9th JEMS Conference 2018
Joint European Magnetic Symposia
3rd – 7th September 2018 • Mainz • Germany
General Chair: Prof. Dr. Jairo Sinova
Co-General Chair: Prof. Dr. Mathias Kläui
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SP 6 Magnetic shape memory, magnetoelastic and multifunctional materials

SP6 - Parallel Session 1

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SP6.1.02

Flexible strain direction sensing devices based on magnetoresistive and magnetoelastic effects

S. Ota, H. Matsumoto, A. Ando, C. Daichi

Text The magnetoelastic effect depends on the sign and the magnitude of the magnetostriction constant of the ferromagnetic materials. When a uniaxial tensile strain is applied, positive (negative) magnetostrictive materials acquire magnetic easy (hard) axis parallel to the strain direction. On the other hand, in a giant magnetoresistive (GMR) device the resistance of the device depends on relative magnetization angle of magnetic layers separated by a non-magnetic layer. Thus, when a stress is applied to two magnetic layers with different magnetostriction constant, relative magnetization angle is modulated and resistance changes. However, these approaches have so far focused on sensing only the magnitude of the strain. Here, we show that a flexible GMR device can be used to detect the direction of strain in a material [1]. A NiFe layer is used as a strain insensitive (zero magnetostriction) layer and a Co layer as a strain sensitive (positive magnetostriction) layer. Tensile strains was applied to different directions and the clear resistance dependence on the strain angle was detected.

[1] S. Ota et al., Nature Electronics **1,** 124 (2018)

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Innovative technique for thin films magnetostriction measurements by scanning probe microscopy

M. Coïsson, M. Cialone, W. Hüttenes, Z. Barber, P. Rizzi, P. Tiberto

Text The direct measurement of magnetostriction in thin films poses serious challenges and requires subnanometer precision in the measurements, that can be achieved by depositing a magnetostrictive film on cantilevers. The expansion or compression of the ferromagnetic film, resulting from application of an external magnetic field, induces a stress on the cantilever that bends upward or downward, according to the direction of the applied field and the sign of the magnetostriction coefficient. In this work we present an alternative to the standard capacitive or optical methods used to measure the deflection of such a bimorph. The working principle is based on exploiting the sub-nanometer precision of a standard atomic force microscope. The vertical displacement of the cantilever is measured in fixed-point contact mode under the application of a variable magnetic field. Standard AFM cantilevers are coated by sputter-deposited, magnetostrictive $Fe_{80}Al_{20}$ (wt.%) films as thin as 70 nm. The measurement technique is discussed and the cantilever deflection values as a function of applied magnetic field and thin film thickness are analysed. The technique is shown to be viable and able to detect cantilever deflections of just a few nanometers.

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SP6.1.04

Influence of atomic disorder on the ground state of Ni-Co-Mn-Sn alloys with regular and inverse Heusler structures

V. Sokolovskiy, V. Buchelnikov, B. Barbiellini, M. Zagrebin

Text Co-doped Ni-Mn-Sn shape memory alloys have drawn a lot of attention in recent years. The Co doping leads to a decrease in both the martensitic transformation temperature and Curie temperature of martensite and to an increase in the Curie temperature of austenite. Besides, the large change in a magnetization in the vicinity of structural transformation can occur. As a result, the tuning of Co and Mn contents can achieve the better magnetocaloric properties [1].

In this work, we focus on the effect of atomic disorder on the structural, magnetic and electronic properties of Ni-Co-Mn-Sn systems by using ab intio calculations, which were based on the density functional theory implemented in the VASP and SPR-KKR packages [2, 3] within the 32-atom supercell and coherent potential approximation, respectively. The ground state calculations were performed for two compositions (Ni13Co3Mn13Sn3 (regular Cu2MnAl-type: #225) and Mn13Co3Ni13Sn3 (inverse Hg2CuTi-type: #216)). It should be noted that the optimized atomic positions for compositions studied were obtained by the USPEX package [4]. With respect to the exchange-correlation potential, a series of ground state calculations were performed using both the GGA-PBE functional and Meta-GGA with SCAN functional [5].

