ISSN 1392 – 1215 ELECTRONICS AND ELECTRICAL ENGINEERING 2012. No. 4(120)
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Experimental Setup for Magnetoresistance Analysis of Lanthanum Manganites Thin Films

V. Novickij, V. Stankevic, A. Grainys, J. Novickij, S. Tolvaisiene
Faculty of Electronics, Vilnius Gediminas Technical University,
Naugarduko str., 41, LT-03227, Vilnius, Lithuania, phone: +370 5 2744762, e-mail: elektrotechnika@vgtu.lt
T. Stankevic
Center for Physical Sciences and Technology, Semiconductor Physics Institute,
A. Gostauto str. 11, LT-01108, Vilnius, Lithuania

http://dx.doi.org/10.5755/j01.eee.120.4.1451

Introduction

Magnetoresistance (MR) is a property of the materials to change its electrical resistance when magnetic field is applied. Manganites like $La_{1-x}(Sr, Ca, Ba)_xMnO_3$ exhibit a colossal magnetoresistance effect (CMR) at an external magnetic field. This property has found many applications in the creation of magnetic field sensors [1] or production of the magnetic memory [2]. However, the investigation of MR of the material involves a lot of measurements making the manual control of the equipment very complicated. The errors due to the human factor take place and must be considered. Also the thermal and magnetomechanic loads must be considered to ensure the accuracy of the experimental setup due to complexity of measurements in high magnetic fields [3]. The purpose of this work was to create a fully automated experimental setup for the MR measurements of the thin lanthanum manganites films. A measurement algorithm was developed and automated using LabVIEW software package. Resulting experimental data for La-Sr-Mn-O and La-Ca-Mn-O films was analyzed and conclusions formed.

Magnetoresistance of the thin manganite films

Magnetoresistance is defined as

$$MR = \frac{\rho_H - \rho_0}{\rho_H} \times 100\%, \tag{1}$$

where ρ_H is resistivity of the material at magnetic field H, ρ_0 is the resistivity of the material without magnetic field. At certain conditions anisotropy of the magnetoresistance appears in the manganite films. It can be described as the dependence of the magnetoresistance on the direction of the magnetic field with respect to the direction of the current and the surface plane of the film. There are three main reasons for the anisotropy in the ferromagnetic materials: (1) the existence of the preferential directions of magnetization (due to the crystalline structure and deformations), (2) resistivity dependence on the angle between the direction of the current and the magnetization vector which is inherent in ferromagnetic materials and (3) the shape anisotropy of the sample (demagnetization effect). The main reason for the anisotropy in the thin polycrystalline manganite films is due to the shape anisotropy [4]. MR of the manganites depends on the magnetic field inside the sample. In turn, the magnetic field inside material depends on the external magnetic field $\boldsymbol{H}_{ext}$ and the demagnetizing field $\mathbf{H}_d$ and can be calculated as: $\mathbf{H}_i = \mathbf{H}_{ext} + \mathbf{H}_d$. The demagnetizing field $\mathbf{H}_d$ is proportional to the magnetization M and the shape anisotropy tensor N: $\mathbf{H}_d = -N \cdot \mathbf{M}$. For thin films for $\mathbf{M}$ normal to the surface the factor $N_x = N_y = 0$ and $N_z = 1$. Therefore, the preferred magnetization vector lies in the surface plane.

In this work, we developed equipment for investigation of magnetoresistance of thin polycrystalline manganite films having different chemical composition. Thickness of the films was 0.4 µm and dimensions of the samples in plane were 400x400 µm^2. In this case, there will be a difference in the magnetoresistance when the magnetic field is applied in parallel and perpendicular to the surface directions. The main reason is magnetoresistance anisotropy, which can be quantitatively defined as

$$MRA = \frac{MR_{II} - MR_{\perp}}{MR_{II}} \times 100\%, \tag{2}$$

where MR_{II} is the magnetoresistance of the thin film when the magnetic field **H** is parallel to the film plane, $MR_{\perp}$ is the magnetoresistance of the film when the magnetic field **H** is perpendicular to the film plane.

