Magnetic Imaging of Ionic Liquid Gated Transition Metal Dichalcogenides

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Abstract:

We report fabrication of superconducting ionic-liquid (IL) gated MoS_2 devices compatible with scanned probe microscopy (SPM). Using a spin-coated IL gate, the thickness of the ionic layer is reduced to less than 0.5 micron, enabling local magnetic measurements of the superconducting state.

Summary of Research:

Atomically thin exfoliated 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, however, this prevents scanned probe measurements due to the macroscopic thickness of the ionic gate on top of the device. 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].

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 [4], 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. 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 the left 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 spin-coated onto the devices, covering the MoS_2 flake and the platinum gate. The device is then transferred into a scanning SQUID microscope and is dessicated under high vacuum for 24 hours before cooldown. Upon cooling to < 10 Kelvin, a superconducting transition is observed. We have measured both DC magnetization and AC magnetic susceptibility of these devices, a first in a van der Waals superconductor. On the right in Figure 2, the AC susceptibility of a device is shown. Positive signals correspond to diamagnetism. The white dashed outline is the device geometry.

Magnetic measurements of the superconducting state are still a work in progress. Magnetic features suggestive of vortex-vortex interactions, including a Berezinskii-Kosterlitz-Thouless transition, are observed but not shown. We continue to improve and refine these measurements and their analysis.

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

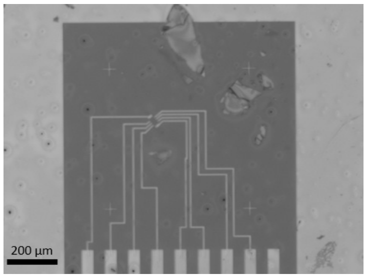

Figure 1: Spin-coated 380 nm ionic gel on MoS_2 few-layer device. Large surrounding metallic region is Pt gate, bars at bottom of image are optically patterned leads to bond pads.

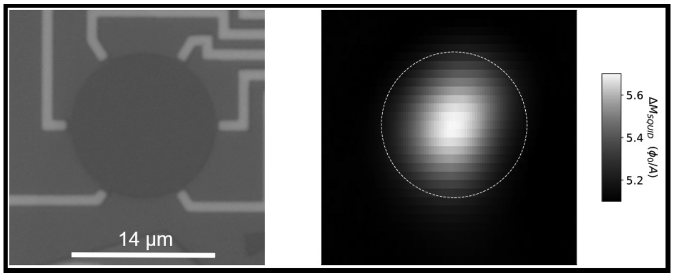

Figure 2: Left, optical image of few layer MoS_2 device fabricated by the authors. Right, magnetic susceptibility map of the same device, as acquired by scanning SQUID microscope.