EPSRC DTP PhD Research Project

Project Title: Ultrafast imaging of valley and spin qubits

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Project Description:

Two-dimensional (2D) van der Waals (vdW) materials feature exotic electrical, magnetic, optical, and structural properties, providing energy and area efficiencies far exceeding what is possible with conventional electronics. Of particular interest here is recently discovered 2D vdW semiconducting antiferromagnet CrSBr [1,2]. CrSBr emerges as an outstanding candidate for quantum application because it possesses spin-correlated excitons with strong anisotropy, exhibiting one of the largest exciton oscillator strengths in solids and high photoluminescence quantum yield. Furthermore, strong light-matter coupling has been recently demonstrated in this material, resulting in a previously unobserved class of quasiparticles with exciton-polaritons being coupled to magnons [1-2].

Recent theoretical calculations suggest that, in combination with other 2D layers such as graphene and transition metal dichalcogenides (TMDCs), CrSBr should allow for ultrafast control of electron spin [3]. TMDCs are particularly compelling due to their electronic band structure *valleys*, which are crucial for developing *valley*-based qubits for quantum computation. This project aims to design metamaterials comprising TMDCs and the 2D magnetic material CrSBr, targeting the creation of a next-generation quantum platform that leverages both *valley* and *spin* degrees of freedom. The integration of TMDCs with 2D magnets presents a significant opportunity for quantum technologies by merging the benefits of solid-state-based qubits and photonic qubits.

The project will primarily focus on time-resolved measurements using ultrafast laser pulses, to probe the dynamics of *valleys* and *spins*. We have recently demonstrated that similar heterostructures based on TMDCs and 2D magnets can lead to exotic phenomena such as all-optical switching via ultrafast charge transfer, and that such materials can be successfully probed in our laboratories in Exeter [4]. Thanks to unique coupling between excitons and magnons in CrSBr [1-2], dynamics of spins can be directly probed in time-resolved measurements, even though the spins form an antiferromagnetic order. In particular, by using recently developed time-resolved beam-scanning microscopy (shown in **Figure 1**), we will be able to perform real-space imaging of dynamic properties of *valleys* and *spins* at low temperatures and under applied fields. Unlike other 2D magnets CrSBr is stable in air, substantially reducing the technological challenges associated with fabrication and making the proposed heterostructures particularly appealing to practical quantum applications.

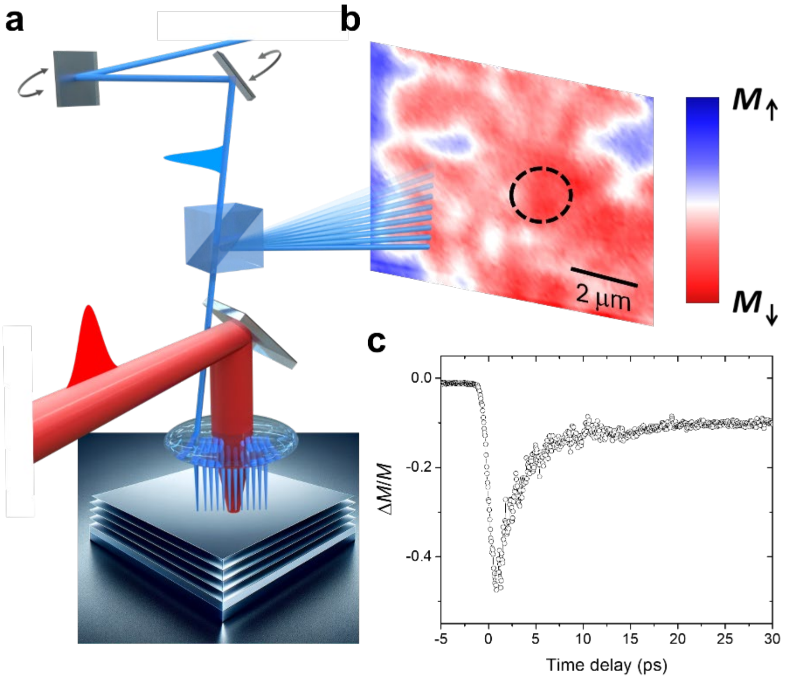

Figure 1: (a) Schematic of time-resolved beam-scanning microscopy. (b) Static MOKE image of a domain structure of a Co/Pt multilayer. (c) Time-resolved pump-probe measurement performed at fixed probe beam position, shown by dashed circle in (b).

References:

[1] Y. Bae *et al*. Exciton-coupled coherent magnons in a 2D semiconductor, Nature vol. 609, 282 (2022).

[2] F. Dirnberger *et al*. Magneto-optics in a van der Waals magnet tuned by self-hybridized polaritons, Nature vol. 620, 533 (2023).

[3] C. Brito *et al*. Charge Transfer and Asymmetric Coupling of MoSe2 Valleys to the Magnetic Order of CrSBr, Nano Letters vol. 23, 11073 (2023).

[4] M. Dąbrowski *et al*. All-optical control of spin in a 2D van der Waals magnet, Nat. Commun. vol. 13, 5976 (2022).