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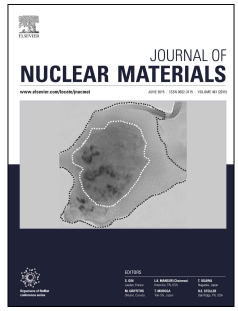

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Irradiation Damage Investigation of Helium Implanted Polycrystalline Copper

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ABSTRACT:

This work features the synthesis of nanoscale cavities using a He ion beam implantation method. A multitechnique (AFM, TEM, nanoindentation) post synthesis approach allows for the characterization of a 200 nm thin implantation region containing nanocavities. It was found that at lower doses, the cavities arrange themselves in a superlattice and are close to equilibrium pressure while at higher doses the self-organization of the nanoscale cavities is lost forming while the cavities change in nature resulting in a degradation of the mechanical properties. Close correlation between theory and experimental observation is achieved considering for the observed phenomena.

INTRODUCTION:

The effects of He accumulation in materials is studied for a variety of applications including fission reactors, spallation sources and fusion reactors [1-2] as well as optical applications [3]. High energy neutrons, as found in fusion reactors and spallation sources, produce insoluble He from (n, α) reactions in the materials. The He can diffuse and agglomerate into bubbles with internal pressures reaching equilibrium with its surrounding. Similar phenomenon can occur when He is injected via implantation from an external source such as accelerators. The injection of He in a material is also accompanied with the production of point defects such as vacancies and interstitials due to the trajectory the ion takes through the material. At elevated temperatures vacancies are mobile allowing them to diffuse and agglomerate to produce cavities with no or reduced gas pressure (voids). These cavities can have a profound effect on the integrity of the materials during its service and can lead to swelling. It is important to point out that swelling due to pressurized He bubbles and swelling due to voids can affect each other but are fundamentally different in nature and need to be discussed separately. It is therefore essential to understand the mechanism of formation of bubbles and cavities in detail to impede the failures of materials involved.

The effects of He bubble formation in materials in general [4-9] and copper specifically has been the subject of intense research for a significant period of time since copper and copper-based alloys have been considered as one of candidate materials for high heat flux components of fusion reactors [10, 11].Previous research has shown that random He bubbles mainly accumulate along sinks such as grain boundaries, precipitates and dislocations [9-14]. However, when implanted at low or medium He dose and at low temperature, compared to melting point T_m ($T \approx 0.35T_{m,}$), a bubble superlattice will form [15-17]. Johnson et al. were the first to report the He superlattice in copper in 1979 [16]. When implanted to high dose at temperature $T<0.35\ T_m$, blisters are also commonly observed on the surface of the samples [19-21]. Johnson et al. identified the bubbles structures directly associated with blistering in copper with transmission electron microscopy (TEM) and scanning electron microscopy (SEM) for the first time [22], providing answers on the nature of these structures. Normally, He bubbles will contribute to the degradation of the mechanical properties [14, 23] of the materials implanted. However, when it came to submicron-sized single-crystalline copper, radiation-induced He nanobubbles actually enhanced ductility [24]. However it is also possible for He-bubble superlattice structure to harden the copper significantly [15].

Recently the irradiation damage behaviors of single crystal, coarse-grained (CG), and nanograined (NG) copper (Cu) films were investigated under He ion implantation at 450 °C with different ion fluences [25]. In the irradiated single crystal films, numerous cavities were created, preferentially on defects or dislocation lines. In the irradiated course-grained Cu, cavities were formed both intra and inter-granularly. In contrast, irradiation-induced cavities in nano-grain Cu were found mainly inter-granular, along the grain boundaries. They concluded that grain boundaries are efficient sinks for irradiation-induced vacancies and proposed that reducing the grain size of materials impedes radiation-induced cavity swelling.