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Observation of Coherent Bremstrahlung by EDX Analysis in a Transmission Electron Microscope. Case of the Martensites of Cu-Al System

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Résumé. — Le “Coherent Bremstrahlung” peut donner lieu, sur les spectres EDS obtenus à partir de monocristaux minces, à des pics qui peuvent être attribués à tort à des éléments chimiques. Dans une première partie sont rappelés brièvement l’origine du CB ainsi que le principe de détermination de l’énergie des pics. Les facteurs contribuant à la hauteur des pics sont aussi mentionnés. Une étude expérimentale menée sur des martensites de cuivre-aluminium montre que, dans de tels cas, la théorie élémentaire utilisée parfois pour identifier les pics n’est pas suffisante et qu’une théorie plus élaborée est nécessaire.

Abstract. — In EDS spectra obtained from thin monocrystals, the coherent Bremstrahlung can give rise to peaks which could be wrongly attributed to chemical elements. In a first part, the origin of the CB as well as the basis of the CB energy determination are briefly mentioned and the factors contributing to the peak height discussed. The experimental study made in a TEM, from Cu-Al martensite monocrystals shows that, in such cases, the elementary theory sometimes used to identify the peaks is no more sufficient and that a more refined treatment is needed.

1. Introduction

A phenomenon sometimes observed in EDS analysis of thin crystals by transmission electron microscopy is the emission of X photons as a consequence of the effect of the crystal periodicity on the electron beam. This X-ray emission forms the *coherent Bremstrahlung* (written “CB” in the following). Unlike the classical Bremstrahlung, which gives rise to a continuous background on the SDS spectra, the CB produces some peaks located in the same energy domain as the characteristic peaks of the chemical elements. Therefore these peaks may be wrongly attributed to chemical elements that are not actually present in the specimen, or also, they can superimpose on peaks of elements that are present. A consequence of this phenomenon is a reduction of the analysis sensitivity threshold, that can pose serious problems for the analysis of elements present

in a small amount. This phenomenon is actually specific to the transmission microscopy of thin crystals: there is no problem in a SEM, or in a X-ray microprobe as far as, in these techniques, the crystalline samples are usually bulk polycrystals so that, the CB peaks overlap and are reduced by the absorption, contributing only to the background.

The CB, well-known in the physics of high energy particles, was first highlighted in the energy range of X-rays in a TEM by Korobochko *et al.* in 1961 [1]. However, it was only in 1983 that Spence *et al.* detected peaks due to this radiation in an analytical microscope, and proposed some practical means to identify and eliminate them as far as possible [2].

According to the experimental work realized by Kenneth *et al.* [3], the CB emerges from the background for sufficiently thin monocrystalline specimens having the least possible number of defects. It is particularly intense for electron beam orientations along the high symmetry zone axis of the crystal. In that case, Spence *et al.* suggested a particularly simple relation which allows the position of the CB peaks in an EDS spectrum to be anticipated [4]. However, we showed in a previous study that CB radiation can appear in two phase heterogeneous systems [5]. In fact, such peaks were observed in Cu-Al alloys hardened by internal oxidation, and therefore containing a fine dispersion of precipitates. In the present paper, it is shown that the CB can also give rise to intense peaks in the case of complex crystallography structures having many defects, such as ordered and non ordered martensitic phases of the copper-aluminium system. However, in these cases, the previously mentioned simplified relation is no longer sufficient to explain the experimental observations and we have thus been led to develop a more precise interpretation of the phenomenon.

2. Expression of the CB Peak Energy

The determination of the CB radiation energy caused by the interaction between an electron beam and a crystal has been given by various authors using different degrees of approximation. The simplest starting model [1] consists in considering the electrons of the beam interacting with the crystal as electric dipoles oscillating with a period equal to the crystal periodicity in the beam direction. The most sophisticated model [6] consists in studying the dynamical inelastic interaction of the electrons with the triperiodic crystalline potential. The interest of this last model is that it highlights another effect of the crystal, namely the *channelling radiation* (CR). However, this radiation is related to an extinction distance so its energy range being of the order of a few tens of eV is not measurable with an EDX detector. Nevertheless, this radiation can be combined with CB, giving rise to a broadening of the CB peaks, or to side bands of these peaks.

In order to specify our notations, we will describe briefly in this paragraph the kinematic theory set up by Korobochko, but making use of the parameters defined by Reese *et al.*, well-adapted to the detector-specimen geometry in a TEM. We use the following notations:

- E, E' : the energy of the electrons before and after the interaction respectively,
- \mathbf{K}, \mathbf{K}' : the corresponding electrons wave vectors.

We are interested in the inelastic interaction between the electrons and the crystal causing an emission of X photons with wave vector \mathbf{q} accompanied by a momentum transfer $-\hbar\mathbf{g}$ to the crystal, \mathbf{g} being a reciprocal lattice vector.

Writing the conservation equations of energy and moment, we obtain:

$$\mathbf{K}' = \mathbf{K} + \mathbf{g} - \mathbf{q}$$

$$E' - E = \hbar c q$$

(\hbar : Planck constant, c : velocity of the light).

