Electron beam-induced magnetism on MoS_2 surface along 1T phase transition

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In this presentation, we propose a simple method to improve transport property and induce room-temperature ferromagnetism through the optimal electron irradiation on the MoS_2 surface. The magnetic moments are found to be attributed to the unpaired spins of Mo^{4+} ions induced by exotic defects, which form a specific shape of concentric circles on the surface region along the 2H/1T phase transition.

The natural-single crystalline MoS_2 samples (SPI) were snipped from a large piece and, after a several exfoliation to take the clean surface, irradiated with different exposure times at the electron acceleration energy (ELV-8 linear accelerators) of 0.7 MeV and 2.0 MeV, respectively, in ambient conditions at room temperature. The area of the electron irradiation at the specific point of 400 ± 50 mm was of width 600 ± 20 × length 20 ± 5 mm^2 with beam diameter of 25 ~ 35 mm. The stability of the beam energy and dose was less than ± 5 %. The electron dose was checked by the dosimeter films.

In comparison with the diamagnetic susceptibility[1] of the pristine MoS_2, the electron dose of 300 kGy induces the diamagnetic to a ferromagnetic phase transition. Interestingly, along the out-of-plane (the *c*-axis) direction, the diamagnetic behavior still remains for higher magnetic fields than ±10 kOe. The saturated magnetizations along the in-plane (the *ab*-plane) and out-of-plane directions are 0.057 emu/g (1.634×10^{-3} μ_B/Mo ion) and 0.030 emu/g (8.60×10^{-4} μ_B/Mo ion) at the H = 35 kOe and 1 kOe, respectively. These weak ferromagnetic states persist up to room temperature, but the saturated magnetizations of 5 K are significantly reduced to 0.011 emu/g (0.315×10^{-3} μ_B/Mo ion) and 0.008 emu/g (0.229×10^{-3} μ_B/Mo ion) at the H = 2 kOe along the in-plane and out-of-plane directions, respectively. The coercivities (0.2 kOe) of both directions at 5 K are also reduced to 0.1 kOe at room temperature. On the other hand, the higher electron dose of 600 kGy induces the diamagnetic to a paramagnetic phase transition along the in-plane direction while the out-of-plane direction still remains diamagnetic.

The electron irradiation with the electron dose of 300 kGy (6.70×10^{14} electrons/cm^2) and the acceleration energy of 0.7 MeV creates the 1T-phase-like (V_{S2}) and 1T-3V_S defects on the MoS_2 surface. These defects reduce the bandgap and improve the transport property. The undulating magnetic domains of the MFM image due to weak ferromagnetic state are considerably related to the 1T-3V_S defects. This optimal electron irradiation to improve the magnetic and transport properties at the atomic-layer scale is a key step for the successful integration of 2D TMDs into possible device applications.

Reference

[1] Han, S. W. *et al*. Controlling ferromagnetic easy axis in a layered MoS_2 single crystal. *Phys. Rev. Lett.* **110**, 247201 (2013).