

Anisotropic Conduction and Magnetoresistance in a Bilayer Antiferromagnetic Semiconductor

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Primary CNF Tools Used: Zeiss Supra SEM, Nabity Nanometer Pattern Generator System, Angstrom E-Beam Evaporator, Oxford 81 Etcher

Abstract:

We fabricate and characterize dual-gated transistors of bilayer chromium sulfur bromide (CrSBr). By fabricating samples where the current can be applied along different in-plane principal axes of the crystal, we characterize the anisotropic character of electronic transport by measuring the conductance as a function of top and bottom gate voltages. When current is driven along the a-axis, the transport reveals n-type semiconducting behavior with an electron mobility of $24 \text{ cm}^2/\text{Vs}$ and an on/off ratio of 10^3 . On the other hand, when current is applied along the b-axis, the on/off ratio is 10. We also characterize the magnetoresistance by applying a magnetic field in the out-of-plane direction. Our measurements reveal that the magnetoresistance is gate-tunable and can be as large as 600% when current is passed along the b-axis at $T = 20 \text{ K}$.

Summary of Research:

van der Waals magnets are promising candidates for next-generation spintronic devices [1]. A-type antiferromagnets display ferromagnetic correlations within the plane while adjacent layers couple antiferromagnetically. As a result, by applying an external magnetic field, the relative orientation of the magnetic moments of the layers can be tuned. Since, the nature and strength of interlayer electronic hybridization depends on the spin configuration, the electronic conduction properties of the antiferromagnet also vary with the orientation of the magnetic moments. CrSBr, is an A-type antiferromagnetic semiconductor with an ordering temperature of 130 K [2]. Here, we characterize the gate-dependent electronic conduction of bilayer CrSBr by performing transport measurements at $T = 20 \text{ K}$.

To fabricate our samples, we pattern and deposit thin Pt Hall bars onto a hexagonal boron nitride (hBN) dielectric layer that is interfaced with a few-layer graphite gate electrode from below. The Hall bar is patterned with

electron beam lithography using the Zeiss Supra SEM and Nabity Nanometer Pattern Generator System. The metal is deposited with the Angstrom E-Beam Evaporator. A top hBN and bilayer CrSBr are then transferred to the prepatterned Hall bar. Contact windows to the Pt Hall bar are then patterned and etched to expose the Pt layer. The etching is performed with a CHF_3/O_2 plasma using the Oxford 81 Reactive Ion Etcher. A final set of contacts to the exposed Pt are patterned and deposited using similar methods. A Ti/Au top gate and contacts to the bottom graphitic gate electrode are also deposited in the final deposition. Figure 1 shows a schematic of the device.

The top gate dependence of the conduction along the a-axis displays n-type semiconducting behavior as depicted in Figure 2. The conductance increases with increasing top gate voltage. In the linear regime, we can extract an electron mobility of $24 \text{ cm}^2/\text{Vs}$. The ratio of the conductance between the off and on state is 10^3 . Figure 3 gives the dependence of conduction along the b-axis with varying top gate voltage. In this case, the conductance is only tunable by one order of magnitude and the off-state conductance is two orders of magnitude higher than when current is passed along the a-axis.

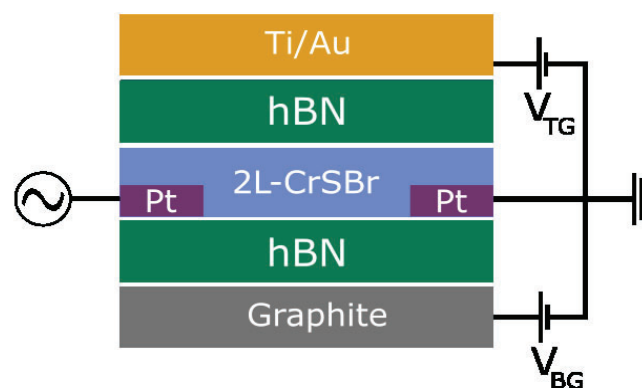


Figure 1: Device schematic of dual-gated bilayer CrSBr transistors. The bottom contacts are Pt, the top gate electrode is Ti/Au, and the bottom gate electrode is few-layer graphite. The CrSBr is encapsulated on both sides with dielectric hBN.

