Application of LTDs to Synchrotron Radiation

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Layout

- Introduction & comparison
- Present & near future applications
  - X-ray Absorption Spectroscopy
  - X-Ray Fluorescence analysis
- Future applications
  - X-ray emission spectroscopy
  - Resonant Inelastic X-ray scattering
  - X-ray Raman Scattering
- Conclusion
+ and - of LTD detectors

+ Low energy resolution
+ Absence of geometrical constraints (scattering angles, beam size, ..)
+ No critical mechanical alignment
+ In vacuum operation

- Low count rate
- Reduced solid angle
- Applicability to hard X-rays?
Energy-resolving x-ray detectors

The GILDA CRG at ESRF

LTD (STJ)

Semiconductor Solid State

Crystal analyzers
## Energy-resolving x-ray detectors

<table>
<thead>
<tr>
<th>Type</th>
<th>( \Delta E ) (eV)</th>
<th>E (keV)</th>
<th>Count Rate</th>
<th>Solid angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>HP-Ge, Si:Li</td>
<td>150-300</td>
<td>0.3-120</td>
<td>( 10^5 ) cps</td>
<td>( 10^{-2} ) sr</td>
</tr>
<tr>
<td>STJ *</td>
<td>10</td>
<td>0 - 1?</td>
<td>( 10^4 ) cps</td>
<td>( 10^{-4} ) sr</td>
</tr>
<tr>
<td>TES *</td>
<td>20</td>
<td>0-10</td>
<td>( 10^3 ) cps</td>
<td>( 10^{-4} ) sr</td>
</tr>
<tr>
<td>Bragg/Grating</td>
<td>0.2</td>
<td>0.1-10</td>
<td>( 10^6 ) cps</td>
<td>( 10^{-3} ) sr</td>
</tr>
</tbody>
</table>

* Couple high resolution to no geometrical constraints
Application fields

Physical parameters defining the energy resolution

-X-ray absorption spectroscopy
-X-ray fluorescence analysis

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Present & near future applications
**X-ray Absorption Spectroscopy**

The GILDA CRG at ESRF

X-ray spectrum coming from the sample

EXAFS spectrum

Monochromatic X-rays of energy $E$

$w \propto \sum_f \langle f \exp(i \vec{e} \cdot \vec{r}) | i \rangle^2 \delta[E_f - E_i - h\nu]$

Local Structure

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Fluorescence flux

Detector:
Collection solid angle = $10^{-3}$ sr

Sample:
concentration = $10^{15}$ Mn / cm$^2$

X-ray beam:
Intensity = $10^{12}$ ph/s @ 6540 eV

K fluorescence
Flux: $10^4$ ph/s

(Neglecting elastic + compton)
Soft X-ray region - XAS

The GILDA CRG at ESRF

STJ detector for soft x-ray fluorescence
(Friedrich et al. RSI 73 (2002), 1629.)

XAS experiment (InGaAsN at the N k edge)
Lordi et al. PRL 90 (2003), 145505
Hard X-ray region - fluorescence

TES detector
300*400*25 $\mu$m$^3$ Sn absorber
TES sensor an Al/Ag multilayer
Count rate $\approx 100$cps
$\Omega \approx 10^{-8}$ sr

Fluorescence spectrum of a Re foil
F. Gatti et al SRN 3 (2003), in press.
See also Poster F03

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Fluorescence analysis

TES Detector

FWHM = 70 eV

Sample of XVI century Italian pottery.

