NEWS AND VIEWS

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Two-dimensional air-stable $CrSe_2$ nanosheets with thickness-tunable magnetism

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Since Geim *et al.* firstly separated graphene from graphite by mechanical exfoliation method in 2004, the research of two-dimensional (2D) van der Waals (vdW) layered materials has begun[1]. Compared with three-dimensional materials, 2D vdW layered materials exposing the most atoms to exterior are more sensitive to external control and have the great potential applications in electronic, optoelectronic and electrochemical area[2].

Recently, a new bright spot has appeared in the research of 2D materials: 2D vdW magnetic materials[3, 4]. Mermin-Wagner theorem shows that isotropic 2D materials can't show long-range magnetism due to thermal fluctuation, thus intrinsic 2D magnetic materials are extensively considered to be nonexistent[5]. However, it is possible to have long range magnetic order in anisotropic 2D materials. The existence of magnetic anisotropy induces the band gap of magnon in the dispersion relation of spin wave, separating. This band gap splits into the ground state and the excited state of the magnon, so that the magnon in the ground state can maintain the spin ordered state and exhibit the intrinsic long-range ordered magnetism[6]. Long-range magnetic order was firstly observed in 2D $FePS_3$[7], $Cr_2Ge_2Te_6$[6] and CrI_3[8] crystals. Due to their ultrathin thickness and combination of vdW forces between layers, their magnetism can be effectively controlled by electric field, chemical modification, thickness and so on. At the same time, some interesting physical phenomena have been revealed in these materials, such as magnetic proximity effect, chiral spin state, exchange bias effect, quantum anomalous Hall effect[3].

What's more, the vdW heterostructures composed by 2D materials have high-quality contact interface and excellent electrical and optoelectronic properties. The electrical conductivity of 2D vdW magnetic materials covers metal (Fe_3GeTe_2), semiconductor ($FePS_3$) and insulator ($Cr_2Ge_2Te_6$)[6, 7, 9]. Through reasonable design, 2D vdW magnetic/non-magnetic material vertical heterostructure with well-matched conductivity and high-quality interface can be constructed. These heterostructures are expected to be applied in spintronic devices with high spin injection efficiency, such as spin transistors and spin valves. The research of 2D magnetic heterostructure is crucial to the field of novel magnetic sensor and storage device.

So far, intrinsic ferromagnetism has been observed in several 2D materials. At present, most of the 2D magnets are not stable in the air environment, their monolayer and few layers can only be obtained by mechanical stripping of bulk materials in controlled environment (such as glove box), with low yield and poor layer thickness control, which is extremely disadvantageous to both basic investigation and practical application. Therefore, it is of great significance to find a stable and scalable 2D magnetic material.

Recently, Duan *et al.* reported the epitaxial growth of 2D vdW magnetic $CrSe_2$ nanosheets on WSe_2 substrates (we can also say this is $CrSe_2/WSe_2$ heterostructure) by chemical vapor deposition method and the thickness can be controlled by synthetic temperature[10]. Polar reflective magnetic circular dichroism (RMCD) measurement shows that 1–3 layers are weak magnetic, and 4 layers and above are ferromagnetic. Magnetic phase diagram shows that the layer thickness can effectively regulate the magnetic coupling and the thick ones show a Curie temperature of about 110 K. The theoretical calculation demonstrated that substrate-doping effect and interlayer kinetic energy gain dominate the magnetic property of 2D $CrSe_2$, which is consistent with the experimental results. The magnetotransport studies based on a standard Hall bar device show that $CrSe_2$ have distinct anomalous Hall effect with a Curie temperature of about 110 K, and there is no obvious change after being exposed to air for several months. Further, the thickness and morphology of the $CrSe_2$ monolayer characterized by atomic force microscopy have no significant change when keeping in air for 45 days. Theoretical calculations also revealed the robustness of $CrSe_2$ against O_2 and H_2O. The results demonstrated the outstanding air stability of 2D $CrSe_2$ nanosheets.

In summary, 2D vdW magnetic materials have attracted condensed attention in novel physical properties, multifunctional spin devices and so on. 2D vdW magnetic metal $CrSe_2$ is stable in air with thickness dependent magnetism, which is expected to obtain excellent performance in future 2D spintronic devices. Controllable synthesis of large-scale and stable 2D vdW magnetic materials with high Curie temperature and achieving high performance spintronic devices based on the heterostructures will be the core issue of the next 2D magnetic materials research.

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