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Studies of interfaces in $Al_{65}Cu_{20}Fe_{15}$

R DIVAKAR, D SUNDARARAMAN and S RANGANATHAN*

Metallurgy Division, Indira Gandhi Centre for Atomic Research, Kalpakkam 603 102, India
*Department of Metallurgy, Indian Institute of Science, Bangalore 560 012, India

Abstract. The study of interfaces in quasicrystalline alloys is relatively new. Apart from the change in orientation, symmetry and chemistry which can occur across homophase and heterophase boundaries in crystalline materials, we have the additional, exciting possibility of an interface between quasicrystalline and its rational approximant. High resolution electron microscopy is a powerful technique to study the structural details of such interfaces. We report the results of a HREM study of the interface between the icosahedral phase and the related $Al_{13}Fe_4$ type monoclinic phase in melt spun and annealed $Al_{65}Cu_{20}Fe_{15}$ alloy.

Keywords. Quasicrystals; rational approximants; interface structures; grain boundaries; high resolution electron microscopy.

1. Introduction

The study of interfaces is important in understanding material properties (Ranganathan *et al* 1993). Quasicrystalline systems exhibit interesting interfacial structures. Compared to the homophase and heterophase grain boundaries seen in conventional materials where a change in orientation, symmetry, chemistry can occur, we have a similar possibility of grain boundaries in a system with a given quasicrystalline symmetry and interphase interfaces between quasicrystals with different symmetries. An additional fascinating possibility is the interface between a quasicrystal and a related rational approximant structure. The atomic configuration at such an interface between the icosahedral quasicrystal and its monoclinic approximant is reported here.

While the study of interfaces in crystalline materials is well documented, the study of interfaces in quasicrystalline materials is relatively new. There have been a few studies on the interface stability, growth and morphology of the quasicrystalline phases (Tsai *et al* 1991a; Chattopadhyay 1993). Facetting in these materials has been recognized as indicating the plane of stable growth and corresponds to the five-fold plane in a few instances (Tsai *et al* 1991b). Icosahedral twin interfaces have also been studied using conventional transmission electron microscopy (TEM) techniques (Singh and Ranganathan 1995).

The $Al_{65}Cu_{20}Fe_{15}$ quasicrystalline alloy has been studied in the melt spun state (Raghunathan *et al* 1990) using TEM. Microstructural features such as facetting of the icosahedral phase in the annealed ribbons have been reported earlier (Divakar *et al* 1992). The icosahedral phase in $Al_{65}Cu_{20}Fe_{15}$ coexists with the monoclinic $Al_{13}Fe_4$. An orientation relation between the two is observed as [010] of $Al_{13}Fe_4$ parallel to [100000] of the icosahedral phase. In the present paper we have examined this relation in more detail using HREM and image simulations. The structure of the icosahedral phase is examined in terms of the $Al_{13}Fe_4$ phase, which shows a tendency for A plane

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*Author for correspondence

twins. We report for the first time results of HREM of interfaces between these phases in melt spun and annealed $Al_{65}Cu_{20}Fe_{15}$.

2. Experimental

Pure elements Al, Cu and Fe were induction melted under an argon atmosphere to form the $Al_{65}Cu_{20}Fe_{15}$ alloy. This was melt spun under an inert atmosphere into ribbons $\sim 30\,\mu m$ thick. Some of the ribbons were annealed in an inert atmosphere for 24 h at various temperatures between 873 and 1093 K. The ribbons were prepared for electron microscopy by mechanical polishing followed by electrolytic polishing in a 22% HNO_3 in methanol bath cooled using liquid nitrogen. A JEOL 2000 EXII TEM with a top entry goniometer was used at 200 kV for the HREM studies. The tilting stage has a maximum tilt capability of $\pm 10°$. Images were recorded at close to the Scherzer defocus. This was confirmed by image simulation for the crystalline phase. For this, the EMS suite of programs for electron microscopy (Stadelmann 1987) was used.

3. Results and discussion

Figure 1 shows a HREM image of the icosahedral quasicrystalline $Al_{65}Cu_{20}Fe_{15}$ in the five-fold orientation. The corresponding quasiperiodic lattice can be generated using the projection formalism from 6D space. The structure of the $Al_{13}Fe_4$ type phase is such that it can be considered to be a stacking of alternate flat and puckered layers perpendicular to the b axis of the unit cell (Black 1955). Orientation relationship between the two is such that a five-fold plane of the icosahedral phase is parallel to these flat and puckered planes. We have studied using HREM, the interface between these

