Master Thesis Projects 2018

spintec
SPIN IN ELECTRONICS

SPINTRONIQUE et TECHNOLOGIE des COMPOSANTS

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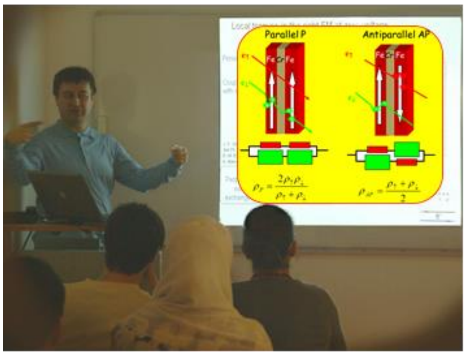
SPINTEC IN BRIEF

SPINTEC is located within the innovation research site of MINATEC in Grenoble, France. Our mission is to act as a bridge between academic research and technological applications in the field of spintronics, which is today recognized as one of the major innovation routes for future microelectronics industries, sensing technology and bio-applications. As such, we are at the cross-roads of nanosciences and technology, with outputs measured with both high-rank publications and a broad portfolio of patents. Our activities are performed in collaboration with academic and industrial partners from around the world. SPINTEC has circa 100 staff, encompassing researchers, engineers, post-doc and PhD students, working cooperatively in an open structure organized around focused research topics.

The research activity of SPINTEC covers the whole spectrum from theory to demonstrators, including the development of innovative functional materials, the experimental validation of novel physics concepts, up to the realization of test structures. The application-oriented topics are: magnetic random access memories, design of spin-based integrated circuits, sensors, biotechnology. Academic research concerns spinorbitronics, spintronics in 2D materials, microwave components, antiferromagnetic spintronics, and exotic spin textures.




SPINTEC FOR YOUR MASTER OR PHD PROJECT

With the objective to train tomorrow's researchers in an active and growing research field, SPINTEC proposes every year topics for (paid) Master projects. The majority of the Master projects will lead over to a PhD thesis project with financial support coming from a variety of funding sources, either from research institutions (bourses ministère, CFR CEA, local foundations), academic contracts (ANR, EU) or industrial partners (bourses CIFRE).

At SPINTEC, you will find a dynamic and multicultural environment that provides all facilities to advance your research project and get yourself known in the academic world via participation at international conferences. Three years after defending their PhD, 90% of our students have a position in academics or in the industry. Come and join us to be part of those who like to revolutionize microelectronics research and applications!

Hoping to see you soon,

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TOPICS FOR MASTER THESIS

MRAM MEMORIES

1 Atomic layer deposition for tunnel barriers in magnetic tunnel junctions

2 Development of optically switchable storage layer materials to be integrated in magnetic tunnel junctions

3 Development of an ultra-fast SOT-MRAM

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MAGNETIZATION DYNAMICS AND MICROWAVE DEVICES

8 Magnon Transport

9 Magnetic tunnel junction as nanosensor to detect propagating spin waves in insulating YIG

10 Spin waves manipulation and detection in conventional metallic spintronics materials

11 Optimisation of spintorque nano-oscillators

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13 Manipulation of spin currents and magnetic state at the nanoscale using the spin orbit coupling

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15 Electron holography for the high-resolution imaging of magnetic nanotubes for spintronics

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16 Development of compact models for the design of hybrid CMOS/magnetic circuits based on newly discovered spintronics phenomena

Stage N° : 1

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Title
Atomic layer deposition for tunnel barriers in magnetic tunnel junctions

Keywords
Spin-electronics; Magnetic memory ; MRAM ; STT-MRAM ; magnetic tunnel junctions

Summary
Atomic-layer deposition is a standard deposition tool on production lines for semiconductor chips, implemented for its particular suitability to deposit oxide layers conformally, with a very good homogeneity and excellent thickness control thanks to its self-limiting, well-defined chemical reactions of gaseous precursors adsorbed at surfaces. The processes for the high-k HfO2 material are especially well controlled for the production of oxide gates. Recently, Mantovan [1] reported the successful ALD fabrication of MgO barriers for MTJs whereas Liu [2] used an alumina-based ALD process, the two standard materials for MTJs. The first HfO2 barriers for MTJs have been reported by S. Fabretti et al [3]. The TMR ratio is sizable, which we view as a proof of concept for the technique, however remains an order of magnitude smaller than for the state-of-the-art PVD textured MgO used for spintronics: 10% has been obtained at room temperature so far. Our objective in this project is twofold: 1/ increase the magnitude of TMR in ALD-based MTJs beyond the current state-of-the-art 2/ characterize ALD MTJs on criteria crucial for applications, such as the scalability of the TMR ratio to small dot size, and the voltage breakdown, both being related to the material quality and homogeneity. We will consider MTJs with both MgO and HfO2 barriers, the former as a comparison with the well-established PVD MgO, the latter as a potential replacement material.

Full description of the subject
Since the discovery of the Giant Magneto-Resistance (GMR) effect in 1988 by Pr Albert Fert and Pr. Peter Grunberg, the Spintronic domain has become very attractive and challenging for many conventional technologies. The development of magnetoresistive stacks such as GMR-based Spin-Valves (1991) and later Magnetic Tunnel Junctions (1995) has revolutionized the magnetic component industry. Nowadays, the Magnetic Tunnel Junction (MTJ) is the core of all Spintronic components and can be compared in importance to the transistor for the micro-electronics industry. The magnetic Hard Disk Drive industry could remain competitive over more than five decades, thanks to fundamental and technological progress. Much enhanced MTJ based magnetic components have also been produced since 2000 based on textured MgO barriers, which are seriously challenging the mainstream CMOS technologies. The MRAM and its various generations is a typical example, but more recently magnetic nano-oscillator exploiting the spin-torque effect is another example of spintronic device that could deeply modify the RF architecture for mobile applications. In addition, the hybridization of MTJ with CMOS for reconfigurable logic is also a new vector of diversification for the spintronic business that is considered seriously for advanced hybrid CMOS-spintronic circuits.
Most of these new magnetic components are built around a Magnesium Oxide (MgO) based tunnel junction that can display a very high magnetoresistive signal compared with the first Aluminum-Oxide based technology. However, the impedance or the voltage constraints have led to continuously decrease the MTJ Resistance x Area (RA) product upon scaling, achieved through thinning the tunnel barrier. Today, the MgO PVD technology seems close to its physical limits around 1nm thickness. Thus, there is a need for enhanced barriers, with alternative methods for improved deposition morphology at the atomic scale, and also new oxide barriers with lower band gap to achieve a given RA

with a thicker barrier, to pursue the RA decrease. The substitute materials require, of course, to maintain a high magnetoresistive signal.

Our project intends to address this critical aspect by providing a new way of depositing tunnel barrier material that could offer better morphology control at atomic level, while retaining a large TMR ratio. This new barrier would be generic for various applications, namely spin-torque based MRAM, nano-oscillators etc.

Atomic-layer deposition is a standard deposition tool on production lines for semiconductor chips, implemented for its particular suitability to deposit oxide layers conformally, with a very good homogeneity and excellent thickness control thanks to its self-limiting, well-defined chemical reactions of gaseous precursors adsorbed at surfaces. The processes for the high-k HfO_2 material are especially well controlled for the production of oxide gates. Recently, Mantovan [1] reported the successful ALD fabrication of MgO barriers for MTJs whereas Liu [2] used an alumina-based ALD process, the two standard materials for MTJs. The first HfO_2 barriers for MTJs have been reported by S. Fabretti et al [3]. The TMR ratio is sizable, which we view as a proof of concept for the technique, however remains an order of magnitude smaller than for the state-of-the-art PVD textured MgO used for spintronics: 10% has been obtained at room temperature so far. Our objective in this project is twofold: 1/ increase the magnitude of TMR in ALD-based MTJs beyond the current state-of-the-art 2/ characterize ALD MTJs on criteria crucial for applications, such as the scalability of the TMR ratio to small dot size, and the voltage breakdown, both being related to the material quality and homogeneity. We will consider MTJs with both MgO and HfO_2 barriers, the former as a comparison with the well-established PVD MgO, the latter as a potential replacement material.