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On the symmetry of the martensitic transformation in Ni_2MnGa

F. Orlandi, A. Cakir, P. Manuel, D. Khalyavin, M. Acet, L. Righi

Text Martensitic transformations are strain driven, displacive transitions pivotal in determining the material's mechanical and physical properties. This is the case in Ni_2MnGa, where the martensite transition is at the basis of the striking magnetic shape memory and magneto-caloric properties. Interestingly, the martensitic transformation is preceded by the premartensite phase, and the role of this precursor and its influence on the martensitic transition and properties is still matter of debate. In this talk we will report the influence of Co doping (up to 10%) on the martensitic transformation path in stoichiometric Ni_2MnGa by neutron diffraction. Small amounts of Co induces a tetragonal strain of the Heusler lattice in the premartensite that increase linearly with the decrease of the temperature, eventually leading to the final modulated martensite. Increase of the doping induces the disappearance of the premartensite in favour of a single step martensite transformation. The use of the superspace formalism to describe the symmetry of the modulated martensite phases, joined with a careful group theoretical analysis allows determining the relations and the different distortions present in the transformation. Finally, a general Landau thermodynamic potential of the martensitic transformation, outlined on the basis of the symmetry analysis, is described highlighting the relation between the structural distortions at the basis of the Ni_2MnGa physical properties.

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Prediction of new quaternary Heusler compounds with half-metallic ferromagnetism and large Curie temperatures

B. Sanyal, A. Kundu, S. Ghosh, R. Banerjee, S. Ghosh

Text Spintronic materials with half-metallicity and high Curie temperatures are perpetually sought for. Here, we present an ab initio study based on density functional theory to explore the structural, electronic and magnetic properties of quaternary Heusler compounds CoX'Y'Si where X' is a transition metal with 4d electrons and Y' is either Fe or Mn. We find five new half-metallic ferromagnets with spin polarisation nearly 100% with very high Curie temperatures. The variation of Curie temperatures as a function of valence electrons can be understood from the calculated inter-atomic exchange interaction parameters. We also identify a few other compounds, which could become half-metals by application of pressure or with controlled doping. Our results reveal that the half-metallicity in these compounds is intricately related to the arrangements of the magnetic atoms in the Heusler lattice and hence, the interatomic exchange interactions between the atomic moments. Our findings may act as a suitable guideline to experimentally synthesize and characterize these predicted compounds.

Reference:

A. Kundu, S. Ghosh, R. Banerjee, S. Ghosh and B. Sanyal, Sci. Rep. 7, 1803 (2017).

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SP6.1.07

Origin of the enhanced magnetostriction of Galfenol at high Ga contents

S. Gallego, J. Cerdá

Text Finding rare-earth free alternatives is of utmost importance in diverse fields of magnetism. Galfenol, a bcc Fe-Ga alloy, plays this role in the search for efficient magnetostrictive materials, due to its high magnetostriction coefficient, ductility and chemical stability. Recent years have witnessed a significant research effort devoted to understand the magnetostriction of Galfenol at moderate Ga contents below 20% Ga. The rich field diagram of Fe-Ga phases and the existence of disorder make of this a complex task, but there are evidences that the nucleation of Ga pairs (B2-like structure) in a disordered FeGa matrix is responsible of the enhanced anisotropy and the emergence of a tetragonal distortion ultimately increasing the magnetostriction coefficient λ_{100}.

However, the abrupt decay of the magnetostriction as the Ga content increases over 20% and the emergence of a higher second maximum of λ_{100} at 30% Ga remain puzzling. Here we present a detailed study of the distribution of Ga atoms in Galfenol for concentrations in the range between both maxima, based on ab initio density functional theory. Our calculations evidence the existence of a change of regime in the Ga distribution at Ga contents around 25%, with consequences in the structural and magnetic properties. The results point to intrinsic differences in the origin of the first and second λ_{100} peaks of Galfenol, offering new perspectives to enhance and tune the magnetostriction of Fe-Ga alloys.

