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AN ATOMIC RESOLUTION STUDY OF PRECIPITATES IN AN Al-Ge ALLOY

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The difficulty of precipitating germanium in dilute aluminum-germanium alloys is due to a large difference in crystal structures (face-centered cubic and diamond cubic) accompanied by a substantial volume expansion of 36%. A great variety of precipitate morphologies and orientation relationships are observed.¹⁻⁴ A frequently found morphology is that of $\langle 100 \rangle$ needles. By selected area diffraction and Moiré fringes it has been established that $\langle 100 \rangle$ Al and $\langle 110 \rangle$ Ge are parallel along the needle axis.⁴ The typical aspect ratio of about 100 has made it difficult in the past to investigate the cross-sectional shape and internal structure of these needles, although some indications of internal twinning were found in plates.⁵ In the present work, the Berkeley Atomic Resolution Microscope was used to examine needles in cross section by imaging along the $\langle 110 \rangle$ Ge $\langle 100 \rangle$ Al needle axis.

In the large number of high-resolution images recorded the particles were found to exhibit a fascinating variety of cross-section morphologies, internal and interface structures, and orientation relationships, even though only needles with $\langle 110 \rangle$ Ge || $\langle 100 \rangle$ Al were examined. At least three primary orientation relationships were observed; (a) $\{111\}$ Ge || $\{100\}$ Al, (b) $\{100\}$ Ge || $\{100\}$ Al and (c) $\{110\}$ Ge || $\{110\}$ Al.⁴⁻⁶ An example of a typical precipitate is shown in Fig. 1. The two longest flat facets are $\{111\}$ Ge planes parallel to $\{310\}$ Al while the shorter facets are another set of $\{111\}$ Ge planes parallel to $\{100\}$ Al. The primary orientation relationship of this precipitate and the one most frequently found is that given in (a) with monoclinic 2/m symmetry. The shape of this particle also has approximately 2/m symmetry along its axis, but the perfect symmetry is disrupted by the internal twins labelled 1, 2 and 3. The central precipitate and its twin 1 have the same (a) orientation relationship because they are mirror related across the $\{100\}$ symmetry plane of the matrix. On the other hand, twins 2 and 3 are in a different (secondary) orientation relationship because their twin plane is the $\{111\}$ Ge plane that is parallel to $\{310\}$ Al. Note that the corresponding interfaces with the matrix are atomically flat on the Ge side, leading to a stepped appearance on the Al side. Closer examination reveals an apparent stacking fault in the Ge layer next to this interface. Further high-resolution microscopy, especially comparison with other morphologies in the same alloy, is expected to provide additional clues on how these particles grow and how they are accommodated in the matrix.⁷

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7. This work is supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Materials Sciences Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

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FIG. 1. -- High resolution image of the needle-or lath-shaped Ge precipitate seen end-on along $\langle 110 \rangle$ Ge. The Al matrix is in $\langle 100 \rangle$ orientation. Segments 1, 2 and 3 are twin-related to the central part of the precipitate whose orientation relationship is $\langle 110 \rangle$ Ge $\parallel$ $\langle 100 \rangle$ Al and $\{111\}$ Ge $\parallel$ $\{100\}$ Al. The flat interfaces lie on $\{111\}$ Ge $\parallel$ $\{310\}$ Al planes.

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