The project will benefit from an excellent match between the expertise of IFW Dresden in ALD materials including for MTJs, a newly dedicated setup and advanced structural characterization, and the expertise of SPINTEC for the nanofabrication (lithography and etching), electrical measurements and their analysis.

[1] R. Mantovan et al, J. Phys. D: Appl. Phys. 47, 102002 (2014)
[2] X. Liu, J. Shi, Appl. Phys. Lett. 102, 202401 (2013)
[3] S. Fabretti et al, Appl. Phys. Lett. 105, 132405 (2014)

Requested skills

Basics in Magnetism,

Possibility to follow with a PhD Yes

Stage N° : 2

Anglais

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Title

Development of optically switchable storage layer materials to be integrated in magnetic tunnel junctions

Keywords

Spin-electronics; Magnetic memory ; MRAM ; STT-MRAM ; magnetic tunnel junctions, all optical magnetic switching, photonics

Summary

Magnetic storage has been used from the very beginning of the computer era and has shown an astounding development in area density and speed, with a 50-million fold increase over the past 50 years. However, the current hard disk storage is a mature technology that is only producing incremental changes, while the demand for storage grows by 40% per year. A radically new technology will be required to keep up with the demand. Spintronic or spin-based memory (STT-RAM), will revolutionize memory technology, as it has the potential to combine the low cost of DRAM, the speed of SRAM, the non-volatility of flash, and has almost no static energy consumption, like hard disks. In practice though, write power and write speed are still too high, compared to the state-of-the-art memory technologies. An interesting trend that improves the write speed and power of such spintronic memory is the discovery, of magnetization reversal by femtosecond laser pulses in thin ferromagnetic Gd/Fe/Co films. It is a conceptually new way to control the magnetic state of a medium, at the highest efficiency and shortest possible time-scale. Recent results show that a wide class of magnetic materials can be switched in this way, including rare-earth free transition metal multilayers and Co/Ir heterostructures. All-optical magnetic switching can be done in the femtosecond regime, promising terabit-per-second magnetic recording, at femtojoule per bit switch energies.

Full description of the subject

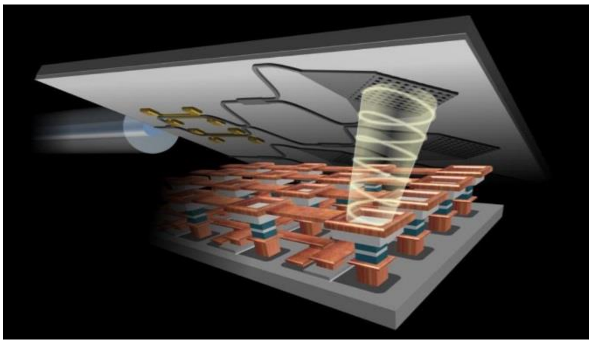
The purpose of this internship will be to develop optically switchable storage layer materials that can be integrated in traditional tunnel junction pillar stacks to be used as MRAM cells.

Development of rare earth/ferromagnetic multilayers of Pt/Co or Tb/Co are the starting points to bring magneto-optic interaction to the field of spintronics. MTJ fabrication will explore various scenarios of photonics-assisted switching, where the optical pulses are used for heating up the MTJ, while simultaneously sending an electrical 'write' current through the MTJ. The developed materials are to be optimized and integrated as an optically-switched layerstack. The aim is to realize an optically switchable magnetization layer in an MTJ stack, having a switching fluence comparable with state of the art for single layers. Taking advantage of the expertise of the laboratory in this field, we propose to participate in the growth of materials by sputtering, to characterize their magnetic and electrical properties. The magnetic stacks will then be nanostructured in our clean room in the form of electrically contacted nanometer pillars. The optical characterization of the MTJ stack will be done in collaboration with Radboud University using top-side illumination, using lensed fibers or high numerical aperture microscope objectives and/or SNOM. This gives the required parameters for integration with and illumination from the photonic layer. This work is part of a 4 year EU FET-open project "SPICE" funded in the framework of Future and Emerging Technologies (FET) program.

Requested skills
Basics in Magnetism

Possibility to follow with a PhD Yes

Figure



Stage N° : 3

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Title:
Development of an ultra-fast SOT-MRAM

Keywords:
Magnetic memory, sub-ns pulses, nanofabrication, spin orbit interaction

Summary
The microelectronics industry will face major challenges related to power dissipation and energy consumption, and the microprocessors scaling will hit a power wall soon. A promising way to stop this trend is the integration of non-volatility in cache memories, the fastest memory located close to the processor. The development of an electrically addressable non-volatile memory combining high speed and high endurance is essential to achieve these goals.
The SOT-MRAM (Spin Orbit Torque MRAM), recently proposed by SPINTEC and developed by ANTAIOS, a start up company, (7 patent proposals), combines these features while being compatible with technological nodes below 22nm.
Its development is currently impeded by the necessity of a static in-plane applied magnetic field.
The purpose of this internship, and of the following thesis, is to develop a “field-free” SOT-MRAM.
This internship is experimental. It will be conducted under the supervision of both SPINTEC and ANTAIOS and will require nanofabrication in clean room, magnetic characterization and sub-ns magneto-transport measurements.

Details of subject
The microelectronics industry will face major challenges related to power dissipation and energy consumption, and the microprocessors scaling will hit a power wall soon. A promising way to stop this trend is the integration of non-volatility in cache memories, the fastest memory located close to the processor. Non-volatility (NV) of a memory means that it keeps the recorded information even if the power supply is turned off. The development of an electrically addressable non-volatile memory combining high speed and high endurance is essential to achieve these goals.
The SPINTEC laboratory has recently proposed a new magnetic memory concept, the SOT-MRAM for "Spin Orbit Torque MRAM", developed now by ANTAIOS (a start-up company from the laboratory). The SOT-MRAM is written by means of a current injected into a track supporting the magnetic nanopilar while the reading is done by measuring the tunnel magnetoresistance (TMR) by means of a current flowing through the stack perpendicularly to the layers (see figure). Compared to STT-MRAM (Spin Transfer Torque MRAM), which is being marketed very soon, notably by Samsung, and is about to become a memory standard, the SOT-MRAM, while being larger, has a much higher write speed (sub-ns) and an infinite endurance. These characteristics, plus its compatibility with technological nodes less than 22nm, make it the most promising candidate for SRAM replacement in cache memories.
Its development is currently impeded by the necessity of a static in-plane applied magnetic field during writing. Generating such a magnetic field poses integration problems and an integrated solution is indispensable to the development of these memories.
The role of this static magnetic field is to break a mirror symmetry. Without this break, the two opposite directions of the magnetization (coding "0" and "1") are perfectly equivalent and the information cannot be coded. This means

that possible solutions are not limited to the integration of a magnetic field but can be more diverse: pillar shape, particular material, particular writing scheme, etc.
The objective of the internship will be to focus on a particular solution that seems to Antaios and Spintec, the most promising in terms of scalability and distribution of critical parameters. Following the results of this internship, the thesis will continue on this solution or integrate other alternatives.
This experimental work will be carried out in the joint environment of SPINTEC and ANTAIOS, for the fundamental aspects (physics of spin orbit interactions, sub-ns magnetization reversal, ...) and applied one (most promising solution from industrial perspective, memory specifications , statistical tests, etc.). It will require nanofabrication in clean room, magnetic characterization as well as magneto-electrical transport under sub-ns pulses.

