

NANOCRYSTALLIZATION PROCESS IN AMORPHOUS ALLOYS DURING SEVERE PLASTIC DEFORMATION AND THERMAL TREATMENTS

Zs. Kovács, P. Henits, S. Hóbor and Á. Révész

Department of Materials Physics, Eötvös Loránd University, Budapest, H-1518, P.O.B. 32, Budapest, Hungary

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Abstract. Nanocrystallization behaviour during severe plastic deformation and linear heating thermal treatment has been compared for $\text{Al}_{88}\text{Ce}_8\text{Ni}_5\text{Co}_2$ and $\text{Cu}_{60}\text{Zr}_{20}\text{Ti}_{20}$ metallic glasses. A short explanation is presented for the preferred formation of phases with small unit cell and small configurational entropy during severe plastic deformation.

1. INTRODUCTION

Metallic glasses are kinetically stabilized metastable materials. For several composition (e.g. $\text{Al}_{88}\text{Ce}_8\text{Ni}_5\text{Co}_2$ [1] and $\text{Cu}_{60}\text{Zr}_{20}\text{Ti}_{20}$ [2]) they exhibit multistage crystallization sequence upon thermally activating the kinetic barrier, accompanied with a simultaneous nucleation of several phases during the first crystallization step.

Recently, severe plastic deformation induced nanocrystallization, e.g. by high pressure torsion (HPT) has received enhanced attention [3]. It was found that these techniques can induce the precipitation of nanocrystals predominantly in shear bands [3]. These processes can promote fast atomic motion and so that permit the metallic glass to change its metastable state. There has been considerable debate in the literature on the formation of the deformation induced nanocrystals. Argon and Spaepen suggested that free volume generation in shear bands supports the local changes in short range order [4,5]. On the other hand, Liu and coworkers proposed that localized adiabatic heating is responsible for nanocrystal nucleation [6]. Nowadays, the interest is renewed about the adiabatic heating in shear bands [7,8].

Recently, it was demonstrated that thermally activated and HPT deformation induced nanocrystal formation result in different crystallization products in $\text{Al}_{88}\text{Ce}_8\text{Ni}_5\text{Co}_2$ amorphous alloy. Consequently, athermal nature of the deformation induced crystallization confirmed in this alloy [9].

2. EXPERIMENTAL

Ingots of $\text{Al}_{88}\text{Ce}_8\text{Ni}_5\text{Co}_2$ and $\text{Cu}_{60}\text{Zr}_{20}\text{Ti}_{20}$ were synthesized by induction melting a mixture of high purity (99.9%) metals. Fully amorphous ribbon was obtained using a single roller melt spinning technique in inert atmosphere. Ribbons were cut into small pieces (flakes) and then loaded between anvils of the HPT device. The shear deformation was performed by subjecting the flake to five whole rotations under hydrostatic pressure of 6 GPa. Microstructure was examined by a Philips X'Pert diffractometer (XRD) and a double crystal diffractometer with a fine focus rotating copper anode (Nonius, FR 591). Linear heat treatments were performed under argon atmosphere in Perkin Elmer DSC at a heating rate of 40 K/min. Further details on experimental background are given elsewhere [9,10].

