Van der Waals Magnetic Tunnel Junctions with Metallic Transition Metal Dichalcogenide Electrodes

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Primary CNF Tools Used: Heidelberg DWL-2000, GCA-AS200 i-line stepper, SC4500 Even/Odd-Hour Evaporator

Abstract:

Magnetic tunnel junctions (MTJs) are a useful platform for studying electrically insulating van der Waals magnets. The evolution of the tunneling current as a function of junction bias and applied external magnetic field has been shown to reveal information about the nature of interlayer exchange, spin-filtering, and two dimensional magnons [1-3]. These previous studies have employed few layer graphene for contact electrodes. Theoretical work [4], however, suggests that by replacing few layer graphene with a metallic transition metal dichalcogenide (TMD), the junction impedance can be lowered and the magnetoresistance increased, making the junctions more favorable for spintronic applications. Here, we fabricate MTJs where the barrier layer is antiferromagnetic $CrCl_3$ and the junction electrodes are $TaSe_2$ and measure the tunneling characteristics as a function of applied magnetic field.

Summary of Research:

$CrCl_3$ is a layered van der Waals magnet where each individual layer hosts ferromagnetic exchange interactions between neighboring spins while adjacent layers couple antiferromagnetically. The moments are pointed in the plane of the layers with no anisotropy within the plane. The weak interlayer coupling allows for the net magnetic moment to be manipulated by an external magnetic field. Previous studies with few layer graphene/$CrCl_3$/few layer graphene junctions have shown that the tunneling current is sensitive to the orientation of the layer magnetic moments relative to one another [1-3]. However, spintronics applications where the tunneling current can be used as a readout of the magnetic state will require lower impedance junctions.

First principles density functional theory calculations indicate that due to more favorable band alignment and higher density states that junctions with electrodes of metallic transitional metal dichalcogenides host larger junction conductivity and magnetoresistance compared to junctions with graphitic electrodes [4].

We fabricate $TaSe_2$/$CrCl_3$/$TaSe_2$ junctions by exfoliating all materials in an inert glove box environment to avoid exposure to ambient oxygen and water. The junction is encapsulated in hexagonal boron nitride from above and below and then transferred to prepatterned metallic electrodes that were prepared with the Heidelberg Mask Writer DWL-2000, GCA-AS200 i-line stepper, and SC4500 Even/Odd-Hour Evaporator. Figures 1 and 2 show a device schematic and micrograph, respectively.

Transport measurements are performed at $T = 2\ K$ by applying a DC bias voltage and measuring the resulting DC tunneling current. All external magnetic fields are applied in the plane of the device. Figure 3 shows the current voltage characteristic of the junction at $B = 0\ T$ and $B = 2\ T$. As the externally applied field is increased, the moments of the individual layers will reorient themselves and approach a parallel configuration to minimize energetic contributions from interlayer exchange and Zeeman effects. At $B = 2\ T$, due to spin filtering, this configuration will have a lower tunneling barrier and thus, a lower threshold voltage for the onset of Fowler-Nordheim tunneling than the antiparallel configuration at $B = 0\ T$.

We then apply a constant DC bias of $V = 1.25\ V$ and measure how the tunneling current evolves as a function of applied magnetic field. The tunneling current increases with an applied field as the moments evolve from antiparallel towards a parallel configuration. This is consistent with the lowering of the tunneling barrier with increasing magnetic field via the spin filtering effect. The magnetoresistance is defined as

$$MR = 100 \times \frac{I(B)-I(B=0\,T)}{I(B=0\,T)},$$

and we measure a magnetoresistance of ~ 150%. Future work will involve exploring different metals as electrode layers and fabricating devices suitable for four-point measurements to avoid contributions from contact resistance.

References:

[1] Klein, D. R., et al. Probing magnetism in 2D van der Waals crystalline insulators via electron tunneling. Science 360, 1218 (2018).

[2] Wang, Z., et al. Determining the phase diagram of atomically thin layered antiferromagnet $CrCl_3$. Nature Nano. 14, 1116 (2019).

[3] Cai, X., et al. Atomically thin $CrCl_3$: An in-plane layered antiferromagnetic insulator. Nano Letters 19, 3993 (2019).

[4] Heath, J. J., et al. Spin injection enhancements in van der Waals magnetic tunnel junctions through barrier engineering. Phys. Rev. Applied 16, L041001 (2021).

