A New Generation of Highly Efficient Full Field Imaging Electron Spectrometers: LARIAT MKI and LARIAT MKII at NSLS-II

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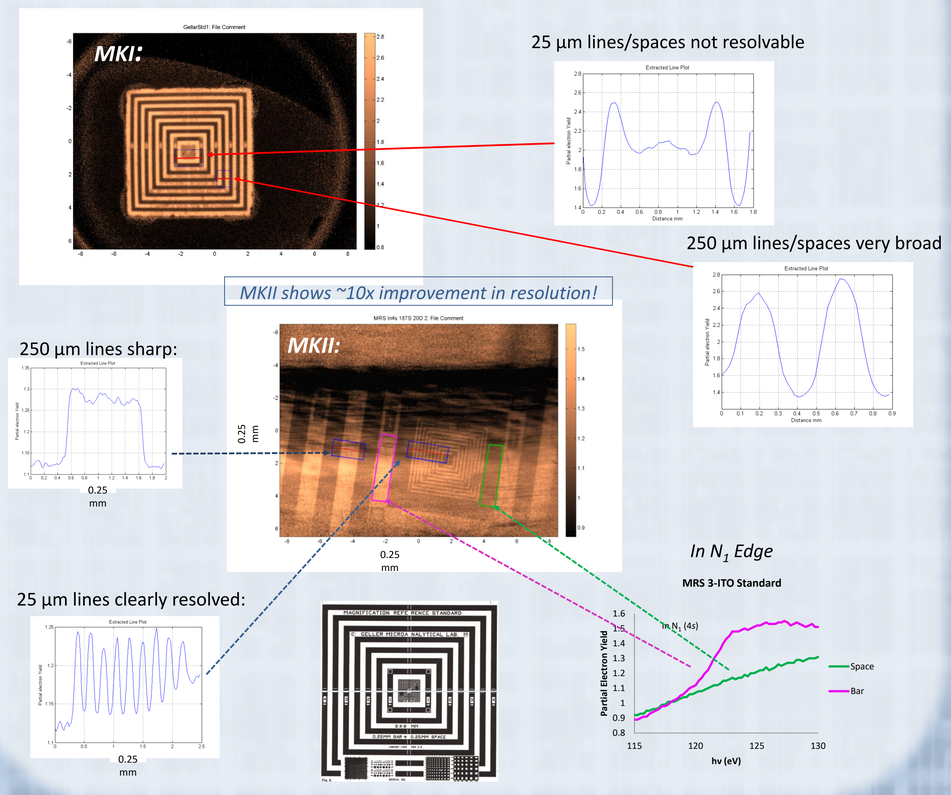
Abstract

LARIAT is an acronym for Large Area Rapid Imaging Analytical Tool. We present on the design and operation of this new class of commercially available full field imaging electron spectrometers which approach 100% transmission efficiency using either conventional electromagnets with a 1 Telsa field at the sample (LARIAT MKI) or a set of superconducting magnets with a 9 Telsa magnetic field at the sample (LARIAT MKII). This NEXAFS tool suite is currently in installation at NSLS-II on the NIST beamline at Brookhaven National Laboratory. Using a novel "beam wobble" principle, the source is painted across a large area (10x10mm on LARIAT MKI and 20x20mm on LARIAT MKII) to image the full field at 4Kx4K pixel density in 1-3 seconds per energy step. The family of chemical maps produced from each beam energy form a hyperspectral data cube with a high depth of field. Lateral resolution depends upon the magnetic field at the sample and electron energy distribution. Without energy filtering the 1T LARIAT MKI achieves ~100um lateral resolution and the 9T MKII achieves ~7um at the carbon edge. Electrostatic high pass filtering on the LARIAT MKII allows tuning of the average electron point spread function and improved spatial resolution. Reflected electrons below the cutoff energy act as an effective charge neutralizer. Both LARIAT systems are EPICS compatible with automated multiple sample handling and unattended data acquisition. A full featured data reduction system optimized for data mining of large hyperspectral data sets is common to both instruments, including principal component analysis, multi-variant spectral imaging analysis and dichroic mapping. The superconducting 9T LARIAT MKII is also capable of variable magnification in excess of 16X by adjusting the detector coil.

