Fabricating Dual-Gated 2D CrSBr Devices to Investigate Nonlinear Transport Effects

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Primary CNF Tools Used: Zeiss Supra SEM, Nabity NPGS Nanometer Pattern Generator System, CVC SC4500 Odd-Hour Evaporator, Oxford 81 RIE

Abstract:

The tremendous interest in 2D van der Waals (vdW) materials in condensed matter physics has led to studies on magnetic materials for potential applications in spintronics and quantum information. CrSBr is a magnetic semiconductor that has garnered interest due to its ability to be exfoliated to the 2D limit. However, transport effects in 2D CrSBr such as the nonlinear Hall effect have yet to be explored. In this project, we aim to fabricate functioning dual-gated CrSBr devices and investigate the existence of a nonlinear Hall effect when subjecting the devices to varying parameters.

Summary of Research:

Two-dimensional materials have generated enormous research interest, and the discovery of new materials and ordered phases continues to expand the scope of the field. One category of 2D materials includes van der Waals (vdW) magnets such as chromium sulfur bromide (CrSBr) [1]. CrSBr is particularly interesting from an experimental standpoint, as it is more air-stable compared to other 2D magnetic materials and can be exfoliated relatively easily to the monolayer limit [2].

CrSBr is a magnetic semiconductor exhibiting A-type antiferromagnetic structure; the magnetic moments within a layer are aligned ferromagnetically (same direction) in the plane, while the magnetic moments in adjacent layers are aligned antiferromagnetically (opposite direction). CrSBr also exhibits intriguing electronic and magnetic anisotropies. Due to CrSBr's electronic structure, particularly the orbital composition of its conduction band, electron transport is massively favored along one direction, with the conductivity along the b-axis (σb) being up to 10,000 times larger than σa [2, 3]. Moreover, 2D CrSBr can exhibit strong coupling between its electronic and magnetic structure, including exciton-magnon coupling in twisted bilayer CrSBr [2, 4].

Although various studies have been conducted on CrSBr, there has yet to be definitive measurements regarding a quantum nonlinear Hall effect (NLHE). NLHE is an extension of the classical Hall effect, where a transverse Hall voltage (VH) is induced when a material carrying current is exposed to a perpendicular magnetic field. However, in NHLE, an applied electric field can induce a nonlinear VH, even without introducing a magnetic field. NHLE has been observed and predicted in various materials [5, 6], but we aim to experimentally investigate the NHLE in few-layer CrSBr.

Methods. In this project, we focused on fabricating dual-gated CrSBr transistors for the purposes of investigating whether a nonlinear Hall effect exists, as well as its dependence on temperature, carrier density, and out of plane electric field. To do so, we conducted optimization trials and referenced previous research [5, 7, 8] to develop a working fabrication process, as outlined below:

1. Perform Scotch tape exfoliation onto blank silicon substrates for crystals of few-layer graphene (FLG) and hexagonal boron nitride (hBN). Search for clean ~40 µm x 10 µm FLG and ~50 µm x 50 µm x 70µm hBN flakes.

2. Utilize PDMS viscoelastic stamping to place FLG-hBN on pre-prepared silicon substrates, leaving a segment of FLG exposed for the bottom gate (if convenient).

3. Pattern inner electrodes (e.g. in a double Hall bar geometry) using KLayout and spin-coat substrates with PMMA A4 followed by PMMA A2.

4. Expose/develop samples and deposit 8 nm of platinum using CNF tools, including the Zeiss Supra SEM, Nabity NPGS, and SC4500 Evaporator. Perform lift-off in acetone and tip-based cleaning using an atomic force microscope (Fig. 1).

5. In an oxygen- and water-free glove box, exfoliate and search for ~10 µm x 5 µm few-layer CrSBr and more hBN flakes. Stamp CrSBr flakes such that the flake contacts all inner electrodes, and stamp hBN to cover all but the exposed FLG.