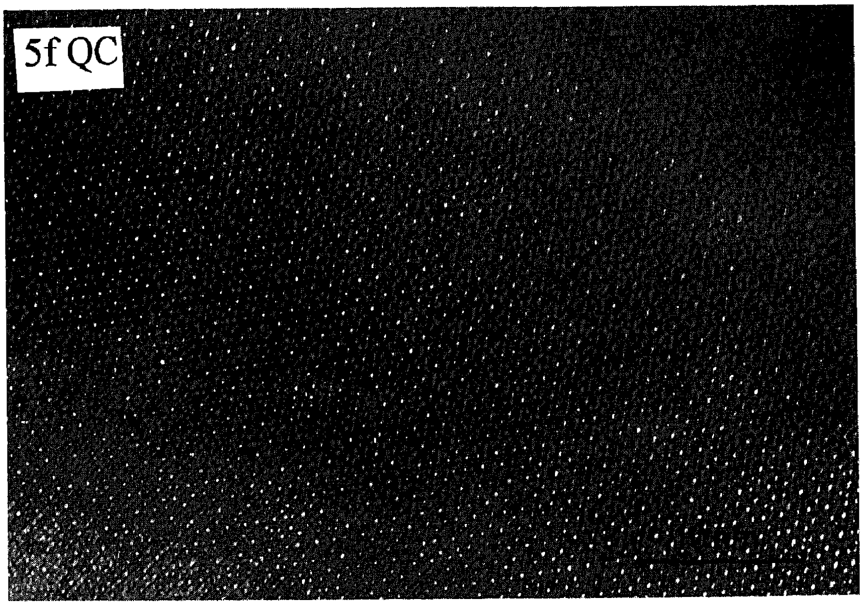


Figure 1. HREM image of the icosahedral quasicrystalline $Al_{65}Cu_{20}Fe_{15}$ along a five-fold (5f) orientation.

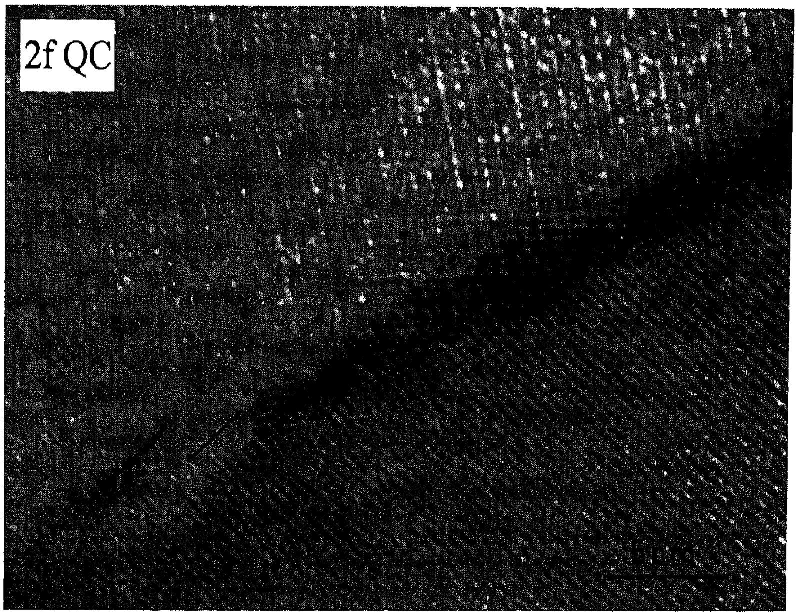


Figure 2. HREM image of the interface between the icosahedral and the monoclinic phases viewed edge on. The icosahedral phase is seen along a two-fold (2f) direction and the $Al_{13}Fe_4$ along [010].

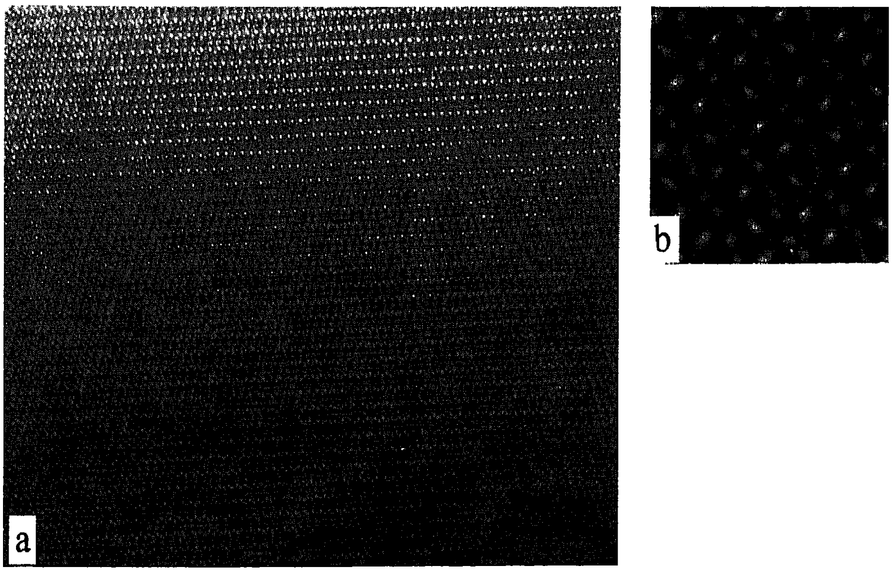


Figure 3. (a) HREM image of the defect free $Al_{13}Fe_4$ phase along [010] and (b) simulated image corresponding to (a).

phases by examining it along a two-fold direction which is approximately perpendicular to the five-fold direction in the icosahedral phase. Figure 2 is one such HREM image of the interface. Before considering the characteristics of this image, it is worthwhile examining the closeness of the structural relation between the monoclinic phase and