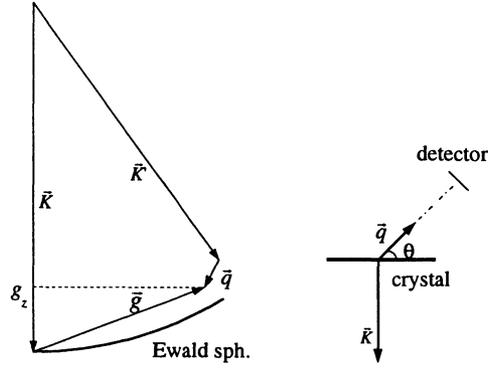


Fig. 1. — Configuration of the diffracted beams in the reciprocal space.

Moreover, E_0 being the energy of the motionless electrons, we have:

$$K^2 = \frac{E^2 - E_0^2}{(hc)^2} \quad K'^2 = \frac{E'^2 - E_0^2}{(hc)^2}$$

Combining these relations and making use of the angles Θ and φ \mathbf{q} makes respectively with \mathbf{K} and \mathbf{g} , we obtain the modulus of \mathbf{q} :

$$q = \frac{-\beta[2\mathbf{K} \cdot \mathbf{g} + g^2]}{2[K - K\beta \cos \Theta - g\beta \cos \varphi]} \quad (\beta = v/c)$$

Thus, the energy of the photons X is:

$$E_{CB} = hcq$$

Practically, the term $g\beta \cos \varphi$ is always negligible compared to the other terms of the denominator, so that, making use of the detection angle: $\theta = \Theta - \pi/2$, we have:

$$E_{CB} = -\frac{hc\beta(\mathbf{n} \cdot \mathbf{g} - g^2/2K)}{1 + \beta \sin \theta} \quad (1)$$

\mathbf{n} : unit vector opposed to the beam direction.

This relation reveals some features specific to the CB:

- E_{CB} varies with β , i.e. with the electron voltage.
- For a given value of $|g|$, E_{CB} is maximum when \mathbf{g} is oriented along the direction \mathbf{n} , opposite to the direction of propagation of the electrons.
- $E_{CB} = 0$ when $\mathbf{n} \cdot \mathbf{g} - g^2/2K = 0$, i.e. when the extremity of \mathbf{g} is situated on the Ewald sphere.
- E_{CB} cannot be inferior to zero. Therefore, the only \mathbf{g} vectors which can give rise to a CB have their extremity inside the Ewald sphere.

3. Height of the CB Peaks

The above formula does not yield any information on the CB intensity corresponding to a given g vector. The probability of a CB emission corresponding to a given g vector has been studied by Reese *et al.* [6]. It emerges from these studies that this intensity is a function of the detection angle θ and of the structure factor at the reciprocal lattice site corresponding to the extremity of g . Reese *et al.* showed experimentally that the CB emission is zero if this structure factor is zero. The CB emission also varies inversely to $|g|$.

The magnitude of a CB peak results from the contribution of the reciprocal lattice sites corresponding to the same CB energy. The above relation shows that for a given θ these sites are determined by:

$$\mathbf{n} \cdot \mathbf{g} - g^2/2K = \text{Cst}$$

This equation corresponds to a set of circles concentric to the Ewald sphere. If we take into account only the g vectors making sufficiently small angles with \mathbf{n} , this equation reduces to:

$$\mathbf{n} \cdot \mathbf{g} = \text{Cst}$$

This relation defines the *Laue zones associated to the given electron beam orientation* (called "LZ" in the following).

The interpretation of this result is immediate: calling g_{Z1} , the value of $\mathbf{n} \cdot \mathbf{g}$ corresponding to the first LZ, one can write the energy associated to the m th zone:

$$E_m = \frac{m\beta g_{Z1}}{1 + \beta \sin \theta}$$

Thus, according to this theory, *to a given electron beam orientation should correspond in principle a series of peaks spaced out by the quantity: $\beta g_{Z1}/(1 + \beta \sin \theta)$, m fixing the rank of the peak.* (In fact, on this basis, one should expect the magnitude of a peak to decrease with its rank, as the number of CB photons decreases with $|g|$.)

Spence and Titchmarch [4] gave a slightly different version of this formula, noticing that the quantity $1/g_{Z1}$ is, in the real space, the atom periodicity L along the zone axis parallel to the beam. The relation for the rank 1 peak thus becomes:

$$E_{CB1} = \frac{hc\beta}{L(1 + \beta \sin \theta)} \quad (2)$$

If it is first supposed that each reciprocal site of a LZ contributes in the same proportion to the formation of a CB peak, one can thus anticipate the effect of a beam disorientation in relation to a high symmetry zone axis (Fig. 2).

In effect, for such an orientation, the LZ are spaced (large g_{Z1}) and their content is dense, giving rise to high and spaced peaks. Any slight change in this position results immediately in the LZ becoming close and their content sparse giving rise to close peaks of small amplitude which can merge with the background. A collapse of the original peak is thus observed. However we show further that this argument, which gives a simple explanation of CB, often in agreement with the experimentation in simple cases such as f.c.c. metals, should be revised in more complex cases such as that of the Cu-Al martensites.

