4.4 PROPERTIES OF IRRADIATED TUNGSTEN AND RECOVERY ON ANNEALING -

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OBJECTIVE

The objective of this work is to understand the impact of neutron irradiation on the mechanical properties of single crystal tungsten and how annealing may recover these properties.

SUMMARY

Samples of (110) single crystal tungsten (SCW) were irradiated in HFIR at 70 to 900°C and fast neutron fluences of 0.01 to 20 ×10^{25} n/m^{2} at E>0.1 MeV [1]. A subset of eleven samples from this group with fluences up to 7×10^{25} n/m^{2} have been selected for the annealing study within the PHENIX collaboration. Hardness testing and positron annihilation spectroscopy (PAS) have been completed on unirradiated control samples. The irradiated samples are being polished in preparation for the upcoming tests.

PROGRESS AND STATUS

Introduction

Tungsten may be used as a plasma-facing material in future fusion devices. However there is a lack of fundamental understanding of the behavior of tungsten under neutron irradiation. To design and build successful fusion devices, more must be known about the effects of irradiation on tungsten's properties. This study aims to further the understanding of microstructure and defect structures in irradiated tungsten and how these defects contribute to irradiation hardening. It is also important to understand if annealing may recover the mechanical properties to pre-irradiation values by healing some of the irradiation induced defects.

Experimental Procedure

The samples in Table 1 have been identified in LAMDA and selected for the annealing study. The samples have been measured, and it was determined that samples 1W05 and 1W25 are large enough to perform PAS. All the samples will be polished and hardness tested. Then, each sample will be annealed for one hour at its respective irradiation temperature. After the annealing, the hardness testing and PAS will be repeated.

Table 1: Samples currently in LAMDA selected for the annealing study.

HFIR Rabbit Capsule	Sample ID	Target Irradiation Temperature (^{o}C)	Fluence 1x10^{25} n/m^{2} (E>0.1 MeV)
TB-300-1	1W01-A	300	0.02
PC1A 'N'	1W05	90	0.02
T9G-11	1W07-A	300	2.82
T9C-14	1W17	500	2.20
TB-500-3	1W20	500	9.00
TB-650-1	1W23	650	0.13
PC2A 'Q'	1W25	90	0.10
PCV4A'V'	1W43-A	90	1.95
TB-300-2	1W47	300	0.10
TB-500-2	1W51	500	0.54
TB-650-2	1W53	650	0.46

Results and Discussion

Unirradiated control samples have been analyzed with PAS and hardness tested. Positron annihilation spectroscopy (PAS) was performed on a SCW (110) sample; the <110> direction was in the plane of the sample. The PAS measured 223.3 ps for the di-vacancies in the control sample (Figure 1).

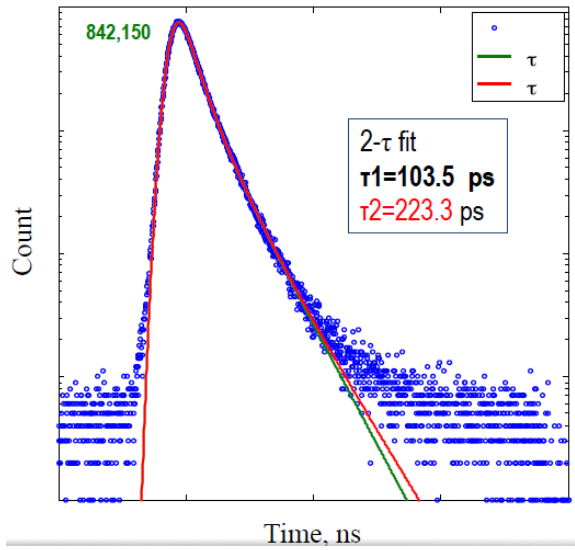

Figure 1. PAS performed on unirradiated SCW (110) sample revealed a value of 223.3 ps for di-vacancies.

Nanohardness of a SCW (110) sample was measured using the Wilson nanohardness indenter with a 10 second dwell time and varying the load between 0.050 and 1 kg (Figure 2). The hardness depends on the indentation load until the load reaches 0.2 kg after which point the hardness plateaus. Future nanohardness tests on tungsten samples should be completed with at least 0.2 kg as the indentation load.

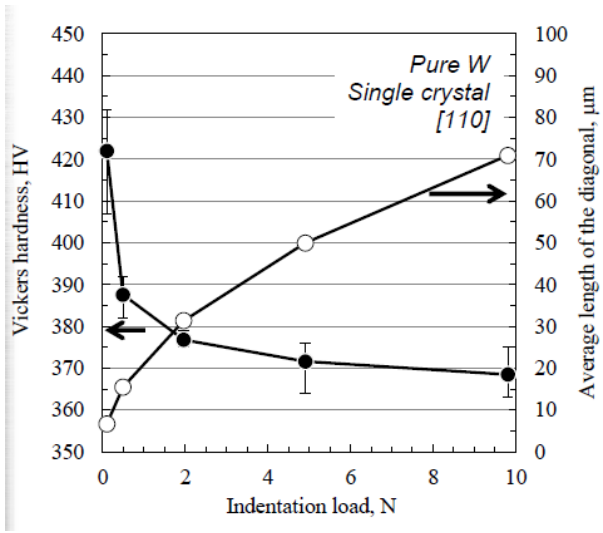

Figure 2. Nanohardness measurement of a SCW (110) sample show that the hardness becomes insensitive to the indentation load above 1.96 N (0.2 kg).

The hardness is also sensitive to the surface polish of the tungsten samples. A sample polished with a final polish step of larger than 3 µm diamond paste showed differing hardness values with rotation of the SCW sample (Figure 3). However when the surface polish was increased to a 1 µm diamond paste, the orientation dependence is largely absent (Figure 3).