Requested skills
Master 2 solid state physics / Condensed matter physics / Material science

Possibility to follow with a PhD Yes/No
Yes

Figure

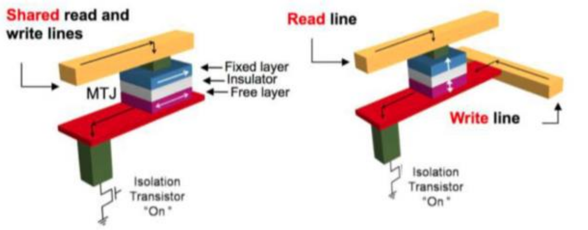

Figure 1: *In STT-MRAM (left), the read and write current share the same path while they are different for the SOT-MRAM (right).*

Stage N° : 4

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Title

Magnetic memory with reduced write current thanks to microwave assistance

Keywords
Spin-electronics; Magnetic memory ; MRAM ; magnetic tunnel junctions; spin transfer torque

Summary
There is an increase interest in microelectronics industry for a new type of magnetic non-volatile memory which have been developed in our lab for more than 10 years called STT-MRAM. In these memories, the storage elements are nanopatterned magnetic tunnel junctions which consist of two ferromagnetic layers separated by a thin tunnel oxide barrier (MgO). The information (0 or 1) is encoded in the relative orientation of the magnetization of the two magnetic layers (Parallel=0; Antiparallel=1), the magnetization of one being pinned in a fixed direction (reference layer) while the magnetization of the other is switchable (storage layer) to reach the P or AP states. These memories are about to be introduced in products for consumer electronics.
Lot of applications (wearable applications such as smartphones, interconnected objects of Internet of Things, etc) require to minimize the electrical consumption, in particular of the memories, to extend the battery lifetime. In this internship, we propose to investigate a novel approach for reducing the energy conception for writing in the memory by assisting the switching of the magnetization of the storage layer thanks to a microwave produced by spin transfer torque. This spintronics phenomenon occurs when an electrical current traverses the magnetic tunnel junction and gets spin-polarized while flowing through the reference layer. It results in magnetic torques exerted on various layers of the magnetic tunnel junction stack yielding the switching of the storage layer magnetization with an energy cost of only a few tens of fJ. The internship will comprise simulations and experiments.

Details of subject
MRAM are non-volatile memories based on magnetic tunnel junctions (MTJ). MTJ consist of two ferromagnetic layers separated by a very thin MgO tunnel barrier (1nm thick). The information is encoded in the magnetic orientation of one of the layer (called storage layer) while the magnetization of the other layer remains fixed. When a current flows through the junction, the resistance depends of the relative orientation of the magnetization of the two magnetic layers (Parallel="0"=low resistance state; antiparallel="1"=high resistance state). This allows to electrically read out the magnetic state of the junction. During write, the magnetic state of the storage layer is switched by a phenomenon called spin transfer torque which results from the exchange interaction between the spin of the tunneling electrons and those responsible for the magnetization of the storage layer. SPINTEC played a leading role in the development of magnetic memories based on these structures which are now about to be widely adopted by the microelectronic industry. This interest is due to the unique combination of assets that no other types of memory gathers: non-volatility (i.e. ability to keep the information when the memory is powered off), relatively low power consumption, high density and almost unlimited write endurance (in contrast for instance to FLASH memories which can only be written 100 000 times). These memories are expected to be launched in volume production in 2018 for embedded memory applications used in consumer electronics.
For wearable applications (smartphones, interconnected objects of IoT, etc) but also for servers, high performance computing (HPC), reducing the power consumption of electronic circuits remains a major goal. We propose here to

investigate a novel write approach in magnetic MRAM which uses the phenomenon of spin transfer torque assisted by microwave. Spin transfer torque (STT) occurs when a spin polarized current is injected in a magnetic nanostructure. Due to the exchange interaction between the injected electrons and those responsible for the magnetization of the nanostructure, a torque is exerted on this magnetization which can have to effects: 1) a switching of the magnetization of the nanostructure, phenomenon already used as write scheme in STT-MRAM but leading to a relatively large power consumption during write , or 2) excitation of a steady precession of magnetization which can be used in spin transfer microwave oscillators.
The idea that we want to explore here consists in combining the two above mentioned effects to reduce the power consumption during write in MRAM. The principle consists in using magnetic tunnel junction stacks in which the switching of the storage layer by STT is assisted by the microwave produced by another layer whose magnetization is driven into precession by the same current flowing through the stack.

This internship which covers both fundamental and applied aspects, will comprise numerical simulations and experiments.
Based on the laboratory expertise in the field, we propose to first evaluate the proposed concept by numerical simulations. We will then grow the corresponding stacks by sputtering, characterize their magnetic and electrical properties at wafer level. We will then pattern the stacks in the form of nanometric pillars in our clean room and characterize their switching by spin transfer torque. The results will be benchmarked with the properties of the existing structures.
We hope that the internship will be pursued in a thesis. This would allow a thorough optimization of the stacks to minimize the write energy in views of wearable applications but also of fast switching memories such as non-volatile SRAM used as CACHE memories.

Requested skills
Basics in programming and magnetism

Possibility to follow with a PhD Yes

Stage N° : 5

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Title

Magnetic tunnel junctions suitable for memory applications over a large range of operating temperatures

Keywords

Spin-electronics; Magnetic memory ; MRAM ; STT-MRAM ; magnetic tunnel junctions

Summary

There is an increase interest in microelectronics industry for a new type of magnetic non-volatile memory which have been developed in our lab for more than 10 years called STT-MRAM. In these memories, the storage elements are nanopatterned magnetic tunnel junctions which consist of two ferromagnetic layers separated by a thin tunnel oxide barrier (MgO). They are about to be introduced in products for consumer electronics. It is envisioned that they could play also a very important role in industrial and automotive applications but for the latter, the specifications are much more stringent in terms of reliability and operating temperatures (up to 150°C instead of 80°C for consumer electronics). In this internship and possibly the subsequent thesis project, we propose to explore several innovative routes in terms of materials and memory dot shape to reduce the influence of the operating temperature on the memory performances in particular in terms of retention (i.e. how long the information can be kept in the memory before being lost).

Details of subject

STT-MRAM are non-volatile memories based on magnetic tunnel junctions (MTJ). MTJ consist of two ferromagnetic layers separated by a very thin MgO tunnel barrier (1nm thick). The information is encoded in the magnetic orientation of one of the layer (called storage layer) while the magnetization of the other layer remains fixed. When a current flows through the junction, the resistance depends of the relative orientation of the magnetization of the two magnetic layers (Parallel="0"=low resistance state; antiparallel="1"=high resistance state). During write, the magnetic state of the storage layer is switched by a phenomenon called spin transfer torque which results from the exchange interaction between the spin of the tunneling electrons and those responsible for the magnetization of the storage layer. SPINTEC played a leading role in the development of magnetic memories based on these structures which are now about to be widely adopted by the microelectronic industry. This represents a major breakthrough which will significantly contribute to reducing the power consumption of electronic circuits. For some applications, further work is however still needed to increase the switching speed (to reach the ns regime with high reliability), to reduce the write current for downsize scalability and to increase the range of operating temperature. In this internship, we propose to investigate various approaches allowing to reduce the impact of temperature on the magnetic and electrical properties of the MTJ. Some of these approaches will rely on material optimization by using materials with high Curie temperature or with double MgO barriers and double polarizers. Another approach will rely on playing with the shape of the memory dot to exploit magnetostatic effects. Based on the previous experience of our laboratory, we propose to grow this type of stacks by sputtering, characterize their magnetic properties as well as their electrical properties at wafer level. We will then pattern the stacks in the form of nanometric pillars in our clean room and characterize their switching by spin transfer torque. The results will be benchmarked with the properties of the existing structures.

