Exchange and spin-orbit interactions in graphene

Artificially lattice-mismatched graphene/cobalt interface

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In Short

- Spintronics
- Electronic structure of graphene
- Nature of interaction at the graphene-metal interfaces
- Interaction of graphene with heavy metals and with ferromagnets

The impact of nano-magnetism on information technologies, such as information data storage or data processing, is experiencing an outstanding rising. In data storage, magnetic memories are currently largely used. Concerning spintronics, which exploits the coupling between the electron motion and its intrinsic magnetic moment, it represents an emerging field predicted to lead to a technological revolution for data elaboration. A huge effort nowadays is dedicated to the development of novel materials liable to increase the existing technology performances or that will enable the exploitation of new properties. In this respect, the discovery of graphene has opened a fascinating research field with ultimate goal of using graphene as a building block for next generation electronics due to the exceptionally high electron mobility [1]. Pristine graphene is a diamagnetic material that makes it not suitable for magnetic storage or magnetic field based technology. Moreover, in graphene, electrons spins experience almost no coupling with electron motion (in a classical picture): spin-orbit interactions are negligible. The latter property has been exploited to build conduction channels through which the spin of the electron is conserved [2],[3]. Therefore, besides spin transport, the common wisdom suggests that pristine graphene has no particular use for spintronic or magnetic data storage applications.

This situation changes dramatically when graphene is interfaced with other materials to form the so-called hybrid systems. In these kinds of systems it is possible to engineer the graphene band structure, thus introducing novel properties, yet preserving the natural high electron mobility of pristine graphene. Moreover, the graphene itself can strongly modify the physical properties of the material to which it is interfaced. These two effects make graphene hybrid systems extremely appealing to develop novel materials with desired properties.

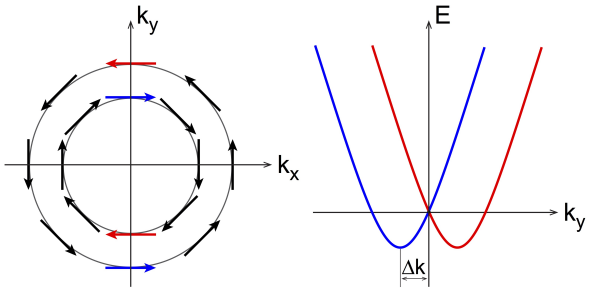

Figure 1: *Rashba-splitting of energy bands for 2D electron gas.*

Thus, for the use of graphene in spintronic applications the ultimate goal is to induce spin polarisation and spin orbit splitting in the graphene band structure without substantially altering the graphene Dirac cones linear dispersion. In this way the coupling between the electrons spin moment and their charge movement could be exploited along with the outstanding electron mobility. A weak spin-orbit splitting in the graphene Dirac cones can be introduced by interfacing graphene with heavy metal with high spin-orbit coupling such as Ir due to Rashba spin-orbit (RSO) splitting (Fig. 1). In this case no net magnetic moment is introduced in the carbon atoms. On the contrary, it has been shown that its interface with ferromagnet (FM) produces a small net magnetic moment in carbon atoms [4],[5],[6] and a spin polarised interface state due to exchange coupling effects [7]. Though in these cases the Dirac cones are destroyed by the strong interaction between graphene and its FM substrate.

Within this proposal we plan to investigate bimetallic graphene hybrid system, which can be seen as an alternative appealing system to realise the desired graphene band engineering. In fact graphene will lies on a HM with which it has a significantly lower interaction compared to the case of FM materials. This interface will induce spin orbit splitting by RSO effect thus changing the Dirac cones structure from the one of pristine graphene (sketched in Fig. 2 a) to spin-orbit split cones (Fig. 2 b). The HM also acquires magnetic moment due to its lower interface with the FM thin film; therefore an exchange splitting in the graphene Dirac cones is also expected (Fig. 2 c). The combination of these two effects could then enable to realise both spin polarisation and spin-orbit splitting in the graphene band structure while keeping intact the dispersion of the Dirac cones (Fig. 2 d).

