SP 10 Magnetic materials for energy applications

SP10 - Parallel Session 1

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SP10.1.01

Fe_5PB_2 and its alloys with Co and 5*d* elements as candidates for rare-earth free permanent magnets

M. Werwinski, A. Edstroem, J. Rusz, D. Hedlund, K. Gunnarsson, P. Svedlindh, J. Cedervall, M. Sahlberg

Text Fe_5PB_2 - identified as promising candidate for permanent magnets [1-3] - with relatively high values of magnetization, Curie temperature and easy-axis magnetocrystalline anisotropy - is investigated computationally with use of full potential full relativistic *ab initio* methods (FPLO, WIEN2k, and SPR-KKR codes). Whole range of Fe/Co substitutions is considered, followed by modeling of 5% doping of 5*d* and 6*p* elements [4]. Research is aimed at finding an optimal composition with the highest magnetocrystalline anisotropy energies (MAE). Calculated MAEs are correlated with spin and orbital magnetic moments. Furthermore, spin moments are considered as parameter in relativistic version of fixed spin moment (FSM) method. The Curie temperatures are calculated based on disorder local moment (DLM) model of paramagnetic state. Moreover, maps of MAE resolved in reciprocal space are combined with Fermi surfaces which gives microscopic picture of MAE origins and introduce new approach to MAE engineering. The alloys with the highest MAE (above 1 MJ m^{-3}) are Fe_5PB_2 with 5 at.% W or Re in place of Fe. $(Fe,Co)_5PB_2$ alloys are also investigated experimentally in respect of anisotropy constants. First author was supported by FNP grant HOMING.

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SP 10 Magnetic materials for energy applications

SP10 - Parallel Session 1

SP10.1.02

Possible highest performance of permanent magnet materials

H. Akai

Text Based on the density functional theory, we conclude that the possible upper limits of saturation magnetic polarization, magnetic transition temperature, and magnetocrystaline anisotropy constant of permanent magnet materials could be ~2.7 T, ~2000 K, and ~1000 MJ/m^3, respectively. It is suggested that a strategy to reach these values for high-performance permanent magnets is to design Fe-based magnets containing a small amount of light rare earth element together with some additional elements including V, Cr, Co, Ni, and possibly typical elements such as B, C, N as interstitials. The idea of realizing high-performance permanent magnets without rare earth elements might not be very realistic.

SP 10 Magnetic materials for energy applications

SP10 - Parallel Session 1

SP10.1.04

Influence of *Sn* substitution on the magnetic and magnetocaloric properties of $Ni_2Mn(In,Sn)$ alloys

G. Cavazzini, F. Cugini, C. Bennati, S. Fabbrici, L. Righi, F. Albertini, M. Solzi

Text The flexible structure of Ni_2MnX Heusler alloys (*X*= *Ga,In,Sn,Sb*) allows, by changing composition, the tuning over a large temperature range of both a second-order and a first-order magnetic transition. This peculiar characteristic is of great interest for application in energy-conversion thermomagnetic devices. In particular, the $Ni_{50}Mn_{35}In_{15}$ alloy shows an austenitic phase with a large ground-state moment and a Curie transition little above RT, at which a large and fully reversible magneto-caloric effect is associated. In this work, we study the magnetic, structural and magnetocaloric features of the $Ni_{48}Mn_{36}In_{16-x}Sn_x$ (*x*= 0-16) alloys series. All the realized samples show a ferromagnetic austenitic phase stable down to 5 K, with the Curie transition that follows a not predictable trend: it decreases with increasing *Sn* up to 8 at. %, while it abruptly rises. This cannot be explained by a possible variation of the *Mn-Mn* distance, being the cell parameter practically unchanged along the series. On the contrary, saturation magnetization linearly decreases with *x*. DFT calculations suggest as a possible explanation the change of the moment on *Ni* atoms due to the presence of *Sn*. Such behaviour determines the observed linear variation with *x* of both the adiabatic temperature change and the isothermal entropy change. These results highlight the occurrence of different physical mechanisms that separately control the saturation magnetization and the critical temperature of the alloy.