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SP6.2.02

Spin transport in graphene on $SrTiO_3$ and its temperature dependence

S. Chen, R. Ruiter, V. Mathkar, B. van Wees, T. Banerjee

Text Graphene is a promising material in spintronics with predicted intrinsic spin relaxation time up to 1 μs and extremely high mobilities. In this work, we report on the first study of spin transport in graphene on an electronically rich platform of $SrTiO_3$ (STO). We obtain spin relaxation time and spin relaxation length as large as 1.2±0.1 ns and 5.6±0.5 μm respectively in graphene on STO using non-local geometry. Temperature dependent studies of transport show the interdependence of the increasing dielectric constant with decreasing temperature as well as the influence of the surface dipoles in STO on spin transport in graphene. Furthermore, using STO as a back gate, we study the gate dependent spin transport in graphene on STO, which shows higher spin relaxation time at positive gate voltage. From the gate dependent spin transport parameters, the relationship between spin relaxation time and momentum relaxation time can be extracted, indicating a predominance of Elliot-Yafet type spin relaxation in graphene.

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SP6.2.03

Domain wall pinning in magnetic shape memory alloys with small and enlarged magnetic hysteresis

L. Straka, L. Fekete, O. Heczko

Text In magnetic shape memory alloys (MSMAs), the ferroelastic martensite microstructure is coupled to ferromagnetic domain structure. This coupling enables unique magneto-mechanical effects such as giant, up to 12%, magnetic field induced strain (MFIS). Magnetic hysteresis or coercivity is typically small in Ni-Mn-Ga-based MSMAs but can be enlarged by boron doping and/or heat treatment. The enlarged hysteresis enables novel magneto-mechanical effects such as mechanically-induced degaussing.

We investigate the mechanisms of domain wall pinning in Ni-Mn-Ga MSMAs. Magnetic domains are observed using magnetic force microscopy. We compare the magnetic domain pattern in single crystals exhibiting MFIS and small magnetic hysteresis with the magnetic domain pattern in single crystals exhibiting MFIS and large magnetic hysteresis.

Clear correlation between the magnetic domain pattern and the location of antiphase boundaries confirms that the domain walls are pinned frequently on antiphase boundaries in single crystals with small magnetic hysteresis. In single crystals with large magnetic hysteresis, the magnetic domains are much finer corresponding to much finer density of antiphase boundaries. Thus, the antiphase boundaries are an important factor governing the magnetic structure and the hysteresis of Ni-Mn-Ga MSMAs. The control of antiphase boundaries is therefore crucial for the design of new MSMAs with large hysteresis and novel magneto-mechanical effects.

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Engineering Hierarchical Martensite Twins in Epitaxial Magnetic Shape Memory Films by Tuning Growth Conditions and Post-Growth Treatments

M. Takhsha Ghahfarokhi, F. Casoli, S. Fabbrici, R. Cabassi, F. Celegato, P. Tiberto, L. Nasi, F. Albertini

Text Ferromagnetic shape memory alloys (FSMA) such as NiMnGa thin films show a strong coupling between magnetic and structural degrees of freedom, which makes them a promising candidate for smart micro and nano-device applications [1]. The ability to control the microstructure at different length scales is of particular interest for the magnetic field induced strain applications. In low-temperature ferromagnetic phase, NiMnGa film consists of differently oriented twins [2,3]. Magnetic properties can be tuned by engineering these twin microstructures [4].
In the present study, NiMnGa films (75-200nm) were epitaxially grown on MgO (100) at 200-380°C using RF sputtering technique. The deposition rate was 3.83 to 6.03nm/min. Morphology, composition, and microstructural characterizations were performed using AFM, SEM, EDS, XRD, and TEM. Magnetic configuration and behavior were studied by MFM, AGFM, and SQUID. Samples were post-treated by annealing, mechanical stress, and magnetic field cooling.
We found that hierarchical configuration of twins and magnetic properties of substrate-constrained films can be manipulated by growth temperature, post-heating, mechanical stress, and field cooling.
References:
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Magnetic characteristics of polycristalline NiTi film