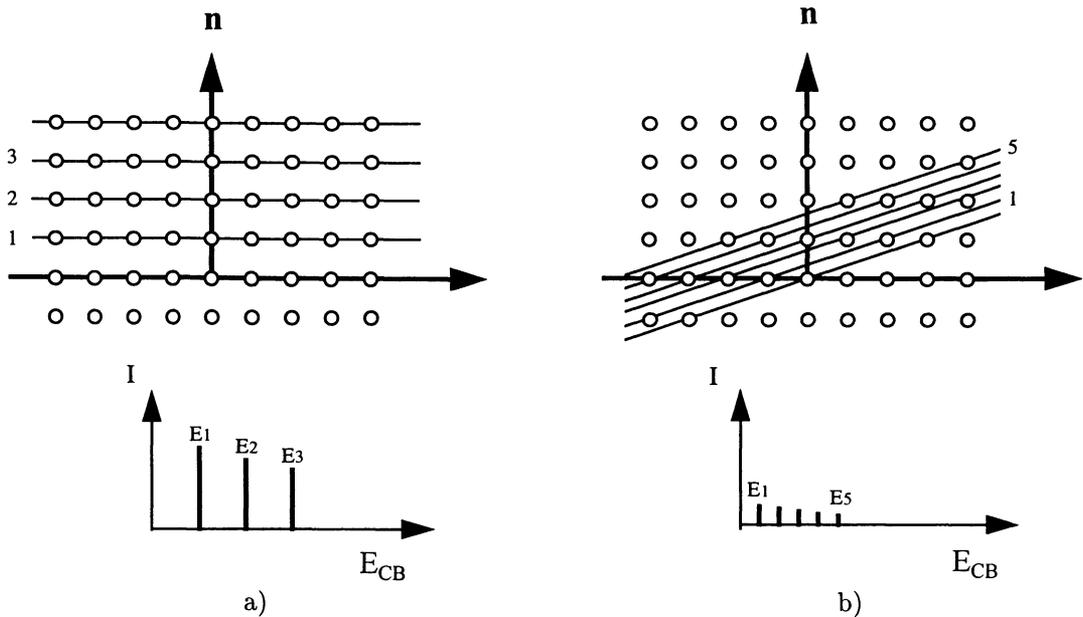


Fig. 2. — Aspect of the Laue zone a) in a high symmetry orientation, b) slightly disorientated from the previous position.

4. Crystallographic Structure of Martensitic β' and β'_1 Phases in CuAl Alloys

By quenching from the c.c. β phase, a Cu-Al alloy undergoes two successive metastable phase transformations [7]:

- a disorder \rightarrow ordered transformation leading to the ordered β_1 phase, with structure DO_3 , (coherent with β);
- a martensitic transformation which leads, increasing the composition, to the polytypic structures 9R (disordered), 18R (ordered) and 4H (ordered).

In fact, on quenching low Al% content specimens, the martensitic transformation occurs first, preventing the ordering, so that the disordered β' martensite is obtained. However, for higher compositions, total or partial ordering occurs before the martensitic transformation. Then, the martensitic phase propagates, making no difference between the ordered and the disordered regions, leading either to β' crystals containing coherent domains ($\beta' + \beta'_1$ monocrystals) or to pure β'_1 crystals containing antiphase walls.

The Figure 3 represents the structure of totally disordered and perfectly ordered Cu-Al martensites.

Such a structure can be considered as a stacking of compact planes, with one stacking fault every 3 planes. For the disordered β' martensite, one can define a monoclinic primitive cell of 3 compact planes or (which is more convenient) an orthorhombic cell of 9 compact planes. When the phase is completely ordered, the compact planes are identical to those of the DO_{22} structure, and the stacking occurs in such a way that the aluminium atoms are in a mutual second neighbouring position, that leads to doubling of the c and a parameters of the orthorhombic β' cell, and the C and A parameters of the monoclinic structure (see Fig. 3). However, the real structures contain many other stacking faults, revealed in certain electronic diffraction patterns by diffuse streaks along the c^* reciprocal direction, which corresponds to the stacking direction of compact planes.