HP-Ge detector

Counts

Energy (eV)

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Wafer surface impurity analysis

- Control of industrial processes
- Synch. Radiation source
- Total reflection condition
- Detection limit: $10^8 - 10^{12}$ at/cm$^2$

Intentionally contaminated Si wafer. Measurement done with a Si:Li detector, $\Delta E=140$ eV.
P. Pianetta et al. RSI 66 (1995), 1293
Future applications
High resolution x-ray emission spectroscopy

- $K_{\alpha}$ and (much more) $K_{\beta}$ lines exhibit variations linked to the chemical environment

- Variations are greater than the natural linewidth of the $K$ state

- The achievement of energy resolution of the order of 1-2 eV could give access to the several experimental techniques techniques

Levels of x-ray fluorescence transitions
Mn K fluorescence

U. Bergmann et al. CPL 302 (1999), 119.

$K_{\alpha 1}$ and $K_{\alpha 2}$ transition from 2p levels: fair chemical sensitivity

$K_{\beta 1.3}$ and $K_{\beta'}$ transition from the 3p states

$K_{\beta 2.5}$ and $K_{\beta''}$ transitions from the valence band

Chemical sensitivity!

Emission from Mn excited above the K edge
**Mn Kβ fluorescence**

Variation of the Kβ lines for various Mn compounds. Excitation well above the edge. (Tsutsumi et al. PRB 13 (1976), 930.)

- Simple chemical characterization
- Data collection currently done with Crystal analyzers
- Possible use of LTD detectors if ΔE=few eV
- Advantage in using LTD detectors: parallel acquisition, no mechanical movement

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Spin selective XAS


- In Mn$^{II}$ compounds it can be shown that $K_{\beta 1,3}$ originates from a spin down electron, $K_{\beta}$ from a spin up electron.

- XAS spectra can be collected by separately monitoring the two lines.

- Differences are observed that reflect the different DOS for the two spin configurations.

- Peak separation 16 eV at 6500 eV.
1) Promotion of a K electron above $E_f$ by photon absorption (virtual state, no energy conservation).

2) Filling of the K hole with an L electron

3) Emission of a photon

The energy of the global process is conserved $E_{in} - E_{out} = \varepsilon - E_L$

The process is resonant, i.e. enhanced near the (K) edge

Access to the electronic structure
Data collected with grating spectrometer

Evidence of a Charge Transfer peak for an excitation energy on the white line

The CT peak disappears for higher excitation energies

Peak separations 5-20 eV at 835 eV
(Non resonant) X-ray Raman Scattering, XRS

\[ Q = k_f - k_i \]

\[ \nu_i, k_i \]

\[ \Theta \]

Transition probability \( w \)

\[
    w \propto (1 + \cos^2 \Theta) \left| \langle f | \exp[iQ \cdot \vec{r}] | i \rangle \right|^2 \delta \left[ E_f - E_i - h(\nu_i - \nu_f) \right]
\]

Same operator as XAS

\[ \langle f |, \langle i |, E_f, E_i = \text{electronic states & related energies} \]

Graphite, Tohji & Udagawa PRB 36, 9410.
XRS

C K edge, graphite 6 keV

• Useful for obtaining bulk information on light atoms: experiment is done at high energy.

• 1eV energy resolution is OK for data collection.

• Signal significantly smaller than Elastic / Compton

U. Bergmann et al.
Microchem. J.
71 (2002) 221
Energy Dispersive X-ray Diffraction (EDX)

Bragg law: $\lambda = 2d \sin \Theta$

- Normally $\lambda$ is fixed and $\Theta$ is varied
- In EDX $\Theta$ is fixed and $\lambda$ is varied

Collimator and EDX detector – at a fixed angle

Diffraction patterns are obtained only of the volume subtended by the collimator with the incident X-ray beam
Typical EDX spectra

Used in the early days of SR for experiments needing small sized beams (High Pressure).

Limitations

- Energy resolution
- Count Rate

Application of LTD detectors to small beams
Conclusion

- High resolution LT-detectors match the requirements for X-ray absorption spectroscopy & fluorescence analysis
  \[ \downarrow \]
  Rise the maximum count rate
  Extend to hard X-rays

- Possible use for X-ray emission spectroscopy & Raman scattering
  \[ \downarrow \]
  Improve the energy resolution down to 1 eV.

- EDX ?