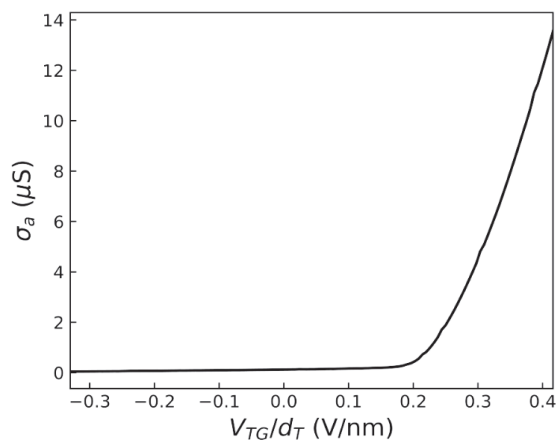


Figure 2: Four-point channel conductance as a function of top gate voltage with current passed along the a -axis. The top and bottom hBN thicknesses are given by d_T and d_B , respectively. The bottom gate is fixed at $V_{BG}/d_B = 0.3$ mV/nm.

We then measure the magnetoresistance of the bilayer by applying an external magnetic field in the out-of-plane direction. As the field increases, the moments of the two sublattices gradually cant towards one another until saturation. Figure 4 shows the magnetoresistance as a function of external field, B . The resistance is maximal at $B = 0$ and gradually decreases with increasing field until reaching a plateau at $B = 1.6$ T [3, 4]. The magnetoresistance is defined as:

$$MR(B) = (R(B) - R(B=3 \text{ T})) / (R(B=3 \text{ T})).$$

The magnitude of magnetoresistance increases with decreasing bottom gate voltage. We observe a maximum magnetoresistance of 600%.

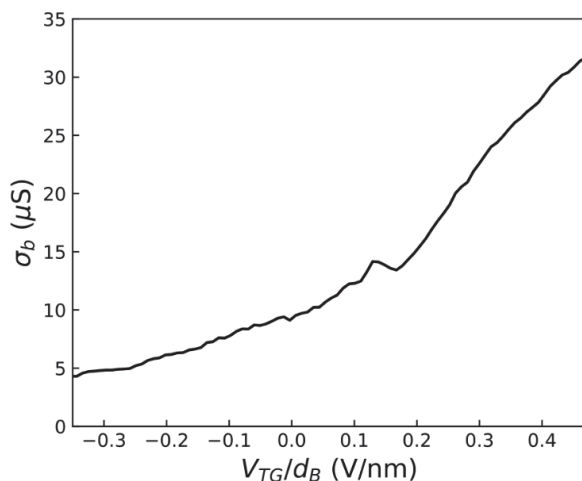


Figure 3: Four-point channel conductance as a function of top gate voltage with current passed along the b -axis. The bottom gate is fixed at $V_{BG}/d_B = 0$ V/nm.

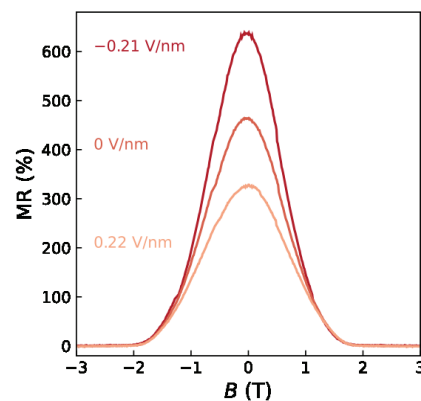


Figure 4: Magnetoresistance along b -axis as a function of out-of-plane magnetic field. The measurements are performed at constant top gate voltage of $V_{TG}/d_T = 0.47$ V/nm. The labels provide the values of V_{BG}/d_B .

Conclusions and Future Steps:

In summary, we have characterized the anisotropic conductance and magnetoresistance of bilayer CrSBr. Our measurements shed light on the relation between magnetic ordering and interlayer electronic hybridization.

References:

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