Building Spintronic Devices with Functional Heterojunctions

Magnetic anisotropy is a material preference that involves magnetization aligned along a specific direction and provides a basis for spintronic devices. Clarifying the ferromagnetic behavior in 2D materials can provide a knowledge that is required to build functional heterojunctions in the future.

After the discovery of graphene, monolayer MoS_2—a layered van der Waals semiconducting transition-metal dichalcogenide (TMD)—has emerged as another two-dimensional (2D) material prototype, which can be obtained by *ex-situ* exfoliation or *in-situ* chemical vapor deposition (CVD). Bulk MoS_2 has an indirect bandgap, which becomes a direct bandgap when its thickness decreases to a monolayer. Moreover, because of the strong spin-orbit coupling and the absence of inversion symmetry in the monolayer regime, spin splitting arises at the boundaries of the surface Brillouin zone, specifically, at points *K* and *-K*, to conserve the time-reversal symmetry. Such a unique band structure provides a possibility to encode information through the material valley pseudospin. Valley-based electronics is described as valleytronics, a name inspired after another famous field, spintronics.

MoS_2 can serve also as a spacer in a spin-valve device to exploit its semiconducting nature and its stable spin polarization in the out-of-plane direction. A MoS_2-based heterostructure is encouraging, but the large discrepancy in magnetoresistance between measurement and prediction indicates that we have yet to identify all factors relevant to the spin-dependent transport in TMD-based spin valves. A direct investigation of the fundamental magnetic properties of ferromagnetic (FM)–TMD heterojunctions is believed to be informative but remains scattered. An experimental study of a Fe/MoS_2 heterojunction found, however, that deposited Fe aggregates into nanoparticles with no sign of magnetic coupling to MoS_2. Co/MoS_2 was suggested to be different, based on a prediction of calculations from first principles, because the energetically favored Co-S bonding at the Co/MoS_2 interface would lead to a spin imbalance on the MoS_2 side.

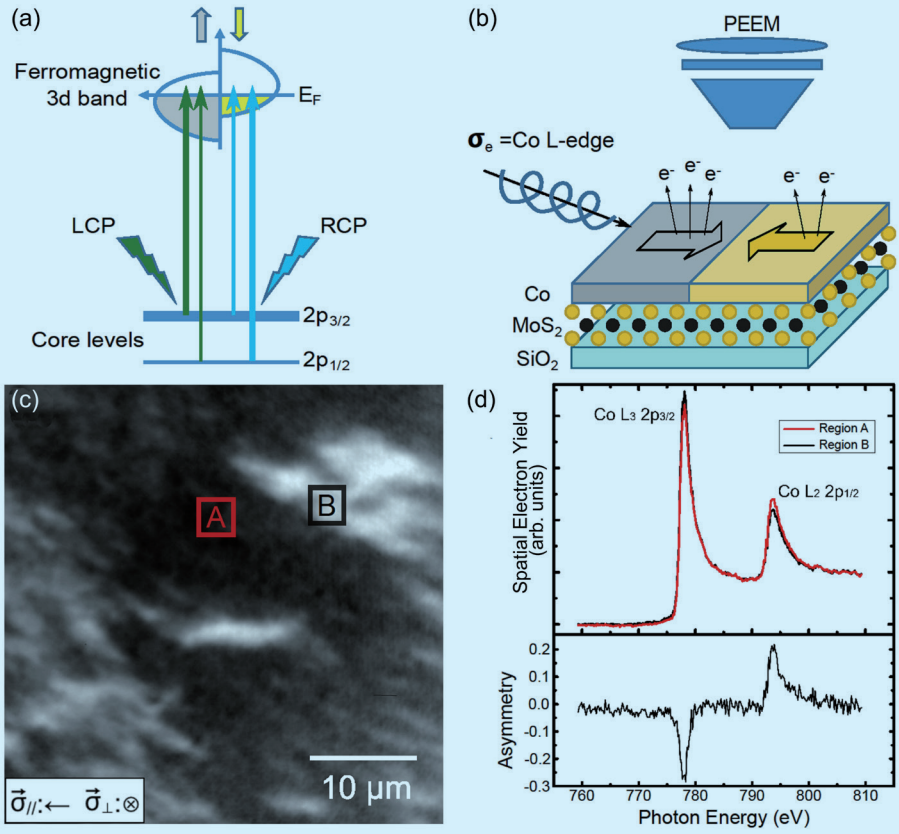

Fig. 1: XMCD. (a) Schematic diagram describing the principle of XMCD. (b) Schematic diagram illustrating the experimental setup. (c) XMCD image of cobalt (9 ML) on monolayer MoS_2. The inset shows the direction of incident light. (d) The corresponding m-XAS of regions A and B, the positions of which are marked in (c), are shown. The bottom spectrum illustrates the asymmetric nature of spectra A and B, that proves the grey-scale contrast in (c) to be a consequence of the XMCD effect. [Reproduced from Ref. 1]

To solve the contradiction between experiment and the prediction of calculation from first principles, Der-Hsin Wei (NSRRC), Yann-Wen Lan (National Taiwan Normal University) and their teams investigated the magnetic domain configuration and chemical states of Co/MoS_2 with a photoemission electron microscope (PEEM) end station located at **TLS 05B2**. An ultrathin film of Co was deposited onto flakes of SiO_2-supported monolayer MoS_2. The spatial distribution of the photo-emitted electrons under the X-ray magnetic-circular-dichroism (XMCD) effect was resolved with the PEEM, allowing the observation of magnetic domains in the Co layer. The authors extracted two micro-area spectra in the photoemission image according to their intensity variation as a function of photon energy. Wei and Lan found that the recorded spectra showed a typical XMCD signature-opposite enhancement at Co L_3 and L_2 resonances in **Fig. 1(c)** that has indeed a magnetic origin.

Their next task was to examine the relevance of the MoS_2 crystalline structure for the domain formation. With careful control of the degree of crystallinity in monolayer MoS_2, they adjusted the lateral dimensions of the magnetic domains from tens of micrometers to sub-micrometers. Because CVD-grown triangular MoS_2 flakes are typically treated as a single crystalline grain, and as the edge of the grain is in either an armchair or a zig-zag configuration, they found that well defined crystallinity in the MoS_2 layer would not only promote the magnetization alignment in a Co layer but also affect how the domains are divided.

In summary, Wei and Lan studied the magnetic domain configuration and chemical states of Co/MoS_2. They confirmed that an ultrathin Co film deposited on monolayer MoS_2 can form ferromagnetic domains of micrometer size. Furthermore, the magnetization and the boundaries of domains have preferred directions or paths that are parallel to either the zig-zag or the armchair directions of the MoS_2 crystal structure. According to the evidence from X-ray photoelectron spectra of charge donation at Co/MoS_2, they suggested that the orbital hybridization at the interface is what distinguishes the magnetic properties of Co/MoS_2 here and Fe/MoS_2 reported earlier. Their work clarifies the puzzle existing from previous experiments and calculations, and provides micro-magnetic and micro-spectral evidence that consolidates the knowledge required to build functional heterojunctions based on 2D materials. (Reported by Cheng-Maw Cheng)

This report features the work of Der-Hsin Wei, Yann-Wen Lan and their collaborators published in Nanoscale Horiz. ***5****, 1058 (2020).*

TLS 05B2 EPU – PEEM

- XPS
- Materials Science, Condensed-matter Physics

Reference

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