III BWMD

III Brazilian Workshop on Magnetization Dynamics
November 19-21, 2014
Santa Maria, RS, Brazil
www.cbpf.br/~magdin

WORKSHOP PROGRAM AND BOOK OF ABSTRACTS

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Brazilian Workshop on Magnetization Dynamics

Dear Colleagues!

Welcome to Santa Maria and to the III Brazilian Workshop on Magnetization Dynamics (III BWMD).

In the last decades, the number of scientists and research groups working on magnetization dynamics has increased considerably. Thus, BWMD aims to put together the Brazilian community of students and scientist working on magnetization process and magnetization dynamics, as well as invited renowned foreign specialists in the field. In this sense, the Workshop program consists of a number of invited speakers who will give lectures on important recent advances in the field, as well as a contributed oral presentations and poster session.

The area of the magnetization dynamics involves a wide range of topics, such as dynamic behavior of nanostructured magnetic systems, statistical aspects of the processes of magnetization, magnetotransport at high frequencies, non-destructive magnetic measurements, computational techniques, sensors and electronic applications, among others. In particular, this is an area of wide application and technology of great interest for fundamental research.

The workshop is expected to cover the following topics:

1. Basic problems, magnetization processes, domains studies, and micromagnetics
2. Magnetization dynamics and magnetization process in nanostructures
    - Spintronics and spin nanoscillators
    - Magnetoimpedance and broadband ferromagnetic resonance
    - Magnetization dynamics on nanoparticles
    - Barkhausen noise in nanostructures
3. Magnetic thin films & nanostructures
4. Spin electronics & applications (non-recording)
    - GMR of multilayers, magnetic contacts and constrictions
    - Magnetic tunneling junctions
    - Spin transfer torque
    - Magnetoresistive and half-metallic materials
    - Complex oxides
    - Multiferroic materials
    - Magnetic semiconductors
    - Transport theory and spin injection
    - MRAM, magnetic logic and devices
    - Organic and carbon-based spin transport
    - Spin-orbitronics (spin-pumping, spin Hall, spin Seebeck)
5. Magnonics
6. Magnetization dynamics in magnetic materials
    - Electrical steels and losses
    - Fe-Ni, Fe-Co, nanocrystalline and amorphous alloys
    - Thin films, metamaterials, novel and special materials
7. Magnetization dynamics under high magnetic fields

8. Statistical aspects of magnetization dynamics
9. Scientific instrumentation and techniques for ultra-short times and high frequencies
10. Non-destructive magnetic measurements and instrumentation
    - Barkhausen noise
    - Magnetoacoustic emission
    - Other techniques to analyse magnetic materials
11. Sensors, high frequency and electronic applications
12. Computational Techniques Applied to Magnetization Dynamics
13. Others

The I Brazilian Workshop on Magnetization Dynamics took place in Rio de Janeiro, RJ, Brazil, on May 6-7, 2010. The II Brazilian Workshop on Magnetization Dynamics was held at the Praiamar Natal Hotel & Convention in Natal, RN, Brazil, on November 28-30, 2012.

The III Brazilian Workshop on Magnetization Dynamics is held at the Universidade Federal de Santa Maria in Santa Maria, RS, Brazil, on November 19-21, 2014. III BWMD is organized by Universidade Federal de Santa Maria.

In this booklet you will find the abstracts submitted to the III BWMD, as well as useful information for your stay in Santa Maria.

We wish you a fruitful workshop and a pleasant stay in Santa Maria.
After all, we hope to see you again in our next edition!

Marcos Carara and Lucio Strazzabosco Dorneles
III BWMD Chairs

III BWMD

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Santa Maria, RS, Brazil

Venue
Universidade Federal de Santa Maria (http://www.ufsm.br)
Avenida Roraima, 1000
Prédio 17, anfiteatro B2
Cidade Universitária
Bairro Camobi
97105-900 Santa Maria, Rio Grande do Sul, Brazil
Telephone: +55-55-3220-8618

Workshop website
http://www.cbpf.br/~magdin/

Contact
iiibwmdyn@ufsm.br

Local Committee
Lucio Strazzabosco Dorneles (Chair), UFSM
Luiz Fernando Schelp, UFSM
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Julian Geshev, UFRGS
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Rubem Luis Sommer, CBPF

Financial support

III Brazilian Workshop on Magnetization Dynamics is financially supported by the following institutions: UFSM, CBPF, UFRN, CAPES, and Chapter BR IEEE Magnetics.

Useful information for visitors

Santa Maria is often referred to as the heart of Rio Grande do Sul. The city is known for the Universidade Federal de Santa Maria and a number of other private universities and colleges, as well as for the Brazilian Air Force and Army.

The city offers you several options to the nightlife, including bars and restaurants. In Santa Maria, you find excellent options to enjoy the well known traditional regional gastronomy, the churrasco, as well as some international cuisines, such as the Italian one.

III BWMD offers the opportunity to all participants and speakers to discover the beauties of Santa Maria. If you wish to get a larger view of the city`s nature beauty, during the workshop you can obtain information on how to visit the main tourist destinations, that will be available at the Workshop registration area or at the Hotel reception.

1. **Bella Trento Restaurante e Pizzaria** (Pizzeria)
Av. João Luiz Pozzobon, 1599 - Km 3
http://goo.gl/ra8DFL
Bairro Dores
Telephone: +55-55-3223-9229
Site: http://www.bellatrento.com.br/
Open hours: daily from 11 am until 3 pm and from 7 pm until 12 pm
Price: $, R$ 40,00
Credit cards:
It is far from the university and from downtown, so we suggest you take a taxi to go to Bella Trento

2. **Bovinus Churrascaria** (Steak house)
Rua Venâncio Aires, 1596
http://goo.gl/LV6AgH
Bairro centro
Telephone: +55-55-3225-1790
Open hours: daily from 11 am until 3 pm and 7 pm until 12 pm
Price: $$, R$ 50,00
Credit cards:

3. **Restaurante Augusto** (International and regional cuisine)
Rua Marechal Floriano Peixoto, 1354
http://goo.gl/9KqH5O
Bairro centro
Telephone: +55-55-3222-0212
Site: http://www.restauranteaugusto.com.br
Open hours: daily from 11 am until 12 pm
Price: $$$, R$ 70,00
Credit cards:

4. **Ponto de Cinema** (Bar, snacks)
Rua Ângelo Uglione, 1567
http://goo.gl/hUDMA5
Bairro centro
Telephone: +55-55-3221-8800
Site: http://www.pontodecinema.com.br
Open hours: daily from 7 pm until 12 pm

5. **Restaurante Las Leñas** (Parrilla)
Av. Fernando Ferrari, 1718
http://goo.gl/hdiRuh
Bairro Nossa Senhora de Lourdes
Telephone: +55-55-3025-2550
Open hours: daily from 7pm am until 12 pm
Price: $$$, R$ 70,00
Credit cards:

6. **Moto Garage** (Bar)
Rua Mal. Floriano Peixoto, 2010
http://goo.gl/YsFMpR
Bairro Medianeira
Telephone: +55-55-3307-6871
Site: http://www.motogarage.com.br
Credit cards:

7. **Restaurante Santa Brasa** (Parrilla)
Rua Mal. Floriano Peixoto, 1989
http://goo.gl/23xb7q
Bairro Medianeira
Site: http://www.santabrasa.com.br
Telephone: +55-55-3028-7707
Credit cards:

8. **Pinus** (Bar)
Rua Erly de Almeida Lima, 444
Av. Roraima rótula BR-287
http://goo.gl/ye6e3Q
Bairro Camobi
Telephone: +55-55-3217-2826
Close to the university
Credit cards:

9. **Paiol Lanches** (Bar and Xis)
Avenida Presidente Vargas, 1872
Bairro Nossa Senhora de Fatima
Telephone: +55-55-3222-9606
Credit cards:

III BWMD Workshop Dinner

The III BWMD Organizing Committee is delighted to invite you to participate in the Workshop Dinner, where you will experience the delicious Italian cuisine. It will be held on November 20, 2014, at the Ristaurante La Sorella (http://www.ristorantelasorella.com.br), located in the city of Silveira Martins.

The costs is R$ 40,00 per participant, including transportation. Buses will be available for the participants to go the Workshop Dinner. The bus departure is scheduled to 18:30, in front of the Department of Physics, building 13, at the UFSM.

Presentations

The workshop language is English. No simultaneous interpretation service will be provided during the meeting.

The Workshop presentations will consist of invited lectures, oral talks and poster sessions, selected by the Program Committee. A single plenary session is planned for all invited and oral presentations.

Invited talks are 1 hour or 30 minutes long, including 5 minutes for questions and discussion, according the III BWMD program presented in table 1. Oral contributions are 30 minutes or 15 minutes long, including 5 minutes for questions and discussion. Both, invited and oral presentations are to be made either using personal laptop or the PC that will be available in the session room (Windows system + Powerpoint and Acrobat Reader). **Please, come to the session room 15 minutes before the session start to upload your presentation to the PC or to set up your laptop connection.**

For contributed poster presentations, the available board area for poster presentations is 90 cm (width) x 100 cm (height). You must provide your own printout of the title, authors and poster itself. Scotch tape and the session paper designation sign will be provided by the Workshop staff. **You are requested to set up your poster on Wednesday or on Thursday morning, and remove it at the end of the Workshop.**

III BWMD Program

Several distinguished scientists and researchers have been invited by the III BWMD Program Committee to give a lecture and to present their work. The complete list of invited speakers is composed by

- ✓ Axel Friedrich Hoffmann, Argonne National Laboratory, USA;
- ✓ Galina V. Kurlyandskaya, Universidad del País Vasco, Spain;
- ✓ Jonas Karl Fransson, Uppsala University, Sweden;
- ✓ Juliano Denardin, Universidad de Santiago, Chile;
- ✓ Leonard Spinu, University of New Orleans, USA;
- ✓ Antônio Azevedo da Costa, UFPE, Brazil;
- ✓ Fernando J. G. Landgraf, USP and IPT, Brazil;
- ✓ Julian Geshev, UFRGS, Brazil;
- ✓ Linilson Padovese, USP, Brazil;
- ✓ Marcio Assolin Corrêa, UFRN, Brazil;
- ✓ Rubem Luis Sommer, CBPF, Brazil.

The III BWMD will feature diverse and up-to-date lectures on several topics. The program, detailed in Table 1, is composed by invited lectures, oral presentations and contributed posters. The list of all contributions to III BWMD is presented in the next pages.

Table 1: III BWMD program. Please, pay attention in the duration time for each talk, since all the present similar sizes in the table, irrespective the duration time they represent.

