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New Approaches to Manipulation of Microbiological Objects

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Abstract

The new concept of nanotweezers based on bimetallic composite $Ti_{50}Ni_{25}Cu_{25}$/Pt with shape memory effect have recently demonstrated the ability to manipulate real nanoobjects, such as CNTs, graphene layers, etc., when heated to 40-60 °C by laser radiation. We demonstrate possibility of manipulation of microbiological objects – fibers from the body of *Culex pipiens* in vacuum chamber of FIB device. Composite microactuator controlled by magnetic field at constant temperature was produced using rapidly quenched ferromagnetic shape memory Heusler alloy $Ni_{53}Mn_{24}Ga_{23}$. The experiments on control of this microactuator by applying magnetic field of 8 T prove the possibility of manipulation of living objects.

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Keywords: nanomanipulation; microbiological objects; Culex pipiens; ferromagnetic shape memory effect; Ni_2MnGa.

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1. Introduction

Currently in the field of manipulation and manufacturing at the nanoscale, there is an urgent need to develop new functional materials in order to fill the gap between the dimensions of modern MEMS and real size of nanoobjects to be manipulated. Recently, the record small mechanical tools based on composites with shape memory effect (SME) were created (Irzhak et al., 2010; Shelyakov et al., 2011; Zakharov et al., 2012; Kalimullina et al., 2014). The application of the technology of selective ion etching allowed for the creation of two-layer composite actuators based on rapidly quenched nonmagnetic alloys with SME, such as $Ti_{50}Ni_{25}Cu_{25}$ (Zakharov et al., 2012). These composite actuators can change their shape reversely and produce mechanical work using only “one-way” SME of the alloy (Irzhak et al., 2010). The overall volume of the actuator of less than 1 μm^3 and thickness of active layer of the $Ti_{50}Ni_{25}Cu_{25}$ alloy down to 70 nm were demonstrated (Zakharov et al., 2012). These achievements of nanotechnology can be used certainly in various branches of biotechnology. The new technique can open the way to developed the tools for manipulation of animate or inanimate biological objects of submicron and nanometer sizes, for example, bacteria, viruses, biological particles of different nature. The first purpose of this paper is to describe the example of experiments on preparation of insect’s fibers of submicron sizes within the vacuum chamber of Focused Ion Beam (FIB) microscope. The development of nanotweezers operating at constant temperature is of particular importance mainly for the manipulation of living biological objects. Thus the second purpose of this paper is to investigate the possibility of production of micro-sized magnetic-field-controlled tools and devices based on Heusler $Ni_{50}Mn_{25}Ga_{25}$ alloy operating at constant temperature.

2. Manipulation of *Culex pipiens* fibers

In order to study the possibility of manipulation of biological objects on a submicron scale, we have manufactured samples of composite $Ti_{50}Ni_{25}Cu_{25}$ nanotweezers using the FIB milling. This technology included 3 stages.

(1) The rapidly quenched $Ti_{50}Ni_{25}Cu_{25}$ alloy ribbon in the as spun state is amorphous (Resnina et al., 2008). At the first stage, the as quenched ribbon of $Ti_{50}Ni_{25}Cu_{25}$ alloy with a thickness of 30–40 μm was annealed for 300 sec in air at 500 °C. This led to recrystallization and shape memory manifestation. The temperatures of the start and finish of the direct and reverse martensitic transformation (MT) in our experiments were M_s = 42 °C, M_f = 39 °C, A_s = 50 °C, and A_f = 52 °C, respectively.

(2) Then, the annealed ribbon was subjected to pseudoplastic tensile deformation. For this purpose, the ribbon was suspended at one end in the vertical position, the other end was loaded with a weight of about 1 kgf, and the sample was heated by passing an electric current of about 1 A. As a result of cooling to room temperature, the sample acquired pseudoplastic tensile deformation 1–3 %.

(3) The formation of composite tweezers and investigation of giant deformation effects under heating by radiation of a semiconductor injection laser were carried out in vacuum chamber of FEI Strata FIB 201 focused ion beam device. The flat area was formed on the side edge of an alloy ribbon and a 500 nm thick platinum film was deposited by Chemical Vapor Deposition (CVD) technology over an area with a width of 1–2 μm and a length of 10–20 μm to obtain an elastic layer. Then, a rectangular hole was made near the platinum layer so that the total thickness of $Ti_{50}Ni_{25}Cu_{25}$ alloy and platinum was within 0.8–1 μm. As a result, the sample acquired the shape of a cantilever with a gap at the end, which provided the possibility of controlled reversible bending (Fig. 1a).

The nanotweezers were controlled by the semiconductor laser diode based on a GaAl/GaAlAs heterostructure generating at a wavelength of λ = 0.9 μm. The laser bias voltage switching on resulted in heating of the $Ti_{50}Ni_{25}Cu_{25}$ layer, which exhibited transition to the austenite state, while the laser switching off led to reverse transition to martensitic state and the restoration of the initial shape due to the elasticity of the metal layer of the composite. The deformation control was carried out in real time in ion microscope with a spatial resolution of less than 30 nm. Thus, the nanotweezers exhibited controllable gap from 1000 downto 0 nm. Video demonstration of the nanotweezers operation is presented in Internet (http://www.youtube.com/watch?v=pEGL_IcLxDs).

The object of the manipulation was insect *Culex pipiens* (mosquito). This species is distributed universally and has a large epidemic importance. The sample was placed into vacuum chamber of FIB device. For positioning in space the nanotweezers was attached to the needle of Omniprobe micromanipulator by CVD process. The experiment included the following steps: the selection of a part of a fiber from *Culex pipiens* body (Fig. 1b), its