In situ TEM straining: understanding the behavior of metals and alloys from the motion of their dislocations

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Abstract The mechanical properties of metals and alloys are dictated by the individual and collective behavior of dislocations but very few techniques allow to observe them dynamically. *In situ* TEM straining is among those, and surprisingly, its use has remained rather confidential over the last 6 or 7 decades.

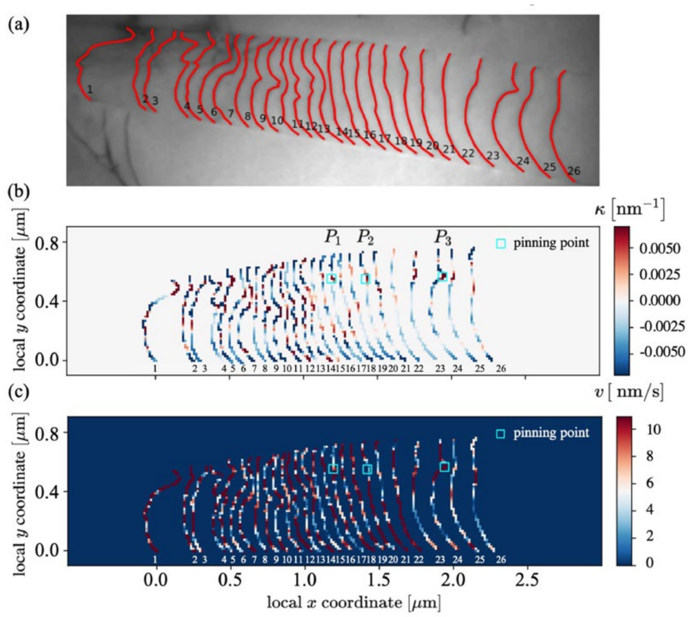

Figure 1 - *Machine Learning analysis of the dislocation position (a), local velocity (b) and local curvature of dislocations moving in a Cantor High Entropy Alloy at 100K. In situ TEM [1].*

The recent advent of *in situ* TEM nanoindentation holders in conjunction with the renewed interest in micro-and nanoscale plasticity have shed light on the possibilities of this technique, sometimes at expenses of the legitimate doubts cast on the intrinsic artifacts linked to *in situ* methods (sample size, image forces, interaction with the high voltage electron beam …)

Being able to measure a force and a deformation on tiny or complex-shaped samples has also become a stand-alone goal of such *in situ* studies, often missing the real opportunities that represent a detailed analysis of the dislocation behavior [2]. We will show here that such analysis, either using classical elasticity theory or by taking advantage of more recent machine learning methods can lead to significant advances in understanding the mechanical properties of new materials such as high entropy alloys, pure metals in the sub-micron scale, or even semiconductors. Dislocations are the ultimate probe to detect obstacles, interaction with the lattice. Observing and quantifying their displacement in a given slip plane thus allows the determination of a near atom-scale landscape (Fig. 1), rough or smooth regarding dislocation motion, free of any *a priori* hypothesis [1].

References

[2] C. Zhang, H. Song, D. Oliveros, A. Fraczkiewicz, M. Legros, S. Sandfeld, *Acta Materialia,* 241 (2022) 118394.

[1] M. Legros, F. Mompiou, D. Caillard, *Nature Materials*, 23 (2024) 20-22.