Doctoral School of Physics - Eötvös Loránd University (ELTE)

Semester report
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ELTE Doctoral School Physics, 2nd semester
Supervisors: Prof. István Groma (ELTE) and Prof. Imre Bakonyi (Wigner RCP, HAS)

Ph.D. Thesis topic:
Magnetic and magnetotransport properties of nanoscale ferromagnetic heterostructures

Introduction: Spintronic and magnonic materials are two important classes of advanced materials the study of which is at the forefront of materials science. Such materials are typically composed of nanoscale ferromagnetic entities separated by either a non-magnetic metal, an air gap or another ferromagnetic metal of different magnetic characteristics. The interest in these materials arises, on the one hand, due to the already existing applications, e.g., in spintronics devices such as the giant magnetoresistance read heads of magnetic hard disk drives. The permanent demand for improving these existing applications necessitates further study of nanoscale magnetic heterostructures. On the other hand, there are prospective technological applications of such structures, e.g., information storage in magnonic crystals. Since the ferromagnetic elements Fe, Co and Ni as well as their alloys with each other are the basic ingredients of these magnetic nanostructures, it is important to have a reliable detailed knowledge of their electrical transport and magnetic properties since it appears from the literature that available data are not always satisfactorily accurate. This justifies revisiting the zero-field electrical resistivity, the magnetoresistance and the magnetization reversal characteristics of these ferromagnets in both the bulk form and in their various nanostructured form such as nanocrystalline state, thin films, nanoscale multilayers and nanowires, both homogeneous and compositionally modulated along their length.

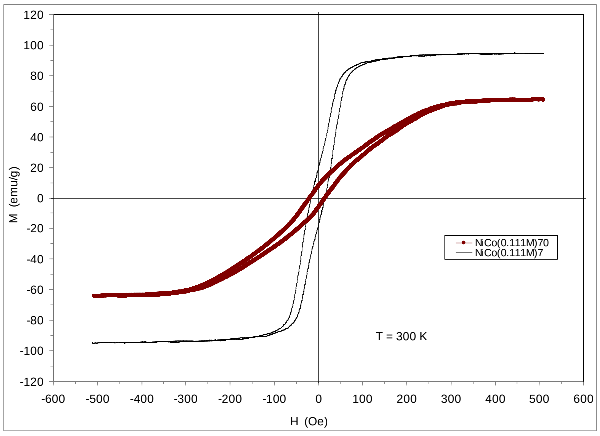
My task for the Ph.D. work will be the preparation of nanoscale magnetic structures by using electrodeposition and the study of their electrical transport properties and their magnetic characteristics. For comparison and as reference materials, I will investigate also bulk homogeneous ferromagnets such as Fe, Co and Ni metals as well as their alloys produced by either electrodeposition or by metallurgical methods in other laboratories.

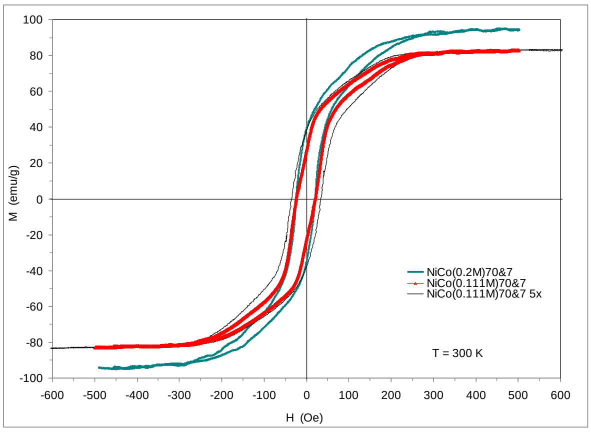
Description of research work carried out in current semester:

List of research training and work :

1. I have got trained to operate two kinds of electrochemical workstations. These two kinds of electrochemical workstation are Elektro-Flex and Iviumstat Electrochemical interface. Iviumstat is a modern electrochemical workstation, it can run on Microsoft Windows programs and has a good interface. By using these interfaces, I can produce thin metal layers with potentiostatic, galvanostatic and mixed mode deposition. I also learnt how to install the electrochemical cell with two electrodes and three electrodes.
2. I have got trained to make the electrochemical solution for electrodeposition and how to calculate the composition of the solution.
3. In this semester, the research task was to produce heterogeneous nanostructures in the Ni-Co system which consist of an alternating sequence of magnetic layers with different magnetic properties. This can be easily accomplished by depositing layers of different compositions. For this purpose, I have studied from a few specific baths the dependence