We hope that the internship will be pursued in a thesis. This would allow a thorough optimization of the stacks to reach specifications compatible with automotive and industrial applications

Requested skills
Basics in programming and magnetism

Possibility to follow with a PhD Yes

Stage N° : 6

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Title

Ultra-sensitive magnetic field sensor for space applications

Keywords
magnetic field, sensor, high sensitivity

Summary
Magnetic sensors for space flight are highly sensitive inductive sensors but they are cumbersome and heavy (150g/axis) which impacts the launching cost. Since many years, research has been performed in order to reduce the sensor size and mass. However, no further progress is expected on this line without a definite change of paradigm. The solution could be spintronic devices provided they could present the proper sensitivity. We are therefore developing a magnetic sensor which combines an innovative architecture with a low-noise magnetoresistive element. Our objective is to improve the sensor performances by including an innovative magnetic tunnel junction that we intend to protect with a patent. The experimental work will be: i) the microfabrication of the device; ii) measurement of the electrical noise; iii) optimization of the junction composition and geometry by numerical simulations.

Details
The aim of this project is to manufacture a magnetic sensor that could be a serious competitor, in term of sensitivity, to those currently shipped onboard the space missions, with a weight reduction of at least two orders of magnitude. Up to now, magnetic field sensor used for space missions are inductive magnetic sensors that have a very high sensitivity, up to few tenths of fT. Nevertheless, this very good sensitivity is achieved at the cost of large size and mass (150g per axis), markedly increasing the launching cost. Solutions to reduce the sensor mass has been systematically tested for years but no further improvement can now be obtained without a change of paradigm. Using nano-devices from spin electronics integrated on silicon would allow a significant progress in the size and mass reduction of vectorial magnetic sensors provided they could have the required sensitivity.
We are therefore developing an ultra-sensitive magnetic sensor that combines an innovative architecture and a low noise magnetoresistive element. It includes a magnetic circuit, a biasing coil and a tunnel junction, made with thin film technology, an electronic circuit in ASIC technology and a feed-back coil made with a micro winding process, the latter responsible for the sensor high performance in terms of linearity and stability. The sensor high sensitivity is obtained by a strong amplification (>300) of the measured magnetic field thanks to the magnetic circuit acting as a flux concentrator, and by using magnetic tunnel junctions with high magnetoresistive ratio.
The originality of the proposed sensor lies in a differential and heterodyne detection combined with a feed-back: the magnetic field to be measured is modulated by an ac biasing field, so that the measurement is translated in the vicinity of the biasing frequency where the noise is low.

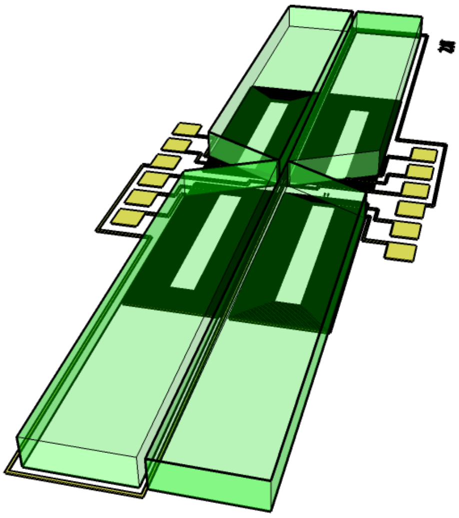
Our objective is now to improve the quality of the flux concentrator by the choice of materials (laminated NiFe layer, multilayer with antiferromagnetic coupling or amorphous alloys) and to replace the current tunnel junction by an innovative junction (patent in progress). Optimizing the new junction will require numerical simulations and experimental tests.

The innovative and ambitious features of the proposed solution should allow to develop a sensor able to detect magnetic fields as low as 100fT/Hz1/2 in the frequency range below 10kHz, which corresponds to a sensitivity three orders of magnitude larger than the best magnetoresistive sensors currently available. Furthermore, a large reduction in size increases the sensor spatial resolution which extends the scope of applications towards the medical sector, biotechnologies or non-destructive control for example.

Requested skills
Solid state physics

Possibility to follow with a PhD Yes/No
Yes

Figure



Stage N° : 7

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Title

Characterizing electrical signature of magnetic skyrmions

Keywords
skyrmions, magneto-optic, magnetotransport, microfabrication

Summary

Skyrmions are chiral magnetic bubbles: magnetization follows a cycloid along a line across the skyrmion. They can appear in heavy metal/ferromagnet/oxide trilayers. Such texture results from the presence of an interfacial interaction called Dzyaloskinskii-Moriya interaction. It makes the skyrmions stable, nearly insensitive to defects and easily moveable by electrical current. They are currently very popular as they could be used as dense storage nanoscale data bits, or for magnetic logic.

Using magneto-optical microscopy, we have recently shown that a gate voltage can modulate the size and density of magnetic skyrmions in ultrathin films, ultimately leading to the realization of a skyrmion switch [1].

Electrical detection of skyrmions is necessary to develop skyrmion-based devices but is still a technological challenge. The aim of the proposed internship is to tackle this prerequisite.

The candidate will explore the electrical response of these magnetic objects while observing them. He(she) will in particular search for a signature of the skyrmion Hall effect and further test the influence of a gate voltage.

The candidate will fabricate microstructures using a clean room facility and perform magneto-optical and magnetotransport characterizations. He(she) will then participate to the result analysis and compare the data with existing models.

[1] M. Schott et al. Nano Lett., 17, 3006 (2017)

Full description of the subject

Skyrmions are chiral magnetic bubbles: their magnetic texture, or topology, is peculiar since magnetization follows a cycloid along a line across the skyrmion. They can appear in ultrathin heavy metal/ferromagnet/oxide trilayers. Such topology results from the presence of an interfacial interaction called Dzyaloskinskii-Moriya interaction (DMI). It is due to the asymmetry of the structure. This DMI makes the skyrmions stable, less sensitive to defects than usual domain walls and easily moveable by electrical current. They are currently very popular as they could be used as dense storage nanoscale data bits, with low power manipulation; they could also be used for magnetic logic with efficient operation.

Using magneto-optical microscopy, we have recently shown that the size and density of magnetic skyrmions in ultra-thin films can be modulated by a gate voltage. Finally we have even managed to create and erase skyrmions with the voltage, thus demonstrating a skyrmion switch device operation [1]. These measurements were done at room temperature with materials compatible with electronics. We have observed this skyrmion switch effect in two types of trilayers, ie. Pt/Co/AlOx and Ta/FeCoB/TaOx, where the origin and contributions of the DMI are different.

Electrical detection of skyrmions is necessary for developing spintronic devices but is still a technological challenge. The aim of the proposed internship is to tackle this prerequisite.