A. Kyianytsia, C.-S. Chang, I. Cinar, R. Lima de Miranda, P. Boulet, E. Gaudry, S. Migot, J. Ghanbaja, B. Kierren, L. Calmels, T. Hauet

Text Although Nitinol physical properties have been heavily studied along with the development of a wide range of applications in industry, military technologies and health care, its magnetic characteristics have been only rarely discussed in the litterature. For instance, some works have been motivated by magnetic resonance imaging artifacts due to the paramagnetic signal from NiTi devices [1]. Here we measured, with commercial SQUID and VSM, the paramagnetic features of a freestanding 20µm thick NiTi polycristalline samples grown by DC magnetron sputtering [2], as a function of magnetic field, temperature and strain. We correlated them with NiTi lattice structure features characterized by TEM and XRD techniques. We showed that structural transformation from B2 to B19 phase(and vis-versa, and including R phase) can be easily revealed from non-invasive magnetometry measurements. Finally, the origin of the paramagnetic signal observed in our NiTi film, as well as its behavior under temperature and strain variation, was investigated in comparing our experimental data to ab-initio calculations and data from the literature.

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[2] R. Lima de Miranda, C. Zamponi, and E. Quandt, Adv. Eng. Mater., 15, 66 (2013)

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Origin of modulation in Ni2Mn1.4In0.6 magnetic shape memory alloy

P. Devi, S. Singh, E. Suard, K. Manna, C. Felser, D. Pandey

Text Ni-Mn based magnetic shape memory alloys shows the structural modulation in low temperature martensite phase. This structural modulation can be explained on the basis of atomic displacement which can be uniform or non-uniform. The martensite phase in Ni2MnGa shows the presence of non-uniform displacement of atoms from their mean positions and phason broadening of satellite peak, follow the soft phonon model [1]. On the otherhand there is no experimental evidence of uniform atomic displacement till now. Here, we present results of a combined temperature dependent high-resolution synchrotron x-ray powder diffraction and neutron diffraction study of phase transition using (3+1)D superspace group approach in Ni2Mn1.4In0.6. Our results show that the martensite phase in Ni2Mn1.4In0.6 results from the austenite phase with uniform atomic displacement assumed in adative phase model, unlike in Ni2MnGa [2]. Our study suggests that the origin of phase modulation may not be universal in different Ni-Mn based magnetic shape memory Heusler alloys.

References:-

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SP6.2.07

Magneto-optical study of spiral domains in amorphous microwires

A. Chizhik, A. Zhukov, J. Gonzalez, P. Gawroński, K. Kułakowski, A. Stupakiewicz

Text The aim of the present study was the search of new types of domain structure in the frame of the optimization of microwire application in magnetic sensors. The investigation has been performed by a magneto-optical Kerr microscopy.
As a result of our study we have found the surface domain structure of spiral type. We have determined the main properties of this type of domain structure. This structure is characterized by the extremely long domain walls. The angle of the inclination of spiral structure depends on the external mechanical torsion stress and may vary from 0 to 90 degree relatively the axial direction of microwires. The giant magneto-impedance (GMI) dependences on magnetic field have been analyzed in terms of spiral domains influence.
Micromagnetic simulations have been performed using mumax, taking into account the spatial distribution of internal magnetoelastic stress. Local magnetoelastic anisotropy is approximated to be uniaxial, with spatial dependence due to the stress distribution. The results of the analysis basically coincide with the results of the magneto-optical experiments. The spiral domains are located close to the surface that determines their contribution to the GMI effect.
Discovering the new type of magnetic domain structure in microwires we have expanded the possibilities of predicting and controlling the behavior of the magnetic system of microwires.