Research and Production Company
ZRF “RITEC” SIA
Riga, LATVIA
Company name: ZRF “RITEC” SIA (RITEC Ltd.)
Legal status: Private limited company
Date of registration: 02.04.1992. It was founded on the basis of the Room Temperature Semiconductor Detectors Laboratory of Semiconductor Detectors Department of the former Riga Research and Scientific Institute of Radioisotope Instrumentation.
Country of registration: Latvia
VAT Reg. No.: LV40103045390
Address: 23 Aizkraukles Str., ofice 407, Riga, LV-1006, Latvia
Head of the company (contact person): Mr. Victor Ivanov (Viktors Ivanovs)
Tel. number: +371-67543304
E-mail: ritec@ritec.lv
Web site: www.ritec.lv

Current number of employees: 9
Staff professional experience: 5-35 years
Business profile:
Research, development and production of room temperature semiconductor detectors (mainly based on CdZnTe) for various applications and some associated electronic.
Main markets:
EC countries, North America, Argentina, international organizations such as IAEA, EURATOM
Agenda

- CdZnTe detectors
- Detection probes
- Examples of applications
## CZT material

### Physical properties:

- **Typical composition**: $\text{Cd}_{0.9}\text{Zn}_{0.1}\text{Te}$
- **Atomic numbers**: 48, 30, 52
- **Density**: 5.8 g/cm$^3$
- **Band gap**: 1.57 eV
- **Dielectric constant**: 10.9
- **Pair creation energy**: 4.64 eV
- **Specific resistance**: $>10^{10}$ $\Omega$* cm
- **Electron mobility, $\mu_e$**: 600-1000 cm$^2$/Vs
- **Electron lifetime, $\mu\tau_e$**: $>10^{-6}$ s
- **Hole mobility, $\mu_p$**: 50-80 cm$^2$/Vs
- **Hole lifetime, $\tau_p$**: $\sim10^{-6}$ s
- **$(\mu\tau)_e$**: $>10^{-3}$ cm$^2$/Vs
- **$(\mu\tau)_p$**: $>10^{-5}$ cm$^2$/Vs

- **High atomic number, high density, wide band gap, high resistance, high value of electrons $\mu\tau$ product and long term stability of semi-insulating Cadmium Zinc Telluride make this material a very suitable for room-temperature semiconductor detectors fabrication.**

- **But because of the poor hole transport special methods and detectors designs must be applied.**
# CZT detectors

<table>
<thead>
<tr>
<th>Types of CdZnTe detectors and detectors array:</th>
<th>Main advantages:</th>
<th>Main applications:</th>
</tr>
</thead>
<tbody>
<tr>
<td>✷ planar counting and spectrometer detectors</td>
<td>✷ room temperature operation</td>
<td>✷ X-ray and gamma-ray spectroscopic applications</td>
</tr>
<tr>
<td>✷ planar detectors with p-n, p-i-n or Schottky contacts</td>
<td>✷ high spectrometric capability</td>
<td>industrial and laboratory</td>
</tr>
<tr>
<td>✷ Hemispherical, quasi-hemispherical and cylindrical detectors</td>
<td>✷ high registration efficiency</td>
<td>homeland security</td>
</tr>
<tr>
<td>✷ co-planar grid detectors</td>
<td>✷ small dimension and weight</td>
<td>safeguards</td>
</tr>
<tr>
<td>✷ various pixilated and strip detectors</td>
<td>✷ stability in time</td>
<td>various X-ray and gamma-ray imaging systems</td>
</tr>
<tr>
<td>✷ various Frisch grid detectors</td>
<td>✷ low leakage current</td>
<td>Medical</td>
</tr>
<tr>
<td>✷ drift detectors</td>
<td>✷ high count rate capability</td>
<td></td>
</tr>
<tr>
<td>✷ 3D depth sensing position sensitive devices</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CZT quasi-hemispherical detectors

Main advantages of hemispherical detectors:

- comparative simplicity of design and production
- good spectrometric characteristic
- wide range of operation temperature
- good stability in time
- less critical for selection of initial CdZnTe crystals
- small dimensions
- ability for application in strong radiation fields and in out-of-the-way places
- commercially availability
- rather low fabrication costs

✓ Hemispherical detectors are well known as detectors where conditions of a single polarity charge collection are realized. Progress in improvement of CZT crystals characteristics allows fabrication of high quality hemispherical detectors.

