

Glass and crystallization like transitions at low temperature in Zr-Cu based glasses by internal friction measurements

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Abstract. Low temperature β internal friction peak evolution upon thermal cycles shows two peculiar peaks similar to high temperature internal friction peak. The modulus softening associated to these peaks suggest a phase transformation phenomenon and the relaxation time τ_0 in order of 10^{-23} – 10^{-35} s, close to that observed in grains boundary sliding are due to interface motions in the amorphous structure under combined thermal and mechanical energies.

1 Introduction

Metallic glassy materials undergo anelastic relaxation phenomena as polymer with a low temperature internal friction (IF) β peak and high temperature internal friction α peak [1]. The latter occurs in the temperature range of the glass transition and crystallization of the glassy structure and usually exhibit anomalous relaxation time about $\tau_0=10^{-23}$ – 10^{-35} s [2]. These relaxation times ‘unreasonably’ low compared to that of the atomic diffusion relaxation time (10^{-13} s) are usually observed in cold-worked crystalline alloys and are characteristic of complex relaxation phenomena [3]. The occurrence of the low-relaxation times in $Zr_{57}Cu_{20}Al_{10}Ni_8Ti_5$ bulk glassy material (BMG) upon thermal cycling at low temperature, as well as the modulus softening, indicate phase transformation phenomena at low temperature through the α IF peak [4].

The purpose of this paper is to describe the complex relaxation in metallic glasses using the peculiar anelastic phenomena in $Zr_{57}Cu_{20}Al_{10}Ni_8Ti_5$ BMG. The complex relaxation is likely a composition of single atomic diffusion and interface motions similar to grain boundary sliding that is consistent with the high-activation energies and the low-relaxation times.

2 Experimental

Bulk amorphous $Zr_{57}Cu_{20}Al_{10}Ni_8Ti_5$ strip has been submitted to internal friction measurements on inverted torsion pendulum. The oscillation frequency is about 1 Hz and the default strain amplitude is about $5 \cdot 10^{-6}$. Various heating rate was adopted for the thermal cycling (TC). Details of the experimental conditions can be found elsewhere [4].

3 Results and discussions

Figs. 1 and 2 present the IF evolution of selected spectra on cooling and on heating at the same experimental conditions. The evolution of the β peak can be easily observed. On cooling (Fig.1), under the thermal IF cycling, the main, broad β peak splits in two peaks (I and II). Furthermore, the I peak shifts towards the lower

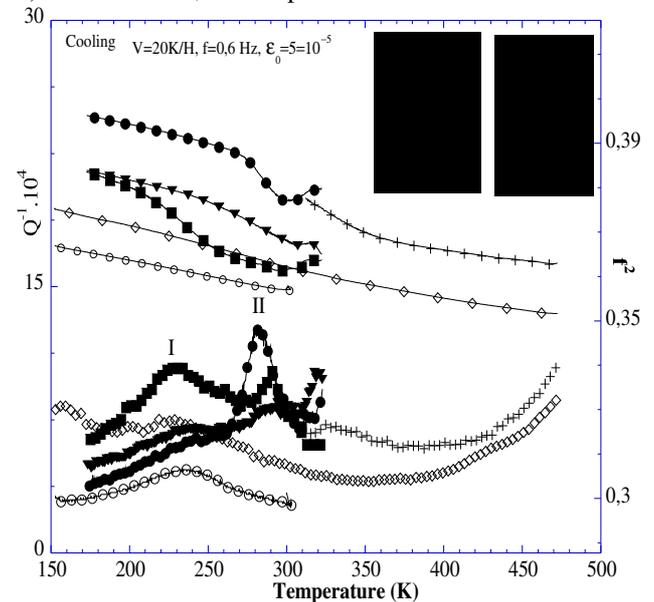


Fig. 1. Internal friction (Q^{-1}) spectra and modulus curves (E^2) of selected thermal runs on cooling.

temperature and the IF level and background increase compared to the first run peak. On heating (Fig.2), the two peaks split into two more stretched peaks separated by a higher transition peak (T). The modulus curves

corresponding to the IF spectra indicate softening (abrupt decrease). In fact, the β peak change began at the 16th run (not shown).

