Electrostatic Gating of MBE-Grown $NdTiO_3$ Thin Films

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Abstract:

With the emergence of ionic gel gating in an electric double-layer transistor, materials that could not be easily chemically doped, or had significant structural changes upon being doped, can now be examined. Neodymium titanium oxide ($NdTiO_3$ or NTO) is a Mott-Hubbard antiferromagnetic insulator, with the insulating state being sensitive to doping and chemical distortions. This experiment explores the use of ionic gel gating to investigate the insulator-to-metal transition in NTO thin films using electrostatic doping. Single crystalline, epitaxial NTO films were grown onto an insulating substrate using a hybrid molecular beam epitaxy technique. The device was patterned using two shadow masks, one for etching with ion milling and the other to deposit metal contacts with sputtering. The ion gel, 1-ethyl-3-methylimidazolium-bis (trifluoromethylsulfonyl) imide (EMI-TFSI), was placed on top of the patterned NTO films and electronic measurements were taken in an electromagnet. Voltage-dependent leakage current through the ionic gel was established, allowing for calculation of injected charge. Temperature-dependent resistivity measurements were performed for each gate bias.

Introduction:

Perovskites, having the general chemical formula of ABO_3, are characterized by a wide range of fascinating functionalities including superconductivity, thermoelectricity and a metal-to-insulator transition. $NdTiO_3$ (NTO), a pseudo cubic perovskite, is a Mott-Hubbard antiferromagnetic insulator with the insulating state being sensitive to doping and chemical distortions. Past research has found a Mott transition induced by chemical doping using holes [1], although it was accompanied by distortions in the structure. These structural distortions may influence the electronic transport properties of NTO; therefore, this experiment used ionic gel to minimize any distortions in the lattice parameters. This experiment was designed to inject electrons and holes using an external bias to control the insulator to metal transition of NTO.

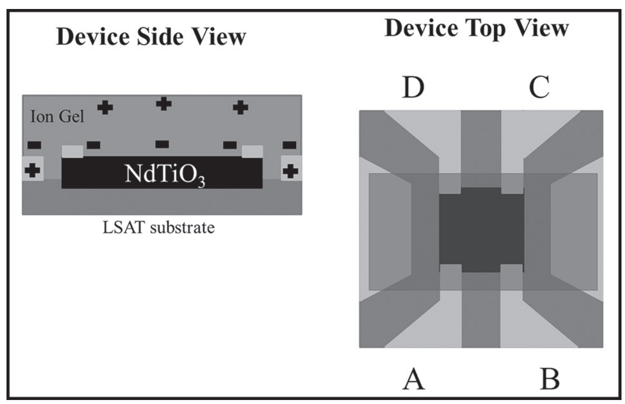

Figure 1: A schematic of the NTO device designed for electrostatic gating using Van der Pauw measurements and side gating.

Experimental Procedure:

A hybrid molecular beam epitaxy technique was used to grow single crystalline, epitaxial neodymium deficient NTO film onto lanthanum aluminate–strontium aluminium tantalite (LSAT), an insulating substrate [2]. A shadow mask was placed over the NTO film and ion milling was used to etch the desired pattern so that Van der Paw geometry could be used to determine resistance. A second shadow mask was positioned to deposit the metal contacts, 40 nm of titanium followed by 100 nm of gold, with sputtering. The ion gel, 1-ethyl-3-methylimidazolium-bis (trifluoromethylsulfonyl) imide (EMI-TFSI), was placed by hand on top of the patterned NTO film, a schematic of the device is shown in Figure 1. The electronic measurements were controlled with a LabView program using a Keithley source-meter K-2400 and electrometer K-6514. Advanced Research Systems cryostat and GMW 5403 electromagnet were used for the temperature dependent measurements. Resistance measurements were taken before device development, once the ion gel was applied and throughout the gating process. The gate voltage was changed at 290 K, when the ion gel was not frozen, and the gate current was measured

