OBSERVATION OF AN ELEMENTARY CUBOCTAHEDRON OF Xe NANOCRYSTAL IN AN Al MATRIX*

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When a noble gas element such as Xe is implanted in an fcc metal matrix such as Al at room temperature, a fine dispersion of precipitates forms. The precipitates are elementary fcc crystals up to diameters of several nanometers (for Xe in Al, 8–10 nm), above which they are non-crystalline. The precipitates exhibit a cube-on-cube orientation relation with the matrices and have lattice parameters which are much larger than those of the matrices ($a_{\text{Xe}} \approx 1.5a_{\text{Al}}$). Thus the interphase interfaces are incommensurate though the lattices are isotactic. The precipitates assume the shape of matrix cavities; for an Al matrix, at equilibrium this is a cuboctahedron, a $\{111\}$ octahedron truncated at the corners on $\{100\}$. Fig. 1 is a sketch of a dispersion of such cuboctahedra, viewed approximately along a $\langle 110 \rangle$.

For this study¹ specimens were prepared in the HVEM-Tandem Facility at Argonne National Laboratory by implanting 35 keV Xe to a dose of $4 \times 10^{19} \text{ m}^{-2}$ into well-annealed 5N Al discs which had been thinned by jet electropolishing. The range of the implant is approximately 25 nm. Specimens were examined at high resolution in the JEOL ARM-1000 high voltage electron microscope (HVEM) at the High Resolution Beam Station of the National Research Institute for Metals (NRIM), Tsukuba, Japan. The HVEM was operated at 1 MeV with a LaB₆ electron source. A series of studies of electron irradiation effects in this material have been conducted, which have revealed a number of irradiation-induced phenomena including migration within the matrix, changes in shape, faulting, melting, crystallization and coalescence of Xe precipitates². In this presentation, the structure of the smallest possible cuboctahedral Xe nanocrystal will be discussed and its apparently random migration under the influence of the electron irradiation will be demonstrated.

Fig. 2(a)–(c) is a series of HREM images grabbed from a segment of video tape during an irradiation experiment. The imaging technique involves tilting the specimen a few degrees off the $[110]$ zone axis and choosing an objective defocus different from Scherzer. These procedures in effect detune the Al lattice image with respect to the Xe image; image simulations have been shown to agree well with experimental observations³. The small precipitate at the center of Fig. 2(a)–(c) is a nearly perfect cuboctahedron composed of the minimum number of Xe atoms for this polyhedron. Fig. 2(d) is a sketch of a model of this precipitate viewed along $\langle 110 \rangle$ showing only exterior atom positions for clarity sake. Along the $[110]$ viewing direction of Fig. 2, the 14 Xe atom columns of this precipitate are composed of 2–4 Xe atoms each; the total number of atoms in the cuboctahedral model is 38. The well-defined image of this Xe precipitate reflects the sensitivity of observation involved in the imaging technique. For a 50 nm thick $\langle 110 \rangle$ foil, for example, there would be about 175 Al atoms and 2 Xe atoms in a $[110]$ column along an (001) face of the minimum sized cuboctahedron.

Figs. 2(a)–(c) illustrate the electron irradiation-induced migration of the small Xe precipitate at 300 K. The figure caption reports the cumulative damage created within the Al matrix corresponding to each image, expressed as the number of displacements per bulk Al atom (1 dpa means on average each Al atom has been displaced once), as determined for a damage cross-section for the bulk Al of $60 \times 10^{-28} \text{ m}^2$ and an electron flux of $6.6 \times 10^{24} \text{ m}^{-2} \text{ s}^{-1}$. The extent of damage in the Xe due to electrons and to Al recoils is not known. The precipitate migration process is random, the Xe nanocrystal remaining crystalline over this damage interval of nearly 10 dpa. The migration process will be discussed in the presentation.

References

1. Research jointly supported by U. S. Department of Energy, BES-Materials Sciences, under Contract W-31-109-Eng-38 and the Science and Technology Agency of Japan.
2. C.W. Allen et al. *J. of Electron Microsc.* (1999) In Review.

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Fig. 1. Assembly of solid cuboctahedra composed of $\{100\}$ (four sided) and $\{111\}$ (six sided) faces, viewed down $[110]$.
 Fig. 2. Motion of a nanometer size, solid Xe precipitate in $[110]$ Al during 1 MeV electron irradiation at 300K. Accumulated electron doses for the bulk Al matrix from the first frame are (b) 1.9 and (c) 9.5 dpa.
 (d) Atomic arrangement of solid Xe cuboctahedron of minimum size, viewed down $[110]$.