New Opportunities for HAXPES at Diamond

Tien-Lin Lee
Diamond Light Source

Acknowledgement:

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Emily Longhi  Insertion Device Physicist
Beni Singh  Senior Accelerator Physicist
Nigel Hammond  Senior Mechanical Project Engineer
Diamond Light Source
Rutherford Appleton Laboratory (RAL)
Funded by UK Government (86%) and the Wellcome Trust (14%)
A 3 GeV machine; horizontal emittance = 2.8 nm-rad
Storage ring = 562 m in circumference (24 straight sections)
First beam in storage ring: 30th May 2006
First Users: January 2007
I06 – Nanoscience beamline

Energy ranges:

First harmonic circular 106-1300 eV
Linear horizontal 80-1500 eV
Linear vertical 130-1500 eV
Imprinting vortex domains in an antiferromagnet
Gambardella et al. ICN-CSIC, Barcelona, Spain

PEEM images showing the magnetisation profile at a Ferromagnetic (FeNi) - Antiferromagnetic (IrMn) interface. The images were recorded at the Fe and Mn L\textsubscript{2,3} edges. Note the opposite contrast at the Fe and Mn edges indicating opposite directions for the FeNi and interface Mn moments.

XMCD recorded from the areas shown by the boxes in the upper left figure. Sum rule analysis yields a value of 0.11 m\textsubscript{B}/Mn ion implying that about 60% of a Mn monolayer is pinned at the interface.

Submitted to APL.
By pulsing a current through a nanostripe a domain wall can be moved and imaged using X-Ray Magnetic Circular Dichroism with the PhotoEmission Electron Microscope. Depending on the dimensions of the nanostripe the domain wall moves by spin or momentum transfer and by different amounts.

**Domain wall pinning at a T-junction**
This image is 2\mu m wide so the structure fork is \sim 100nm wide. At the T junction the magnetic domain pattern is resolved. The colour image shows the direction of the magnetisation at the T.
I09 – **Surface and Interface Structural Analysis (SISA)**

**Beamline**
- Soft (200 – 2100 eV) and hard (2.1 – 20 keV) x-ray branch lines with independent sources and optics
- Soft and hard x-rays on same samples
- Linearly and circularly polarized x-rays

**Main research areas**
- Monolayer adsorption and surface reconstructions in UHV
- Thin films, nano-particulates and epitaxy
- Large molecules and complex organic films
- Surfaces and interfaces under non-UHV environments
- Magnetism and magnetic thin-films (dichroism in absorption and photoemission)
- Hard x-ray photoelectron spectroscopy (bulk properties and buried interfaces)
**I09 (SISA) – X-ray techniques**

### Photoelectron Spectroscopy

**Core-levels**

- Pr 4d
- Si 2p

![Pr 4d and Si 2p spectra](image1)

**Gate oxide Pr$_2$Si$_2$O$_7$/Pr$_2$O$_3$/Si(001)**

- Valence band spectra
- cleaned silicon
- no O$_2$
- 1x10$^8$ mbar O$_2$
- 5x10$^8$ mbar O$_2$

![Valence band spectra](image2)

*L. Libraless et al.*

*Appl. Phys. Lett. 90, 222905 (2007)*

### X-ray absorption spectroscopy

**Experiment**

- S K-edge NEXAFS: Au(111)/methylthiolate
- emission angles: 4°, 12°, 37°

![S K-edge NEXAFS](image3)

**Theory**

- intensity (arb. units)
- excitation energy (eV)
- hollow, bridge, atop
- $\theta_p = 0^\circ$, $60^\circ$

![Intensity vs. excitation energy](image4)

*A. Chaudhuri et al.*

*J. Chem. Phys. 130, 124708 (2009)*
I09 (SISA) – X-ray techniques

**Photoelectron Diffraction**

- Roman Fasel et al.

**X-ray Standing Waves**

- Hauschild et al.