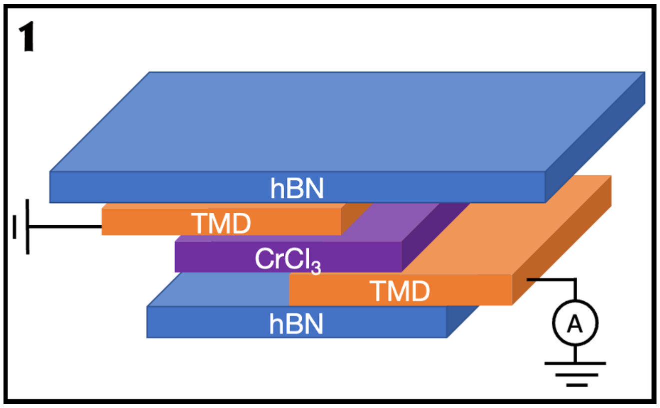

Figure 1: Device schematic of $TaSe_2/CrCl_3/TaSe_2$ magnetic tunnel junction. Hexagonal boron nitride is used to encapsulate the $CrCl_3$ to prevent degradation from ambient oxygen and water.

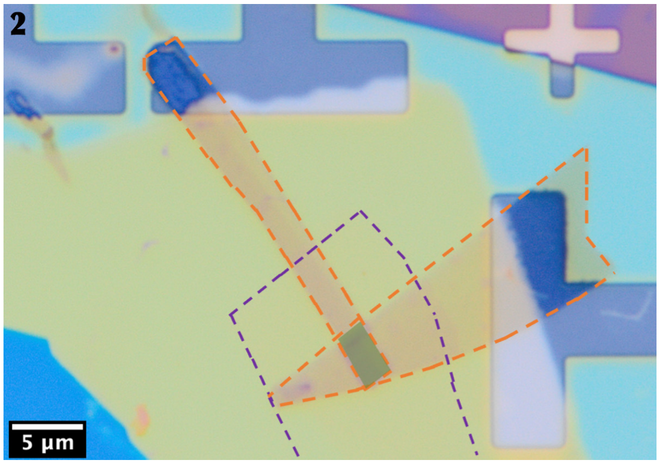

Figure 2: Micrograph of $TaSe_2/CrCl_3/TaSe_2$ magnetic tunnel junction. The $TaSe_2$ and $CrCl_3$ layers are outlined with the dashed orange and purple lines respectively. Scale bar: 5 µm.

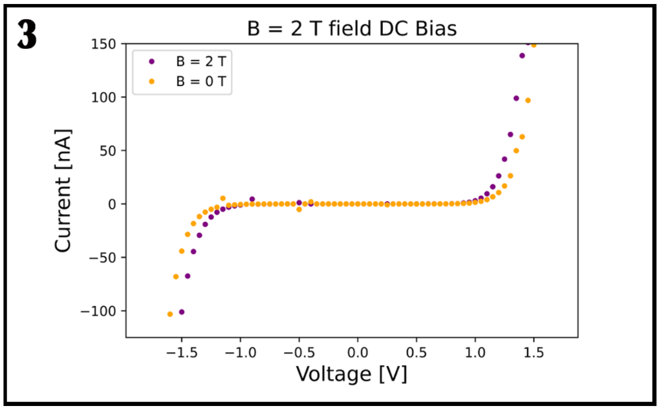

Figure 3: Tunneling current as a function of applied DC bias. The tunneling current at B = 0 T is orange and at B = 2 T is purple. Measurements are performed at T = 2 K, and the magnetic field is applied in the plane.

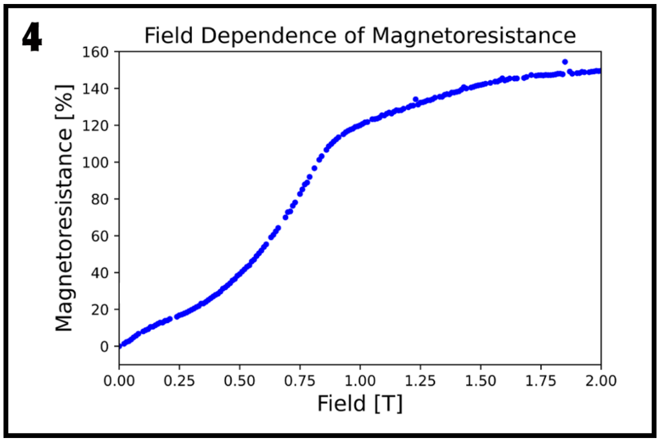

Figure 4: Magnetoresistance as a function of in-plane magnetic field. A constant DC bias of V = 1.25 V is applied. The tunneling current increases as the moments of the individual layers approach a parallel configuration.