The latest development on the superconducting LARIAT MKII NEXAFS imaging spectrometer is a 100nm spot modality achieved using zone plate insertion device with an integral scanning stage. This novel method produces a scanning reflection x-ray microscopy (SRXM) mode. The ability to switch in-situ from full field imaging to 100nm lateral resolution in the SRXM mode combines the highly efficient "forest" perspective with the detailed "trees" perspective. We have also devised and proven a compressed sensing adaptive scanning for the SRXM mode in order to reduce the acquisition time.

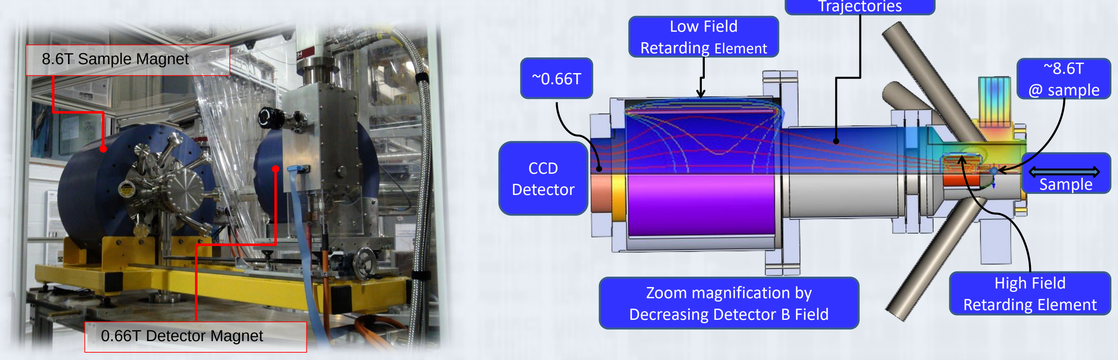
LARIAT MK I & MKII Full Field Imaging Comparison

Microscopy Standard - Cr/CrO_x Patterned on ITO (Gellar Microanalytical). Sample consists of boxes with 250 µm lines and spaces, with central boxes of 25 µm



LARIT MKII: Full Field Imaging Modality

- Full Field Imaging over 400mm² area
- 7um Lateral Spatial Resolution
- 16Mp image every 3 seconds
- Tunable magnification
- Multiple "Grid-Less" ES Filters
- Automated 4 sample carousel



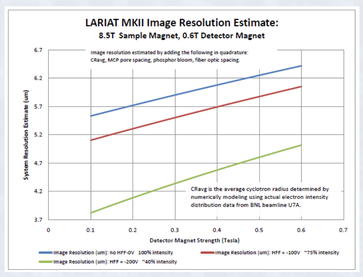
Initially proven at NSLS I Beamline U8B, the system is undergoing installation at NSLS II. The NIST SST beamline planned for NSLS II will have six end-stations including the LARIAT MKI and II microscopes. The MKII will have an accessible energy range of 100 – 1000 eV. It is also equipped with a separate ultra violet lab source to add complementary information.

Theory of Operation

The LARIAT spectrometer uses magnetic fields to "steer" electrons emitted from the sample onto a phosphor screen, which is in turn imaged with a CCD camera. Emitted electrons feel a Lorenz force, $\boldsymbol{v} \times \boldsymbol{B}$, causing them to spiral along the magnetic field lines. Grid-less electrostatic lenses create high pass filters and control information depth. Transmission function is theoretically 100% !

