The effect of frequency on the velocity and attenuation of the bulk metallic glass $Zr_{41.2}Ti_{13.8}Cu_{12.5}Ni_{10.0}Be_{22.5}$ under high pressure

2002 J. Phys.: Condens. Matter 14 11311

(http://iopscience.iop.org/0953-8984/14/44/473)

INSTITUTE OF PHYSICS PUBLISHING JOURNAL OF PHYSICS: CONDENSED MATTER

J. Phys.: Condens. Matter **14** (2002) 11311–11314 PII: S0953-8984(02)53979-5

The effect of frequency on the velocity and attenuation of the bulk metallic glass $Zr_{41.2}Ti_{13.8}Cu_{12.5}Ni_{10.0}Be_{22.5}$ under high pressure

Ruju Wang[1], **Fengying Li, Weihua Wang and Zhicheng Qin**

Institute of Physics, Chinese Academy of Sciences, Beijing 100080, China

E-mail: chenlc@aphy.iphy.ac.cn (Ruju Wang)

Received 27 September 2002
Published 25 October 2002
Online at stacks.iop.org/JPhysCM/14/11311

Abstract

Using the pulse echo overlap method and the pulse superposition method, the acoustic velocities V_l, V_s and the attenuations α_l, α_s of $Zr_{41.2}Ti_{13.8}Cu_{12.5}Ni_{10.0}Be_{22.5}$ bulk metallic glass have been measured below 2 GPa with 10 and 20 MHz carrier frequencies, respectively. The results reveal that V_l and V_s increase linearly with increasing pressure (P); the slope of the V_l–P curve decreases with increasing frequency, while that of the V_s–P curve increases with increasing frequency. This means that there is a slight dispersion of sound under pressure. The attenuation increases obviously with the carrier frequency from 10 to 20 MHz. The effects of frequency on the velocity and attenuation under high pressure are discussed.

1. Introduction

$Zr_{41.2}Ti_{13.8}Cu_{12.5}Ni_{10.0}Be_{22.5}$ bulk metallic glass (Zr/Ti BMG) prepared by the melt-quenching technique is a new multicomponent amorphous alloy material. This amorphous alloy has generated great interest in recent years, because it exhibits many unique physical properties and has potential for applications [1]. However, some of the properties are still ambiguous, so it is important to establish the inherent relations between the physical properties and microstructure for this amorphous alloy.

Acoustic velocity and attenuation are two very useful parameters in ultrasonic studies. The velocity of an acoustic wave propagating through an elastic medium is related closely to the structure and state of the medium itself. It can be represented by a function of the density and elastic constants. Acoustic attenuation characterizes the energy loss caused by viscosity, anelasticity, relaxation, etc, when an acoustic wave propagates through a medium. Measuring the velocity and attenuation of BMG under high pressure and at different frequencies can

[1] Author to whom any correspondence should be addressed.

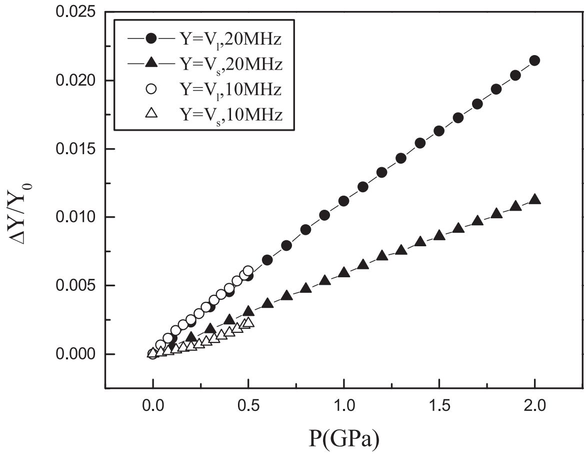

Figure 1. The relative changes of V_l and V_s measured under high pressure using the PEO and PSP techniques, respectively.

provide many significant experimental data relating to elastic behaviour, plastic deformation, the equation of state, etc, and can also provide some important information about the behaviour when its general structure and microstructure are changed.

2. Experiment

The pulse echo overlap (PEO) [2] and pulse superposition (PSP) [3] methods are two different techniques based on ultrasonic interferometry. They are used to measure the time taken to travel through the sample; the measured quantity is the frequency, which is measured with a precision better than 10^{-5}.

Usually, the acoustic attenuation coefficient α is defined [4] by

$$\alpha\ (\text{dB cm}^{-1}) = (20/2L)\log_{10}(E_n/E_{n+1})$$

where L is the length of the sample, and E_n and E_{n+1} represent the amplitudes of two arbitrary neighbouring echoes in the pulse echo series.

V_l and α_l for longitudinal waves were measured simultaneously by a MATEC ultrasonic measuring system. V_s and α_s for shear waves were measured in a similar manner.

High-pressure experiments were completed in a two-piston–cylinder high-pressure apparatus using the PEO and PSP techniques. The pressure was calibrated using a manganin resistance gauge. In the PEO study, pressure was exerted up to 0.5 GPa, the carrier frequency was 10 MHz, and the pressure medium was a 1:1 liquid mixture of transformer oil and kerosene. In the PSP study, pressure was exerted up to 2 GPa, the carrier frequency was 20 MHz, and the pressure medium was a 1:1 liquid mixture of pentane and isopentane. Here it is worth noting that changes of the length and density for the sample under the high pressure of 2 GPa have to be considered. We made corrections to the length and elastic modulus from the experimental data using the Cook method [5].

