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Conference Paper

Application of Laser Radiation for Fabrication of Micromechanical Actuator Based on Two-Way Shape Memory Effect

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Abstract

The work deals with production and research of experimental samples of micromechanical actuator based on the rapidly quenched TiNiCu alloy, in which a two-way shape memory effect is formed as result of impact of the laser radiation. By the technique of focused ion beams an element with thickness of 5 microns, width of 7 microns and 100 microns in length was obtained, bending reversibly to 2.5 microns in the heating-cooling cycle.

Keywords: shape-memory alloy, thin ribbon, two-way shape memory effect, laser treatment, micromechanical actuator

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1. Introduction

Shape memory materials by virtue of their unique properties have found application in various engineering branches. Currently the ranges of use of these materials is extremely wide and include such areas as space technology, medicine, robotics, micro-electromechanical systems (MEMS) and others household applications [1-3]. Today scientific and technological progress requires the creation of miniature executive elements capable of manipulating micro- and nano-objects. At present the main area of application of shape memory alloys in MEMS is the manufacture of devices acting in the heating-cooling cycle, and here the two-way shape memory effect (TWSME) is preferable, when the shape change in the element occurs both process - heating (realizing a one-way shape memory effect) and cooling (due to return mechanism, for example, by the way of an external elastic element or the field of internal mechanical stresses). In particular TWSME occurs under certain conditions in TiNiCu-based alloys with a layered amorphous-crystalline structure. There are several ways to create such composite structure. One of them is ultrafast quenching from the liquid state (methods of spinning and planar casting) [4, 5]. Also it is possible to obtain a local amorphous-crystalline structure in a thin TiNiCu ribbon with extreme actions on its surface, for example, by laser treatment [6, 7].

In this paper, we present a technique of the manufacturing of a micromechanical devices based on TWSME for capturing micro- and nanoobjects. Microactuator is formed from a thin amorphous ribbon that is obtained by ultrafast quenching from a melt followed by mechanical rolling and electrochemical etching. The ribbon is locally modified by a short laser pulse and focused ion beams (FIB). The goal of the work is the production of the microactuator with presented technique and investigation its micromechanical properties.

2. Experimental

An amorphous ribbon of $Ti_{50}Ni_{25}Cu_{25}$ alloy (at.%) was chosen as the subject of the investigation. The ribbon with a thickness of 35 μm was obtained by the rapid quenching from a melt [8] and then was rolled on a mill to a thickness of 19-20 μm. By means of two-sided electrochemical etching a thickness of 5 μm was achieved. Such a small thickness is necessary in FIB-technique to minimize surface damage in an ion milling area. As a solution for etching, electrolyte ”PLS/3” manufactured by ”NTC TECHNOCOM AS” was used. Etching of the ribbon was carried out in the polishing mode with current and voltage on a sample of 110 mA and 4 V, respectively. Additionally to increase the quality of the ribbon's samples the etching current was reduced to 70 mA when the thickness reached 10 μm. The total duration of the etching was 90 minutes.

The amorphous ribbon with 5 μm thickness was isothermally crystallized in a furnace at the temperature of 500 °C for 6 minutes to give the shape memory of the bending state with a bending radius R = 0.5 mm.

For the formation of TWSME in crystalline samples, the method of the extreme action of laser radiation on their surfaces, described in [6, 7], was used. Samples of a thin ribbon with the bending shape memory are straightened and fixed in a straight line state. Then, a single laser pulse acts on the surface layer of samples in the bending zone and modifies there structure. In this way a structural composite with TWSME is formed in the ribbon.

To simulate the effect of laser radiation on the surface of samples and to select processing parameters, modeling of thermal processes performed in [9] was used.

At Figure 1 present the temperature distribution over the sample depth at different time intervals after the start of laser treatment at P = 10^{12} W/m^2. The melting temperature of the alloy T_m = 1420 K is reached at a depth of about 0.4 μm.

