SORBONNE UNIVERSITÉ

CHINA SCHOLARSHIP COUNCIL

Appel à projets
Campagne 2022
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Title of the research project :

Novel two dimensional Rashba materials for spintronics.

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Research Unit

Name : Laboratoire de Physique et d’Etude des matériaux (LPEM)

Code *(ex. UMR xxxx)* :

UMR 8213

Doctorate School

Thesis supervisor’s doctorate school (candidate’s futur doctoral school) : EDPIF

PhD student currently supervised by the thesis supervisor (number, year of the first inscription) :

2, 2018 and 2019

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Code *(ex. UMR xxxx)* :

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École doctorale

Joint supervisor's doctorate school : Or, if non SU :

EDPIF

PhD student currently supervised by the joint supervisor (number, year of the first inscription) :

0

Joint supervisor :

Name : Surname :

Title :

email :

Professional adress :
(site, dresse, bulding, office…)

Research Unit

Name :

Code *(ex. UMR xxxx)* :

École doctorale

Joint supervisor's doctorate school : Or, if non SU :

PhD student currently supervised by the joint supervisor (number, year of the first inscription) :

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Description of the research project (*ENGLISH*):

Introduction:

Spintronics, which aims to exploit the electrons spin for the development of novel information storage or logic devices [1], is nowadays a major and competitive research field in physics. Exploiting spin degree of freedom increases the functionality of electronic devices and enables such devices to overcome physical limitations related to speed and power. Currently, one of the most promising way to achieve the desired control of the electrons spin is by the application of external electric field in presence of the so called Rashba spin–orbit coupling (SOC). The essential feature of Rashba SOC is that a spin-polarized electron moving in an electric field experiences an effective magnetic field which drives the precession of the spin orientation even without an external magnetic field [2].

Since Bychkov and Rashba suggested a simple relationship between charge and spin [3], Rashba SOC has been a major topic of interest in the field of spintronics. Rashba SOC has led to a tremendous number of new discoveries and theories in physics, and to useful applications in electronics [4]. Furthermore, the strength of the Rashba effective magnetic field can be modulated by an external gate voltage. Over the past few decades, the Rashba effect has been extensively investigated in various systems including semiconductor quantum wells, heavy atoms and alloy surfaces, oxide interfaces, perovskite-structured compounds, topological insulators, and low-dimensional nanomaterials [2 and references therein].

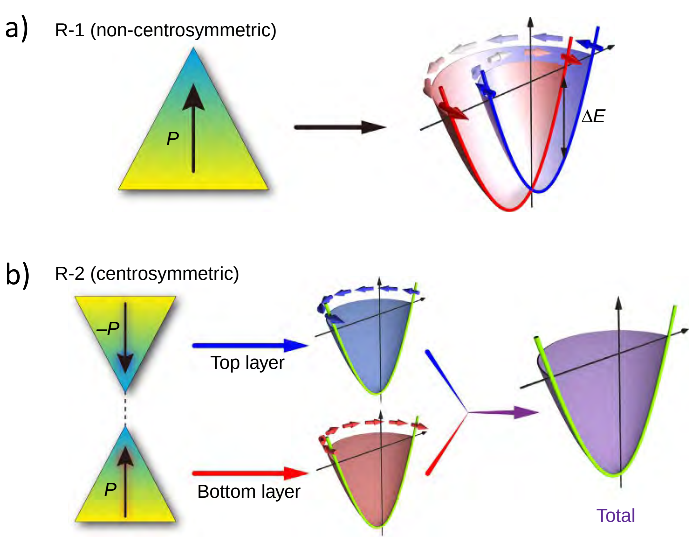

Figure 1 a) R-1 Rashba effect in non-centrosymmetric materials. The inversion symmetry is broken and there is a net dipole field. The right panel shows schematically the typical spin-resolved band structure induced by R-1 Rashba effect with a spin splitting in energy. b) R-2 Rashba effect in centrosymmetric materials. The inversion symmetry is preserved and there is a local site dipole field in spite of the vanishing total dipole field. The right panels illustrate the schematic spin texture induced by R-2 Rashba effect. The two kinds of spin texture with opposite helicities are spatially separated in different layers, resulting in overall zero spin polarization. (adapted from [5])

