Magnetism in Monolayer Transition Metal Dichalcogenides

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Van der Waals heterostructures hold the promise of combining materials with only weak interlayer interaction. This could allow integration of materials with diverse properties and minimize the influences of chemical interface interactions on materials and device properties. Of particular interest is the integration of magnetic materials in such van der Waals heterostructures. Although it has been recently demonstrated that ferromagnetism may be preserved down to the monolayer limit, there exists no known layered van der Waals material with Curie temperatures close to room temperature-- which is a pre-requisite for most applications. Thus there has been excitement by theoretical (DFT) predictions of high Curie temperature ferromagnetism in monolayer materials such as VSe_2, a material that is known to be paramagnetic in bulk-form. In addition, there exist increasing evidence of dilute magnetic semiconductors (DMS) in van der Waals materials. In this presentation, we illustrate direct growth of VSe_2 monolayers on van der Waals substrates (Fig. 1) and demonstrate that these (sub)monolayers indeed exhibit ferromagnetic properties to above room temperature [1], while multilayers exhibit strongly suppressed magnetization (Fig. 2). Recent angle resolved photoemission spectroscopy (ARPES) characterization, however, indicate that VSe_2 monolayers do not exhibit spin-split bands as predicted by DFT. In this talk we discuss possible alternative explanations for the observed magnetism. Moreover, we show evidence for magnetic coupling between monolayer VSe_2 and a van der Waals substrate, which gives rise to an exchange bias that can be measured by magnetometry. Finally, we discuss an alternative approach to induce magnetism in 2D materials. Specifically, we show the formation of DMS by incorporation of magnetic impurities (Fig. 3) by a novel doping mechanism [2] in $MoTe_2$.

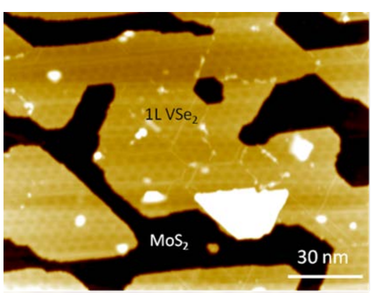

Figure 1: STM of MBE grown sub- monolayer VSe_2 on MoS_2 substrate.

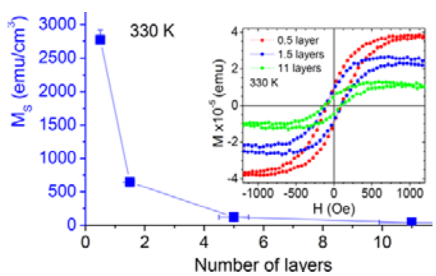

Figure 2: M-H hysteresis and layer dependent magnetization measurements for VSe_2 films.

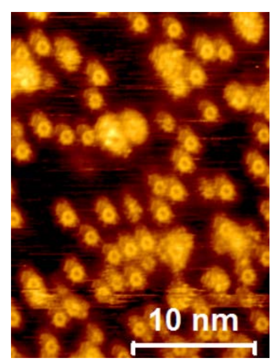

Figure 3: STM of Magnetic dopants in $MoTe_2$.

[1] M. Bonilla et al. 'Strong room-temperature ferromagnetism in VSe_2 monolayers on van der Waals substrates' Nat. Nanotechnol. **13**, 289-203 (2018).

[2] P.M. Coelho et al. 'Post-Synthesis Modifications of Two-Dimensional $MoSe_2$ or $MoTe_2$ by Incorporation of Excess Metal Atoms into the Crystal Structure' ACS Nano **12**, 3975-3984 (2018).