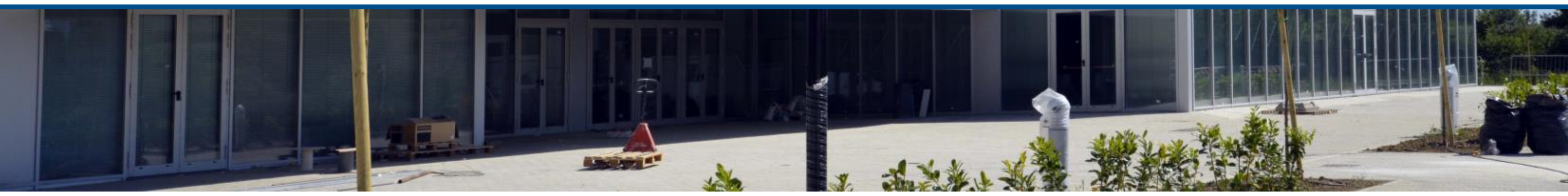
AIMagn Colloquia

New directions in spintronics



Friday, June 23rd 2023
11:30 am – 5:15 pm
Università di Pisa

Dipartimento di Chimica
e Chimica Industriale
Via Giuseppe Moruzzi 13, Pisa

Chairs
F. Pineider, Università di Pisa
C. Sangregorio, CNR-ICCOM Firenze

Local Committee
A. Gabbani – Università di Pisa
B. Muzzi – CNR-ICCOM Firenze
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D. Petti, Politecnico Milano
P. Tiberto, INRIM Torino

KEYNOTE SPEAKER
John Michael David Coey
Trinity College, Dublin (Ireland)
'Ferrimagnetic spintronics'

INVITED SPEAKERS
***Ilaria Bergenti**, CNR-ISMN Bologna*
***Giovanni Carlotti**, Università di Perugia*
***Alessio Gabbani**, Università di Pisa*
***Andrea Meo**, Politecnico di Bari*
***Christian Rinaldi**, Politecnico di Milano*

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Book of Abstracts

AIMagn

COLLOQUIUM

New directions

in Spintronics

Pisa, June 23rd 2023

http://www.aimagn.org/conferenze/aimagn-colloquia/

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The event belongs to a series of scientific talks, the AIMagn COLLOQUIA, organized by the Italian Association of Magnetism, aimed at promoting the dialogue and exchange between renowned international researchers in the field of Magnetism and the Italian community of Magnetism.

Program

June 23rd 2023

11:30 – 11:45	Opening Remarks **Paola Tiberto** – INRIM, Torino – AIMagn President **Francesco Pineider** – Università di Pisa **Claudio Sangregorio** – CNR-ICCOM, Firenze
11:45 – 12:45	Ferrimagnetic Spintronics **John Michael David Coey** – Trinity College, Ireland
12:45 – 14:00	Lunch
14:00 – 14:30	Magnon-spintronics meets chirality: Spin waves in presence of interfacial Dzyaloshinskii–Moriya interaction **Giovanni Carlotti** – Università di Perugia
14:30 – 15:00	Molecules on magnetic surfaces: An effective way to manipulate the spin states **Ilaria Bergenti** – CNR-ISMN, Bologna
15:00 – 15:30	Magnetoplasmonics in heavily-doped semiconductor nanocrystals: Lessons from spintronics **Alessio Gabbani** - Università di Pisa
15:30 – 16:00	Coffee Break
16:00 – 16:30	The novel frontier of spintronic MEMS **Andrea Meo** – Politecnico di Bari
16:30 – 17:00	Ferroelectric control of the spin-charge conversion for ultralow power spintronics **Christian Rinaldi** – Politecnico di Milano
17:00 – 17:15	Closing Remarks

Abstracts

John Michael David Coey
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Ferrimagnetic spintronics

Spin electronics has largely been concerned with spin polarized electron transport in thin films of ferromagnetic metals. We need thin films because unlike charge, spin is not conserved and spin diffusion lengths, although a multiple of the mean free path, are still in the nanometer range. Ferromagnetic films are now often used in stacks that incorporate films of metals with strong spin-orbit coupling that generate pure spin currents. Phenomena of most interest have been magnetoresistance, switching, memory, oscillations and spin ↔ charge conversion. The role of exchange is simply to create the ferromagnet.

Antiferromagnets have attracted attention in recent times (beyond their original use for exchange bias to pin the direction of a ferromagnetic reference layer) on account of their high- frequency spin dynamics, the absence of any stray field, the possibility of switching the antiferromagnetic axis through 90° in certain crystal structures and the existence of an anomalous Hall effect in some cases. The high-frequency (THz) spin dynamics are associated with intersublattice exchange interactions; a consequence is that the Walker breakdown that limits domain wall motion can be km/s. Antiferromagnets are predominantly insulators with localized magnetic moments, which are unable to deliver the power (the product of voltage and current) on which applications depend.

