Forum H   Magnetic Materials

H01 (Invited)

Dynamic Magnetic Susceptibility Near Ferromagnetic Resonance

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The dynamic magnetic susceptibility of magnetic materials nearferromagnetic resonance (FMR) is very important in interpreting dc-voltage obtained in an electrical detection of FMR. Based on the causality principle and the assumption that the usual microwave absorption lineshape of a homogeneous magnetic material around FMR is Lorentzian, general forms of dynamic magnetic susceptibility of an arbitrary sample and the corresponding dc-voltage lineshapes of the electrical detection of FMR were obtained. Our main findings are: 1) The dynamic magnetic susceptibility is not a Polder tensor for a material with an arbitrary magnetic anisotropy. Two off-diagonal matrix elements of the tensor near FMR are not in general opposite to each other. However, the linear response coefficient of the magnetization to the total radio frequency (rf) field (sum of the applied external rf field and the internal rf field due to the precessing magnetization, a quantity cannot be measured directly) is a Polder tensor. This may explain why two off-diagonal susceptibility matrix elements are always assumed to be opposite to each other in analyses. 2) The frequency dependence of dynamic magnetic susceptibility near FMR is fully characterized by six real numbers while its field dependence is fully characterized by seven real numbers. 3) A recipe of how to determine these numbers by standard microwave absorption measurements for a sample with an arbitrary magnetic anisotropy is proposed. Our results allow one to unambiguously separate the contribution of the anisotropic magnetoresistance to dc-voltage signals from that of the anomalous Hall effect. With these results, one can reliably extract the information of spin pumping and the inverse spin Hall effect, and determine the spin-Hall angle. 4) The field-dependence of the susceptibility matrix elements at a fixed microwave frequency may have several peaks when the effective magnetic field is not a monotonic function of the applied magnetic field. In contrast, the frequency-dependence of the susceptibility matrix elements at a fixed applied magnetic field has only one FMR peak. Furthermore, in the case that resonance frequency is not sensitive to the externally applied static magnetic field, the field dependence of matrix elements of the dynamic magnetic susceptibility, as well as dc-voltage, may have another non-resonance broad peak. Thus, one should be careful in interpreting observed peaks.

H02 (Invited)

The effect of anti-site disorder in Heusler alloys

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Heusler alloys have been intensively investigated in both experiment and theory because many attractive materials have been found in these alloys, like half-metal, shape memory alloy, topological insulator and spin gapless semiconductor etc. However, the anti-site disorder is easy to occur in Heusler alloys and usually is harmful to the functional performances. In this report, we will show a viewpoint that the anti-site disorder is possible to be in availability in some cases. Three main examples to friendly take advantage of anti-site disorder are reported: 1) A proper quantity of anti-site disorder content can induce the thermal-reversible first-order phase transition; 2) the anti-site disorder induces the diluted magnetism; 3) the anti-site disorder induce completely compensated ferrimagnetism.

H03 (Invited)

Phase transition of magnetic skyrmion by Lorentz transmission electron microscopy

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Magnetic skyrmion has launched new concepts for memory devices due to its topologically vortex-like magnetic structure. Here, we report the first experimental observation of the skyrmion chain in FeGe nanostripes by using high resolution Lorentz transmission electron microscopy. Under an applied field, we observe that the helical ground states with distorted edge spins would evolve into individual skyrmions, which assemble in the form of a chain at low field and move collectively into the center of nanostripes at elevated fields. Such a skyrmion chain survives even when the width of nanostripe is much larger than the single skyrmion size. This discovery demonstrates a new way of skyrmion formation through the edge effect, and might, in the long term, shed light on potential applications.

During recent years, our group focus on the investigation of phase transformation issue and domain wall behavior of magnetic materials by using featured TEM techniques: Lorentz TEM techniques, electron holography, in situ cooling experiments, electron energy loss spectroscopy, and more. For example, focus on three-dimensional reconstruction of a single manganese selenide nanoparticles and its associated with magnetic block temperature physics. The electron spin/down can be mapped within high-spatial-resolution. Moreover, electric/magnetic potential can be directly imaged by electron holography using in situ cooling TEM experiments.

