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A New Method for Studying He Damage in Materials Demonstrated on Nanotwinned Cu Nanopillars

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Ion implantation has been used for decades to investigate the response of materials to radiation damage. While displacement damage is caused due to an incoming particle, in high neutron energy environments gases are also produced due to transmutation or fission events. In particular fusion, fast reactor and spallation sources suffer from high He/dpa (displacements per atom) ratios. Understanding the effect of He in materials is a key aspect in these applications. It is known that interfaces are beneficial for radiation damage due to the fact that interfaces act as defect sinks. In the past He-denuded zones around grain boundaries have often been observed which prove that He can be managed by offering defect sinks [1]. Only a few studies have been performed investigating the effect of twin interfaces on He management [2]. The studies performed are rather limited in exploring different doses due to the fact that implanting the same grain with different doses and subsequent characterization of the resulting defects are challenging and rather time consuming, thus limiting systematic studies. Moreover, in order to obtain a direct comparison ideally one implants the same sample and same grain to different doses. Recently the Zeiss ORION NanoFab instrument was released which allows He and Ne ion beams in combination with a Ga ion source to quickly and efficiently manufacture nanostructures and direct He implantation [3]. In this work we utilize the combined Ga-He beam system to increase sample throughput and manufacture nanopillars with subsequent He implantation in a fast and efficient manner. Using this novel method one can manufacture nanopillars and implant these targeting the exact same grain in one session, thereby allowing for better and more accurate comparison and effect evaluation due to better controlled separate effect testing.

In this work several nanopillar samples were manufactured in one grain of a nanotwinned Cu sample. Each pillar was implanted to a different dose using 25keV He ions generated by the ORION NanoFab instrument. The maximum dose was 10^{19} He^{+}/cm^{2}. Each pillar was then tested using a JEOL 2010 TEM equipped with a Hysitron PI95 nanomechanical testing system. Quantitative stress-strain data were collected in situ leading to a fundamental understanding of the deformation mechanism of the implanted pillars.

It was found that the approach of directly implanting He into nanotwinned Cu nanopillars can easily be conducted using the ORION NanoFab. Figures 1a and b show two nanotwinned pillars cut from one grain using a Ga ion source and then implanted with different doses of He. In the case of samples implanted with a high dose (e.g. 10^{18} $He+/cm^{2}$) He bubbles were formed in the material, as shown in the defocused bright field image in Figure 1c. Micro compression testing leads to the stress-strain curve shown in Figure 2. The strength of the nanopillars significantly depends on the dose of He.

Taking advantage of the accurate and controllable micro area He implantation technique described, different doses of He ions were implanted into Cu nanotwinned pillars manufactured in one grain. The influence of various He doses on the mechanical properties of nanotwinned Cu was systematically studied by in situ mechanical testing. This novel technique makes it feasible to evaluate He ion damage and its effect on small volume materials.

References:

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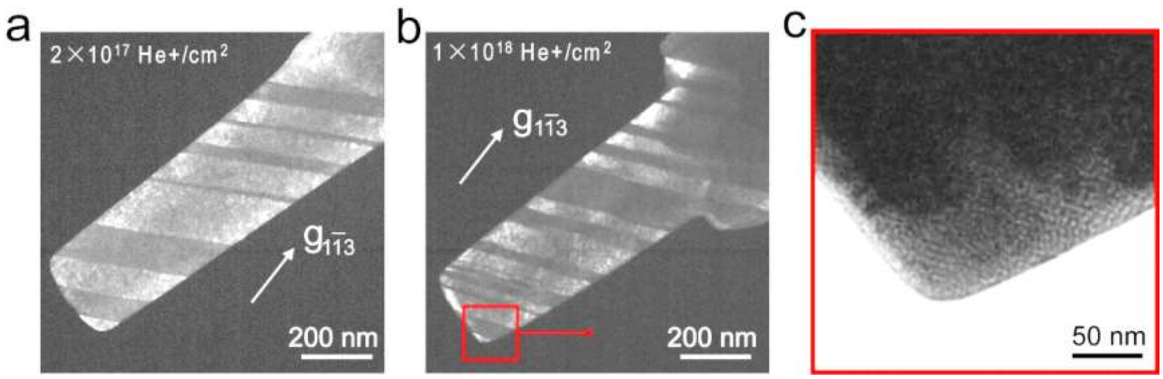

Figure 1 nanotwinned pillars with different doses of He.

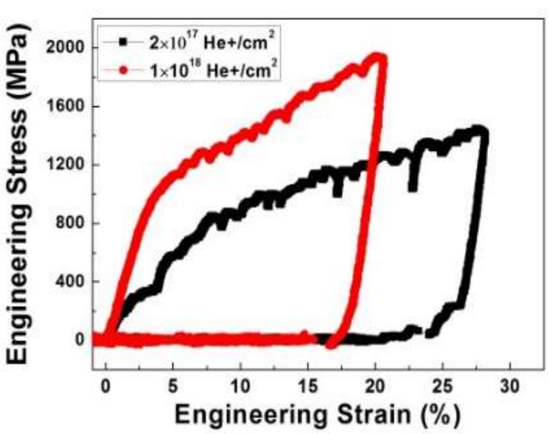

Figure 2 Engineering stress versus engineering strain curves of nanotwinned Cu nanopillars implanted with two different doses of He.