The detector resolution is defined by the maximum cyclotron radius, derived from electrons emitted nearly parallel to the surface. For a 250 eV electron in a 8.5 T field, the maximum radius is 6.3 µm.

$$r_c = \frac{3.4\sqrt{E_0}\cos\theta}{B_0}$$



By using divergent magnetic fields, a magnification is given. The magnification value is given by the square root of the ratio of the magnetic fields. Under typical conditions, images will be magnified at 3.8x.

$$M = \sqrt{B_0/B}$$

Features & Benefits

A Complete Turn-Key Spectrometer, Control Platform & Hyperspectral Data Analysis

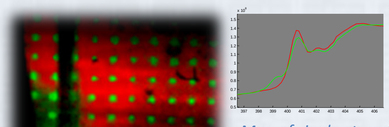
- Magnetic projection electron imaging
- Electrons follow magnetic field lines to form a parallel imaging system
- Low charging sensitivity
- EPICS Control Platform
- Wobble mirror large area scanning
- 16Mp image every 3 seconds
- Multi-Variant Analysis of Data Cubes
- Multiple "Grid-Less" ES Filters
- Automated 4 sample carousel
- Optional NanoSpotModality™
- Nearly 100% collection efficiency
- High throughput of ~725 images per hour
- Large depth of field ~1cm to image curved and recessed surfaces
- Dichroic image acquisition and data reduction
- Three gridless electrostatic energy filters provide depth and energy selectivity

NEXAFS Spectroscopy

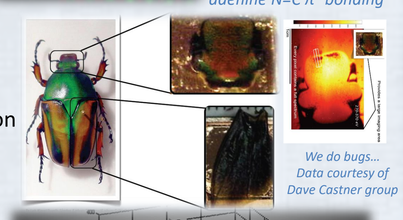
- Elemental sensitivity
- Chemical bonding selectivity
- Molecular Bond Orientation
- Near surface information

VUV Spectroscopy

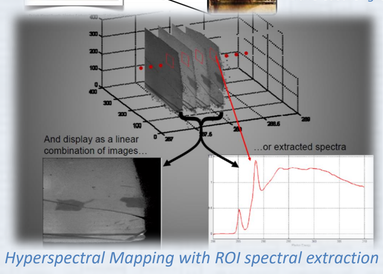
- Valence band information
- Highest lateral resolution of the spectrometer



Map of single-strand DNA according to adenine N=C π bonding*



We do bugs... Data courtesy of Dave Castner group

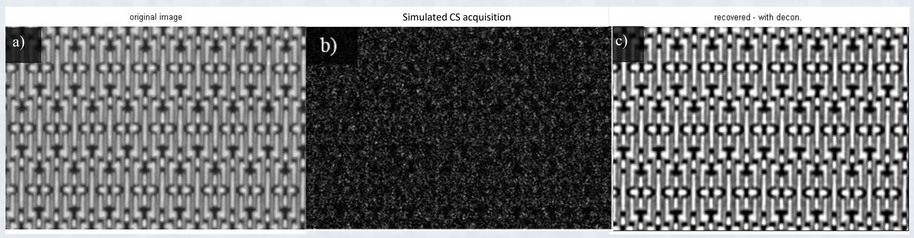


Hyperspectral Mapping with ROI spectral extraction

LARIAT MKII: NanoSpot Modality

Synchrotron Research, Inc. has developed a multiple zone plate insertion device integrated to a precision scanning stage to allow the LARIAT to change from Full Field Modality to NanoSpotModality™. The system features a precision insertion device with tunable and replaceable zone plate optics. The initial setup employs 100nm optics tuned to Carbon, Nitrogen and Oxygen. The custom design transferable sample holder compatible with the transferable sample holder on the four sample carousel. NanoSpotModality™ features include:

- X travel: ± 5 mm
- Y travel: ± 5 mm
- Z travel: ± 10 mm
- Compressed Sensing Scanning to minimize acquisition time
- Angular trajectories convert to radial distance on detector plane



Implementation of Compressed Sensing is implemented with NanoSpotModality™ to reduce scanning time by up to 80%. This is employed in combination with Point Spread Function Deconvolution of the source for optimal resolution.