MA 45: Joint Session "Magnetic Shape Memory Alloys II" (jointly with DS, MM)

Time: Thursday 15:00–18:45 Location: H 0112

MA 45.1 Thu 15:00 H 0112

Stress accomodation in polytwinned NiTi nanograins studied with the phase-field method — •Christian Mennerich[1], Frank Wendler[1], Marcus Jainta[1], Anna Weisshaar[1], and Britta Nestler[1,2] — [1]Karlsruhe University of Applied Sciences — [2]Karlsruhe Institute of Technology

During the martensitic transformation in NiTi shape memory alloys, grains of a critical radius below about 50 nm do not transform into martensite. A multi-phase field model of Allen-Cahn type is used to analyse the accomodation of a spherical nanograin inclusion embedded in the austenite phase at room temperature. The model is based on a Helmholtz free energy density formulation and includes elastic and eigenstrain energy contributions. The model is implemented using finite differences, assuming staggered grids for the components of the elastic displacements. We present the techniques used to describe the time-spatial evolution of the system oppose this to the simulation of a mechanical equilibrium. The model is successfully applied to Eshelby's inclusion problem to verify the correctness of the implementation. With this model, we study the stress accomodation of polytwinned spherical NiTi nanograins that are embedded in an austenite matrix. The results are compared to analytical solutions and numerical results from the literature.

MA 45.2 Thu 15:15 H 0112

Structure and magnetic properties of epitaxial Fe-Pd-Cu films — •Sandra Kauffmann-Weiss[1], Sven Hamann[2], Markus E. Gruner[3], Peter Entel[3], Ludwig Schultz[1], Alfred Ludwig[2], and Sebastian Fähler[1] — [1]IFW Dresden, Institute for Metallic Materials, P.O. Box 270116, 01171 Dresden — [2]Ruhr-Universität Bochum, Institut für Werkstoffe, Universitätsstraße 150, 44780 Bochum — [3]University of Duisburg-Essen, Theoretical Physics, Lotharstraße 1, 47048 Duisburg

Epitaxial films are promising candidates for magnetic shape memory (MSM) applications on the microscale. We investigated the magnetic properties of $Fe_{70}Pd_{30-x}Cu_x$ ferromagnetic shape memory alloys with different Cu contents (x = 0, 3, 7) in strained epitaxial films. For the MSM alloy $Fe_{70}Pd_{30}$ we recently demonstrated, that a tetragonal distortion up to 54 % can be induced into the crystal lattice by strained epitaxial film growth [S. Kauffmann-Weiss et al., Phys. Rev. Lett. 107, 2011, 206105]. Due to the tetragonal distortion intrinsic magnetic properties like Curie temperature, saturation magnetisation and magnetocrystalline anisotropy can be controlled. Epitaxial $Fe_{70}Pd_{27}Cu_3$ and $Fe_{70}Pd_{23}Cu_7$ films show slightly lowered values for spontaneous polarisation and Curie temperature, but strongly increased magnetocrystalline anisotropy constants compared to the binary $Fe_{70}Pd_{30}$ alloy and the Ni-Mn-Ga prototype system. These results indicate that alloying of $Fe_{70}Pd_{30}$ with Cu is a promising route to fabricate films with excellent magnetic properties to be used for the MSM effect.

This work is supported by DFG through SPP1239.

MA 45.3 Thu 15:30 H 0112

Dynamic simulation of the giant magnetocaloric effect in Ni-Mn-based Heusler alloys — •Tino Gottschall[1], Jian Liu[1], Konstantin Skokov[1], James David Moore[1], and Oliver Gutfleisch[1,2] — [1]IFW Dresden, Helmholtzstraße 20, 01069 Dresden, Germany — [2]2Technische Universität Darmstadt, Institut für Materialwissenschaft, Petersenstr. 23, 64287 Darmstadt, Germany

The origin for the inverse magnetocaloric effect in Ni-Mn-based Heusler alloys is a first-order magnetostructural transition between a low temperature paramagnetic/antiferromagnetic martensite and a high temperature ferromagnetic austenite phase. Performing direct measurements, we report a large adiabatic temperature change ΔT_{ad} exceeding -6 K at a field change of 2 T in a novel Ni-Mn-In-(Co) alloy. Such a giant magnetocaloric effect makes them potential candidates for energy efficient magnetic refrigeration. Far from an ideal first-order transition material, a wide transition temperature range was observed in this sample probably due to the existence of a local inhomogeneity over the sample. The transition distribution has the shape of a Gaussian function. Based on these considerations we were able to simulate the temperature change under adiabatic conditions, which agrees very well with the experimental data. Three parameters to manipulate the dynamic cooling process, namely field dependency, transition width and potential temperature change, are discussed for an in-depth understanding of the underlying physics behind the observed giant magnetocaloric effect.

