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Spin-Orbit Torque in van der Waals Heterostructures of Magnetic Two-Dimensional Materials

The bilayer heterostructures composed of an ultrathin ferromagnetic metal (FM) and a nonmagnetic material hosting strong spin-orbit coupling (SOC) are a principal resource for spin-orbit torque (SOT) [1] and spin-to-charge conversion [2] effects in next generation spintronics. The key to understand these effect is current-driven nonequilibrium spin density [3]. For example, it generates SOT when it is noncollinear to the direction of local magnetization and it can arise due to variety of microscopic mechanisms, including the spin Hall effect, spin-orbit proximity effect and different interfacial scattering mechanisms. The recently discovered two-dimensional (2D) magnetic materials [4] offer new avenue for highly efficient and gate- or disorder-tunable SOT in van der Waals (vdW) heterostructures composed of few monolayers of atomically thin materials where the spin Hall effect from the bulk is absent. Using first-principles quantum transport calculations, which combine nonequilibrium Green functions with noncollinear density functional theory [1], we predicted [5] that injecting unpolarized charge current parallel to the interface of bilayer-CrI3/monolayer-TaSe2 vdW heterostructure will induce SOT-driven dynamics of magnetization on the first monolayer of CrI3 that is in direct contact with metallic transition metal dichalcogenide (TMD) TaSe2. By combining calculated complex angular dependence of SOT with the Landau-Lifshitz-Gilbert equation for classical dynamics of magnetization, we find that this can reverse the direction of magnetization on the first monolayer to become parallel to that of the second monolayer, thereby converting bilayer CrI3 from antiferromagnet to ferromagnet which can be detetected by passing vertical current and is of potentially great interest to magnetic memory applications since it does not require any external magnetic field. We explain the mechanism of such current-driven nonequilibrium phase transition by showing that first monolayer of CrI3 becomes conducting due to doping by evanescent wavefunctions injected by metallic TaSe2, while concurrently acquiring strong SOC via this proximity effect. Another vdW heterostructure exhibiting SOT is doubly proximitized graphene, which is neither magnetic nor hosts SOC in its isolated form, but proximity induced magnetic moments will exhibit SOT in Cr2Ge2Te6/graphene/WS2 vdW heterostructure which can be tuned by two orders of magnitude via the gate voltage [6]

References

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Figures

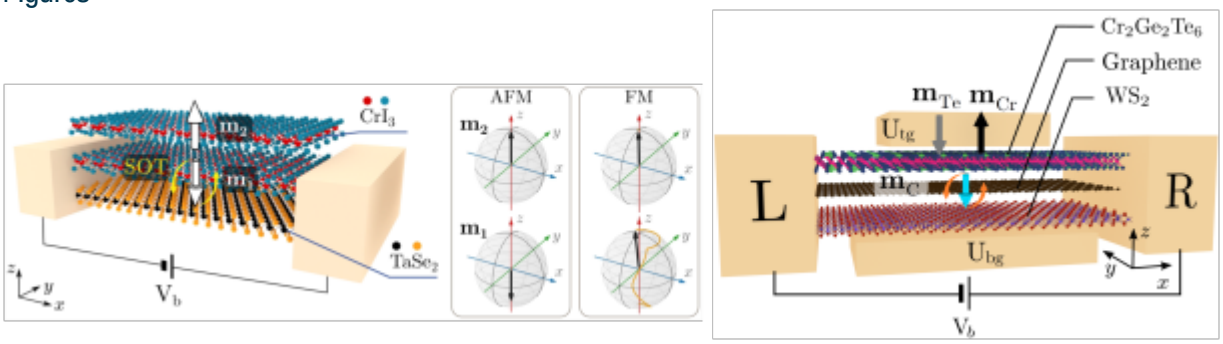

Figure 1: Spin-orbit-torque-operated van der Waals heterostructures from Ref. [5] (left panel) and Ref. [6] (right panel).