SP 10 Magnetic materials for energy applications

SP10 - Parallel Session 1

A Magnetic Composite Approach For Harvesting Energy from Wideband Low Frequency Vibrations

M. A. Khan, J. Kosel

Text Harnessing the vast untapped potential of ambient low frequency vibrations is an attractive solution to power the multitude of electronic systems that make up the Internet of Things.
The energy harvester presented in this work has three components: (i) a magnetic composite (MC) proof mass, (ii) a 10x10 array of hair like MC structures and (iii) a planar microfabricated coil. The MC is made by mixing polydimethylsiloxane (PDMS) with permanent magnetic NdFeB micropowder. It is then molded to form an array of high aspect ratio (10:1 i.e. 200 µm wide and 2 mm tall), highly flexible pillars with the MC proof mass affixed on top of it. This structure occupies a volume of 1.44 cm^2 and has two resonant modes in close proximity to each other, resulting in a broadband frequency response. Underneath this structure is a planar coil, which occupies an area of 1 cm^2. Ambient vibrations are efficiently converted into an oscillating magnetic field by the composite structure. This magnetic field is in turn converted into an electric voltage by the planar coil.
This harvester generates an open circuit voltage of amplitude 868µV at 52 Hz, when subject to a 3g vibration. It has a second resonant peak at 61 Hz. The operating band of this energy harvester is from 49 Hz to 68 Hz. Its r.m.s. power density is $1mW/m^3$, when coupled to a matched load, which is 3 orders of magnitude better than the previous best results for an MC energy harvester.

SP 10 Magnetic materials for energy applications

SP10 - Parallel Session 1

SP10.1.06

Structure, magnetism of MnxFe2-xP0.6Si0.4 compounds

X. You, M. Maschek, N. van Dijk, E. Brück

Text Magnetocaloric materials (MCMs) show great potential for utilization in magnetic refrigeration techniques and energy conversion methods in thermomagnetic generators (TMGs). A thermomagnetic motor (TMM) prototype utilizing Gd was built by Swiss Blue Energy and can convert low-temperature waste heat to electrical or mechanical energy. To enhance the efficiency, appropriate advanced magnetocaloric materials having strong magnetization changes with low hysteresis should be used to replace Gd.
Materials with suitable Curie temperatures and small hysteresis can be found in the quaternary (Mn, Fe)2(P, Si) system. To find suitable compounds, a large fraction of the phase diagram of MnxFe2-xPi-ySiy (0<Mn< 2, 0.33≤Si≤0.6) has been investigated.
Suitable materials for applications having Curie temperatures around room temperature, large magnetization changes and small hysteresis can be found in the Mn-rich (x >1.2) and Fe-rich (x<0.7) region. Furthermore, we observe an antiferromagnetic (AFM) to paramagnetic (PM) phase transition for Mn1.9Fe0.1P0.6Si0.4. X-ray diffraction shows that all the MnxFe2-xP0.6Si0.4 compounds with 0.5<x<1.9 crystallize in Fe2P-based hexagonal structure. The lattice parameter a expands with increasing manganese content. The lattice parameter c expands with increasing Manganese concentration for Mn concentration (0.3<x< 1) and then shrinks for Mn concentration (x >1). The transition temperature decreases with increasing manganese concentration.

SP 10 Magnetic materials for energy applications

SP10 - Parallel Session 1

SP10.1.07

Tuning direct and inverse magnetocaloric effect in Ni-Mn-In Heuslers for room temperature magnetic refrigeration

C. Bennati, S. Fabbrici, F. Cugini, A. Pepiciello, R. Cabassi, D. Calestani, C. Visone, M. Solzi, F. Albertini

Text Room temperature magnetic refrigeration (MR) requires materials with large and reversible magnetocaloric effect, i.e. isothermal entropy change (ΔS_m) and adiabatic temperature (ΔT_{ad}) changes at room temperature for applied fields < 2T.
Ni-Mn-In based Heuslers hold a great promise thanks to their huge inverse magnetocaloric effect (MCE) at the martensitic transformation, yet the associated hysteresis is detrimental for ther cyclic exploitation in MR. In this contribution, by taking advantage of the great flexibility of Heuslers compunds due to the possibility of chemically tuning magnetic and structural transitions (number, order, critical temperatures), we have explored two strategies to overcome irreversibility: (i) samples with second order transitions close to room temperature and (ii) samples with converging magnetostructural and Curie transitions, which display a quasi-superposition of direct and inverse MCEs.
$Ni_{2+x}Mn_{1+y}In_{1+z}$ (x+y+z=0) alloys of different composition and with partial substitutions by Cu and Fe were prepared by arc melting. The compositions were tuned to obtain transition temperatures close to RT. Their structural and magnetic properties were fully characterized. In-field calorimetry and ΔT_{ad} measurements were performed to reveal the reversible and irreversible contributions to the MCE. By studying the ΔT_{ad} curves we will also discuss the possibility to exploit the concurrent direct and inverse MCEs in alternative refrigeration cycles.