Time	November 19 (Wed)	November 20 (Thu)	November 21 (Fri)
9:00 - 9:30		Talk 1 - L. Spinu	Talk 10 - A. Hoffmann
9:30 - 10:00			
10:00 - 10:30		Talk 2 -G. Kurlyandskaya	Talk 11 - J. Fransson
10:30 - 11:00			
11:00 - 11:15		Coffee break	Coffee break
11:15 - 11:45		Talk 3 - M. A. Corrêa	Talk 12 -F. J. G. Landgraf
11:45 - 12:00		Talk 4 - D. G. Chavez	Talk 13 - L. Padovese
11:00 - 12:15		Talk 5 - R. Dutra	
12:15 - 14:00		Lunch	Lunch
14:00 - 14:30		Talk 6 - J. C. Denardin	Talk 14 - A. Azevedo
14:30 - 15:00		Talk 7 - R. B. da Silva	Talk 15 - A. D. C. Viegas
15:00 - 15:30		Talk 8 - P. Pureur	Talk 16 - J. Geshev
15:30 - 16:00		Talk 9 - P. Landeros	Talk 17 - F. Béron
16:00 - 16:15		Coffee break	Coffee break
16:15 - 16:45		Poster session	Talk 18 - R. L. Sommer
16:45 - 17:00			Chapter BR IEEE Magnetics
17:00 - 17:30			
17:30 - 18:00	Registration		
18:00 - 18:30			
18:30 - 19:00			Closing
19:00 - 19:30	Opening		
19:30 - 20:00	Welcome reception		
20:00 - 20:30			
20:30 - 21:00		Workshop Dinner	
21:00 - 21:30			
21:30 - 22:00			
22:00 - 22:30			
22:30 - 23:00			

Wednesday, November 19 (Wed)

17:30 - 19:00	Registration
19:00 - 19:30	Opening
19:30 - 21:00	Welcome Reception

Thursday, November 20 (Thu)

09:00 - 10:00	Talk 1 (Invited) - Broadband ferromagnetic resonance studies of two dimensional periodic magnetic nanostructures *L. Spinu, Advanced Materials Research Institute and Department of Physics, University of New Orleans, New Orleans, USA*
10:00 - 11:00	Talk 2 (Invited) - Magnetic nanoparticles obtained by electric explosion of wire and composites for “smart” material applications *G. V. Kurlyandskaya, Basque Country University, Leioa, Spain*
11:00 - 11:15	Coffee Break
11:15 - 11:45	Talk3 (Invited) - Exploring the Magnetoimpedance effect as a tool for the study of the magnetization dynamics at high frequencies *M. A. Corrêa, UFRN, Natal, RN, Brazil*
11:45 - 12:00	Talk 4 - Broadband permeability tensor measurements of a synthetic anti-ferromagnet *D. G. Chavez, CBPF, Rio de Janeiro, RJ, Brazil*
12:00 - 12:15	Talk 5 - Broadband FMR of the magnetic vortex state in elliptical dots *R. Dutra, CBPF, Rio de Janeiro, RJ, Brazil*
12:15 - 14:00	Lunch
14:00 - 14:30	Talk 6 (Invited) - Giant magnetoimpedance in NiFe/Ta antidot and nanodomes arrays on alumina nanoporous membranes *J. C. Denardin, Universidad de Santiago de Chile, Santiago, Chile*
14:30 - 15:00	Talk 7 - Asymmetric giant magnetoimpedance in exchange biased NiFe/IrMn multilayers *R. B. Silva, UFSM, Santa Maria, RS, Brazil*
15:00 - 15:30	Talk 8 - Hopkinson effect in the RCO12B6 (R = Y and Gd) compounds studied by impedance measurements *P. Pureur, UFRGS, Porto Alegre, RS, Brazil*
15:30 - 16:00	Talk 9 - Splitting of spin-wave modes in thin films with arrays of periodic perturbations: theory and experiment *P. Landeros, Universidad Técnica Federico Santa María, Valparaíso, Chile*
16:00 - 16:15	Coffee Break
16:15 - 17:30	Poster Session
18:30 - 19:00	Bus departure to the Workshop Dinner
20:30 - 23:00	Workshop Dinner

Friday, November 21 (Fri)

09:00 - 10:00	Talk 10 (Invited) - Connecting Spin Waves to Charge Currents *A. Hoffmann, Argonne National Laboratory, Argonne, USA*
10:00 - 11:00	Talk 11 (Invited) - Electrical and Thermal Control of Magnetic Exchange Interactions *J. Fransson, Uppsala University, Uppsala, Sweden*
11:00 - 11:15	Coffee Break
11:15 - 11:45	Talk 12 (Invited) - Energy Dissipation in the hysteresis of electrical steels *F. J. G. Landgraf, USP, São Paulo, SP, Brazil*
11:45 - 12:15	Talk 13 (Invited) - A look at Magnetic and Micro magnetic Non Destructive Testings *L. Padovese, USP, São Paulo, SP, Brazil*
12:15 - 14:00	Lunch
14:00 - 14:30	Talk 14 (Invited) - Interplay between magnetization dynamics and spin current in magnetic hybrid structures *A. Azevedo, UFPE, Recife, PE, Brazil*
14:30 - 15:00	Talk 15 - Magnetic properties of concentric asymmetric nanorings *A. D. C. Viegas, UFSC, Florianópolis, SC, Brazil*
15:00 - 15:30	Talk 16 (Invited) - Negative rotatable anisotropy due to spin-flip-like transitions in exchange-biased IrMn/NiFe films *J. Geshev, UFRGS, Porto Alegre, RS, Brazil*
15:30 - 16:00	Talk 17 - Magnetic properties of Ni nanowires with modulated diameter: a bottle-neck pinning *F. Béron, UNICAMP, Campinas, SP, Brazil*
16:00 - 16:15	Coffee Break
16:15 - 16:45	Talk 18 - Magnetization dynamics at CBPF: an overview and recent advances *R. L. Sommer, CBPF, Rio de Janeiro, RJ, Brazil*
16:45 - 18:30	Chapter BR IEEE Magnetics
18:30 - 19:00	Closing

Poster Session

IIIBWMD-01	Hysteresis and anomalous losses *A. A. de Almeida, USP, São Paulo, SP, Brazil*
IIIBWMD-02	Annealing effect on the static and dynamic magnetic properties of films of FeNbCuSiB *M. J. P. Alves, CBPF, Rio de Janeiro, RJ, Brazil*
IIIBWMD-03	Effect of electric current on domain wall dynamics *F. Beck, Unipampa, Alegrete, RS, Brazil*
IIIBWMD-04	Development of a graphical tool to study magnetic systems *J. Guimarães, UFRGS, Porto Alegre, RS, Brazil*
IIIBWMD-05	Correlation between dynamic, static and structural properties in CFA/Ag/CFA Heusler alloy trilayered *V. M. Escobar, UFRN, Natal, RN, Brazil*
IIIBWMD-06	Ferromagnetic resonance studies in exchange biased $Ni_{81}Fe_{19}/Ir_{20}Mn_{80}/Ta$ multilayers *P. R. Kern, UFSM, Santa Maria, RS, Brazil*
IIIBWMD-07	Magnetic actuator based on giant magnetostrictive material Terfenol D with strain and temperature monitoring using FBG optical sensor *G. V. Kurlyandskaya, Basque Country University, Leioa, Spain*
IIIBWMD-08	The effect of recovery heat treatment on the magnetic hysteresis of electrical steels *T. S. P. Nishikawa, USP, São Paulo, SP, Brazil*
IIIBWMD-09	Functionalization and surface characterization of a magnetoelastic biosensor for detection of Escherichia Coli *A. L. Possan UCS, Caxias do Sul, RS, Brazil*
IIIBWMD-10	Study of unidirectional anisotropy and rotational hysteresis in exchange bias systems *J. N. Rigue, Instituto Federal Farroupilha, Santo Augusto, RS, Brazil*
IIIBWMD-11	Anisotropic magnetoresistance response tuned by the angle between current and exchange bias in IrMn/NiFe thin films *R. L. Seeger, UFSM, Santa Maria, RS, Brazil*
IIIBWMD-12	Structural, static and dynamic properties of CFA and CFA/Ag multilayers grown on Si(100) and glass substrates *A. M. Silva, UFRN, Natal, RN, Brazil*
IIIBWMD-13	Linewidth and damping in electrodeposited $Ni_{81}Fe_{19}/Cu$ multilayered films: a study using magnetoimpedance *B. Silva, CBPF, Rio de Janeiro, RJ, Brazil*

IIIBWMD-14	Thickness dependence of the dynamic magnetic behavior in Permalloy films *E. F. Silva, UFRN, Natal, RN, Brazil*
IIIBWMD-15	Tunable asymmetric magnetoimpedance effect in ferromagnetic NiFe/Cu/Co films *E. F. Silva, UFRN, Natal, RN, Brazil*
IIIBWMD-16	Exchange Bias in multilayers Py/IrMn/Ta: a study through the anisotropic magnetoresistance *J. V. de Siqueira, UFSM, Santa Maria, RS, Brazil*
IIIBWMD-17	Magnetic interactions in exchange-coupled unbiased FM/AF system with $T_C << T_N$ *K. D. Sossmeier, UNILA, Foz do Iguaçu, PR, Brazil*
IIIBWMD-18	Spin transfer analysis via Landau-Lifshitz-Gilbert equation *M. C. Sulzbach, UFRGS, Porto Alegre, RS, Brazil*
IIIBWMD-19	Remanence plots method applied to exchange bias systems *A. Harraes, UFRGS, Porto Alegre, RS, Brazil*

Abstracts

Invited and contributed oral presentations

Talk 1

Broadband ferromagnetic resonance studies of two dimensional periodic magnetic nanostructures

Nicolas Vargas[1,2], Shankar Khanal[1], Daniel Adams[1], Dorin Cimpoesu[3], Junjia Ding[4], Adekunle Adeyeye[4], Laurentiu Stoleriu[3], Alexandru Stancu[3] and Leonard Spinu[1]

[1]*Advanced Materials Research Institute - AMRI and Department of Physics, University of New Orleans, New Orleans, LA 70148, USA*
[2]*Departamento deFísica, Universidad de Santiago de Chile, 917-0124 Santiago, Chile*
[3]*Faculty of Physics, Iasi University, Romania*
[4]*Dept of Electrical & Computer Engineering, National University of Singapore, Singapore*

Magnetization dynamics in nanosized magnetic objects is of great importance for fundamental studies and technological applications. Understanding the magnetization switching of nanomagnets subject concurrently to a static and a GHz frequency range excitation is essential for the development of future generations of magnetic storage devices with increased data transfers and recording densities.
The static limit of magnetization switching in the case of a magnetic element with uniaxial anisotropy can be elegantly represented graphically by the well-known Stoner-Wohlfarth astroid [1]. When an additional microwave field is present the static astroid picture is not anymore valid and a dynamical representation is needed which takes into account the ferromagnetic resonance (FMR) phenomenon. In this work we investigate experimentally and theoretically the influence of frequency and magnetic interactions on the magnetization dynamics of two-dimensional magnetic nanowire arrays. The experimental and theoretical data are analyzed using a magnetic field critical curve approach, where the maxima of the susceptibility tensor are plotted in a polar graph, similarly to the static astroid.
In this work we will present our results in probing the dynamics of two-dimensional $N_{80}Fe_{20}$ nanowire arrays with different strength of interwire interactions using angular dependent microwave absorption spectroscopy. The nanowires were fabricated directly on top of a coplanar waveguide (CPW) using electron beam lithography and followed by electron-beam deposition and lift-off process. The experimental results are analyzed in terms of a new graphical representation of the resonant absorption data through a critical-curve-like approach [2]. This new representation has the advantage of offering a direct and complete visual representation of anisotropy, interactions and magnetization dynamics effects in nanomagnet arrays. The proposed image of polar resonant absorption curves offers the benefit of a pictorial fingerprinting-like method, while being complete and accurate, which is useful for a rapid differentiation of samples of different morphologies and/or subject to different microwave irradiations. In this talk we will reveal the connection between this new representation and the static switching field critical curves.

Work supported by the National Science Foundation through Grant Nos. ECCS-1028547 and EPS-1003897 with additional support from the Louisiana Board of Regents.

