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High Resolution Mapping of Diffusion Characteristics in General Microstructures

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General microstructures possess multiscale features (~10^{-10} m – 10^{-3} m) comprised of a vast number of atoms, and their properties cannot be directly reconstructed by the characteristics of their constituents. Therefore, a general quantitative understanding of microstructure-property-relationships remains elusive. To address this challenge, we propose local deformation mapping (LDM) as a characterization technique to determine mass transport characteristics.

LDM is capable of probing microstructures with a resolution all the way down to ~50 nm^2 over macroscopic dimensions of ~cm^2, resulting in ~10^{12} simultaneous data points. This is experimentally achieved by pressing a nanomold with an array of nanopores against the microstructure, creating local stress gradients that force the material from the microstructure into the nanopores. The diffusing or slipping material from the microstructure fills these nanopores to form an array of nanorods on top of the microstructure. The nanorod array represents the microstructure's local plastic response which is spatially separated from the underlying microstructure[1]. This separation enables sensitive kinetic and chemical characterization of this mass transport response. Collectively, these nanorods constitute a set of ~10^{12} measurements forming the deformation response map generated in a single step. The local variations in a microstructure (due to the presence of the various microstructural features) which affect the local plastic deformation response are captured as the variation in the nanorod length L(x,y) map created via LDM. We then use the analytical models developed to transform these L maps to the local material transport properties map. Thus, we reveal spatial (or local) microstructure-property variations by mapping these transport properties and their variations onto the underlying microstructural features. Thus, these characteristics, such as diffusivity, and dislocation density and velocity, which contribute to the overall mechanical response of the microstructure, are mapped as a function of the local microstructural features with high-resolution[2].

We focus primarily on creating local diffusivity maps related to the high homologous temperature deformations. We hypothesize and then use LDM to reveal the differential responses of various microstructural features, including different types of grain boundaries, grain orientations, various phases, and chemical segregation. As particular examples, we demonstrate one-step determination of grain boundary diffusivity for a polycrystalline microstructure, and the mapping of phase boundaries which have revealed fast diffusion microstructural features for eutectic phase containing alloys[1, 3].

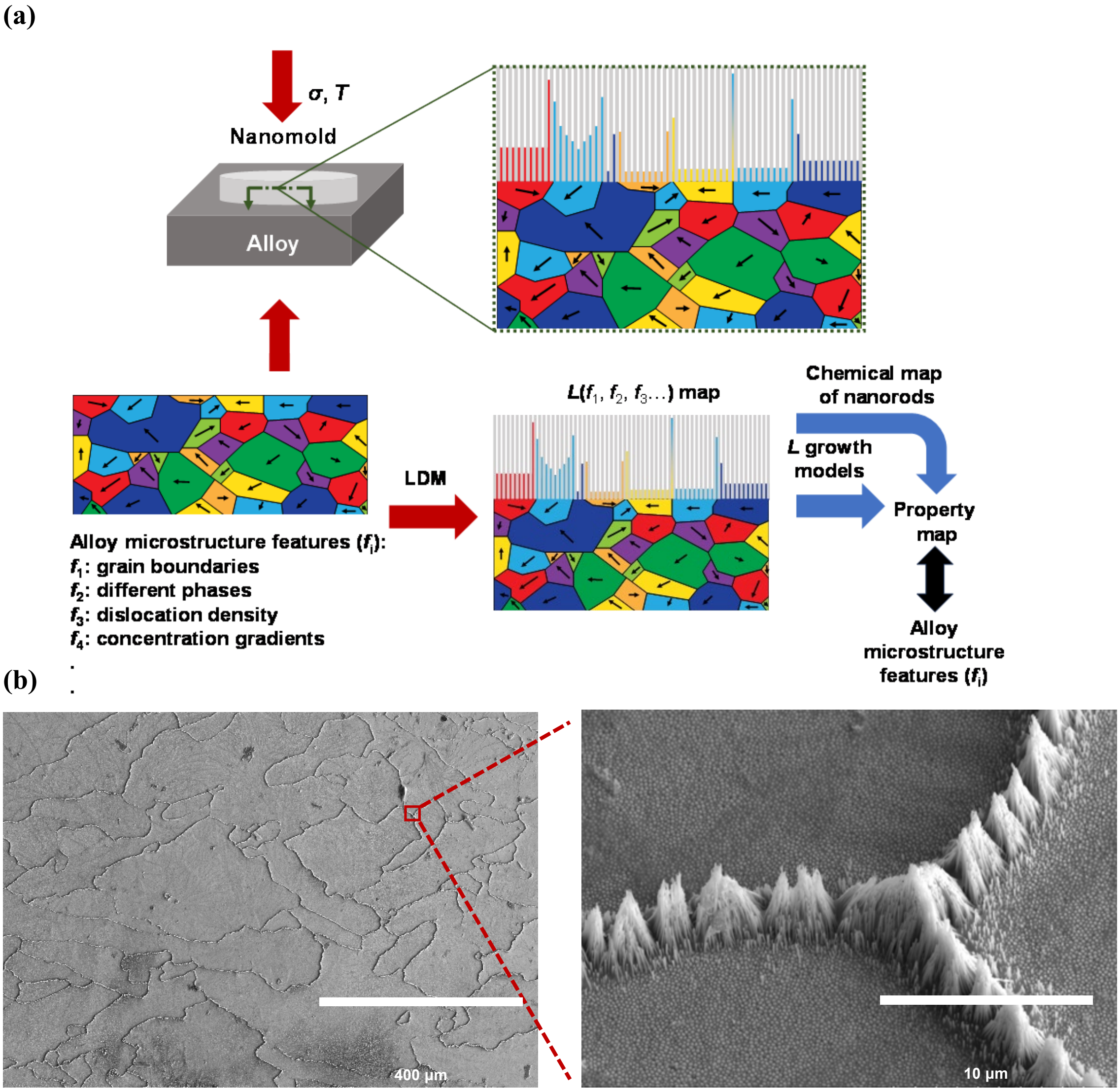

Fig. 1. (a) Local Deformation Mapping (LDM) involves pressing a nanomold (grey) onto a crystalline microstructure (alloy). The nanomold induces ~10^{12} simultaneous local deformation spots onto a microstructure (~cm^2). A general microstructure may contain several types of features including different phases, grain orientations, grain and phase boundaries, etc. The growth rate of nanorods depends on the material characteristics of the particular microstructure, which can result in a variation in the length of the nanorods. Thereby, $L(t)$ of the nanorods can then be used to extract material-related D values, mapped back onto the microstructural features. **(b)** LDM results from a polycrystalline Ag microstructure with SEM images showing long nanorods along the grain boundaries of the sample.

References

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