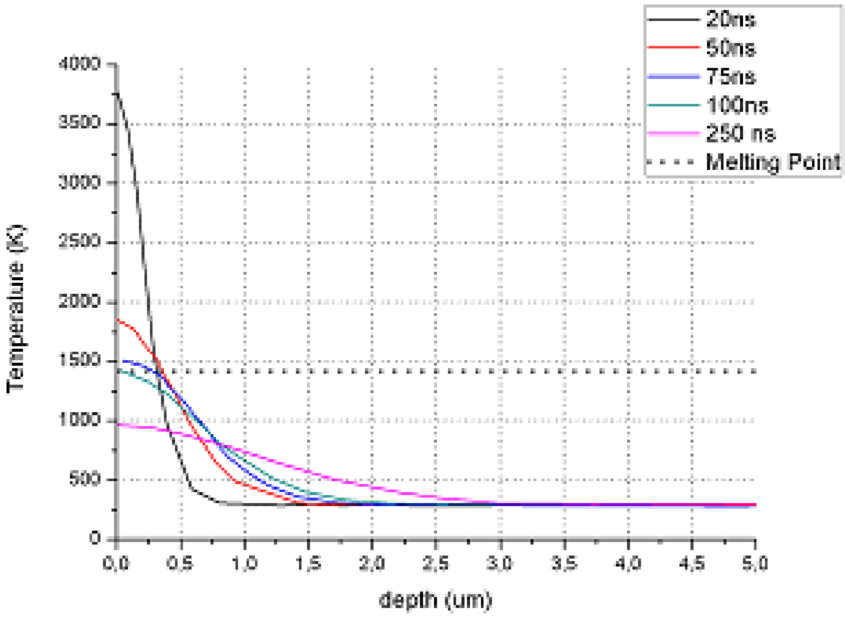

Figure 1: Temperature distribution along the depth of the sample after beginning of the action of the laser pulse (τ = 20 ns, P = 10^{12} W/m^2).

The calculated from the obtained curves cooling rate of the melt is 10^8 K/s, which is sufficient to amorphize the TiNiCu alloy. Thus processing of the TiNiCu alloy with laser radiation with such parameters can lead to the formation of an amorphous structure in the surface layer.

In accordance with calculations, TiNiCu alloy samples are treated with using a single pulse of the CL7000 series excimer laser with a KrF gas mixture with a wavelength 248 nm, a pulse duration 20 ns and a pulse energy density 6 mJ/mm^2. As a result the local amorphous-crystalline structure (thickness of the amorphous layer 0.4 μm) (fig. 2) and TWSME (fig. 3) are obtained.

A micromechanical device is formed from the irradiated ribbon with the TWSME by the FIB method. The sample is cut at middle of the modified area, where the presence of TWSME is guaranteed. A lamella with a width of 7 μm and a length of 100 μm is cut from the sample by means of a FIB. A free end of the lamella is fed with a manipulator needle and soldered by ion-stimulated vapor deposition. After soldering another end of the lamellae is cut off from the ribbon. The process is shown at Figure 4.

To test the lamella's TWSME a heating device consisting of two metal plates with the Peltier element "Kryotherm LCB-127-1.0-1.3" between them is used. One of the

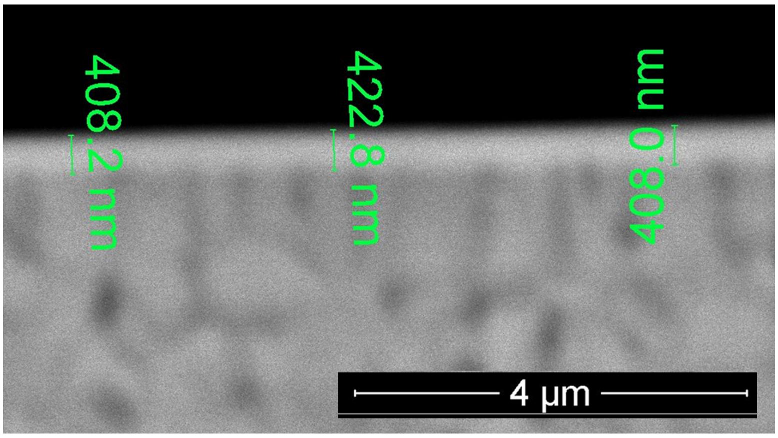

Figure 2: The cross-section of the irradiated by laser radiation $Ti_{50}Ni_{25}Cu_{25}$ ribbon.

