Direct Observations of Small Scale Plasticity by a New In-situ Diffraction Technique

In the classical picture plasticity in metals is mediated by dislocation nucleation, propagation and multiplication mechanisms, determining the strength of metallic structures. Recently it has been revealed that strengthening in a single crystal can be achieved by simply reducing the object dimensions to the micron or submicron range [1], hereafter referred to as "*smaller is stronger*". In such experiments single crystalline metallic volumes with dimensions of only a few microns are compressed uni-axially and an inverse scaling of strength with the pillar diameter was observed, questioning classical deformation theories that do not incorporate length scale dependencies. The suspicion that structural defects, i.e. deviations from perfect crystalline structures would play an important role in the *smaller is stronger effect*, especially since samples are usually made using ion sputter techniques, could not be verified because of the lack of an appropriate measuring technique. Ex-situ diffraction experiments on undeformed micro pillars demonstrated preexisting strain gradients present in micro sized pillars [2].

In "*Time resolved Laue diffraction of deforming micro pillars*" we demonstrate that real-time micro-diffraction goes well beyond the current measurement techniques, providing the detailed dynamics of deformation mechanisms in micron sized Au pillars. Figure 1 shows the experimental setup (left) and the compression indenter above a sample row (right).

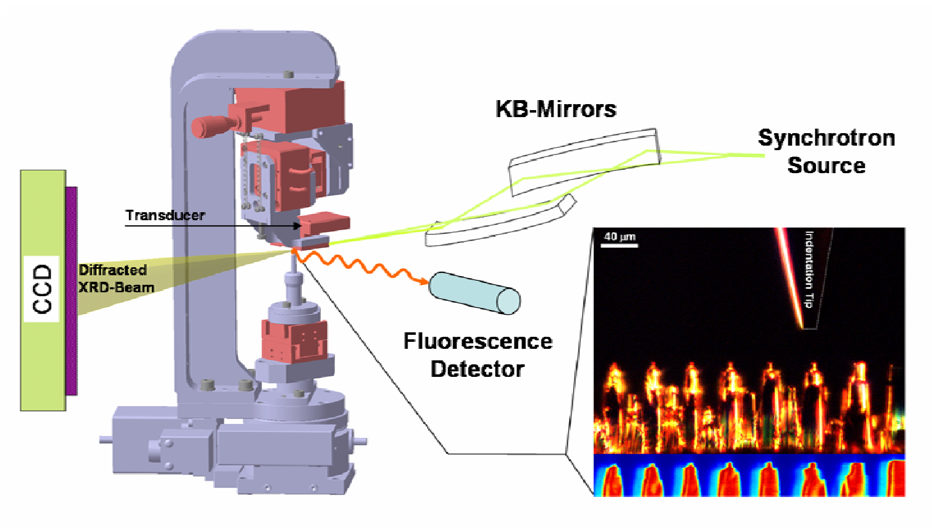

Figure 1: *Schematic of the experimental set-up, showing the micro compression device in the synchrotron beam line environment and as inset an optical image of a row of Au pillars with diameters ranging from 10 to 2 µm from right to left. Also visible in the inset is the approaching flat-punch indenter and the X-ray fluorescence map of the pillar row.*

The dynamics of the Laue patterns demonstrate the occurrence of crystal rotation, which prior to these finding was not addressed in micro compression[#]. Additionally is could be shown that increased strengthening of smaller pillars can be explained by plasticity on a slip system that is geometrically not predicted but selected because of the character of the preexisting defect structure. Our in-situ diffraction observations are in good agreement with post-mortem scanning electron microscopy that shows multiple slip lines on the smaller samples, but geometrically predicted slip lines on the larger samples. All samples had identical initial crystallographic orientation.

Time resolved Laue diffraction presents a different picture on the "*smaller is stronger*" paradigm, questions the dislocation starvation theories [3] and urges the use of in-situ methods to study small scale plasticity, providing the correct input for the development of predictive mesoscopic models. This unique technique is the only way to exclude pre-existing micro-structural inhomogeneities that blur the understanding [4] of the reported size effect on metallic micro pillars and will in the future provide valuable contribution to its understanding.

References

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Publications

- **Time-Resolved Laue Diffraction of Deforming Micropillars**
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[#] Movies on Laue spot dynamics can be found at
http://netserver.aip.org/cgi-bin/epaps?ID=E-PRLTAO-99-002738

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