MA 45.4 Thu 15:45 H 0112

Element-specific temperature dependence of the Ni and Mn magnetization in $Ni_{51.6}Mn_{32.9}Sn_{15.5}$ — •Bernhard Krumme[1], Alexander Auge[2], David Klar[1], Frank Stromberg[1], Andreas Hütten[2], and Heiko Wende[1] — [1]Faculty of Physics and CeNIDE, University of Duisburg-Essen, D-47048 Duisburg, Germany — [2]Thin Films and Nanostructures, Department of Physics, University of Bielefeld, D-44801 Bielefeld, Germany

Off-stochiometric compositions of the Heusler compound Ni_2MnSn with an increased content of Mn are known to be ferromagnetic shape memory alloys (FSMA). This class of materials shows a structural phase transition influencing the magnetization as well as the electric resistivity. Therefore, such materials are of interest for applications, e.g. as actuators. We investigated the influence of the structural phase transition on the element-specific magnetization and electronic structure of Ni and Mn in $Ni_{51.6}Mn_{32.9}Sn_{15.5}$ by means of X-ray absorption spectroscopy (XAS) and X-ray magnetic circular dichroism (XMCD). Due to the element-specificity we were able to reveal a different temperature dependence of the ratio of orbital to spin magnetic moment of Mn compared to Ni. In parallel a change of the electronic structure of Mn is observed, whereas for Ni almost no modifications occur. By applying a magnetic field of 3T in the martensite phase it is possible to reduce the ratio of orbital to spin magnetic moments indicating a field induced reverse martensitic transition (FIRMT).

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MA 45.5 Thu 16:00 H 0112

Effect of the film thickness on the martensitic transformation in Ni-Mn-Sn ultra-thin films — •Niclas Teichert, Alexander Auge, and Andreas Hütten — Department of Physics, Thin Films and Physics of Nanostructures, Bielefeld University, Universitätsstraße 25, 33615 Bielefeld

Off-stoichiometric Ni-Mn-Sn is a ferromagnetic shape memory alloy (FSMA) in certain Mn-rich compositions. The studied alloy shows a phase transformation during cooling from a cubic high temperature austenite phase to a martensite phase with lower symmetry. Subsequent heating leads to the inverse transformation back to austenite. We have produced highly epitaxial $Ni_{51.6}Mn_{32.9}Sn_{15.5}$ thin films of thicknesses between 200 nm and 20 nm on MgO substrates via cosputtering. The dependency of the martensitic transition on the film thickness was determined by conductivity and anomalous Hall effect (AHE) measurements in the temperature range between 20 K and 340 K. These measurements give us information about the transformation characteristics such as transition temperatures, temperature dependent saturation magnetization and the amount of transforming material for the different films. The AHE is used to analyze the scattering mechanisms during the transformation.

MA 45.6 Thu 16:15 H 0112

Hysteretic aspects of the inverse magnetocaloric effect in martensitic alloys. — Mehmet Acet[1], •Ivan Titov[1], Antoni Planes[2], Lluis Mañosa[2], David Gonźalez-Alonso[2], and Thorsten Krenke[3] — [1]Fachbereich Physik, Experimentalphysik, Universität Duisburg-Essen, D-47048 Duisburg, Germany — [2]Facultat de Fisica, Departament d'Estructura i Constituents de la Matéria, Universitat de Barcelona, Diagonal 647, E-08028 Barcelona, Catalonia, Spain — [3]Thyssen Krupp Electrical Steel GmbH, D-4588 1 Gelsenkirchen, Germany

