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as of 24-Jul-2018

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Proposal Number: 60051MSSR **Agreement Number: W911NF-04-D-0003**

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Final Report for Period Beginning 15-Sep-2011 and Ending 14-Mar-2017
Title: The Physics and Chemistry of Graphene-Functional Oxide Interfaces
Begin Performance Period: 15-Sep-2011 **End Performance Period:** 14-Mar-2017
Report Term: 0-Other
Submitted By: Daniel Dougherty Email: dbdoughe@ncsu.edu
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Distribution Statement: 1-Approved for public release; distribution is unlimited.

STEM Degrees: **STEM Participants:**

Major Goals: The project explores the creation and characterization of oxide films on graphene. In the final project year, this goal was extended from graphene to the broader class of 2D materials. For this reason, we also moved to incorporate new electronic structure characterization tools as described in the final report.

Accomplishments: See uploads

Training Opportunities: Graduate student Dan Nevola was trained in the installation and calibration of advanced time and angle resolved photoelectron spectroscopy.

Results Dissemination: Nothing to Report

Honors and Awards: Nothing to Report

Protocol Activity Status:

Technology Transfer: Nothing to Report

PARTICIPANTS:

Participant Type: Graduate Student (research assistant)
Participant: Daniel nevola
Person Months Worked: 12.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

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Article Title: Magnetoelectric oxide films for spin manipulation in graphene
Authors: S. C. Stuart, B. Gray, D. Nevola, L. Su, E. Sachet, M. Ulrich, D. B. Dougherty
Keywords: magnetoelectrics, spintronics, Cr2O3, films, graphene, spin field effect transistors, scanned probe microscopy
Abstract: The challenge of creating a graphene spin field effect transistor (spin-FET) demands a magnetic gate dielectric material whose magnetization can be switched electrically. We have grown films of Cr2O3 on top of graphite and graphene by pulsed laser deposition that shows this crucial functionality. We demonstrate that the Cr2O3 films are magnetoelectric by poling them in combined electric and magnetic fields and then using magnetic force microscopy to observe spontaneous surface domain structure as a function of poling field. In addition, we show that the electric field created by a conducting AFM tip can be used to write magnetic patterns in the film that demonstrate the kind of continuous magnetoelectric control needed for a prototype spin-FET.
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Marc S. Ulrich and Daniel B. Dougherty

Overview:

In the final project period, research efforts were re-directed to the installation and calibration of an advanced electronic structure and dynamics characterization facility aimed at 2D materials and complex oxide films. This materials focus is a natural extension of the earlier project work integrating graphene with magnetic oxides. It pushes research in a direction that is more broad than the original scope of the project but that address similar advanced materials needs relevant to Army interests in computing, information processing, and sensing.

Activities:

The new electronic structure and dynamics characterization facility integrates time resolved two photon photoemission spectroscopy (2PPE) and traditional angle resolved photoemission spectroscopy (ARPES) in a redesigned ultra-high vacuum system. This system is coupled to an ultrafast pump-probe laser system for the 2PPE excitation and includes UHV sample preparation and characterization facilities (especially low energy electron diffraction for k-space alignment of samples).

During the final project period, a new hemispherical electron spectrometer (Specs PHOIBOS 150) with 2D detector for ARPES was coupled to an existing UHV system and integrated with an ultrafast laser spectroscopy lab (Prof. K. Gundogdu). This required extensive modification to the geometry, pumping, and bakeout scheme of the vacuum system. After the physical modifications and installation, calibration of the photoelectron system was carried out on standard reference samples.

Outcomes and Future Work:

The new instrumentation was successful installed and calibrated over the course of the final project period. Figure 1b shows a reference band map of the famous surface state on Au(111) that demonstrates the performance of the electron spectrometer and 2D detector for ARPES. This is the crucial capability in characterizing electronic structure of 2D materials such as graphene and transition metal dichalcogenides. In addition, the time resolved dynamical capabilities have been calibrated using reference oxide samples. Figure 1b shows the determination of temporal beam overlap on such a surface that is the starting point for dynamic studies. Planned future experiments include the characterization of surface doping effects on 2D materials and the band structure of 2D magnetic materials.

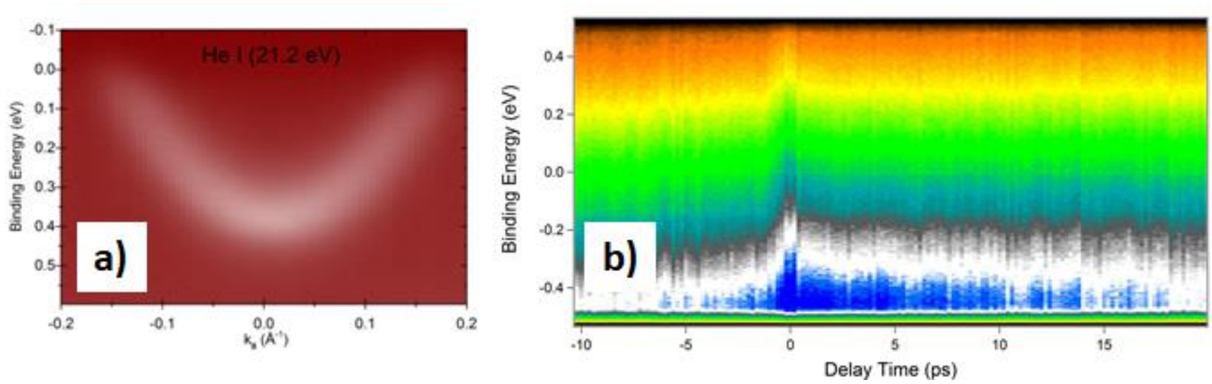

Figure 1. a) Band structure of Au(111) for calibrating ARPES; b) Time scan showing zero delay overlap in pump-probe 2PPE on a reference oxide.