16 

Jasper Wesseling:
Provides an insight into Dutch research and development from the Netherlands' Ministry of Economic Affairs

152 

Willem Jonker:
CEO Willem Jonker explains how EIT Digital is taking on an increasingly data-intensive healthcare sector

165 

Philippe Amouyel:
The JPND chair outlines the future of neurodegenerative research

Pan European Networks

Science & Technology

IN THE MIX

Innovation and diversity in science are key to providing the energy sources of tomorrow

Front cover inspired by:

INSTITUTE OF SOLID STATE PHYSICS
UNIVERSITY OF LATVIA

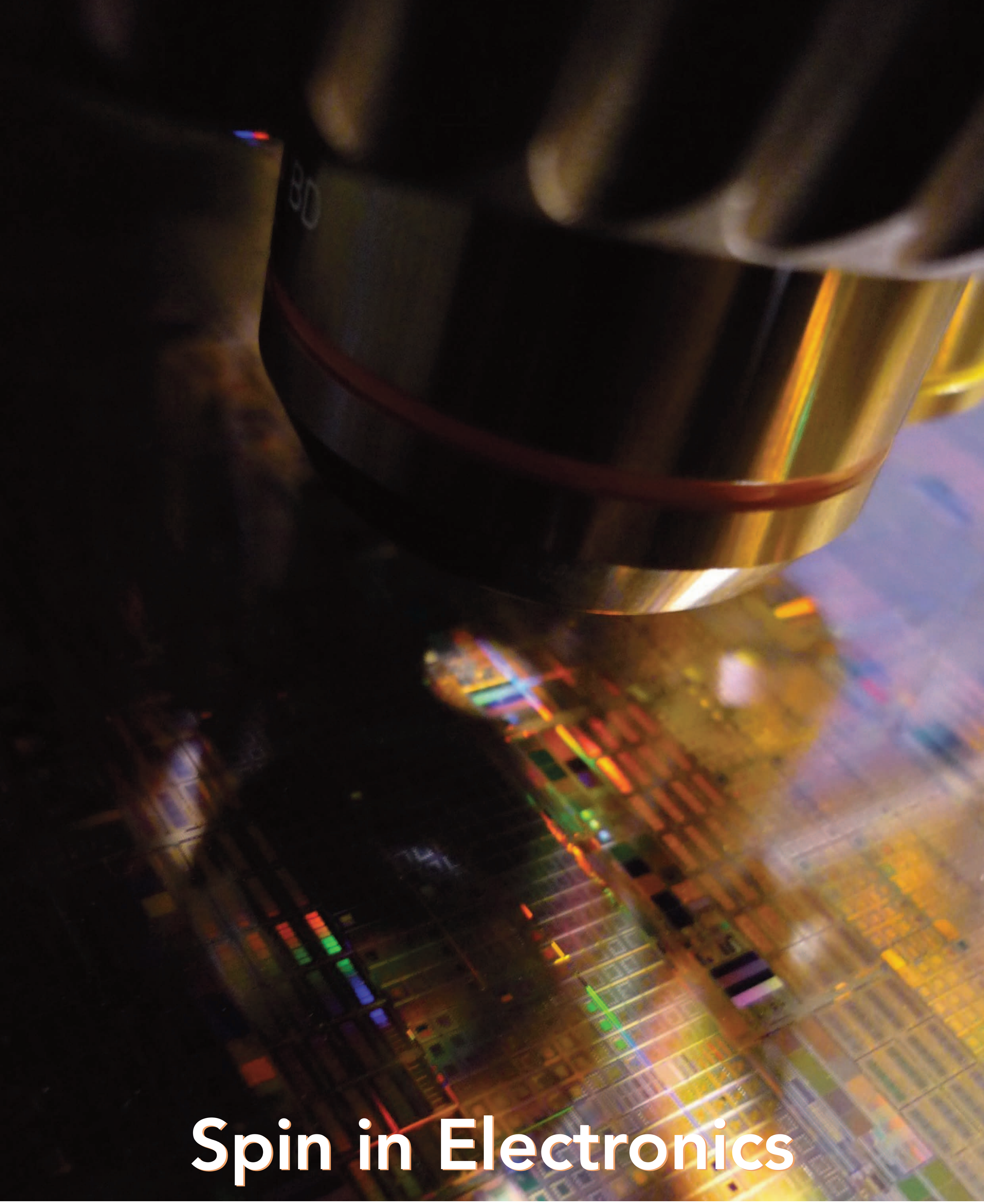
In association with:

spintec

ecohydrology research group

3U PARTNERSHIP
GREATER DUBLIN UNIVERSITIES
DCU·MAYNOOTH·RCSI

July 2017 • issue 23



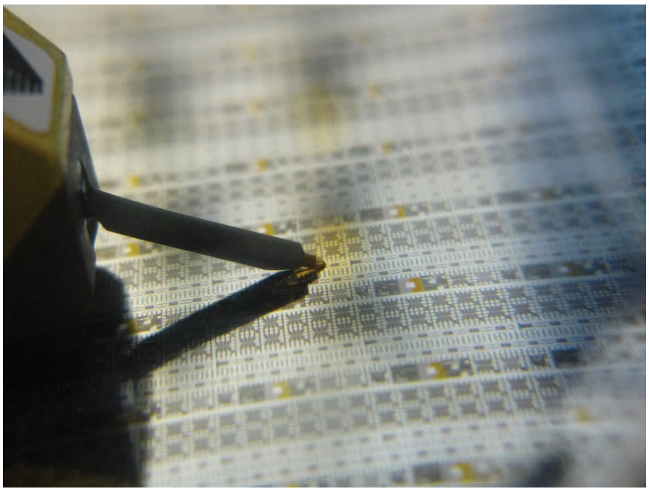
Spin in Electronics

spintec
SPIN IN ELECTRONICS

SPINTRONICS: ULTRA-LOW POWER ELECTRONICS

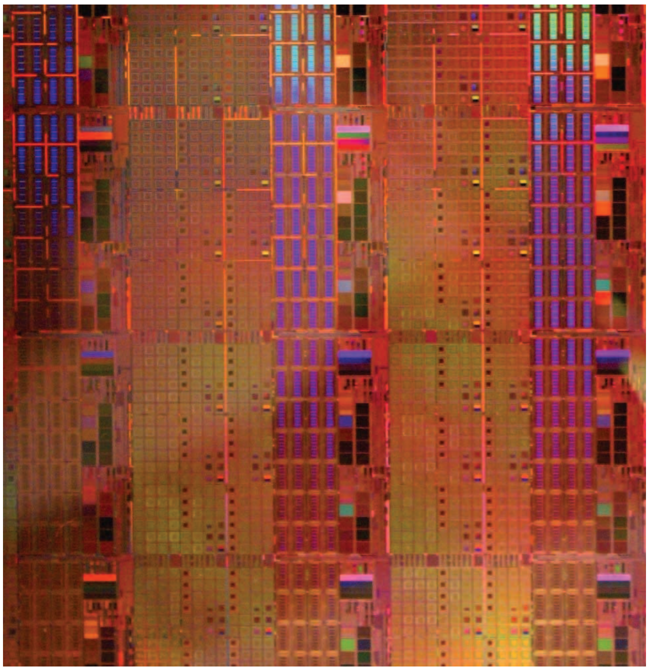
SPINTEC chief scientist Bernard Dieny introduces the primary achievements on the road to ultra-low power electronics

Power consumption in microelectronics becomes an increasingly serious problem as the critical size of microelectronic components (transistors) keeps on shrinking along Moore's law. This is due to both increasing current leakage in these components contributing to a static power consumption, and the large energy required to continuously transfer data from the memory where they are stored to the logic blocks where they are processed (dynamic power consumption). This power consumption seriously limits the battery lifetime of wearable applications (mobile phones, tablets, interconnected objects of the internet of things) and causes severe problems of heat management in server farms, high-performance computing (HPC) and even smartphones.



Breakthroughs in spintronics

Spintronics is a merging of semiconductor-based microelectronics and magnetism. This field emerged in 1988 with the discovery of giant magnetoresistance (GMR) in magnetic multilayers by Professors Albert Fert and Peter Grünberg, who in 2007 were awarded the Nobel Prize in Physics for this major breakthrough. Spintronics aims at using the spin of the electrons in addition to their charge to reveal new phenomena, and uses them to improve the performances or create new functionalities in microelectronic systems. The spin is a quantum characteristic of electrons which yields to each electron a small magnetic moment. Magnetic materials can be used to polarise and analyse the spin of the electrons as polarisers and analysers do in optics with photons.



The first major application of spintronics was in hard disk drives wherein very sensitive spintronic magnetic field sensors were developed to read out the information stored on magnetic hard disks (HDD). Over the past 20 years this has allowed an increase in the areal density of information in HDD by three orders of magnitude (from 150Mbit/cm² to 150Gbit/cm²). In the meantime, several other breakthrough discoveries have been made in the field, each opening new perspectives and applications.