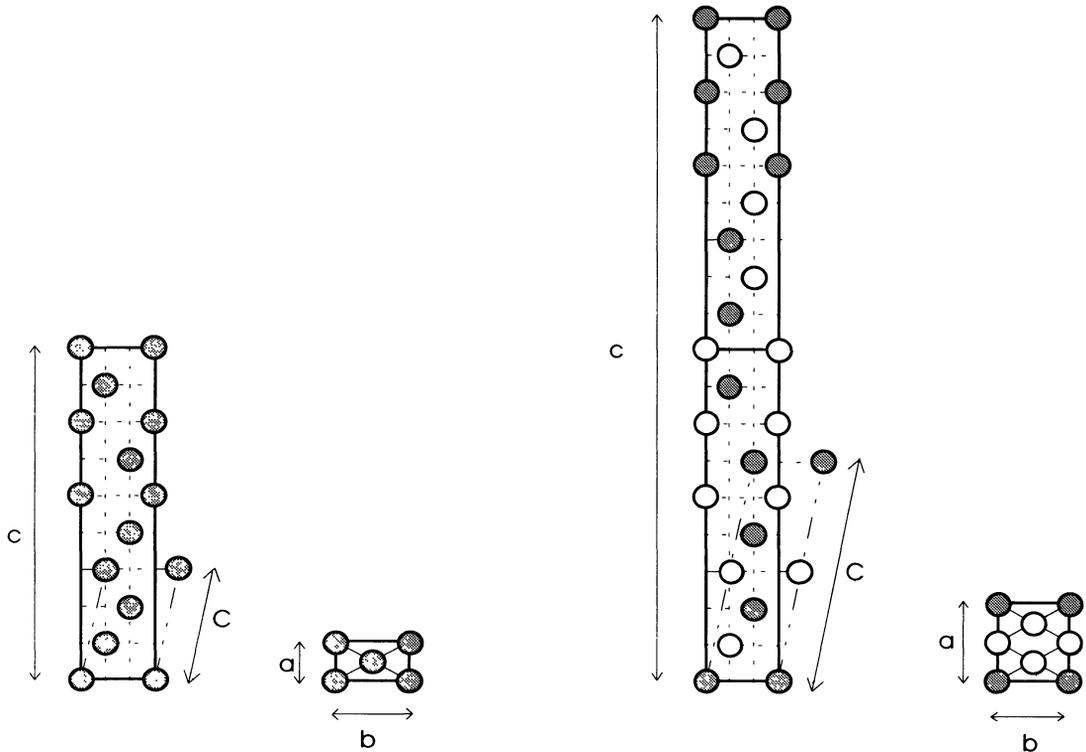


Fig. 3. — Structure of the β' (disordered) phase and β'_1 (ordered) phase.

5. Experimental Methods

This study was realized on disordered and totally ordered martensites respectively. Preparation and thinning of the specimens is described elsewhere [8]. Most samples were mounted on a copper grid, but some of them were mounted on a chromium grid in order to check their composition. In general, the specimens were illuminated by approximately parallel electrons. However, a few experiments, which will be only briefly discussed further, were carried out using a convergent electron beam. This work only deals with high symmetry orientation [100], [010] [001]; although other orientations were studied they need a separate interpretation.

In most cases, the regions of possible observations in a specimen were large enough to enable the selection of crystals with a zone axis which could be orientated along the electron beam by a tilt of less than a few degrees. In order to limit any effect due to the unavoidable bending of the samples during their preparation, for a given zone axis, the position and size of the electron probe were adjusted on the crystal so that the probe covered only the common part of the extinction contours corresponding to the Bragg reflections. If necessary (for example in the case of [001] zone axis orientation), the orientation was checked by means of convergent beam electron diffraction. The disorientations relative to a high symmetry position were performed by shifting the electron probe out of the extinction contours' intersection.

The EDX spectra were obtained with a LINK detector set in a JEOL 2000 FXII microscope (detection angle: 70° , resolution power: 138 eV for manganese). The acquisition time was fixed to standard values (120 s or 200 s; dead time: 25 – 35%). In these conditions, the count rates range was about 1000-2000 cnts/mn.

First, the energy of the CB peaks was calculated by means of the simplified relation (2), with $\beta = 0.493$ (corresponding to an electron voltage of 200 kV), and $\theta = 70^\circ$. In those conditions, the CB energy associated with the first Laue zone is given by:

$$E_{CB1} = \frac{5.236}{L} \quad E_{CB1} \text{ in keV} \quad L \text{ in Angström}$$

The selected zone axis for the β' and the β'_1 phases and the corresponding expected value of E_{1CB} are reported in the following tables. In these tables, Δ represents the direction of the compact plane stacking; a, b, c are the parameters of the orthorhombic cell, a, b, C are those of the primitive cell.

Table I. — *Values of the energy of the rank-1 peak for the selected orientations of the β' phase.*

Zone axis	[100]	[010]	[001]	$[01\bar{1}]$
Position	$\perp \Delta$	$\perp \Delta$	$// \Delta$	$// C$
L (Å)	$= a$ (2.59)	$= b$ (4.49)	$= c$ (19.06)	$= C$ (6.53)
E_{1CB} (keV)	2.02	1.16	0.275	0.8

Table II. — *Values of the energy of the rank-1 peak for the selected orientations of the β'_1 phase.*

Zone axis	[100]	[010]	[001]	$[01\bar{2}]$
Position	$\perp \Delta$	$\perp \Delta$	$// \Delta$	$// C$
L (Å)	$= 2a$ (5.12)	$= b$ (4.49)	$= 2c$ (19.06)	$= 2C$
E_{1CB} (keV)	1.01	1.16	0.138	0.4

6. Results

Apart from the expected characteristic peaks (Cu, Al, and sometimes Cr) and occasionally their associated escape peaks, the K_α Si peak was often observed. This could be attributed to a detector fluorescence. The CB peaks were recognized *via* their position and their behaviour when the crystal is disoriented from a high symmetry position.

The Figure 4 shows, for the β' and β'_1 the martensites, some spectra obtained from crystals where the zone axis parallel to the beam are respectively [100], [010], [001].

