Performance Achievements of the Soft X-ray Spectromicroscopy (SM) Facility at the Canadian Light Source Inc.

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Soft X-ray Spectromicroscopy Facility

➢APPLE II type Elliptically Polarizing Undulator (EPU)

Fe 2p and Co NEXAFS spectra from an Al capped Fe/Co alloy (90% Co; courtesy Y. Acreman, SSRL) recorded with left and right circularly polarized light

- Circular right and circular left polarization (100 – 1000 eV); elliptical (>80% circular) above 1000 eV
- Horizontal and vertical polarization; polarization at inclined angles from -90 to +90° (100 – 4000 eV)
- Direct user control
- Fast switching of polarization (future)

➢ Entrance slit-less Plane Grating Monochromator (PGM)

Resolving power of >10,000 for the N 1s → π transition in N_2 (g)*

- Three gratings for energy range from 100 to 2600 eV (LEG 250 l/mm: 100-400 eV; MEG 500 l/mm: 400-2600 eV; HEG 1250 l/mm:1500-2600 eV)
- Energy resolving power during normal operations is ~ 3000

➢Endstations

- **Scanning Transmission X-ray Microscope (STXM)**
- 30 nm spatial resolution with 10^8 ph/s
- Image shifts by ~100 nm for an energy scan of about 50 eV

Peak photon flux in the first order in linear horizontal polarization measured using MEG after the zone plate in STXM

Au/Si_3N_4 test object (40 nm bars; test pattern fabricated by Applied Nanotools)

➢X-ray Photoemission Electron Microscope (X-PEEM)

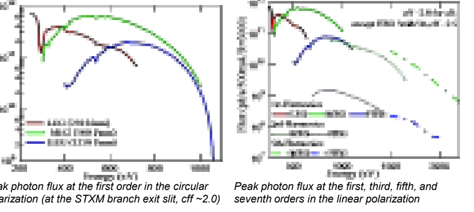
- Beam spot is <50 µm with 10^{12} ph/s, stable beam on sample over ~100 eV scan ranges
- Spatial resolution is 50-100 nm (down to 25 nm in ideal samples)
- Imaging energy filter for photoemission spectromicroscopy

Peak photon flux in the first order in circular polarization measured using MEG just after the exit slit in PEEM branch

X-PEEM image of a nickel test pattern, prepared by Applied Nanotools (www.appliednt.com). Recorded at the energy of the Ni 2p3/2 → 3d transition. The lines at the center of this pattern are 25 nm wide.

Beamline Flux

- beamline flux from 250 – 2600 eV in the fundamental, 3rd, 5th, and 7th harmonics of the EPU
- ~70% drop in flux between 275 and 285 eV due to carbon contamination of the X-ray optics

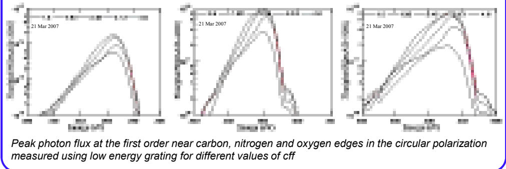


Peak photon flux at the first order in the circular polarization (at the STXM branch exit slit, cff ~2.0)

Peak photon flux at the first, third, fifth, and seventh orders in the linear polarization

Flux at C 1s, N 1s, and O 1s

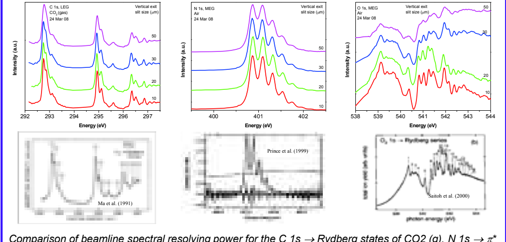
- photon flux higher at cff values between 1.75 and 2.5 at carbon, nitrogen, and oxygen edges
- second order contribution lower at cff values between 1.75 – 2.5 at carbon edge for low and medium energy gratings.



Peak photon flux at the first order near carbon, nitrogen and oxygen edges in the circular polarization measured using low energy grating for different values of cff

Resolution at C 1s, N 1s and O 1s

- resolving power >10,000 at C 1s, N 1s, and O 1s regions



Comparison of beamline spectral resolving power for the C 1s → Rydberg states of CO2 (g), N 1s → π transition in N2 (g), O 1s → Rydberg series of O_2 (compared to literature results)*

STXM – Advanced Techniques and Tools

- new techniques and tools available at SM were developed in collaboration with beam team, ALS, and users

Azimuthal Rotator *to verify polarizing properties of EPU (Hernández-Cruz et al. 2007)*

Tomography *for 3-d chemical mapping of wet and dry samples in STXM (Johansson et al. 2007)*

Inclined stage *to measure magnetic dichroism of in-plane magnetized samples*

Science with STXM

Differentiating SAN (blue) and PIPA (green) from matrix polyurethane (red) in a polymer composite sample (Comparison with ALS-STXM5.3.2)

Liquid crystal film dichroic measurements using EPU polarization variation (Kaznatcheev et al. 2007)

$CaCO_3$ biomineralization in river biofilms (Obst et al. 2007)

Science with STXM

Redox chemistry in a liquid cell (Hanhan 2007) (a) Optical image after STXM – Newton fringes indicate water in wet cell. (b) STXM image (c) Fe(II), Fe(III) water component maps from Fe 2p stack (d) extracted spectra showing both Fe(II), Fe(III) are present

Correlative microscopy of Quantum-dot labeled polysaccharides using (a) confocal, (b) STXM@CLS, (c) TEM@mac, (d) NEXAFS of Q-dots, (e), (f) TEM-EDX (Dynes et al. 2007)

Linear dichroism of a carbon nanotube revealed by inclined polarization measurements (Najafi et al. 2008)

Magnetic vortex state (~ 10 – 20 nm) resolved with 25 nm zone plates in STXM (Waeyenberge et al. 2008)

Effect of humidity on the homogeneity of the orientation of protein β-sheets in spider silk (Pézolet et al. 2008)

Science with PEEM

Polystyrene / polymethylmethacrylate blend (Urquhart et al. 2008).

PS-285.1 eV **PMMA-288.5 eV**

PEEM microscopy of a phase separated 2:1 arachidic acid : perfluoro-etradecanoic Langmuir-Blodgett thin film: (right) AFM images (lower left): Secondary electron emission spectra showing workfunction differences between phases; (lower right) SEEM images showing domains size variation with relative electron kinetic energy (Christensen et al. 2008)

-0.5 eV 0 eV +0.5 eV

Stainless steel grain boundaries in an HP45 sample after extended service (Red = Cr rich; Blue = Ni rich; Green = Fe rich). Inset: purple phase (Nb/Cr./Ni./Si composition) implicated as source of liquidation cracking by PEEM

Haines et al. 2008, sample c/o Syncrude Canada Ltd.

Magnetically patterned hard drive surface (sample courtesy Hitachi Global Storage Technologies) recorded at the energy of the Co 2p(3/2) → 3d energy with left circular polarized X-rays

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