dislocation intersects the

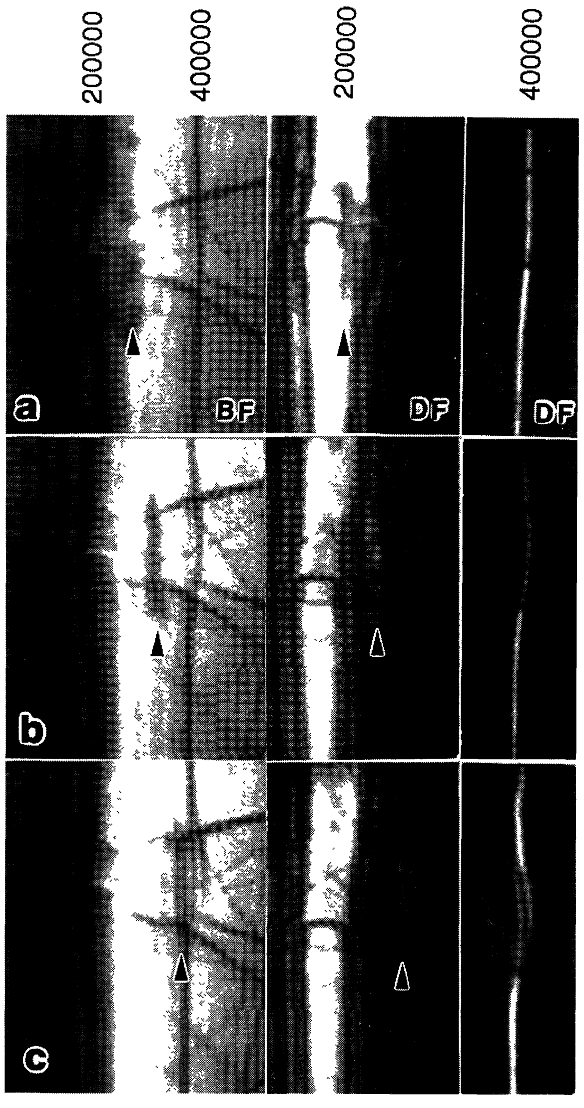

Fig. 3. — LACBED patterns of the edge dislocation marked in figure 2a taken with the beam cross-over below the specimen. Left: BF; Middle: (200000) DF; Right: (400000) DF. Arrows point the images of the dislocation with different position in the LACBED patterns.

(400000) and (600000) diffraction fringes and causes them split. From these we know this dislocation exists and where is it located. As pointed by Cherns and Preston [4] and Tanaka, Terauchi and Kaneyama [2], in LACBED or the defocus CBED mode, the high-order Laue zone (HOLZ) lines show n nodes at the region crossed by a dislocation in a crystal when $| \mathbf{g} \cdot \mathbf{b} |= n$, where $\mathbf{g}$ is a diffraction vector and $\mathbf{b}$ the Burgers vector of the dislocation. Moreover, Niu, Wang and Lu [8] pointed out that the twist direction of the HOLZ lines lying on the $\mathbf{u} \times \mathbf{c}$ side of the dislocations parallel to the Burgers vector $\mathbf{b}$ of this dislocation, where $\mathbf{u}$ is the direction of the dislocation line, $\mathbf{c}$ is a vector points from the center of the illuminated specimen area to the crossover of the incident beam. Hence the sign of the $\mathbf{g} \cdot \mathbf{b}$ can also be obtained. Recently, Wang and Dai [9] extened this method to the case of icosahedral quasicrystal to determine the Burgers vector of dislocations. In figure 4b, the (400000) splits into 3 nodes which means $| \mathbf{g}_{(400000)} \cdot \mathbf{b} | = 3$ and hence $\mathbf{b} = \pm[3/400000]$. In this case, the vector $\mathbf{u} \times \mathbf{c}$ is shown in figure 4b and the dificient line (400000) at the side pointed by $\mathbf{u} \times \mathbf{c}$ shifts to the upper side which means the sense of the Burgers vectors is along the positive A10 direction. Therefore it is a right-hand screw dislocation with the Burgers vector $\mathbf{b} = [3/400000]$.

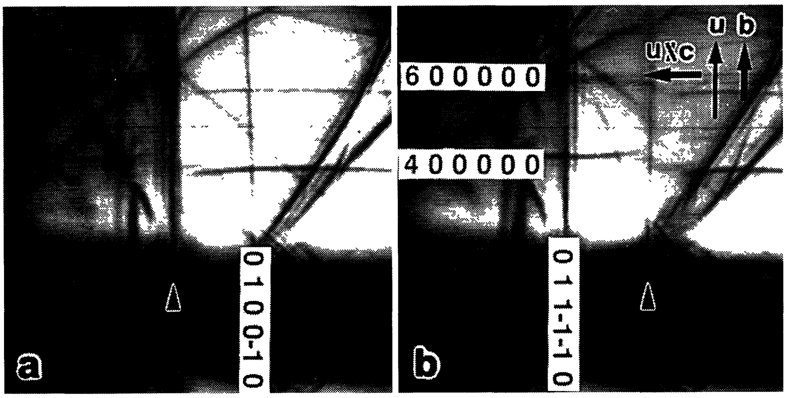

Fig. 4. — LACBED patterns of the screw dislocation marked in figure 2b taken with the beam cross-over below the specimen. Arrows point the position of the dislocation.

The above results show the effects of dislocation strain fields on Bragg lines in Al-Co-Ni decagonal quasicrystal are similar as that in conventional crystal observed by Xin and Duan [6]. This means the CBED techniques in crystals can be extended to the case in quasicrystals.

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