A first major breakthrough has been the giant tunnel magnetoresistance of MgO-based magnetic tunnel junctions. These junctions consist of two magnetic layers separated by a very thin oxide barrier, typically 1nm thick. When a current flows through the junction, electrons 'jump' by quantum mechanical tunnelling through the oxide barrier. Their ability to pass through the barrier depends on the relative orientation of the magnetisation in the two electrodes, which translates into a resistance change of the device between the parallel magnetic configuration and the antiparallel one (for instance 4kΩ in parallel configuration and 20kΩ in the antiparallel one). This can be used to store information in new types of solid-state memories called magnetic random access memories (MRAM).

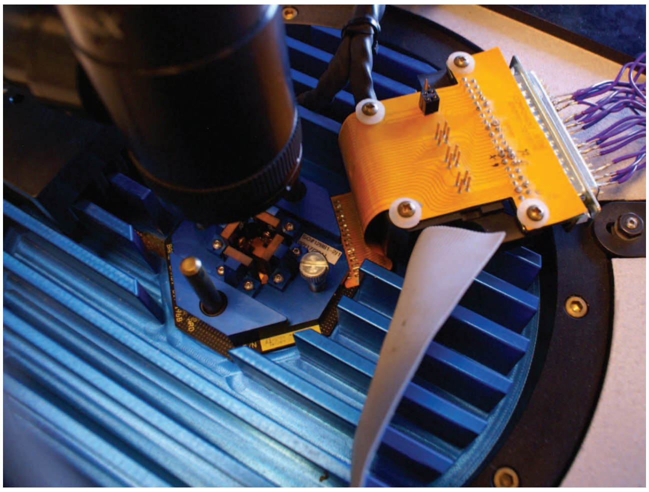
A second breakthrough discovery, called spin transfer torque (STT), consisted of the observation that above a certain current density threshold, a spin-polarised electrical current can be used to directly switch the magnetisation of a nanomagnet. Prior to this discovery, the only way to manipulate the magnetisation of nanostructures was with a magnetic field that consumes quite a lot of energy and does not allow a very local magnetisation manipulation.

The advent of 'spin transfer torque memory'

STT provides a very convenient way to switch the magnetic configuration in MRAM with much less energy and much reduced write error rate than per magnetic field. Following this discovery, a new class of MRAM emerged called spin transfer torque MRAM (STT-MRAM). These are currently receiving considerable interest within the microelectronics industry. Indeed, they combine a unique set of assets: they are non-volatile, meaning that once written they can keep the information without being electrically powered; they can be made quite dense (almost as DRAM (dynamic random access memory)); they switch fast (a few nanoseconds); and, importantly, they have an almost infinite write endurance, meaning that they can be written an unlimited number of times. This contrasts with the semiconductor-based non-volatile FLASH memories used in USB keys or solid-state drives, which can only be written 100,000 times. As a result, STT-MRAM can be used as a working memory in microcontrollers or microprocessors. Their non-volatility then constitutes a key asset. By regularly saving the processed data in this non-volatile memory, all parts of an electronic circuit that are temporarily unused can be automatically powered off and instantaneously restarted on demand, thus saving most of the leakage energy. In addition, magnetic tunnel junctions can be grown above silicium-based logic circuits, allowing vertical integration of logic and memory functions. This contrasts with conventional microelectronics where logic and memory have to lie side-to-side on the silicon wafer, since both types of components use the properties of the silicon substrate. This vertical integration in hybrid semiconductor/magnetic technology allows for a much more efficient communication between memory and logic, thereby reducing the dynamic power consumption as well as the circuit footprint on the wafer, which immediately translates into a reduced cost.

Commercial STT-MRAM products were released in 2013 by the US company EVERSPIN, and numerous announcements were made in the microelectronics press in 2016 about the forthcoming volume production of STT-MRAM-based chips. The first envisioned market is the replacement of embedded FLASH memories which are quite costly to fabricate. At a second stage, SRAM (static random access memory) replacement is considered, which would save lot of space on the wafers since SRAM have a large footprint. For high-density memory application such as DRAM replacement, progress still has to be made concerning the patterning of these magnetic materials at a very small feature size (sub-14nm) and a very narrow pitch.

