SISPAD 2016

Workshop WS2: Spin-Dependent Phenomena for New Device Applications

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Abstracts of Workshop Presentations

Ultrafast and Gigantic Spin Injection in Semiconductor

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The injection of spin currents in semiconductors is one of the big challenges of spintronics. Motivated by the ultrafast demagnetisation and spin injection into metals, we propose an alternative femtosecond route based on the laser excitation of superdiffusive spin currents in a ferromagnet such as Ni. Our calculations show that even though only a fraction of the current crosses the Ni-Si interface, the spin current is still gigantic compared to typical semiconductor currents and other means of spin injection. It corresponds to a record spin polarisation of about 80%. Beyond that it is pulsed on the time scale of 100 femtoseconds which opens the door for new experiments and ultrafast spintronics.

Theoretical Insights into Spintronic and Spin-Orbitronic Phenomena in Magnetic Tunnel Junctions and Interfaces

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This talk will be devoted to an overview of spintronic phenomena in layered structures based on interfaces between ferromagnetic (FM) and nonmagnetic (NM) materials with attention paid to demonstrating how theory helps advancing device applications.
The first part of the talk is devoted to theory of spin transfer torques (STT) in magnetic tunnel junctions (MTJ) which in particular allowed prediction of STT voltage dependences and provided solutions for magnetic random access memory (STT-MRAM) applications [1,2]. STT properties in case of various cases of asymmetric MTJs will be discussed [2,3,4,5]. Also the properties of interlayer exchange coupling (IEC) in MTJs under different growth and interfacial oxidation conditions [6] as well as IEC oscillations as a function of ferromagnetic electrode thickness [7] are discussed.
The second part of the presentation addresses spin-orbit coupling based phenomena such as perpendicular magnetic anisotropy (PMA) and Dzyaloshinskii-Moriya interaction (DMI) at interfaces between FM metal and NM insulator or metal. First, the nature of PMA control at Fe|MgO interfaces is unveiled by evaluating the orbital and layer resolved contributions to magnetic anisotropy in Fe/MgO interfaces and MTJs with different interfacial conditions [8,9]. Mechanisms of the optimisation of the effective anisotropy as well as of its electric field control are discussed [10,11,12]. Next, the main features and microscopic mechanisms of DMI behavior are elucidated in Co/Pt and other Co/NM bilayers [13]. Furthermore, several approaches for DMI enhancement and manipulation will be presented including, in particular, physical mechanisms of DMI behavior in Pt/Co/MgO structures [14,15] allowing observation of room temperature skyrmions [15]. Finally, a possibility of electric field control of DMI in such structures is also discussed [14].
These results clarifying underlying mechanisms of STT, PMA and DMI at FM/NM based structures should help optimizing material combinations for spintronic memory and storage devices based on STT, skyrmions and domain walls.

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Logic-In-Memory: A Non-Volatile Processing Environment for the Post CMOS Age

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Since the advent of the first barely working transistors their development went through a breathtaking race for ever smaller, more frugal, and faster devices. This competition had and still has an enormous impact on our economy and society down to everyone's daily life. However, the miniaturization reached a level where every new technology generation not only brings new and perpetual harder obstacles but also becomes significantly more expensive. Two of these obstacles are of major concern right now - the power dissipated by leakage and the energy needed for the information transport. A simple and efficient way to reduce the leakage is to shutdown unused circuit parts. But this comes at the price of loosing the information stored in the circuits. Therefore, the lost information must be copied back, when they are powered up again, which adds additional strain on the already limited available energy budget for the information transport. In order to avoid the information loss while keeping at the same time the information transport costs manageable, one has to introduce non-volatile elements into the circuits.
Here spintronics (spin electronics) comes into play. It is perfect for such applications, since it exhibits advantageous features like non-volatility, high endurance, fast operation, and radiation hardness. First commercial off-the-shelf spintronic products, i.e. magnetic RAM, are already available and further applications will surely follow soon.
Even better, spintronic devices give us the unique opportunity to merge logic and memory on many different levels and thus holds the possibility to shift away from the nowadays performance limiting Von Neumann architecture. In order to harvest the full potential of this feature, one has to rethink how the information in the circuits is processed and moved as well as a reconsideration and redesign of all basic logic CMOS building blocks is necessary. Currently, there is a plethora of ideas about how to realize such spintronic non-volatile computing systems. The first part of the talk will give a short overview of -in our opinion- more realistic spintronic ideas and solutions, while the second part will concentrate on our work related to logic-in-memory applications and their (very) large scale integration**.**

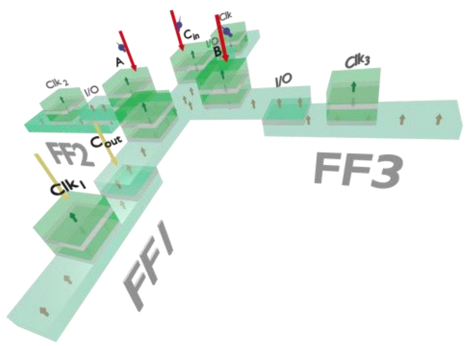

Fig.1 Non-volatile environment consisting of spin-torque majority gates and magnetic flip-flops (FF).