In this paper the measurement methodology, the algorithms of the automated measurement system and the experimental measurement results are presented.

Experimental

The polycrystalline thin $La_{1-x}Sr_xMnO_3$ and $La_{1-x}Ca_xMnO_3$ films were deposited on the lucalox substrates by the Metal Organic Chemical Vapor Deposition (MOCVD) [5-6]. Resistance of these manganite films was measured in the wide range of magnetic field (from 0 T to 2.5 T) and temperature (from -5 ^{0}C to 50 ^{0}C). The samples with two contacts were positioned between the poles of the electromagnet and the temperature was stabilized using a water-cooled solid state thermostat. The schematic diagram of the experiment setup is shown in Fig. 1.

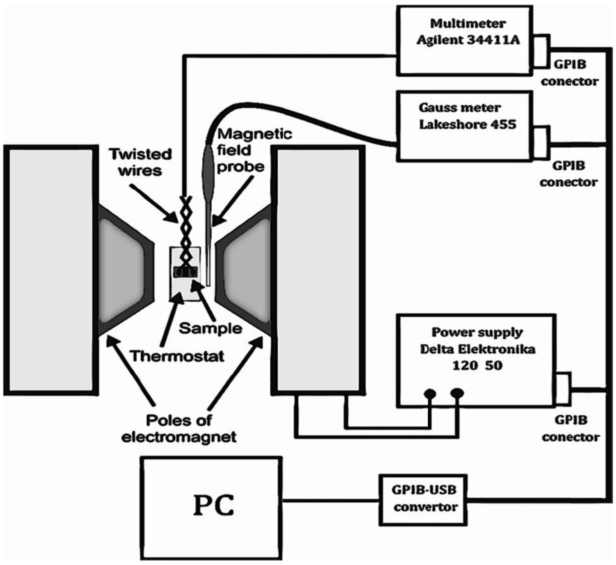


Fig. 1. Schematic diagram of the experiment setup

The thermostat with the sample can be fixed between the poles of the electromagnet in two positions in order to apply magnetic field in two configurations: parallel and perpendicular to the film surface. The electromagnet was powered by the "Delta Elektronika 120–50" programmable power supply. Magnetic field between the poles was measured using the "Lakeshore 455" gaussmeter. A magnetic field in the range of 0 – 2.5 T was created by changing the current through the electromagnet from 0 A to 50 A. A multimeter "Agilent 34411A" was used to measure resistance of the samples. Control of all used devices was made by personal computer through GPIB cables and GPIB-USB converters.

Requirements for the measurement system

The measurement system consists of the electromagnet, power supply, gaussmeter and resistance measurement device (multimeter). Change of the resistance *vs*. magnetic field is measured by changing the magnetic field created by the electromagnet. In turn, the magnetic field can be changed by changing the current through the coils of the electromagnet. The magnetic field dependence on the current is presented in Fig. 2. It is clear that magnetic field increases more rapidly at low current. Therefore, to obtain approximately equal steps of magnetic field, the current though electromagnet should be changed with increasing steps. Thus there is need to program several ranges of the current with different steps. In addition, the low field range is of a greater interest.

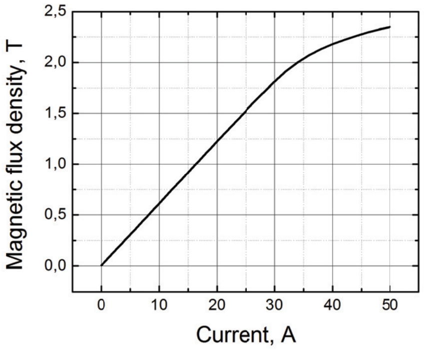


Fig. 2. Magnetic field between poles of electromagnet dependence on the current

To measure very small changes of the manganite resistance it is necessary to avoid the signal noise. Major disturbances arrive from the rapid change of the magnetic field. The allowed fluctuation level of the parameters in this system is 50 mT for the magnetic flux density and 0.001 % for the resistance. The automated measurement algorithm is shown in Fig. 3.

