Stage N° : 9

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Title

TUNING SPIN-ORBIT COUPLING IN SILICON AND GERMANIUM FOR SPIN GENERATION, DETECTION AND MANIPULATION

Keywords

Spintronics, semiconductors, silicon, germanium, spin-orbit coupling

Summary

The aim of semiconductor spintronics is to use the electron spin in addition to its charge in microelectronics devices. The spin degree of freedom adds new functionalities to existing devices and will allow to reduce power consumption. The three requirements for the development of such technology are the generation, detection and manipulation of spin polarized electrons in Si or Ge (the materials of today's microelectronics). A new paradigm has recently raised in the spintronics community which consists in using the spin-orbit coupling to complete those three operations. The spin-orbit coupling couples the electron momentum and spin. Hence, it makes possible the spin manipulation by electric fields but also the inter-conversion between charge currents and spin currents by the spin Hall effect in bulk materials or the Rashba effect at interfaces. Unfortunately, in bulk Si and Ge, the spin-orbit coupling is too weak and this is the objective of this internship and following thesis work to study ways to enhance it. First, we will focus on metal/Si(111) and Ge(111) interfaces where the Rashba spin-orbit coupling is predicted very strong. Then, two more promising systems will be investigated: topological insulator/Si(111) and Ge(111) interfaces as well as Si and Ge thin films doped with heavy atoms. The candidate will benefit from the long standing experience of our group in semiconductor spintronics and from the close collaboration with the CEA LETI.

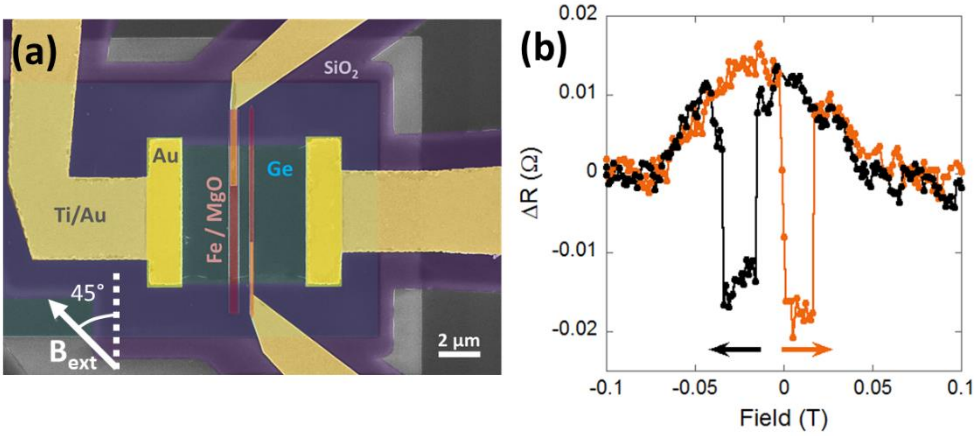
Details of subject

The aim of semiconductor spintronics is to use the electron spin in addition to its charge in microelectronics devices. The spin degree of freedom adds new functionalities to existing devices and will allow to reduce power consumption. The first requirement for the development of semiconductor spintronics is to generate a population of spin polarized electrons in silicon or germanium, the materials of today's microelectronics. This out-of-equilibrium spin population will diffuse into the semiconductor creating a spin current. In our laboratory, we managed to generate and detect electrically, from a ferromagnetic electrode, a spin accumulation and current in Si and Ge at room temperature. The next step for the development of semiconductor spintronics is the spin manipulation. Magnetic fields can be used to manipulate the spin state but they cannot be easily implemented in microelectronics. Instead, the spin can be manipulated by electric fields in combination with the spin-orbit coupling. However, Si and Ge are rather light atoms with weak spin-orbit coupling preventing any efficient spin manipulation by electric fields. During this internship and the following thesis work, we will propose new strategies to enhance the spin-orbit coupling in Si and Ge to manipulate the spin but also to generate and detect spin currents. First, we will study the two-dimensional spin transport into the Rashba states at metal/Si(111) and metal/Ge(111) interfaces where the Rashba spin-orbit coupling is predicted to be very strong. In this case, the electric field originates from the crystal symmetry breaking at the interface. Moreover, the Rashba spin-orbit coupling is so strong that it becomes possible to generate a spin current from a charge current and vice-versa into the interface states at room temperature. Hence, we will explore a new paradigm in semiconductor spintronics: the use of spin-orbit coupling instead of ferromagnetic electrodes to generate and detect spin currents in Si and Ge. During the PhD thesis, other systems will also be investigated like Si and Ge doped with heavy atoms to induce large bulk spin-orbit coupling and topological insulators grown on Ge(111) or Si(111) in which surface states allow for efficient spin-to-charge inter-conversion.

To do this, the student will benefit from the experience of our team in semiconductor spintronics and in the fabrication of nanodevices made of Si and Ge as shown in the figure. A cryostat (2K-300K, 0-7 Tesla) will also be available specifically for these experiments. An electron paramagnetic resonance spectrometer will be used to perform dynamical spin injection into silicon and germanium from a ferromagnetic electrode at resonance. The candidate will also benefit from all the equipments available at Spintec and from the close collaboration with the CEA LETI in Grenoble and Unité Mixte CNRS THALES in Palaiseau. This work will be financially supported by the French Research Agency project TOP-RISE.

Requested skills
Solid state physics, spintronics and nanomagnetism
Material growth by molecular beam epitaxy, semiconductor physics, surface and interface science

Possibility to follow with a PhD Yes



<u>Figure:</u> (a) Nanodevice used for electrical spin injection and detection in germanium at room temperature. (b) Corresponding non-local spin signal.