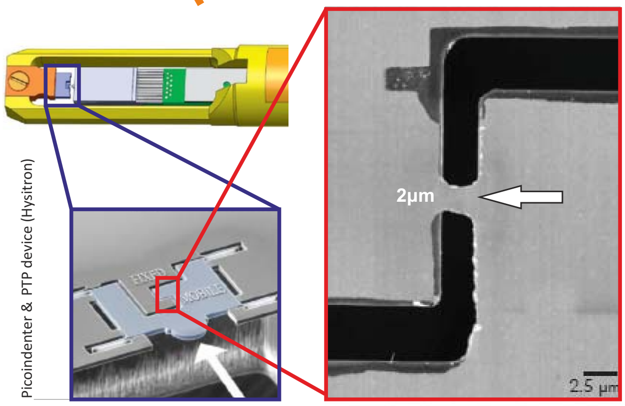
In-Situ Plastic Deformation of Nano-Crystalline Thin Films

Understanding the deformation mechanisms of nanocrystalline metals by the combination of in-situ straining and ASTAR

topspin



Nanocrystalline materials exhibit superior mechanical properties such as hardness, strength and fatigue, compared to their coarse-grained counterparts. However, due to strain localization and low strain hardening, nanostructured metals and alloys often show poor ductility. To correlate deformation mechanisms to grain orientation and size changes, a new approach of imaging while deforming a thin film in tension using a Picoindenter Push-to-Pull (PTP) (Hysitron) device was developed. Automated crystal orientation mapping in TEM using ASTAR - TopSPIN software and DigiSTAR device was applied to quantify microstructural changes at high resolution.

Gold thin films were deposited on carbon coated mica by RF magnetron sputtering using a target of Au with 99.99% purity. The thin films were transfered onto the PTP, cut into a dog bone shaped tensile test sample (see above image) and fixed to the PicoIndenter sample mount. A maximum final strain of 9.7%, which was measured by image correlation, was applied with a nominal strain rate of $6x10^{-4}$. At the end of each displacement ramp, 45 min. hold segments were allowed for orientation mapping acquisition. Two distinct regions were observed during loading, Fig. 1: initial straining up to 4.5% did not show any significant load increase indicating that the initially bent film was unbending (unfolding or straightening), and then the load increased rapidly indicating that the film is under tensile stress.

The challenge:	*in situ* deformation of nanocrystalline metals to investigate the deformation mechanisms active during loading
Solution:	ASTAR -TopSPIN precession diffraction & *in situ* straining inside the TEM using the PTP and Picoindenter from Hysitron

Even though the global grain size analysis initially showed no significant increase in grain size, local analysis of the orientation maps by ASTAR revealed that individual grains started deforming plastically already during the early stages of loading. The orientation maps showed that big grains grow by "eating" small grains already during "unbending". The size of grain 1 in Figure 2 decreased by approximately 6% during the "unbending" stage, which was followed by another 20% shrinkage during the "loading" stage. Furthermore, it was observed that twinning and detwinning occurred simultaneously in different grains throughout the deformation experiment, and grain rotation of individual grains was observed during later stages of straining to accommodate the deformation.

Experimental Data

TEM type: Tecnai F20
Map resolution: 3 nm
Scanned area: 1.38 x 1.38µm

Crystal Structure

Au: Fm-3m cubic
a = 4.08 Å

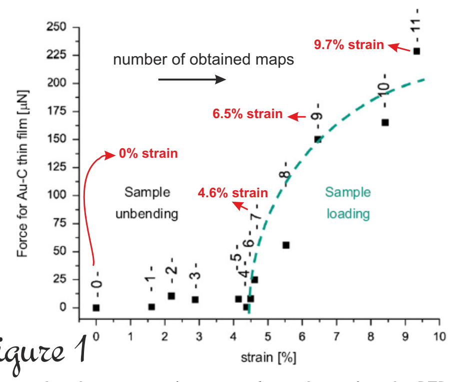
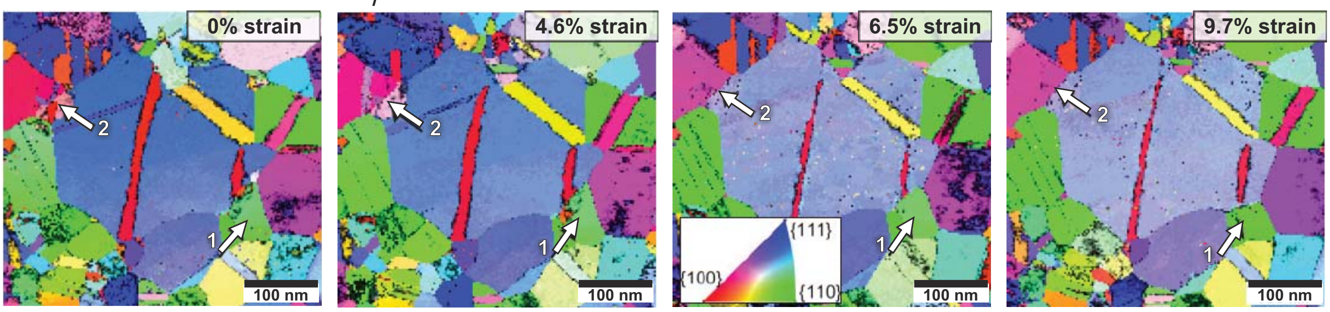


figure 1 Load versus strain curve after subtracting the PTP contribution. Strain percentage corresponding to fig 2 is shown

figure 2 Microstructural evolution with increasing tensile strain indicates smaller grains (indicated by white arrows) are merging with the large blue grain. Inset shows color code of crystal orientation



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