✓ The high level of electrons transport characteristic \((\mu \tau)_e \geq 10^{-2} \text{ cm}^2/\text{Vs})\) of modern CZT crystals allows fabrication hemispherical detectors with volumes from a very small of 0.5-1 mm\(^3\) to a large volume about few cubic centimetres.
Single charge collection

Planar Detector

Hemispherical Detector

$dN/dQ$ vs $Q_0$
Possible types of quasi-hemispherical detectors
CZT hemispherical and quasi-hemispherical detectors

For simplification of manufacturing of hemispherical detectors, in practice are made quasi-hemispherical detectors with rectangular shape of sensitive volume with dimensions of \( axaxd \). Distribution of an electrical field in the quasi-hemispherical detector strongly differs from an ideal distribution in an ideal hemispherical detector. There are areas with a low electric field in a detector's corners.
Hemispherical detectors

- $(\mu \tau)_e$ product - as high as possible, at least not less than $10^{-3}$ cm$^2$/V
- $(\mu \tau)_p$ product - as low as possible, at least ratio $(\mu \tau)_e / (\mu \tau)_p$ must be more than 20
- High level of uniformity, absence of significant composition variation and crystalline defects in the detector sensitive volume
- High specific resistance
- Optimal relation for big and small radiuses of hemispherical detector electrodes for certain sets of parameters $(\mu \tau)_e$, $(\mu \tau)_p$ and operating voltage must be kept
- Geometrical shape - for best results is necessary to use ideal hemispherical shape, but for simplification of manufacturing of hemispherical detectors, are made quasi-hemispherical detectors with rectangular sensitive volume
Measured hemispherical gamma-ray detectors energy resolution (FWHM) at 662 keV vs. electron mobility-lifetime product
Registration efficiency of CZT quasi-hemispherical detectors

Insensitive areas reduce the detector sensitive volume. It is the reason of essential disagreement of calculated and measured results for small detectors.

With using of experimental dates about the total absorption peak efficiency the effective sensitive volume of quasi-hemispherical detectors was calculated. For small sizes detectors it is about 80% from the total detector volume.

The exceeding of measured efficiencies for larger detectors over-calculated is connected with an unaccounted contribution of multievent Compton absorption.

Measured (dots) total absorption peak efficiencies and calculated photoabsorption efficiency versus quasi-hemispherical detectors thickness, assuming that the whole (1) and only 78% (2) of detector volume is sensitive to the radiation.
Typical detectors manufacturing process

Raw material:
• Ingots
• Slices
• Blank samples

Cutting

Blank samples

Blank samples with rough dimensions

Mechanical lapping

Blank samples with exact dimensions

Mechanical polishing

Blank samples

Chemical etching

Blank samples

Visual and IR inspection

Selected samples

Contact deposition

Contacted samples

Testing

Selected detectors

Mounting

Mounted detector

Testing

Selected mounted detectors

Encapsulation

Encapsulated detectors

Testing

Selected encapsulated detectors

Long-term stability test

Selected detectors

Temperature test

Selected detectors

High-count capability test

Selected detectors

Final characterization

Selected detectors

Serial product

High-count capability test

Final characterization

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Energy resolution of CZT quasi-hemispherical detectors

Dependence of the quasi-hemispherical detectors energy resolution versus gamma-radiation energy. In the first approximation there is linear dependence between these parameters.

The best energy resolutions at 662 keV line measured with quasi-hemispherical detectors of different volumes.