In the longer term, further reduction in power consumption can be envisioned by using even more recently discovered spintronics phenomena. One is the possibility to act on the magnetisation of magnetic nanostructures by pulses of voltage without any current flow, which may yield a decrease by two orders of magnitude of the energy required by write event in magnetic memory or magnetic logic gate. Another is the ability to convert charge current into spin current and *vice versa* by using a quantum phenomenon called spin orbit coupling. A whole new paradigm of ultra-low power non-volatile logic circuits results from these recent discoveries. This is particularly important for wearable applications, the internet of things, server farms, and HPC, for which power consumption is a key issue.



SPINTEC

In Europe, SPINTEC, which is based in Grenoble, France, is a leading laboratory in the field. Launched in 2002, this government laboratory is affiliated to CEA, CNRS and Grenoble Alpes University, covering the chain from basic research in spintronics to the development of functional spintronic demonstrators.

Its scientific director, Dr Bernard Dieny, received two advanced research grants in the field from the European Research Council (ERC). The first was granted in 2009 to explore all the potentiality offered by this hybrid semiconductor/magnetic technology for low-power electronics, resulting in the creation of a fabless start-up company to design such hybrid circuits (EVADERIS). The second, granted in 2014, aims at developing multifunctional chips combining magnetic field sensing, memory, logic and wireless communication functions all based on this hybrid technology. This kind of chip is particularly suited to realise interconnected objects for the internet of things. The laboratory is open to collaboration with all industrial partners interested in spintronics technology.

spintec
SPIN IN ELECTRONICS

Bernard Dieny
Devices Group
SPINTEC

+33 4 3878 3870

bernard.dieny@cea.fr
http://www.spintec.fr/

Reproduced by kind permission of Pan European Networks Ltd, www.paneuropeannetworks.com
© Pan European Networks 2017

SPINTEC, a lab at the forefront of spintronics in Europe

Positioned at the crossroads of science and technology, SPINTEC (SPINtronics and TEChnology of Components) is one of the leading spintronics research laboratories worldwide, see www.spintec.fr. Ideally located on the MINATEC campus in Grenoble, France, SPINTEC gathers, in a flexible and project-oriented organisation, physicists and engineers from the academic and industrial worlds. The laboratory was created in 2002 and rapidly expanded to reach 100 persons, of which 38 are permanent staff and around 40 are PhD students, post-docs and international visitors. The scientific institutions taking part in the lab are: CEA, CNRS and the University of Grenoble Alpes.

Spintec's objective is to bridge fundamental research and innovative devices technology in the emerging field of spin electronics (spintronics). The international technology roadmap for semiconductors (ITRS) now reckons that spintronics devices will play a major role in tomorrow's semiconductor chips, with the potential to totally displace the standalone (e.g. DRAM) and embedded memory market. Other fast-developing fields include magnetic field sensors and bio-applications. As such, it is critical to be at the forefront of research, to generate a strong IP position, and to establish the proper partnerships for technology transfer.

Spintec's unique positioning brings together top-level scientists and applicative engineers that work in close collaboration in order to ensure that new paradigms can be swiftly translated into technology proof of concepts and functional devices. As such, the outcome of the laboratory is not only scientific publications and communications in international conferences, but also a coherent patents portfolio and implementation of relevant functional demonstrators.

Whereas the fundamental research is mostly operated through collaborative (financed) projects with other research laboratories, the applied research is very often carried out in partnership with private actors. These can be large corporations (Applied Materials, ST Microelectronics, Thales, Samsung, Seagate, etc.), SME's (SNR, Singulus) or start-ups (Crocus, Menta, Spin Transfer Technologies, Evaderis,). Spintec has already spun-off four start-up companies, Crocus Technology in 2006, eVaderis in 2014, and HProbe and Antaïos in 2017.

Crocus Technology is developing magnetic random access memories and magnetic field sensors based on a proprietary technology called Magnetic Logic Unit (MLU) (https://crocus-technology.com/).

eVaderis is a fabless company of design of microelectronics circuits based on hybrid CMOS/magnetic technology (http://www.evaderis.com/). These circuits benefit from the remarkable combination of assets of spin transfer torque magnetic random access memory for low power. They are particularly suited for the rapidly expanding field of the internet of things (IoT).

HProbe builds automated wafer electrical probers for MRAM with the unique capability of applying magnetic field in any direction in space (https://www.hprobe.com/). These probers are very useful for the characterisation and optimisation of the magnetic and electrical properties of tunnel junctions for all types of magnetic memories as well as magnetoresistive or MEMS sensors.

