Correlative analytical transmission electron microscopy applied to the characterization of deformation features in amorphous materials

Rösner, H.[1], Hieronymus-Schmidt, V.[1,2] and Wilde, G.[1,2]

[1] Institute of Materials Physics, University of Muenster, Germany, [2] Wilhelm-Klemm-Str. 10, 48149 Muenster, Germany

When an external stimulus such as stress is applied to a material, it deforms elastically and when strained beyond the yield point, plastically. While the deformation mechanisms in crystalline matter are well understood in terms of dislocations and twinning, a similar understanding of deformation in amorphous materials, e.g. bulk metallic glasses (BMG), is incomplete. Shear transformation zones (STZ) were proposed by Argon as carriers for the plasticity in metallic glasses [1]. Macroscopically shear events are noticed as shear steps when penetrating through the surfaces of the deformed BMG. Such deformed regions are called shear bands. It is currently believed that shear bands are associated with a structural change such as local dilatation caused by the local stress fields, implying a volume change and thus a change in the atomic density, ρ [1-4]. An important issue is therefore the local quantification of free volume or density inside shear bands. Recently, the local density was quantified in shear bands of various metallic glasses using the intensity ratios of matrix, I_M, and shear band, I_{SB}, taken from high angle annular dark field scanning transmission electron microscopy (HAADF-STEM) micrographs [5]. These analyses showed alternating high and low density regions along the propagation direction of the shear bands (Fig.1) [5-7]. Thus, densification, in addition to the expected dilatation, also occurred as a response to shear deformation. The structural analysis was supplemented by electron-energy spectroscopy (EELS), energy-dispersive X-ray analysis and fluctuation electron microscopy (FEM) revealing characteristic signatures for different parts of the shear bands. Especially, FEM analyses provided clear evidence that the short- and medium range-order was changed in the shear band segments suggesting that shear alters the packing of tightly bound short- or medium-range atomic clusters. We propose a model using an alignment of quadrupolar stress field perturbations for the plastic events to describe these new observations quantitatively for a series of glass forming alloys with vastly different fragility, kinetic stability and deformability in compression suggesting a generic deformation behavior for all amorphous solids in general.

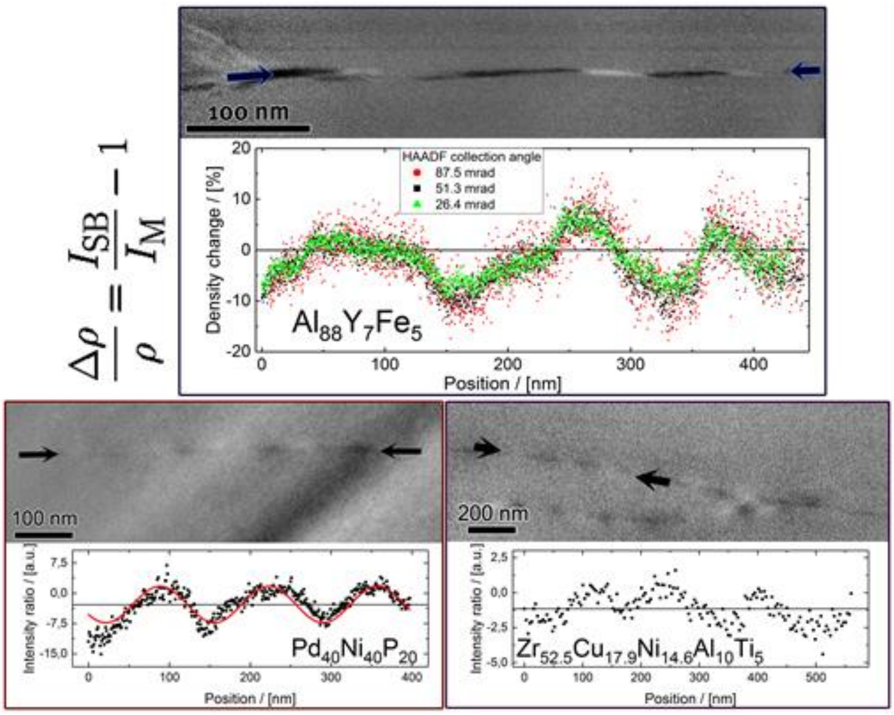

Fig.1. Alternating (periodic) high and low density regions in shear bands for different metallic glasses.

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