[1] J. C. Slonczewski, "Theory of Magnetic Hysteresis in Films and Its Application to Computers," IBM Research Center Poughkeepsie Research Memorandum R.M. 003.111.224, 1956.
[2] D. Cimpoesu et al., "Angular resonant absorption curves in magnetic nanowire arrays," *Appl. Phys. Lett.*, vol. 102, pp. 232401, 2013

Talk 2

Magnetic nanoparticles obtained by electric explosion of wire and composites for "smart" material applications

G.V. Kurlyandskaya[1], I.V. Beketov[2,3], A.P. Safronov[2,3], S.M. Bhagat[4]

[1] *Dept. Electricity and Electronics, Basque Country University UPV-EHU, Leioa, Spain*
[2] *Institute of Electrophysics UD RAS, 106 Amundsen Str., 620016, Ekaterinburg, Russia*
[3] *Ural Federal University, Mira 3, 620002, Ekaterinburg, Russia*
[4] *Dept. of Physics, Unversity of Maryland, College Park, MD 20742, USA*

Magnetic nanoparticles (MNPs) and nanocomposites exhibit unique properties suitable for a large variety of applications [1]. Magnetite is one of the most versatile ferromagnetic materials with a high saturation magnetization, a Curie temperature well above room temperature, a relatively weak magneto-crystalline anisotropy and superparamagnetic behaviour in the MNP state. Magnetite MNPs can be considered the most studied nanomaterial designed for applications. There are different methods for MNPs' fabrication: hydrothermal synthesis, microemulsion, co-precipitation, autocombustion, biomioneralization, etc. Despite the advantages of traditional chemical techniques there are well known disadvantages: low production rate, limited purity or a high environmental cost, etc. In this work we describe our experience of preparation, fractionation and characterization of ensembles of MNPs of iron oxide produced by thermal dispersion of material in gas technique - the electric explosion of wire (EEW) [2-3] - using different techniques and modeling. This method is ecologically safe, it provides production rates up to 200 g/h, requires small energy consumption and ensures fabrication of MNPs with an average particle size of 20-100 nm and very low level of contamination. The main focus was on the fabrication of the de-aggregated spherical magnetite nano-particle ensembles with a narrow size distribution as the potential basis for on-purpose designed magnetic nanofluids. The second type of MNPs obtained by the EEW method are metallic nanoparticles of Fe, Ni, FeNi, Cu, Al, etc., developed because of their high frequency applications: magnetoimpedance (MI) sensors, microwave switches and absorbers, etc. For this purpose careful processing of the MNPs and design of polymer-MNPs composites including the composites with thin films components are hot areas of the "smart" material applications and flexible electronics. Although flexible substrates offer a number of advantages (low weight, excellent adaptability in multipurpose devices with complex shapes, etc.), they also serve as the basis for new research lines as the problems with the thermal energy dissipation, static charges or adhesion level become crucially important. In the case of magnetic flexible electronics there is a need for the development of combinations of magnetic multi-layers and compatible polymers which are stable at the appropriate fabrication conditions. The composite top layer can ensure corrosion stability, play the role of magnetoactive covering with change of temperature or stress or enhance the sensitivity of magnetic field detectors. Small amounts of Cu or Al nanoparticles in a polymer matrix change the conductivity and the dielectric properties of the composites. This work was supported by CRDF− UB RAS RUE2-7103-EK-13 from the U.S. Civilian Research & Development Foundation (CRDF Global) with funding from the United States Department of State. The opinions, findings and conclusions stated herein are those of the authors and do not necessarily reflect those of CRDF Global or the United States Department of State. We thank A. I. Medvedev, A. M. Murzakaev and A.V. Bagazeev for special support. [1]Y.-W. Jun, J.-W. Seo, and J. Cheon, Acc. Chem. Res. **41**, 179 (2008). [2] Yu. A. Kotov, J. Nanopart. Res. **5**, 539 (2003). [3] G.V. Kurlyandskaya, S. M. Bhagat, A.P. Safronov, A. P. Beketov, A. Larrañaga, A. AIP Adv. **1**, 042122 (2011).

Talk 3

Exploring the Magnetoimpedance effect as a tool for the study of the magnetization dynamics at high frequencies

M. A. Corrêa[1], C. Chesman[1], F. Bohn[1], R. L. Sommer[2]

[1]*Departamento de Física, Universidade Federal do Rio Grande do Norte, Natal, RN, Brazil*
[2]*Centro Brasileiro de Pesquisas Físicas, Dr. Xavier Sigaud 150,Urca, Rio de Janeiro, RJ, Brazil*

Magnetoimpedance (MI) effect has become a versatile tool for both aspects, investigation of ferromagnetic materials and application in sensor elements of electronic devices. Basically, the MI effect is the change of the electrical impedance of a metallic samples when submitted to an external magnetic field. In this work, we present a general overview of the distinct research lines of our group. Actually, four main lines are in progress. All of them are based in the MI in the thin film geometry with distinct structures and/or applications. The first one is related with the results obtained in Co_2FeAl/Ag multilayered samples [1]. The Co_2FeAl (CFA) is a full-Heusler alloy that can present low damping parameter and high spin polarization, becoming a promissor candidate to Spintronics application. The second line is related to ferromagnetic/(Ag, Cu, Ta) multilayered samples grown on flexible substrate (Kapton) [2]. The ferromagnetic materials selected for this study are $Ni_{81}Fe_{19}$, $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ and Co, which present distinct magnetostriction constants, and aim to study the effect of the magnetostriction on the magnetization dynamics at high frequencies. The third one is based on the our recent study performed in biphase magnetic materials composed by NiFe/Cu/Co multilayer films [3], where the possibility of tuning the asymmetric magnetoimpedance effect is considered, providing hints to its application in magnetic sensors devices. Finally, we present the recent theoretical approach developed to describe the MI effect in thin films structures [4]. The theoretical approach corresponds to a robust way to calculate the longitudinal MI effect and is based in the appropriate description of the free magnetic density energy for the studied sample, as well as in a general model for the magnetic permeability calculation [5].

[1] M. A. Corrêa et al., Appl. Phys. Express, **6**, 093001 (2013).
[2] K. Agra et al., J. Magn. Magn. Mater. **355**, 136 (2014).
[3] E. F. Silva et al., Appl. Phys Lett. **105,** 102409 (2014).
[4] M. A. Corrêa et al, Submitted to Phys. Rev. B.
[5] L. Spinu et al., J. Magn. Magn. Mater. **296**, 1 (2006).

Talk 4

Broadband permeability tensor measurements of a synthetic anti-ferromagnet

<u>D. E. Gonzalez-Chavez,</u> R. Dutra and R. L. Sommer

Centro Brasileiro de Pesquisas Físicas, Dr. Xavier Sigaud 150,Urca, Rio de Janeiro, RJ, Brazil

Ferromagnetic resonance (FMR) has been proved to be one of the most useful method for characterizing thin magnetic films and nanostructures. In the last decade, broadband FMR techniques has been developed, were the vector network analyzer ferromagnetic resonance (VNA-FMR) is one of the mostly used. With this technique we can measure the dynamic properties (permeability or absorption) in a frequency range from few MHz to dozens of GHz. Moreover the measurements can be performed at variable magnetic fields. Therefore, besides measuring the saturated states as in traditional FMR, a broadband measurement can be performed on unsaturated states, and even at zero field. We can also change the orientation of the exciting radio frequency (RF) field in order to measure the different components of the permeability tensor, at any given magnetic configuration of our sample. In a previous work [1] we showed experimentally and explained by a simple model the influence of the relative direction between the RF field and the sample's magnetization orientation on the resonance spectra. In this work we give further insights on this subject by analyzing a sample with a synthetic anti-ferromagnet (SAF) behavior NiFe(20nm)/Ru(1nm)/NiFe(20nm)/IrMn(20nm). In this sample each NiFe layer behaves as two macrospins coupled to each other trough the Ru spacer. This coupling is anti-ferromagnetic such that at zero field both macro spins are in opposite directions, by increasing the external static field on the sample, it goes to saturation by gradually rotating the magnetization until fully alignment to the external field. This behavior allows us to carefully study the FMR response in the anti-parallel, rotating and saturated states under different RF field directions. We performed VNA-FMR measurements with in-plane exciting RF field in both parallel and perpendicular directions relative to the applied static field direction. Both measured spectra showed the same dispersion relation but with absorption amplitudes on the resonant branches depending on the RF field direction (see Fig. 1). These amplitudes are related to the permeability tensor component been probed by the RF field. We use the model explained in a previous work [1] to fully describe the experimental results and give further insights into magnetization dynamics of this kind of systems.

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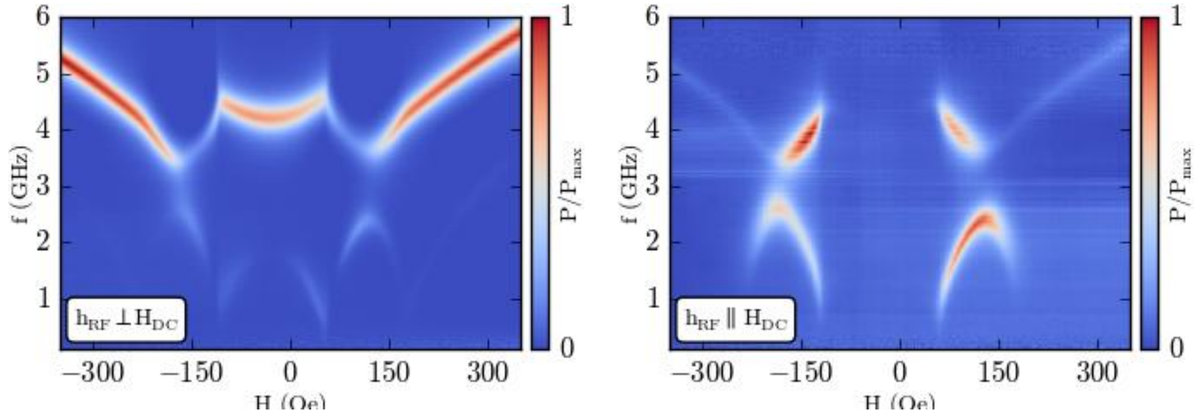

Figure 1: Broadband FMR spectra of a SAF obtained with RF field perpendicular (right) and parallel (left) to the applied external field.

Talk 5

Broadband FMR of the magnetic vortex state in elliptical dots

R. Dutra, Diego Gonzalez-Chavez, T. Marcondes and R. L. Sommer

Centro Brasileiro de Pesquisas Físicas, Dr. Xavier Sigaud 150,Urca, Rio de Janeiro, RJ, Brazil

The dynamical properties of patterned magnetic sub-micrometric elements have attracted an increasing interest in the last decade because of the observation of new effects induced by the lateral confinement on the spin excitation spectrum. In this work we explore the magnetization dynamics of periodic arrays of $Ni_{80}Fe_{20}$ patterned elements using the vector network analyzer ferromagnetic resonance technique (VNA-FMR). Two examples are presented: an array of disks with diameter of 1μm and array of ellipses with dimensions of 2.4 μm x 1.4 μm, both with 50 nm thickness. Our arrays were produced, onto a Si wafer, by combining e-beam lithography, magnetron sputtering and lift-off techniques. We were able to control the magnetostatic interaction in the arrays by varying the the spacing between the elements. The samples were characterized by alternating gradient force magnetometry and magnetic force microscopy. The obtained M vs. H curves showed the typical behavior inherent to vortex states. From the broadband measurements we obtained the dispersion relations for fields up to ± 800 Oe, for two radio frequency field configurations ($h_{rf} \perp H_{dc}$) and (h_{rf} // H_{dc}). In the saturated states, were the magnetization of each element of the array is aligned to the external field, we observed the uniform Kittel and magnetostatic modes. On the other hand for the vortex states a rich structure of spin-wave modes was observed, such as modes with integral numbers, m and n, which represent the azimuthal and radial modes. Micromagnetic simulations were performed in order to have a further insight of the experimental results. With them we obtained the details of the excited spin eigenmodes in the frequency domain at a given bias field.

Talk 6

Giant magnetoimpedance in NiFe/Ta antidot and nanodomes arrays on alumina nanoporous membranes

R. B. da Silva[1], R. D. Della Pace[1], L.S. Dorneles[1] and J.C. Denardin[2]

[1]Departamento de Física, Universidade Federal de Santa Maria, 97105-900 Santa Maria, RS, Brazil
[2]Departamento de Física, Universidad de Santiago de Chile (USACH), Avda. Ecuador 3493, 917-0124 Santiago, Chile

The giant magnetoimpedance effect (GMI) is the change in electrical impedance observed when a soft magnetic material is submitted to an alternate current and to a DC external magnetic field [1]. The effect is of technological interest due to the application of GMI materials as probe elements in sensor devices for low-field detection [2]. Typical materials that may give rise to GMI effect are amorphous wires, amorphous ribbons and multilayered films. For films, the sandwich structure is the traditional approach to improve GMI ratio, but the high working frequency constitutes the major negative factor for sensor applications. On the other hand, fabrication of multilayers in modulated nanostructures could induce a transversal moment distribution, allowing the modulation of the linear region of the GMI curves. The magnetic nanostructures usually referred as antidots are based on magnetic thin films with periodic arrays of holes. In an antidot array, magnetic features such as coercive field, anisotropy axes and reversal mechanisms, among others, can be tailored by tuning the geometric parameters of the array. Antidots of permalloy (NiFe) have been widely studied [3-4] and they have higher coercivity as compared to continuous films. In this work we used ordered nanoporous alumina membranes (NAMs) as substrate for deposition of [NiFe(20nm)/Ta(2nm)]x20 multilayers. The films have been deposited by sputtering in the surface of NAMs, forming antidots, and in the bottom of NAMs, forming nanodomes. A reference sample was also deposited under the same conditions on a glass substrate. Images obtained by scanning electron microscope (SEM) show that the samples replicate the substrate modulation when deposited on NAMs. Magnetization curves show an increase of coercivity of the antidots as compared with the continuous film and the nano-dome system. Impedance measurements where performed up to 4 GHz with a network analyzer using as sample holder a planar transmission line (micro-strip) in which the sample is the conductive strip. The samples modulation is responsible for changes in GMI response. The correlation between nanostructure and GMI are discussed.