<table>
<thead>
<tr>
<th>Detector sizes, mm</th>
<th>Volume, mm³</th>
<th>Energy resolution, keV (%)</th>
<th>Peak-to-Compton ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0x1.0x0.5</td>
<td>0.5</td>
<td>7.1 (1.1)</td>
<td>2.0</td>
</tr>
<tr>
<td>1.5x1.5x0.75</td>
<td>1.7</td>
<td>5.1 (0.8)</td>
<td>3.6</td>
</tr>
<tr>
<td>2.0x2.0x1.0</td>
<td>4.0</td>
<td>5.5 (0.8)</td>
<td>4.4</td>
</tr>
<tr>
<td>2.5x2.5x1.25</td>
<td>7.8</td>
<td>7.6 (1.2)</td>
<td>5.0</td>
</tr>
<tr>
<td>5.0x5.0x2.5</td>
<td>62</td>
<td>7.1 (1.1)</td>
<td>7.2</td>
</tr>
<tr>
<td>10.0x10.0x5.0</td>
<td>500</td>
<td>8.2 (1.2)</td>
<td>8.0</td>
</tr>
<tr>
<td>15.0x15.0x7.5</td>
<td>1687</td>
<td>15 (2.2)</td>
<td>7.0</td>
</tr>
</tbody>
</table>
Peak-to-Compton ratio of CZT quasi-hemispherical detectors

Dependencies of the peak-to-Compton ratio versus energy resolution at 662 keV line for large quantities of quasi-hemispherical detectors with two different volumes.

There is correlation between these parameters.
Mounted detectors, detection probes, some associated electronic
CZT Large Volume Detectors CZT/500(S), CZT/1500 and Spectrometric Detection Probe SDP310/Z

CZT/1500

CZT500(S) with preamplifier PA101

SDP310/Z/(LC)/(S)
Spectrometric Detection Probe
Model SDP500(S)
Subminiature Spectrometric Detection
Probe SDP313
CdTe/CdZnTe Detection Probes

- Miniature gamma-ray spectrometric detection probe SDP310 with hemispherical detector

- Gamma-ray spectrometric detection unit with hemispherical detector cooled by a single stage Peltier element

- X-Ray spectrometric detection unit with p-i-n CdTe detector cooled by two or three stage Peltier element
Temperature Stabilized Detection Unit
TSDP410

Temperature dependence of energy resolution (FWHM) at 662 keV line for two different quasi-hemispherical detectors and for detection probe TSDP410 with thermostabilized detector of 10 mm$^3$.

Removable probe of temperature stabilized detection unit TSDP410 can operate up to $+70^\circ$C. Thermostabilization broad of TSDP410 supports the detector's operation temperature and for signals by sound and visual about operating troubles.
Spectra registered by CZT probe SDP310/Z/60S

Detector volume 60 mm³
Spectra registered by CZT detector
CZT/500S

- **U-235**
  - 186 keV
  - 144 keV
  - 163 keV
  - 205 keV

- **Ra-226**
  - 186 keV
  - 242 keV
  - 295 keV
  - 352 keV
  - 609 keV

- Old wristwatch

Counts vs. Channels
Spectrum registered by SDP310/Z/60S

Spectrum of reactor grade plutonium sample
Efficiency of CZT quasi hemispherical detector

Spectra of U-235 registered by detectors assembly of 2 cm$^3$ and by NaJ ($\varnothing$1"x1") detector. Time and conditions of measurements are the same for both cases.

Measured total absorption peak efficiency and calculated photoabsorption efficiency versus gamma radiation energy for CZT detector for CZT detector with a thickness of 5 mm.
Input count rate depending on radiation dose rate for various detectors volumes

500 mm³ (a), 40 mm³ (b), 14 mm³ (c), 0.5 mm³ (d)
Spectrum of Cs-137 measured by the probe SDP310/Z/005 with CZT detector of 0.5 mm$^3$
CdTe p-i-n detector

Detector size – 4x4x0.6 mm$^3$
Operation temperature - -35 °C
Planar detector with application of pulse selection-correction device

\[\text{Spectrum measured without application of pulse selection-correction device}\]

\[\text{Spectrum measured with application of pulse correction device}\]

\[\text{Spectrum measured with application of pulse correction-selection device}\]
Common spectrum of Ba-133, Cs-137 and Co-60 measured with application of selection-correction device

Planar CZT detector, size 10x10x2 mm$^3$
Samples of applications
Safeguards application. Three storage types of irradiated fuel assemblies in cooling pond.
Spend Fuel Attribute Tester (SFAT). Chamber for underwater measurements.
Nuclear power plant, spent fuel cooling pond. Places for measuring probe insertion.
Scheme of measurements of suspended fuel assemblies
Irradiated fuel assembly spectrum
Burn-up 180 MWd/FA. Cooling time 21 months.
Gamma spectrum of 1 year old spent fuel measured with SFAT

