GaAs:Cr as a material for a new generation of detectors

<table>
<thead>
<tr>
<th>Material</th>
<th>Density g/cm³</th>
<th>Atomic number</th>
<th>Band gap, eV</th>
<th>μ cm/V</th>
<th>p%</th>
<th>n%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>2.35</td>
<td>14</td>
<td>1.12</td>
<td>1</td>
<td>1</td>
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<tr>
<td>GaAs</td>
<td>5.22</td>
<td>32</td>
<td>1.43</td>
<td>10⁴</td>
<td>10¹</td>
<td>10²</td>
</tr>
<tr>
<td>Ge</td>
<td>5.65</td>
<td>48</td>
<td>1.5</td>
<td>10⁵</td>
<td>10²</td>
<td>10³</td>
</tr>
<tr>
<td>HgI₂</td>
<td>6.4</td>
<td>81</td>
<td>2.13</td>
<td>10⁵</td>
<td>10²</td>
<td>10³</td>
</tr>
<tr>
<td>PbI₂</td>
<td>6.16</td>
<td>83</td>
<td>2.32</td>
<td>10⁴</td>
<td>10¹</td>
<td>10²</td>
</tr>
</tbody>
</table>

Low atomic number and small efficiency for Y conversion of Si, prompted to search for new materials, one of which is GaAs. First GaAs samples were produced using well-known the liquid encapsulated Czochralski (LEC) technique for growing the semi-insulating GaAs (Si:GaAs) that samples have a number of disadvantages:

- low electron lifetime τₑ ≤ 0.2 ns,
- non-uniform electric field distribution through the detector thickness,
- high concentration of EL₂ centers, with a large cross section for electron capture that limits the charge collection efficiency (CCE).

Manufacturing of GaAs compensated with Cr

A group of scientists from TSU (Tomsk) has developed a new technology which allows to decrease EL₂ centers concentration by adding the compensating deep acceptor Cr. As a result semi-insulating GaAs:Cr sensors made of n-GaAs material using the precision chromium doping technique. The properties of this material is that mainly electrons participate in the charge collection due the low value of mobility lifetime product for holes (μτₑ). Thus CCE is close to 50% for unirradiated sensors at 100% electron collection.[2]

- Resistivity increased more than an order of magnitude to (0.5-2)-10² Ω·cm
- Electron life time increased enough to collect 100% of electrons.
- Sensor area up to 4 inch's wafer size with effective thickness up to 1 mm.

Radiation hardness of new samples needs to be investigated

800 MeV electron linear accelerator (LINAC) at JINR.

- 21 MeV beam channel was used for sensors irradiation. Electron beam:
  - bunch current up to 10 mA,
  - duration 5 μs,
  - frequency from 1 to 25 Hz.

Electron beam is shaped by the collimator 5x5 mm passed through the 5x5 mm sensor, radiographic film and finally reaches the copper Faraday cup.

Measured beam charge is converted to absorbed dose using GEANT4 simulation.

Uniformity of beam distribution is controlled by radiographic film.

Setup for CCE and I-V measurement

Electrons from Si³⁺ source are well collimated and triggered by 2 scintillators. It allows to get the signal only from electrons passed through the sensor with energy from 1 to 2 MeV and collect spectra close to MBP (minimum bias point).

Pedestal was collected separately, trigger started from the generation under the same conditions. The width of pedestal determines the resolution of sensor+amplifier setup.

For the direct comparison with GaAs:Cr, two n-type silicon pads were studied:

1. n-type Si made from E2-Si (Wacker), orientation (111), 2 p = 4.4·10¹⁵ cm⁻³ (MBH, Zelenograd, Russia)
2. n-type Si, slice by Polysens (Polysens, Russia)

I-V and CCE after irradiation

- Si - dark current increases almost four orders of magnitude, CCE remains above 80% of initial!
- GaAs:Cr - not a strong increase in dark current, but CCE drops 10 times!

Cooling & C-V measurements

Cooling of irradiated sensors reduces dark current, which improves the signal-to-noise ratio, which is especially important for Si!

For both Si and GaAs:Cr CCE is not dependent on cooling.

Conclusions

- Irradiation of the high-resistance GaAs:Cr and n-type Si sensors by 21 MeV electron beam was performed at the LINAC accelerator. Radiation damage in the sensors was studied.
- After dose of 1.5 MGy:
  - in GaAs:Cr sensors signal CCE drops to ~10% of initial, when in Si above 80%
  - dark current grows 3-7 times in GaAs:Cr and 4 orders of magnitude in Si.
  - In Si full depletion voltage is rising with irradiation, more strong for tick HPK sensors.
- At room temperature, the signal-to-noise ratio in GaAs:Cr sensors is higher than that for Si sensors after a dose of 1.5 MGy. While at a temperature of -20°C the inverse ratio is observed.

This work was supported by the BMBF-JINR program for detector R&D.