1.4 INFLUENCE OF ION IRRADIATION DIRECTION ON GROWTH OF NANOPRECIPITATES IN MODEL CNAs—L. Tan (Oak Ridge National Laboratory), B.K. Kim (ORNL), G.S. Was (Univ. of Michigan)

OBJECTIVE

Characterize the irradiation response of CNA steel alloys.

SUMMARY

Transmission electron microscopy of irradiated CNA alloys and statistical quantitative analysis of the ultrafine particles after heavy ion irradiation indicates that these experiments may not represent the precipitate stability under neutron irradiation. The dependence of nanoprecipitate evolution on ion beam direction is one process that may be unique to ion irradiation.

PROGRESS AND STATUS

Introduction

Castable nanostructured alloys (CNAs) are being developed at Oak Ridge National Laboratory, to favor the formation of a larger amount of ultrafine precipitates in reduced-activation ferritic-martensitic steels [1]. Model CNAs were developed to explore the stability of specific types of nanoprecipitates [2], since evolution of precipitates may directly influence the mechanical properties and even corrosion-related properties of alloys. However, reports on evolution of radiation-modified precipitates in morphology, size and density are limited.

Experimental Procedure

The influence of Fe^{2+} ion irradiation on the evolution of vanadium nitride (VN) thin-lath-shaped nanoprecipitates at 500°C was investigated in a model CNA. Because of the preferential orientation of the VN nanoprecipitates in the ferritic matrix, different grains were characterized after 5 MeV Fe^{2+} irradiation. SRIM (the stopping and range of ions in matter) was used to calculate the depth-dependent profiles of irradiation dose in displacements per atom (dpa) and implanted Fe in atomic percentage (at.%) with the recommended parameters [3]. The calculated profiles in two levels of irradiation damages with peak doses up to ~49 and ~240 dpa, respectively, are shown in Figure 1. Transmission electron microscopy (TEM) was used to characterize the nanoprecipitates within 300–700 nm from irradiated-specimen surface. Examples of the nanoprecipitates at ~650 nm from irradiated-specimen surface are shown as insets of Figure 1. The relationship between the ion beam direction and the initial length direction of nanoprecipitates (ppt) is marked on each inset, indicating three orientation conditions with the angle between beam and ppt ($\angle$beam−ppt) as ~12°, ~20°, and ~82°.