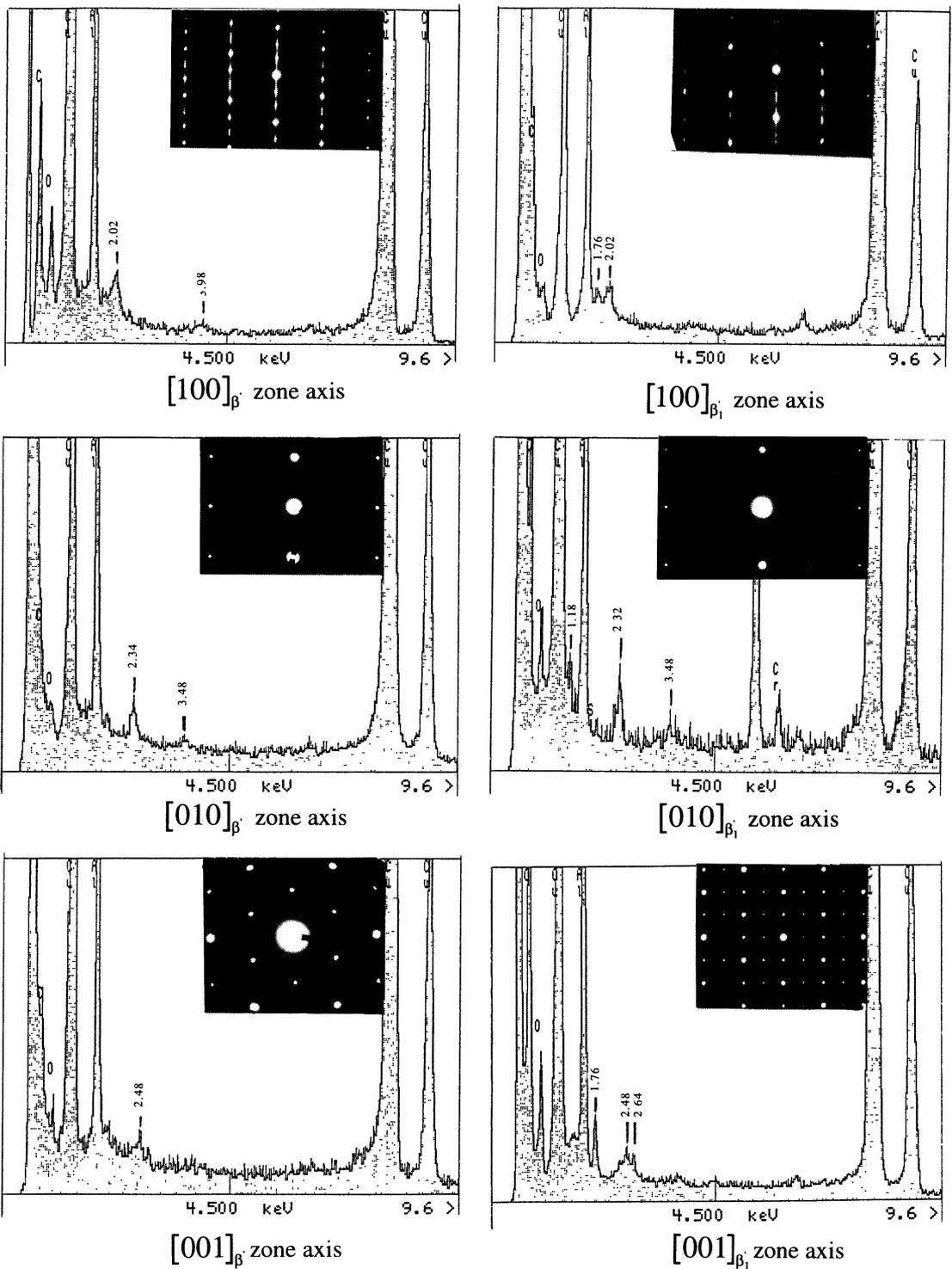


Fig. 4. — Spectra collected on disordered and ordered Cu-Al martensite for the zone axis orientations mentioned.

In the first two cases (zone axis perpendicular to Δ), 1 to 3 peaks are observed (in addition to the characteristic peaks), their position being in perfect agreement with the calculated positions for the first 3 corresponding Laue zones (cf Tabs. I and II). On the other hand, in the last case (zone axis parallel to Δ), only one peak is observed and its position, compared to the fundamental peak E_1 expected from the calculation, corresponds to the 9th rank for the β' martensite, and to the 18th rank for the β'_1 martensite.

In the case of ordered martensite, no extra peaks are observed contrary to what was expected; the only exception was, perhaps, the presence of satellites on the peak corresponding to $(001)^*$ (Fig. 4). This will be discussed later. Moreover, the peaks observed for the ordered alloy are often higher and better defined than those in the disordered alloy.

Figures 5 and 6 show the effect of a slight tilt from the above orientations: a different evolution of the corresponding peaks is observed, according to whether the initial zone axis is perpendicular or parallel to Δ . In the first case, the peaks collapse as expected from the above theory. However, in the second case, the initial peak does not usually collapse, but loses its shape and shifts from its initial position.

Figure 7 shows two spectra in which the CB peaks is intense, namely for the C zone axis direction, and for two adjacent crystals with a common zone axis orientation.

