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Influence of low-frequency vibrations on the structure of amorphous $Ti_{40.7}Hf_{9.5}Ni_{44.8}Cu_5$ alloy

Sergey Belyaev [a,b], Natalia Resnina [a,b,*], Vasili Rubanik [c,d], Vasili Rubanik Jr. [c,d], Alexander Shelyakov [e], Viktoria Niapomniashchaya [c,d], Eugenii Ubyivovk [a], Igor Kasatkin [a]

[a] Saint-Petersburg State University, 7/9 Universitetskaya nab., Saint-Petersburg 199034, Russia
[b] B.P. Konstantinov Petersburg Nuclear Physics Institute, NRC"Kurchatov Institute", Orlova roshcha, Gatchina 188300, Russia
[c] Institute of Technical Acoustics NAS of Belarus, Ludnikova pr. 13, Vitebsk 210023, Belarus
[d] Vitebsk State Technological University, Moskovski Ave 72, Vitebsk 210035, Belarus
[e] National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe shosse 31, Moscow 115409, Russia

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ABSTRACT

The amorphous $Ti_{40.7}Hf_{9.5}Ni_{44.8}Cu_5$ melt-span ribbon samples were subjected to low-frequency vibrations (20 Hz) with an amplitude of 1 or 4 μm at room temperature to study the influence of the vibrations on the structural relaxation and the crystallization of amorphous alloy. The results obtained showed that the samples retained the amorphous structure after low-frequency vibrations but the resistivity decreased due to some structural relaxation. It was found that the low-frequency vibrations with an amplitude of 4 μm led to the formation of nanoclusters with ordered atomic position in the amorphous structure, but it hardly affected the crystallization temperatures.

1. Introduction

It is well known that the ultrasound vibrations applied to the melt during the crystallization strongly influence the grain structure and this method is widely used to control the grain size and distribution, chemical homogeneity and other grain structure parameters [1]. The amorphous alloys are characterized by the frozen melt structure hence, the ultrasound vibrations should influence the crystallization of amorphous alloys in the same way as during the crystallization of the melt. In [2–5] it was found that heating of some amorphous alloys (ZrAlNiCu, PdNiP, PdNiCuP) under ultrasound vibrations influenced the crystallization parameters such as temperature and heat. Moreover, the ultrasound vibrations (f = 0.35 MHz, T = 290 °C, t = 18 h) at a constant temperature ($T < T_g$) led to full crystallization of $Pd_{42.5}Ni_{7.5}Cu_{30}P_{20}$ alloy, while holding the sample at the same temperature for 75 h without ultrasound vibrations did not result in the appearance of the crystalline phase [5]. High resolution transmission electron microscopy (HRTEM) showed that the crystalline clusters (5–10 nm) appeared in the amorphous matrix and grew during ultrasound vibrations, while the amorphous matrix transformed to the crystalline phase. It was shown that the chemical and phase composition were the same for alloys crystalized under ultrasound vibrations or without, which allowed the conclusion to be drawn that the reason for ultrasound assistance for the crystallization was not due to the diffusion and it was caused by the atomic jumps and the rearrangement associated with the β relaxation [5]. Taking into account that the β relaxation occurs in a wide temperature range below T_g (glass transition temperature) [6] and a decrease in vibration frequency does not suppress the effect of mechanical vibrations on the structure variation observed in amorphous alloys [5], it may be assumed that any mechanical vibrations (low or high frequency) applied to the amorphous alloy at low temperatures (much lower than T_g) should influence its structure and the crystallization parameters. The effect of low-frequency vibrations on the structure of amorphous alloys has not been studied and this is the aim of the present work.

2. Materials and methods

$Ti_{40.7}Hf_{9.5}Ni_{44.8}Cu_5$ melt-span amorphous thin ribbon samples with a thickness of 40 μm, a width of 1.6 mm and a length of 20 mm (working length was 10 mm) were subjected to 10 min low-frequency vibrations in Dynamical mechanical analyser

* Corresponding author at: 7/9 Universitetskaya nab., Saint. Petersburg 199034, Russia.
E-mail address: resnat@mail.ru (N. Resnina).

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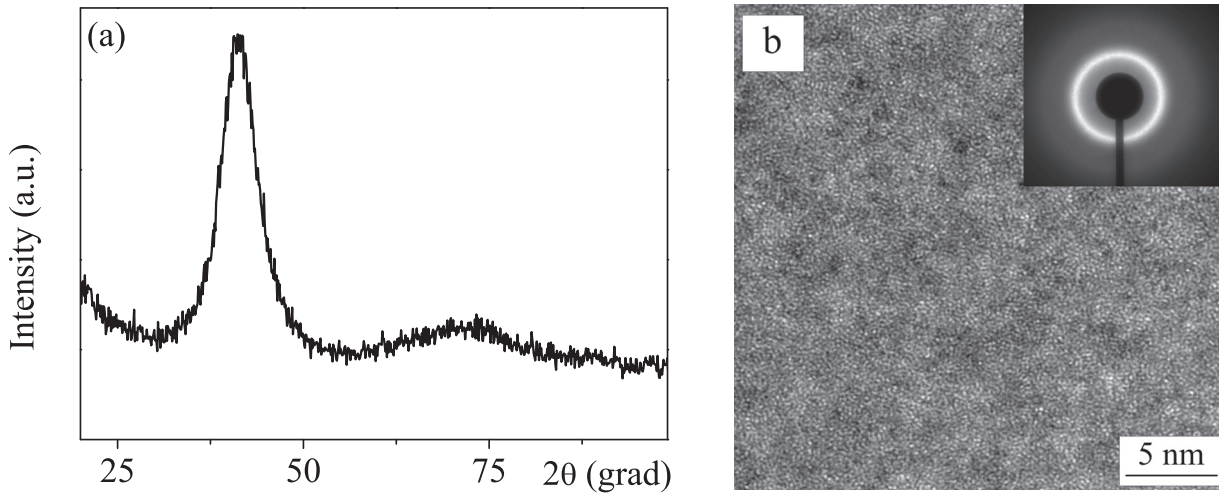

Fig. 1. X-ray patterns (a) and high-resolution transmission electron microscopy image (b) of the amorphous $Ti_{40.7}Hf_{9.5}Ni_{44.8}Cu_5$ alloy structure.

