SECTOR: Higher Education Institution

LOCATION: France, Grenoble

RESEARCHER PROFILE:

- First stage researcher,

INSTITUTION: Univ. Grenoble Alpes, University of Innovation

One of the major research-intensive French universities, Univ. Grenoble Alpes enjoys an international reputation in many scientific fields, as confirmed by international rankings. It benefits from the implementation of major European instruments (ESRF, ILL, EMBL, IRAM, EMFL*). The dynamic ecosystem, grounded on a close interaction between research, education and companies, has earned Grenoble to be ranked as the 5th most innovative city in the world. Surrounded by mountains, the campus benefits from a natural environment and a high quality of life and work environment. With 7000 foreign students and the annual visit of more than 8000 researchers from all over the world, Univ. Grenoble Alps is an internationally engaged university.

A personalized Welcome Center for international students, PhDs and researchers facilitates your arrival and installation.

In 2016, Univ. Grenoble Alpes was labeled «Initiative of Excellence". This label aims at the emergence of around ten French world class research universities. By joining Univ. Grenoble Alpes, you have the opportunity to conduct world-class research, and to contribute to the social and economic challenges of the 21st century ("sustainable planet and society", "health, well-being and technology", "understanding and supporting innovation: culture, technology, organizations" "Digital technology").

* ESRF (European Synchrotron Radiation Facility), ILL (Institut Laue-Langevin), IRAM (International Institute for Radio Astronomy), EMBL (European Molecular Biology Laboratory), EMFL (European Magnetic Field Laboratory)

Key figures:

- + 50,000 students including 7,000 international students
- 3,700 PhD students, 45% international
- 5,500 faculty members
- 180 different nationalities
- 1st city in France where it feels good to study and 5th city where it feels good to work
- ISSO: International Students & Scholars Office affiliated to EURAXESS
Mandatory References:

ISP-Idex project: DOMINO
SUBJECT TITLE: Magnetic Domain Wall Manipulation in Mn4N
RESEARCH FIELD: Physics, Technology, nanosciences, spintronics, condensed matter, magnetism, thin films, electronic transport, domain wall
SCIENTIFIC DEPARTMENT (LABORATORY’S NAME): Institute for Nanosciences and Cryogenics, SPINTEC Laboratory
DOCTORAL SCHOOL’S: Physics
SUPERVISOR’S NAME: ATTANE Jean-Philippe

Subject Description:

1] Summary of the subject

The aim of the PhD is to study the potential of a new magnetic material, Mn4N, for spintronics. This material indeed possess ultra large magnetic domains, a huge anisotropy and a small magnetization leading to a very high magnetic domain wall spin transfer efficiency.

Half of this PhD will be done in Tsukuba, in Japan (for the deposit and the characterization of thin films), the other half in Grenoble, France (for the nanofabrication, and the electronic transport experiments).

2] State of the art and project originality

Room-temperature spin manipulation exhibits substantial potential for becoming over the next decade the basis of an alternative information processing technology. Hard disk drives still dominate information storage, and the magnetic random access memory (MRAM) is increasing its share of the memory market, with several major industries involved in the development or commercial products\(^1\). Nanomagnetic systems could provide unique opportunities to complement or to be the basis of a post-CMOS technology, possessing new or enhanced functionalities (non-volatility, 3D stacking, resistance to irradiation, rf communication abilities based on spin precession, etc.).

This PhD belongs to this thrilling quest toward disruptive spintronics technologies.

A magnetic Domain Wall (DW) is an interface, separating magnetic domains of different orientations in a ferromagnetic material. DW manipulation has been the subject of intense studies since the discovery that electrical currents can induce DW motion, which allows several memory and logic applications to be envisioned.

After a decade devoted to classical spin transfer experiments, the focus of the DW community partly shifted in 2011-2012 towards additional contributions appearing in specific multilayers and due to SO effects\(^2\). Moreover, electric-field control of the magnetic properties can be used as an additional tool to manipulate domain-wall motion\(^3,4\).

