Phys. Status Solidi C **11**, No. 5–6, 1023–1025 (2014) / **DOI** 10.1002/pssc.201300718

physica status solidi c
www.pss-c.com
current topics in solid state physics

Magnetic shape memory microactuator

E. Kalimullina[1], A. Kamantsev[*,1,2], V. Koledov[1,2], V. Shavrov[1], V. Nizhankovskii[2], A. Irzhak[3,4], F. Albertini[5], S. Fabbrici[5], P. Ranzieri[5], and P. Ari-Gur[6]

[1] Kotelnikov Institute of Radio-engineering and Electronics of RAS, 125009 Moscow, Russia
[2] International Laboratory of High Magnetic Fields and Low Temperatures, 53-421 Wroclaw, Poland
[3] National University of Science and Technology ''MISiS'', 119049 Moscow, Russia
[4] Institute of Microelectronics Technology and High-Purity Materials of RAS, 142432 Chernogolovka, Russia
[5] IMEM-CNR, 43124 Parma, Italy
[6] West Michigan Unversity, Kalamazoo, MI 49008, USA

Received 30 October 2013, revised 23 November 2013, accepted 11 December 2013
Published online 9 April 2014

Keywords ferromagnetic shape memory effect, strong magnetic field, microactuator, nanomanipulation

* Corresponding author: e-mail kama@cplire.ru, Phone: +7 495 629 3506, Fax: +7 495 629 3678

Bimetallic composite nanotweezers based on Ti_2NiCu alloy with shape memory effect (SME) have been recently proved to allow the manipulation of real nano-objects, such as nanotubes, and bionanoparticles while heated up to 40-60 °C by laser radiation. The possibility of developing nanotweezers operating at a constant temperature is of particular importance mainly for the manipulation of biological objects. In this work, a microactuator was produced using a composite bilayer made of a layer of rapidly quenched $Ni_{53}Mn_{24}Ga_{23}$ ferromagnetic shape memory Heusler alloy and an elastic layer of Pt. The size of the microactuator is 25×2.3×1.7 μm^3. The controlled bending deformation of the actuator is 1.2 %, with a deflection of the end of the actuator higher than 2 μm has been obtained by applying a magnetic field of 8 T at T = 62 °C The possibility of the development of new technologies for magnetic-field-controlled nanotools operating at a constant temperature using the new multifunction magnetic shape memory alloys will be discussed.

1 Introduction Heusler alloys attract great interest due to the combination of ferromagnetism and thermoelastic martensitic transition, which is accompanied by shape memory effect (SME) [1]. Recently, application of the technology of selective ion etching allowed creating two-layer composite actuators and tools based on rapidly quenched nonmagnetic alloys with SME, such as Ti_2NiCu [2]. These composite actuators can change their shape reversely and produce mechanical work using only "one-way" SME of the alloy [3]. This opens possibility of creating technology for production of micro-sized magnetic-field-controlled tools and devices on the base of Heusler alloys. 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 dimensions of modern MEMS and real size of nano-objects to be manipulated. Recently the operation of nanotweezers using layered composites based on alloy with SME driven by thermal actuation has been demonstrated [2-4]. The operation of the Ti_2NiCu/Pt composite actuator driven by heating was proved, with the overall volume of the actuator being less than 1 μm^3 and thickness of active layer of the T_2NiCu alloy being as small as 170 nm [2]. The idea of the present work is to exploit the application of the phenomenon of magnetic-field-controlled SME in Heusler alloy Ni_2MnGa for design of composite magnetic microactuator with SME operating at constant temperature.