SP10 - Parallel Session 2

SP10 - Parallel Session 2

SP10.2.02

Atomic scale microstructure and local composition of recycled high performance $Nd_2Fe_{14}B$ permanent magnets for energy applications

U. Rohrmann, M. Schönfeldt, J. Gassmann, K. Güth, O. Gutfleisch

Text The increasing demand for renewable energy production and e-mobility results in a rapidly growing market for high performance permanent magnets. Heavy rare-earth enriched Nd-Fe-B magnets show excellent suitability for these applications. However, the supply of rare-earth elements is highly critical from an ecological and economic perspective, especially in the context of the current evolution of global economics. Europe has no significant natural mineral deposits of rare earth elements and is therefore fully dependent on the supply from non-EU countries. To ensure a safe supply of these critical resources it is therefore necessary to develop recycling strategies to obtain magnets with excellent properties from end-of-life products.

For the production of high energy density sintered permanent magnets a hydrogen-based powder metallurgical process was developed, using primarily scrap magnet material with a small addition of fresh NdH_2 and/or DyH_2 particles (2-6 wt.%). In this presentation, the recycled magnets are investigated by atom probe and scanning electron microscopy, in order to correlate the resulting microstructure and local composition with the bulk magnetic properties. The talk focuses on the distribution of oxygen, originating from the scrap magnet material, and the rare-earth metals that are added to adjust the composition in order to meet the delicate requirements for high remanence and high coercivity necessary for the efficient use in energy applications.

SP 10 Magnetic materials for energy applications

SP10 - Parallel Session 2

SP10.2.03

Tailored Metal Injection Moulding Of Isotropic NdFeB Hard Magnets Based On Recycled Powders With And Without Nd-Additions

B. Podmiljsak, C. Burkhardt, O. Weber, J. Gonzalez-Gutierrez, C. Kukla, M. Degri, I. R. Harris, A. Walton

Text As the raw materials used for permanent magnets production is critical to the low carbon future envisioned by the European Union, the Horizon 2020 project Resource Efficient Production of Magnets aims to address the issue of sustainability of RE permanent magnets by developing an innovative automated manufacturing route called SDS process (Shaping, Debinding and Sintering). This process will allow economically efficient production of net shape or near net shape magnetic parts with complex structures and geometries, whilst being waste-free through the use of fully recycled raw material and a 100% material efficiency in the consequent processing steps shaping, debinding and sintering. The REProMag SDS processing route is based on the use of powder obtained from end of life rare earth magnets by using the hydrogen processing for magnetic scrap (HPMS) process. A proprietary binder system has been developed for producing a mouldable SDS feedstock. NdFeB magnets were processed in modified injection moulding equipment that were consequently debinded and sintered under tailored conditions. The processing steps and their challenges, the influence of debinding and sintering conditions on the microstructure and magnetic properties of isotropic sintered SDS parts with and without Nd-additions are presented and discussed. Special attention is given to temperature control, gas pressure conditions and atmospheres during thermal debinding and sintering.

SP 10 Magnetic materials for energy applications

SP10 - Parallel Session 2

SP10.2.04

From binary Mn-Ga to ternary Mn-Al-Ga: the formation, stability and magnetic properties of the $L1_0$ structure