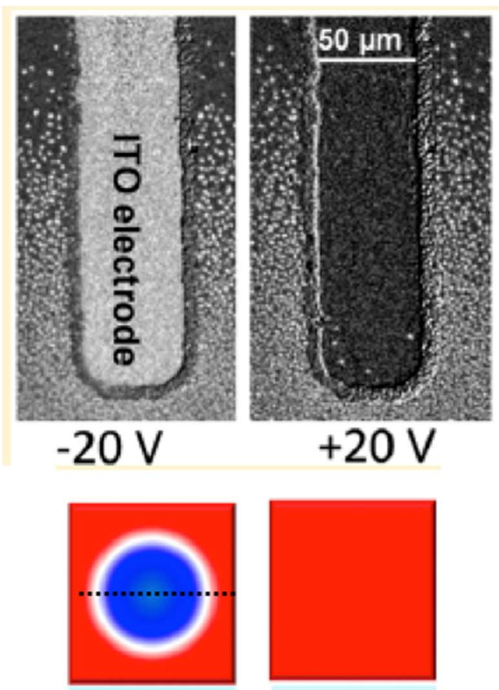
The candidate will explore the electrical response of these magnetic objects while observing them. For this purpose, he(she) will use a dedicated Magneto-optical Kerr effect microscope with a sample stage allowing to observe the sample and measure magnetotransport at the same time. He(she) will in particular search for a signature of the skyrmion Hall effect and further test the influence of a gate voltage on this electrical signature. For the observation through the gate, we have developed a microfabrication process with a thick oxide (50nm) and a transparent electrode, which allows applying a voltage up to ±20V over large areas (typically 500 x 50 µm2).
The candidate will thus fabricate the microstructures using the clean room facility located in the same building as Spintec (etching, atomic layer deposition, optical lithography,…) and perform the magneto-optical and magnetotransport characterizations. He(she) will then participate to the result analysis and compare the data with existing models.

[1] M. Schott et al. Nano Lett., 17, 3006 (2017)

Requested skills
Master 1 condensed matter,

Possibility to follow with a PhD (Yes/No)
Yes

Figure



(Up) Kerr effect microscopy images showing evolution of skyrmion density (bright dots) under the electrode for negative (large density) and positive (very low density) applied voltages. (Down) schematics of the electrically controlled skyrmion switch: presence (-20V) or absence (+20V) of skyrmion depending on the applied gate voltage. The magnetic texture of the skyrmion along the dotted line is peculiar (see text).

Stage N° : 8

Contact

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Title

Magnon Transport

Summary

The recent demonstrations that spin orbit torques (SOT) in non-magnetic materials allow one to generate and detect pure spin currents has triggered a renewed effort to develop communication technologies based on the spin degree of freedom. Within this new paradigm, magnetic materials play the role of spin conductors, since they can propagate spin waves (or their quanta, magnons), which are the information carriers. Interestingly, magnetic insulators are usually better spin conductors than magnetic metals, and amongst them yttrium iron garnet (YIG) is the best material, as it is famous for having the lowest known magnetic damping parameter [1-4].
From a purely fundamental point of view, this topic is very interesting because, in contrast to spin transfer process in confined geometries (*e.g.* nano-pillars or nano-contacts) where usually the uniform magnon mode dominate the dynamics, very little is known about spin transfer in extended geometries, which have continuous spin-wave spectra containing many modes which can take part in the magnon-magnon interactions. The studies of magnon transport in YIG by means of the direct and inverse spin Hall effects provide new means to alter efficiently the energy distribution of magnons and, potentially, even to trigger Bose condensation [5,6].
This topic is currently recognized as one of the important emerging research direction in modern magnetism [7]

The studies in this internship will concentrate on the characterization of the propagation and control of spin waves via the spin Hall effect in YIG devices that have been realized within our group. This work will introduce the student to the topic of magnetization dynamics, the concepts of propagating spin waves, and the concept of spintronics (spin polarized transport, pure spin currents, spin Hall effect).

Bibliography :

[1] Y. Kajiwara, et al., Nature 464, 262 (2010).
[2] A. Hamadeh et al. Phys. Rev. Lett. 113, 197203 (2014).
[3] M. Collet, et al. Nature Commun. 7, 10377 (2016).
[4] N. Thiery et al. arXiv:1702.05226 [cond- mat.mtrl-sci].
[5] S. A. Bender, R. A. Duine, and Y. Tserkovnyak, Phys. Rev. Lett. 108, 246601 (2012).
[6] S. O. Demokritov, et al. Nature 443, 430 (2006).
[7] E.G. Sander et al. Journal of Physics D: Applied Physics 50, 363001 (2017).

Requested skills
M2 level, sound knowledge of solid state physics and/or Nanophysics and Nanosciences

Possibility to follow with a PhD: Yes

Stage N° : 9

Contact

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Ursula EBELS
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Title

Magnetic tunnel junction as nanosensor to detect propagating spin waves in insulating YIG

Summary

This project proposes to explore an alternative technology based on magnetic insulating magnonic materials to be used in **microwave analog front-end technology** that has a critical role in the emission/reception chain of **wireless telecommunication.** Existing technologies make use of parallel channels combining Low Noise Amplifiers (LNA) with thin-film surface/bulk acoustic resonators, which work on the interconversion of the electromagnetic signal into a slow propagating acoustic wave traveling in a compact delay line. Magnonic materials are here a timely replacement to the acoustic analogue, since the acoustic attenuation increases rapidly above a couple of GHz, and will be limiting in future technologies that foresee a shift of the carrier frequency towards tens of GHz and higher. This project proposes to use the propagation of **spin-waves** (SWs) or their quanta **magnons** to perform delay line functions, since they are expected to be more efficient loss-wise and are easily tunable over a wide frequency range by simply varying the strength of an external (global or local) magnetic field. This is a substantial asset since tuning the frequency in the microwave range does not generally come easily. Here $Y_3Fe_5O_{12}$ / **Yttrium Iron Garnet** (YIG) stands as the best material to propagate SWs [01]. The idea is to open a new era of miniature YIG-based **microwave analog front-end** through our unique ability to fabricate high quality YIG ultra-thin films, to nanostructure them using standard nano-lithography techniques and potentially to integrate them with other spintronics technologies. This project focuses on the latter aspect, by exploring the **integration of Magnetic Tunnel Junctions** (MTJ) with YIG. Such integration will provide innovative solutions to **inter-convert** the spin waves propagating in thin films into large electric signals at high gain. The two key advantages are i) the reduced size of MTJs provides near field solutions for sensing magnons, with the benefit of optimizing the coupling to the propagating SW and ii) biasing the MTJ will result in large output voltages, thus providing a large gain due to the large magneto-resistance ratios, without the need of integrating a local amplifier.

This internship will be carried out in collaboration with the University of Brest, who provides the YIG films,the CEA-Saclay who provides the MTJ materials and the platform of nanofabrication in Grenoble. The student will characterize the hybrid YIG magnonic / MTJ devices using electrical characterization techniques that will provide a novel technique for characterization of propagating spin waves. Once the technique is established this will be applied for the study of specific aspects of the non-linear dynamics of propagating spin waves.

Requested skills

M2 level, sound knowledge of solid state physics and/or Nanophysics and Nanosciences

Possibility to follow with a PhD: Yes

Stage N° : 10

Contact
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Title:
Spin waves manipulation and detection in conventional materials

Keywords:
Spintronics, Spin waves, spin orbit coupling, magnetization dynamics, ferromagnetic resonance

Summary
The miniaturization of CMOS devices becomes increasingly difficult due to fundamental limitations and the increase of leakage currents responsible for increased power consumption and over-heating. Large research efforts are devoted to find alternative concepts that allow for increased data-density at low power consumption as compared to conventional semiconductor approaches.
Spin waves have been identified as a potential technology that can complement and outperform CMOS in complex logic applications, profiting from the fact that these waves enable wave computing on the nano-scale.
The practical application of spin waves, however, requires the demonstration of scalable, CMOS compatible spin-wave detection schemes in material systems compatible with standard spintronics as well as semiconductor circuitry.
This internship will focus on the manipulation and detection of spin waves, based on spin orbit coupling phenomena (e.g. the inverse spin Hall effect and the spin orbit torques). It will involve nanofabrication of devices using clean room facilities and RF measurements of magnetization dynamics.

