Time-of-flight as an efficient HAXPES spectrometer: A proof of principle

Giovanni Stefani
CNISM and Dipartimento di Fisica, Università Roma Tre, Rome, Italy

Francesco Offi\textsuperscript{a}, Guido Paolicelli\textsuperscript{b}, Giancarlo Panaccione\textsuperscript{c}
\textsuperscript{a}CNISM and Dipartimento di Fisica, Università Roma Tre, Rome, Italy
\textsuperscript{b}CNR-INFM-S3, Modena, Italy
\textsuperscript{c}Laboratorio Nazionale TASC-INFM-CNR, Area Science Park, Basovizza-Trieste, Italy
HAXPES

Quest for
High energy resolution/throughput

- Core spectroscopy
- Photoelectron diffraction
- Auger diffraction
- Valence spectroscopy
- Summary of requirements
- TED: proposed solution
- Conclusions
Core spectroscopy

$\Delta E = 100 \text{ mEv}; \Delta \Theta = 2^\circ$

$\text{V}_2\text{O}_3$ paradigmatic Mott-Hobbard

Satellite disappear when crossing the MIT - Huge transfer of spectral weight

G. Panaccione et al., PRL 97, 116401 (2006)
Photoelectron diffraction PED

$\Delta E = 100 \text{mE} \text{v} ; \Delta \Theta = 0.2^\circ$

Bulk vibrations, dislocations, defects...

$\pm \theta_{hk\ell} = \pm \sin^{-1}\left(\frac{\lambda_e}{2d_{hk\ell}}\right)$

$\pm \theta_{hk\ell} = 1.5^\circ @ 10 \text{KeV}$

Auger diffraction

$\Delta E = 100\text{mE}v; \Delta \Theta = 2^\circ$

Direct method for detecting the electronic and magnetic structure of each atomic layer at the surface: Ni/Cu(100)

F. Matzui et al. PRL 100, 207201 (2008)
The oxygen peak is more asymmetric and shifted of about 100 meV metal-insulator transition. The shift in the oxygen peak may be the result of a charge transfer to oxygen atoms.

Prominent shoulder on the Mn 2p core level observed below $T_C$: increased nonlocal screening in the ordered ferromagnetic phase?

La$_{1.2}$Sr$_{1.8}$Mn$_2$O$_7$ ($T_C \sim 120$ k) - $h\nu = 5.9$ KeV

Valence spectroscopy

Still one order of magnitude difference in energy resolution between ARPES and HAXPES.

Is there any residual direct transition to be observed in HAXPES?

Example: La$_{1.2}$Sr$_{1.8}$Mn$_2$O$_7$

\[ \Delta E = 10 \text{meV}; \Delta \Theta = 0.1^\circ \]

# Table of requirements

<table>
<thead>
<tr>
<th>Application</th>
<th>$\Delta \Theta$</th>
<th>$\Delta E$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photoelectron diffraction</td>
<td>0.2°</td>
<td>100 meV</td>
</tr>
<tr>
<td>Core Spectroscopy</td>
<td>2°</td>
<td>100 meV</td>
</tr>
<tr>
<td>Auger diffraction</td>
<td>1°</td>
<td>100 meV</td>
</tr>
<tr>
<td>Valence spectroscopy</td>
<td>0.1°</td>
<td>10 meV</td>
</tr>
</tbody>
</table>
Present electron spectrometers

Hemispherical deflector analyzer (HDA) composed by a hemispherical dispersing element and an electrostatic input lens has been chosen as the most common solution to obtain high energy resolution and parallel energy acquisition from most of the groups operating HAXPES setups.

✔ Made in house VOLPE [P. Torelli et al., RSI 76, 023909 (2005); F. Offi et al., NIMA 550, 454 (2005)]

✔ Scienta 4000 [M. Taguchi et al., PRL 95, 177002 (2005); M. Gorgoi et al., NIMA 601, 48 (2009)]


✔ Made in house ESA-31 [L. Kövér et al., SIA 19, 9 (1992)] \( \Omega \sim 0.003 \text{ sr} \quad \Delta E \sim 300 \text{ meV} \)

✔ Focus HV-CSA Cylinder Sector Analyzer [J. Rubio-Zuazo et al., SIA 40, 1438 (2008)]

\( \Omega \sim 0.003 \text{ sr} \quad \Delta E \sim 300 \text{ meV} \)
A Time of Flight Spectrometer for HAXPES

Time-energy dispersion (TED) characteristics of a spherical electrostatic mirror allow to design a time-of-flight analyzer for high energy photoemission experiments: A mirror based construction allows to achieve good energy resolution and large accepted solid angle within reasonable dimensions.

By a position sensitive detector flight and position of the impacting electron on the detector plane are measured and kinetic energy and take-off angle are deduced.

A window at beam waist adds to the TOF spectrometer an efficient band pass Filter.

Unique correspondence between a arrival point flight time and electron trajectory.

Mirror geometry used in display-type analyzer

O. M. Artamonov et al., JES 120, 11 (2001)

H. Daimon, RSI 59, 545 (1988)
Back of an envelop idea: TOF+Reflector

TOF + Reflector

TED = TOF + Wide Band Pass

Feature =
- Wide Accepted Solid Angle
- Multi Channel In Energy
- Multi Channel In Angle
At high energy a large radius and a large ratio between internal and external radius are necessary in order to obtain a good energy resolution.

Example:
- External radius 200 cm
- Internal radius 4 cm
- Ratio 50
- ΔE=20 meV/100 ps
- Solid angle ~ 0.1 sr (±10°)
- Total flight time ~ 1 μs
- Δ flight time < 100 ps
**Electron detector**

**Snapshot mode in HAXPES**

- **Time Resolution**: 27 ps
- **Spatial Resolution**: 60 µm
- **Max counts rate**: $1 \times 10^6$ events/sec
- **Decoupling**: up to 10 kV
- **Dark Counts**: <0.3 events/(secxcm²)

---

**G. Panaccione, et al., NIM A 547, 56 (2005)**

---

**G. Cautero et al., NIM A 595, 447 (2008)**
Angular resolution with PSD

\[ \Delta x = 60 \, \mu m \]

\[ \pm 10^\circ \rightarrow 7 \, mm \]

\[ \Delta x/x = 8 \times 10^{-3} \]

\[ \Delta \Theta = 0.04^\circ \]
**Comparison between HDA and TED when used at high energy**

<table>
<thead>
<tr>
<th></th>
<th>HDA</th>
<th>TED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy resolution</td>
<td>Below Below 100 meV</td>
<td>Below 20 meV</td>
</tr>
<tr>
<td>Energy range (in “one shot”)</td>
<td>Few eV</td>
<td>Hundreds eV</td>
</tr>
<tr>
<td>Accepted angle</td>
<td>~ 0.02 sr</td>
<td>~ 0.1 sr</td>
</tr>
</tbody>
</table>
Conclusions

HAXPES bulk sensitivity can be exploited to gather both electronic and structural characters of complex materials.

Experimental requirements posed by the different kind of high energy electron spectroscopies are hardly met by a single spectrometer.

TED, already tested at lower energies, might constitute an interesting option for HAXPES as well.