The presence of a large positive entropy change around the martensitic transformation in $Ni_{50}Mn_{35}Sn_{15}$ and in $Ni_{50}Mn_{33.5}In_{16.5}$ is expected to lead to substantial cooling on applying a magnetic field. However, unlike in Ni-Mn-In, the relatively low temperature-shift of the hysteresis with applied field in Ni-Mn-Sn could limit cooling. In both cases we measure direct temperature-change on applying a magnetic field around the reverse and forward branches of the martensitic transition. In Ni-Mn-Sn we initially detect cooling on applying a magnetic field (inverse MCE) and again further cooling on removing the field (conventional MCE). When the field is reapplied once more we detect only warming due to the irreversibility of the metallurgical state of the alloy. In Ni-Mn-In, the temperature change is largely reversible due to the strong shift in the martensitic transformation temperature with applied field. In this case the metallurgical state of the sample can be partially recovered. The results are discussed in relation to the form of the hysteresis and its thermal shift with applied magnetic field.

MA 45.7 Thu 16:30 H 0112

Twin boundaries in trained 10M Ni-Mn-Ga single crystals — •Robert Chulist[1], Alexei Sozinov[2], Ladislav Straka[2,3], Thomas Lippmann[4], Carl-George Oertel[1], and Werner Skrotzki[1] — [1]Institut für Strukturphysik, Technische Universität Dresden, D-01062 Dresden, Germany — [2]AdaptaMat Ltd., Yrityspiha 5, Helsinki, FIN-00390, Finland — [3]Laboratory of Engineering Materials, Aalto University, PL 14200, FIN-00076 AALTO, Finland — [4]Institut für Werkstoffforschung, Helmholtz-Zentrum Geesthacht, D-21502 Geesthacht, Germany

The arrangement of twin boundaries in trained 10M Ni-Mn-Ga single crystals was investigated by electron backscatter diffraction (EBSD) in the scanning electron microscope. Precise monoclinic structure data including direction of modulation were used to determine all possible boundaries. Besides type I, II and compound twins typical for monoclinic symmetry a boundary between two directions of modulation was also detected. Compared to EBSD analysis done with simple tetragonal structure for 10M Ni-Mn-Ga alloys, a more complex microstructure with new boundaries is revealed. The crystallographic results have also been confirmed by diffraction of high-energy synchrotron radiation.

15 min. break

MA 45.8 Thu 17:00 H 0112

Blocking effects of twinning microstructure in Ni_2MnGa thin films — •Tobias Eichhorn, Richard Hausmanns, Peter Klaer, Hans-Joachim Elmers, and Gerhard Jakob — Institut für Physik, Johannes Gutenberg-Universität Mainz, 55099 Mainz

The Heusler compound Ni_2MnGa is one of the rare materials showing a shape memory effect that can be controlled by an external magnetic field. Huge magnetic-field-induced strains (MFIS) of almost 10 % have been demonstrated for bulk single crystals, which makes the compound interesting for actuator applications. Freestanding epitaxial films, as prepared in this work, open up possibilities for miniaturized devices. So far the absence of MFIS in thin film samples at ambient temperature hinders technical implementation. We identify the twinning microstructure, as induced by the film-substrate interaction, to be responsible for blocking effects. The detailed variant configuration and twinning structure for different crystallographic orientation is studied by means of X-ray diffraction and microscopy methods. While (100) oriented samples show an entangled twinning structure, films of (110) orientation possess a promising martensite structure.

Complementary to magnetometry we employ X-ray magnetic circular dichroism measurements to uncover the origin of the magnetocrystalline anisotropy in the system.

This work is part of the DFG priority program SPP 1239.

MA 45.9 Thu 17:15 H 0112

Vibrational properties of Ni-Mn-Ga ferromagnetic shape memory alloys in the austenite phase — •Semih Ener[1], Jürgen Neuhaus[1,2], and Winfried Petry[1,2] — [1]Technische Universität München, Lehrstuhl für Funktionelle Materialien, Garching, Germany — [2]Technische Universität München, Forschungsneutronenquelle Heinz Maier-Leibnitz (FRM II), Garching, Germany