6. Pattern openings to the inner electrodes. Spin-coat and expose/develop. Etch the exposed segments to remove the hBN using Oxford 81 RIF.

7. Pattern outer electrodes, a top gate, and bottom gate(s) to connect to the pre-prepared bonding pads. Spin-coat, expose/

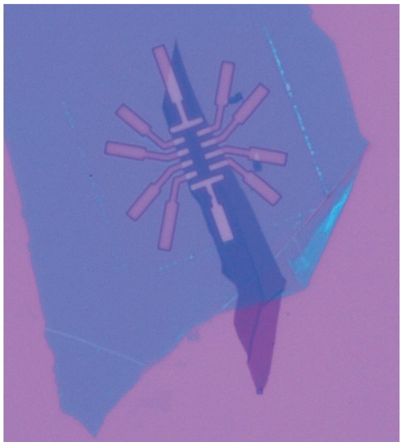

Figure 1: Image of an example of device after step 4 of the fabrication process.

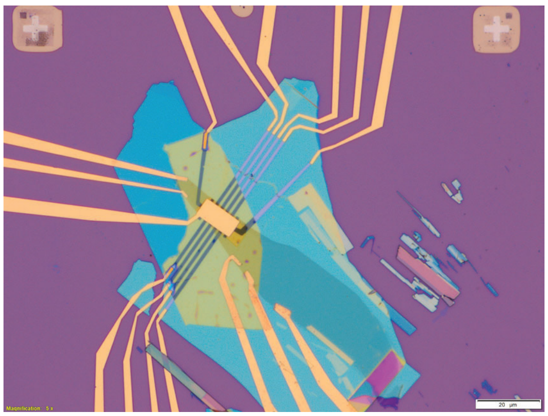

Figure 2: Image of an example device after the full fabrication process.

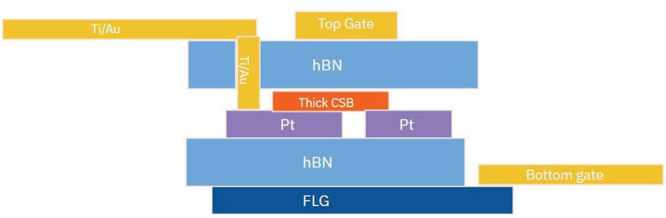

Figure 3: Transverse view of the device "stack", with colors corresponding to Figure 2.

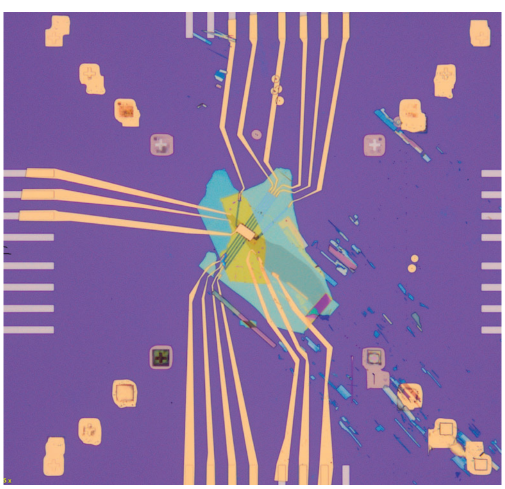

Figure 4: Zoomed-out image of Figure 2.

develop, deposit 10nm Ti/90 nm Au, and perform lift-off (Fig. 2-4).

Conclusions and Future Steps:

Through extensive testing and trial-and-error, we have established a working fabrication process for creating dual-gated 2D CrSBr devices. Despite the supposed air stability of CrSBr, the exfoliation in the glove box and complete insulation by the top hBN were required to prevent the CrSBr from degrading and losing electrical contact after several hours. Our fabrication process may also apply to other air-sensitive 2D materials with transport properties of interest.

With our obtained measurements, we aim to extract the conductivity tensors of few-layer CrSBr in the near future. Further studies can be conducted to verify the obtained results improve the fabrication efficiency.

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