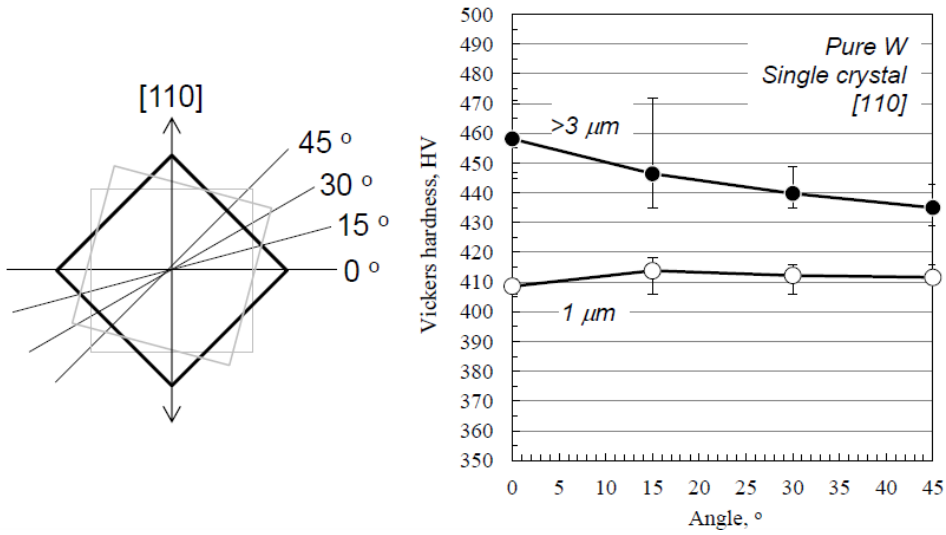

Figure 3. On the sample that was polished with greater than 3 µm paste, a difference in hardness value with orientation was observed.

Electron backscattered diffraction (EBSD) was performed on the SCW sample that showed a change in hardness value with rotational angle of indentation. The SCW samples originated from a grown cylindrical crystal with <110> along the axis of the cylinder. To produce samples, the cylinders are sliced parallel to the cylinder axis and then cut perpendicular to the first direction to create rectangular samples. Thus, it is known that the <110> direction is along one edge of the samples, but EBSD was needed to determine the plane on the face of the samples. Although the sample is a single crystal, the surface finish is not perfect and the slight damage in the polishing scratches can be seen in the EBSD scan, which interpreted the different regions between the scratches as different grains with slightly different orientations (Figure 4). When the orientations of all the "grains" identified by the EBSD are plotted on an inverse pole figure, it can be seen that there is a slight spread in orientations around (889) with data points in other areas of the figure are noise from the scratched regions (Figure 5). The average orientation of the sample surface was determined to be (889) with the <81$\bar{8}$> direction parallel to the vertical direction in the image (Figure 4). The sample is known to have the <101> direction along the edge that is identified as <81$\bar{8}$>, so the 5 degrees difference in the rotational orientation of the plane identified by EBSD is likely due to a slight rotation in the mounting of the sample in the instrument.

Connecting this information with the difference in hardness with rotation, the 0 degrees indentation in Figure 3 would have essentially the same rotational orientation in Figure 4, with the diagonals vertical and horizontal on the page. This orientation of the indentation had the highest hardness value. For the 0 degrees indent, the diagonals of the hardness indenter would have been essentially parallel to [101] family directions on the sample surface. For the other orientations of the indenter, the diagonals would not have been aligned with a principle direction on the sample surface.

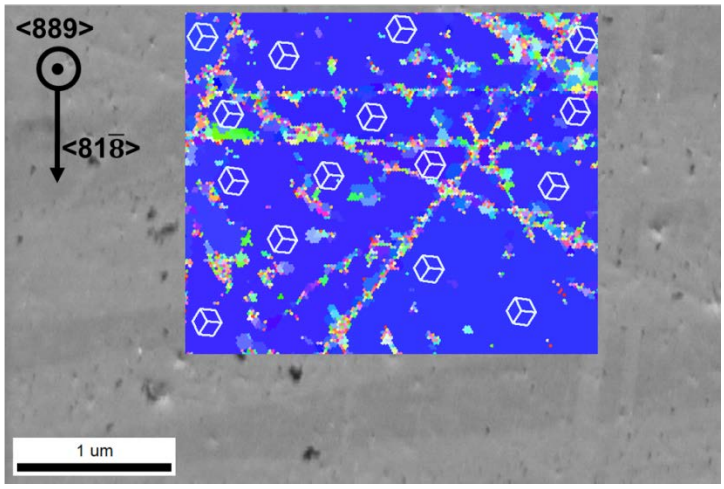

Figure 4. EBSD revealed the surface plane on the SCW sample to be (889).

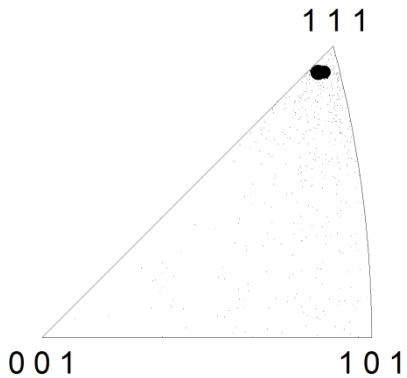

Figure 5. The large spot on the EBSD inverse pole figure for the SCW sample shows the orientation of the face of the sample to be approximately (889), while the smaller data points in other regions of the figure are noise from the scratched regions of the sample.

REFERENCES

[1] Y. Katoh, J.L. McDuffee, Fusion Materials Semiannual Progress Report for Period Ending June 30, 2013, DOE/ER-0313/54, 229-232.