In the ferromagnetic shape memory Ni-Mn-Ga alloys the structural transition can be driven either by an external magnetic field or temperature. In this work we investigate the effect of temperature on the vibrational properties of Ni_2MnGa and $Ni_{49}Mn_{32}Ga_{19}$ in the austenite phase by using mainly inelastic neutron scattering. The measurements were done at the Forschungsneutronenquelle Heinz Maier-Leibnitz (FRM II), Garching. The Born-von Kármán model is applied to the Ni_2MnGa full phonon dispersion in the austenite phase and macroscopic properties are calculated from this model. The effect of temperature on the phonon softening in TA_2[110] phonon branch is investigated in detail in a wide temperature range for both Ni_2MnGa and $Ni_{49}Mn_{32}Ga_{19}$. The relations between the phonon softening and the structural transition are well understood for both compositions but the effect of magnetic ordering is not comprehended especially for the off-stoichiometric composition.

MA 45.10 Thu 17:30 H 0112

Correlation Between Microstructure and Magnetic Properties in Epitaxial Ni-Mn-Ga Thin Films — •Gesa Welker[1], Aleksej Laptev[1], Mikhail Fonin[1], Yuansu Luo[2], and Konrad Samwer[2] — [1]Fachbereich Physik, Universität Konstanz, 78457 Konstanz — [2]I. Physikalisches Institut, Georg-August-Universität Göttingen, 37077 Göttingen

Ni-Mn-Ga and related alloys exhibit a magnetic shape memory effect and have been subject to research due to their large magnetic field induced strain of up to 10% [1]. So far, only few investigation of their magnetic domain structure has been done on thin films [2].

Here we investigate the morphology and magnetic domain configurations in epitaxial Ni-Mn-Ga thin films grown on MgO(001) substrates by dc-magnetron sputtering [3] as well as in free-standing microstructures released from the rigid substrate by etching. We investigated Ni-Mn-Ga films of different compositions and thicknesses at varying temperatures by means of atomic force microscopy (AFM) and magnetic force microscopy (MFM) in remanence. In the martensitic state we found large domains with out-of-plane magnetization. The domain walls are oriented perpendicular to the martensitic twin boundaries direction. On a smaller scale, the magnetic domain structure is governed by the orientation of the easy axis of the martensitic variants.

Our results could be helpful for the construction of microscale actuators or sensors based on Ni-Mn-Ga thin films.[1] K. Ulakko et al.,Scripta Mater. 36, 1133-1138 (1997)[2] Q. Pan et al., J. Appl. Phys. 91, 7812-7814 (2002)[3] Y. Luo et al., J. Phys. 13, 013042 (2011)

MA 45.11 Thu 17:45 H 0112

Influence of the addition of platinum on the magnetic shape memory alloy Ni_2MnGa — •Mario Siewert, Markus E. Gruner, Heike C. Herper, and Peter Entel — University of Duisburg-Essen, Faculty of Physics

We have studied the influence of the addition of platinum on the magnetic shape memory alloy Ni_2MnGa by means of *ab initio* calculations. In particular, the quaternary system $Ni_{2-x}Pt_xMnGa$ was studied for $0 \leq x \leq 2$. As a main result, the preference of a tetragonal distortion increases with the amount of Pt that is added to the system. The increased preference of the tetragonal $L1_0$-structure goes hand in hand with the onset of antiferromagnetic tendencies in the Pt-rich alloys. The martensitic trends which are observed in the phase diagram of Ni-Mn-Ga are also observed for the alloy systems containing platinum. In particular, the transformation temperature can be further increased when substituting Ga by Mn which introduces additional antiferromagnetic tendencies. The modulated 14M structure which is responsible for the magnetic shape memory effect in Ni_2MnGa, also appears in systems with excess Pt. It turns out that the shape memory effect is about 14% and therefore larger than in Ni_2MnGa.