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Talk 7

Asymmetric giant magnetoimpedance in exchange biased NiFe/IrMn multilayers

R. B. da Silva,[1] M. A. Corrêa,[2] F. Bohn,[2] E. F. Silva,[2] T. J. A. Mori,[1] R. D. Della Pace,[1] R. Dutra,[3] and R. L. Sommer[3]

[1]Departamento de Física, Universidade Federal de Santa Maria, 97105-900 Santa Maria, RS, Brazil
[2]Departamento de Física, Universidade Federal do Rio Grande do Norte, 59078-900 Natal, RN, Brazil
[3]Centro Brasileiro de Pesquisas Físicas, 22290-180 Rio de Janeiro, RJ, Brazil

Giant magnetoimpedance (GMI) is the large variation of AC impedance of soft magnetic conductor due to the action of a DC external magnetic field [1]. The effect has attracted much attention in the last years because the potential for applications in sensitive magnetic field sensors. Although GMI materials are highly sensitive they show a nonlinear response next zero fields which prevents the detection signal of the field. Usually, to overcome this problem, a bias field is applied to the sample to induce asymmetric GMI (AGMI). However, this increases the power consumption and makes difficult the device miniaturization, explaining the interest in AGMI materials which presented an asymmetric static magnetic configuration due to magnetostatic interactions [2] or exchange bias [3]. In this work, we report how tuning around zero field linear regions of AGMI curves of NiFe/IrMn exchange biased multilayers change the NiFe thick, the angle between the external and the exchange bias field and the frequency of measurements. The samples, [NiFe(t_{NiFe})/IrMn(20nm)/Ta(1nm)] × 20 with t_{NiFe} = 10, 20 and 40 nm, were grown on glass substrates in a magnetron sputtering. The crystalline structure and static magnetic response were inferred by X-ray diffraction and magnetization measurements, respectively. The components of impedance were measured up to 3 GHz using a network analyzer and microstrip line sample holders which the samples are the conductive strip and the glass substrates the isolated layer. Our results shown the GMI sensitivity at zero fields reaches values as high as 160 mΩ/Oe at frequencies that depended on both thickness of sample and orientation of exchange bias field.

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Talk 8

Hopkinson effect in the $RCO_{12}B_6$ (R = Y and Gd) compounds studied by impedance measurements

F. Mesquita[1], G.L. F. Fraga[1], O. Isnard[2], P. Pureur[1]

[1] *Instituto de Física, Universidade Federal do Rio Grande do Sul, 91501-970 Porto Alegre, RS, Brazil*
[2] *Institut Néel, CNRS and Univerté Joseph Fourie, Grenoble, Isère, France*

We report on impedance measurements in the inter-metallic compounds $RCo_{12}B_6$ (R = Y and Gd) as a function of temperature, frequency and applied magnetic field. Experiments were performed in temperatures varying between 20 K and 300 K in the presence of fields up to 450 Oe. Frequencies in the range between 37 Hz and 1.5 MHz were employed. It was found that these systems order magnetically at 155 K and 163 K for R = Y and Gd, respectively. While the first compound is ferromagnetic the former is ferrimagnetic, displaying a compensation temperature around 50 K. A spontaneous and frequency dependent contribution to the impedance was observed in a narrow temperature interval encompassing the Curie point T_c in both samples, being more intense in the sample where R = Gd. This spontaneous and peaked contribution is ascribed to the Hopkinson effect, that has its origin in the domain-wall dynamics yielding an enhanced magnetic permeability in temperatures near to a critical point. For the sample where R = Y the impedance is weakly dependent on the applied field in the whole investigated temperature interval. For this system, the estimated magnetic anisotropy field becomes progressively smaller as the temperature decreases. The impedance plotted as a function of temperature shows a clear change of slope at the compensation temperature in the compound with R = Gd, but the application of a magnetic field does not modify significantly the zero-field behavior when the temperature decreases below this characteristic point.

Talk 9

Splitting of spin-wave modes in thin films with arrays of periodic perturbations: theory and experiment

R. A. Gallardo,[1] A. Banholzer,[2,3] K. Wagner,[4] M. Körner,[2,3] K. Lenz,[2] M. Farle,[4] J. Lindner,[2] J. Fassbender,[2,3] and P. Landeros[1]

[1]*Universidad Técnica Federico Santa María, Av. España 1680, Valparaíso, Chile.*
[2]*Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, Bautzner Landstraße 400, D-01328 Dresden, Germany.*
[3]*Technische Universität Dresden, D-01062 Dresden, Germany.*
[4]*Fakultät für Physik and Center for Nanointegration Duisburg-Essen (CeNIDE), Universität Duisburg-Essen, Lotharstraße 1, D-47048 Duisburg, Germany.*

A joint theoretical–experimental study focusing on the description of the ferromagnetic resonance response of thin films in the presence of periodic perturbations introduced on the upper film surface is presented [1-2]. From the viewpoint of theory, these perturbations may exist in the form of any kind of one- or two-dimensional rectangular defect arrays patterned onto one surface of the magnetic film. Indeed, the defects may be pits or bumps, or ion- implanted regions with a lower saturation magnetization. The complete set of response functions, given by the components of the frequency and wave-vector dependent dynamic magnetic susceptibility tensor of the film exposed to microwave excitation, are provided and are used to explain the experimental data. This allows us to obtain the response of the system due to microwave absorption, from which the zero wave-vector spin-wave modes in the field- frequency spectra, including their intensity, are calculated. Explicit calculations for periodic defects featuring the shape of stripes, dots and rectangles are given in detail, as well as experimental results for stripe-like defects prepared either by topographical depressions or by ion implantation of thin magnetic films. The excellent agreement of the theoretical and experimental results manifests the validity of the presented model.

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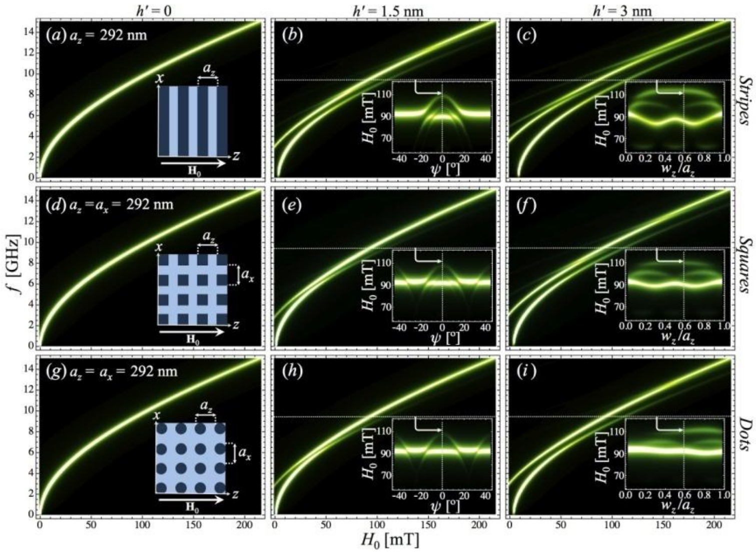

Figure 1: Imaginary part of the dynamic susceptibility (color-coded) as a function of the microwave frequency and in-plane external field, calculated for three defect depths *h'*. The defect shape are (a-c) stripes, (d–f) squares and (g–i) dots. For *h >0* additional branches appear in the resonant response with the strongest splitting for the film with stripe defects.

Talk 10

Connecting Spin Waves to Charge Currents

A. Hoffmann

Materials Science Division, Argonne National Laboratory, Argonne, IL 60439, USA

Spin waves are becoming attractive for information encoding and processing due to their long coherence lengths and times in ferromagnetic insulators with low magnetization damping. Nevertheless, in order to integrate devices based on spin waves with existing electronics it is necessary to manipulate spin waves with charge currents and voltages. One possible pathway for electric spin wave manipulation is via spin Hall effects [1], which intermix spin and charge currents. In particular, the transverse geometry of spin Hall effects is ideally suited for the integration with magnetic insulators, where the spin current can be coupled to magnetization dynamics via spin transfer torque and spin pumping. This is demonstrated in Pt/yttrium iron garnet (YIG) bilayers, where a charge current passed through the Pt layer can either reduce or increase the linewidth of ferromagnetic resonance in the YIG layer [2]. Aside from spin accumulations from spin Hall effects, another pathway for manipulating spin waves is via the Oersted magnetic fields that accompany charge currents. This can be used for guiding spin waves through curved waveguides, where otherwise the spin wave propagation is suppressed by the inherently anisotropic spin wave dispersion in thin films [3]. This same concept can be further generalized for switching spin waves between multiple waveguides [4]. Beyond manipulating spin waves with electric currents, it is also desirable to detect spin waves with electric voltages. It turns out that in metallic ferromagnets, anomalous Nernst effects enable the thermoelectric detection of spin waves [5]. Namely, the dissipation associated with the damping of spin waves, results in a local heating that for thin film structures drains into the substrate, therefore resulting in a temperature gradient perpendicular to the film plane. This in turn generates a Nernst voltage along the film, which can be detected with high signal-to-noise even far from the location of the actual spin waves. One interesting aspect of this detection scheme is that it is insensitive to the wavelength of the spin wave, and, therefore, overcomes limitations given by optical or inductive detection approaches. This work was supported by the U.S. Department of Energy, Office of Science, Materials Sciences and Engineering Division. Lithographic patterning was carried out at the Center for Nanoscale Materials, which is supported by DOE, Office of Science, BES (#DE-AC02-06CH11357).

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Talk 11

Electrical and Thermal Control of Magnetic Exchange Interactions

J. Fransson[1], **J. Ren**[2], **and J. –X. Zhu**[2]

[1]*Dept. Physics and Astronomy, Uppsala University, Uppsala, Sweden*
[2]*Theoretical Division, Los Alamos Natl. Lab., Los Alamos, NM, USA*

We investigate the far-from-equilibrium nature of magnetic anisotropy and exchange interactions between molecular magnets embedded in a tunnel junction. By mapping to an effective spin model, these magnetic interactions can be divided into three types: isotropic Heisenberg, anisotropic Ising, and anisotropic Dzyaloshinski-Moriya contributions, which are attributed to the background non-equilibrium electronic structures. We further demonstrate that both the magnetic self and exchange interactions can be controlled either electrically by gating and tuning voltage bias, or thermally by adjusting temperature bias. We show that the Heisenberg and Ising interactions scale linearly, while the Dzyaloshinski-Moriya interaction scales quadratically, with the molecule-lead coupling strength. The interactions scale linearly with the effective spin-polarizations of the leads and the molecular coherence. Our results pave a way for smart control of magnetic exchange interactions at atomic and molecular levels.

Talk 12

Energy Dissipation in the hysteresis of electrical steels

Fernando J. G. Landgraf

Universidade de São Paulo, São Paulo, SP, Brazil

Twelve million tons of electrical steels are used per year and its Magnetic Power Loss is a very important parameter for the performance of electrical machines. Although subjected to debate, Loss separation in three parts (hysteresis, parasitic and anomalous) has been used for decades by many to discuss the effects of microstructural variables. We will show a new geometrical approach to localize the anomalous loss in the 60 Hz hysteresis and relate it to energy dissipation mechanisms. We will also show the effect of some microstructural variables on each of the three parts and discuss the possible implications to the understanding of energy dissipation mechanisms.

Talk 13

A look at Magnetic and Micro magnetic Non Destructive Testings

L. Padovese[1]

[1]*Universidade de São Paulo, São Paulo, SP, Brazil*

This presentation deals with some aspects of Magnetic and Micro Magnetic applications in industry, in the context of Non Destructive Testing techniques, particularly, for some industrial problems, these techniques represent an essential and unique solution. The subject will be introduced by a brief presentation of physical concepts of Magnetism and Barkhausen Noise, and of related sensors, equipment and measurement techniques. Then we will tackle signal processing methods to treat results, such as those based on time, frequency, time-frequency and time-scale representations, pattern recognition methods, and so on. Subsequently, the presentation will discuss new approaches on surface scanning techniques, such as linear and rotational surface scanning. In this context, related industrial cases are pointed out. Finally, the presentation will address some important industrial challenges and needs that persist at present: residual stress measurement, thermal and plastic degradation, mechanical stress tensor evaluation, steel phases characterization, and some applications on welding inspection problems.

