Workshop EDXRS

Energy Dispersive Detectors

Peter WOBRAUSCHEK
Denver X-Ray Conference 2007

Mentioning of companies is NOT a recommandation!
What Detector is this ???
Main Characteristics of a Detector

- **Crystal material:** active area, thickness
- **Performance:** energy resolution, throughput, Peak to background ratio
- **Cooling:** Peltier, LN2, LHe
- **Array:** single – multi, linear, area
- **Cryostat:** down – side – up looking
Detector Materials

- Silicon
- Germanium
- Mercury Iodine
- Cadmium Telluride
- Sodium Iodine
- Gas filled

Si (Lithium drifted)
Ge (Hyperpure)
Hg I
Cd Te
Na I
Ar-CH4, Xe, Kr
Energy dispersive semiconductor detector

**Principle**

- Be window
- Contact layer
- X-rays
- Si dead layer
- Negative high voltage

**Efficiency**

- Efficiency vs. Energy (keV) for Si(Li) 3 mm thickness
- Transmittance vs. Energy (eV) for AP1.3, AP1.4, AP1.7
ED detector LN$_2$ cooled Si(Li)
Fundamental Working Principle

- Absorbed photons create an energy dependent number of charge carriers (electron – hole pairs)

- This number is \( n = \frac{E}{\mathcal{E}} \)

- \( E \) = photon energy

- \( \mathcal{E} \) average energy for one el-hole pair

- \( \mathcal{E} \): Si 3.6 eV, Ge 2.8 eV, Gas 3.0 eV, STJ ~ m eV
Energy Resolution of ED, FWHM

\[ \text{FWHM (eV)} = \sqrt{(\text{FWHM})^2_{\text{NOISE}} + (2.35\gamma E)^2} \]

- \( F = 0.1 \)
- \( E = \text{Photon energy (eV)} \)
- \( \gamma = 3.9 \text{ eV} \) (average energy to create hole-electron pair at LN temperature)
Parameters for ED Detectors

- FWHM at the reference energy 5.9 keV
- Best values 125 eV for Si and Ge
- Window material: Be 8μm – 25 μm
  Polymer, 300nm on a support Si grid
- Crystal area: typically 5 – 80 mm²
- Thickness 0.3 – 4 mm
- Throughput 40,000 cps to 1 Mcps
Unpleasant Artefacts of ED Detectors

- **Escape effect**

\[ E_{esc} = E_0 - E_{SiK\alpha} \]

Escape peaks occur in the measure spectrum and simulate fluorescence lines \( Cu - Fe, K - Al, Ca - P \)

In the efficiency curve discontinuous jumps are observed
Escape Effect in Ge Detectors

- Escape lines are more dominant in the energy range
  \[ E_{\text{K-abs}} = 11.1 \text{ keV} \text{ and above} \]
  E.g. Ag Ka and Ag Kb
  exciting lines 4 escape lines are observed
  
  \[ 22.16 - 9.88 = 12.28 \]
  \[ 22.16 - 10.98 = 11.18 \]
  \[ 24.94 - 9.88 = 15.06 \]
  \[ 24.94 - 10.98 = 13.96 \]
Germanium vs Si(Li) detector

Ge excellent up to 100 keV - strong escape lines above 11.1 keV – P/B better as Si
Si(Li) excellent from 150 eV to 22 keV efficiency drops for higher E
Sum Effects

- At high counting rates two photons might arrive at the same time or in the time interval the processing of the previous pulse is done at the collecting electrode. This leads either to a sum peak at the double energy of the individual photon energies if 2 photons arrive together at the same time or to a continuum with high background in the energy interval up to the double energy.
- Problem artificial lines in the spectrum e.g. Cu – Zr, Ca – Ni, Al -- Ar

⇒ A puls pile up rejector suppresses this effect strongly
AMPTEK

New From AmpTek

5 mm² x 500 μm XR-100CR X-Ray Detector
- High Efficiency
- Internal Silver Collimator
- No Liquid Nitrogen

25 mm² x 500 μm XR-100CR X-Ray Detector

X-Ray Fluorescence of Aluminum from "Fe2O3"
(20 μs shaping time, optional)

X-Ray Fluorescence of Stainless Steel 216 from "Cu"
(20 μs shaping time, optional)

Applications
- X-Ray Fluorescence
- Process Control
- OEM
- Environmental Monitoring
- Nuclear Medicine
- X-Ray Lithography
- Lead Detectors
- Vacuum Applications
- Paper Analysis
- Nuclear Plant Monitoring
- Semiconductor Processing
- Nuclear Safeguards Verification
- Plastic & Metal Separation
- Coal & Mining Operations
- Sulfur in Oil & Coal Detection
- Smoke Stack Analysis
- Plating Thickness
- Research & Teaching
- Art & Archaeology

MARS PATHFINDER ROVER

Alpha-Proton-X-Ray Spectrometer (APXS)

AMPTEK XR-100T X-RAY DETECTOR

All spectra in this brochure taken with AmpTek MC2000A Multichannel Analyzer

AMPTEK INC.
6 De Angelo Drive, Bedford, MA 01730-2304 USA
Tel: +1 (781) 275-2242  Fax: +1 (781) 275-5370  email: sales@amptek.com
www.amptek.com
• SDD available 7mm$^2$ 500 µm

• Larger areas in progress
Silicon Drift Detector with Circular Geometry

Small size of output capacitance:
- high energy resolution
- high count rate capability

Low leakage current level:
- operation at high temperature
Horizontal electric field by:
- division of diodes into strip
- applying of increasing bias at strips

Charge collection:
- electrons are drifting to readout anode
- low noise amplification of signal at anode

signal height ⇒ energy of radiation
drift time ⇒ position of radiation
Function of Silicon Drift Detector

Charge Collection:

Event 1  signal 1
Event 2  signal 2
Event 3  signal 3
KETEK AXAS SYSTEM high count rate performance
Ketek Si drift detector Peltier cooling

Finger length 100 mm
10 mm$^2$ active area
(100 mm$^2$ prototype)
Multi-array design
SII Nano Technology USA Inc.

