

Formation of Icosahedral Aluminum-Manganese by Electron, Laser and Ion Beams

J. A. Knapp and D. M. Follstaedt
Sandia National Laboratories
Albuquerque, NM 87185, USA

Last year at the National Bureau of Standards, examination of certain aluminum-manganese alloys which had been melted and the rapidly cooled on a spinning copper wheel showed that the atomic arrangement of the resulting solid exhibited long-range order with icosahedral orientational symmetry. This means, for example, that certain directions show five-fold rotational symmetry in electron diffraction patterns. The discovery is surprising because five-fold rotational symmetry is impossible for a crystalline material, and all previously examined solids with long-range order have been found to be crystalline.

The problem is illustrated by an analogy in two dimensions: a floor cannot be tiled using a periodic array of pentagons (five-fold symmetry) without either overlapping tiles or leaving gaps. Naturally, the observation of an ordered material exhibiting icosahedral symmetry has generated intense interest. Currently, many workers interpret the experimental observations in terms of a "quasicrystalline" atomic arrangement. Again, the analogy of tiling a floor is helpful: a floor can be covered using two differently shaped tiles in a non-periodic array such that the overall symmetry of the pattern is five-fold. The pattern does not repeat, so no two areas of the floor have exactly the same local arrangement of tiles.

Such a pattern is called a "Penrose tiling," after its inventor. A "quasicrystal" would be a three-dimensional Penrose tiling, where two different groupings of atoms are arranged in a non-periodic array to

form the solid. Such a solid would be able to diffract electrons like a crystal, but symmetries such as icosahedral would be allowed. If this explanation is correct, quasicrystals are an entirely new class of ordered materials.

In order to determine the properties of the "icosahedral phase" and to explore other techniques which might lead to its formation, we have examined thin surface layers of aluminum-manganese produced by surface alloying techniques. First, alternating aluminum and manganese layers are deposited onto an aluminum or iron substrate to a total thickness of 50-100 nm. This surface layer is then treated with an electron beam, a laser beam, or a high-energy ion beam to form the icosahedral phase. If a laser or fast electron beam treatment is used, the surface layer is melted and then frozen very quickly (within less than one millionth of a second); this treatment produces a layer of small icosahedral particles, typically 30 nm in diameter. If a slower electron beam treatment is used, and the substrate is iron, the molten layer cools more slowly and grains of the icosahedral phase up to a micrometer in diameter are formed. Although generally similar to other liquid quenching techniques which have been used to form the icosahedral phase, the laser and electron beam treatments have well-known temperature histories which allow us to place limits on the melting point of the icosahedral phase (between 660 and 960°C) and the time needed for the phase to start forming (less

than 20 ns).

The other method of reacting the layers involves bombarding the sample with high-energy ions, and is called ion-beam mixing. This is a new way of forming the icosahedral phase which is quite different from melt quenching. A beam of xenon ions accelerated to an energy of 400 keV is used to intermix the layers on an atomic scale by producing localized atomic displacements. The xenon ions pass through the layers and come to rest in the substrate underneath; they do not become part of the alloy. By bombarding the layers for a sufficient time with the material heated to 80-100°C, the aluminum and manganese are converted into small grains of the icosahedral phase. If the same bombardment is done with the material held at room temperature, the layers are instead converted to an amorphous phase, which has no long-range ordering at all, either crystalline or quasicrystalline. This amorphous (or glassy) layer can then be converted to the icosahedral phase by heating the sample to 300°C. Further heating to 400° converts the layer to a crystalline phase.

These studies are providing fundamental information about such things as the melt times and cooling rates needed to form this new phase. These unique materials may prove to have unusual and useful physical properties; if so, the information our work provides will be needed to help develop practical applications of "quasicrystals."

MRS

Carbon in Crystalline Silicon

Ronald C. Newman
University of Reading
Reading, UK

Atoms of a crystal are arranged in a regular array to form a lattice which is analogous to a stack of chess boards one on top of the other, with one atom located on each square. The geometrical arrangement adopted depends on the constituent atoms and is different for iron, copper, or silicon. It has been found that each silicon atom

links or bonds to four neighboring silicon atoms to form a pyramidal or tetrahedral structure, which is exactly the same as that for carbon atoms in diamond. Therefore, it is not surprising that during the growth of a silicon crystal some atoms can simply be replaced by carbon atoms present as an inadvertent impurity. Such a crystal con-

tains "imperfections." The incorporation of carbon introduces strain into the crystal which arises because carbon atoms are smaller than silicon atoms. As a consequence, only a limited number of impurities can be present, and this number becomes smaller as the temperature of the crystal is reduced.

Continued