H04 (Invited)

New Devices based on the Magnetoelectric Effects of Multiferroic Materials

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The magnetoelectric (ME) effects, i.e., the control of electric polarization by magnetic field and magnetization by electric field,have attractedenormous interests due to their promise in developing new functional devices. Recently, we have successfully employed the ME effects to realize the fourth fundamental circuit element as well as a new type of nonvolatile memory device.In electric circuit theories, three two-terminal passive fundamental circuit elements, resistor R, capacitor C, and inductor L, are defined in terms of a relationship between two of the four basic circuit variables, charge q, current i, voltage v, and magnetic flux φ, respectively. From a symmetry concern, there should be a fourth fundamental element defined from the relationship between q and φ. We present both theoretical analysis and experimental evidences to demonstrate that a two-terminal passive device employing the ME effects can exhibit a directq-ϕrelationship and thus function as the fourth element. Based on our work, a full map of fundamental circuit elements is constructed, consisting of four linear elements (resistor, capacitor, inductor, and transtor) and four nonlinearmemory elements (memristor, memcapcitor, meminductor, and memtranstor).Especially, the memtranstor based on nonlinear ME effects is able to be used for nonvolatile memory with many virtues, such as simple structure, easy operations in write and read, low power consumption, fast speed, and low cost.

H05

Voltage Induced Magnetization Switching in Ferroelectric/Ferromagnetic Heterostructures

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A series of ferroelectric/ferromagnetic (FE/FM) heterostructures were fabricated by direct-current magnetron sputtering using a single crystal ferroelectric $[Pb(Mg_{1/3}Nb_{2/3})O_3]_{0.68}$-$[PbTiO_3]_{0.32}$ (PMN-PT) substrates with large piezoelectric coefficient. The voltage induced magnetization switching was obtained between the two in-plane orthogonal directions due to the strain mediated converse magnetoelectric effect. Moreover, voltage induced magnetic anisotropy variation were obtained. Finally a non-volatile magnetic memory cell with resistance and electric field, respectively, as the media and writing field was realized.

H06 (Invited)

Research Progress in the Preparation of High Silicon Steel Thin Strip by Near Net Shaping

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The latest research progress in the preparation of 6.5%Si steel thin strip by the single-roller spinning method and the high silicon steel thin strip by the strip cast-rolling method are described in this paper. The microstructure and properties of high silicon steel thin strip with different production processes are analyzed. The major process factors affecting the forming ability of Fe-6.5 wt. % Si alloy thin strip prepared by the rapidly solidified method are presented. The development prospect of high silicon steel thin strip using the near-net shaped method are also forecasted.

H07 (Invited)

Effect of Hot Band Thickness on the Microstructure, Texture and Magnetic Properties of Fe-1.0%Sinon-oriented Electrical Steel by

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Hot-rolled Fe–1.0%Si alloy bands with different thickness were produced and subsequently cold rolled and recrystallization annealed. The microstructure, texture evolution and magnetic properties were investigated in detailby optical microscopy, X-ray diffraction. It was found that the fraction of fine equiaxed grains at the surface layerof hot band was increased with the decrease in thickness, together with the strengthening of {110} texture. After cold rolled, the samples of the thickest hot band exhibited more elongated grains with low stored energyand the texture was dominated by α-fiber (<110>//RD)texture and γ-fiber (<111>//ND) texture. After annealing, the final sheets of the thickest hot band showed a little more homogeneous recrystallization microstructure with larger grain size than those of other two bands, and a lowest iron loss ($P_{15/50}$=4.65W/kg) was displayed. In addition, the recrystallization texture was dominated with Goss ({110}<001>) and γtexture. With decreasing in hot-band thickness, the Goss recrystallized texture was gradually enhanced while the intensity of the γ-fiber texture was reduced, leading to highest magnetic induction (B50=1.755T).