2 Samples The microactuators have been prepared by standard Focused-Ion-Beam and Chemical-Vapor-Deposition (FIB-CVD) processes in FEI Strata 201 FIB device (see Fig. 1) [5]. The melt-spun ribbons of 30-μm-thickness of nominal composition $Ni_{53}Mn_{24}Ga_{23}$ have been prepared by melt spinning. Some pieces of ribbons were annealed in vacuum at 800 °C for 5 and 72 hours. At room temperature all samples were in the ferromagnetic and martensitic state. Their Curie point (T_C) as well as their start and finish temperatures of the austenite-martensite and martensite-austenite transformations (M_s, M_f , A_s and A_f , respectively) were determined by using the DSC. For the sample annealed for 72 hours M_s = 49.5, M_f = 41.2, A_s = 50.4, A_f = 60.7, and T_C = 72.5 °C. More details on the preparation and other parameters of the ribbons are given elsewhere [5-8]. The principle of actuation of composites with SME requires that at a first stage the active layer of SME alloy is prestrained Then a passive elastic layer is to be deposited on the active one (Fig. 1a) [1]. After that the composite should be nanofabricated by ion beam cutting from the ribbon surface. Cantilever type micro-actuators of size 25×2.3×1.7 μm^3 are then prepared and moved by Omniprobe micromanipulator from surface of the ribbon and attached by CVD process to Si substrates (Fig. 1b).

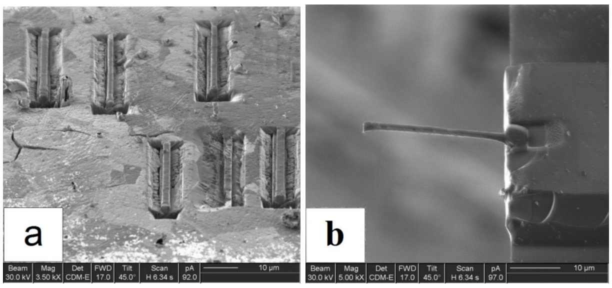

Figure 1 Preparation of microactuators on the base of $Ni_{53}Mn_{24}Gs_{23}$/Pt composites with SME: (a) preforms of composites on the surface of prestrained $Ni_{53}Mn_{24}Gs_{23}$ melt spun ribbon; (b) composite microactuator attached to Si substrate.

3 Experimental part The experiments on magnetic actuation have been carried out in 8 T Bitter coil at the International Laboratory of Strong Magnetic Fields and Low Temperatures, Wroclaw, Poland. For the observation of the magnetic-field-controlled giant bending strain of the microactuators (see Fig. 2) a non-magnetic optical microscope with vacuum thermostat for temperature control was purpose-built.

The effect of magnetic-field-controlled MT in ferromagnetic alloys with SME is based on the temperature shift of MT in magnetic field (see Fig. 3a) due to different magnetization values of the martensitic and austenitic phase of the alloy. So by choosing the temperature near Mf one can cause the reversible MT turning on the sufficiently strong magnetic field. The sensitivity of MT of the alloy $Ni_{53}Mn_{24}Gs_{23}$ to magnetic field is near 1 K/T [8]. Therefore, an almost complete reversible MT accompanied by giant bending strain of the composite can been observed in a field of 8 T (Fig. 3b). The relative bending strain has been determined from the microscopic images of the composites using the formula: $\varepsilon = h/2R$, where h – thickness of the composite, R – radius of the composite curvature. The controlled stroke of the tip of composite is not less than 1.2%. The composite is bent in zero field and straitened almost completely at μ_0H = 8 T due to the interaction between the elastic and pre-strained active SME layers.

Recently the new metamagnetic Heusler functional alloys Ni-Mn-In-Co have been object of intensive investigation [9]. The martensitic phase of these alloys is almost nonmagnetic and with a shift of MT to lower temperatures in a magnetic field with sensitivity up to 10 K/T [9]. Further work is still needed to diminish the hysteresis of MT in order to use lower fields (H < 2 T) and to optimize the temperature range of the actuation suitable for dealing with biological object. The new technology of magnetic field controlled actuation of living microobjects using technological and cheap permanent magnets could help to resolve important medical and biological tasks, such as single cell manipulation, microsurgery operations at micro- and submicrometer level. The new visualization techniques on submicron scale should also be developed.