Talk 14

Interplay between magnetization dynamics and spin current in magnetic hybrid structures

<u>A. Azevedo</u>[1], O. Alves Santos[1], L.H. Vilela-Leão[1], R.O.Cunha[1], R. Rodríguez-Suárez[2], and S. M. Rezende[1]

[1]*Departamento de Física, Universidade Federal de Pernambuco, 50670-901, Recife, PE, Brasil.*
[2]*Facultad de Física, Pontificia Universidad Católica de Chile, Casilla 306, Santiago, Chile.*

While the electron charge is the basic means to generate and process electronic signals, the electron spin is the basic means to carry and store information in the area spintronics. Besides the long known existence of electron and heat currents, the pure spin current phenomenon has been attracting the attention of the people working with spintronics since its proposal in the beginning of this century. Normally, the generation and manipulation of pure spin current is obtained by means of the spin pumping and spin Hall effects [1, 2], as well by applying a temperature gradient along magnetic materials, the so called spin Seebeck effect [3]. Also, the mutual conversion between spin current and charge current can be obtained by means of the spin Hall effect and its reciprocal inverse spin Hall effect [4]. As a consequence, it has been also discovered that spin current and magnetization excitation can interact each other in a very rich and challenging way [5]. In this talk we will review the basic concepts and present experimental results showing the interaction between spin current and spin wave in magnetic hybrid structures. In particular, we will present new results of experiments in which microwave driven DC and AC spin pumping is reported in bilayers made of yttrium iron garnet and platinum. In these experiments, we investigate the nonlinear dynamics involving the driven spin wave mode and a pair of magnon modes with half-frequency. This process is obtained when the frequency is lowered below a critical value so that a three-magnon splitting process with energy conservation is made possible. The dynamics can be explained by a model with coupled nonlinear equations describing the time evolution of the magnon modes. This work has been supported by the Brazilian agencies: CNPq (Project #480724/2012-1), FACEPE (APQ-1292-1.05/10) and CAPES.

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Talk 15

Magnetic properties of concentric asymmetric nanorings

J. I. Avila, M. A. Tumelero, A. A. Pasa, A. D. C. Viegas

Laboratório de Filmes Finos e Superficies, Departamento de Física,
Universidade Federal de Santa Catarina, CP 476, Florianopolis, SC, Brazil.

Magnetic rings have been considered as memory systems, promising high density and stability. In perfectly symmetric magnetic rings, at zero external field there appear two characteristic states, one with a head- to-head and a tail-to-tail domain wall, the `onion state', and another of a unique circular domain called the `vortex state'. Trying to attain any of those states by applying uniform external magnetic fields does not lead to deterministic results when it is removed [1]. Another metastable state found is the `twisted' state consisting of a `V' state containing a 360º wall. In the case of *asymmetric* rings, it has been experimentally found that the `V' state dominates over the others at zero external field. This depends on the dimensions of the ring and the direction of the applied field with respect to the asymmetry axis [2]. Moreover, the chirality of the magnetization can be manipulated by the external field.

In spin injection in semiconductors, ferromagnetic electrodes are used to create and detect spin polarized currents in a semiconductor channel. The ferromagnetic electrodes used in electrical transport measurements are rectangularly shaped thin film bar magnets, which have high stray magnetic fields along the easy axis, of the order of the saturation magnetization [3], so the contacts must have dimensions of several micrometers to reduce the influence of the stray fields. Magnetic nanorings have low or ideally no stray fields, in the case of a perfectly symmetric rings, and portray robust magnetic states that make them well suited as contacts for spintronics devices magnetic states that make them well suited as contacts in spintronics devices.

In this work, numerical micromagnetic calculations of permalloy asymmetric nanorings of different thickness, sizes and geometries were made for uniform external magnetic fields, using software nmag [3]. The state of circular magnetization or `vortex' state was found to appear above a threshold thickness. Analytic formulas for the remanent magnetization of asymmetric rings in the vortex state were derived. A *concentric double asymmetric ring* structure with vortex remanent states, whose chiralities can be switched from parallel to antiparallel, is proposed for spin injection experiments.

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Talk 16

Negative rotatable anisotropy due to spin-flip-like transitions in exchange-biased IrMn/NiFe films

D. Schafer,[1] P.L. Grande,[1] L.G. Pereira,[1] G.M. Azevedo,[1] A. Harres,[1] M.A. de Sousa,[2] F. Pelegrini,[2] and J. Geshev[1]

[1]*Instituto de Física, UFRGS, Porto Alegre, 91501-970 Rio Grande do Sul, Brazil*
[2]*Instituto de Física, UFG, Goiânia, 74001-970 Goiás, Brazil*

The exchange bias phenomenon results from the magnetic interactions between a magnetically-hard material, usually an antiferromagnet, and an adjacent softer ferromagnet. Although this effect has been extensively studied and is already used in spin-valve and magnetic-tunnel-junction devices, the specific mechanism that governs the interfacial coupling of such systems is still a rather controversial topic. Typically, the exchange-bias shift is negative, i.e., the magnetization hysteresis loop shift is opposite to the direction of the magnetic field applied during either sample growth or post-deposition annealing or low-energy light-ion bombardment. The positive exchange bias, i.e., a shift in the applied field direction, has become largely known after its observation in Fe/FeF_2 [1], being the antiparallel coupling at the interface a necessary condition for its manifestation.

In the present work we report on negative rotatable anisotropy estimated via ferromagnetic resonance measurements and model simulations in as-made, annealed and ion-irradiated IrMn/NiFe bilayers. Contrary to previous observations [2], an inverse correlation between rotatable anisotropy and coercivity is observed. Also, the exchange-bias field, determined from hysteresis loop measurements, is higher than that obtained from ferromagnetic resonance for all samples. The results are discussed in terms of majority antiparallel coupling and magnetic-field-induced transitions from antiparallel to parallel states of uncompensated spins at the ferromagnet/antiferromagnet interface. It is worth noting that a model which takes into account field-induced spin-flip transitions of the interfacial spins [3] has been able to reproduce the positive exchange bias induced by athermal training as well as the recovery of training effects after application of strong magnetic fields. We claim that experimental observations of negative rotatable anisotropy provide evidences for antiparallel interface coupling even in systems presenting conventional exchange bias.

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Talk 17

Magnetic properties of Ni nanowires with modulated diameter: a bottle-neck pinning

L. C. C. Arzuza, R. Lopez, F. Béron, K. R. Pirota

Instituto de Física Gleb Wataghin, Universidade Estadual de Campinas, Campinas, SP, Brazil

Since nanowire arrays magnetic behavior essentially depends on nanowires shape anisotropy and dipolar interactions, modulation of the nanowire geometry constitutes an effective way to control the intrinsic array magnetic properties. For instance, locally varying the nanowires diameter changes the effective anisotropy and can create a pinning center in the ferromagnetic nanowires. This control can be advantageous for nanowire arrays use in high-density magnetic storage devices based on magnetic domain wall propagation[1]. It was recently found that, in fairly large bi-diameter nanowires (150 and 250 nm), magnetization reversal occurs in two steps: vortex domain walls are created and propagated along the thicker segment, before propagating through the thinner one [2]. Since magnetization reversal process, and therefore domain wall pinning, is strongly affected by the nanowire diameter, similar behavior could be created with smaller diameter difference in thinner nanowire arrays, thus increasing the information density.

In this work, we studied the influence of the length of a thicker nanowire segment (55 nm), keeping similar the thinner one (35 nm), in Ni nanowire arrays. Two-diameter nanoporous alumina templates were obtained by performing an acid etch enlarging the alumina pores, before continuing the second anodization process. Ni nanowires were electrodeposited into the templates to investigate only the geometry influence on the magnetic behavior. Major hysteresis curves and first-order reversal curves (FORC) were acquired both along out-of-plane (OOP) and in-plane directions. Both techniques yield an OOP coercivity increase in the presence of bottle-neck, which we assume to arise from domain wall pinning. As expected, the interaction field increases with the thicker segment length. However, the OOP FORC distributions for bi-diameter nanowire arrays present a curved shape indicating strong inhomogeneity in the magnetization reversal. We think that it is caused by both a stronger interaction field in the thicker segments part and differences in the domain wall propagation in both segments.

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Talk 18

Magnetization dynamics at CBPF: an overview and recent advances

R. L. Sommer

Centro Brasileiro de Pesquisas Físicas, Dr. Xavier Sigaud 150,Urca, Rio de Janeiro, RJ, Brazil

We present an overview and recent results on magnetization dynamics experimental and micromagnetic studies in micro and nanostructured materials performed at CBPF. In particular, we report studies on the magnetoimpedance of nanostructured electrodeposited materials as well as broadband FMR studies of synthetic antiferromagnets, multilayered materials, exchange biased materials, magnonic crystals and spin-torque based nanooscillators. The available experimental techniques are described in detail, with emphasis on the experimental limits for signal detection, sample fabrication, etc. Finally, we discuss the perspectives for this area this field in our institution and in Brazil.

Abstracts

Contributed poster presentations

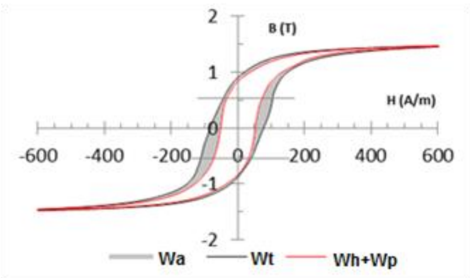
IIIBWMD-01

Hysteresis and anomalous losses

A. A. de Almeida[1], F. J. G. Landgraf[2]

[1,2]Universidade de São Paulo, Escola Politécnica, Departamento de Metalúrgia e Materiais, São Paulo, SP, Brazil

Magnetic loss, or iron loss, is commonly divided in three parcels: hysteretic (or quasi static), classical eddy current (or parasitic) and anomalous loss (or excess loss). This analysis method has been applied by the industry for decades [1]. Microestructural characteristics affect the three parcels behavior. Other publications [2-5] reported that features like grain size and texture have influence over the hysteretic and anomalous loss. While hysteresis loss is calculated as the area of a experimentally measured hysteresis loop, allowing the discussion of energy dissipation mechanisms [6-8] in different areas of the curve, anomalous loss is obtained as the rest of a sum, giving no chance to such discussion. The present work proposes a procedure to draw the hysteresis of eddy current loss and, by geometrical differences, calculate and draw the hysteresis curve of anomalous loss. Applying these procedures to non-oriented and grain oriented samples, energy dissipation mechanisms [6-8] in anomalous loss are discussed. For this purpose two kinds of electrical steels were analyzed: grain oriented steel (GO) and non-oriented steel (NO). The GO steel was produced by Aperam South America with thickness 0.27 mm, resistivity 49 μΩ.cm, density 7650 Kg/m^3, grain size 3 mm. One groups of samples NO steel with 3.3 wt. %SI, was used. There were 7 samples, with dimensions 305 mm 30 mm x 0.64 mm, laminated on the rolling direction, with density of 7700 kg/m^3 and electrical resistivity of 43.4 μΩcm. The samples were continuously annealed at increasing temperatures in order to obtain different grain sizes through grain growth. Based on the proposed methodology to identify areas of the total loss hysteresis for the anomalous loss, it is proposed that most of anomalous loss is due to domain wall speed but nucleation and annihilation mechanism also contribute significantly as energy dissipation mechanisms of the anomalous loss (see Figure 1(a)). Domain annihilation dissipates more energy than domain nucleation and this difference becomes greater with the increase in grain size. On the other hand, in grain oriented samples (see Figure 1(b)), the results indicate remarkable participation of anomalous loss in high induction region. In this case, there is influence of the lancet domains nucleation/annihilation phenomenon.