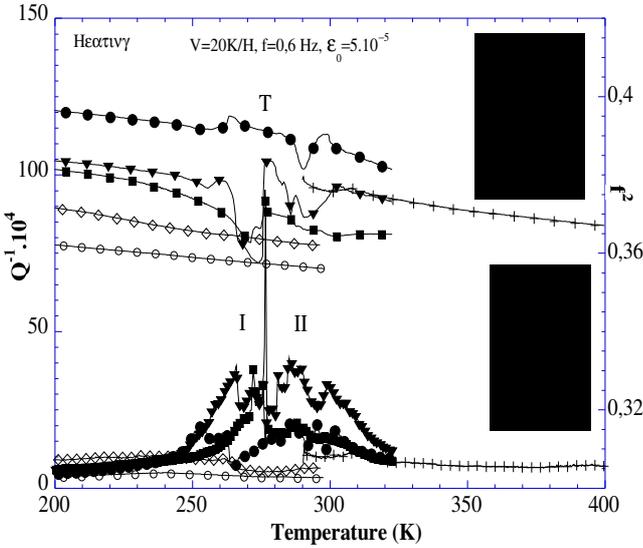


Fig. 2. Internal friction (Q^{-1}) spectra and modulus curves (E^2) of selected thermal runs on heating.

Typically, the phenomena involved in the β peak are ascribed as local atomic movements [2] namely an anelastic relaxation that must be independent of the strain amplitude. This characteristic allows one to calculate the activation energy and relaxation time as a thermally activated phenomena:

$$\tau = \tau_0 \cdot \exp(-E/kT) \quad (1)$$

However since, numerous peaks occur, the calculated activation energy $E=0,5 \text{ eV} - 1 \text{ eV}$ [4, 5] and relaxation time $\tau_0=10^{-14} - 10^{-23}\text{s}$ indicate the presence of hysteretic phenomena within the β anelastic relaxation.

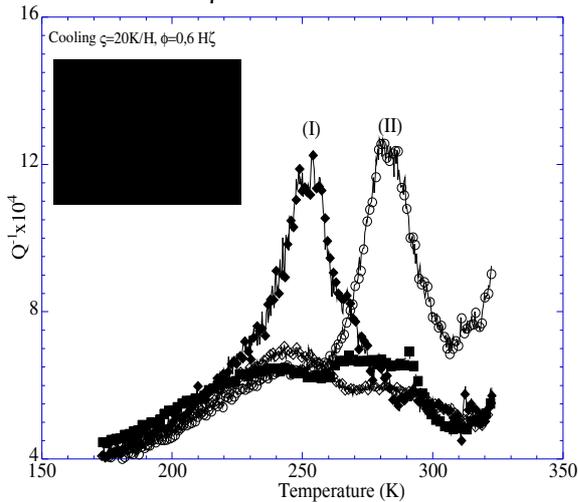


Fig. 3. Internal friction (Q^{-1}) spectra of selected thermal runs during cooling following various strain amplitudes.

The dependence of the peaks I and II upon strain amplitude, are shown in Figs. 3 and 4. On cooling (Fig.3), the peak I levels increase and the peak II levels decrease following the increase of the strain amplitude ϵ . The same trend is observed following the thermal cycles

(TC). For heating (Fig.4), the I peak levels increase and the peak II levels decrease when ϵ increases. Hence the peaks dependence on ϵ and thermal energy (TC) highlight the contribution of storage mechanical energy by cycle. However, the 53rd cycle does not follow the above description due mainly to peak II. This later is a transient peak from the evolution of peak I. The continuous internal structure reorganization of the sample tends to reach stability bringing the β peak to its initial position, which the help of thermal energy (TC) and mechanical energy distribution (ϵ). This trend is observed both on heating and on cooling for the 53rd cycle on Figs. 3 and 4.