H08 (Invited)

Soft Magnetic Perovskite Fe_4N Films and Its Heterostructures

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Fe_4N has a research history of more than eighty years, which was firstly studied to be used as a catalyst for the production of ammonia and treatment for steel surface. Fe_4N has many excellent characteristics, such as the relatively simple chemical composition, lattice structure, ferromagnetic characteristic, high wear and corrosion resistance, metallic conductivity, high Curie temperature, high chemical stability, thermal stability, structural stability, and high spin polarization, etc. Therefore, Fe_4N has attracted a tremendous amount of interests in fundamental research and practical applications in the fields of magnetic materials, magnetic coating material and spintronic devices. The Fe_4N films, Fe_4N/CoN and Fe4N/Alq_3/Co heterostructures were fabricated by reactive facing-target sputtering with a pair of facing Fe targets in the gas mixture of N_2 and Ar. The epitaxial Fe_4N films with different orientations on the single crystal substrates were fabricated by changing the flow of N_2 and substrate temperature. Then, the Fe_4N films composite with other materials to form heterostructures. The structure, magnetic and transport properties of the samples are studied in details.

H09

Controlled Synthesis and Microwave Electromagnetic Properties of Micro–nano MnO2 Powder

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The manganese dioxides, in combination with their novel chemical and physical properties, have paved the way for their wide use as catalysts and electrochemical materials, but the microwave absorption properties of MnO2 have not been exploited. Our research group has found that manganese dioxides own excellent dielectric loss. However, the magnetic loss is relatively low. Besides, the low frequency absorption performance is relatively poor and the bandwidth is relatively narrow. On these bases, our research group synthesized new type of manganese dioxides absorbent in high magnetic field and by doping with magnetic cations. As a result, we found that the magnetic loss was significantly enhanced and the effective absorption bandwidth was broadened evidently as well. In view of the above important experimental phenomena and the existent problems, our group investigated the magnetic loss property and the related mechanism of the new type manganese dioxides absorbent prepared in high magnetic field as well as doped with magnetic cations systematically. Interestingly, through the investigation of the growth behavior of MnO_2 prepared in high field and the doped MnO_2, we found that the morphology of MnO_2 synthesized under high magnetic field is sea urchin ball chain shape, and the permeability was clearly increased under a high magnetic field. Results showed that, after Ni/Co doping, the phase structure and morphology of α-MnO_2 were kept the bunchy nanowires as those before doping, while the imaginary part of complex permittivity and the dielectric loss tangent were increased with evident frequency response character. Dipoles relaxation polarization was the main polarization mechanism. Ionic doping extended the relaxation time, resulting in more obvious frequency dispersion. The partial density states of O 2p, Mn 3d, and Ni 3d hybridized with each other, enhancing the strength of dipole polarization and electronic polarization, which certified the enhanced dielectric loss capacity. The effects of Fe doping on dielectric property of MnO_2 were different from those of Ni/Co doping. Both the phase structure and morphology were changed after Fe doping. The morphology of Fe-doped MnO_2 was hollow sea urchin ball-like shape, and at the same time the real and imaginary parts of complex permittivity and dielectric loss tangent were all decreased with the increased Fe doping concentration. The results of the first-principles calculation corresponded with experimental phenomena. Fe doping enhanced the strength and thus the potential energy of metal-O covalent bonds. Consequently, it reduced the damping force response of electron cloud to external electric field and finally decreased dielectric loss of MnO_2. Furthermore, the density of states of spin-up and spin-down electron of MnO_2 exhibited an obvious unsymmetrical distribution. The spin polarization of electronic states was promoted to transform MnO_2 from non-magnetic to mangnetic, resulting in an increase of permeability.

H10

Study of self-assembly TiO_2 nanostructures and their applications in photo-degradation (catalysis) and photo-detection (UV sensors)

Meizhen Gao
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A generalized and fundamental approach to molecular self-assembly synthesis of TiO_2 nanostructures is reported in this article. The formation mechanism of the nanostructures was proposed in detail. The products were characterized by X-ray diffraction, scanning electron microscopy, and transmission electron microscopy. The as-prepared TiO_2 nanomaterials were then used to examine the photodetector performance under ultraviolet (UV) light irradiation, and the device exhibited excellent photoresponsivity and stability. This work should provide a new concept to design and fabrication of other nanostructured metal oxide with enhanced properties for microelectronics, optoelectronics, and other applications.