The relative changes of V_l and V_s measured by the PEO and PSP techniques under high pressure are shown in figure 1. Those of α_l, α_s are shown in figure 2.

Incidentally, the data measured using the PEO and the PSP techniques for a given sample are in conformity [6], and have the same measuring precision.

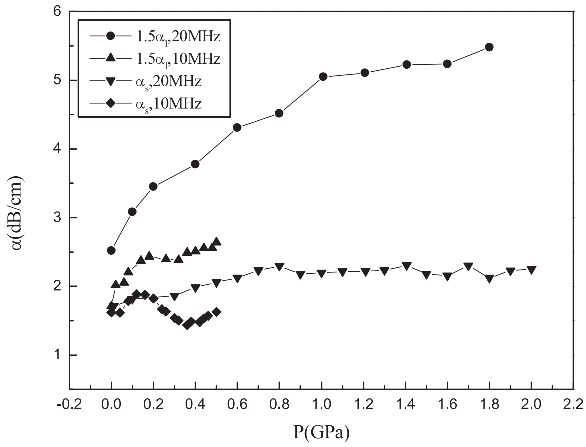

Figure 2. The curves for α_l and α_s versus pressure obtained using the PEO and PSP techniques, respectively.

3. Results and discussion

Figure 1 reveals that both V_l and V_s increase linearly with pressure up to 2 GPa, because Zr/Ti BMG exhibits the properties of a homogeneous elastic solid in the compressed state. The slopes of the V_l–P and V_s–P curves at 10 MHz are 5.97×10^{-2} and 1.1×10^{-2} km s^{-1} GPa^{-1}, respectively. The slopes of the V_l–P and V_s–P curves at 20 MHz are 5.52×10^{-2} and 1.39×10^{-2} km s^{-1} GPa^{-1}, respectively. By comparison, in the pressure range below 0.5 GPa, the slope of the V_l–P curve decreases slightly when the carrier frequency is raised from 10 to 20 MHz, but that of the V_s–P curve increases. This means that there is a slight dispersion of sound under high pressure for Zr/Ti BMG.

Similarly, figure 2 reveals that α_l and α_s increase monotonically with pressure up to 2 GPa. The changes for the longitudinal modes (V_l and α_l) are much larger than those of the shear modes (V_s and α_s) at both 10 and 20 MHz, and α_l, α_s increase with the frequency. This is because the propagation of an ultrasonic wave is basically an adiabatic process. When a compressive wave passes through the sample, the heat flow between the compressed and expanded parts in it leads to energy loss. This loss is related to the frequency [7] and the longitudinal velocity. In contrast, at lower frequency (10 MHz), the α_s–P curve shows a fluctuation below 0.5 GPa: there is a maximum near 0.15 GPa and a minimum near 0.35 GPa.

The random arrays of atoms of the metallic glass and the local anomalous areas in the random arrays can affect the elasticity and anelasticity. The fluctuations of the local structure and density under pressure can lead to fluctuation of the local stress on the atomic scale. The local tensile stress areas can achieve viscous flow easily under pressure; a 'liquid-like-state' viscosity is exhibited. But the local compressive stress areas have more difficulty in flowing; a 'solid-like-state' rigidity is exhibited.

The bulk modulus B and its pressure derivative B' can be obtained from the measured pressure dependences of V_l and V_s under 2 GPa. B_0 and B_0' determined for Zr/Ti BMG are 114.75 GPa and 4.059, respectively. So the isothermal Murnaghan equation of state can be written as follows:

$$P = (B_0/B_0')[(V_0/V)^{B_0'} - 1] = 28.27[(V_0/V)^{4.059} - 1].$$

Here V is the volume.

4. Conclusions

In the short range, correlating closely with atomic configurations, non-metallic glasses such as oxide glasses form chain-like or network structures; the bond angles between atoms change under pressure, and this leads to negative pressure dependence. All BMGs have densely randomly packed microstructures with metallic bonds. The velocity and attenuation are related to the microstructural configuration and the glass-forming ability [8]. For Zr–Ti BMG the pressure dependence exhibits different characteristics as compared with that for oxide glasses. The experimental results show that both V_l and V_s increase with pressure and the slopes of the V_l–P and V_s–P curves change with the carrier frequency. These findings indicate a stiff modulus and a slight dispersion of sound under hydrostatic pressure. The attenuation increases obviously with carrier frequency from 10 to 20 MHz. The α_s–P curve shows a fluctuation.

Acknowledgments

The authors would like to thank, for financial support, the National Natural Science Foundation of China (Grant Nos 19874075, 59871059) and the Outstanding Youths of the National Science Foundation of China (Grant No 59725105).

References

[1] Peker A and Johnson W L 1993 *Appl. Phys. Lett.* **63** 2342
[2] Papadakis E P 1967 *J. Acoust. Soc. Am.* **42** 1045
[3] McSkimin H J 1961 *J. Acoust. Soc. Am.* **33** 12
[4] Szilard J 1982 *Ultrasonic Testing; Non-Conventional Testing Techniques* (New York: Wiley)
[5] Cook R 1957 *J. Acoust. Soc. Am.* **29** 445
[6] Wang Ruju *et al* 1994 *Chin. J. High Pressure Phys.* **8** 177
[7] Testardi L R, Krause J T and Chen H S 1973 *Phys. Rev.* B **8** 4464
[8] Wang Weihua *et al* 1999 *Appl. Phys. Lett.* **74** 1803