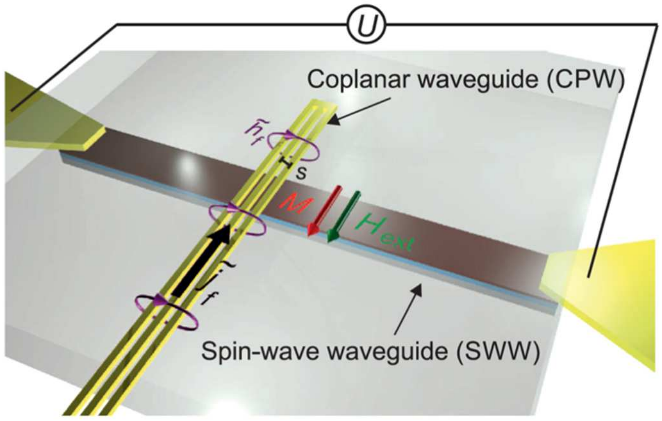
Details of subject
The miniaturization of CMOS devices becomes increasingly difficult due to fundamental limitations and the increase of leakage currents responsible for devices large consumption and over-heating. Large research efforts are devoted to find alternative concepts that allow for a larger data-density and lower power consumption than conventional semiconductor approaches.
Spin waves have been identified as a potential technology that can complement and outperform CMOS in complex logic applications, profiting from the fact that these waves enable wave computing on the nano-scale.
Magnonics explores the physics of spin waves and magnons as well as their use in information transport and processing: proof of concept of a magnon transistor, a spin-wave multiplexer, … Nevertheless, their large sizes and the unconventional materials used prevent their direct integration in CMOS circuits.
The use of these spin waves in practical applications requires demonstrating that they can be generated, manipulated and detected by scalable nanoscale devices made of standard spin electronics materials and compatible with CMOS technology.
The spin orbit coupling provides a new "family" of interesting effects for the manipulation and detection of these spin waves. The inverse spin Hall effect (iSHE), for example, would allow local electrical detection of propagating spin waves while the spin orbit torques would allow their local manipulation.
The internship will focus on these two aspects. The experimental work will take place at Spintec, pioneer in the study of these phenomena. The spin orbit torques influence will be studied in the case of an overall and uniform excitation of the magnetic material (ferromagnetic resonance) and in the case of propagating spin waves. The detection will be done using the iSHE by optimizing the devices materials and geometry.

The samples, whose sensitive elements will be around the hundred nanometer, will require nanofabrication in clean room. They will be studied by RF measurements of magnetization dynamics under the action of a DC current.
The student will be introduced to the concepts of spintronics (spin polarized transport, spin orbit torques, spin Hall effect), the concept of magnetization dynamics under spin current and high frequency measurement techniques.

Requested skills
Master 2 solid state physics / Condensed matter physics / Material science

Possibility to follow with a PhD Yes/No
Yes

Figure



Schematic of an investigated sample: an asymmetric magnetic stack is patterned into a spin-wave waveguide (SWW) with two leads (yellow) to measure the DC voltage (spin wave detection). An insulating Al_2O_3 separates the SWW from a nanometric, shorted coplanar wave guide (CPW) that acts as a spin-wave excitation source.

Stage N° : 11

Contact
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Title

Optimisation of spintorque oscillators

Keywords
Spintronics, magneto-resistive devices, magnetic tunnel junctions, magnetization dynamics

Summary
One of the basic concepts of spintronics is the spin momentum transfer where spin polarized conduction electrons can transfer a magnetic moment to the local magnetization of a thin ferromagnetic film. This magnetic momentum transfer is responsible for the excitation of high frequency (Gigahertz range) magnetization oscillations when a DC current is injected into a magneto-resistive device. SPINTEC studies these effects of spin momentum transfer from a fundamental point of view to better understand the non-linear magnetization dynamics of nansocale devices, but also in context of potential applications for the development of integrated microwave components.
In particular, the effect can be used to generate microwave signals as well as to detect microwave signals. The combination of the two could lead to a novel concept for a wireless communication system..

Details of subject
The non-linear dynamics of a spin transfer torque oscillator and its microwave signal generation have been studied in the past by our group as well as by numerous others. Good results in terms of output power and spectral purity have been obtained for oscillators emitting in the 0.2-1GHz range. Operation at higher frequency ranges (1-10GHz) of interest for applications, still suffers from too high a phase noise, making implementation for instance into a phase locked loop (PLL) difficult. The aim of the present internship project is to explore different magnetic stack configurations (magnetization in-plane and/or out of plane for polarizer and/or free layer), allowing for more stable and robust oscillations. The evaluation of these oscillator devices will be carried out in relation to the optimization of the nanofabrication process that plays a crucial role in defining the device microwave performances. A specific aspect will be the development of a field line that will allow the application of a microwave field to the device in order to either injection lock or modulate the generated microwave signal efficiently. The student will work in close collaboration with other group members responsible for the device nanofabrication. The central aspect of the internship studies will be the high frequency characterization of the different devices that the student will carry out in full autonomy. The result will be a data base that permits selecting the devices and configuration of best performances, in order to test the insertion into a phase locked loop (PLL), which will be tested in collaboration with the University of Dresden.
The student will obtain a sound training in high frequency measurement techniques which include operation of a spectrum analyser, a fast single shot oscilloscope and a signal generator. Besides, the student will be introduced to the concepts of spintronics (spin polarized transport, magnetic tunnel junctions, spin momentum transfer) as well the magnetization dynamics concepts (ferromagnetic resonance, auto-oscillations, non-linear dynamic effects).

Requested skills
The project is well adapted for M1 students, but also for M2 including more advanced studies. Motivated student should have a sound background in solid state physics, nanosciences and magnetism.
Possibility to follow with a PhD Yes/No
No for M1, potentially yes for M2

Stage N° : 12

Contact
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Bernard DIENY, bernard.dieny@cea.fr Tel : 04.38.78.38.70

Title

Spintorque-diode detectors for intrachip wireless communication

Keywords
Spin-electronics; magnetic tunnel junctions; spin transfer torque; RF oscillators; spintorque-diodes

Summary
Spin electronics is a merging between electronics and magnetism. It aims at using the spin of the electrons to reveal new phenomena and try to use them in devices showing new functionalities or improved performances. Magnetic memories called MRAM using spintronic materials and phenomena are about to be launched in volume production. Besides, a phenomenon called spin transfer torque (STT) can be used to conceive radiofrequency oscillators as well as microwave detectors called spin-diodes. These devices are based on magnetic tunnel junctions or spin-valves in which steady precession of magnetization are excited by a spin-polarized current flowing through them due to STT. This internship which covers fundamental and applied aspects, is part of a larger effort funded by an ERC Advanced grant aiming at exploring the possibility of using these devices for short distance wireless communication (intrachip distance of the order of 1mm). The internship will particularly focus on the detection part using spin-diodes. It will comprise numerical simulations and experiments.