T. Mix, L. Schultz, T. G. Woodcock

Text The intrinsic magnetic properties of the $L1_0$ phase in binary Mn-Al and Mn-Ga alloys are highly promising for applications as rare earth free permanent magnets. Binary Mn-Ga alloys were produced in the range from 55 to 65 at.% Mn. The best intrinsic magnetic properties for permanent magnetic applications were found in $Mn_{55}Ga_{45}$. Improved extrinsic properties were obtained through the production of powder, which could also be partially aligned and hot compacted.
Although the thermodynamically stable nature of the $L1_0$ phase in Mn-Ga alloys is an advantage, the critical nature of global Ga supplies and the associated high raw materials cost precludes the use of Mn-Ga alloys in permanent magnet applications. A possible solution to this problem may be found in ternary Mn-Al-Ga alloys, where lower raw materials costs compared to Mn-Ga and higher thermal stability compared to Mn-Al may be achieved. To investigate the formation of the $L1_0$ phase, alloys of the form $Mn_{55}Al_{45-x}Ga_x$ with $0 \leq x \leq 45$ were produced. For alloys with $5 < x \leq 9$ a two-step heat treatment resulted in the formation of a stable and a metastable $L1_0$ phase in one sample, both with low Ga content. The magnetic properties of the ternary phases were equivalent or slightly superior to those of the binary analogues. Long term stability studies showed an improved of the thermal stability of the metastable phase compared to the binary Mn-Al system due to the addition of only a few atomic percent of Ga.

SP 10 Magnetic materials for energy applications

SP10 - Parallel Session 2

SP10.2.05

Development of permanent magnet properties in gas-atomized MnAl particles

J. Rial, P. Švec, E. M. Palmero, J. Camarero, P. Švec Sr., A. Bollero

Text The development of most technological devices (energy, transport and electronic systems) is directly linked to the use of permanent magnets (PMs) as fundamental constituents. The critical situation (geographical and environmental) of rare earth elements used in high-performance PMs could lead to a bottleneck for the development and growth of emerging technologies.
MnAl has been presented as an alternative to traditional NdFeB-based PMs. The high anisotropy of the ferromagnetic τ -phase and the low density of the MnAl make it one of the best candidates to substitute NdFeB in many light-PMs applications.
It has been reported recently that the stable and non-magnetic β -phase increases coercivity (H_c) in MnAl [1]. In this study, nanostructuraction through rapid milling by using unprecedented short milling times (< 5 min), followed by post-annealing, makes possible tuning dramatically morphology and microstructure, i.e. magnetic properties, in gas-atomized MnAl particles. In this manner we are able of producing isotropic MnAl powders with H_c (2.8 kOe) two times larger than that of the starting gas-atomized powder while maintaining remanence, and MnAl powder with a decreased remanence but H_c>4.5 kOe [2]. The extremely short processing times makes of this route a promising one to be used in the production of isotropic nanocrystalline MnAl powder with tailored PM properties.

[1] J. Rial et al., J. Phys. D: Appl. Phys. 50, 105004 (2017).
[2] J. Rial et al. Submitted.

SP 10 Magnetic materials for energy applications

SP10 - Parallel Session 2

SP10.2.06

Multicaloric effects in Magnetic Shape Memory Alloys

A. Gracia-Condal, M. F. Mor, A. Planes, T. Gottschall, K. P. Skokov, O. Gutfleisch, L. Manosa

Text Magnetic Shape Memory alloys are among the most promising caloric materials for solid-state refrigeration. They have been shown to exhibit giant magnetocaloric, barocaloric and elastocaloric effects under the influence of magnetic field, hydrostatic pressure and uniaxial stress, respectively.

The caloric response of materials subjected to more than one external field (i.e. multicaloric effect) is gaining considerable interest. It is expected that application of a secondary field can help in overcoming some of the main limitations existing for the practical uses of caloric materials such as hysteresis and the requirement of high magnetic fields. The cross-response of Magnetic Shape Memory alloys to both magnetic and mechanical fields make these materials excellent candidates for the study of multicaloric phenomena.

Here we report on the preliminary results from the study of the multicaloric response of a prototypical Magnetic Shape Memory alloy, Ni-Mn-In, by means of a bespoke differential scanning calorimeter which operates under the application of magnetic field and uniaxial stress.

SP 10 Magnetic materials for energy applications

SP10 - Parallel Session 2

SP10.2.07

Degrading effect of cold working on the magnetocaloric performance of a Ni50Mn34In16 Heusler alloy