7. Discussion

7.1 BEHAVIOUR OF THE CB ACCORDING TO THE ZONE AXIS ORIENTATION . — Our aim here is to investigate the reasons for which the behavior of the CB is different according to whether the zone axis is parallel or perpendicular to Δ . These reasons are of three sorts and will be discussed separately:

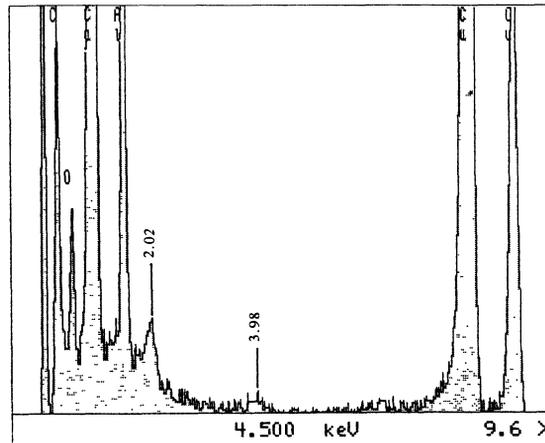
- role of the structure factor corresponding to the spots of a given Laue zone;
- number of spots in a Laue zone contributing to the formation of a given peak;
- influence of the stacking faults.

7.1.1 Role of the Structure Factor of the Spots of a Given Laue Zone . — The Figure 8 shows a few Laue zones obtained by simulation, and corresponding to the orientations studied for the β' martensite.

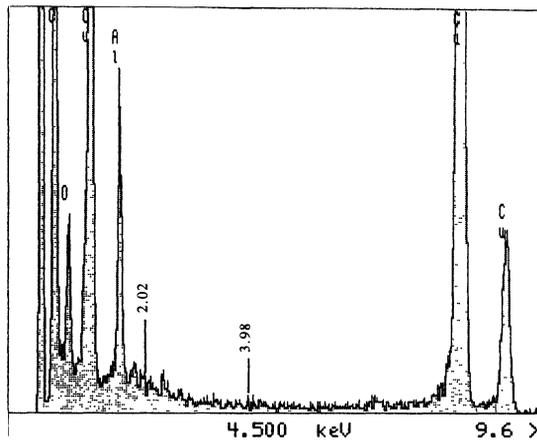
The radius of the circles representing the spots of the reciprocal space is proportional to the structure factor of the corresponding site, calculated in kinematic approximation. It is seen that the zones corresponding to the [100] orientation are identical (within a translation vector parallel to the zones). The same situation occurs for the [010] orientation. On the other hand, the LZ corresponding to the [001] orientation are very different from each other. Particularly, the sites of the LZs with a rank which is a multiple of 3, but not a multiple of 9 have a zero structure factor. This fact explains the absence of peak of rank 3 and rank 6. On the contrary, the sites of the LZs with a rank which is a multiple of 9 are intense. This fact explains the presence of the associated peak. It is the same for the β'_1 martensite except that in the [001] orientation for which the periodicity is doubled, it is the ranks which are multiples of 18 which are favored.

7.1.2 Effect of the Distance of a Site of a Given ZL from the Center of this Zone . — The approximate relation (2) supposes that in the (1) relation the term $g^2/2K$ can be neglected compared to the term $g \cdot n$. In fact, the CB energy corresponding to a LZ site far from the centre of the zone differs from the value given by the equation (2) by the quantity:

$$\delta E = A \cdot \frac{g^2}{2K} \quad \text{with} \quad A = \frac{hc\beta}{1 + \beta \sin \theta}$$



a)



b)

Fig. 5. — Spectra obtained by tilting from the [100] orientation. a) Perfect orientation. b) tilted orientation.

It is then reasonable to think that the LZ sites for which δE is higher than a given value δE_D (corresponding, for example, to the resolution power of the detector) does not contribute to the formation of the nominal peak. This leads to the exclusion of the sites outside of a circle the radius of which is:

$$R = \sqrt{g^2 - (\mathbf{n} \cdot \mathbf{g})^2}$$

or

$$R = \sqrt{\frac{2K\delta E_D}{A} - g_z^2}$$

The Figure 8 shows the influence of this effect for every considered LZ: Two circles are drawn in a given zone: one corresponding to the estimated resolution detector in the range of CB energy (100 eV), the other corresponding to $\delta E = 50$ eV. The contribution of the sites outside the largest