VORTEX Radiant detector
Vortex™ multi-cathode x-ray detectors (MCD) feature the largest single active area (50 mm²) available. Vortex detectors are produced from high purity silicon using state of the art CMOS production technology. They feature excellent resolution (<160 eV FWHM is typical) and a high-count rate capability (>1 Mcps). At a very short peaking time of 0.25μs, an energy resolution < 250 eV FWHM is achieved with commensurate output count rates of greater than 400 Kcps. A unique feature of these detectors is their ability to process high-count rates with virtually zero loss in resolution and no peak shift with count rate.

Features:
- Large single area Multi-Cathode detector (50 mm²)
- Superb energy resolution
- Detector temperature stabilization
- Advanced vacuum system ensures limitless temperature cycles
- Additional sizes are available under special contracts

Up to 1 Mcps
Area 50 mm²
FWHM 140 eV @ 5.9 keV
Signal Processing Preamplifier Output (Canberra catalogue)
Digital Pulse Processors
Signal Processing

- Analog Amplifier converts analog preamp signal to several V, ADC and MCA
- Gaussian shapers $t = 1 - 12 \, \mu s$ the higher the better FWHM
- Digital Pulse Processing converts the analog preamp signal into digital, MCA
- DPP Peaking time from 0.25 to 64 \mu s
- Lower noise and high throughput, shaping times range from 250 ns to \mu s
- Dead time correction better 0.5% up to 120,000 cps
Scheme: EDXRS Electronics

source

detector

sample

preamplifier

amplifier

ADC

MCA

PC

Or Digital Pulse Processors
Multielement spectrum
Spectral data evaluation – software packages qualitative!

Free: www.IAEA.org  QXAS  www.esrf.fr  Pymca

Commercial: Canberra: winaxil, Companies code

Quantitative analysis packages

Fundamental parameters, emission – transmission method, matrix corrections,
Specials

- High energy resolution detectors cryogenic
- Large area detectors - Arrays
- Light element detectors UTW
- High Z element K-shell detection Ge
- Position sensitive detectors
- Si CCD multipixel detectors
Superconducting Tunnel Junction  LLL and LBL  S.Friedrich et al

Figure 1. Schematic and photograph of the ADR cryostat. The STJ detector operates at a temperature of 0.1 K at the end of the detector snout that can be inserted into a UHV chamber.
Superconducting tunnel junction (STJ)

Of Josephson Junctions, Quasi-particles, and Cooper Pairs

Stephan Filetrich inserts a sample in the Lawrence Livermore superconducting-tunnel-junction (STJ) detector cryostat at the Stanford Synchrotron Radiation Laboratory. X rays from the synchrotron enter the cryostat through the beamline on the left and strike the sample, producing x-ray fluorescence, which is measured by the STJ detector.

Mathias Frank et. al. LLNL
Fig. 6. Cross-sectional drawing of the ADR cryostat, not to scale. The height and diameter of the cylindrical cryostat are 69 cm and 35 cm, respectively. The length of the snout is 17 cm.
Metrology for Materials Characterization
Improved Analysis - New X-ray Detector
98/99 Commercial Beta of NIST Microcalorimeter

Martinis, et al.  
Energy (eV)
Spectrum of Fe – 55 source

D.A. Wollmann et al.
1997

Fig. 4. Weighted least-squares fit of the $^{55}$Fe microcalorimeter spectrum to the convolution of the Gaussian instrument response and the Lorentzian natural linewidths of Mn Kα1 (2.13 eV) and Mn Kα2 (2.60 eV). The ratio of the Kα2 peak integral to the Kα1 peak integral is constrained to be 0.5097. The fit yields an instrument-response energy resolution of 7.2 eV ± 0.4 eV FWHM at 5.89 keV, which is consistent with the heat pulse energy resolution of 7.1 eV ± 0.2 eV FWHM at 5.33 keV.
Multiarray detector
Light element detector

e2v scientific instr.
(Gresham Sirius) Detector

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Sirius 10</th>
<th>Sirius 30</th>
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<tbody>
<tr>
<td>Active area</td>
<td>10 mm²</td>
<td>30 mm²</td>
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<tr>
<td>Noise</td>
<td>55 eV</td>
<td>60 eV</td>
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<tr>
<td>Resolution</td>
<td>130 eV</td>
<td>136 eV</td>
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<tr>
<td>Peak: Background</td>
<td>20,000:1</td>
<td>20,000:1</td>
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<tr>
<td>Tail Factor</td>
<td>&lt;0.1%</td>
<td>&lt;0.1%</td>
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Measured on in-house test equipment
General hints

1. Avoid ground contact – mount detector completely isolated
2. External shielding around nose and front window
3. Shielding collimator – multielemental e.g. W,Ag,Cu,Al,Carbon
4. Detectors with polymer windows are light sensitive (POF) dark environment
5. External high frequency electric fields (generator, Nim Bin) noise source, degrades FWHM
6. Check LN2 manually or electronically before HV on
CONCLUSIONS

• Almost all elements detectable by ED
• Simultaneous detection of elements present
• Advances in energy resolution
• Throughput up to 1 Mcps
• Data processing high performance electronics
• New cooling & detector technology result in handheld detectors
• Price ????
• Larger variety for individual applications