F. Cugini, L. Righi, L. van Eijck, E. Brück, M. Solzi

Text The magnetic refrigeration, based on the magnetocaloric effect (MCE), represents a promising efficient and environmentally friendly alternative to replace the gas-compression technology. (Ni,Mn)-based Heusler alloys are among the most studied materials to be used as active elements in magnetic refrigerators thanks to their large MCE, tuneable with the composition, across both their structural martensitic transformation and the Curie transition of the austenitic phase.
In this work, we discuss the impact of cold working on the magnetocaloric properties of these alloys at their Curie transition. The result of manual crushing and subsequent heat treatment on the magnetic, structural and magnetocaloric properties of a Ni50Mn34In16 reference sample are presented. The observed degradation of magnetic and magnetocaloric properties is discussed on the basis of X-rays and neutron diffraction data and of NMR and Moessbauer experiments, reported in literature. An explanation of this effect is proposed, by considering the antiferromagnetic coupling of the Mn atoms near the structural defects, induced by cold working. This degrading effect points out the strong correlation between microstructural and magnetic properties of these materials and results determinant for the technological application of Mn-based Heusler alloys.
F. Cugini, et al., J Alloys Compd, 2018, DOI: 10.1016/j.jallcom.2018.03.293.

SP 10 Magnetic materials for energy applications

SP10 - Parallel Session 3

SP10 - Parallel Session 3

SP10.3.01

Rapidly quenched ultra-thin soft magnetic amorphous ribbons for high-frequency power applications

A. Masood, H. Baghbaderani, Z. Pavlovic, K. Ackland, P. S. Stamenov, P. McCloskey, C. O'Mathuna, S. Kulkarni

Text With significant advances in the power semiconductor industry in faster and more efficient power switches, the requirement of smaller and more efficient magnetic components becomes more critical at higher frequencies. Over the last decade, there has been significant research focused on developing high flux density soft magnetic amorphous materials to replace existing bulky and large ferrite based solutions. We present a rapid quenching approach to synthesis ultrathin soft magnetic tapes of amorphous metals with a novel alloy Co-Fe-B-Si-Nb system for high-frequency (>100 kHz) power applications. The novel alloy system significantly reduces the material costs and eliminates the need for post-processing steps while improving the high-frequency loss performance. In addition, the alloy composition incorporates rapid glass-forming elements enabling deposition of amorphous tapes with a thickness of 5.5 µm in the as-quenched state. The static and dynamic properties of the as-quenched ultra-thin tapes were measured by a BH-loop tracer and by an in-house high-frequency power loss system respectively. The in-plane hysteresis loop revealed very low coercivity (Hc < 4 A/m) in the as-quenched state. The materials’ high power loss performance was investigated in the frequency range of 100-500 KHz and showed lower power loss compared to the commercial soft magnetic ribbons (20 µm). Further details on magnetic characterization and power circuit testing will be presented in the full paper.

SP 10 Magnetic materials for energy applications

SP10 - Parallel Session 3

SP10.3.02

Permeability of $Nd_2Fe_{17}N_x$-resin composites at micro-wave frequency range

N. Imaoka, K. Ozaki, T. Nakagawa

Text We successfully produced the $Nd_2Fe_{17}N_x$ electromagnetic compounds for high frequency system application [1]. This paper reports that novel magnetic composites of $Nd_2Fe_{17}N_x$ [1,2] and resin have high imaginary permeability μ " at 1-50 GHz . By our nitrogenation method using an NH_3-H_2 mixed gas [3] and a jet milling, we have prepared $Nd_2Fe_{17}N_x$ micro powders (2-3 μ in size) [1], which were dispersed in the epoxy resin or polyamide-ester-ether elastomer resin. We obtained μ ">1 at 10 GHz for $Nd_2Fe_{17}N_x$/epoxy resin composites and at 20 GHz for $Nd_2Fe_{17}N_x$/polyamide-ester-ether resin composites, our whole experimental range based on the S-parameter method. Such a high permeability was obtained even in the microwave range because $Nd_2Fe_{17}N_x$ has strong saturation magnetization and high planar anisotropy. Having very high electric resistance [1,4] as compared to the other metal magnetic materials, the $Nd_2Fe_{17}N_x$-resin composites are in essential quite advantageous for applying to the noise suppressor sheet operated at frequencies higher than 10 GHz.