(a)


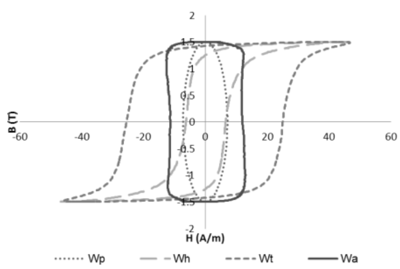
(b)


Figure 1: (a) Loss separation for NO samples using peak induction 1.5 T and frequency 60 Hz. (b) Loss separation for GO samples using peak induction 1.5 T and frequency 60 Hz.

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IIIBWMD-02

Annealing effect on the static and dynamic magnetic properties of films of FeNbCuSiB

M. J. P. Alves, D. E. González-Chavez and R. L. Sommer
Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, RJ, Brazil

F. Bohn
Universidade Federal do Rio Grande do Norte, Natal, RN, Brazil

The development of microelectronic devices operating at high frequencies requires soft magnetic materials on nanometer scales with high permeability and low loss in the GHz range. Nanocrystalline magnetic films are good candidates for high frequency applications that demand very high signal/noise ratio [1]. In general, these nanocrystalline magnetic materials have the structure of magnetic nanograins immersed in an amorphous magnetic matrix [2]. For bulk nanocrystalline materials $Fe_{73.5}Nb_3Cu_1Si_{13.5}B_9$, sample has high saturation (about 10^3 emu/cm^3), low coercivity and anisotropy quenching [3]. In this work we investigated the effect of annealing temperature on the magnetic and structural properties of films $Fe_{73.5}Nb_3Cu_1Si_{13.5}B_9$. Films with thickness of 100 nm were produced by RF Magnetron Sputtering and were treated for 1 hour under high vacuum. The structural and static magnetic properties of the films as deposited and heat treated were made by Grazing incidence X-ray diffraction (GIXRD) and vibrating sample magnetometer (VSM), respectively. The high-frequency magnetic response of all samples was measured using a coplanar waveguide connected to a Rohde Schwarz ZVA24 vector network analyzer (VNA-FMR) in the range between 1.0 GHz and 8.0 GHz. The relaxation mechanisms of the magnetization were analyzed through the behavior of the FMR linewidth as function of frequency. We considered three terms to fit the FMR linewidth: linewidth due to inhomogeneities, two-magnon scattering processes and intrinsic Gilbert. It was observed that the FMR linewidth is dominated by the term associated to inhomogeneities in the samples. The results are discussed in terms of the granular structure and residual stress in the samples.

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IIIBWMD-03

Effect of electric current on domain wall dynamics

F. Beck[1], J. N. Rigue[2], M. Carara[3]

[1]*Universidade Federal do Pampa - Campus Alegrete.*
[2]*Instituto Federal de Educação, Ciência e Tecnologia Farroupilha - Campus Santo Augusto.*
[3]*Universidade Federal de Santa Maria.*

Amorphous glass-coated microwires are materials with soft magnetic properties suitable for various technological applications, mainly magnetic sensors [1]. One of the outstanding properties of microwires with positive magnetostriction is the magnetic bi-stability, that means, the inversion of the magnetization is done by one magnetic domain wall displacement along the wire [2]. In this work, we have measured the domain wall velocity in the low field regime and studied the domain wall dynamics in Joule-annealed amorphous glass-covered microwires with positive magnetostriction. In order to measure of the single domain wall dynamics under different conditions, an electrical current was applied to the wire simultaneously to the mechanical stress and driving magnetic field. We have observed that the applied stress decreases the domain wall mobility. When the dc current is applied to the sample, an increase or a decrease is observed on the axial domain wall mobility, depending on the current direction. When we have treated the orthogonal motion of the domain wall, the current influence is not detected. On the other hand, it was verified a modification on the domain wall length. It was also observed a change in the domain wall shape from conical to parabolic one. These results are explained in terms of the change in the magnetic energy promoted by the additional Oersted field which, by its time, modifies the length and shape of the conical domain wall, in such a way that the orthogonal domain wall velocity is not changed by the applied current.

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IIIBWMD-04

Development of a graphical tool to study magnetic systems

J. Guimarães, A. Harres, R. Cichelero, and J. Geshev

Instituto de Física, UFRGS, Porto Alegre, 91501-970 Rio Grande do Sul, Brazil

The Exchange Bias (EB) [1] phenomenon is associated with the exchange anisotropy at interfaces between antiferromagnetic (AF) and ferromagnetic (FM) materials (Figure 1). It was discovered by Meiklejohn and Bean in 1956 and has been investigated for decades. Still, there is no single model that can explain the whole range of experimental results. EB has been observed in many systems as inhomogeneous materials and thin films. Computer simulations are one of the main tools used to understand magnetic properties of matter [2]. In this work, computer modeling was used to develop a graphical interface for a software that can simulate the behaviour of magnetic systems like those where EB is observed. Using the programming language Python 2.7.6, different types of 2D and 3D graphics were obtained. Numpy, Scipy and Matplotlib libraries were employed to create 2D graphics, while 3D Scientific Data Visualization and Plotting Mayavi 4.3.1 were applied to produce 3D images. Parameters as the magnetic energy of multilayer systems, its magnetization and anisotropy were analyzed to build the graphics. With help of this tool, it was possible to improve the magnetic system analyses and upgrade the way the information about magnetic structures is viewed. It is possible, for example, to observe the energy variation and evolution of the magnetic moments during a hysteresis loop trace, helping to understanding magnetic properties, e.g., the exchange bias effect.

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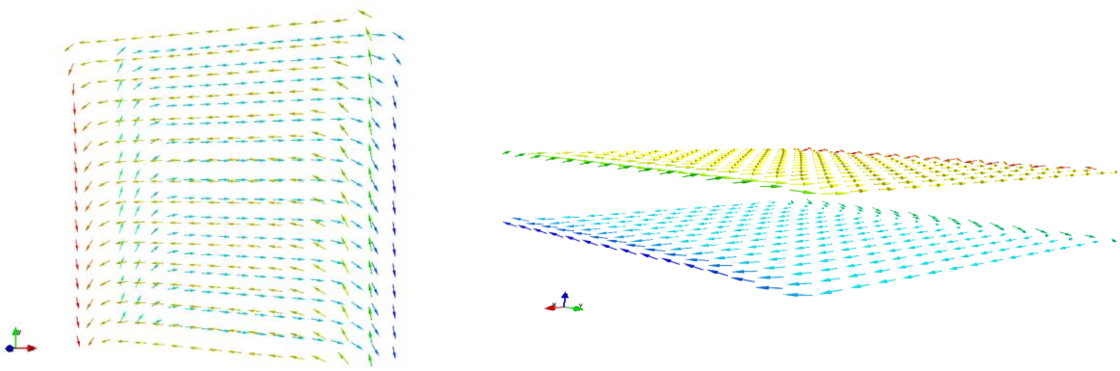

Figure 1: Interface coupling between FM/AF bilayers. Figure that was obtained using the developed tool.

IIIBWMD-05

Correlation between dynamic, static and structural properties in CFA/Ag/CFA Heusler alloy trilayered

V. M. Escobar[1], G. L. Callegari[2], F. Bohn[1], C. Chesman[1], M. A. Corrêa[1]

[1]DFTE, Universidade Federal do Rio Grande do Norte, Natal, Brazil
[2]DF, Universidade Federal de Santa Maria, Santa Maria, Brazil

The so-called Heusler alloys [1] has become an important topic of study due to its interesting electric and magnetic properties. The Heusler alloys have stoichiometry of X_2YZ or XYZ, where X and Y are transition metals and Z is a s-p metal. The usual combinations of these elements lead to the same cubic crystal structure. On the other hand, the cubic structure can present distinct degree of disorder, related to the position of the respective elements. In particular, the L21 structure represents the complete order of the X, Y and Z elements, while the A2 one corresponds to the complete disorder of these elements. Beyond the degree of disorder, the electric and magnetic features are strongly dependent on the parameters of the deposition, as the temperature and gas pressure. In this sense, the Co_2FeAl (CFA) alloy can present low Gilbert damping parameter [2] and high spin polarization, making it a promising candidate for applications in RF frequency devices [3]. Thus, the study of the magnetization dynamics becomes crucial, and the magnetoimpedance effect corresponds to an important tool for this investigation. In this work, we present the recent results obtained for the Co_2FeAl[500nm]/Ag[100nm]/Co_2FeAl[500nm] multilayer grown by magnetron sputtering in amorphous glass substrate. The correlation between structural and static and dynamic magnetic properties is shown and discussed. Despite the obtained A2 structure, the sample presents strong induced anisotropy, an important factor to the MI effect. The MI results clearly reflects this difference between easy and hard axes to a wide range of frequencies, as expected. Hence, the MI results open new possibilities for applications of this kind of alloy, such as junctions tunnel [4], and switching devices [5].

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IIIBWMD-06

Ferromagnetic resonance studies in exchange biased $Ni_{81}Fe_{19}/Ir_{20}Mn_{80}/Ta$ multilayers

P. R. Kern[1], J. V. de Siqueira[1], O. E. da Silva[1], A. M. H. de Andrade[2], M. Carara[1]

[1]*Departamento de Física, Universidade Federal de Santa Maria, Santa Maria, RS, Brazil*
[2]*Instituto de Física, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil*

The exchange bias phenomenon occurs in thin films due to the coupling between a ferromagnetic layer to an adjacent antiferromagnetic one. In this work, we have studied the presence of the exchange bias in $Ni_{81}Fe_{19}$(100 Å)/$Ir_{20}Mn_{80}$(120 Å)/Ta(30 Å) multilayers, with different number of trilayers, grown by magnetron sputtering on Si(100) substrates. The magnetic properties were determined through magnetization curves and ferromagnetic resonance (FMR). The magnetization measurements were obtained using an alternate gradient field magnetometer while the FMR dispersion relations were obtained by measuring, with a vector network analyzer, the reflection coefficient of a microstrip transmission line loaded with the sample. The measuring frequency range was from 1 GHz to 8 GHz and the applied magnetic field from -600 Oe to 600 Oe. The measured FMR dispersion relations were fitted to the Smit-Beljers equation. To the fitting, the magnetization equilibrium angles were calculated by the minimization of the free magnetic energy which includes Zeeman, Uniaxial, Unidirectional and Magnetostatic energies.

IIIBWMD-07

Magnetic actuator based on giant magnetostrictive material Terfenol D with strain and temperature monitoring using FBG optical sensor

H. García-Miquel[1, 2], R. Amat[1], D. Barrera[1], S. Sales[1], G.V. Kurlyandskaya[3]

[1] *ITEAM Research Institute, Universitat Politécnica de Valencia, C/Camino de Vera s/n, E-46022 Valencia, Spain. raammar@teleco.upv.es*
[2] *Department of Electronic Engineering, Universitat Politécnica de Valencia, C/Camino de Vera s/n, E-46022 Valencia, Spain. hgmiquel@eln.upv.es*
[3] *Department of Electricity and Electronics, University of Basque Country UPV-EHU, 48080 Bilbao and Ural Federal University, Lenin Ave 51, 6200083Ekaterinburg, Russia* galina@we.lc.ehu.es

We have designed a magnetic actuator based on giant magnetostrictive material Terfenol-D (Tb0.3 Dy0.7 Fe1.92). It is widely known that this material modifies its magneto-elastic properties as a function of the combination of both magnetization and prestress effects, however, other effects such as temperature may affect its optimal operation point. In order to simultaneously monitor these effects, we have implemented a system based on two FBGs connected in series, where one is physically attached to a structure which contains a cylindrical Terfenol-D rod and the other rests freely next to the first one with the aim of measuring and compensating the thermal offset and sensitivity drift. We have designed a strain amplification structure for get higher sensitivity in the strain measurement with the FBG sensor. This proposal allows to measure at long distance without adding additional components such as active elements or other sensors and also allowing to decouple the thermal offset and sensitivity drift. We have measured the Magnetostriction in the axial direction and in the perpendicular direction of the Terfenol-D rod with two perpendicular FBGs. In Figure 1(a) it is shown a schematic of the monitoring system with the strain amplification structure. It consists of a cylindrical structure made of brass containing the sample of Terfenol-D and surrounded by the coil needed to apply the axial magnetic field. In Figure 1(b) it is shown the amplified strain signal achieved by the strain amplification structure and the strain signal without amplification (directly attached to Terfenol) as a response to an applied a triangular magnetic field of 200kA/m amplitude and 0.002Hz frequency.