Nanomagnetic Logic --- from Micromagnetics to Circuit-level Simulations

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Boolean logic with ferromagnetic islands is one promising technology in beyond CMOS device research. In the form of perpendicular Nanomagnetic Logic (pNML), it provides intrinsically non-volatile computational states, atto-joule dissipation per bit operation and estimated data throughputs competitive with state-of-the-art high performance CMOS CPUs.
In this work, both a 2D planar implementation of pNML and the path to monolithically 3D integrated systems is discussed. Rather than CMOS substitution, additional functionality is added by a co-processor architecture as a prospective back-end-of-line (BEOL) process.
For modelling of Boolean gates and circuits, a three step approach is found to be well suited. First, micro-magnetic finite element simulations provide insight in the physics of magnetization reversal dynamics and domain-wall propagation of single pNML islands and devices. Second, together with magneto-optically characterized test-structures, switching distributions of magnets are extracted and simplified behavioural models are formulated. Third, the parameterized compact models form the basis of Verilog-A simulations, utilizing the well-known strength of abstraction in system level simulation.

Electrical Switching of an Antiferromagnet

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Louis Néel pointed out in his Nobel lecture that while abundant and interesting from theoretical viewpoint, antiferromagnets did not seem to have any applications. Indeed, the alternating directions of magnetic moments on individual atoms and the resulting zero net magnetization make antiferromagnets hard to control by tools common in ferromagnets. Strong coupling would be achieved if the externally generated field had a sign alternating on the scale of a lattice constant at which moments alternate in antiferromagnets. However, generating such a field has been regarded unfeasible, hindering the research and applications of these abundant magnetic materials. We have recently predicted that relativistic quantum mechanics may offer staggered current induced fields with the sign alternating within the magnetic unit cell which can facilitate a reversible switching of an antiferromagnet by applying electrical currents with comparable efficiency to ferromagnets. Among suitable materials is a high Néel temperature antiferromagnet, tetragonal-phase CuMnAs, which we have recently synthesized in the form of single-crystal epilayers structurally compatible with common semiconductors. We demonstrate electrical writing and read-out, combined with the insensitivity to magnetic field perturbations, in a proof-of-concept antiferromagnetic memory device.

References:

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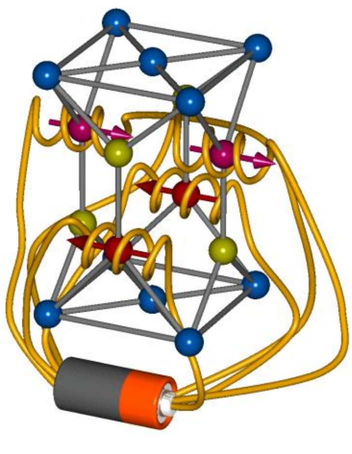

Fig.1 Relativistic quantum mechanics offers a possibility of purely electrical reversible switching of an antiferromagnet by means of the staggered magnetic fields delivered individually to each magnetic sublattice.

Silicon Quantum Spintronics: Progress and Prospects

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After serving as the workhorse of the transistor technology for decades, silicon is also emerging as an ideal platform for a technology that utilizes quantum confined spins to process information. In this talk, I will survey the recent progress in silicon quantum spintronics in the context of quantum computation, and show how atomistic modeling has helped to understand and guide cutting-edge experiments. I will discuss how spins bound to donors and quantum dots can be manipulated and utilized to design quantum logic gates. I will describe recently observed spin-dependent phenomena in silicon such as spin blockade, Stark shift of hyperfine coupling, valley-dependent g-factors, exchange coupling in two-qubit gates, and spin relaxation in donors and quantum dots. A large-scale atomistic tight-binding method is employed in conjunction with electrostatic simulations and many-particle configuration interaction technique to understand spin properties in the complex solid-state environment of silicon. The atomic level understanding of quantum spins in silicon may help achieve the ultimate goal of a scalable quantum computer and may lead to various spintronic applications along the way.