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SP 10 Magnetic materials for energy applications

SP10 - Parallel Session 3

SP10.3.03

Characterization of magnetic properties of grain-oriented electrical steel after elasto-plastic loading using magneto-optical Kerr microscopy and micromagnetic multiparameter, microstructure and stress analysis (3MA) system

S. Deldar, M. Smaga, T. Beck

Text Electrical steel is one of the first ferromagnetic materials on which magnetization inhomogeneities were visualized [1]. Based on their high magnetic flux density and low iron loss, electrical steels have been conventionally used as magnetic cores of the interior permanent magnet (IPM) motors. Due to the recent developments in the electric vehicles (EV), hybrid electric vehicles (HEV), and efficiency enhancement of internal combustion engines, the tendency to enhance magneto-mechanical properties of electrical steels has skyrocketed [2, 3].
Electrical steels are applied to extreme cyclic loadings induced by fluctuating rotational speed and hence, the centrifugal force applied on the core during operation of the motor [3]. Consequently, studying fatigue behavior of the rotor core [4, 5] and mechanically induced changes in their magnetic parameters [6] will be useful to increase durability and efficiency.
In the present work, magneto-optical Kerr microscopy and a micromagnetic multiparameter, microstructure and stress analysis (3MA) system were employed to Characterize the magnetic domain structure, magnetic Barkhausen noise, and permeability of a grain-oriented Fe-3%Si. Monotonic loading tests, as well as loading-unloading experiments, were performed on the flat tensile specimen to imitate strain accumulations during fatigue. The influence of these mechanical deformation processes on the magnetic measurements is presented and discussed.

SP 10 Magnetic materials for energy applications

SP10 - Parallel Session 3

SP10.3.04

Magnetic losses reduction in non-oriented electrical steels via strain-induced grain boundary migration effects.

I. Petryshynets, F. Kovac, V. Puchy, J. Fuzer, P. Kollar

Text Non-oriented (NO) electrical steels belong to important group of the soft magnetic materials that are typically used as core parts in a variety of electrical rotating equipments. Typical applications of NO electrical steel sheets are motors and generators. Their good soft magnetic characteristics strongly rely on the ability to control the grain size, texture and chemistry of the final steel sheets products. The most appropriate texture for NO steels is “rotating cube” texture, which provides isotropic magnetic properties in all plane directions of non-oriented steels.
In the present work, we have used an adjusted temper rolling process for development of particular textures {100}< 0vw > in vacuum degassed NO silicon steels with primary recrystallized microstructure. The main idea behind the improvement of soft magnetic properties relies on formation of columnar or huge grains with desired orientation. The coarse grained microstructure with pronounced intensity of cube and Goss texture components was achieved by using deformation induced growth of ferrite grains during annealing at dynamic conditions. EBSD was used to determine the crystallographic orientations of grains with respect to individual rolling planes and directions. The magnetic properties of the experimental samples were measured in DC and AC (50Hz) magnetic field. These measurements demonstrated that the DC coercivity of investigated steels treated by suggested approach were decreased from 67 A/m to 18 A/m.

SP 10 Magnetic materials for energy applications

SP10 - Parallel Session 3

SP10.3.05

Siliconisation of grain oriented electrical steel through the method of diffusion annealing

S. Sarma, R. Anderson, Z. Husain, F. Robinson, M. Cichuta

Text Grain oriented electrical steel (GOES) is used in electrical transformers and typically contains ~3.2wt.% silicon [1]. In order to reduce power loss, there is a motivation to increase the silicon content up to an optimum 6.5wt% during the production of GOES. Increasing the silicon content of GOES causes a rise in the electrical resistance which then reduces eddy current formation and diminishes the power losses caused. However this also introduces brittleness in the conventional cold rolling stage of steelmaking.

The process of increasing the silicon content is termed siliconisation and requires coating and later diffusion annealing silicon into the steel substrate as a final step in the process. Previous studies by JFE have highlighted a successful method in chemical vapour deposition [2], but this was achieved through a complicated process.

In this study, a simpler alternative approach is explored where GOES samples were dip-coated in a silicon based coating, oven-cured and then diffusion annealed inside a furnace at 500˚C/1100˚C with a reducing atmosphere. Samples were characterised using analytical techniques such as GDOES, XPS etc., which indicated that siliconisation had occurred up to a few microns in depth. In accordance with the surrounding literature on metallurgy [3], other atmospheric conditions are being explored to reduce oxide formation. The samples are to be further analysed using SEM/EDX to measure the silicon content depth profile.