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Fluorescence x-rays or photoelectrons

XSW

Cu(110)

Ag(111)

PTCDA

**Cu(110)**

**Ag(111)**

**PTCDA**

Roman Fasel et al.

Hauschild et al.
Design of a long (8 m) straight section – I09

Beam direction

$\beta_X$ – modified

$\beta_X$ – unmodified

$\beta_Z$ – unmodified

$\beta_Z$ – modified

$Y$ (m)

$\beta(m)$

$x$?
Source properties (assuming 2-m IDs)

Photon beam profile

Horizontal

Vertical

Source size

Source divergence
Helical undulator (Apple-II)
2 – 3 m HU60 or HU56 (min. gap = 16 mm)

In-vacuum undulator
2.8 m hybrid U24 (min. gap = 6.15 mm)
or
2 m cryo-cooled hybrid U21 (min. gap ~ 5 mm)

Insertion devices

A modified Apple-II (with all 4 magnetic axes moveable) is being designed → 180° rotation of linear polarization
Insertion devices

**Hard X-rays**
- U19 Cryogenically Cooled 2m
- U24 Hybrid 2.8m

**Soft X-rays**
- Horizontal Polarization
  - HU56
  - HU60
  - HU64
- Vertical Polarization
  - HU56
  - HU60
  - HU64
- Circular Polarization
  - HU56
  - HU60
  - HU64
**Monochromator – Hard X-rays**

**Si(111) double-crystal monochromator**

- Max. Bragg angle = 70°
- LN₂ cooled (both crystals)
- Fixed exit (2nd crystal on a vertical slide)

**High-resolution monochromator (2 axes) – required by both XSW and HAXPES**
Monochromator – Soft X-rays

Plane grating monochromator using collimated light


Fixed focus constant: \( c_{ff} = \frac{\cos \beta}{\cos \alpha} \)

Plane grating efficiency

- Plane grating monochromator using collimated light

Vertical size of exit slits = 10 \( \mu \)m
Distance of exit slits to focusing mirror = 10.5 m
Ray tracing

Branch 2A (6.0 keV)

Beam at sample

Size

Divergence

Branch 3 (500 eV)
Beamline layout
End-stations

End-station 1 (EH1, hard x-rays)
• Six-circle kappa diffractometer (capable of carrying small to mid-size cells/chambers)
• XSW and reflectivity studies of samples in UHV, gases and under liquids

End-station 2 (EH2, soft and hard x-rays)
• A UHV surface-science system
• Electron analyzer (10 keV) with 2D detector
• High-precision goniometer
• Sample cooling (≤ 30 K)
• Preparation chamber (in-situ deposition and characterization)

End-station 3 (CC3, soft x-rays)
Photoelectron spectroscopy under environmental pressure conditions

A proposal has been submitted by a number of user groups to the UK Science & Technology Facilities Council (STFC) to build a mobile end-station for high-pressure photoemission studies of
• Ice surfaces
• Surfaces of liquids
• Electrochemical and biochemical interfaces
• Catalyst surfaces under mild reaction conditions

G. Held (Reading), R. A. Bennett (Reading), M. Bowker (Cardiff), J. O’Shea (Nottingham) ...
# I09 – SISA Timeline

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Date</th>
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<tr>
<td>Conceptual Design Report Review</td>
<td>06/08/08</td>
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<tr>
<td>Technical Design Report Review</td>
<td>07/05/09</td>
</tr>
<tr>
<td>Hutches Complete</td>
<td>11/03/10</td>
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<tr>
<td>Hutches, Cabins and Services complete</td>
<td>15/11/10</td>
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<tr>
<td>Beamline installation complete</td>
<td>17/06/11</td>
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<tr>
<td>No beam commissioning complete</td>
<td>02/08/11</td>
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<tr>
<td>With beam commissioning complete</td>
<td>20/12/11</td>
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<td><strong>I09 First User</strong></td>
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