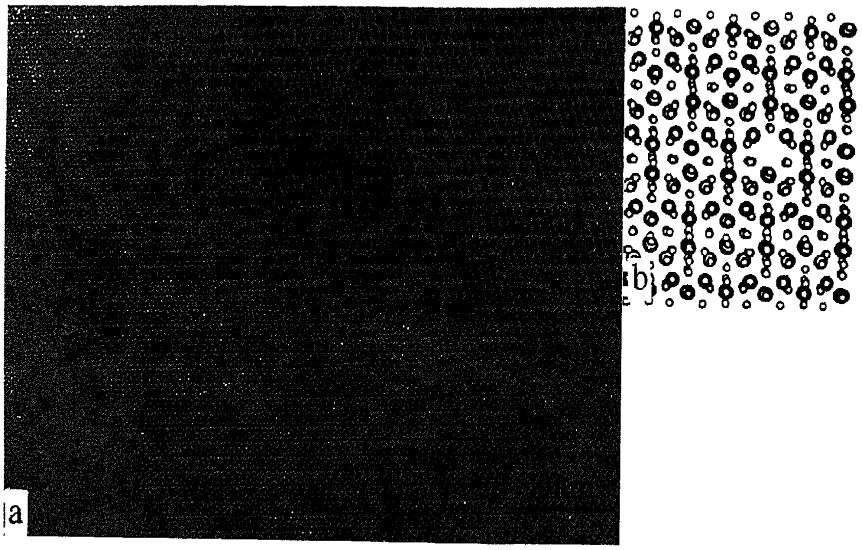
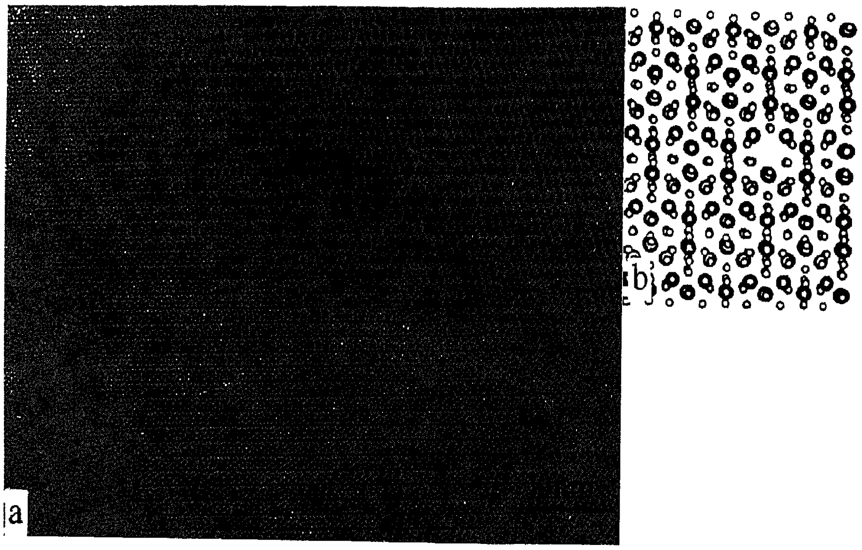


Figure 4. (**a**) HREM image of A plane twinned $Al_{13}Fe_4$ phase along [010] direction and (**b**) projected supercell structure corresponding to the image in (**a**).

the icosahedral phase. Figures 3a and 4a are the HREM images for the crystalline phase in the perfect and twinned state respectively. Figures 3b and 4b are the corresponding simulated image for the perfect crystal and the projected structure for the twinned structure. It is qualitatively seen that the monoclinic phase is more closely related to the icosahedral phase in the A plane twinned state. The propensity for twinning in the crystalline phase associated with the annealed icosahedral phase where a solute redistribution took place has earlier been reported (Divakar *et al* 1992). Hence, coherency over short length scales can be expected between the two phases, interrupted by interface defect structures to make up for the mismatch between the two lattices. Returning to the interface between the two phases, ledge structures are frequently seen along the interfaces. One such structure is shown in figure 2.

The first observation of the interface between the icosahedral and the decagonal phase was made by Chattopadhyay *et al* (1985). A facetted interface, distributed with some ledges, was observed by Kim *et al* (1990) in a decagonal grain growing from an icosahedral grain in an Al–Mn alloy during a solid state reaction. While Kim *et al* (1990) claimed that the ledges led to growth along the periodic ten-fold axis, Sun and Hiraga (1993) in a later study of similar ledges in an Al–Pd–Mn alloy asserted that the ledges led to growth along a quasiperiodic direction. Further studies of such ledges and their comparison with those in purely crystalline systems are warranted.

In precipitation and growth studies in crystalline materials, interfacial ledges have been studied for long and may be classified into structural and growth ledges. Structural ledges remain at interfaces whereas growth ledges are consumed as a result of interfacial movement. Distinguishing between the two is not possible using static HREM images and requires detailed *in situ* hot stage HREM experiments (Howe and Benson 1995). In view of the above discussion regarding the structural relation between the two phases, the interfacial ledge structure in the present case seems to be of the structural type.



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