SP 10 Magnetic materials for energy applications

SP10 - Parallel Session 3

SP10.3.06

Relationship between microstructure and properties of soft magnetic materials for electric motor applications

D. Goll, D. Schuller, D. Hohs, T. Kunert, J. Schurr, T. Bernthaler, G. Schneider

Text The demand for higher efficiency in electro mobility requires innovative, powerful and economic motor concepts. Here, tailored production processes of the soft magnetic core material are one of the key elements to further improve the electric motor system. During the last few decades, the quality of electrical steel for core applications was continuously increased and optimized towards lower dynamic losses by means of higher silicon content and increasingly thinner sheets. Soft magnetic composites (SMC) allow further minimization of eddy current losses due to higher electrical resistivity. Additive manufacturing of soft magnetic components offers new opportunities like optimized alloy compositions (e.g. FeSi6.5) and novel topological and multilayered structures.
In this work, correlative microscopy techniques are used to identify and investigate critical microstructure parameters (size, shape and orientation of the grains, inclusions, plastic deformation and elastic stress) which are then correlated to the materials' magnetic performance. The microstructure of the affected edge of punched or laser cut electrical steel material is presented. The effect of the powder metallurgical process of SMC material on eddy current losses is shown. Finally, the influence of different additive manufacturing parameters on the structure and magnetic properties of soft magnetic test specimen is discussed.

SP 10 Magnetic materials for energy applications

SP10 - Parallel Session 3

SP10.3.07

Magnetocaloric effect and magnetoelectric coupling in Fe-Rh films

A. Amirov, A. Aliev, V. Rodionov, V. Komanicky

Text Recently,the studies of FeRh-based materials has been intensified due to their potential applications. In particularly, multiferroic composites consisting of piezoelectric (PZ) and ferromagnetic (FM) layers, an applied to PZ layer electric field induces mechanical strain on FM layer, which then can be used for control of magnetocaloric effect (MCE).
In the present work, we deposit an alloy film with a composition of Fe48Rh52 (FeRh) on a piezoelectric PbZr0.53Ti0.47O3 (PZT) substrate and investigate the MCE and magnetoelectric (ME) effect in them.Fe48Rh52 films with thickness 50,100,150 nm were prepared by co sputtering from Rh (99.99%) and Fe (99.99%) targets in AJA Orion magnetron sputtering system.Composition of the films were verified by EDAX analysis.
The magnetic, magnetocaloric and ME properties of FeRh-PZT composite were measured around room temperature. The MCE of FeRh-PZT composites were studied in measurements of the adiabatic temperature change using an infrared camera. The entropy changes were estimated from isotherms of magnetization curves using Maxwell relations. ME effect was studied by measuring a voltage generating across the sample under alternating magnetic field.
For all composites the maximums of MCE and its correlation with ME effect around temperature of phase transition of FeRh in range 305-325 K were observed.
The research was supported by the Russian Science Foundation (№ 18-12-00415) and Russian Foundation for Basic Research (№ 18-32-01036 mol_a)

SP 10 Magnetic materials for energy applications

SP10 - Parallel Session 3

SP10.3.08

Micromagnetic simulations of the dynamics in an antiferromagnetic spin-Hall oscillator

V. Puliafito, M. Carpentieri, B. Azzerboni, V. Tiberkevich, A. Slavin, G. Finocchio

Text We have developed a micromagnetic code which performs numerical simulations of an antiferromagnetic (AFM) layer by solving the Landau-Lifshitz equations of motion for the magnetizations of the two AFM sublattices. Here, we propose an AFM spin-Hall oscillator, consisting of an AFM layer coupled to a heavy metallic layer. The AFM layer has in-plane dimensions 40x40 nm^2, and it is modeled with in-plane anisotropy. The heavy metal is designed with 4 terminals that can be used to apply a charge current, and/or to read the device resistance. The direction of the spin-Hall polarization depends on the direction of the current, and it can be modified by applying the current differently at the terminals.
Simulations show that, whatever the direction of the spin-Hall polarization, the magnetizations of the sublattices precess around that direction, with uniform magnetic configurations. Moreover, excitation shows a hysteretic behavior, since the current to switch off the dynamics is lower than the ignition current. Frequency of dynamics is in the range of THz, and increases with the applied current. Such properties, highlighted within a systematic study performed by varying the exchange constant, damping, and thickness of the AFM, agree with theoretical predictions. Micromagnetic simulations have also predicted that dynamics in presence of Dzyaloshinskii–Moriya interaction are characterized by a translation of non-uniform domain walls along the AFM layer.