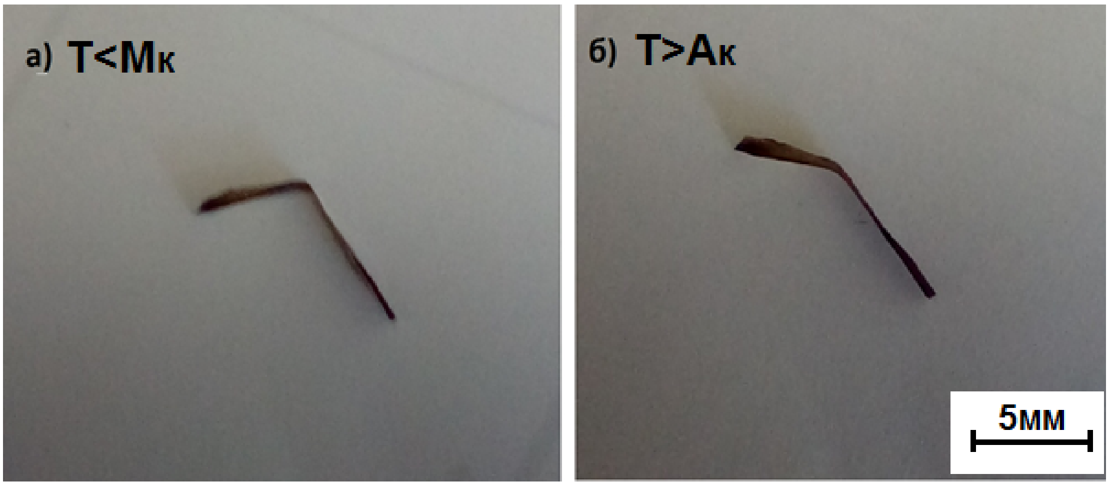

Figure 3: The variation in the shape of the irradiated by laser radiation $Ti_{50}Ni_{25}Cu_{25}$ ribbon at room temperature (a) and when heated above A_f (b).

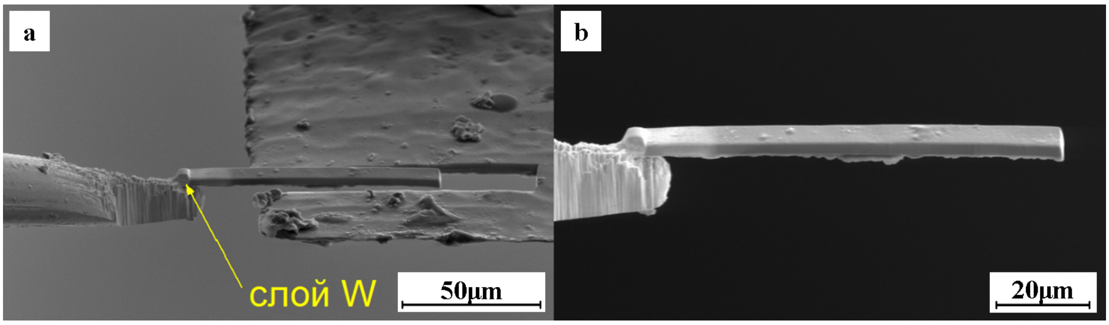

Figure 4: Images taken on an SEM show: (a) the process of removing the needle with the lamella from the ribbon, (b) the final view of the lamella.

plates is a heat sink and on the second there is a groove in which a needle with the manufactured lamella is fixed. The lamella reversibly bends by about 2.5 μm (with a lamella length of 100 μm) in the heating-cooling cycle, i.e. it has a two-way shape memory effect (Figure 5).

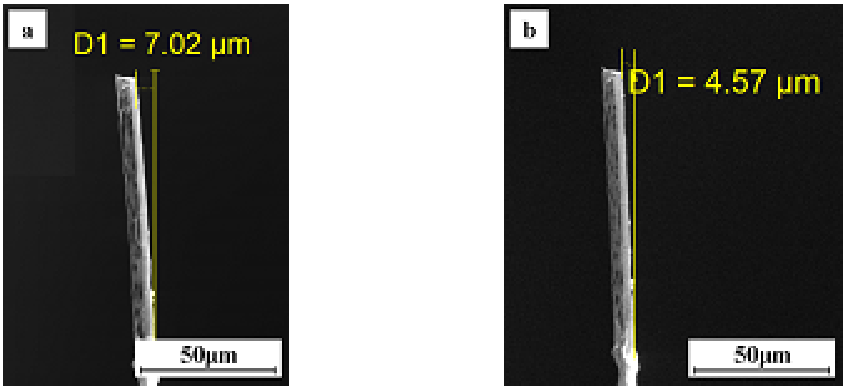

Figure 5: Two-way shape memory effect in the lamella: (a) at room temperature, (b) when heated.

3. Summary

The results are summarized as follows.

1. An amorphous $Ti_{50}Ni_{25}Cu_{25}$ (at.%) alloy ribbon of the 35 μm thick was made by the rapid quenching from a melt, was rolled on a mill to a thickness of 19-20 μm and was etched to a thickness of 5 μm by electrochemical polishing.

2. An amorphous-crystalline composite, exhibiting two-way shape memory effect, was formed by the action of the pulse laser radiation (a wavelength of 248 nm, a duration of 20 ns and an energy density of 6 mJ/mm^2) at the surface of previously isothermally crystallized and pseudoplastically deformed ribbon.

3. Using a method of focused ion beams, a lamella is made of a thickness of 5 μm, a width of 7 μm and a length of 100 μm from an amorphous-crystalline composite. It is shown that the lamella bend reversibly with the displacement of its end by 2.5 μm.

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