Antaïos is focused on the development of spin orbit torque magnetic random access memory (SOT-MRAM) (www.antaios.fr). Spintec holds several key patents on this technology based on a discovery made in 2011: the possibility to switch the magnetisation of magnetic nanostructures thanks to an interaction between the spin of the conduction electrons and their orbital motion in the material, yielding a so-called 'spin orbit torque'. These types of memories are particularly interesting for fast memory applications such as non-volatile SRAM.

All these start-ups are currently expanding and illustrate the vitality of the field and its economic potentiality. More will likely emerge in the coming years. Besides, larger European microelectronics players will hopefully join the spintronics arena.

eVaderis antaios CROCUS TECHNOLOGY Hprobe spintec SPIN IN ELECTRONICS

Spintronics worldwide development and European position

Since its birth in the late 1980s, spintronics has been an extremely vivid area of research and development. Breakthrough discoveries have been made almost every two years, each of them opening new perspectives for applications. This is illustrated by the two 'sunny diagrams' respectively showing the various phenomena discovered in the field in the past 25 years, and the variety of applications which already result or may emerge from them.

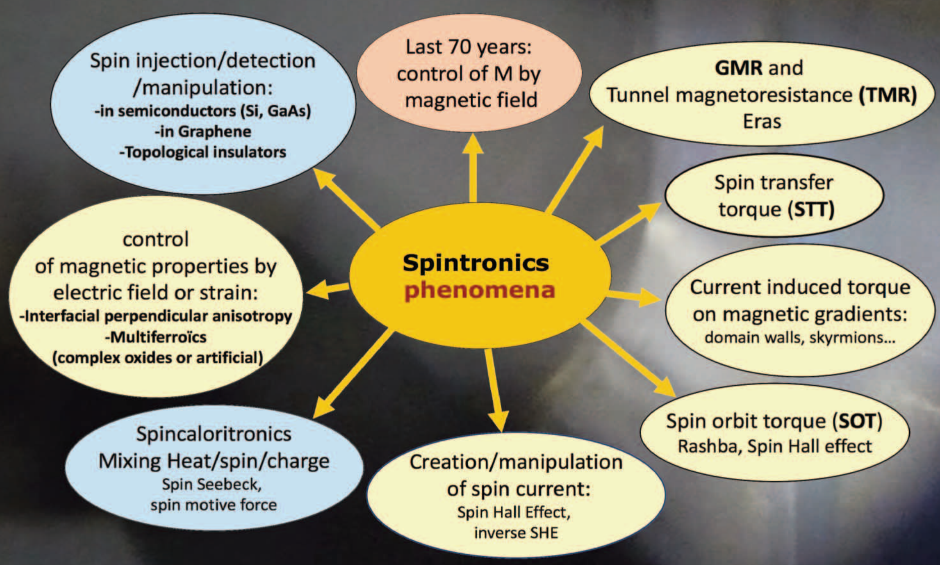
From the point of view of fundamental research, Europe is very well positioned in the field, particularly in France and Germany. GMR was discovered in Europe by Professor Albert Fert (France) and Professor Peter Grünberg (Germany), who were awarded the Nobel Prize for this discovery in 2007. The possibility to switch the magnetisation of magnetic nanostructures by spin orbit torque switching was first demonstrated in France, as well as the possibility to vary the magnetic properties of metallic magnetic thin films by electrical field.

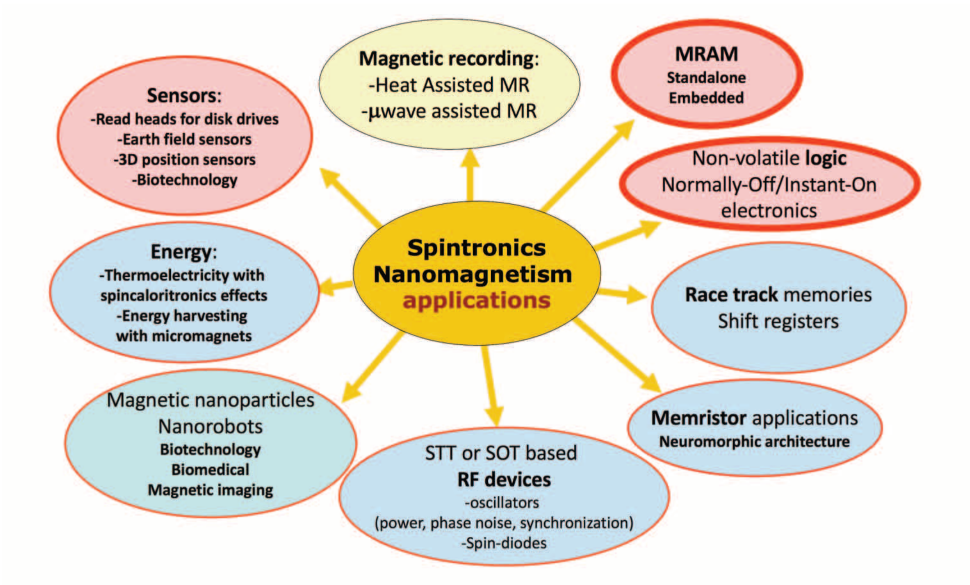
Concerning the applications, magnetic recording technology highly benefitted from the progress in spintronics by allowing to develop extremely sensitive nanoscale magnetic field sensors based on giant magnetoresistance (GMR spin-valves, used between 1998 and 2004) and later on tunnel magnetoresistance (since 2004). Unfortunately, despite GMR being discovered in Europe, and Grünberg from Jülich University being the inventor of the basic patent on GMR sensors, all subsequent industrial developments in magnetic recording technology took place in Asia and the US.

