HIERARCHICAL POROSITY IN QUASICRYSTALS INVESTIGATED BY COHERENT X-RAY IMAGING

L. MANCINI[1,2], J. GASTALDI[1], E. REINIER[1], P. CLOETENS[2,3], W. LUDWIG[2], C. JANOT[4,6], J. HÄRTWIG[2], M. SCHLENKER[5] AND J. BARUCHEL[2]

1 CRMC2-CNRS, MARSEILLE (FRANCE)
2 ESRF, EXPERIMENTS DIVISION
3 EMAT-RUCA, ANTWERP (BELGIUM)
4 DIP. SCIENZE DELLA TERRA, UNIV. 'LA SAPIENZA', ROMA (ITALY)
5 LABORATOIRE LOUIS NÉEL, CNRS, GRENOBLE (FRANCE)
6 LABORATOIRE DE CRISTALLOGRAPHIE, CNRS, GRENOBLE (FRANCE)

An unexpected kind of solids, the quasicrystals, with long range translational order but no periodicity, was discovered in 1984 [1]. A lot of effort was devoted, from that moment, to understand their peculiar properties, in particular their growth mechanism and stability.

The observation, by hard x-ray phase imaging [2-4] and phase microtomography [4,5], of oriented dodecahedral holes, located in the bulk, of high-quality, centimetre-size, single grain icosahedral AlPdMn quasi-crystals, is considered by the scientific community concerned as a crucial result. It was made possible by the high spatial coherence of the beam at the «long» (145 m) ID19 beamline. Figure 1 shows one of the central results: the sizes of the observed holes display a discrete distribution, with peaks at 22, 5 and slightly more than 1 μm. Gas bubbles would lead to a continuous distribution. The jump from one size to the next corresponds to the factor τ^3, where τ is the golden mean ($\tau = 2 \cos 36° = 1.62$), a basic ingredient in all theoretical approaches of quasicrystals. The three-dimensional reconstruction resulting from phase microtomography shows that the average distance between neighboring holes is, again, about τ^3 times the hole size (Figure 2).

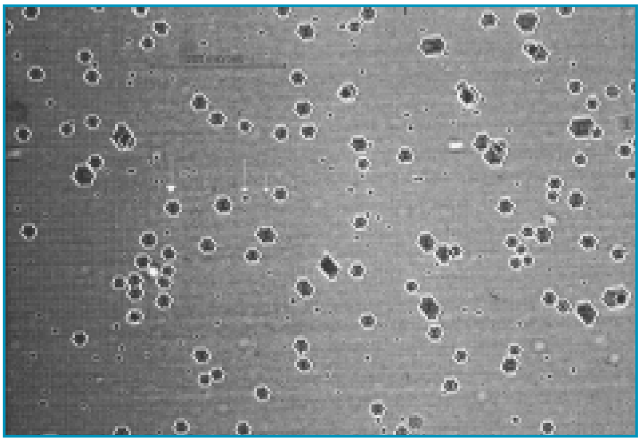

Fig. 1: Phase radiography of an AlPdMn quasicrystal (sample-to-detector distance 50 cm, λ = 0.35 Å) showing three families of dodehahedral holes (arrows).

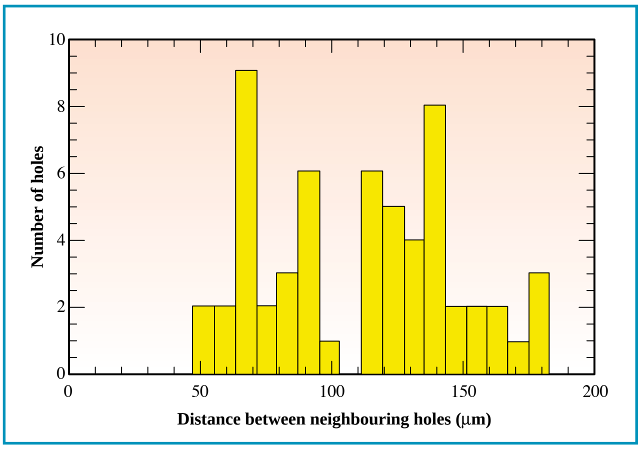

Fig. 2: Three-dimensional reconstruction resulting from a phase microtomography (sample-to-detector distance 50 cm, λ = 0.52 Å) of an AlPdMn quasicrystal, showing the holes locations.

Figure 3 shows that annealing alters the shape and sizes of the holes and reduces their number. The discrete distribution of sizes flattens out and changes gradually into a continuous one. It was often observed that lamella-shaped crystalline inclusions form in the neighborhood of the holes.

Figure 4 shows a diffraction image («topograph») and a phase image corresponding to a hole. The topograph shows a white-black contrast which indicates that a gradient of distortion is present in the hole neighborhood. This contrast can be simulated by simply assuming, as a first approximation, that the deformation field is similar to the classical one around a spherical inclusion in a crystal [4].

