INITIATION OF FATIGUE DAMAGE IN ULTRA-FINE GRAINED THIN FILMS: SCHMID, TAYLOR OR HALL-PETCH?

Oleksandr Glushko, Erich Schmid Institute, Leoben, Austria
oleksandr.glushko@oeaw.ac.at

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The evolution of fatigue damage in metallic films is usually described by several subsequent stages. First, the dislocation slip induces formation of slip steps and slip bands. Application of further cyclic mechanical load leads to formation of extrusion/intrusion couples and, finally, crack propagation. Although this general description of the fatigue damage development is well established and can be generally applied to different materials, surprisingly little is known about the very early stage of fatigue damage initiation especially for ultra-fine grained (UFG) and nanocrystalline thin films. From the point of view of classical plasticity theory, the plastic slip should occur first within most favorably oriented grains with the highest resolved shear stress that corresponds to the lowest Taylor factor or the highest Schmid factor. The core question which this presentation will try to address can be formulated as following: is it possible to predict where the fatigue damage will be initiated for a given UFG thin film with a given microstructure?

Polymer-supported thin Au and Cu films with UFG microstructures were subjected to cyclic strain with different amplitudes. By means of in-situ resistance measurements the cycle numbers corresponding to the very early stage of damage initiation were deduced. The surface and the microstructure of the films were then analyzed by the scanning electron microscopy and electron backscatter diffraction (EBSD).

The very early stage of damage initiation in 250 nm thick gold films with log-normal grain size distribution and strong (111) texture is demonstrated in Fig. 1. The enlarged picture shows clear slip steps, extrusions and a crack which is initiated inside a single large grain. The EBSD analysis shows that the damage initiation sites are the large (in comparison to the rest of the film) grains which have neither a low Taylor factor nor a high Schmid factor. The damage initiation in these gold films is a two-step process: first the room-temperature grain coarsening occurs and then the slip bands, extrusions and cracks are formed within the coarsened grains. The very early stage of damage initiation in 250 nm thick Cu films with bi-modal distribution of initial grain sizes is shown in Fig. 2. The EBSD analysis reveals that the observed sparsely distributed extrusions are formed within the larger grains with preferable (100) orientation normal to the surface. These grains, again, have neither a low Taylor factor nor a high Schmid factor in comparison to the surrounding grains.

By considering further examples of UFG thin films it is suggested that the local grain size plays more important role for the initiation of fatigue damage than the local grain orientation. According to the Hall-Petch relationship, larger grains yield at lower stress value and thus act as damage initiation sites. Additionally, the role of twin boundaries and grain boundary migration phenomenon will be discussed in the context of fatigue damage initiation.

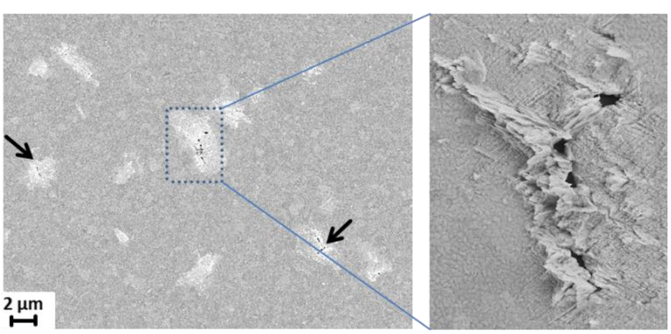

Figure 1 – Fatigue damage initiation in 250 nm thick polymer-supported Au film. The enlarged picture on the right shows extrusions and a crack inside a single grain. The arrows show further examples of crack initiation sites.

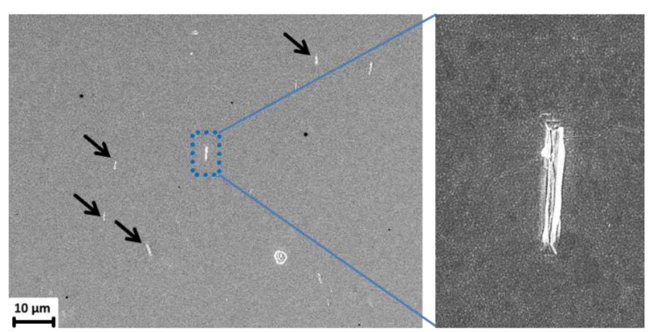

Figure 2 – Fatigue damage initiation in 250 nm thick polymer-supported Cu film. The enlarged picture on the right shows a single extrusion/intrusion couple. The arrows show further examples of crack initiation sites.