

Probing the growth and dissolution of quasicrystals in real-time

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Keywords: X-ray tomography, in-situ, quasicrystal, growth mechanism

Summary: How does a quasicrystal grow? To answer this question, we have performed synchrotron-based experiments on a decagonal (i.e., two-dimensional) quasicrystal with a composition of Al-8wt%Co-8wt%Ni. High-flux x-ray tomography enabled us to capture projections at temperature, during continuous cooling. By reconstructing the data in three dimensions, we were able to obtain new insights on the growth and dissolution pathways of the quasicrystals.

1. Introduction

Since the discovery of quasicrystals (QCs) in 1984 [1], QCs have attracted considerable interest due to their unique structure. The uniqueness stems from the QCs' ordered but aperiodic structures, which cannot be described by conventional crystallography. To explain the emergence of this aperiodicity, several models, e.g., the ideal [2], cluster-based [3], and random [4] tiling models, were proposed. However, these models lack experimental support; they do not provide detailed information regarding the growth and dissolution mechanisms of real QCs. Thus, there are still remaining questions in terms of the kinetics, surface properties and defects.

There exist two classes of stable QCs: the 3D (icosahedral) variant, and its 2D (decagonal) analogue. In the latter case, the 2D QC is stacked periodically about a decagonal (i.e., ten-fold) axis. One example of the decagonal QC (denoted d-QC) has been found in the Al-Co-Ni system [5]. Recently, Nagao et al. [6] observed the growth of one solid Al-Co-Ni d-QC grain into another, via in-situ high resolution transmission electron microscopy (HRTEM). Their results indicate that QC order is not always maintained during growth. Instead, growth occurs by an "error-and-repair" process of the QC order. While their work contributes to a greater understanding of grain growth in the aperiodic directions, it does not explain how the d-QC grows along the periodic, ten-fold axis. Thus, it is clear that a 4D approach (i.e., 3D space plus time) is needed to fully resolve the complexities of QC growth.

In our talk, we will present our efforts on tracking the growth of a d-QC in the Al-Co-Ni system via 4D, synchrotron-based X-ray tomography (4D XRT). These results were obtained by continuously cooling our sample from above the liquidus temperature (1273 K) into the solid-liquid regime. Following the experiment, we succeeded in visualizing the d-QC at different times during growth and dissolution. Given the wealth of information afforded by 4D XRT, we were then able to quantify the evolution of local interfacial orientations and velocities. To the best of our knowledge, we have obtained the first-ever three-dimensional reconstructions of a quasicrystal in a liquid, that makes it possible to observe kinetic phenomena at the quasicrystal-liquid interface.

2. Experimental method

High purity alloy samples of composition Al-8wt%Co-8wt%Ni were prepared under vacuum arc re-melting at Ames National Laboratory. The tomographic experiments were carried out at sector 2-BM at the Advanced Photon Source (APS) at Argonne National Laboratory (ANL) in Lemont, IL, United States. During the synchrotron experiment, the sample was cooled at a rate of 1 °C/min for 60 minutes while projections were recorded. Owing to the small size of the sample (1 mm in dia.), the temperature distribution was assumed to be uniform. The projections were collected

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at a rate of 50 Hz, with 1000 frames distributed evenly for every 180° rotation. These parameters provide a temporal resolution of 20 s between each of the 180 reconstructions. The achieved data was then processed using Tomopy [7]. Further data processing was accomplished using the image processing toolbox in MATLAB R2016b. For quantitative analysis, the segmented structures were meshed (or represented by a sequence of triangles and vertices). Using the mesh triangle and vertex positions, we calculated the distribution of local interfacial normals [8] and local interfacial velocities [9]. Provided that the d-QC is a single crystal, the interfacial normals in the laboratory frame are equivalent to those in the crystallographic frame. Our approach is illustrated in Fig. 1.

3. Results

We have determined that the interfacial velocities of the d-QC vary strongly with orientation: the growth velocity in the periodic direction (approximately greater than 55 $\mu\text{m/s}$) is over two order of magnitude greater than in the aperiodic direction (approximately 0.1 $\mu\text{m/s}$). As a result of this marked anisotropy, the d-QC resembles a faceted rod-like structure (Figs. 1(a-b)), wherein the long axis of the rod corresponds to the fastest-growing, periodic direction, $\langle 00001 \rangle$. The structural origins of this anisotropy will be presented and discussed in our talk. In addition, we have confirmed the presence of decagonal symmetry by calculating the distribution of interfacial normals along the $\langle 00001 \rangle$ zone axis (Fig. 1(c)). Indeed, there are ten peaks in the distribution corresponding to the ten facets in the aperiodic directions. These facets belong to the $\langle 10000 \rangle$ family. Interestingly enough, the pole intensities are not the same, which indicates that the $\langle 10000 \rangle$ facets do not all have the same area. The variation in the facet areas is most likely caused by differing local growth conditions, although this peculiarity necessitates further investigation.

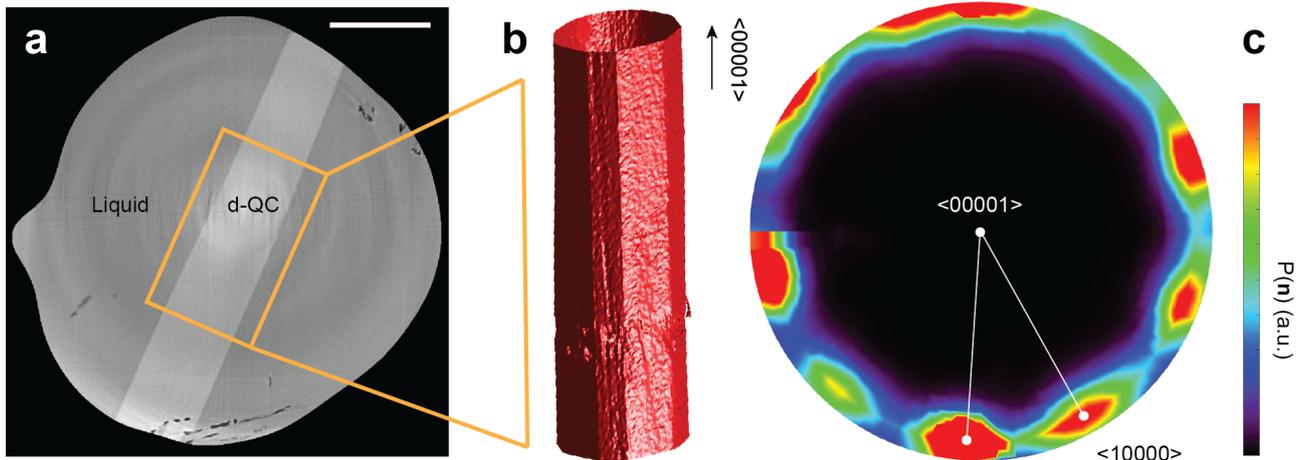


Figure 1: (a) Reconstructed slice of the 3D volume, at 28.3 min and 1144.7 K during the growth process. Two phases are visible: the d-QC and the surrounding liquid. Scale-bar measures 250 μm . (b) Three-dimensional reconstruction of the d-QC taken from the middle of the d-QC. (c) A stereographic projection of the local interfacial normals, measured about the $\langle 00001 \rangle$ zone axis in (b). The angle between the two white lines is 34° , which agrees well with the angle between $\langle 10000 \rangle$ planes of the same family (36°).

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