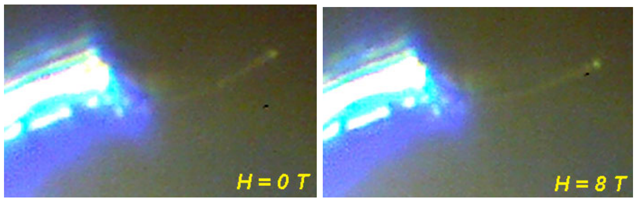

Figure 2 Giant magnetic-field-controlled bending strain of composite microactuator in Bitter coil at constant temperature The composite is bent in zero field and straitened almost completely at μ_0H = 8 T due to interaction of the elastic and prestrained active layers with SME.

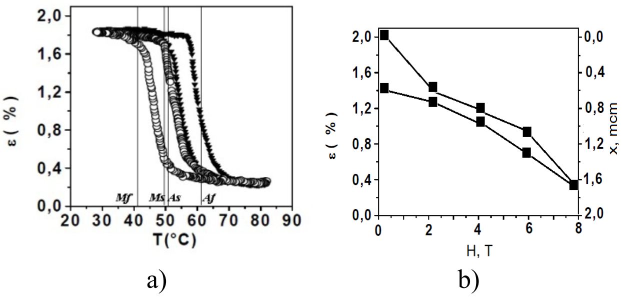

Figure 3 Magnetic-field-controlled SME in $Ni_{53}Mn_{24}Gs_{23}$ alloy: (a) relative strain of $Ni_{53}Mn_{24}Gs_{23}$ melt-spun ribbon versus temperature at μ_0H = 0 T (○) with transition temperatures and μ_0H = 6 T (▼) [8]. (b) Magnetic-field-controlled bending strain ε and stroke x of $Ni_{53}Mn_{24}Gs_{23}$/Pt composite microactuator at constant temperature T = 62 °C.

4 Conclusions (1) The microactuator was created by standard FIB-CVD process starting from a composite bilayer made of one layer of rapidly quenched ferromagnetic shape memory alloy based on Ni-Mn-Ga and an elastic layer of Pt. The size of the microactuator is 25×2.3×1.7 μm^3. (2) A controlled bending strain of the actuator of 1.2% was obtained and the stroke of the actuator was not less than 1.6 μm in a magnetic field μ_0H = 8 T at a constant temperature T = 62 °C.

Acknowledgements Authors are grateful to Professors V. Pushin, S. Belyaev for discussions. The work was supported by RFBR grants No. 12-08-01043-a, 12-07-00656-a, 12-08-31340-мол_а, Russian Ministry of Science and Education Agreement No 8571, RAS-CNR Joint Research Program, and by the PRRIITT Program of the Emilia-Romagna Region in the frame of the MIST E-R Laboratory. The equipment of CKP MIPT and REC "Nanotechnology" of MIPT has been used in this work.

References

[1] A. A. Cherechukin, I. E. Dikstein, D. I. Ermakov et al., Phys. Lett. A **291**, 175 (2001).
[2] D. Zakharov, G. Lebedev, A. Irzhak et al., Smart Mater. Struct. **21**, 052001 (2012).
[3] A. Irzhak, V. Kalashnikov, V. Koledov et al., Tech. Phys. Lett. **36**, 329 (2010).
[4] A. V. Shelyakov, N. N. Sitnikov, A. P. Menushenkov et al., Thin Solid Films **519**, 5314 (2011).
[5] F. Albertini, S. Besseghini, A. Paoluzi et al., J. Magn. Magn. Mater. **242**, 1421 (2002).
[6] P. Algarabel, C. Magen, L. Morellon et al., J. Magn. Magn. Mater. **272**, 2047 (2003).
[7] F. Albertini, S. Besseghini et al., J. Commun. Technol. Electron. **50**, 638 (2005).
[8] K. Akatyeva, V. Afonina, F. Albertini et al., Solid State Phenom. **190**, 295 (2012).
[9] J. A. Monroe, I. Karaman, B. Basaran et al., Acta Mater. **60**, 6883 (2012).