Currently, a huge effort is made by the scientific community to develop novel materials with strong and controllable Rashba SOC to promote the fabrication of more advanced spintronic devices. The key ingredients necessary to achieve this goal are:

1) A source of spin-orbit coupling which locks together the electrons momentum and spin
2) A net or local dipole field which lift the spin degeneracy (energetically and/or spatially) via spin-orbit interaction without inducing a net magnetic moment in the system
3) The possibility to use the spin-polarized states as conduction channels in the device.

Since the atomic SOC depends on the atom mass, the first requirement can be achieved by including heavy elements (such as Au, Pt etc…) in the material. The dipole field can be ensured in two ways: by breaking the inversion symmetry in non-centrosymmetric systems (for example at surfaces or interfaces) lifting the spin-degeneracy of the electronic bands (figure 1 a)), or by a local dipolar field due to the crystallographic structure and reduced dimensionality of the system (ultra-thin films) which lead to the spatial separation of the spin-polarized states on the opposite sides of the sample (figure 1b)) [5]. The last requirement implies that the "Rashba material" has to be grown on a non-metallic substrate.

Objectives:

We have recently developed a method which allows us to **implement these three key ingredients in one single process of sample preparation**. By growing a surface alloy between a well-chosen heavy element and a semiconductor (such as Ge or Si) in ultra-high vacuum (UHV) environment by molecular beam epitaxy (MBE), we are able to prepare an ultrathin metallic film (alloy) with thicknesses of the order of 1 nm, which possess high spin-orbit interaction due to the heavy element, on top of a non-metallic substrate (see Figure 2). Moreover, with our method, the thickness of the alloy can be controlled becoming a tunable parameter for the strength of the Rashba-SOC.

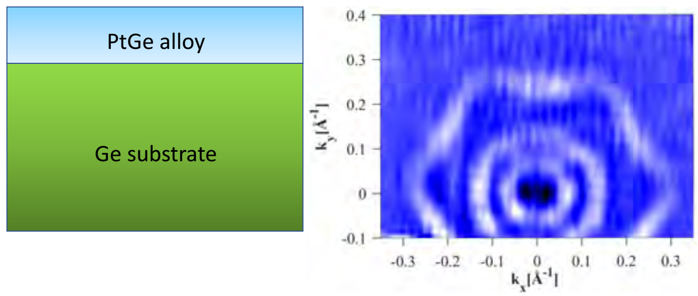

Figure 2: Left, schematic representation of the sample. Right, constant energy map (100 meV below Fermi level) measured by ARPES. Two circularly iso-energetic contours can be easily distinguished at the center of the Brillouin zone (0,0) demonstrating the presence of high Rashba effect.

This research project focuses on the study of the electronic properties of PtGe ultrathin films on Ge substrate grown with the preparation procedure described above. Our preliminary results demonstrate the presence of a giant Rashba SOC in the alloy (Figure 2). Moreover, our preliminary transport measurements showed the possible implementation of such growth method for device fabrication. Our objectives are:

1) Identify the role of the different growth parameters in the development of Rashba-SOC
2) Implement a capping layer to protect the sample for ex-situ measurements
3) Use the alloy for device fabrication

Strategy:

The objectives stated above requires a multi-technical approach.
To address the first objective, we will grow PtGe alloys with different chemical composition and alloying temperature in UHV environment by MBE. Each sample will be analyzed by angle resolved photoemission electron spectroscopy (ARPES) which provides the band structure of the system from which the strength of the Rashba SOC can be directly determined. A structural characterization will be achieved by diffraction techniques in the laboratory and at synchrotron facilities (in collaboration with ESRF-Grenoble).
Once the role of the different parameters will be identified, we will proceed to the development of a protective layer on top of our sample in order to preserve as much as possible the Rashba SOC when the sample will be exposed to air. The capping we are targeting consists in an ultrathin film of semiconductor oxide (one or two atomic layer) which will be prepared in UHV before air exposure. ARPES and scanning tunneling microscopy measurements (STM) will be implemented to address the oxide structure and the preservation of the alloy electronic properties.
The last objective is to study the Rashba SOC in capped thin films by electronic transport and assess the potential of PtGe alloys for the future realization of spintronics devices. For that we will perform measurements of Hall effect and magnetoresistance (MR) under strong magnetic field (14T) in cryogenic environment. In particular, we will investigate the Bilinear MagnetoResistance (BMR) in a