Corresponding author: Zs. Kovacs, e-mail: kovacszs@metal.elte.hu

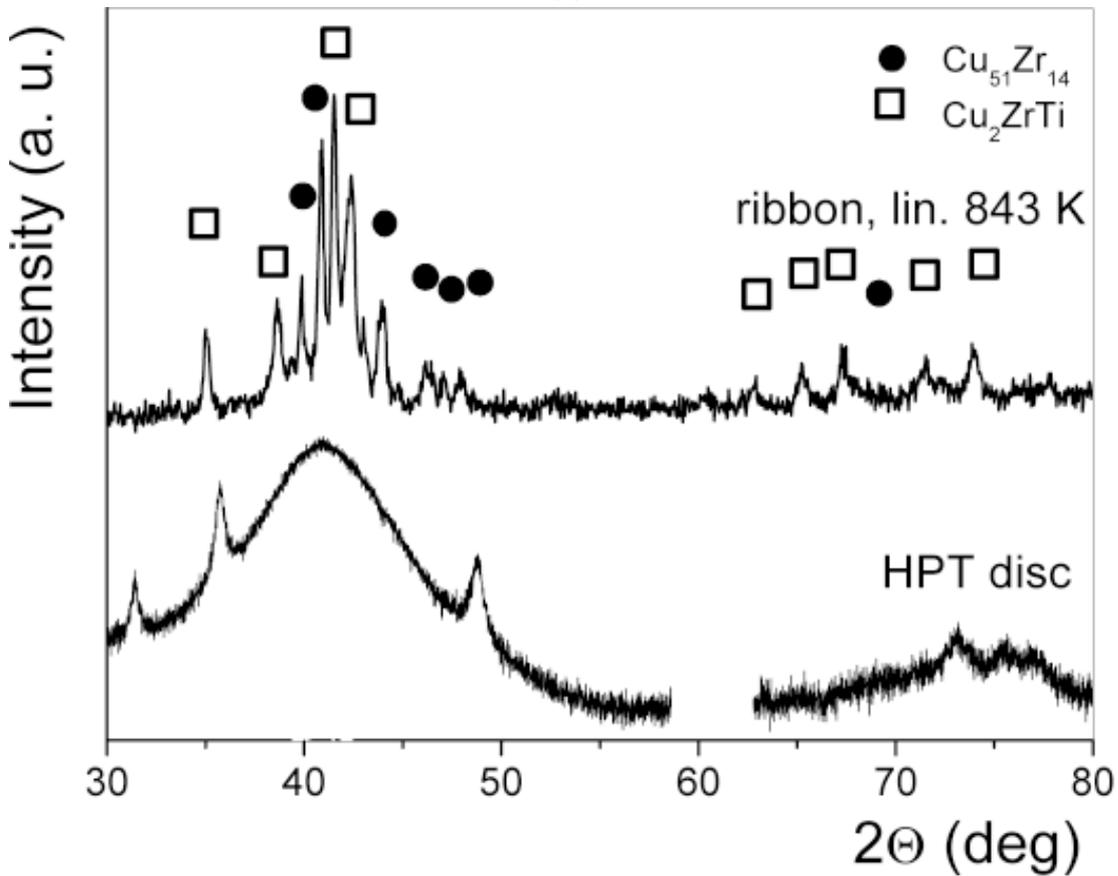
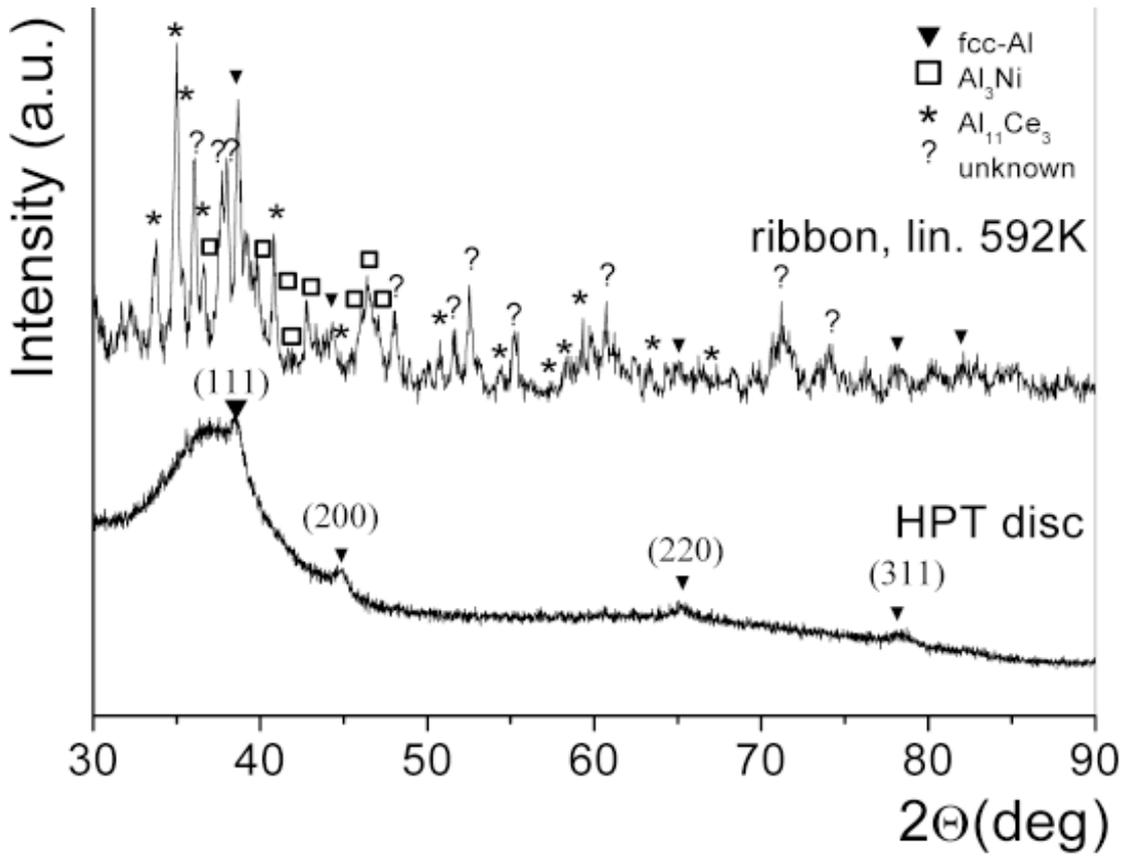


Fig. 1. XRD pattern of Al₈₈Ce₈Ni₅Co₂ (a) and Cu₆₀Zr₂₀Ti₂₀ (b) amorphous alloys obtained after linear heat treatment and HPT deformation.