H11

In-plane Isotropic Microwave Performance of CoZrTrilayerin GHz Range

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We investigate the high frequency performance of $Co_{90}Zr_{10}/SiO_2/Co_{90}Zr_{10}$trilayers. It is demonstrated that the in-plane isotropic microwave performance is theoretically derived from the solution of the Landau-Lifshitz-Gilbert equation and experimentally achieved in that sandwich structured film. The valuable isotropic behavior comes from the superposition of two uncouple ferromagnetic layers in which the uniaxial magnetic anisotropic fields are equivalent but mutually orthogonal. Moreover, the isotropic microwave performance can be tuned to higher resonance frequency up to 5.3 GHz by employing the oblique deposition technique. It offers a convenient and effective way to achieve an unusual in-plane isotropic microwave performance with high permeability in GHz,holding promising applications for the magnetic devices in the high frequency information technology.

H12 (Invited)

Electric Field Manipulation of Magnetic Properties in Ni-Mn based Ferromagnetic Shape Memory Alloys/Piezoelectrics Composites

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Magnetoelectric (ME) coupling has attracted ever-increasing interest due to its novel physical mechanism and potential applications. One promising approach to attain the coupling between magnetic and electric orders concerns the use of magnet/piezoelectric bilayer structures, in which excellent ME performance can be realized using strain-mediated mechanism. Ni-Mn based ferromagnetic shape memory alloys (FSMAs) are good candidate for gaining large ME effect since the strain can drive their martensitic transformation and give rise to large magnetization change. It is well known that FSMAs are multifunctional materials which show many interesting magnetic effects. In this talk, we report the electric field control of magnetocaloric and exchange bias effects in Ni-Mn based FSMAs/piezoelectrics composites.

H13 (Invited)

Direct Imaging of Cross-sectional Magnetization Reversal in the Exchange biased CoFeB/IrMn Bilayer

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Magnetoelectronic devices have been widely used in magnetic storage and sensor. The pinned ferromagnetic layer with a unidirectional magnetic anisotropy is an important reference layer in the devices. Ferromagnetic material is pinned by antiferromagnetic material at the interface through exchange bias effect. Although this effect has been studied for many years, some phenomena still has not been explained very well, such as the measured exchange bias field is much smaller than the calculated value. The formation of exchange spring structure in ferromagnetic or antiferromagnetic layers has been proposed for the reason, and it has also been used to explain many related phenomena. Here, I will present our recent results of direct imaging of cross-sectional magnetization reversal in the exchange biased CoFeB/IrMn bilayer by using Lorentz transmission electron microscopy (Lorentz-TEM).

H14 (Invited)

Synthesis of Magnetic Metal-Semiconductor Hybrid Nanocrystals with Controlled Morphologies for Photocatalytic Applications

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Xiamen University

Metal-semiconductor hybrid nanocrystals have received intensive research interests because of their multiple functionalities which can be applied in wide fields such as photocatalysis, solar energy utilization, electronic devices and biomedical sensing. In the photocatalytic applications, enhanced photocatalytic activities can be achieved by combining semiconductors with noble metals to form hybrid nanostructures. However large-scale application of such hybrid nanostructures is limited by the high cost of noble metals. Moreover the efficient separation of catalyst particles after reactions is also important. An idea to overcome the above limitations is to incorporate low-cost magnetic transition metals into the hybrid nanostructures. The incorporation of magnetic component not only can promote the effective charge separation for improving photocatalytic efficiency but also provides convenience for the particle dispersion and collection via magnetic separation. In this study, we report solution strategies to combine magnetic metal Ni with semiconductors ZnO to form various hybrid nanostructures. The first synthetic strategy utilizes Au seeds formed in situ to induce the formation of Ni shells which in turn act as hetero-nucleation sites for the growth of ZnO nanocrystals to eventually form Au-Ni-ZnO core-shell ternary hybrid nanostructures. This strategy can be easily developed for the synthesis of magnetic Ni-Au-ZnO hybrid nanomultipods, nanorods and nanopyramids. In addition, we also report a method for the synthesis of Ni-ZnO hybrid nanocrystals by direct decomposition of ZnO on the pre-formed Ni seeds. Finally we demonstrate that the as-prepared nanocrystals can be applied for the photocatalytic degradation of organic dye. Excellent photocatalytic activities have been observed in the photodegradation of Rhodamine B in aqueous solutions. Most of the hybrid nanocrystals exhibit room-temperature superparamagnetism, and can be easily separated and re-cycled by applying external magnetic field. The as-prepared hybrid nanocrystals possess both semiconducting and magnetic or even plasmonic functionalities within a single nano-entity, and are expected to find more wide potential applications that are not limited in the photocatalysis.

