Developing Surface Micro-Spectroscopy to study Nanomaterials' Electronic Structure

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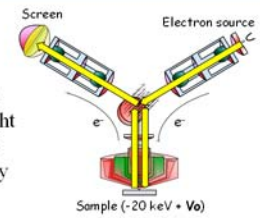
Introduction

The mechanical, optical, and electronic properties of nanomaterials are often distinctively different from their parent materials, and can be strongly affected by their size, shape, and the surrounding environment. The objective of our activities is to develop a spectroscopy tool to evaluate the electronic properties of individual nanomaterials using a microscope with nano-meter resolution. We realize this goal by using surface electron microscopy commonly called low energy & photoemission electron microscopy (LEEM-PEEM).

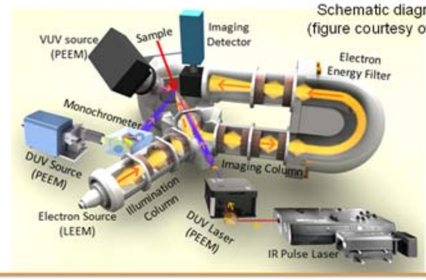
A wide range of materials can be investigated using LEEM-PEEM with a variety of image contrast mechanisms including electron scattering, thermionic emission, and photoemission processes. We focus on using the photoemission process, which is sensitive to the occupied electronic states, to investigate nanomaterials' electronic properties. Detailed understanding of the electronic properties allows us to devise new approaches to use nanomaterials in electronics and opto-electronic components.

Low energy & photoemission electron microscopy

Basic components of low energy & photoemission electron microscopy (LEEM-PEEM) include an electron source, a separator, an objective lens, a sample, and a detector. A number of light sources have been added to the LEEM-PEEM at CINT to enhance its capability to study electronic properties.

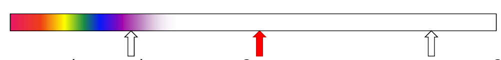


Schematic diagram of LEEM (figure courtesy of F. El Gabaly)



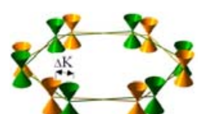
Light source development

Because the photoemission cross section varies considerably for different wavelengths in the deep UV (DUV) and vacuum UV (VUV) regimes, PEEM measurements using various light sources can provide a wealth of information regarding the electronic properties of materials. To exploit this unique aspect of photoemission, we are developing various light sources coupled to the LEEM-PEEM.



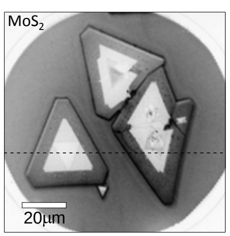
Tunable CW DUV & CW VUV light sources

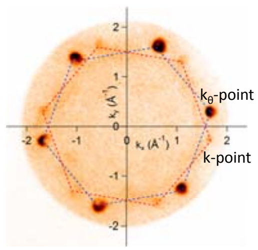
We image nanomaterials in real space and in diffraction space to see the local variations of the electronic states and the electronic dispersion.



Li et al., Nature Physics 6, 109 (2010)

Two examples of such imaging approaches are shown here: (below) a surface image of MoS_2 flakes composed of single, double, triple, and quadruple layers, and (right) a constant energy contour of the electronic dispersion of two overlapping graphene sheets.

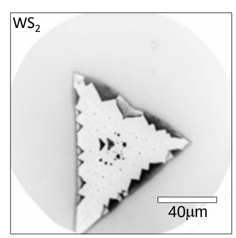




Ultrafast DUV pulse laser

Because of their nano-scale dimension and unique dielectric environment, charge carrier dynamics in nanomaterials are expected to be notably different from those in bulk materials. An established approach to determine carrier lifetimes is pump-probe spectroscopy. We aim to develop pump-probe microscopy by coupling an ultrashort pulse laser to LEEM-PEEM.

The image to the right is our first image using a 210nm femto-second laser as a DUV source. The next phase of development includes construction of an infrared delay beamline. In addition, we plan to establish light polarization control to explore the possibility of dichroic imaging to study spin polarization.



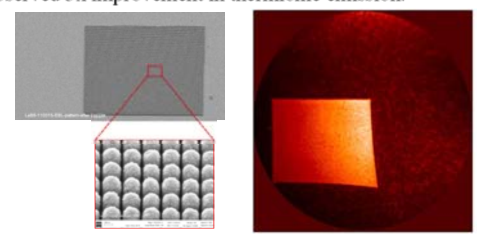
Applications of the technique

User project (RA2015A0029)

Thermionic emission of nanostructured LaB_6 surfaces

Scientific question: can we enhance thermionic emission by structuring the surface at the nano-scale?

We observed 3x improvement in thermionic emission.



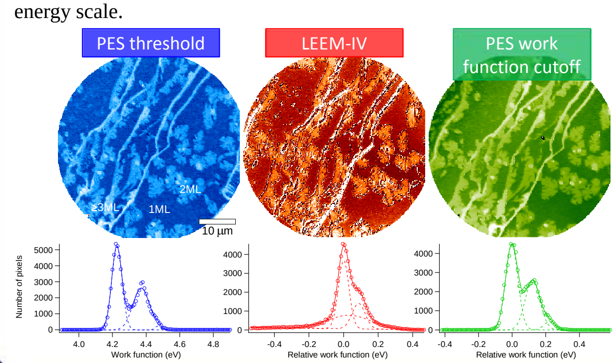
Comparing the thermionic emission from the nanostructured LaB_6 and the non-structured area at 1040C

CINT Science

Mapping work function variations of multilayer graphene films

Scientific question: how do the electronic properties of few-atom-thick films vary as a function of thickness?

We determined the work function of a metallic film on an absolute energy scale.



Contributors

The work presented here is carried out in collaboration with M. Berg and R. G. Copeland. User project RA2015A0029 is conducted by C. Mann. The MoS_2 and WS_2 work is conducted in collaboration with A. Mohite and K. Keyshar (User project U2014B0004). The work on two overlapping graphene sheets is carried out in collaboration with J. T. Robinson.

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