Metallic ferrimagnets offer the advantages of both worlds, plus some unique benefits of their own. When half-metallic, they combine high spin polarization with little or no net magnetization or stray field near compensation. Domains can be imaged directly. The magnetization dynamics can be excited electrically by spin-orbit torque, resonance frequencies are high, coercivity and anisotropy field can be huge, there are prospects of switching a single layer by spin-orbit torque and ultra-fast all-optical toggle switching can be observed, with re-switching on a 10 ps timescale. Mn-based metals are good ferrimagnets because exchange is antiferromagnetic at nearest-neighbour distances and ferromagnetic for more distant neighbours. The ferrimagnetic structures are often non-collinear. These features will be illustrated with reference to the original zero-moment half metal, Mn_2Ru_xGa, which has the XA Heusler structure, and the versatile series of ordered alloys $Mn_{4-x}Z_xN$ that are based on the interstitial metal Mn_4N. Future prospects and challenges will be outlined.

Michael Coey, Professor Emeritus at Trinity College Dublin, has spent his career studying magnetism and magnetic materials. He has made contributions to amorphous and disordered magnets, permanent magnets, magnetism of soils and minerals, dilute oxides and magneto-electrochemistry. More recent interests are spin electronics, d-zero magnetism and effects of magnetic field on water. A Fellow of the Royal Society and International Member of the US National Academy of Science, he has been Chair of the IUPAP Magnetism Commission (where he inaugurated the Néel medal) and a Divisional Associate Editor of Physical Review Letters. Founder of Magnetic Solutions Ltd and the Trinity College Science Gallery, he was an enthusiastic promoter of CRANN, Ireland's nanoscience research centre. Honours include an Albert Einstein Professorship of the CAS, a 1000 Talents Professorship at Beihang University, a Humboldt Prize, the 2019 Max Born Medal of the DPG and honorary degrees from Le Mans and Grenoble.

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Magnon-spintronics meets chirality:
Spin waves in presence of interfacial Dzyaloshinskii-Moriya interaction

In the framework of chiral magnetism, there is currently a great interest towards the influence of the interfacial Dzyaloshinskii–Moriya interaction (i-DMI), provided by a heavy metal underlayer, on the propagation of spin waves (SWs) in extended films and multilayers, with emphasis given to the induced SW non-reciprocity. However, the characteristics of SW eigenmodes induced by i-DMI in laterally confined spin structures and in artificial magnonic crystals have been less studied and there is a scarcity of experimental data in the relevant literature.

In this talk, after a short review of the different causes of spin-waves non-reciprocity, I will focus on the non-reciprocal behavior induced by i-DMI in artificially nanostructured systems consisting, for example, of laterally confined magnetic nanostructures. For these systems, micromagnetic simulations predict a substantial red-shift of the eigenmodes frequencies because of the presence of i-DMI, as well as the appearance of new peaks in BLS spectra, corresponding to odd modes that would remain invisible in the absence of DMI. Moreover, recent BLS experimental data relative to arrays of dots and wires provide evidence of a substantial suppression of the frequency asymmetry between counter-propagating spin waves (corresponding to either Stokes or anti-Stokes peaks in BLS spectra), when the lateral confinement is reduced from 400 nm to 100 nm, i.e. when it becomes lower than the light wavelength. Such an evolution reflects the modification of the spin-wave character from propagating to stationary and indicates that the BLS-based method of quantifying the i-DMI strength from the frequency difference of counter-propagating spin waves is not applicable in the case of magnetic elements with lateral dimension below about 400 nm. As for the influence of DMI in the propagation in magnonic crystals, we have recently provided experimental evidence for a strong asymmetry of the spin wave amplitude induced by the modulated interfacial DMI, with the formation of flat spin-wave bands at low frequencies in the band diagram. Calculations reveal that depending on the perpendicular anisotropy, the spin-wave localization associated with the flat modes occurs in the zones with or without DMI.

Giovanni Carlotti received his master's degree in physics at the University of Perugia in 1987. He did the PhD in condensed matter physics at the University of L'Aquila (1989-1992). In 2000 he became associate professor of physics at the University of Perugia (Faculty of Engineering). He has participated to several national and european projects. He is author of more than 230 publications on international journals about Condensed Matter Physics, and over 100 presentations, some of them invited, at national and international conferences. His main scientific interests are focused on: surface and interface phonons in solids; inelastic Brillouin scattering from surface phonons in solids, Elastic and vibrational properties of multilayers and superlattices, both metallic and semiconductors; design and managing of ultra-high vacuum systems for the epitaxial growth of materials. magnetic properties of thin films and multilayers; spin waves and Brillouin scattering; production of nanostructured materials by e-beam lithography, x-ray lithography and focused ion beam; investigation of structural properties by techniques based on the use of photons and electrons; magnonic crystals; spintronics; topological magnetic materials; skyrmions; micromagnetism.