In Europe, however, a strong economic activity related to spintronics magnetic field sensors has arisen in the past 20 years. Indeed, several companies such as SENSITEC, INFINEON and NXP, play an important worldwide role in this field. Besides, the European IP portfolio in spin-electronics is quite strong with several key patents due to the European excellence at low technology readiness levels (TRL). This allowed the launching of several European spin-off or start-up companies related to memories (Crocus Technology), innovative architectures benefitting from MRAM unique assets (EVADERIS), RF components (Nanosc), biosensors (Magnomics), deposition tools (Singulus) and characterisation tools (HProbe), etc. SPINTEC, based in Grenoble, France, has been particularly active in this effort with four start-ups launched in the past ten years.

As explained in the article entitled 'Spintronics: towards ultra-low power electronics', spintronics memory (called STT-MRAM) is about to enter in volume production at major integrated circuits manufacturers. Samsung Electronics, world-first global producers of memories, and TSMC, the first microelectronics foundry, both announced volume production of embedded STT-MRAM by 2018. This will mark the entry of the hybrid silicium (CMOS)/magnetic technology in microelectronics and will greatly help this technology to mature. But this is only the beginning. As explained above, numerous other phenomena were discovered, opening new perspectives of development towards less power hungry and more efficient electronic circuits.

Considering these perspectives of development, huge public investments in spintronics were made in Asia and the US in recent years. As an example, at Tohoku University in Sendai, Japan, almost $1bn (~€0.9bn) has been invested and a complete 300mm back-end magnetic line has been built to enable the fabrication of hybrid CMOS/magnetic circuits.





In Europe, the effort at intermediate and high TRL levels is comparatively very weak and should be reinforced. STT-MRAM are almost ready to be launched in production for e-FLASH replacement, but a lot of further developments can be envisioned. STT-MRAM should be considered as the entry point of spin-electronics in the microelectronics industry, and again, a lot of subsequent developments will follow.

To ease the progression of spintronics towards higher TRL levels in Europe, the spintronics community recently decided to create a co-ordination structure called SpinFactory (STF) (http://magnetism.eu/90-stf-structure.htm), which already gathers more than 70 European groups active in spin-electronics. The aims of this structure are:

1. To promote synergies and collaborations across Europe between universities, research facilities and industries, eventually leading to collaborative proposals where some of the most promising spintronic concepts developed in academic laboratories will be promoted towards proofs-of-concept, functional demonstrators and chips prototypes;
2. To construct a business-oriented roadmap for Spintronics with related SWOT analysis for each application segment;
3. To work towards the potential launching of a Spintronics Flagship gathering academic and industrial partners;
4. To federate activities and co-ordinate actions in Brussels: a common voice representing the spintronics community; and
5. To mutualise resources and facilities across Europe with nodes of excellence becoming innovation hubs.

SpinFactory is itself under the umbrella of a wider European organisation called the European Magnetism Association (EMA), which aims at structuring the whole magnetics community (http://magnetism.eu).