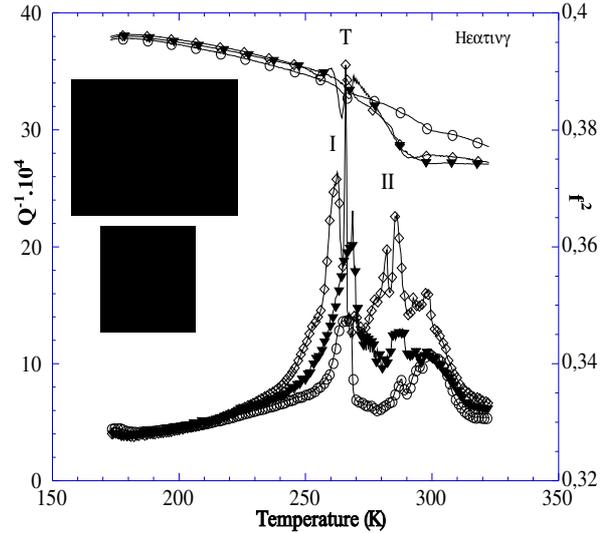


Fig. 4. Internal friction (Q^{-1}) spectra and modulus curves (E^2) of selected thermal runs during heating following various strain amplitudes.

Fig. 5 shows the isothermal IF spectrum and modulus evolution during the 38th run at the position of the peak II.

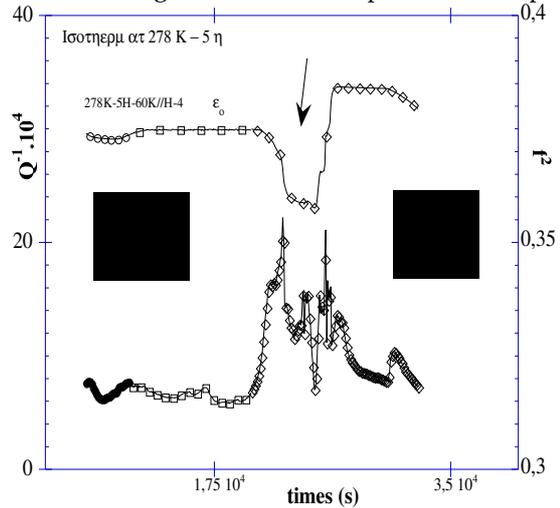


Fig. 5. Isothermal internal friction (Q^{-1}) spectrum and modulus curve (E^2) at 278 K during 5 h.

The evolution is clearly the same as that observed at high temperature for glassy materials. The peaks are too stretched to be relaxation ones, and the modulus softening is unambiguous (see arrow). Moreover, a temperature rise is observed during the isotherm indicating exothermic phenomena [4].

The activation energies calculated for peak II are within a range of 1 eV, and the relaxation times are in the range of 10^{-20} s- 10^{-23} s. Since the amorphous structure is free of grain boundary, the relaxation time must be related to interface motions that are intended in a cooperative atomic diffusion. That is, a collective diffusion of atomic groups having the quasi-same activation energy (same sized sites). Therefore, the relaxation time will be lower (composition of single relaxation time) giving justification of the lower value. However, at temperature close to crystallization, a motion of atoms having different activation energy (composition of activation energy) is dominant, justifying activation energy over 1eV [2]. This latter case is not the purpose of this paper.

In conclusion, we describe the change of β low temperature relaxation into α -type relaxation at lower temperature induced during thermal cyclic internal friction measurements. The relaxation times of the α -type relaxation is in the order 10^{-20} s- 10^{-23} s that suggests phase transformation phenomena dependent of the temperature, stress or /and strain, Investigations are in progress to reach better understanding of the collective atomic phenomena.

References

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