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Molecules on magnetic surfaces: An effective way to manipulate the spin states

Hybridization at the interface between molecular entities and ferromagnetic metals leads to drastic changes of the properties of both layers. Notably, an increase of spin polarization of states around the Fermi level, modulation of the magnetic anisotropy and spin re-orientation transitions were observed in ferromagnetic layers as well as the appearance of spin polarized states in the molecular material. Effects of hybridization have been detected not only at the interfaces with metals but also with magnetic oxides that notably are characterized by weak interfacial coupling with molecules. Such hybrid interfaces with unexpected spin functionality act as a key element for engineering the properties and the performance of spin-devices. Beside the static interfacial configuration, the key idea is to take advantage of the unique capabilities of molecules to respond to electrical and optical stimuli in order to actively manipulate the hybrid states at the interface.

Ilaria Bergenti received her PhD degree in Physics from the University of Parma in 2004. She became a Researcher at the Institute of Nanostructured Materials of CNR, Italy in 2010. Her main research activity concerns the field of molecular spintronics, in particular the investigation of spin/charge correlation at the interface between molecular π-conjugated materials and ferro- and antiferromagnetic layers. Her skills span from the growth of thin films, heterostructures and devices in UHV as well their characterization by means of magneto-optics, electron and vibrational spectroscopies.

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Magnetoplasmonics in heavily-doped semiconductor nanocrystals: Lessons from spintronics

The excitation of free charge carriers in plasmonic nanomaterials allows the manipulation of light at the nanoscale. Tuning plasmonics with an external stimulus, i.e., active plasmonics, could provide a superior control on light-matter interaction, triggering the development of nano-optical components such as refractometric sensors or tunable meta-lenses. To this aim, the use of magnetic field represents a promising approach, as its action on charge carriers is ultrafast and fully reversible. Nevertheless, achieving large magnetic modulation of the plasmonic resonance without broadening the optical response represents a great challenge in material choice for magnetoplasmonics and several approaches to overcome this issue are being proposed.

In this talk the use of heavily doped semiconductor nanocrystals (NCs) for magnetoplasmonics will be discussed. These NCs are able to support sharp plasmonic resonances in the infrared, due to the free carrier density (10^{18}-10^{21} cm^{-3}) introduced through aliovalent doping. Using non-magnetic plasmonic semiconductor NCs, we demonstrated an enhanced magnetoplasmonic response compared to noble metal NCs. Furthermore, a proof-of-concept field-modulated refractometric sensing experiment demonstrated a superior refractive index sensitivity of our plasmonic semiconductor NCs with respect to ferromagnetic metal-based magnetoplasmonic systems reported in the literature.

The possibility of doping plasmonic doped semiconductor NCs with magnetic cations can potentially further improve the magnetoplasmonic performance of these NCs by 2 orders of magnitudes, paving the way for their applications in real-life devices. Such perspective will be discussed, also revisiting the work on dilute magnetic semiconductors, interesting materials for spintronics, where a giant magneto-optical response was demonstrated at the bang gap transition. The full exploitation of this effect at the plasmonic resonance would represent a game-changer in magnetoplasmonics.

Alessio Gabbani received his bachelor’s and master’s degree at the University of Florence. He then obtained a PhD in Chemistry and Materials Science from the University of Pisa (2017-2020). During his PhD he spent 6 months at NanoGune (San Sebastian, ES) as visiting PhD student in the Nanomagnetism group, working on magneto-optical and chiro-optical effects in nanostructures. He now holds a post doc position at the Department of Chemistry and Industrial Chemistry of the University of Pisa. His main scientific interests are in plasmonics, nanomagnetism, magneto-optics and magnetoplasmonics applied to nanostructures, and in the preparation of nanoparticles by colloidal chemistry approaches. He worked also on optical and magnetic hyperthermia effects in plasmonic, magnetic or magnetic-plasmonic nanoparticles. He is co-author of 20 scientific articles in peer reviewed international journals in the fields of chemistry, physics and materials science, and he presented his work in 20 international conferences and workshops.