Details
Spin electronics is an extremely vivid field of research and development which merges microelectronics with magnetism. Lot of new phenomena were discovered in this field in the past 20 years, each of them opening new perspectives of applications. Spin-electronics is about to become a mainstream technology in microelectronics with the forthcoming launching of volume production of magnetic memories called Magnetic Random Access Memories (MRAM). Besides memory, another very important field of research and development in spin-electronics concerns radiofrequency components for wireless communication. These components use the phenomenon of spin transfer torque (STT). STT
occurs when a spin-polarized current is injected in a magnetic nanostructure. Due to the exchange interaction between the spin of the injected electrons and those responsible for the local magnetization, a magnetic torque is exerted on the magnetization of the nanostructure. Under certain circumstances, it can drive the magnetization of the nanostructure into a steady precessional motion. By using this phenomenon in spin-valves or magnetic tunnel junctions, nanometer scale radiofrequency (RF) oscillators can be conceived. SPINTEC has already been working on such RF oscillators for more than 10 years. The goal was so far to produce RF voltages across magnetic tunnel junctions.
In this study which is part of an ERC advanced grant, we want to use these RF oscillators in a different way. The idea is to use the microwaves that they emit in the free space around them to achieve short distance wireless communication. For that, several such oscillators will be synchronized to increase the power of the microwave and its propagation range up to several hundreds of microns. Then microwave detector will be developed called spin-diodes. The internship will actually focus on this detection part. These spin diodes which consist of magnetic tunnel junctions convert the RF stray field received by the device into a DC voltage as diodes do. By modulating the emitted RF signal, an information can be transmitted to the spin diode. The internship will comprise simulations and experiments. Simulations will be used to evaluate the amplitude of the signal detected by the spin-diode depending

on the composition of the MTJ stack constituting the spin-diode and on the amplitude of the RF field to which it is submitted. The simulations will allow to find the optimal operation conditions for the foreseen communication application.

Next, benefiting from the expertise of the lab in the field, the optimal magnetic stacks identified by simulations will be deposited by sputtering and magnetically and electrically characterized at wafer level.

If time allows during the internship, the wafers will then be patterned in our clean room in the form of electrically contacted nanopillars constituting the spin-diodes of interest. The rectification properties of the spin-diodes will then be electrically characterized.

The work will be performed in collaboration with the permanent staff of the magnetization dynamics team at SPINTEC as well as with a postdoctoral fellow hired on the ERC Advanced grant to work on this RF intrachip communication.

We hope that the internship will be pursued in a thesis. This would allow a thorough optimization of the stacks, spin-diode configuration and complete test of the short distance communication.

Requested skills

Basics in programming and magnetism

Possibility to follow with a PhD (Yes/No)

Yes

Stage N° : 13

Contact
Laurent Vila, laurent.vila@cea.fr, 0438780355 (SPINTEC)

Title

Manipulation of spin currents and magnetic state at the nanoscale using the spin orbit coupling

Keywords
Spintronics, nanoelectronic and devices, nanomagnetism

Summary
Very recently, a collection of Spin Orbit based spin- to-charge interconversion mechanisms (Spin Hall effects, Rashba and Topological Insulators) were observed experimentally. It appears in the set of non-magnetic metals, semiconductors or oxydes, and sorts the carriers according to their spin state. It allows injecting and detecting spins without necessarily using magnetic materials or a magnetic field, which is both conceptually and technologically very interesting. In this framework, we wish to create lateral nanostructures taking advantage of pure spin current generated by harnessing the Spin Orbit coupling for both spin to charge interconversion mechanisms and the manipulation of magnetization state of nano-object (dot or magnetic domain wall) by absorption of this current and spin transfer torque.

Full description of the subject

The development of spin electronics, or spintronics, allows to imagine many devices taking advantage of an electronics no longer based solely on the electrical charge of the carriers but also on their spin. This new degree of freedom offers additional means of conveying information, and introduces new ways to manipulating it.

Very recently, a collection of Spin Orbit based spin- to-charge interconversion mechanisms (Spin Hall effects, Rashba and Topological Insulators) were observed experimentally. It appears in the set of non-magnetic metals, semiconductors or oxydes, and sorts the carriers according to their spin state. It allows injecting and detecting spins without necessarily using magnetic materials or a magnetic field, which is both conceptually and technologically very interesting.

In this framework, we wish to create lateral nanostructures taking advantage of pure spin current generated by harnessing the Spin Orbit coupling for both spin to charge interconversion mechanisms and the manipulation of magnetization state of nano-object (dot or magnetic domain wall) by absorption of this current and spin transfer torque. Material of interest will be metals, oxydes and topological insulators to generate or detect spin currents, and will be applied to the manipulation of the magnetic state of a nanoelement, an example of a recent realization being given on the figure.

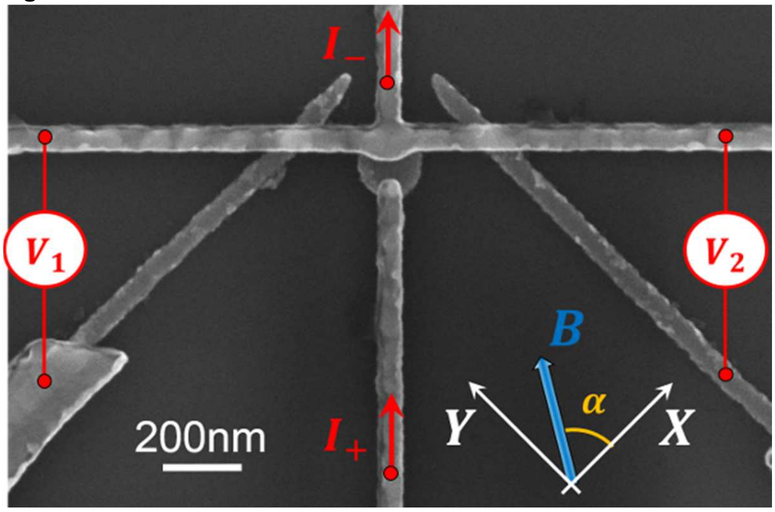
If subjects related to the spin transfer by absorption of a pure spin current are very competitive, they are scientifically rich, and currently booming. This area of research is still largely open to exploration, and we are benefiting from our recent development of efficient injection and detection devices.

The proposed topic lies in basic research but with a clear opening towards applied research. The trainee will benefit from the technical and scientific environment of the laboratory, and the collaborations put in place with the major actors of the field at the international level. This project is supported by funding from the ANR.

Requested skills
Master in Condensed Matter and Physics. Experimental physics, measurement of electronic spin transport properties, nanofabrication, modelisation

Possibility to follow with a PhD (Yes/No)
Yes

Figure



Stage N° : 14

Contact
BALTZ Vincent
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04 38 78 03 24

Title
Antiferromagnetic spintronics

Keywords
spintronics, nanomagnetism; antiferromagnetic

Summary
Antiferromagnetic materials (antiparallel alignment of the atomic magnetic moments) could represent the future of spintronic applications thanks to the numerous interesting features they combine: they are robust against perturbation due to magnetic fields, produce no stray fields, display ultrafast dynamics and are capable of generating large magneto-transport effects. Intense research efforts are being invested in unraveling spin-dependent transport properties in antiferromagnetic materials. Whether spin-dependent transport can be used to drive the antiferromagnetic order and how subsequent variations can be detected are some of the thrilling challenges to address.

Details of subject
The purpose of this internship is to study the spin dependent properties and functionalities of antiferromagnetic materials. The main challenges are to quantify and understand the spin-dependent transport in antiferromagnetic materials and particularly the parameters that govern it. The nature of the elements constituting the antiferromagnetic material and the quality of the interfaces will be the adjustable parameters. We will consider mainly the efficiency of spin injection and the interfacial filtering, the absorption of spins in the core of the material and the absorption characteristics lengths, the order temperatures and the magnetic susceptibility, and the efficiency of the spin-orbit coupling via the spin Hall effect.

This internship is experimental. It will build on the many techniques of fabrication and characterization at SPINTEC and benefit from the collaboration with the SYMMES/RICC CEA laboratory for experiments with a resonant cavity.