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1 Samsung, Everspin, TDK, Omicron, Intel, Toshiba, Global Foundries...
2 Miron, Moore, ... & Gaudin, *Nature Materials* 10(6), 419-423 (2011)
Several applications of current-induced DW motion have already been proposed, from memristors to DW logic devices\(^5\). The closest to marketability are probably two memory technologies in which the information is coded using the DW position: the « race-track memory »\(^6\), and the DW-MRAM\(^7\).

**A key issue for the development of such memories is the power and current density needed to induce domain wall motion.** Systems with perpendicular magnetic anisotropy have attracted increasing interest, because they allow combining low switching currents and energies with high data retention time. Most studies have thus been done on Co-based tri or multilayers, such as CoFeB or Co/Pt\(^8\), but the quest towards low dissipation has also led to several experiments using L1\(_0\) systems such as FePt\(^9\) or on ferromagnetic rare-earth based alloys\(^10\).

Lower threshold current densities for current-induced domain wall motion and higher domain wall (DW) velocities are expected if the spontaneous magnetization \(M_S\) gets smaller. Therefore, magnetic materials possessing both a high perpendicular magnetic anisotropy and a small \(M_S\) are very interesting candidates for spintronic devices\(^11\).

**This project consists in exploiting the potential for current-induced DW motion of a new system: ferrimagnetic Mn\(_4\)N thin films.** These films possess both a high perpendicular anisotropy and a very small magnetization, and are promising candidates for the study of spin-transfer torques, spin-orbit torques, and electric field control.

### 3] Scientific or technologic challenges

This PhD will combine the expertise of the Tsukuba group on Mn\(_4\)N growth by molecular beam epitaxy, with the experience of domain wall manipulation of the Grenoble group.

Preliminary experiments have been conducted to develop the Mn\(_4\)N growth, to measure the magnetic properties of these films\(^12\), and to perform the first experiments of domain wall propagation, under magnetic fields and currents (but without using spin-orbit effects or electric field control)\(^13\).

We showed that the deposit method developed by the Tsukuba group allow obtaining both the very high anisotropy \((K_u \sim 10^5 \text{ J/m}^3)\) and the small magnetization \((M_S=110 \text{ kA/m})\) interesting for current-induced domain wall motion applications. Note also that this system is only composed of light and inexpensive elements (Mn and N).

\(^5\) Xu, Xia, ... & Li, *Nature nanotechnology* 3(2), 97-100 (2008).
More spectacularly, the quality of these films is underlined by observations of Mn₄N/STO thin films by magnetic force microscopy and by magneto-optic Kerr effect microscopy (collaboration with S. Pizzini, Louis Néel Institute, Grenoble), which shows incredibly smooth and long domain walls, in the mm range rather in the usual micronic or submicronic range (cf. fig. 2).

**STANDARD SPIN TRANSFER TORQUE**

First experiments, made on relatively thick Mn₄N wires, allowed us to successfully observe the effect of STT on the coercive field, and to perform CIDWM. The first estimation of the spin transfer torque efficiency is found to be very high, around $7 \times 10^{-12}$ T.m²/A, and the DW velocity reaches already 200 m/s, without any optimization, nor assistance of an external field.

**SPIN ORBIT EFFECTS AND GATE VOLTAGES**

When using spin-orbit effects, an adjacent non-magnetic layer produces a pure spin current that is directly absorbed by the magnetic layer, leading to spectacular effects, such as high velocities, DW motion against the flow of electrons, and efficient magnetic switching. The understanding and optimization of spin-orbit effects is one of the most exciting scientific challenges in spintronics.

The Grenoble group has a strong expertise in this topic. We demonstrated recently, using spin pumping, that strong pure spin currents could be created at the interface between STO and magnetic materials. We plan to investigate, the role of the Rashba STO/Mn₄N interface, using spin pumping and thinner samples.

Moreover, the STO is a good substrate to apply electric fields. We plan to use this electric field to control the magnetic properties (first attempts on thick samples seems to indicate large effects on the coercive fields). More importantly, we might be able to tune the properties of the Rashba STO/Mn₄N interface, and thus of spin-orbit effects, using a gate voltage. This will be studied using both spin-orbit torques experiments on domain walls and spin-pumping methods on thin films.