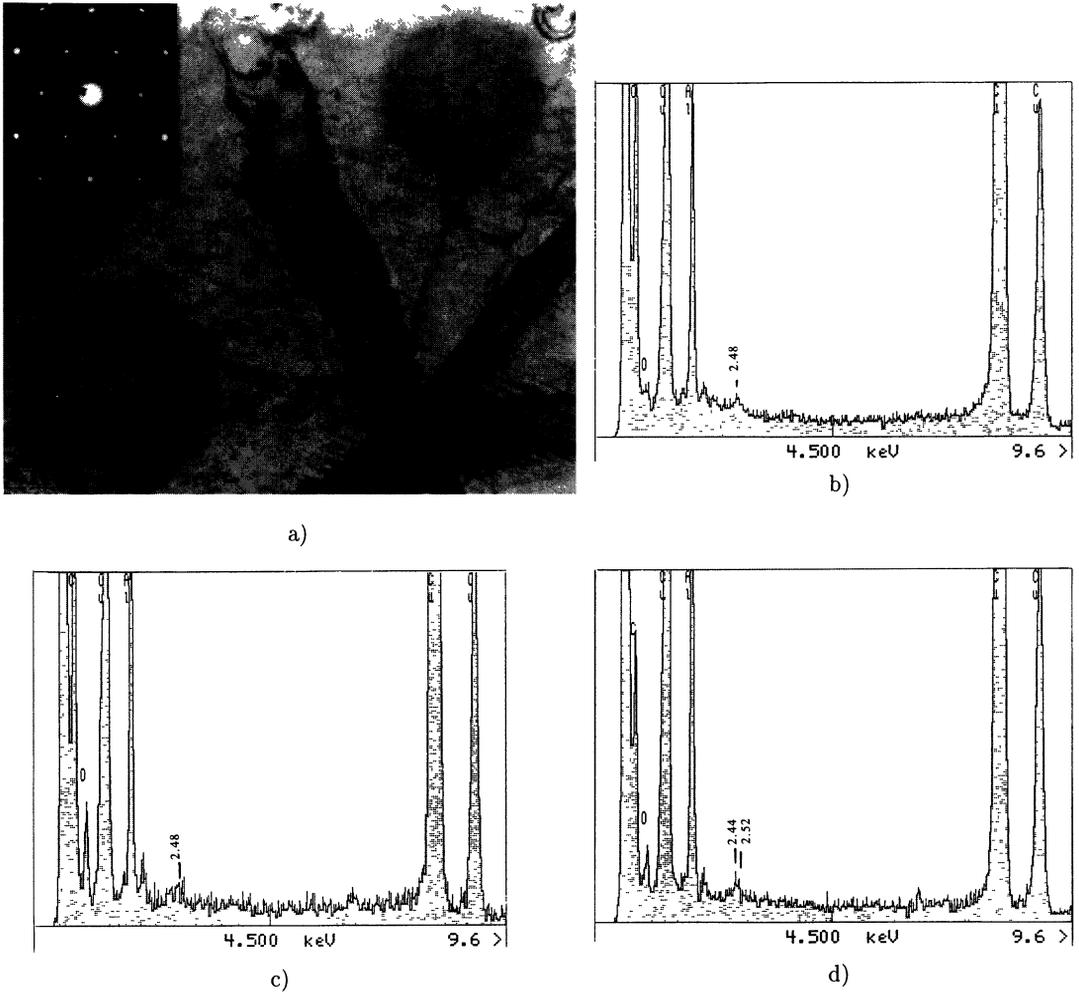
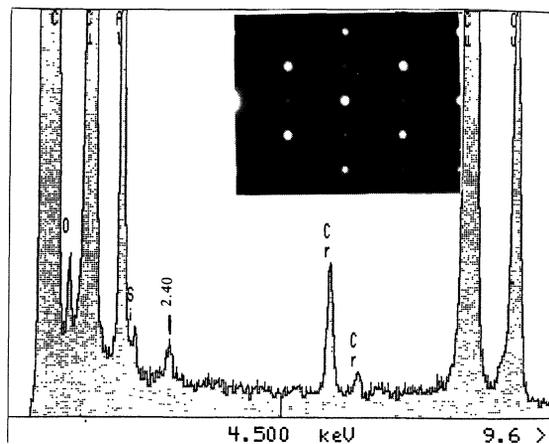


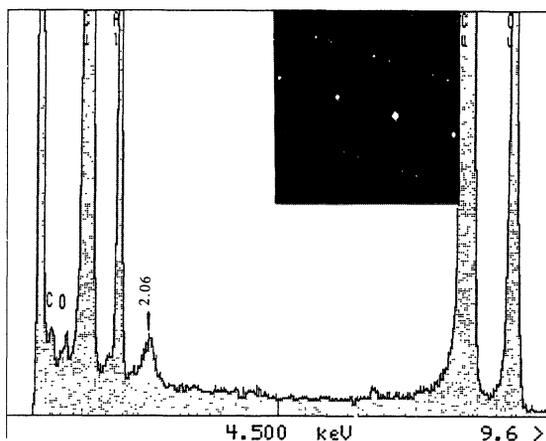
Fig. 6. — Spectra obtained by tilting from the perfect [001] orientation. a) Image of the crystal. NB the contaminated circular regions. b) Perfect orientation. c) Probe in the 1 region. d) Probe in the 2 region.

limiting circle is zero. For the sites located between the two circles, the contribution is probably very weak. This effect could play an important role in the case of the 9th zone corresponding to the [001] orientation, (phase β'), for which the first neighbouring spots of the (009)* spot are very distant from this central spot, thus contributing very weakly to the corresponding peak. In fact, the situation in that case is very similar to the 2-beams situation described by Reese *et al.* [6] ((000)-beam in the ZOLZ and (009)*-beam in the FOLZ). In this case the relation (2) does not apply because the relevant distance which intervenes is not the interatomic periodicity L in the [001] direction, but the distance d between the compact planes which is a submultiple of L .