H15

Preparation and magnetic properties of anisotropic bulk MnBi/NdFeB hybrid magnets

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The MnBi low-temperature phase (LTP) has high magnetocrystalline anisotropy and a remarkable positive temperature coefficient of coercivity below 300 ℃, but it is difficult to obtain the high purity. In order to obtain the MnBi powders with high Ms and coercivity, low-energy-ball-milling was applied. Furthermore, the anisotropic bulk MnBi magnets were prepared by improved sintering process. To further improve the properties of MnBi magnets, anisotropic bulk MnBi/NdFeB hybrid magnets were prepared. An energy product $(BH)_{max}$ of 10 MGOe has been obtained at NdFeB content of 50 wt. %, which is substantially higher than any reported values of the energy density for bulk MnBi-based magnets.

H16 (Invited)

Ferromagnetic CrTe nanostructures with high coercivity synthesized by chemical solution method

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Nanoscale magnetic materials have been extensively investigated due to both their unique properties and great potential for many important technological applications, including spin-based electronics, recording media, permanent magnets and magneto-caloric refrigeration. Recently nanoparticles of transition metal chalcogenides such as Fe3Se4 have been synthesized. Giant coercivity exceeding 4 tesla has been reported, resulting from the change in magnetization reversal mechanism of these nanostructures. However, their magnetization is low since Fe3Se4 possesses antiferromagnetic exchange coupling. On the other hand, it is known that some Cr Te based compounds are ferromagnetic. However, nanoscale Cr Te materials are rarely investigated. In this work, we report for the first time Cr Te nanostructures synthesized by a facile organic solution phase process. The as-synthesized nanostructures were characterized by transmission electron microscopy and X-ray diffraction. The morphology and sizes of the nanoparticles can be tuned by synthesis parameters including the temperature and type of solvents. Their phases range from Cr_2Te_3 to Cr_5Cr_8 depending on the molar ratio of the precursors used and the synthesis temperature. Their magnetic properties can change from soft magnetic with very low coercivity to very hard with a coercivity of 8-10 k Oe. The Curie temperature is around 180K. Doping with other transition metal elements such as Co has been attempted to modify their magnetic properties.

H17

The Memory Wffect of Magnetoelectric Coupling and Related Phenomena Induced by Anisotropic Strain Field

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In perovskite manganites, the strong coupling among charge, orbital, spin and lattice leads to various novel physical phenomena such as double exchange coupling, colossal magnetoresistance, metal-insulator transition and phase separation. It is known that electron-phonon coupling could induce the split of eg electron energy level and result in a distortion of MnO_6 octahedral, i.e. Jahn-Teller distortion. Such effect reduces the energy of eg single electron and traps the carrier at Mn^{3+}, resulting in many novel physical phenomena. Recently, many experiments have shown that the lattice strain can change the distortion of MnO_6, modulate the Jahn-Teller coupling and double exchange coupling effectively, and even can modulate many physical properties of manganite film through changing the electron localization.

