Medium-range ordering in Mg–Cu–Gd glasses induced by annealing at the glass transition temperature and high pressure

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Abstract
The $Mg_{61}Cu_{28}Gd_{11}$ (at.%) metallic glass, characterized by a glass transition temperature of approximately 196 °C, was subjected to high-pressure/high-temperature treatment in order to investigate the early stages of structural reorganization preceding crystallization. The amorphous alloy was annealed in the range of, and above, the glass transition temperature, e.g., at 200 and 300 °C under a pressure of 7.8 GPa. Structural characterization of the recovered samples was performed by high-angle annular dark-field scanning transmission electron microscopy and high-resolution transmission electron microscopy at atomic resolution. HAADF-STEM imaging revealed nanoscale motifs enriched in Mg–Gd, indicating local chemical heterogeneity within the amorphous matrix. HRTEM analyses, supported by fast Fourier transform and inverse fast Fourier transform processing of selected micrographs, demonstrated the coexistence of distinct glassy states after pressure–temperature treatment. Additional analysis of selected-area electron diffraction patterns was performed to evaluate changes in medium-range order. Intensity profiles extracted from SAEDPs, together with the corresponding pair distribution function analysis, revealed variations in the width and shape of the diffuse halo rings. These changes indicate modifications in the degree of medium-range ordering within the amorphous structure, allowing the pressure–temperature-induced structural rearrangement to be distinguished even in the absence of detectable crystallization. The results show that high pressure and temperature promote structural reorganization in Mg–Cu–Gd metallic glass through local densification, chemical partitioning, and the formation of ordered amorphous motifs. A decrease in the effective glass transition temperature after high-temperature treatment further suggests a correlation between pressure-assisted densification mechanisms, enhanced medium-range ordering, and the thermal stability of the amorphous phase.

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