This effect explains the difference in the CB peaks behavior in relation to the zone axis when a slight shift from the exact high symmetry orientation is introduced: a shift from the orientations [100] or [010] strongly modifies the number of active spots of the associated zones. On the other hand, a modification from the exact orientation [001] merely shifts the only significantly active spot (009)* continuously from its central position. This is the reason why a shift of the peak is



a)



b)

Fig. 7. — a) Spectrum for a zone axis $[01\bar{2}]_{\beta'_1}$ (\parallel C). b) Spectrum from two adjacent crystals with the same zone axis orientation.

observed rather than a collapse. We thus have some strong reasons to think that it is possible to shift the peak continuously from the position 2.48 keV, (corresponding to the c orientation), to the position 2.40 keV, corresponding to the C orientation of the primitive cell when it becomes parallel to the beam, but the examination of the corresponding Laue zone shows that other spots should intervene, reinforcing the magnitude of the peak. The previous discussion supposes that the resolution and the sensitivity of the spectrometer used do not allow a differentiation between the CB energies corresponding to two vectors in the same ZL. However, Spence and Lund [10] were able to underline such a difference, using a WDS spectrometer whose the resolution was 42 eV.

7.1.3 Influence of the Stacking Faults . — The preceding argument does not explain the absence of the peaks corresponding to rank 4 and rank 5 for $[001]$ orientation of β' (see Fig. 8), although



Fig. 8. — β' phase: ZL associated with the studied axis orientations for a CB energy range of 1-4 keV. a) [100] orientation. b) [010] orientation. c) [001] orientation.

the corresponding LZ contains intense spots. This is all the more surprising as the peaks related to the 1th and 2nd Laue zones for the [010] orientation really are present though their structure is practically equivalent to that of the 4th and 5th Laue zones of the [001] orientation. The reason for this anomaly is probably related to the numerous stacking faults. The study of the structure factor of a compact planes periodic stacking shows, usually, that introducing stacking faults does not modify the position of the spots corresponding to values of the Miller index k which are multiples of 3, but dilutes and shifts the other spots in the stacking direction [9]. Thus, for the [010] orientation, the spots of 1st and 2nd zones are diluted but stay in the zones, while the spots of the 4th and 5th zones for the [001] orientation are not only diluted but also go out of the zones. The corresponding peaks, in this last case will probably be merged in the background. From this, it emerges that, contrary to expectations, the 9R stacking mode cannot be characterized using the D

direction as an orientation parallel to the beam. This does not mean that such a characterization is not possible, but an oblique orientation must be used. A possible zone axis is the previously defined C direction, but other zone axes are needed as cross check.

7.2 INFLUENCE OF THE BEAM CONVERGENCE . — Our few experiments showed that increasing the beam convergence for a given crystal orientation could either reinforce a peak or weaken it. At present, no definitive explanation of this fact can be given, but it is thought that this is a consequence of the local curvature of the crystals. If the local curvature centre is situated on the same side of the sample as the convergence centre of the electrons, the periodicities encountered by the electrons are close whatever the direction of the electrons is. In that case, increasing the beam convergence from the parallel position should produce a more accentuated peak, up to a limiting value for which the convergence centre coincides with the curvature centre. On the contrary, if the local curvature centre of the crystal is situated in the opposite direction to that of the electrons, an increase of the beam convergence should lead to a weakening of the peaks.

7.3 INFLUENCE OF THE ORDERING . — The effect of the aluminium atom ordering is to double the atomic periodicity of the β' phase in the [100] and [001] directions. Consequently, it was expected that new peaks in these orientations would be observed. In fact, no such peaks were observed, there could be three reasons for this:

- the lack of sensitivity of the detector and the strong background in the low energy range of the spectra, which does not enable the low rank peaks due to the order to be observed;
- the relatively weak structure amplitude $f_{Al} - f_{Cu}$ of the superlattice spots;
- the strong possibility that the beam passes through an antiphase wall (the size of the ordered domain is about 200 nm for the composition studied). This leads, in fact, to a destruction, in the electron direction, of the mean periodicity due to the order. In effect, the periodicity of the domain located on the exit face of the sample, for the electrons, is in phase opposition in relation to the domain situated on the entry face.

However, it cannot be excluded that the ordering could be at the origin of the satellites peaks sometimes observed for the [001] orientation. Nevertheless, these satellites could be due to other effects, such as channelling radiation.

Another effect observed on the ordered crystal is a better definition of the peaks (see, for example, the peaks corresponding to the [010]). However, in our opinion, it is to be attributed to the low number of stacking faults in the ordered crystals rather than to the ordering. As a general rule in the Cu-Al martensites, the stacking fault density is larger in the β' than in the β'_1 phase.

8. Conclusion

CB peaks can appear in any EDX spectrum obtained from a monocrystal, even an imperfect one, or from a few adjacent crystals having a common orientation. These peaks often are intense enough to be detected even in a qualitative treatment of the spectrum. Their identification can be difficult because, more often than not, only one or two peaks appear, which prevents the use of any program involving their periodicity, such as the program (only used for the f.c.c. samples) sometimes integrated into spectra processing devices.

A practical means of recognizing such a peak is to check its behavior when the sample is tilted. According to whether it results from the contribution of a large or a small number of (inelastic) diffracted beams, the peak collapses or shifts on tilting the sample. In the first case, the peak position results (if it is isolated) from the atomic periodicity on the files of atoms along the beam.

In the second case, it is rather the smallest reticular plane distance along the beam which gives the peak position.

It is certain that the improvement of the detectors' resolution and the use of low temperatures recommended for methods such as ALCHEMI should lead to a reinforcement of the importance of CB peaks in a spectrum. It is therefore essential to be able to recognise this phenomenon, the applications of which should be investigated.

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