Here, we report the effect of electric-filed-induced anisotropic strain on the magnetoelectric coupling in the wide-band $Pr_{0.7}Sr_{0.3}MnO_3$ film. By introducing an electric-field-induced in-plane anisotropic strain-field during the cooling process from room temperature, we observed an in-plane anisotropic and nonvolatile modulation of the magnetic properties in the wide-band PSMO film at low temperature. This anisotropic memory effect of magnetoelectric coupling can be ascribed to the preferential seeding and growth of the ferromagnetic(FM) domains under the anisotropic strain-field. By taking into account the competition between the thermal energy and the potential barrier of the metastable magnetic state induced by the anisotropic strain field, this distinct memory effect of magnetoelectric coupling can be well explained. Furthermore, it was found that the anisotropic strain field plays an important role in the strain-mediated magnetoelectric coupling effect.

H18

Magnetoresistance Amplification Effect in Silicon Transistor Device

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Large magnetoresistance discovered in nonmagnetic semiconductors offers an alternative route to renew magnetoelectronics without ferromagnets. However, it is still a great challenge to retain such large magnetoresistance under low magnetic field below Tesla. In this work, analogous to current amplification in the transistor, we propose a magnetoresistance amplification effect in silicon transistor device, where the device current is significantly controlled by magnetic-field-manipulated coupling of two p-n junctions in transistor. As a direct consequence, large magnetoresistance of 50,000% with high sensitivity of 50% Oe^{-1} is yielded at magnetic field of only 0.1 T. Our results not only provide a new proposal compatible with current semiconductor technology to achieve large magntoresistance at low magnetic field, but also realize magnetic-field-manipulated transistor, which is a step for magnetoelectronics.

H19

From lighting-ferroelectric to photovoltaic properties of $Pb(Zr,Ti)O_3$ (PZT) thin film with symmetric/asymmetric interface energy barrier

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Recently, ferroelectric (FE) materials have been intensively investigated for photovoltaic (PV) applications due to the existence of internal polarization field which acts as a drive force to separate electron-hole pair. Lead zirconate titanate, $Pb(Zr,Ti)O_3$(PZT), as one of the most commonly used ferroelectric materials, has been extensively studied because of its high remanent polarization (Pr) and the low coercive field (Ec). In this work, PZT thin film devices based on symmetric (ITO/PZT/ITO) and asymmetric (Pt/PZT/ITO) structure were studied. It was found that the remanent polarization always increases after second lighting for both devices. However, at the first lighting, Pr decreases for Pt/PZT/ITO and increases for ITO/PZT/ITO, which may be attributed to the stronger interface field in the asymmetric device than the symmetric one. The difference of electric fields at two interfaces weakens spontaneous polarization. This study also found the net polarization of the asymmetric structure is significantly higher with light soaking, but the one of the symmetrical structure is substantially stable. Furthermore, it was found that the leakage current increases when light is on and decreases when light is off, indicating that the increase of Pr when light is on is mainly resulting from the increase of leakage current, and in fact, the net polarization decreases or keeps indifferent at the light condition. The different PV performance of two solar cells can be interpreted to be related to the symmetry of the interfacial barrier.

H20

Effects of Doped Element on Structure and Magnetic Performance of Nanocrystalline Sm_5Co_{19} Alloy

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In this study, permanent magnetic nanocrystalline $Sm_5Co_{18.5}Ni_{0.5}$ 、 $Sm_5Co_{18.5}Fe_{0.5}$ and $Sm_5Co_{18.5}Nb_{0.5}$ alloys with high coercivity were prepared. The microstructure, crystal structure and magnetic properties of these alloys were studied. The results show that Ni, Fe and Nb doping do not lead to phase decomposition of the Ce_5Co_{19} type crystal structure,mean while by these elements doping homogeneous fine-grain microstructures can be obtained. The room-temperature magnetic analysis confirmed that all the elements of Ni, Fe and Nb can improve the coercivity of the nanocrystalline Sm_5Co_{19}–based alloy. In particular, Ni doped nanocrystalline Sm_5Co_{19} alloy has the largest coercivity,which is increased by 28.8%as compared with that of the binary nanocrystalline Sm_5Co_{19} alloy. The high-temperature magnetic analysis indicated that addition of the magnetic elements of Ni and Fe can remain good magnetic performance at high temperatures. The results of this study may promote the design of new type Sm-Co alloys with high magnetocrystalline anisotropy and intrinsic coercivity.