WWER-440; 1 year old fuel
Hemispheric CdZnTe 60 mm²
SDP310/Z60
NPS Paks, unit 4 upper layer
Underwater measuring system of bundles of fuel elements in basket

Main features and dimensions

Equipped underwater measuring system

Configuration of internal lead shielding and collimators for application with CZT/500S

Internal lead shielding
Measuring scheme of spent fuel bundles in basket
Basket with spent fuel bundles

View from above, 4 m under water
Spectra of spent fuel bundles stored in baskets

Spectrum of fuel bundle, burn-up 1676 MWd/FA, cooling time about 8 years

Spectrum of fuel bundle with shank, burn-up 1857 MWd/FA, cooling time about 13 years
PU/U attribute test system with CZT/500S detector and MCA-166
Detector module with quasi hemispherical CZT detector

- CZT detector of size 10x10x5 mm$^3$
- High voltage power supply
- Charge sensitive preamplifier and shaping amplifier
Mounted planar CZT detectors for various application
Surgical gamma-probes

Schematic drawing of the surgical probe head
Linear arrays of planar CZT detectors

5 elements module (with preamplifiers)

16 elements assembly
Personal radiation detector (PRD) γ-TRACER GT1

Used CZT detector:
- area 2 cm²;
- volume 0.4 cm³.
Geological borehole logging probe

Probe external diameter 20 mm
Used detector:
- CsI(Tl) with Si PIN photodiode;
- Detector dimensions $\varnothing 12 \times 50$ mm;
- Energy resolution FWHM@662 keV about 9%
*CZT detector can be used too.*
Spectra of Cs-137 measured with quasi-hemispherical detector of 10x10x5 mm³ under IR stimulation

Cs-137
Detector size 10x10x5 mm³

Operating voltage – 1000V
Illumination by IR LED IR 204, 940 nm
Radiant power:
1 – without illumination
FWHM@662 keV – 14.9 keV
2 – 200 mkW
FWHM@662 keV – 8.6 keV
3 – 250 mkW
4 – 300 mkW
5 – 340 mkW
Spectra of Am-241 and Cs-137 measured with quasi-hemispherical detectors without and with IR illumination

**Am-241**
- Detector size 10x10x5 mm³
- 3.9 keV
- 6.3 keV

**Cs-137**
- Detector size 5x5x1.5 mm³
- 4.2 keV
- 7.2 keV

1 – without IR illumination
2 – with IR illumination 940 nm
Spectrometric characteristics of different CdZnTe quasi-hemispherical detectors measured without and with IR stimulation

<table>
<thead>
<tr>
<th>No.</th>
<th>Detector size, mm³</th>
<th>Operating voltage, V</th>
<th>Energy resolution (FWHM) at 662 keV, keV</th>
<th>Peak-to-Compton ratio at 662 keV</th>
<th>Energy resolution (FWHM) at 59.5 keV, keV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Without IR illumination</td>
<td>With IR illumination</td>
<td>Without IR illumination</td>
</tr>
<tr>
<td>1</td>
<td>10x10x5</td>
<td>900</td>
<td>20.6</td>
<td>9.6</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>10x10x5</td>
<td>1400</td>
<td>9.8</td>
<td>8.1</td>
<td>7.1</td>
</tr>
<tr>
<td>3</td>
<td>7x7x3.5</td>
<td>600</td>
<td>27.1</td>
<td>16.2</td>
<td>2.5</td>
</tr>
<tr>
<td>4</td>
<td>7x7x3.5</td>
<td>600</td>
<td>6.4</td>
<td>5.1</td>
<td>9.4</td>
</tr>
<tr>
<td>5</td>
<td>5x5x2.5</td>
<td>500</td>
<td>24.5</td>
<td>10.8</td>
<td>1.8</td>
</tr>
<tr>
<td>6</td>
<td>5x5x2.5</td>
<td>500</td>
<td>7.2</td>
<td>4.7</td>
<td>7.4</td>
</tr>
<tr>
<td>7</td>
<td>3x3x1.5</td>
<td>300</td>
<td>6.9</td>
<td>5.5</td>
<td>5.4</td>
</tr>
</tbody>
</table>
Thank You for attention!

http://www.ritec.lv
e-mail: ritec@ritec.lv