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PNNL-30284

New Quantum Phenomena by Combining 2D Materials with Complex Oxides

August 2020

Scott Chambers
Peter Sushko,
Tim Droubay

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Project background:

- Heterojunctions of electronic and magnetic materials have been the basis for many important scientific discoveries (quantum Hall effect, giant magnetoresistance) and technological innovations (high-speed transistors, laser diodes, photodiodes, GMR sensors).
- Very little has been done on heterojunctions of epitaxial oxides and 2D materials.

Project goals:

- To enhance the magnetic properties of isolated 2D materials by controlled synthesis.
- To explore of the magnetic & electronic properties of 2D materials upon interaction with magnetic oxides.
- To gain atomic-scale insight into 2D magnets by first-principles modeling.

Project team (complete list of participants)

- Xiaodong Xu, Jiun-Haw Chu, David Cobden, Daniel Gamelin, Xiaosong Li, Michael De Siena*, Ryan Beck*, Jiayi Zhu*, (UW -- *postdocs and graduate students).
- Scott Chambers, Peter Sushko, Tim Droubay (PNNL).

Research design and methodology:

- Colloidal nanoplatelet [CrI_3, $CrBr_3$, $Cr(I_{1-x}\ Br_x)_3$] and single-crystal (Fe_3GeTe_2) synthesis of 2D materials
- Molecular beam epitaxial (MBE) growth of single-crystal oxide films (NiO, a-Cr_2O_3, Fe_3O_4)
- 2D material/oxide clean interface formation by storage and transfer in N_2
- Materials characterization by XPS, XRD, HRTEM.
- Magnetic characterization by reflective magnetic circular dichroism (RMCD), vibrating sample magnetometry (VSM) and electronic transport.
- First-principles modeling by density functional theory (DFT).

Results:

- First observation of robust ferromagnetism in a 2D material with nanometer lateral dimensions.
- Magnetic interactions in quasi-two-dimensional $CrI_{3-x}Cl_x$ from DFT.
- Establishment of 2D material/oxide electronic device fabrication capability.
- Observation of exchange bias at the interface of a 2D material ferromagnet and an oxide antiferromagnet.

Publications:

- De Siena, Creutz, Regan, Malinowski, Jiang, Kluherz, Zhu, Lin, De Yoreo, Xu, Chu, Gamelin, *Nano Lett.*, 2020, *20*, 2100.
- Two other papers in preparation, but not likely to be done this FY.

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