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4] Scientific approach and work plan

The deposit of the films will be realized in Tsukuba. The PhD student will spend around half his PhD in Tsukuba, depositing, characterizing and optimizing the samples. One of the major aims is to obtain thinner films, to enhance the SO effects, while conserving the astonishing magnetic properties of the Mn4N samples.

The nanofabrication will be done in Grenoble in Spintec laboratory, supervised by L. Vila. We have access to cutting-edge clean room facilities for basic research, including an e-beam nanowriter (8nm lines). Magnetic characterization (MFM, transport measurements, SQUID) and magnetotransport measurements will be done in Grenoble, as well as spin-pumping experiments. The experiments will be realized on the 5 transport set-ups we already possess, four of them equipped with cryostats (up to 8T and down to 2K), with noise levels down to 2 nV. If there is a need for a faster characterization device, we also have access to a wafer prober under magnetic fields. Additional characterization to determine the spin polarization will be performed by creating lateral spin-valves. MOKE measurements of the Dzyaloshinskii Moriya Interaction and of domain wall velocities under currents will be done in collaboration with S. Pizzini at institute Neel. Theoretical and numerical calculations will be done in collaboration with A. Marty. A particular attention is thus paid to the training of the PhD student, by ensuring that his activities are not reduced to a single task (e.g., nanofabrication), but involve several of the main tasks (theory, materials, nanofabrication and transport).

Here is a timetable of the main tasks for the 36 months of the PhD:

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<td>Dzyaloshinskii Moriya Interaction measurements</td>
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5] International positioning of the project

EXPERTISE OF THE TSUKUBA PARTNER IN THIN FILM GROWTH

Takashi Suemasu is Full Professor at the Faculty of Pure and Applied Science of Tsukuba University, and is a world expert on molecular beam epitaxy, with more than 300 publications in the fields of thin films growth and characterization (mostly for semiconductor physics).

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EXPERTISE OF THE GRENOBLE PARTNER IN DW MANIPULATION IN NANOSTRUCTURES

Jean-Philippe Attané is Assistant Professor at Grenoble Alpes University, and member of the "Institut Universitaire de France". Several groups world-wide also possess the ability to detect and manipulate DWs in nanostructures. The Grenoble group originality lays in the fact that we have developed a high expertise in perpendicular (FePt, FePd) systems, that we manipulate DWs in thinner wires (<50nm) than most of our competitors, and in the fact that we are major actors in both innovative electrical DW detection\textsuperscript{20} and spin transfer experiments\textsuperscript{21}. Also, we are at the top international level concerning the measurement of spin to charge conversion by spin-orbit coupling, using either spin pumping\textsuperscript{15,17} and lateral spin-valves\textsuperscript{22}.

ELIGIBILITY CRITERIA

Applicants must hold a Master's degree (or be about to earn one) or have a university degree equivalent to a European Master's (5-year duration).

Applicants will have to send an application letter in English and attach:
- Their last diploma
- Their CV
- A short presentation of their scientific project (2 to 3 pages max)
- Letters of recommendation are welcome.

Address to send their application: jean-philippe.attane@cea.fr ; laurent.vila@cea.fr

SELECTION PROCESS

Application deadline: 13/07/2018 at 17:00 (CET)

Applications will be evaluated through a three-step process:

1. Eligibility check of applications in 13/07/2018
2. 1st round of selection: the applications will be evaluated by a Review Board the 13/07/2018. Results will be given the 13/07/2018.
3. 2nd round of selection: shortlisted candidates will be invited for an interview session in Grenoble in September 2018 (if necessary)

TYPE of CONTRACT: temporary-3 years of doctoral contract
JOB STATUS: Full time
HOURS PER WEEK: 35
OFFER STARTING DATE: 01/06/2018
APPLICATION DEADLINE: 12/07/2018
Salary: between 1768.55 € and 2100 € brut per month (depending on complementary activity or not)

\textsuperscript{21} Burrowes et al., Nature Physics 6(1), 17-21 (2010).