MA 45.12 Thu 18:00 H 0112

Mapping local elasticity of twinned martensitic NiMnGa films using atomic force acoustic microscopy — •Yuansu Luo[1], Walter Arnold[1,2], and Konrad Samwer[1] — [1]I.Physikalisches Institut, Universität Göttingen — [2]Fachbereich Werkstoffwissenschaften der Universität des Saarlandes, Saarbrücken

Local elasticity of magnetic shape memory films NiMnGa was mapped qualitatively and quantitatively on nanometer scale by means of atomic force acoustic microscopy (AFAM). The films (100nm) used were prepared on MgO substrates by magnetron sputtering. The first bending resonance vibrations of the AFM cantilever were measured by sweeping the frequency from 0.5 to 3MHz. Different contact stiffness was measured in this way for martenstic twin variants due to their anisotropic crystallography. Broad and multi-resonance behavior was observed, reflecting the damping and multi-variant properties of 7-layer modulated martensite. The stiffness image mapped by the measured resonance frequency exhibits however a contrast opposite to the height image mapped by conventional AFM. The result can be associated with the mobility of twin boundaries, namely they are mobile at the top and immobile at bottom of twin lamellas. The load dependent contact indentation was measured. A softening emerges at a critic force and can be contributed to moving of twin boundaries under the local mechanical load. The local elastic moduli were calibrated by a standard sample (SrTiO3). The values evaluated are in the range from 170 to 230 GPa, enlarged by a factor of about 10 compared to stress-free bulk samples. (Supported by BMBF-13N10061)

MA 45.13 Thu 18:15 H 0112

Martensitic and magnetic microstructure of epitaxial Ni-Mn-

Ga films — •Anett Diestel[1,2], Anja Backen[1,2], Volker Neu[1], Sandra Kauffmann-Weiss[1,2], Ludwig Schultz[1,2], and Sebastian Fähler[1] — [1]IFW Dresden, Institute for Metallic Materials, P.O. Box 270116, 01171 Dresden, Germany — [2]Dresden University of Technology, Department of Mechanical Engineering, Institute of Materials Science, 01062 Dresden, Germany

The modulated 14M martensite phase of the magnetic shape memory (MSM) alloy Ni-Mn-Ga shows huge strains up to 10 % by magnetically-induced reorientation of martensitic variants. The interaction between the crystallographic short and the magnetic easy axis is an essential requirement for the MSM effect. For Ni-Mn-a bulk materials a staircase-like domain pattern with 90°- and 180°-domain walls is already known. To understand this interaction in thin films we analyzed the martensitic and magnetic microstructures of epitaxial Ni-Mn-Ga films of different thicknesses by atomic and magnetic force microscopy. The observed domain pattern of thin epitaxial films differs considerably from the bulk concept. Due to the reduced variant width magnetic exchange coupling has to be considered. An interaction between the martensitic microstructure and the magnetic out-of-plane stripe domain pattern was established and a correlation between the domain width periodicity Λ_{DW} and the film thickness d according to $\Lambda_{DW} \sim d^{1/2}$ was identified in good agreement with the theoretical band domain model of Kittel. This work was funded by DFG through SPP 1239.

MA 45.14 Thu 18:30 H 0112

High resolution surface study of modulation in martensites.

— •Aleksej Laptev[1], Mikhail Fonin[1], Yuansu Luo[2], Konrad Samwer[2], Emmanouel Pagounis[3], and Markus Laufenberg[3] — [1]Fachbereich Physik, Universität Konstanz, 78457 Konstanz — [2]I. Physikalisches Institut, Georg-August-Universität Göttingen, 37077 Göttingen — [3]ETO MAGNETIC GmbH, 78333 Stockach, Germany

In our work we address the preparation of high-quality surfaces of Ni-Mn-Ga single crystals with different stoichiometries as well as of epitaxial Ni-Mn-Ga films [1] and the investigation of their surface structure down to the atomic scale by variable temperature scanning tunneling microscopy (VT-STM) in ultra-high vacuum (UHV) conditions. The (001)-oriented sample surface was studied at different temperatures in both austenitic and martensitic phase. The samples reveal on the nanometer scale in the martensitic state a pronounced surface corrugation which was shown to arise from the modulation in martensites [2]. For off-stoichiometric samples seven- (films) and ten-layered (single crystal) modulation periodicities were found. Atomically resolved pictures reveal atomic rows stacked in sequences with varying periods and occasional stacking faults. On the other hand the stoichiometric single crystal with the 5M modulation shows a very regular modulation periodicity and a different shape of the modulation corrugation. This work was supported by the BMBF-Projects MSM-Sens 13N10061 and 13N10062.

[1] Y. Luo et al., *New J. Phys.* **13**, 013042 (2011).
[2] P. Leicht et al., *New J. Phys.* **13**, 033021 (2011).