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rotating magnetic field, which is a new kind of MR reported in materials with strong spin-orbit coupling [6]. The underlying mechanism of the BMR is related to the existence of a current-induced magnetic field acting on the electron spins due to the spin-momentum locking. The strength of the Rashba SOC extracted from the BMR will be compared to the value obtained from ARPES.

PhD involvement:

The PhD student will be in charge, after an extensive training period, of the sample preparation and the ARPES measurements. He/She will be therefore become an expert of sample growth in ultraclean environment, band structure characterization by ultimate spectroscopic techniques and local probe microscopy. A careful guidance from the supervisors will be always assured. He will also participate to device fabrication and the transport measurements to expand his experimental skills.

Candidate profile:

The successful candidate should possess a good background in solid state physics and quantum mechanics. He/She should be at ease in the experimental work, be able to work in team and driven by natural curiosity for science. Experience in experimental research in physics will be a plus.

References:

[1] I. Zutic, *et al.*, Rev. Mod. Phys. **76**, 323 (2004).
[2] H. C. Koo *et al.*,Adv. Mater. **32**, 2002117 (2020).
[3] Y. A. Bychkov *et al.*, JETP lett. **39**, 78 (1984).
[4] A. Manchon *et al.*, Nat. Mater. **14**, 871 (2015).
[5] W. Yao *et al.*, Nat. Commun. **8**, 1 (2017).
[6] D. Vaz et al. Phys. Rev. Mater. **4**, 071001(R) (2020).

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CALENDRIER DE LA CAMPAGNE

26 juillet

Lancement de la campagne
Diffusion de l'appel à projets par les écoles doctorales auprès de leurs encadrantes et encadrants.

Jusqu'au 17 septembre

Les chercheurs/enseignants-chercheurs et chercheuses/enseignantes-chercheuses de Sorbonne Université soumettent des propositions de projets de recherche doctoraux à leur directeur et directrice d'école doctorale (en utilisant le formulaire joint) et à l'adresse suivante :
https://inscriptions.sorbonne-universite.fr/lime25/index.php/344242?lang=fr

Jusqu'au 24 septembre

Les écoles doctorales valident le cas échéant les projets et notifie le collège doctoral de leur décision à l'adresse suivante : **csc-su@listes.upmc.fr**

1er octobre

Mise en ligne des projets validés sur le site web de Sorbonne Université et ouverture des candidatures
https://www.sorbonne-universite.fr
Les candidats chinois prennent contact avec les porteurs et porteuses de projets et leur envoient un dossier de candidature.
Les candidates et les candidats déposent leur dossier à l'adresse suivante :
https://inscriptions.sorbonne-universite.fr/lime25/index.php/383154?newtest=Y&lang=fr

31 janvier

Fermeture des candidatures
Les porteurs et porteuses de projet ont transmis la candidature retenue après audition des candidates et candidats à leur école doctorale

Jusqu'au 21 février

Après examen, les écoles doctorales envoient les lettres de pré-admission signées et tamponnées des candidats et candidates retenues au collège doctoral

28 février

Le collège doctoral envoie les lettres de pré-admission aux candidates et candidats

Jusqu'au 31 mars

Les candidates et candidats retenus par Sorbonne Université candidate sur le site internet du CSC

31 mai

Diffusion des résultats par le CSC auprès de SU
Envoi résultats aux candidates et candidats ainsi qu'aux porteurs et porteuses de projet