Spintronics with Black phosphorus

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Spintronics is a paradigm focusing on spin as the information vector in fast and ultra-low-power non-volatile devices such as the new spin-transfer-torque Magnetic Radom Access Memory (MRAM). Beyond its widely distributed applications, spintronics aims at providing more complex architectures and a powerful beyond CMOS solution from storage to quantum information. The recent discovery of graphene, and other 2D materials such as hexagonal boron nitride (h-BN) or dichalcogenides (WS2…), has opened novel exciting opportunities in terms of functionalities and performances for spintronics devices[1]. Typically, graphene has shown a strong versatility by providing both highly efficient spin information transport properties [2] and potential for strong spin filtering in 2D-MTJs[1]. However, the lack of a gap has led to extensive research to find a semiconducting sibling of graphene that would display its good properties in addition to a gap.
In this direction, Black phosphorus (BP) has attracted an explosive interest since 2014 as it displays major properties for (opto-)electronic devices: (a) high hole and electron mobilities in thin layers exfoliated BP (about 3000 cm^2/Vs) and (b) high ON/OFF current ratio (about 10^5) in a transistor configuration with ambipolar characteristics. Additionally, the bandgap of BP is predicted to be widely tunable in relation to the number of stacked layers and remains direct from the bulk to the monolayer. Thanks to the natural low spin-orbit coupling of phosphorus, BP is expected to present highly efficient spin information transport, similarly to graphene [2] but with the addition of a band gap. This difference with graphene is fundamental for the implementation of spin manipulation schemes and the experimental realization of a spin gate.
However, the key issue for BP devices has been the handling of its degradation under atmospheric conditions. While the mechanism has been well understood [3] this still remains a clear problem for applications. We will present a recently developed in-situ approach to circumvent the issue of degradation under atmospheric conditions [4]. By passivating the BP without exposing it to air we achieve protection down to the monolayer with 1nm Al_2O_3. We will further discuss how this passivation layer can play the role of the tunnel barrier required for efficient spin injection [2,4] and provide a high potential path for spintronics applications from vertical to lateral devices. In addition, we will talk about the demonstration of BP integration into Co/BP/Co spin valves showing large spin signals. We will discuss a novel selective spin-splitted transport mechanism as supported by first-principle theoretical investigation. This illustrate the potential of BP for spin injection/detection, strongly supporting BP's vision as an outstanding platform for spintronics.

References

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