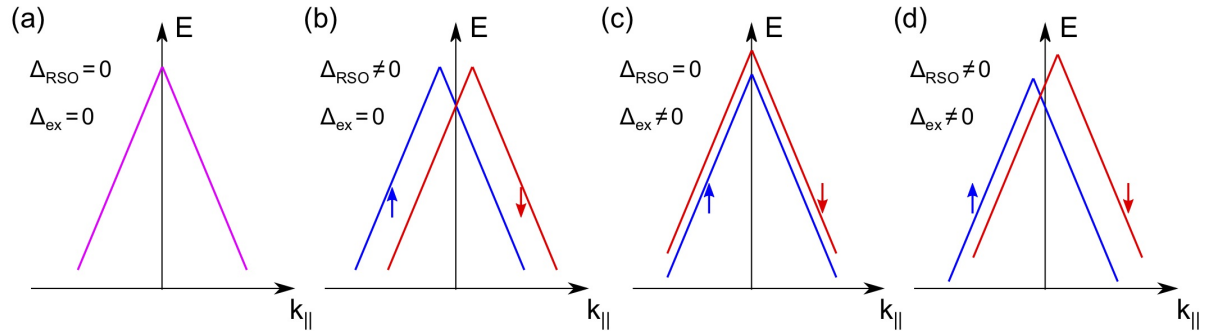

Figure 2: *Schematic representation of the energy dispersion of a) Graphene Dirac cone with b) Rashba spin-orbit interactions, c) ferromagnetic exchange, d) Rashba and ferromagnetic exchange. Arrows indicate the electrons spin polarisation.*

Two main objectives driving this project are the following: (1) to study the mutual effect of exchange and spin-orbit coupling interactions on the graphene band structure and (2) to propose a new class of highly stable ultra-thin magnetic materials with desired spin texture. Overall, our long-term plan is to study the following series of systems: graphene/Co/Ir(111); graphene/Pd/Ir(111); graphene/Pd/Co(0001). The obtained results will be compared with those for two reference systems - graphene/Co(0001) [6] and graphene/Ir(111) [8],[9]. Within the next four quarters we plan to realise about one-third of this programme.

We will start our studies with the graphene/Co/Ir(111) system (Fig. 3). Upon intercalation, Co grows epitaxial on Ir(111), resulting in a lattice-mismatched graphene/Co system. We expect, that the intercalated Co layer will yield a pronounced buckling of the graphene film due to the transition from a weakly to a strongly interacting graphene-metal system. A comparison between three systems: (i) lattice-matched strongly-interacting graphene/Co(0001), (ii) lattice-mismatched weakly-interacting graphene/Ir(111), and (iii) lattice-mismatched strongly-interacting graphene/Co/Ir(111) will allow us to disentangle the two key properties of lattice matching and strength of electronic interaction (hybridisation of graphene-π and metal d-states and the resulting modification of the graphene band structure: from opening of a small gap at the Dirac point to a complete destruction of the characteristic conical structure). Besides, a comparative study of induced magnetic properties of graphene as function of lattice parameter of underlying Co will be performed. Our findings will be compared with the available experimental results.

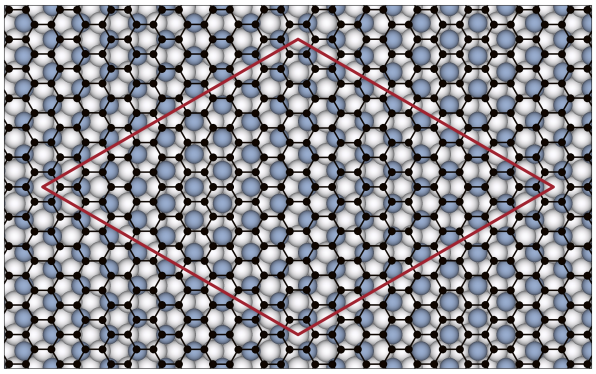

Figure 3: *Crystallographic structure of graphene/Co/Ir(111). The supercell marked with rhombus has a (10×10) lateral periodicity with respect to graphene and a (9×9) lateral periodicity with respect to the metal substsrate.*

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More Information

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Project Partners

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