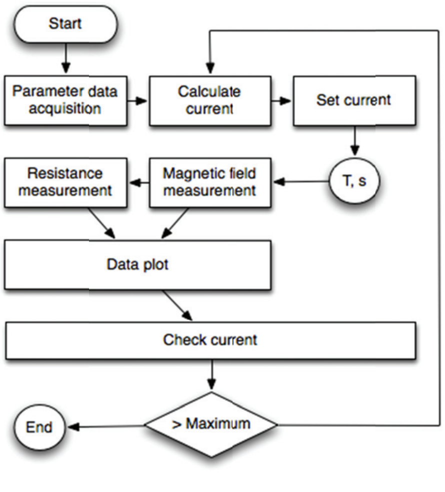
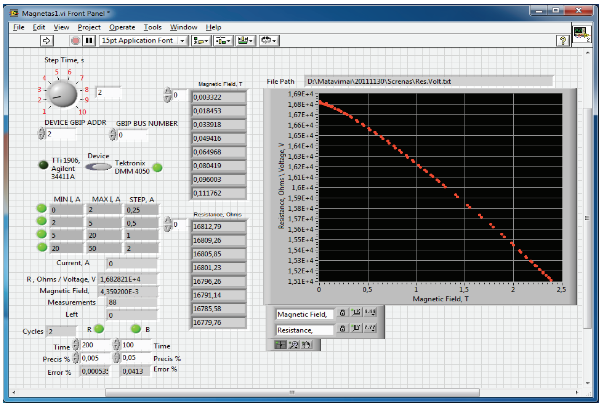


Fig. 3. Automated measurement algorithm

As it is shown in Fig. 3, parameter data acquisition is the first step of the algorithm, which involves the data acquisition from the user interface. The parameters are the following: the number of the measurement steps, waiting time for each step *T,* the maximum current and precision settings. The second and third algorithm steps are responsible for setting the current that is supplied to the electromagnet. The current must be altered using different steps so that the analysis of the MRA could be performed later. The fourth step is the delay time, which is defined by the user. It is needed to make sure that the magnetic field at the measurement site has stabilized. The sixth and the seventh algorithm steps are responsible for the magnetic field and the resistance measurements and checking whether precision requirements are fulfilled. Later the data is calculated and a MR graph versus magnetic field is plotted. The final algorithm step is the current check step. If the current is lower than the maximum selected by the user, the algorithm is restarted and the next higher current value is used. When the current is equal or exceeds the maximum selected by the user the algorithm comes to an end.

Automation using LabVIEW

LabVIEW is a graphical programming environment, which offers integration with the hardware devices and provides tools for advanced experimental data analysis and data visualization [7, 8]. Using the programming environment offered by the LabVIEW the measurement system has been successfully automated. In Fig. 4 the front panel design of the virtual instrumentation program is shown.



Step Time, s: 2

DEVICE GBIP ADDR: 2

GBIP BUS NUMBER: 0

TTi 1906, Agilent 34411A — Device — Tektronix DMM 4050

MIN I, A	MAX I, A	STEP, A
0	2	0,25
2	5	0,5
5	20	1
20	50	2

Current, A: 0

R, Ohms / Voltage, V: 1,682821E+4

Magnetic Field,: 4,359200E-3

Measurements: 88

Left: 0

Cycles: 2

	R	B
Time	200	100
Precis %	0,005	0,05
Error %	0,00053	0,0413

Magnetic Field, T	Resistance, Ohms
0,003322	16812,79
0,018453	16809,26
0,033918	16805,85
0,049416	16801,23
0,064968	16796,26
0,080419	16791,14
0,096003	16785,58
0,111762	16779,76

File Path: D:\Matavimai\20111130\Screnas\Res.Volt.txt

Fig. 4. Front panel design of the virtual instrumentation program

As it is shown in Fig. 4 the major part of the front panel was dedicated to the plot area where MR versus magnetic field is plotted. Also the front panel includes the waiting time switch, current steps selector and measurement indicators to show the measured values in real time.