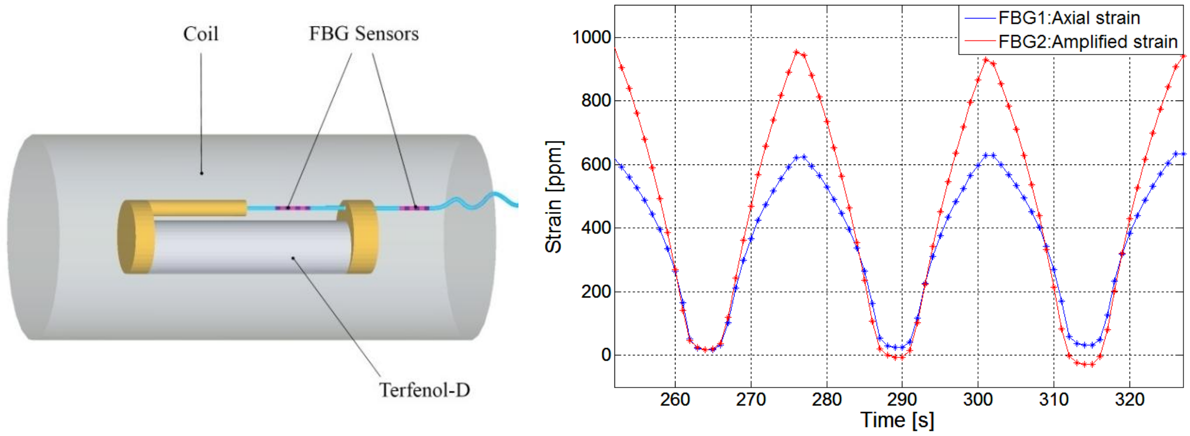

Fig. 1: (a) Schema of the Magnetostrictive actuator with strain and temperature measurement using FBG optical sensors, (b) Axial strain measured for an applied axial triangular magnetic field of 200kA/m amplitude and 0.02Hz frequency, with: FBG directly attached to Terfenol-D (red plot), and FBG attached to the amplification strain structure (red plot).

IIIBWMD-08

The effect of recovery heat treatment on the magnetic hysteresis of electrical steels

T. S. P. Nishikawa, F. J. G. Landgraf, D. L. Rodrigues Junior

Universidade de São Paulo, São Paulo, SP, Brazil

This paper discusses the effect of the recovery heat treatment on the magnetic properties of non oriented electrical steel. The samples were cold rolled with 5 and 10% total thickness reduction. The material was annealed at 300, 400, 500, 600 and 700°C for 30, 60 and 90 minutes. The magnetic properties were analyzed from the extraction of the hysteresis cycles using Epstein frame with exciting frequency of 5 mHz and maximum induction of 1 and 1.5 T. The data was analyzed using two approaches. The first one was the hysteresis subdivision in high and low induction, the second one was the subdivision per quadrants. Results show that the variation on the hysteresis area is concentrated on the odd quadrants, this implies that the recovery treatment varies the energy dissipated mainly on the magnetization of the samples.

IIIBWMD-09

Functionalization and surface characterization of a magnetoelastic biosensor for detection of Escherichia Coli

A. L. Possan[1], C. Menti[2], M. Beltrami[1], M. Roesch-Ely[2], A. D. Santos[3], F. P. Missell[1]

[1]*Laboratório de Caracterização Magnética, Universidade de Caxias do Sul, Caxias do Sul, RS, Brazil*
[2]*Laboratório de Genômica, Proteômica e Reparo de DNA, Universidade de Caxias do Sul, Caxias do Sul, RS, Brazil*
[3]*Instituto de Física, Universidade de São Paulo, São Paulo, SP, Brazil*

Magnetoelastic sensors have been used in many applications, including the detection, identification and quantification of bacteria. Modification of sensor surfaces with biomaterials such as cystamine have a significant impact on their performance. The utilization of antibodies for recognition of certain biomolecules results in highly sensitive tests. Ribbons of the magnetoelastic alloy Metglas 2826MB3 ($Fe_{45}Ni_{45}Mo_7B_3$) were covered with films of Cr and Au, which facilitate the adsorption of thiols and disulfides on the surface and thereby the formation of self-organized monolayers. On surfaces amino-functionalized with the reagent cystamine, the E. coli antibodies were immobilized at the non recognizing region of the antigen. Measuring the resonant frequency of the ribbon (f_0 ~ 450 kHz) it is possible to observe a reduction in that frequency, indicating an increase in mass which is indicative of the presence of bacteria. The characterization of the cystamine was carried out using Fourier transformed infrared spectroscopy (FTIR). The sensor surface was analyzed with scanning electron microscopy (SEM) and fluorescence microscopy. The results demonstrate the utility of functionalizing the biosensor surface for *E. coli* bacteria.

IIIBWMD-10

Study of unidirectional anisotropy and rotational hysteresis in exchange bias systems

J. N. Rigue[1], F. Beck[2], A. M. H. de Andrade[3], P. R. Kern[4], J. V. Siqueira[4], M. Carara[4]

[1]*Instituto Federal Farroupilha, C. Santo Augusto, RS, Brazil.*
[2]*PPG em Engenharias, Universidade Federal do Pampa, Alegrete, RS, Brazil.*
[3]*Instituto de Física, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil.*
[4]*Departamento de Física, Universidade Federal de Santa Maria, Santa Maria, RS, Brazil.*

The exchange bias (EB) phenomenon occurs due to the coupling between ferromagnetic and antiferromagnetic material and the main characteristics are the rise of unidirectional anisotropy and the rotational hysteresis in torque curves [1-2].

In this work we have investigated how the unidirectional anisotropy and the rotational hysteresis are influenced by the change of some characteristics in thin films samples. Among these are the stacking of layers, the roughness at the interface between the two materials, the difference in the ferromagnetic layer thickness and the difference between the antiferromagnetic materials. The study was performed by using magnetic torque measurements [3] which were interpreted using a granular model for the EB. The parameters obtained from the fitting of the model to the torque curves has also permitted to reproduce data obtained through different magnetic techniques, especially on samples where the unidirectional anisotropy is greater than the uniaxial anisotropy. In NiFe/IrMn samples, the unidirectional anisotropy is favored by stacking layers, by increasing of the interfacial roughness and by the decrease of the ferromagnetic layer thickness, while the rotational hysteresis is substantially increased as the interfacial roughness increases. For the NiFe/FeMn sample the highest values of the unidirectional anisotropy and rotational hysteresis were found, as well as a dependence of these parameters on the measuring magnetic field.

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IIIBWMD-11

Anisotropic magnetoresistance response tuned by the angle between current and exchange bias in IrMn/NiFe thin films

R. L. Seeger[1], T. J. A. Mori[1], R. D. Della Pace[1], L. F. Schelp[1], R. B. da Silva[1]

Departamento de Física, Universidade Federal de Santa Maria, Santa Maria, RS, Brasil

Anisotropic magnetoresistance (AMR) is the scattering cross section dependence of the *d* orbital anisotropy in ferromagnetic materials on the angle between magnetization and current directions [1]. In this sense AMR-based sensors are used to measure both angular and linear positions, for example. The angle between external magnetic field and probe current direction determines whether a sample's resistance will get increased (H//I) or decreased ($H \perp I$) after the saturation of R vs. H curves [2]. A systematic study regarding to current and magnetic anisotropy directions is important since sensitivity and shape of such curves strongly depend on their relationship. This work aims to combine such study with exchange bias effect in order to tune R vs. H curves to be able to build auto-biased AMR-based sensors. We have grown IrMn/NiFe exchange biased thin films by magnetron sputtering onto glass substrates. By applying a static magnetic field during the deposition, both uniaxial and unidirectional exchange anisotropies are induced in situ. Usual AMR R vs. H curves (for different angles between external field and current) have been measured for different angles between exchange bias field and current directions. By varying with both orientations as well as taking advantage of the shift due to the exchange bias effect it is possible to get a linear AMR response around zero field as we have tuned both shape and magnitude of the curves.

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IIIBWMD-12

Structural, static and dynamic properties of CFA and CFA/Ag multilayers grown on Si(100) and glass substrates

A. M. Silva[1], V. M. Escobar[1], F. Bohn[1], M. A. Corrêa[1]

[1]*DFTE, Universidade Federal do Rio Grande do Norte, Natal, RN, Brazil*

The dynamic magnetic behavior is investigated through the magnetoimpedance (MI) effect in multilayered Co_2FeAl/Ag films grown onto Si(100) and glass substrates. The MI measurements are performed in a wide range of frequency (from 0.5 up to 3.0 GHz) and are interpreted in terms of the structural and quasi-static magnetic properties of the films. The structural properties present a strong dependence on the geometry of the sample (eithersingle film or multilayer). Despite of this, the results of the structural analysis indicate that the samples present an A2 structure for CFA alloy. At the same time, quasi-static magnetic properties performed using a vibrating sample magnetometer show a behavior that is reflected in MI measurements. From a general point of view, the multilayers present a low uniaxial magnetic anisotropy when grown on amorphous substrate and an isotropic behavior when growth on Si(100) oriented substrate. The main goal of this work resides in the fact that the produced multilayered films present a good MI performance, irrespectively of the employed substrate, opening new possibilities for applications and making easier the integration of these samples as sensor element in MI based electronic devices.

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IIIBWMD-13

Linewidth and damping in electrodeposited $Ni_{81}Fe_{19}$/Cu multilayered films: a study using magnetoimpedance

B. Silva, D. González-Chávez, J. Gomes Filho, R.L. Sommer

Centro Brasileiro de Pesquisas Físicas, Dr. Xavier Sigaud 150,Urca, Rio de Janeiro, RJ, Brazil

Cylindrical magnetic layers electroplated on non-magnetic wires are good candidates to produce magnetoimpedance (MI) based devices as they allow tailoring the MI ratio as well the Z vs. H curves yet making use of the convenient cylindrical geometry. The MI effect corresponds to the impedance variation of a ferromagnetic material when simultaneously subjected to an external magnetic field and an alternating magnetic field, associated with an alternating current. The origin of this effect is the strong dependence of the penetration length (skin depth) with the applied external magnetic field. The electroplating is a very suitable technique for preparing samples with cylindrical symmetry. It provides a homogeneous deposition and high reproducibility over the magnetic properties. In this work, we investigate the linewidth and damping behaviors for multilayered NiFe/Cu films electroplated on 120um diameter copper wires from magnetoimpedance measurements. The static magnetic properties for these samples were investigated with a vibrating sample magnetometer operating in a field range of -±300 Oe. The magnetization dynamics and magnetoimpedance were studied using a Rohde & Schwarz ZVA24 vector network analyzer in the range of 0.1 GHz to 7.0 GHz. The shapes of the curves show an increase in the demagnetizing field with increasing thickness of NiFe layers (80 nm – 1000 nm). The high-frequency measurements showed a strong dependence of the magnetoimpedance with skin effects and ferromagnetic resonance. The FMR linewidth obtained from ferromagnetic resonance spectra were large for all the samples, above 60 Oe, which decreases with an increment of the NiFe thickness. The increase of copper thickness resulted in a strong increase in the linewidth, possible related to the increase of the roughness at permalloy/Cu interfaces. This result indicates a high anisotropy dispersion and a strong contribution by the magnon scattering through nonuniform magnetization.