For more information on antiferromagnetic spintronics, feel free to visit the following link, which reviews research conducted around the world on this theme: http://arxiv.org/abs/1606.04284

Requested skills
Internship for Master 2 students (materials science, solid state physics), fluent in English or in French

Possibility to follow with a PhD
Yes

Stage N° : 15

Contact

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Olivier Fruchart
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Title

Electron holography for the high-resolution imaging of magnetic nanotubes for spintronics

Keywords

Transmission electron microscopy, magnetic imaging, nanotubes, simulation, micromagnetism

Summary

The objective of the internship is the study by transmission electron microscopy (TEM), of magnetic nanotubes synthesized by a chemical method. We are studying these as models objects to explore the concept of information storage in 3D magnetic media, based on the propagation of magnetic walls along one-dimensional structures. Physico-chemical study of the material and magnetic imaging at the nanometer scale will be used to explore and understand the arrangement of domains and domain walls in these systems, whose synthesis has been achieved recently.

The experimental techniques used are the chemical and structural analysis by electron diffraction and high-resolution imaging, and high-resolution and sensitivity magnetic imaging by electron holography, in a transmission electron microscope. The student will perform sample preparation for electron microscopy, will participate in the imaging, and will have a key contribution in the image processing needed to analyze the data. .

The work also includes participation in micro-magnetic simulations to support the physical understanding of the measurements. These will be done in collaboration with the joint simulation group SPINTEC / NEEL.

Full description of the subject

To perform the structural and magnetic microscopy we benefit from the latest and world-leading equipment for chemical analysis, images of matter at the atomic scale and also to visualize magnetic fields. The work will be largely experimental:

- The chemical and structural analysis by electron diffraction
- The high-resolution images
- The magnetic imaging and electron holography with a resolution and sensitivity of a few nanometers.

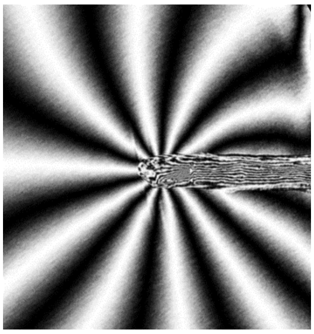
The experimental systems are under control, and will be made available, under the collaboration with chemist experts and also by physico-chemists at Institut NEEL. In recent experiments with photoelectron microscopy (PEEM, experiments with synchrotron radiation) we evidenced azimuthal domains (magnetization curling around the perimeter of the tubes), thus with flux-closure. This closure is very interesting in the context of a 3D memory because it minimizes the effects of long-range dipolar fields, and thus cross-talk between elements. However it is unexpected with respect to the axial direction. Following this, in this internship we will try to clarify the reason for this orientation, in connection with the microstructure. Moreover, thanks to our high spatial resolution we will seek to clarify the type of magnetic walls occurring between the domains, which have a crucial impact on their dynamics expected in a magnetic field or spin-polarized current.

The student will handle the sample preparation for electron microscopy (dispersion of tubes initially in solution, possible use of etching by focused ion beam), will participate in the experiments in the TEM microscope, under static conditions and possibly under magnetic field or elevated temperature, for the study of the magnetization pattern inside matter and magnetic stray field around the tubes. A key task of the student will be to take part in processing steps and its analysis with micromagnetic simulation.

In the framework of a PhD work, the topic would be enlarged, to progressively shift from a nanomagnetics focus, to spintronics objectives. We will consider tubes connected electrically, to control their magnetization state under polarized current in the microscope, and in particular move domain walls. We will also consider core-shell shell structures, as multilayered systems is a requirement to develop spintronic effects such as giant magneto-resistance and efficient spin injection through the spin-Hall effect. A perspective will be dynamic studies with a nano-device operation (eg polarized current flow inducing precessional dynamics) in the microscope.
Finally, efforts will be made on simulated images and simulations micromagnetism. These calculations will be performed in collaboration with the joint SPINTEC / NEEL simulation group, to interpret our results.

Requested skills
Experimental physics, understanding of condensed matter physics, computer skills

Possibility to follow with a PhD
YES



Iso-lines of magnetic phase arising from a Ni nanowire in a magnetic state close to saturation. The dense lines within the nanowire are indicative of magnetization, while the lines in vacuum pertain to the stray field of dipolar origin created by the wire.

Stage N° : 16

Contact
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Bernard DIENY, bernard.dieny@cea.fr Tel : 04.38.78.38.70

Title

Development of compact models for the design of hybrid CMOS/magnetic circuits based on newly discovered spintronics phenomena

Keywords
Spin electronics ; compact models ; CADENCE ; circuits design ; spin orbit

Summary
Spin electronics is a merging of microelectronics and magnetism which aims at taking advantage of the best of the two worlds. Magnetism is very appropriate for memory functions since it allows encoding information in a nonvolatile way via the direction of magnetization of magnetic nanostructures. Magnetic memories called MRAM (Magnetic Random Access Memories) are about to be launched in volume production at several major microelectronics companies. For readout, these memories use the tunnel magnetoresistance of magnetic tunnel junctions while the writing is performed by using the magnetic torque that a spin-polarized current exerts on the magnetization of a magnetic nanostructure (spin transfer torque). But spinelectronics keeps on progressing and new phenomena have been discovered since then on which our laboratory is actively working. These new phenomena which rely on spin-orbit interactions allow conceiving memories and non-volatile logic circuits exhibiting extremely low power consumption. The purpose of this internship will be to develop the compact models describing these new phenomena, integrate them within the CADENCE suite and design a few simple circuits based on these phenomena.

Details
SPINTEC is a laboratory entirely dedicated to spin-electronics and aiming at bridging basic research in magnetism with applications in microelectronics. Spin-electronics merge magnetism and microelectronics to try circumventing some of the limits of conventional CMOS microelectronics. In particular, a new type of non-volatile memories has emerged in the field called MRAM (Magnetic Random Access Memories). They combine a number of assets that no other type of memories gathers: non-volatility, speed, density and practically unlimited write endurance.
A number of academic studies have demonstrated the advantages that can be expected in terms of performances, energy consumption and new functionalities from the implementation of MRAM in electronic systems for various applications. Major industrial players are getting more and more interested by this technology, so far in its most standard version, i.e. based on spin transfer torque writing (STT). However, while the technology is getting more and more mature and close to commercialization, new generations are emerging, such as writing with voltage control of magnetic anisotropy and reading by conversion between spin current and charge current using spin-orbit effects. Even more interesting performances are expected from these new generations of circuits. However, those are still at the theoretical and material development levels.
Purpose of the internship :
The purpose of the internship will be to evaluate in a preliminary approach the advantages that could be obtained from memories and logic circuits based on these new phenomena, from electronics point of view. For that purpose, it will be necessary to develop compact models allowing to simulate electronic components based on these newly discovered phenomena, then to implement these models within CADENCE design suite. These design tools will

subsequently be used to design simple circuits and in the longer term evaluate more complex hybrid CMOS/magnetic circuits. Practically, two main tasks will be carried out during the internship:
-The development in VerilogA, of electric compact models for the simulation of electronic circuits based on these newly discovered phenomena;
-The design, based on these models, of read/write circuits for the emerging devices.
This internship will be continued by a PhD thesis aiming at a thorough evaluation of the performances of these components once implemented in more complex circuits, in particular the gain in terms of power consumption as well as new possible functionalities.

Requested skills
The candidate will have a Master 2, from University or Engineer School. His background will include analog microelectronic design, ideally using CADENCE software. Notions of programing with Verilog A would be a plus. The candidate will be fluent enough in spoken and written English for reading and writing articles in English. An interest for research and multidisciplinarity is required for this internship. A will to pursue with a PhD is strongly wished.

Possibility to follow with a PhD YES