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Functional Nanostructured Strongly Correlated Solids

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14. ABSTRACT

This project was dedicated to the synthesis and investigation of a very promising class of strongly correlated quantum materials. The approach we utilized went beyond serendipitous discovery of new properties, but used deliberate, proven techniques, that lead to the discovery of novel functionalities non-existent in nature. To get a fundamental understanding of their properties we studied the effect of charge injection and external strain in a variety of configurations. We developed new functionalities by applying external driving forces such as steady state and dynamical electric fields, light, and temperature on properly engineered nanostructured, strongly correlated materials. These studies have major effects on potential applications in the field of microelectronics and novel computer paradigms.

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FINAL REPORT
AFOSR FA9550-20-1-0242
Principal Investigator: Prof. Ivan K. Schuller
Institution: UCSD
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1. Accomplishments

DETAILS

- **Major activities;**

  This project was dedicated to the synthesis and investigation of a very promising class of strongly correlated quantum materials. The approach we utilized went beyond serendipitous discovery of new properties, but used deliberate, proven techniques, that lead to the discovery of novel functionalities non-existent in nature. To get a fundamental understanding of their properties we studied the effect of charge injection and external strain in a variety of configurations. We developed new functionalities by applying external driving forces such as steady state and dynamical electric fields, light, and temperature on properly engineered nanostructured, strongly correlated materials. These studies have major effects on potential applications in the field of microelectronics and novel computer paradigms.

- **Specific objectives;**

  We investigated and developed novel functional materials and devices using strongly correlated quantum materials. The comprehensive approach combined **preparation** of nanostructures using thin film (Sputtering and MBE) and lithography (electron beam and self-assembly) techniques, **characterization** using surface analytical, scanning probe microscopy, high-resolution quantitative X-ray scattering and microscopy techniques and **measurement** of physical properties (steady state and fast time dependent magnetotransport, and magnetooptical). All preparation of unique materials and devices and structural and physical characterization were performed in the PI's laboratory at UCSD. We have established a battery of instrumentation and continue expanding our experimental capabilities at UCSD and elsewhere. This provides an important infrastructure for future state of the art work in the field.

  We investigated general physical phenomena, including; **a)** induced phenomena by the application of external driving forces such as time varying electric and magnetic fields, light and other types of radiation and **b)** developed unique structures which exhibit new and useful functionalities. In all cases, a crucial ingredient was the reduction of complex or highly correlated materials to the nanoscale, or their incorporation into spatial inhomogeneous geometries (heterostructures) where fundamental changes may occur in their physical properties. The classes of materials we investigated include strongly correlated transition metal oxides, nitrides and fluorides. In addition to steady state experiments, we performed unique time dependent experiments to investigate the very unusual dynamics present in many hybrid strongly correlated system

- **Significant results or key outcomes, including major findings, developments, or conclusions (both positive and negative);**

  Highlights from this research include:

1. Discovered that the Schottky barrier between the strongly correlated LSMO and the ferroelectric BTO can be modified by application of ultraviolet light.
2. Showed that cobaltite thin films undergo so called topotactic transformation as a function of oxygen concentration.
3. We showed that the metal-insulator transition of a strongly correlated vanadate (V_2O_3) is governed through the transfer of spectral weight in the electronic structure
4. We demonstrated that in one of the vanadates (V_3O_5) the metal insulator transition can be triggered purely by electric means.
5. We managed to add additional optical functionality in the strongly correlated V3O5 by incorporating it into a heterostructure with photosensitive CdS
6. In a series of papers, we have performed an experimental theoretical study of the local hysteretic properties of strongly correlated oxides
7. We have developed and validated a highly sophisticated method for the control of Oxygen stoichiometry in complex oxides.
8. We have investigated the spatial distribution of ramp reversal memory in oxides.

DISEMINATION

The research was disseminated through a series of papers in the first class refereed literature, talks at major conferences, lectures at other research institutions, participation in committees in relevant committees and organization of conferences in the field.

2. Impacts

1) Development of discipline

The types of materials we studied include highly correlated oxides in a variety of configurations, we developed measurements of electronic structure of highly correlated materials, and have developed highly sensitive transport measurements of highly correlated oxides. In addition we developed a gas dosing system which allows for highly controlled method to incorporate oxygen in complex materials,

2) Other disciplines

The research done here has impact especially in the field of, microelectronics, electrical engineering, sensors and hardware development for novel computing schemes. These fields are impacted because many advances are based on the development of new materials with novel functionalities as pursued in this project. As an example, we have applied the gas evolution technique developed under this grant to support and validate research on batteries.

3) Human resources

It is very important to point out that many students and postdocs working under this project are presently employed in the high-tech industry or as educators in science and technology. These has a highly multiplicative effect.

4) Teaching and educational

The young investigators involved in this research are trained in the development and use of state-of-the-art high technology techniques which form the basis of important future science and engineering. This is especially important in the field of microelectronics and novel computing.

5) Infrastructure

We have developed state of the art techniques to: synthesize unique oxide systems, control and modify oxygen stoichiometry, and unique interfaces between complex materials. These techniques was used for much of the research done under this project and remains available as an important infrastructure at UCSD for future related research.

6) Impact on society

The development of new science expands the understanding of science and technology by the public in general and provide quantitative analysis techniques of societal problems. The research done here also explains and extends in a natural way to future technologies which potentially can benefit society in an important and transformative way. The PI has spent considerable effort in outreach to the general public to explain the importance and impact of this type of research in daily life. In addition, the PI has produced over the years full length and you tube videos explaining complex physical phenomena to the public in general.