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The novel frontier of spintronic MEMS

Sensors such as accelerometers and gyroscopes are an essential component in many areas such as automotive, consumer electronics, industrial applications and the expanding internet of things. Current requirements demand devices that are scalable, have low cost, low energy consumption and are very efficient. The compatibility with CMOS manufacturing processes, versatility, radiation hardness and scalability make spintronics suitable to replace the current silicon-based technology. Magnetic tunnel junction (MTJ) devices are the fundamental brick of spintronics thanks to their nanometric size, non-volatility, low power requirements, inexpensive and standard fabrication processes. In this talk we will illustrate the proposal of novel spintronic MEMS devices that represents a potentially competitive and scalable solution to current capacitive MEMS-based approaches. We will discuss the operational principles behind this device idea that exploit the magneto-mechanical coupling between MTJs and the potential of the spin torque nano oscillators, with focus on the application as an accelerometer device.

Andrea Meo is a postdoctoral researcher at the Politecnico di Bari in the department of Electrical and Information Engineering. He received his M.S. degree in Physics from the University of Milano Bicocca in 2014 and obtained the PhD in Physics from the University of York in 2019 with a thesis on the atomistic spin modelling of magnetic tunnel junctions for memory applications. His research fields include: modelling of magnetic systems, spintronics, magnetic storage, antiferromagnetic systems, spin transport.

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Ferroelectric switching of spin-to-charge conversion for ultralow power spintronics

Information and communication technology is reaching 20% of global electricity production in a few years. Architectures far beyond the well-established CMOS platform are required for electronics to switch greener. A remarkable pathway was suggested by Intel in the work titled “Beyond CMOS computing with spin and polarization”. New-generation computing devices require non-volatility to preserve their functionality without memory refresh and this is conveniently implemented by either ferromagnetism or ferroelectricity. Furthermore, the information processing of such devices must conveniently scale with the geometrical dimension so as to allow for increased efficiency at high packing densities. A viable path in this respect is the exploitation of spin-to-charge current conversion mechanisms such as inverse spin Hall or inverse Rashba-Edelstein effects, in which a spin current or accumulation is translated into either a charge current or a voltage.

Ferroelectric Rashba semiconductors (FERSC) such as germanium telluride (GeTe) offer an intrinsic link of ferroelectricity and Rashba-type spin-orbit coupling. As a major consequence, the ferroelectric polarization of epitaxial thin films of GeTe can be reliably switched back and forth by electrical gating and used to reverse the sizeable spin-to-charge conversion by the spin Hall effect.

Here we discuss the doping and alloying of germanium telluride as a perspective to achieve control over ferroelectricity, conductivity, electronic band structure and spin-to-charge current conversion. We will show the advancement in the development of scalable and energy-efficient non-volatile ferroelectric spin-orbit logic devices, in which information is conveniently stored in the ferroelectric state, while processing and read-out are enabled by polarization-dependent spin-to-charge current conversion.

GeTe and its alloys may represent a viable path towards spintronic-based transistors with ultralow power consumption, possibly facilitated by the monolithic integrability with silicon.

Christian Rinaldi is an associate professor at Politecnico di Milano (Italy), where he received a PhD in Physics in 2013. His research is focused on spin-dependent transport phenomena in semiconductors, ferroelectrics, ferromagnets and any combination thereof. He pioneered the study of non-magnetic spin-textured ferroelectrics, with reference to ferroelectric Rashba semiconductors. He discovered the ferroelectric switching of spin-to-charge conversion in germanium telluride. He has about 60 publications and 1000 citations. He is regularly invited to the most recognized international conferences and universities. He coordinated and participated in several scientific projects. He is a member of the Executive Board of the Italian Association of Magnetism, responsible for several scientific websites and an active reviewer for scientific journals. For more information, visit http://rinaldi.faculty.polimi.it.

Practical information

Colloquium venue

The Colloquium will be held at the Department of Chemistry and Industrial Chemistry of the University of Pisa. The address is:

Via Giuseppe Moruzzi 13, 56124 Pisa.

How to reach the Department of Chemistry and Industrial Chemistry:

How to reach Pisa

By Plane

Pisa International Airport "Galileo Galilei" offers a large and ever-growing number of flight connections with Europe, America and Asia. It is the preferred hub in Tuscany for Low Cost companies as well as for major airlines. The airport is close to the city centre, and can be quickly reached by bus, rail shuttle (people mover) or taxi (taxi service: phone number +39 050 541600). www.pisa-airport.com

By Train

Pisa Central railway station offers frequent connections with Florence, Lucca, Viareggio and other Tuscan destinations as well as with main Italian and European cities. A train journey to Rome takes 3 hours. For further information see the official FS Italiane website. www.trenitalia.com

Urban Bus

The urban bus service is operated by the AT-Bus (Autolinee Toscane, www.at-bus.it). The easiest way to rich the department the Pisa central railway station is the bus *LAM Verde*. The department is 2 minutes walk from the bus stop *Volpi-CNR*, and it is in via Giuseppe Moruzzi 13, after the CNR campus.

Given the size of the city, moving on foot (30-40 minutes walking from the train station) or by bicycle is extremely convenient and popular.

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