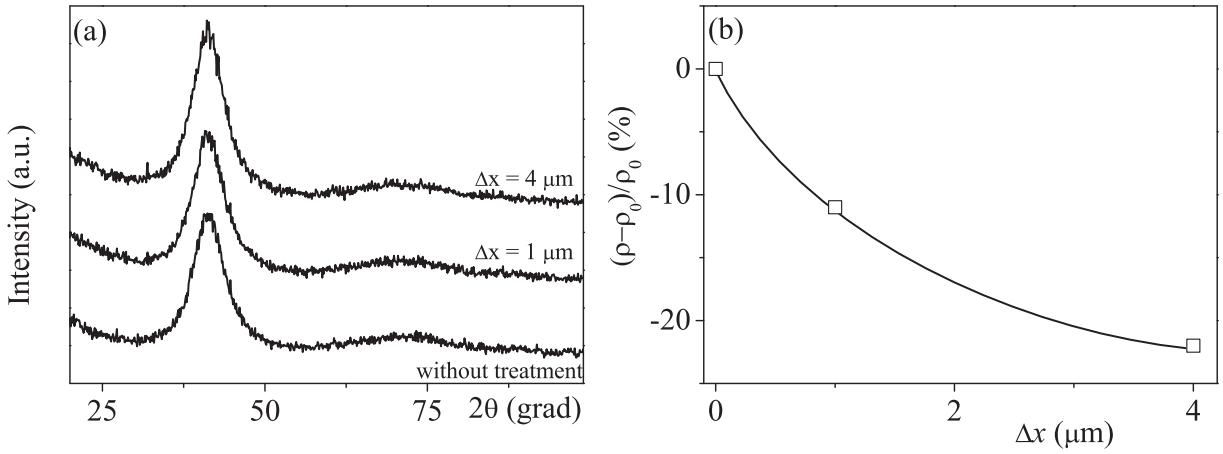

Fig. 2. X-ray patterns of the amorphous $Ti_{40.7}Hf_{9.5}Ni_{44.8}Cu_5$ alloy samples after low-frequency vibration (a) and resistivity variation on vibration amplitude (b).

(DMA) Mettler Toledo 831 at room temperature (25 °C) with a frequency of 20 Hz and displacement amplitude (Δx) of 1 or 4 μm in tensile mode. During vibration the constant load of 0.5 N was applied to the sample to prevent the sample compression. The values of displacement amplitude were chosen as 1 or 4 μm to provide the deformation of the sample within the elastic region which was determined using the stress-strain diagram that has been preliminarily obtained on tension of the amorphous sample in DMA at a temperature of 25 °C. Before and after low-frequency treatment the structure of amorphous alloy (10 mm of central part of the samples) was studied by X-ray diffraction method (XRD) using the Bruker D8 DISCOVER diffractometer ($Cu_{K\alpha}$) at the X-ray Diffraction Centre, Saint Petersburg State University, high resolution transmission electron microscopy (HRTEM) using Libra 200 FE TEM at the Interdisciplinary Resource Centre for Nanotechnology, Saint Petersburg State University and the 4-points resistivity method. Crystallization parameters were studied on heating of the samples (3 mm of the central part) from 25 °C to 530 °C (heating rate of 20 °C/min) in a Mettler Toledo 822e differential scanning calorimeter (DSC).

3. Results and discussion

Fig. 1 presents the XRD pattern and HRTEM image of the initial amorphous alloy; it can be seen that the halos are found in XRD pattern (Fig. 1a) and this shows that the initial alloy is fully amorphous. It is verified by the HRTEM image presented in Fig. 1b, where there is no long-range order in the atom positions observed. The resistivity of the initial samples was equal to 220 ± 5 μΩ·cm.

Fig. 2a shows the X-ray patterns obtained in the samples subjected to mechanical vibrations with two displacement amplitudes of 1 and 4 μm together with the pattern obtained in the untreated sample. It is found that there are no reflexes from any crystalline phases hence, mechanical vibrations do not result in crystallization of the amorphous samples. At the same time, in the samples subjected to mechanical vibrations, the resistivity decreases as compared to the untreated amorphous sample (Fig. 2b). So, 10 min of vibrations with a displacement amplitude of 1 μm results in a decrease in resistivity to 11%, whereas an increase in displacement amplitude to 4 μm leads to a decrease in resistivity to 22%. A decrease in resistivity in amorphous alloys may be due to two reasons: structural relaxation in the amorphous phase or crystallization [7,8]. The XRD data presented in Fig. 2a shows that the crystallization does not occur hence, a decrease in resistivity measured in the amorphous samples subjected to mechanical vibrations is caused by the structural relaxation occurred in the amorphous alloys.

According to [8], the structural relaxation includes three stages: a decrease in free volume, a change in chemical and topological order and the formation of ordered clusters. To find which stage