IIIBWMD-14

Thickness dependence of the dynamic magnetic behavior in Permalloy films

E. F. Silva[1], R. D. Della Pace[2], L. S. Dorneles[2], O. Alves Santos[3], A. Azevedo[3], S. M. Rezende[3], C. Chesman[1], M. A. Corrêa[1], F. Bohn[1]

[1]Departamento de Física Teórica e Experimental, Universidade Federal do Rio Grande do Norte, 59078-900 Natal, RN, Brazil
[2]Departamento de Física, Universidade Federal de Santa Maria, 97105-900 Santa Maria, RS, Brazil
[3]Departamento de Física, Universidade Federal de Pernambuco, 50670-901 Recife, PE, Brazil

The Magnetoimpedance (MI) effect corresponds to the strong dependence of the impedance of a soft magnetic conductor under an applied magnetic field. MI effect is widely employed to characterize ferromagnetic materials and can be an important tool to the comprehension of fundamental physics associated to the magnetization dynamics, providing us information on the dynamics in both, low and high frequency ranges. The main issue to the MI effect is the control and knowledge of the differential magnetic permeability which, in turn, depends on several structural and magnetic parameters, such as effective anisotropy, crystalline structure, and geometry and thickness of the sample. In this work, we investigate the magnetoimpedance effect in ferromagnetic polycrystalline Permalloy films with thicknesses in the range between 50 nm and 1000 nm, in order to understand the effects of the film thickness on the magnetization dynamics at high frequencies. The films are produced by magnetron sputtering, with nominal composition of $Ni_{81}Fe_{19}$, and thicknesses of 50, 100, 150, 200, 300, 400, 500, 750, and 1000 nm. We obtain the structural and quasi-static magnetic characterization via X-ray diffraction and magnetization curves, respectively. The dynamical magnetic behavior is studied through magnetoimpedance measurements, obtained in a wide range of frequencies, from 1 MHz up to 3 GHz, as well as via the traditional ferromagnetic resonance experiment. Films with thicknesses below 150 nm exhibit a well-defined in-plane uniaxial magnetic anisotropy and just one ferromagnetic resonance mode in the magnetoimpedance curves, as well as one absorption peak when the field is applied along the film plane in the ferromagnetic resonance experiment. For films thicker than 200 nm, magnetization curves indicate isotropic in-plane magnetic properties with an out-of-plane anisotropy contribution, a behaviour related to the stress stored in the film, and to the columnar microstructure. Magnetoimpedance curves present complex magnetic behavior, depicted by several ferromagnetic resonance modes detected at relatively low fields. Ferromagnetic resonance presents more than one absorption peak, suggesting the excitation of non-uniform modes. We discuss the experimental results in terms of the different mechanisms that govern the magnetoimpedance effect observed at distinct frequency ranges, film thickness, and stress contribution to the magnetic anisotropy of the samples.

IIIBWMD-15

Tunable asymmetric magnetoimpedance effect in ferromagnetic NiFe/Cu/Co films

E. F. Silva[1], M. Gamino[2], A. M. H. de Andrade[2], M. A. Corrêa[1], M. Vázquez[3], F. Bohn[1]

[1]Departamento de Física Teórica e Experimental, Universidade Federal do Rio Grande do Norte, Natal, RN, Brazil
[2]Instituto de Física, Universidade Federal do Rio Grande de Sul, Porto Alegre, RS, Brazil
[3]Instituto de Ciencia de Materiales de Madrid, CSIC, Madrid, Spain

Magnetoimpedance (MI) corresponds to the change of the electrical impedance of a ferromagnetic conductor caused by the action of an external magnetic field through the magnetic permeability and skin effect. Since it was first observed, magnetoimpedance effect has attracted considerable interest not only for its contribution to the understanding of fundamental physics associated to magnetization dynamics, but also due to the possibility of application of materials exhibiting magnetoimpedance as probe element in sensor devices for low-field detection. For this reason, experimental studies on magnetoimpedance have been widely performed in magnetic ribbons, microwires and, in recent decades, in magnetic films with several structures, such as single layered, multilayered, and structured multilayered samples. However, although soft magnetic materials are highly sensitive to small field variations at low magnetic fields, they essentially have nonlinear MI behavior around zero magnetic field, preventing the derivation of an appropriate signal for sensor applications that need to detect the magnetic pole sign. To overcome this fact, usually, a bias field or an electrical current is applied to the ordinary MI element, inducing asymmetric effects, shifting the sensor operational region, and leading to the linearization of the MI behavior at around zero magnetic field [1]. However, this approach increases the electrical power consumption, making difficult the miniaturization of the sensor device, a fact that explains the recent interest in materials that present asymmetric magnetoimpedance (AMI) effect. These materials are obtained by inducing an asymmetric static magnetic configuration, usually done by magnetostatic interactions, or exchange bias [2].

In this work, we investigate the magnetization dynamics through the magnetoimpedance effect in ferromagnetic NiFe/Cu/Co films [3]. We observe that the magnetoimpedance response is dependent on the thickness of the non-magnetic Cu spacer material. We verify asymmetric magnetoimpedance in films with biphase magnetic behavior and explore the possibility of tuning the linear region of the magnetoimpedance curves around zero magnetic field by varying the thickness of the spacer, and probe current frequency. We discuss the experimental results in terms of the different mechanisms governing the magnetization dynamics at distinct frequency ranges, quasi-static magnetic properties, thickness of the spacer, and the kind of the magnetic interaction between the ferromagnetic layers. The results place films with biphase magnetic behavior exhibiting asymmetric magnetoimpedance effect as very attractive candidates for application as probe element in the development of auto-biased linear magnetic field sensors.

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IIIBWMD-16

Exchange Bias in multilayers Py/IrMn/Ta: a study through the anisotropic magnetoresistance

J. V. de Siqueira[1], **P. R. Kern**[1], **O. E. da Silva**[1], **A. M. H. de Andrade**[2], **M. Carara**[1]

[1]*Departamento de Física, Universidade Federal de Santa Maria, 97105-900 Santa Maria, Rio Grande do Sul, Brazil*
[2]*Instituto de Física, Universidade Federal do Rio Grande do Sul, 91501-970 Porto Alegre, Rio Grande do Sul, Brazil*

In this work we have studied the exchange bias phenomena in Py/IrMn/Ta multilayers through anisotropic magnetoresistance. The samples, differing in the number of bilayers, were grown by magnetron sputtering on Si (100) substrates, with an applied magnetic field in the sample plane in order to define the anisotropy direction. The polycrystalline character of the samples was checked by X-ray diffraction, revealing that the Permalloy and Iridium Manganese grow towards (111). The angular dependence of the magnetoresistance (AMR) was measured at different applied magnetic field and fitted. In order to fit the AMR curves, the equilibrium angle of the magnetization was determined using a coherent rotation model with four energies terms (Zeeman, uniaxial, unidirectional and magnetostatic). The experimental curves were well fitted and the obtained fitting parameters (uniaxial and unidirectional anisotropies) were close to that ones that obtained from the magnetization curves. By comparing the magnetization curves of the multilayers samples it can be seen that the anisotropy dispersion increases as the number of bilayers increase, on the other side, no significative evolution with the number of bilayers was seen in the uniaxial and unidirectional anisotropies values obtained by the fitting of the AMR curves.

IIIBWMD-17

Magnetic interactions in exchange-coupled unbiased FM/AF system with $T_C << T_N$

K. D. Sossmeier[1], R. Cichelero[2], A. Harres[2], J. E. Schmidt[2] and J. Geshev[2]

[1]*Instituto de Ciências da Vida e da Natureza, Universidade Federal da Integração Latino-Americana, Foz do Iguaçu, PR, Brazil*

[2]*Instituto de Física, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil*

Systems composed of a ferromagnet (FM) exchange-coupled to an antiferromagnet (AF) have shown a great potential for technological applications. These normally evidence exchange bias (EB), i.e., a shift of the magnetization curve along the magnetic field axis, often accompanied by a coercivity enhancement. Recently, we showed that unconventional AF/FM (NiO/NiCu) bilayers exhibit EB [1] despite that their Curie temperature is lower than the AF's Neel temperature. We also explored NiCu coupled to a stronger AF, i.e., IrMn and the variation of HC with magnetic annealing or ion irradiation of NiCu/IrMn bilayers characterized by $T_C < T_N$ have been studied [2]. It has been found that, by choosing adequate ion fluence or annealing temperature, one can controllably vary, by more than one order of magnitude, HC of this exchange-coupled though unbiased FM/AF system. Given that none of the post-deposition treatments used has resulted in enhancement of the coercivity of the respective film containing FM layer only, it seem unambiguous that magnetic coupling at the FM/AF interface is responsible for the significant enhancement of HC. We found that the coercivity enhancement in this system results from the presence of the AF in accordance with theoretical predictions that the AF breaks the FM layer into domains and the FM domain size is smaller than that of a FM layer alone [3]. Although certain information of the magnetization reversal can be extracted from experimental hysteresis loops using, e.g., their Fourier decomposition or by fitting demagnetization curves only, the remanence plots technique is by far the method mostly used for estimation of magnetic interactions in both particulate and thin-film systems. This technique makes use of the so called magnetic field (H) dependent remanence curves, i.e., the isothermal remanence magnetization [IRM, or mr(H)] and dc demagnetization [DCD, or md(H)] ones, and is very sensitive to small changes in the remanence. In the present work we employ the remanence plots technique in order to estimate the nature of the interactions present in unbiased IrMn/NiCu bilayers that evidence the enhancement of HC after magnetic ion irradiation. We compared data acquired on the as-made film with those of a film irradiated with Ge and He ions, both showing isotropic in-plane magnetic behavior. The remanence plots obtained from the DCD and IRM curves showed several distinct and interesting characteristics. E.g., the Henkel plots of the as-made and irradiated samples obtained after dc demagnetization appear to be practically identical despite the great difference in coercivity, indicating that the irradiation-induced coercivity enhancement should not be associated with interactions. However, the plots obtained after ac demagnetization, though rather different, indicate strong (magnetizing) exchange interactions.

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IIIBWMD-18

Spin transfer analysis via Landau-Lifshitz-Gilbert equation

Milena Cervo Sulzbach, Rafael Cichelero, Artur Harres de Oliveira, Luis Gustavo Pereira

Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brasil

The idea of spin transfer as a way to control magnetization was introduced independently by Slonczewski and Berger in 1996. This fenomena can be understood as a torque applied in a magnetization due to spin angular momentum transference between the spin-polarized electric current momenta and those present in the ferromagnet [1]. Since the discovery, this effect has been the subject of numerous studies, especially for potencial applications in nonvolatile magnetic memories and high-frequency oscillators.

For the observation of this fenomena it is necessary a high current density (10^6 to 10^8 A/cm^2), which is experimentally achieve restricting the current in small cross section to few nanometers square, in our case using tungsten tips as electric contact [2]. Moreover, the sample must be a metallic multilayer containing two ferromagnets separated by a non-magnetic. The first ferromagnetic layer has pinned magnetization and is responsible for polarize the electric current. The second layer is called free, because its magnetization can change due to the transference of angular momentum.

The effective volume in which spin transfer occurs can be understood as a small cone in contact with the tungsten tip. However, the behavior of this region can influence or be influenced by the other magnetic momenta present in the multilayer. A qualitative idea about this effect can be obtained by numerical simulations via Landau-Lifshitz-Gilbert equation included by Slonczewski term [3]. The purpose of the present work is to observe how the magnetic momenta behave with the current passing thought a finite region using different current regime.

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IIIBWMD-19

Remanence plots method applied to exchange bias systems

A. Harres, R. Cichelero, J. Guimarães, J.E. Schmidt and J. Geshev

Instituto de Física, UFRGS, Porto Alegre, 91501-970 Rio Grande do Sul, Brazil

The Exchange bias (EB) phenomenon [1] emerges from the exchange coupling between a ferromagnetic material (FM) and uncompensated interfacial spins in an adjacent antiferromagnet (AF). Among its most know characteristics, we may highlight the hysteresis loop shift along the magnetic field axis, H_{eb}, and the enhanced coercivity, H_c, compared with that of an uncoupled FM. EB have been studied thoroughly in the past decades. Despite this fact, some of its features remain unexplained. Understanding the role of magnetic interactions in AF/FM interfaces seems to be fundamental to achieve further development in the topic.

In the present work, magnetic properties of EB thin films are analyzed using the remanence plots method. This procedure is commonly employed to probe magnetic interactions in systems presenting symmetrical hysteresis curves. However, since the two remnant magnetization values of a biased loop may differ, this technique cannot be readily applied in its classical form. An adaptation is proposed here and tested in a variety of AF/FM bilayers. It involves a redefinition of the coordinate system and gives rise to a number of distinct plots, revealing the intrinsic asymmetry between the two magnetization branches of EB samples.

Results obtained for sputtered Co/Cu(t_{Cu})/IrMn thin films [2] with different thickness of the copper spacer layer and ion bombarded IrMn/NiCu samples [3] will be discussed. Henkel plots and δM curves will be displayed and their deviations from the non-interacting behavior investigated, tracing a parallel with EB parameters such as H_{eb} and H_c.

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