of magnetic behavior of Ni-Co alloys by varying the deposition current density which, on the other hand, controls the layer composition. The experiments were carried out on planar electrodes to get layered films and this experience will then be later transferred to produce nanowires with alternating magnetic sequence. To start with, first I have produced several kinds of thin metal layers with electrodeposition such as pure Ni, pure Co, NiCo series, NiCo bi-layer series, NiCoCu series and NiCoCu tri-layer series. For all of these series, I have made the magnetic property analysis by using Vibrating Sample Magnetometer and obtained the experimental data (coercivity, remanence, hysteresis loop and magnetic saturation). The following two diagrams illustrate some of the results obtained. The left panel shows the magnetic hysteresis loops of two Ni-Co layers produced with 7 and 70 mA deposition current and we can see that the two layers exhibit different magentic behaviours. On the right panel, the hysteresis loops of bilayers produced with 7 and 70 mA are displayed and also for a sandwich structure consisting of 5 repetitions of the 7mA/70mA bilayer. All the single layer films as well as the bilayer and multilayer films had a total thickness of 10 micrometers. These data indicate that the different magnetic behaviours of the individual magnetic layers with different chemical composition are retained also in a bilayer and even in a multilayer with individual layer thicknesses of 2 micrometers. Experiments are going on with smaller individual bilayer thicknesses.





Publications: The experimental results (electrical resistivity, magnetoresistance, coercivity, remanence and magnetic saturation) I obtained in the first and second semester at room temperature on several thin metal layer samples which were partly placed at my disposal and partly prepared by myself will be incorporated into several papers which are currently in preparation. The papers which are intended to be submitted to international peer-reviewed journals to be selected later are as follows:

1. I. Bakonyi, V.A. Isnaini, T. Kolonits, Zs. Czigány, J. Gubicza, L.K. Varga, E. Tóth-Kádár, L. Pogány, L. Péter and H. Ebert: The specific grain-boundary resistivity of Ni and Cu metals. *(accomplishement level: 90 %)*
2. V.A. Isnaini, T. Kolonits, Zs. Czigány, J.Gubicza, S. Zsurzsa, L.K. Varga, E. Tóth-Kádár, L. Pogány, L. Péter, H. Ebert and I. Bakonyi: Room-temperature magnetoresistance of Ni metal: influence of grain size down to the nanocystalline state. *(accomplishement level: 40 %)*
3. I. Bakonyi, F.D. Czeschka, L.F. Kiss, J. Gubicza, V.A. Isnaini, A. Krupp, E. Tóth-Kádár, L.K. Varga, L. Pogány, S. Zsurzsa, L. Péter, S.T.B. Goennenwein, R. Gross and H. Ebert:

High-field magnetoresistance measurements at 300 K and 3 K on microcrystalline and nanocrystalline Ni metal. *(accomplishement level: 80 %)*

4. I. Bakonyi, J. Báskay, V.A. Isnaini, L.K. Varga, L. Pogány, L. Péter, F.D. Czeschka, A. Krupp, B. Jóni, Á. Révész, S.T.B. Goennenwein, R. Gross and H. Ebert: Resistivity and magnetoresistance of fcc Ni-Co alloys: room-temperature data. *(accomplishement level: 40 %)*

Educational activities in current semester:

1. Course in ELTE : Physical Materials Science I with Prof. István Groma (8 Credits).
2. Course in ELTE : Transmission electron microscopy and electron diffraction with Prof. György Radnóczi (8 Credits).
3. Course in ELTE : Guided research work with Prof. István Groma and Prof. Imre Bakonyi (18 Credits).

Conferences in current semester:

List of attending department and institution seminars :

1. 2018. January 30 in MTA Wigner FK, Presenter : Christian Schilling, Topic : Universal upper bounds on the Bose-Einstein condensate.
2. 2018. February 6 in MTA Wigner FK, Presenter : Pavlo Pyshkin, Topic : How to speed up Holonomic Quantum Computation: Net Zero-Energy-Cost Control in Decoherence-Free Subspace.
3. 2018. February 20 in MTA Wigner FK, Presenter : Oroszlány László, Topic : A new class of topological materials: nodal loop semimetals.
4. 2018. April 12 in MTA Wigner FK, Presenter : Hamed Merdji, Topic : High harmonic generation in 2D and 3D semiconductors.
5. 2018. April 19 in MTA Wigner FK, Presenter : Alexey Ganin, Topic : Activating the basal plane of a 2D chalcogenide for electrocatalytic hydrogen evolution reactions.
6. 2018. May 03 in MTA Wigner FK, Presenter : Thomas O'Brien, Topic : Quantum error correction for near-term devices.