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A Novel Experimental Approach to Determine Density Changes in Shear Bands of Metallic Glass by Correlative Analytical TEM

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The deformation processes in metallic glasses are quite different from those in crystalline materials because there are no defects such as dislocations, twins or grain boundaries available that can act as deformation carriers for an easy flow mechanism. Deformation tests on metallic glasses have shown that the plastic flow is confined to narrow regions called shear bands when the applied load exceeds the elastic range [1]. Such shear bands are locally softer than the surrounding matrix allowing the accommodation of external shear stresses via slip. Hence, unraveling the mysteries of shear bands can lead to a better understanding of the underlying physics of plastic deformation of metallic glasses. It is common belief [2] that such shear bands are associated with a structural change like local dilatation, implying a volume change and thus a change in density. An important issue is thus the quantification of free volume inside shear bands.

Here, we describe a novel experimental approach for measuring density changes between shear bands and their surrounding amorphous matrix in metallic glasses [3]. We use the relation of the dark-field intensity I/I_0 (scattered electrons collected by an high-angle annular dark-field (HAADF) detector) and the mass thickness according to $I/I_0 \sim \rho^*t$. The foil thickness, t, is obtained from the low-loss region of the electron-energy loss spectrum, which is acquired simultaneously to the HAADF signal, using a refractive index-corrected Kramers-Kronig sum rule. The study is completed by energy-dispersive X-ray (EDX) and nano-beam diffraction analyses.

We found that the sheared zones in melt-spun $Al_{88}Y_7Fe_5$ ribbons can exhibit either increased or decreased densities, ρ, relative to the matrix (Fig. 1). We associate the decrease in density mainly with an enhanced free volume in the shear bands and the increase in density with concomitant changes of the local chemical composition. This interpretation is further supported by changes in the zero loss/plasmon signal originating from such sites (Fig. 2). In addition, nano-beam diffraction shows that the local order in both parts of the shear band varies. Whereas the high-density shear bands exhibits similar medium range order as the matrix, regions of extended medium range order/nanocrystals are embedded in the low-density shear bands. The limits of this new approach for measuring density differences are discussed.

References:

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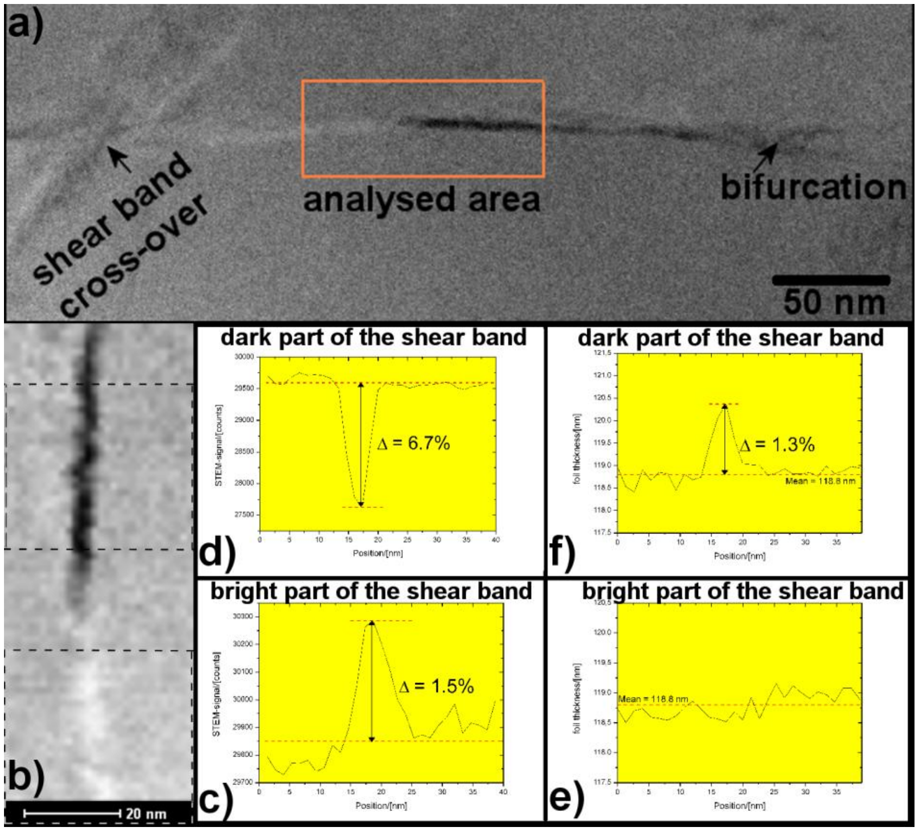

Figure 1. (a) Z-contrast (HAADF-STEM) image (overview) showing characteristic shear bands of a cold-rolled $Al_{88}Y_7Fe_5$ melt-spun ribbon. A cross-over of shear bands is seen on the left side. The horizontal shear band displays a contrast change from bright to dark in the box (analyzed area) and a bifurcation at the end. (b) HAADF detector signal corresponding to the box (analyzed area) shown in (a) rotated 90° anti-clockwise. (c, d) Averaged profiles of the HAADF detector signal from the boxed areas indicated in (b). (e, f) Averaged profiles of the foil thickness from the boxed areas indicated in (b).

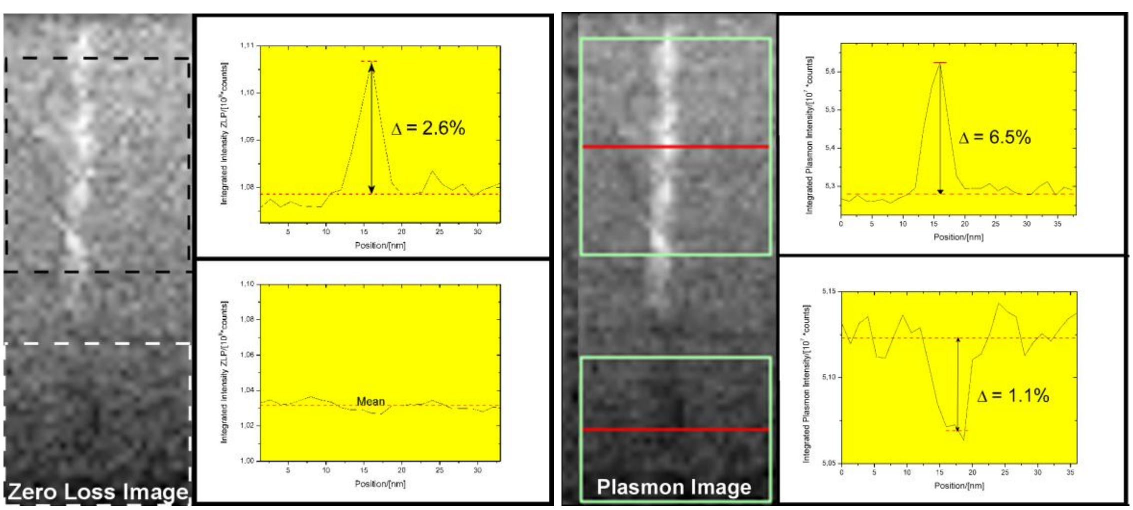

Figure 2. (a) Image of the zero loss peak (ZLP) extracted from the individual EEL spectra and averaged profile as indicated by the boxes. Note the contrast inversion compared to the HAADF detector signal in Fig.1. (b) Image of the plasmon signal extracted from the individual EEL spectra and averaged profile as indicated by the boxes.

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