Educational activities have also been launched to promote spintronics. An example is the Introductory Course on Magnetic Random Access Memories (InMRAM), organised annually in Grenoble. This course aims at narrowing the cultural gap that exists between magnetics and microelectronics communities. It is intended to help students, researchers and engineers having little or no background in magnetism to better understand the physics and working principles of MRAM. Various aspects of MRAM technology are covered: the basic spintronics phenomena involved in MRAM, the materials, the various categories of MRAM (pros/cons, performances, degree of maturity), comparison with other technologies of non-volatile memories in terms of working principle, performances, foreseen applications (Phase Change RAM and Resistive RAM), the fabrication process, and the perspectives of low-power electronic circuits based on this hybrid CMOS/magnetic technology. The fourth edition took place in July 2017 gathering more than 80 attendees, among which a third came from microelectronics companies, see www.inmram.com

Let us take the right decisions and work so that the European excellence in spintronics at fundamental research level benefits our microelectronics industry. Spintronics is about to become a mainstream technology in microelectronics. Europe should not miss this train.

Spintronics and nanomagnetism for biotechnology and biomedical applications

Spintronics' magnetic field sensors and magnetic micro or nanoparticles can have many applications for both diagnosis and therapeutics. Various techniques of magnetic imaging are already widely used, including magnetic resonance imaging (MRI) or magnetoencephalography (MEG). Others, such as magnetic nanoparticles imaging, are still under development. These techniques use ultrasensitive magnetic field sensors, but magnetic nanoparticles have been used as contrast agents in MRI since the late 1980s. Since then, numerous studies have addressed the wide potentiality of the use of magnetic nanoparticles in diagnosis (e.g. contrast agents, sorting and detection of targeted biological species) and therapeutics (e.g. regenerative medicine, cancer treatments, etc.).

The interest in magnetic micro/nanoparticles is in the diversity of their size, which ranges from nanometres to tens of microns; their shape (spheres, cubes, nanowires, disks, donuts, etc.); their magnetic properties (superparamagnetic, vortex, synthetic antiferromagnetic); and their surface functionalisation, which allows targeting of specific species. The interest is also in their ability to create local magnetic fields or be remotely actuated by the application of external magnetic field. When they are attached to a targeted biological species by a specific functionalisation, magnetic particles can be used to exert forces or torques on biological species. This is used in cells sorting and is useful in orienting the growth of cells in specific directions. It also yielded a new approach towards cancer treatment which is investigated in just a few laboratories worldwide, in particular at SPINTEC in Grenoble in collaboration with SYMMES, and an INSERM team at CLINATEC.

This new approach towards a cancer treatment is based on the use of magnetic microdisks that are fabricated at SPINTEC by a top-down approach (see Fig.1). These microdisks are then functionalised to target cancer cells. When the particles encounter the cancer cells, they bind to the membranes where, typically after 24 hours, they can become internalised. By applying a low frequency magnetic field of moderate amplitude (typically tens of mT at about 20Hz), the particles are mechanically shacked, creating a stress on the cells which triggers their death. This is illustrated, for instance, by the in vitro assays results shown Fig.2, which compares the evolution over 42 hours of an assembly of glioblastoma cancer cells (brain cancer) not submitted to this treatment (control sample) and submitted to the magnetic particles vibrations.

Fig. 2 shows that the cells have proliferated in the control samples, whereas in the treated sample the cells were destroyed and did not grow again. The efficiency of this approach has already been successfully demonstrated in vitro on human renal carcinoma cells, glioblastoma cells and murine melanoma cells. In vivo tests are in progress in collaboration between SPINTEC and the INSERM/Brain Tec Lab in Grenoble.

This study exemplifies how the possibility to exert forces and torques on biological species via magnetic nano- or microparticles can be used for innovative therapeutics treatments.