Measurement results

The system was used for measurement of the magnetoresistance and the anisotropy of the manganite films. Fig. 5 presents the dependence of MR *vs.* magnetic flux density for two films of different chemical composition: La-Ca-Mn-O and La-Sr-Mn-O. The measurements were performed at two directions of the magnetic field. The current through electromagnet was changed from 0 to 50 A. This range was divided into four sub-ranges with different current steps. In the range 0-2 A the step was 0.25 A; in the range 2-5 A – 0.5 A; for 5 - 20 A the step was 1 A and in the range 20 – 50 A the step was 5 A. The measurement results were written to the data file only when the fluctuations of the magnetic field and resistance were less than 0.01% during 200 ms. During measurements the temperature of thermostat was kept 20 ^{0}C.

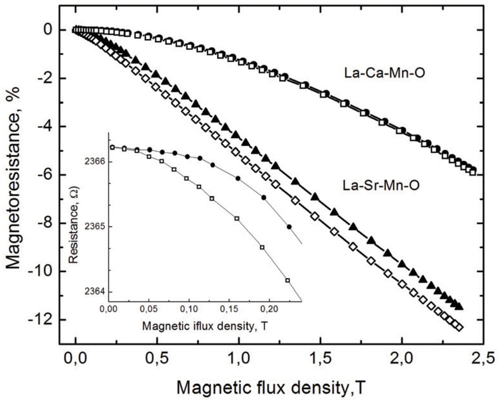


Fig. 5. MR dependence on magnetic flux density for La-Sr-Mn-O and La-Ca-Mn-O films. Insert: Resistance of La-Ca-Mn-O film changing in low magnetic field. In both cases magnetic field is applied in two directions: parallel to plane of film (opened symbol) and perpendicularly (closed symbol)

Obtained results were used to calculate the MR of manganites films *vs.* magnetic flux density. One can see in Fig. 5 that for the La-Sr-Mn-O film the MR is much higher than for La-Ca-Mn-O. Also, the difference between MR when magnetic field is applied parallel and perpendicular to the surface of sample is higher too for La-Sr-Mn-O film. The small difference of MR for La-Ca-Mn-O films can be explained by weak magnetization of the films. It is known that films with chemical composition La-Ca-Mn-O have the temperature of maximal resistance lower than La-Sr-Mn-O. That is a reason for weak dependence of resistance *vs.* magnetic field. The resulting accuracy acquired in the experiments is sufficient for further calculations. Fig. 6 presents a MRA *vs.* magnetic field calculated according to the equation (2). Despite to small changes in magnetoresistance of La-Ca-Mn-O when magnetic field was applied in parallel to the surface of the film and perpendicular direction, the results obtained are very satisfying.

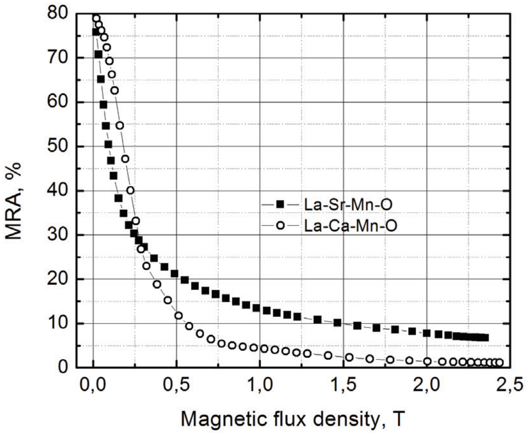


Fig. 6. MRA dependence on magnetic field

At low magnetic field the anisotropy of MR is highest and achieved 80%, whereas at magnetic field higher than