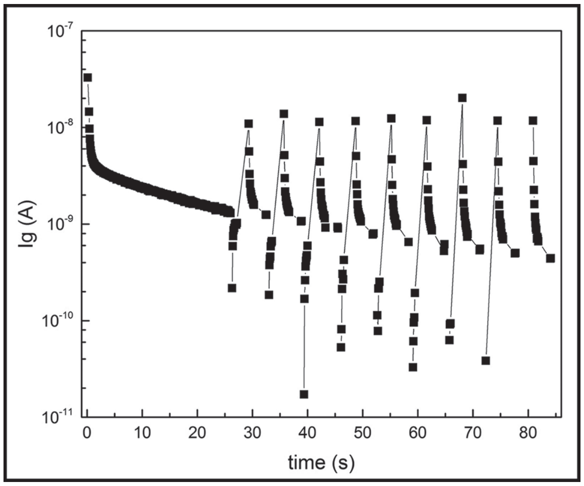

Figure 2: The gate current was measured with respect to time when the gate voltage was changed from -1 to 0 V at 290 K and is representative of the other gate current measurements. The periodic noise was a result of measuring the resistance with van der Pauw geometry, thus applying an alternating current.

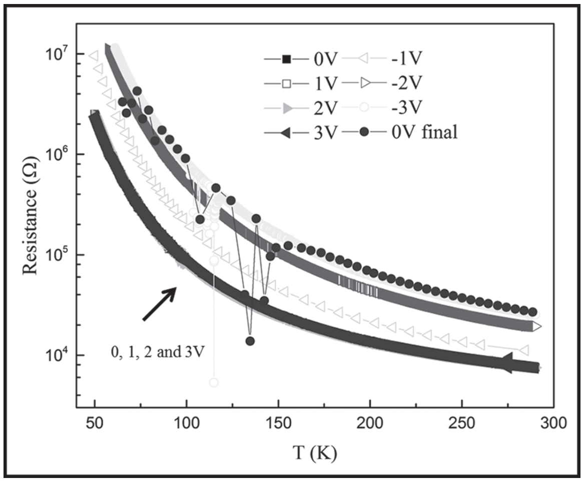

Figure 3: Resistance of NTO was measured with respect to temperature in an electromagnet. The positive gate voltages corresponded with electron injection and no noticeable change in resistance was observed. The negative gate voltages, hole injection, corresponded with an increase in resistance that remained high when the gate voltage was returned to zero.

as a function of time. The device was then cooled to 50 K and resistance versus temperature was measured up to 290 K, at which point the gate voltage was altered and the process repeated.

Results and Conclusions:

The gate current was integrated with respect to time to determine the charge injected, verifying that positive gate voltages resulted in electron injection while negative gate voltages resulted in hole injection. The data was not clean due to measuring resistance, thus applying a current, too early. This created periodic noise in the data, as seen in Figure 2, which affected the calculation of charge injection.

The resistance data from the experiment was compared to determine the effects of electrostatic gating on NTO. It was determined that positive gate voltages, electron injection, did not change the resistance of the sample, evidenced in Figure 3, while the resistance increased with negative gate voltages, hole injection. At this point it is unclear if these trends are due to electrostatic or electrochemical properties.

NTO thin film was successfully patterned with ion milling and an ion gel was applied. Electrostatic gating resulted in an increase in resistance with hole injection, while electron injection had no observable change in resistance.

Future Work:

In continuing this research, different gate voltages should be examined to develop a better understanding of the entire system. Larger positive gate voltages should be used to determine if NTO can be affected by electron injected using electrostatic gating. Negative gate voltages should be examined in further detail to determine if there is a maximum and at which point it is no longer reversible. The increase in resistance, which accompanied the negative gate voltages, should be examined for evidence of degradation. Other samples of NTO with different neodymium vacancies should be used to determine the effect of stoichiometry. Future research should also examine the effect of ion gel on NTO.

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References:

[1] Sefat, et al., Phys. Rev. B 74, 104419 (2006).

[2] Xu, et al., Appl. Phys. Lett. 104 082109 (2014).