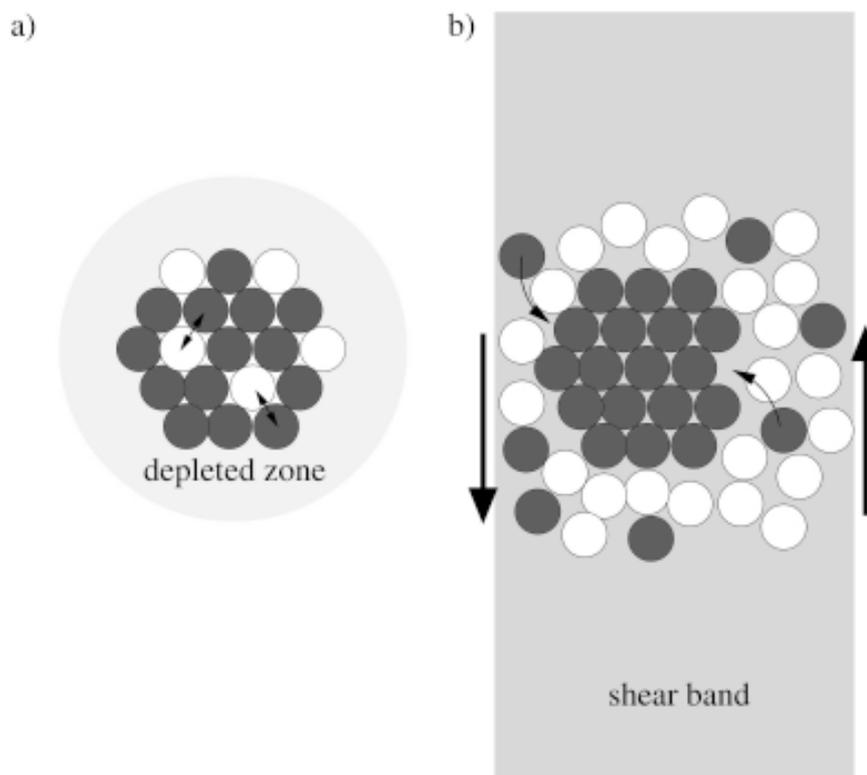


Fig. 2. Schematic view of the nanocrystallization process during a thermal treatment (a) and in a deformation shear band (b).

3. RESULTS AND DISCUSSION

Fig. 1 shows the XRD patterns corresponding to the $\text{Al}_{85}\text{Ce}_8\text{Ni}_5\text{Co}_2$ and $\text{Cu}_{60}\text{Zr}_{20}\text{Ti}_{20}$ metallic glasses devitrificated by high pressure torsion and by linear heat treatment experiments [9,10]. In the $\text{Al}_{85}\text{Ce}_8\text{Ni}_5\text{Co}_2$ alloy linear heating above the first crystallization peak (592K) shows the simultaneous formation of α -Al, orthorhombic $\text{Al}_{11}\text{Ce}_3$, orthorhombic Al_3Ni and unidentified metastable phase, while HPT deformation results in primary Al-precipitation (Fig. 1a). As seen in Fig. 1b, the $\text{Cu}_{60}\text{Zr}_{20}\text{Ti}_{20}$ alloy shows common precipitation of hexagonal Cu_2ZrTi and hexagonal $\text{Cu}_{51}\text{Zr}_{14}$ phases during linear heating, however, only Cu_2ZrTi with smaller unit cell appears in the HPT deformation [10]. Noteworthy, in both alloys nanocrystal formation follows a different route during severe plastic deformation from that during heat treatment, and prefers the formation of the phase with smaller unit cell and smaller configurational entropy.

Differences between the two devitrification processes are illustrated in Fig. 2. During heat treat-

ment thermally activated diffusion supports atomic motion and consequently crystalline growth, however, a depleted zone gradually forms around nanocrystals. Therefore, further atomic transport and crystalline growth are restricted in the metallic glass, but configurational redistribution of the atoms in the newly formed crystal is still permitted by the thermal activation (Fig. 2a).

During deformation atomic motion activated only in the shear bands is governed by external stresses and no further configurational redistribution of the atoms is possible inside the nanocrystals due to the low temperature (Fig. 2b). Consequently, the formation of the phase with the smallest configurational entropy is the most preferable among the phases allowed by the Gibbs free energy production.

4. CONCLUSIONS

Preferred formation of phases with small unit cell and small configurational entropy has been observed for $\text{Al}_{85}\text{Ce}_8\text{Ni}_5\text{Co}_2$ and $\text{Cu}_{60}\text{Zr}_{20}\text{Ti}_{20}$ metallic

glasses during high pressure torsion. The changes of the phase formation is explained by the lack of configurational atomic redistribution in the nanocrystals at low temperature during the deformation process.

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