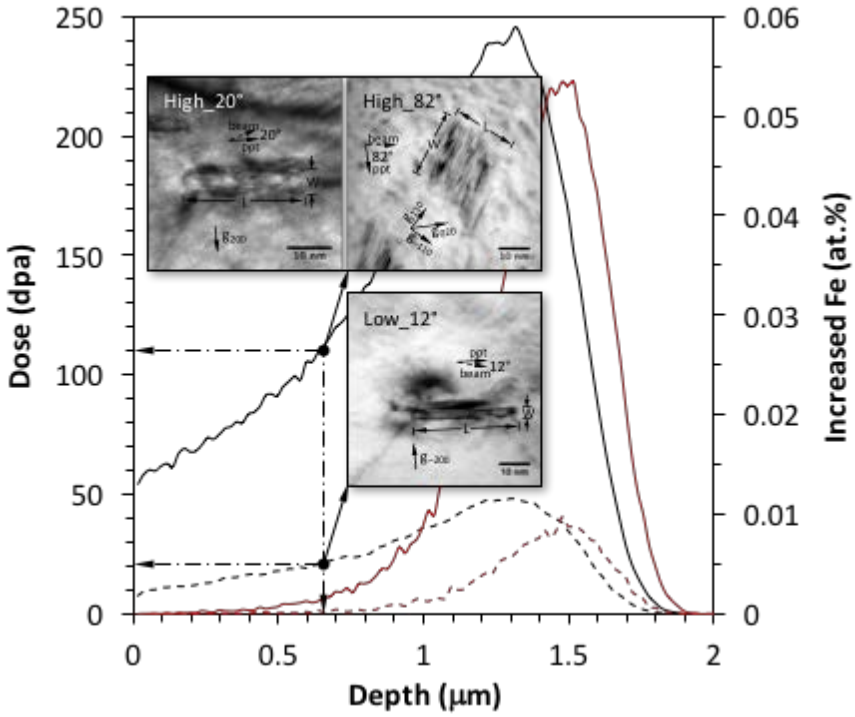

Figure 1. SRIM-calculated depth profiles of dose (black) and implanted Fe (red) after two levels of irradiation damage in dashed and solid lines, together with insets of high-resolution BF-TEM images at depth of ~650 nm from irradiated-specimen surface.

Analysis of the nanoprecipitates within 300–700 nm from irradiated-specimen surface indicates that the nanoprecipitates generally grew longer and sectioned into shorter lengths at higher dpa, resulting in higher particle densities, when the ion irradiation direction was approximately aligned with the initial nanoprecipitate length (i.e., smaller ∠beam–ppt). As ion irradiation deviated from nanoprecipitate length direction (i.e., larger ∠beam–ppt), some nanoprecipitates sectioned lengthwise and then dissolved, resulting in decreased particle densities. Surviving nanoprecipitates were transformed into parallelograms as shown in the high angle, 82°, inset of Figure 1.

The aspect ratio of the nanoprecipitates is defined as length/width (L/W as indicated in the insets of Figure 1). The aspect ratio frequency of the nanoprecipitates is shown in Figure 2, illustrating significant reductions in aspect ratio of the particles to ~2.4 in average after the high-dose irradiation compared to ~6.8 in average of the low-dose irradiated sample, both of which having small ∠(beam–ppt) angle of 20° and 12°, respectively. The larger ∠(beam–ppt) angle of 82° further decreased the aspect ratio to ~1.1 in average after the high-dose irradiation. Compared to the aspect ratio (~7.3) of the nanoprecipitates prior to irradiation, aspect ratio of the nanoprecipitates was decreased by higher doses, but more significantly by irradiation direction (∠(beam–ppt).

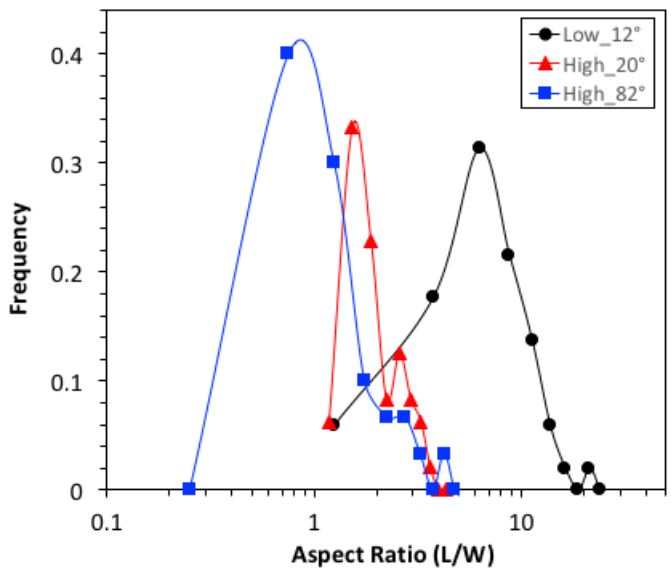

Figure 2. Aspect-ratio-dependent frequency of the particles within 300–700 nm away from irradiated-specimen surface.

Results

This study indicates that statistical quantitative analysis on the stability of ultrafine particles under heavy ion irradiation experiments may not be able to represent their stability under neutron irradiation situation. The dependence of nanoprecipitate evolution on ion beam direction is one process that may be unique to ion irradiation. Detailed information about this topic is contained in a paper submitted for journal publication.

References

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[3] R.E. Stoller, M.B. Toloczko, G.S. Was, A.G. Certain, S. Dwaraknath, F.A. Garner, Nucl. Instrum. Meth. Phys. Res. B 310 (2013) 75.