Ex- and in-situ investigation of dislocation cell formation during uniaxial compression of copper single crystal

Sándor **Lipcsei** [a], *Szilvia* **Kalácska** [b,c], *Dávid* **Ugi** [a], *Péter* **Ispánovity** [a], *István* **Groma** [a]

[a] *ELTE, Eötvös Loránd University, Department of Materials Physics, 1117 Budapest, Pázmány Péter sétány 1/A, Hungary*

[b] *Empa, Swiss Federal Laboratories for Materials Science and Technology, Laboratory of Mechanics of Materials and Nanostructures, CH-3602 Thun, Feuerwerkerstrasse 39., Switzerland*

[c] *CNRS, UMR 5307 LGF, Mines Saint- Étienne, Centre SMS, 158 cours Fauriel 42023 Saint-Étienne, France*

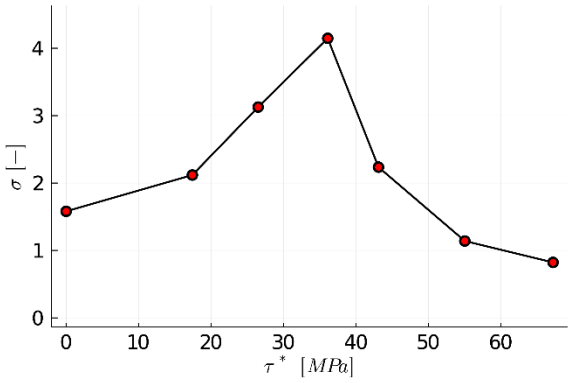

Figure 1: The average dislocation density fluctuation has a sharp maximum at stress level corresponding to the transition between the 2nd

The formation of dislocation cell structures during uniaxial compression in FCC metals is already studied in details both experimentally [1, 2] and theoretically [3, 4, 5, 6]. In the last decade, however, with the development of the *high resolution electron backscatter diffraction (HR-EBSD)* [7, 8] a new possibility arisen in the qualitative and quantitative analysis of dislocation cells, beside TEM and x-ray line profile (XRD) analysis.

In the first part of the work presented we report XRD results on the statistical properties of dislocation ensembles obtained on the surface of bulk copper single crystals deformed uniaxially along the [100] crystallographic direction. Results obtained (Fig.1) are in agreement with the ones reported earlier by I. Groma et. al. [9]. Applying the new HR-EBSD measurement technique the stress and GND density maps (Fig.2) were also analyzed, not only qualitatively, but also

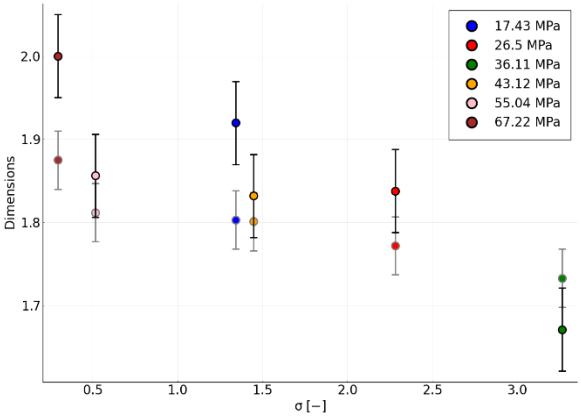

Figure 3: Hausdorff-dimension (gray marker stroke) and correlation-dimension (black marker stroke) versus the average dislocation density fluctuation.

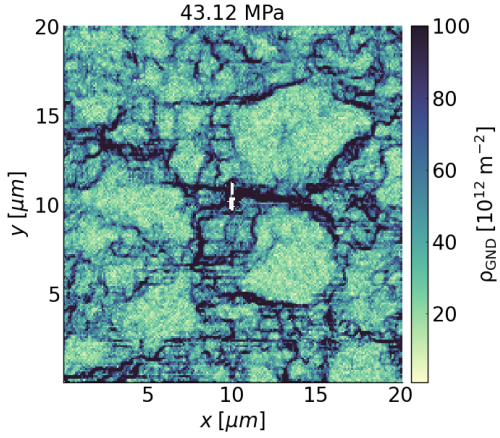

Figure 2: GND density map obtained by HR-EBSD measurement on the surface of the uniaxially compressed copper single crystal;

quantitatively. Fractality of dislocation cell structures was studied, yielding high correlation between the average dislocation density fluctuation and Hausdorff and correlation dimensions (Fig.3). Finally, the dominant Burgers-vectors were also studied, according to a novel method by Zoller et al. [10] (Fig.4).