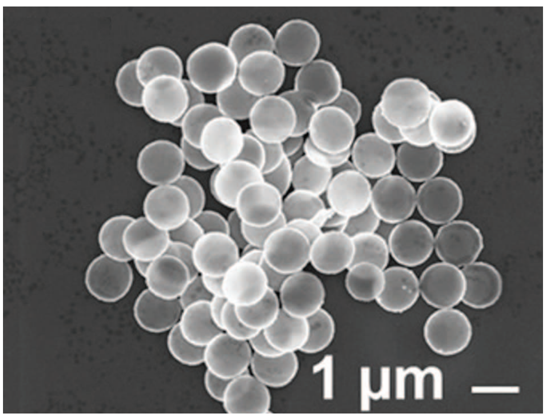


Fig.1

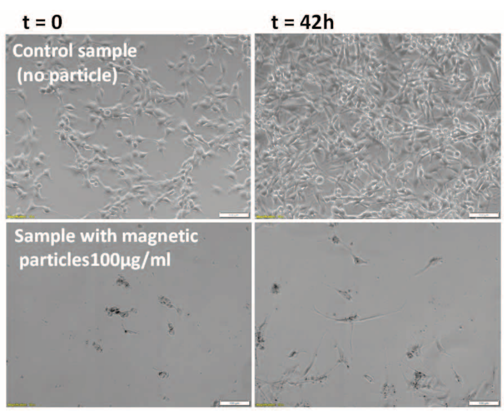
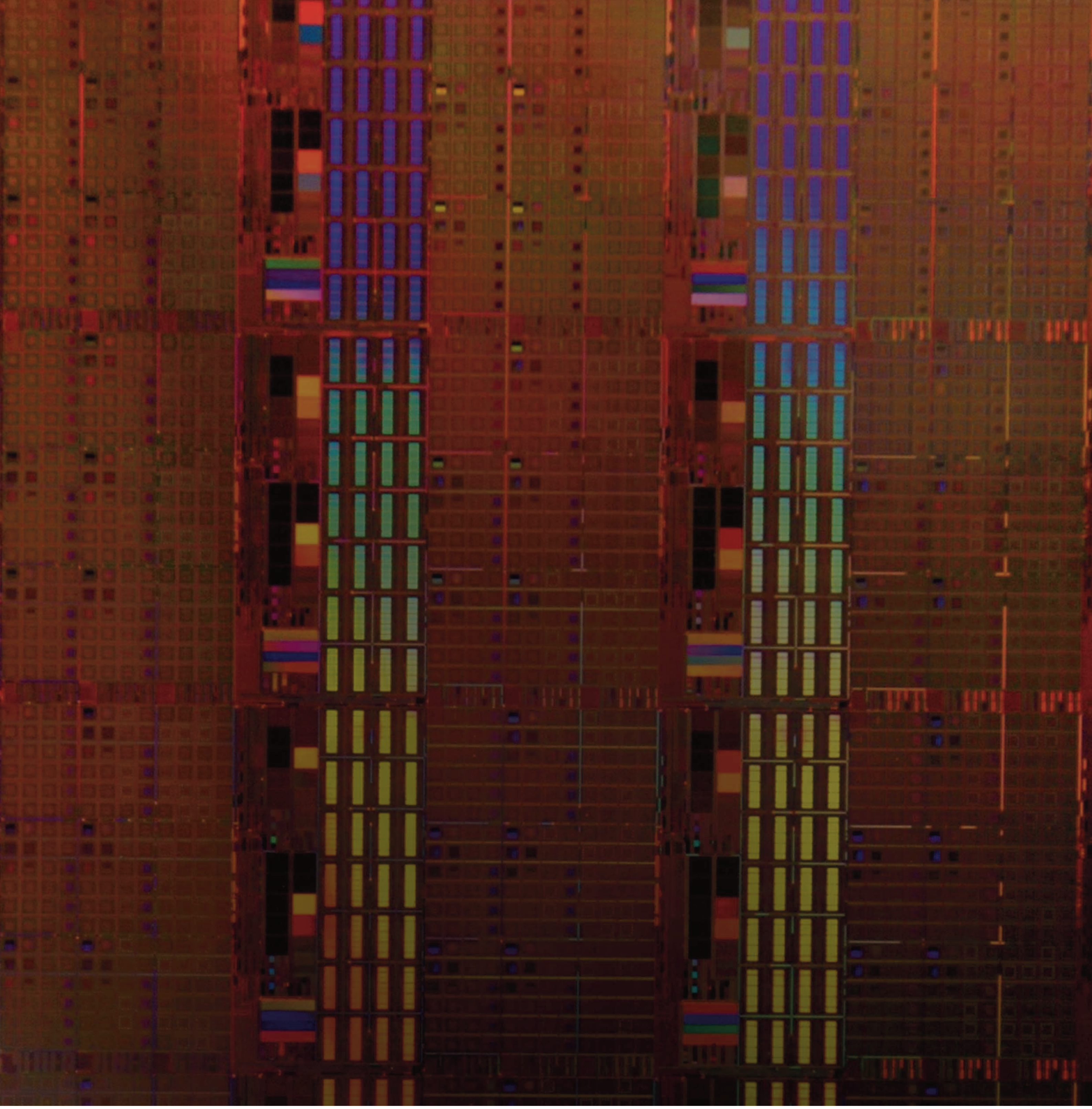


Fig.2



Bernard Dieny
SPINTEC

+33 4 3878 3870
bernard.dieny@cea.fr
http://www.spintec.fr