1 T the MRA decreases and at B = 2 T achieves 7.7% for La-Sr-Mn-O and 1.7 % for La-Ca-Mn-O films.

Conclusions

A measurement and automation equipment for measuring the manganite resistance dependence on magnetic field was created. Equipment consists of the electromagnet, the programmable power source, the magnetic field meter and the resistance measurement device. All devices are connected to PC by the GPIB cables and the GPIB-USB converter. The control program was created using the LabVIEW software package. The system was used for measurements of manganite films magnetoresistance dependence on magnetic field. The accuracy, which was achieved using this equipment, allows calculations of magnetoresistance anisotropy of the films despite to small changes of their resistance at low magnetic field. Also the measurement data allowed calculations of MR of manganites films *vs.* magnetic flux density to be performed. It was determined that for the La-Sr-Mn-O film the MR is much higher than for La-Ca-Mn-O. The difference between MR when magnetic field is applied parallel and perpendicular to the surface of sample is higher for La-Sr-Mn-O film. The small difference of MR for La-Ca-Mn-O films can be explained by weak magnetization of the films. Despite to small changes in magnetoresistance of La-Ca-Mn-O when magnetic field was applied in parallel to the surface of the film and perpendicular direction, the results obtained were very satisfying.

Acknowledgments

This work was supported by Agency for Science, Innovation and Technology (MITA) High-Tech Development Programme project MAGEPS (No. 31V-149).

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Received 2011 10 24
Accepted after revision 2011 12 17

V. Novickij, V. Stankevic, A. Grainys, J. Novickij, S. Tolvaisiene, T. Stankevic. Experimental Setup for Magnetoresistance Analysis of Lanthanum Manganites Thin Films // Electronics and Electrical Engineering. – Kaunas: Technologija, 2012. – No. 4(120). – P. 47–50.

A measurement and automation equipment for measuring the manganite resistance dependence on magnetic field is designed and developed in this work. Equipment consists of the electromagnet, the programmable power source, the magnetic field meter and the resistance measurement device. All devices are connected to PC by the GPIB cables and the GPIB-USB converter. The control program was created by using the LabVIEW software package. It enabled to change the steps of the current through the electromagnet in different ranges of the magnetic field and to set desired measurement accuracy and duration. The system was used for measuring of the magnetoresistance of the manganites films dependence on the magnetic field. The accuracy, which was achieved using this equipment, allows calculating anisotropy of MR of the manganites films despite to small changes of the resistance at low magnetic field. Ill. 6, bibl. 8 (in English; abstracts in English and Lithuanian).

V. Novickij, V. Stankevič, A. Grainys, J. Novickij, S. Tolvaišienė, T. Stankevič. Eksperimentinė įranga lantano manganitų plonųjų sluoksnių magnetovaržos analizei atlikti // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2012. – Nr. 4(120). – P. 47–50.

Sukurta matavimo ir automatizavimo įranga manganitų sluoksnių varžos priklausomybei nuo magnetinio lauko tirti. Įranga susideda iš elektromagneto, programuojamo maitinimo šaltinio, magnetinio lauko matuoklio ir varžos matavimo prietaiso. Visi prietaisai yra valdomi kompiuteriu per GPIB-USB keitiklį ir GPIB kabelius. Kompiuterinė valdymo programa sukurta naudojant LabVIEW programinės įrangos paketą. Ši programa leidžia keisti per elektromagnetą tekančios srovės kitimo žingsnį įvairiuose magnetinio lauko diapazonuose ir matavimo tikslumą bei trukmę. Sukurta sistema buvo panaudota lantano manganitų sluoksnių magnetovaržai, sukeltai magnetinio lauko, matuoti. Tikslumas, kuris buvo pasiektas naudojant šią įrangą, leidžia apskaičiuoti sluoksnių magnetovaržos anizotropiją, nors varžos pokyčiai silpname magnetiniame lauke yra labai maži. Il. 6, bibl. 8 (anglų kalba; santraukos anglų ir lietuvių k.).