Magnetic Imaging of Ionic Liquid Gated Transition Metal Dichalcogenides

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Primary CNF Tools Used: Heidelberg DWL2000, SC4500 evaporators, JEOL 6300, Veeco Icon AFM, Oxford 81

Abstract:

We report progress on developing superconducting ionic liquid-gated MoS_2 devices compatible with scanned probe microscopy. We have developed a spin-on ionic gate for our MoS_2 devices, allowing us to push the material into the metallic regime. We discuss progress on improving our nanofabrication to observe superconductivity.

Summary of Research:

Atomically thin exfoliated molybdenum disulfide (MoS_2) devices have been reported to superconduct at an *n*-type charge carrier density of ~ 10^{14} cm^{-2} [1] with a critical temperature of approximately ~ 2 K in a monolayer [2]. To achieve the high charge carrier density ionic gating has been employed in the literature, and we wish to replicate this approach while adapting it to be compatible with mesoscale imaging. Our group is interested in imaging the magnetic response of the superconducting state, using scanning Superconducting QUantum Interference Device (SQUID) microscopy.

This technique can be used to measure the superfluid density of a superconductor as a function of temperature, which can reveal information about the order parameter [3]. Recent work on superconducting MoS_2 indicates the order parameter may not be fully gapped, suggesting a non-Bardeen-Cooper-Schrieffer (BCS) superconducting state [4]. Superfluid density measurements would complement the existing data, further illuminating the nature of the order parameter of this system.

Our device fabrication is performed in the CNF. First, optical contact lithography is used to pattern liftoff resist for bond pads, long leads from the device area to the bond pads, and a large gate for biasing the ionic liquid. A completed device is shown in Figure 1 which includes these features. The SC4500 electron beam evaporator is then used to deposit a Ti/Pt/Au trilayer. The gold is wet etched in the gate region, exposing the platinum. Thus, the device side of the electrolytic capacitor is gold, and the gate side is platinum, with the aim of minimizing electrochemistry during gating. Using the polymer stamp transfer techniques developed for graphene heterostructures [5], MoS_2 flakes are transferred onto these prepatterned substrates, and any polymer residue is removed by a chloroform dip. Then, contacts are patterned to the flake using the JEOL 6300 electron-beam lithography system, connecting it to the long leads and bond pads. These contacts are then metalized in the SC4500 with Ti/Au.

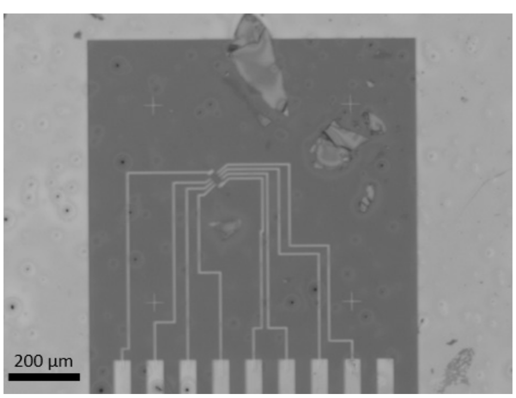

Figure 1: Spin-coated 380 nm ionic gel on MoS_2 few-layer device. Large surrounding metallic region is Pt gate, bars at bottom of image are optically patterned leads to bond pads.

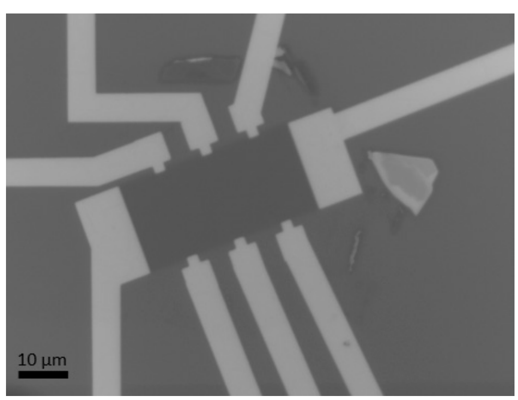

Figure 2: Few layer MoS_2 device fabricated by the authors.

Next, a Hall bar geometry is defined with the JEOL 6300, and the Oxford 80 is used to etch the MoS_2. Finally, a vacuum bake is used to remove any residue from the devices. A completed MoS_2 device before liquid gating is shown in Figure 2.

In our lab, an ionic gel is prepared from diethylmethyl(2-methoxyethyl)ammonium bis(trifluoromethylsulfonyl) imide (DEME-TFSI) and polystyrene-poly(methyl methacrylate)-polystyrene (PS-PMMA-PS). In an inert atmosphere, this gel is spun onto the devices, covering the MoS_2 flake and the platinum gate. The device is then transferred into a measurement cryostat insert with < 15 minutes of total air exposure, and pumped on for > 12 hrs at room temperature to remove water. The devices are then cooled to 4 Kelvin using a helium-4 cryostat, to determine if they are superconducting. An integrated variable temperature stage allows the sample temperature to be increased to the melting point of the ionic liquid (220 K) as it is insensitive to gate voltage changes below that temperature. We have not yet observed superconductivity in our devices, but are actively working on this issue.

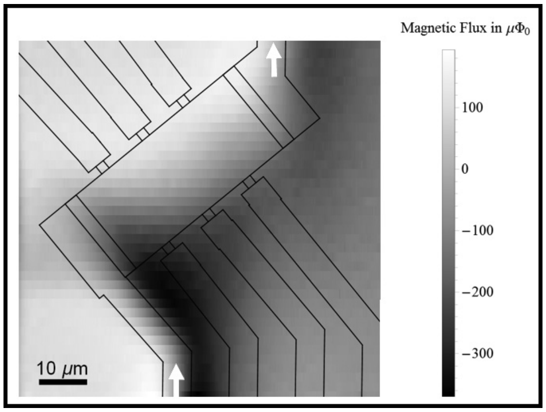

Figure 3: Scanning SQUID image of ionic liquid gated, metallic MoS_2 device. White arrows indicate current source and drain, black outline is device shape. Sample temperature approximately 10 Kelvin.

Magnetic imaging is performed in our 4 Kelvin cryogen-free scanning squid microscope. By spinning the gel to < 500 nm thick, we can image magnetism from currents flowing in the MoS_2 flake. Figure 3 shows such a magnetic image of one of our liquid-gated devices.

As we continue to improve our processing, we hope to soon observe superconductivity in these devices. We are working to ensure all our chemical processing is fully compatible with the MoS_2, as the superconductivity is expected to exist primarily in the first few atomic layers of the MoS_2 flake [1], which we suspect would make it sensitive to chemical processing during fabrication. We also suspect that the time in vacuum at ambient temperature may be insufficient to remove water absorbed from the air, and are working on developing a bake in the measurement cryostat to remove water from the gel.

References:

[1] J. T. Ye, et al., Science 338, 1193 (2012).

[2] D. Costanzo, et al., Nature Nanotechnology 11, 339 (2016).

[3] J.A. Bert, et al., PRB Vol 86 (2012).

[4] D. Costanzo, et al., Nature Nanotechnology 13, 483-488 (2018).

[5] P. J. Zomer, et al., Appl. Phys. Lett. 105, 013101 (2014).