Observation of shear transformation zone in metallic glasses

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The promising application of metallic glasses is limited by their lack of toughness and catastrophic failure under plastic deformation [1-2]. Shear transformation zones (STZs) are known as transient defects in metallic glasses (MGs) and are believed to be responsible for the large-scale plastic deformation [3]. Understanding STZs is quintessential to establish a general theory of the nature of glasses and their mechanical deformation for a larger-scale application of metallic glasses. Here, we carried out a detailed structural investigation, i. e. nanoscale strain and local density mapping on deformed metallic glasses using a 4-dimensional scanning transmission electron microscope (4D-STEM) technique as shown in Figure 1a. Our approach considers the elliptic distortion of the amorphous diffraction ring under strain, and the area circled by the ring to quantify the relative atomic density and reveal their spatial-correlative variance. We experimentally imaged STZs and their surrounding quadrupolar strain field (Figure 1b-g). The STZs percolate through quasi-linear arrangement during the shear banding process (Figure 1g). We observed strong vortex features of the elastic fields between STZs, which further revealed a cross-talking behavior between STZs. The results provide an experimental visualization of the STZs and their interaction at the nanoscale. Our findings explain the microscopic origin of the plastic deformation of metallic glass.

Keywords: Metallic glass, Shear transformation zone (STZ), Shear band, 4-dimensional scanning transmission electron microscope (4D-STEM), Strain field

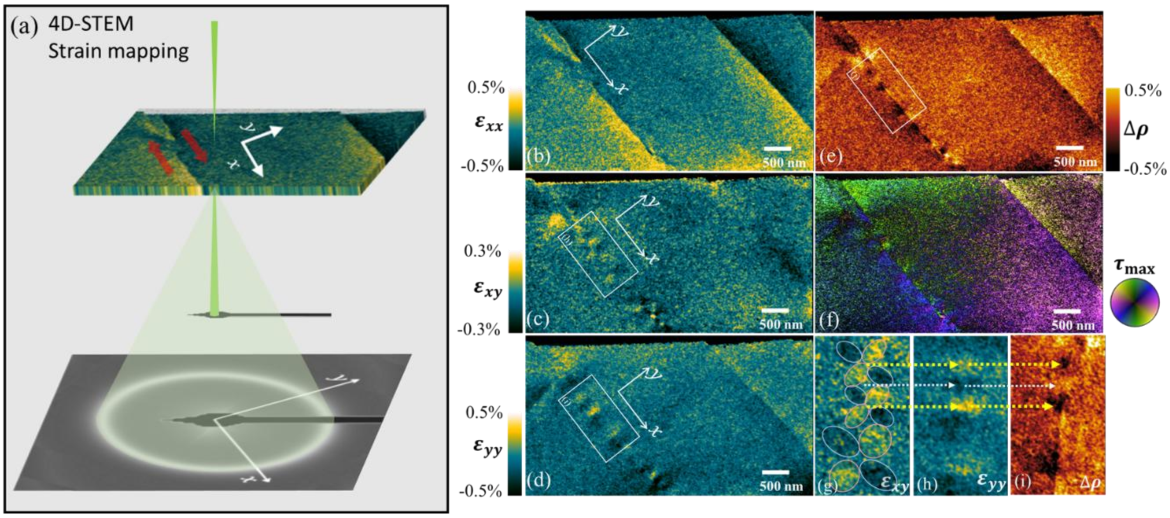

Figure 1: (a) Schematic illustration of 4D-STEM experiment setup used for this study. The spatially-resolved diffraction patterns are collected covering shear bands of a deformed MG. (b)-(i) Results obtained from deformed $Fe_{85.2}Si_{0.5}B_{9.5}P_4Cu_{0.8}$ MG ribbon, where (b)-(d) are strain components, (e) is density map, (f) is the maximum shear strain in vector map format, (g) is enlarged from the region of the white rectangle box.

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References:

[1] T.C. Hufnagel, C.A. Schuh, M.L. Falk, Deformation of metallic glasses: Recent developments in theory, simulations, and experiments, Acta Materialia, 109, 2016 375-393.
[2] C. Schuh, T. Hufnagel, U. Ramamurty, Mechanical behavior of amorphous alloys, Acta Materialia, 55, 2007, 4067-4109.
[3] D. Sopu, A. Stukowski, M. Stoica, S. Scudino, Atomic-Level Processes of Shear Band Nucleation in Metallic Glasses, Physics Review Letter, 119, 2017, 195503.