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14. ABSTRACT Electrostatically modulating the carrier density of semiconductors, where the physics is relatively simple and well-understood, has long been the foundation for electronic devices. What if we could apply these techniques to a much broader range of materials? This short grant aimed at demonstrating such large potential modulations in correlated electron materials using a technique known as electrolyte gating. This plan built on my group's recent demonstration of electrolyte gating in Strontium Titanate, using an atomically thin hexagonal Boron Nitride barrier to prevent disorder and chemical modification of the surface of the Strontium Titanate during the electrolyte gating.					
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Report Title

Final Report: STIR: Novel Electronic States by Gating Strongly Correlated Materials

ABSTRACT

Electrostatically modulating the carrier density of semiconductors, where the physics is relatively simple and well-understood, has long been the foundation for electronic devices. What if we could apply these techniques to a much broader range of materials? This short grant aimed at demonstrating such large potential modulations in correlated electron materials using a technique known as electrolyte gating. This plan built on my group's recent demonstration of electrolyte gating in Strontium Titanate, using an atomically thin hexagonal Boron Nitride barrier to prevent disorder and chemical modification of the surface of the Strontium Titanate during the electrolyte gating. During the course of this grant, we refined our exfoliation techniques and learned to apply thin hexagonal Boron Nitride to single crystals of materials expected to show some of the most exciting correlated electron behavior which could be modulated by gating: spin liquids (e.g. a layered Sodium Iridate compound) and multiferroics (e.g. Bismuth Ferrite). We did not complete the process of electrolyte gating such materials, but did make important progress on it.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

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Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

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TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

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(d) Manuscripts

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TOTAL:

Number of Manuscripts:

Books

Received Book

TOTAL:

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TOTAL:

Patents Submitted

Patents Awarded

Awards

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Names of Post Doctorates

<u>NAME</u>	<u>PERCENT_SUPPORTED</u>
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME

PERCENT SUPPORTED

FTE Equivalent:

Total Number:

Names of Under Graduate students supported

NAME

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Names of other research staff

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Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

Technology Transfer

STIR: Novel Electronic States by Gating Strongly Correlated Materials

David Goldhaber-Gordon, Stanford University

W911NF1410375, Army Research Office

Electrostatically modulating the carrier density of semiconductors, where the physics is relatively simple and well-understood, has long been the foundation for electronic devices. What if we could apply these techniques to a much broader range of materials? Strongly-correlated materials, where the electrons behave collectively rather than as independent particles, have a much richer and less well-understood landscape of phases. The physics of strongly-correlated materials is at the heart of some of the most important current problems in condensed matter physics, and Army interest in these systems is reflected in heading 6.1.1 of the BAA. For example, electron interactions can turn materials that are expected to be metals into insulators. Advances in modern electronics already depend on systems of electrons that do not behave independently from one another. Applying field-effect gating techniques to modulate chemical potential could allow us to explore a broad range of strongly-correlated systems in a novel way.

In conventional electrostatic gating, the breakdown voltage of the oxide dielectric that separates the gate from the channel limits induced electron density changes to approximately 10^{13} cm^{-2} . This is sufficient to gate semiconducting materials, where the electronic bandgaps and charge carrier densities are small. Because energy scales in strongly-correlated systems are generally much higher, order-of-magnitude greater swings in potential or density are required to modify the electronic properties and tune through interesting phase transitions. Chemical doping of strongly-correlated systems can achieve these large density swings, and has led to remarkable phenomena.

This short grant aimed at demonstrating such large potential modulations in correlated electron materials using a technique known as electrolyte gating. This plan built on my group's recent demonstration of electrolyte gating in Strontium Titanate, using an atomically thin hexagonal Boron Nitride barrier to prevent disorder and chemical modification of the surface of the Strontium Titanate during the electrolyte gating. During the course of this grant, we refined our exfoliation techniques and learned to apply thin hexagonal Boron Nitride to single crystals of materials expected to show some of the most exciting correlated electron behavior which could be modulated by gating: spin liquids (e.g. a layered Sodium Iridate compound) and multiferroics (e.g. Bismuth Ferrite). The challenges involved in trying to do subsequent lithographic patterning on irregularly shaped, millimeter or smaller single crystals proved formidable, so we decided to fall back to electrolyte gating of insulating (small gap) single crystals and conductive films. While we were not able to electrolyte gate other complex oxides in the ~6 month run of the grant, we succeeded in electrolyte gating graphene, apparently without strong suppression of mobility. This offers the near-term prospect of a material with better room temperature conductivity than the best known conductors (silver and copper). This was not the main aim of the grant, and has still not been published, but is an important step

toward the target of gating a wide variety of materials without worrying about chemical compatibility and interaction between electrolyte and substrate, and without generating substantial disorder.

One graduate student was partly supported on the grant. He should graduate in the next 1.5 years. One researcher who had just finished undergraduate studies was also supported. He has been admitted to Ph.D. programs in Physics, largely based on research performed under this grant, and will likely attend one in the Fall.