In the second part of the presentation the results of the in-situ HR-EBSD investigations on the dislocation cell structure formation in compressed micropillars are reported. With the help of *focused ion beam (*FIB) technology different sized copper pillars were fabricated with [100] orientation. Using our custom made nanoindenter we were able to carry out the compression of micropillars and HR-EBSD investigation step-by-step at different strains. With this setup we could study how the size of the pillars influences the dislocation cell formation. Moreover, with FIB slicing methodology [10,11] we could also study the final 3D dislocation structure.

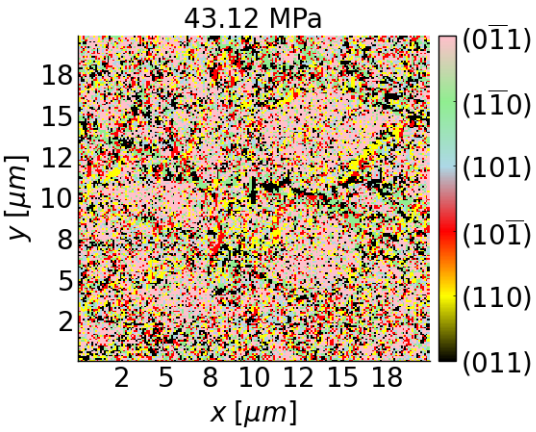

Figure 4: The calculated dominant Burgers-vector map yields similar type Burgers-vector dominancy for regions with lower dislocation content and any other Burgers-vector for regions with high content;

Bibliography

1. Ungar, T., Mughrabi, H., Rönnpagel, D., & Wilkens, M. (1984). X-ray line-broadening study of the dislocation cell structure in deformed [001]-orientated copper single crystals. *Acta Metallurgica*, *32*(3), 333-342.
2. Mughrabi, H., Ungar, T., Kienle, W., & Wilkens, M. (1986). Long-range internal stresses and asymmetric X-ray line-broadening in tensile-deformed [001]-orientated copper single crystals. *Philosophical magazine A*, *53*(6), 793-813.
3. Mughrabi, H. (1983). Dislocation wall and cell structures and long-range internal stresses in deformed metal crystals. *Acta metallurgica*, *31*(9), 1367-1379.
4. Hähner, P., & Zaiser, M. (1999). Dislocation dynamics and work hardening of fractal dislocation cell structures. *Materials Science and Engineering: A*, *272*(2), 443-454.
5. Hähner, P. (2002). Statistical mechanics approach to dislocation cell patterning. *Scripta materialia*, *47*(6), 415-421.
6. Groma, I., & Bakó, B. (2000). Dislocation patterning: from micro-to mesoscale description. *Physical review letters*, *84*(7), 1487.
7. Kalácska, S., Groma, I., Borbély, A., & Ispánovity, P. D. (2017). Comparison of the dislocation density obtained by HR-EBSD and X-ray profile analysis. *Applied Physics Letters*, *110*(9), 091912.
8. Kalácska, S. (2017). Experimental investigation of plastic deformation induced dislocation systems.
9. Szekely, F., Groma, I., & Lendvai, J. (2001). Statistic properties of dislocation structures investigated by X-ray diffraction. *Materials Science and Engineering: A*, *309*, 352-355.
10. Zoller, K., Kalácska, S., Ispánovity, P. D., & Schulz, K. (2020). Microstructure evolution of compressed micropillars investigated by in situ HR-EBSD analysis and dislocation density simulations. *arXiv preprint arXiv:2011.08587*.
11. Kalácska, S., Ast, J., Ispánovity, P. D., Michler, J., & Maeder, X. (2020). 3D HR-EBSD characterization of the plastic zone around crack tips in tungsten single crystals at the micron scale. *Acta Materialia*, *200*, 211-222.