The features observed on as-grown grains could support the predictions of a model which describes the quasicrystal structure in terms of a hierarchical self-similar packing of overlapping atomic clusters. An inflation scale factor τ^3 preserves long-range order but generates a hierarchy of holes and a fractal structure. The observations appear to be in fair

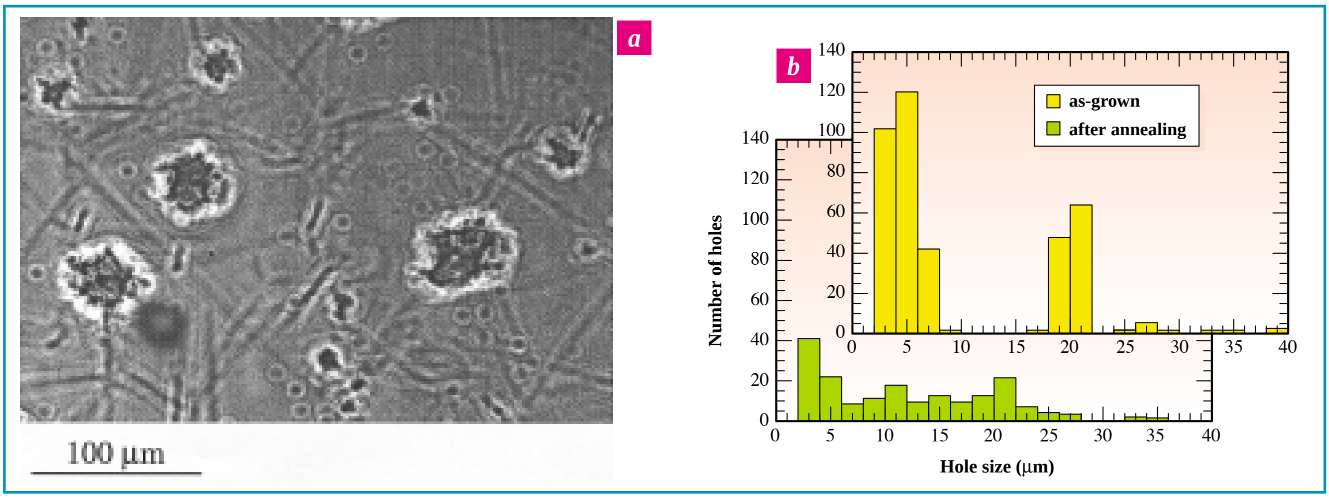

Fig. 3: Phase radiography after an annealing treatment showing deformation of the hole shapes and the appearance of lamellas of a crystalline phase.

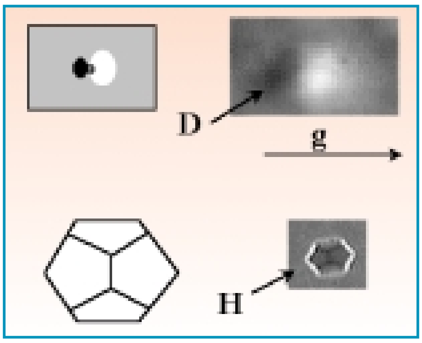

Fig. 4: a) diffraction and b) phase image of a hole; the diffraction image shows that the presence of a hole is associated with a distortion of the quasicrystal in its neighborhood.

agreement with these predictions [6], albeit with no indication about holes with size below the experimental resolution limit of about 1 µm, and with lower volume fractions and a flattened hierarchy. This flattening could result from the quasicrystal single grains having effectively, because of their low thermal conductivity, suffered annealing even in their as-prepared state. But the lower volume fractions of holes clearly indicate that the present model is not a final point. Systematic experiments are being performed to further clarify this topic. ■

References

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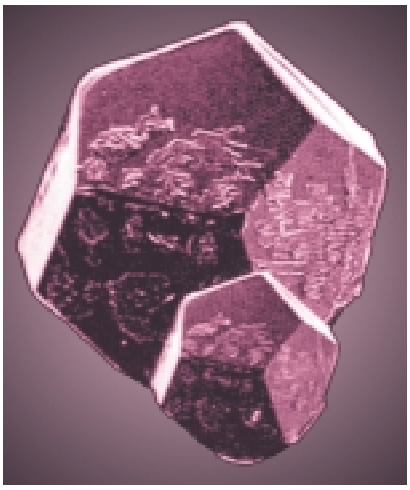
WHAT ARE QUASICRYSTALS ?

Quasicrystals are solids which have a new type of long-range order, such that their diffraction patterns show Bragg reflections revealing symmetries which are incompatible with periodicity (five-fold or ten-fold axis, for instance). Large single grains can be grown for some of the quasicrystalline alloys, like AlPdMn. Their quality is such that dynamic diffraction effects have been observed. Quasicrystal structures can be described in different ways. One of them consists in filling with atoms an appropriate quasiperiodic tiling, produced from two basic tiles and matching rules (Fibonacci chain in 1D, Penrose tiling in 2D,...). Another approach involves only one basic unit (a cluster of atoms) and a replication process; it implies some overlaps and holes.

In a higher dimensional space it is possible to describe the 3D-quasiperiodic structure as a periodic one. The actual quasiperiodic structure in the 3D-physical space is obtained from the hyperspace structure by an appropriate projection/section technique. The Bragg peaks observed on the AlPdMn quasicrystals, for instance, can be indexed in a 6D periodic hyperspace.

Aside from their peculiar structure, quasicrystals also exhibit very unexpected properties. This includes very high electrical and thermal resistivities: quasicrystals are therefore insulator alloys containing about 70% of aluminium! Other interesting properties involving, for instance, adhesion, corrosion, friction, and hardness suggest that quasicrystals are



promising materials for industrial applications, particularly coatings.

Reference

See, for instance, C. Janot, «Quasicrystals: a primer», Oxford Univ. Press, 2nd edit. (1994)