GaAs:Cr for HEP - radiation tests

IHEP, Protvino
NCPHEP, Minsk
SIPT, Tomsk
ICBP, Puschino

Yuri Arestov, IHEP
Our predecessors

- RD-20, CERN   Si, GaAs
- RD-48, CERN   Si, GaAs
- A. Vorobiev, IHEP  GaAs, Si
- P. Sellin e al, 1995  GaAs
  neutrons, 1 MeV, fluence up to $1 \cdot 10^{14}$ n/cm$^{-2}$
- A. Vorobiev, IHEP, 2002
  GaAs cooling, temperature dependence
- FNAL, D0 report, 2002
- Silicon detectors from ELMA, ST, Ham., ... and many others
Doping GaAs by Chromium – the 5-year practice of a new technology in Tomsk

<table>
<thead>
<tr>
<th>structure type</th>
<th>Si</th>
<th>GaAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>p-i-n</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>π-ν-n</td>
<td>NO</td>
<td>YES</td>
</tr>
</tbody>
</table>

- Resistive Si structures have not been obtained so far.
- World studies of GaAs irradiation tolerance related mainly to GaAs structures of the previous generation.

A new unique production technology of GaAs:Cr (doped by Chromium) belongs to Tomsk.

As was earlier shown by estimates and by the first measurements (Protvino, RAL), GaAs:Cr radiation hardness can be higher than that of Si by a factor of 10 or larger.
GaAs pad 1cm × 1cm

General view. The detector is shielded by 5µm gold cover.
GaAs:Cr  general properties

<table>
<thead>
<tr>
<th>Property</th>
<th>GaAs</th>
<th>Si</th>
<th>PbWO₄</th>
<th>Pb</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>X₀, cm (rad. length)</td>
<td>2.30⁴</td>
<td>9.36</td>
<td>0.89</td>
<td>0.56</td>
<td>0.35</td>
</tr>
<tr>
<td>Rₘ, cm (Moliere radius)</td>
<td>2.63⁵</td>
<td>4.91⁵</td>
<td>2.2</td>
<td>1.60⁵</td>
<td>0.89(0.91⁵)</td>
</tr>
<tr>
<td>λᵣ, g/cm² (nucl. Int. length)/cm</td>
<td>140⁶/</td>
<td>106/</td>
<td>/</td>
<td>194/</td>
<td>185/</td>
</tr>
<tr>
<td>ρ, g/cm³ (density)</td>
<td>5.36</td>
<td>2.33</td>
<td>8.28</td>
<td>11.35</td>
<td>19.3</td>
</tr>
<tr>
<td>Z/A</td>
<td>Ga: 31/70 As: 33/75</td>
<td>14/28</td>
<td>82/207</td>
<td>74/183.8</td>
<td></td>
</tr>
<tr>
<td>Eₑ, MeV, electron critical energy⁶</td>
<td>18.35</td>
<td>40.03</td>
<td>7.33</td>
<td>8.11</td>
<td></td>
</tr>
<tr>
<td>dE/dx, MeV/cm per mip</td>
<td>7.44</td>
<td>3.6</td>
<td>13.0</td>
<td>~13</td>
<td>~23</td>
</tr>
</tbody>
</table>

⁴ - taken as for Ge with Z=32 and A=72.6 and ρ=5.32 g/cm³.
⁵ - calculated as Rₘ = X₀·21 MeV/Eₑ.
⁶ - calculated as Eₑ = 610 MeV/(Z+1.24)
## GaAs vs Si

<table>
<thead>
<tr>
<th>Properties (by courtesy of O.P. Tolbanov)</th>
<th>Si</th>
<th>GaAs:Cr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ionization density, $dN/dx$ (pair/µm)</td>
<td>90</td>
<td>177</td>
</tr>
<tr>
<td>Charge drift velocity, $cm/sec$</td>
<td>$3\cdot 10^6$</td>
<td>$1\cdot 10^7$</td>
</tr>
<tr>
<td>Response (amplitude of induced current per mip), µA</td>
<td>0.4</td>
<td>3</td>
</tr>
<tr>
<td>Radiation hardness in terms of CCE, Charge Collection Efficiency</td>
<td>30% at ~10^{12} cm^{-2}</td>
<td>50% at ~10^{14} cm^{-2}</td>
</tr>
<tr>
<td>Leakage current</td>
<td>Refrigeration needed</td>
<td>No refrigeration</td>
</tr>
</tbody>
</table>
GaAs test series

- Proton beam at IHEP booster
- Gamma source in Puschino
- Data analysis in Protvino and Tomsk
Absorbed dose – is it known accurately? -- YES

- Direct measurement with Al foils -- Г.И. Бритвич
- Verification with booster beam profiles – А.С. Гуревич

<table>
<thead>
<tr>
<th>Mrad</th>
<th>0.4</th>
<th>3.5</th>
<th>120</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluence, p/cm**2</td>
<td>1.7\cdot10^{13}</td>
<td>1.5\cdot10^{14}</td>
<td>5.0\cdot10^{15}</td>
</tr>
<tr>
<td>Beam density, p/bunch</td>
<td>2\cdot10^{11}</td>
<td>6\cdot10^{11}</td>
<td></td>
</tr>
</tbody>
</table>
GaAs diodes \( NN = 1\div7 \)  
Low beam intensity \( I_p = 2 \times 10^{11} \) p/pulse

**VACs before /after**

NOTE. Diode N3 was irradiated up 40 Mrad, and later it was found to be damaged mechanically due to an unknown reason.
Stand at work

A.G. Kholodenko, 14.01.2004
Это сбор заряда от напряжения, просто данные и центры тяжести сигнального и пьедестального пиков.
GaAs:Cr 1cm•1cm detectors in 1.7 GeV/c proton beam (Dec. 2003)

14 GaAs detectors were exposed, and 7 of them to 'low intensity' beam with $2 \cdot 10^{11}$ p/pulse and 7 to high-intensity beam with $6 \cdot 10^{11}$ p/pulse. The absorbed doses were the same in both sets and they corresponded to fluences from $2 \cdot 10^{13}$ p/cm$^2$ to $5 \cdot 10^{15}$ p/cm$^2$. 

Yuri Arestov, IHEP

LCWS, April 19-23, 2004
GaAs tests: booster run Nov. 2003

- CH. COLLECTION
  - 0 Mrad #4
  - 0.40 Mrad #12
  - 0.43 Mrad #28
  - 1.80 Mrad #26
  - 3.50 Mrad #25

- det. #4
- det. #28
- det. #26

- $V_{\text{opt}} = U_{\text{off plateau}}$

- Detector Recovery
  - 0.4 Mrad
  - 0.43 Mrad
  - 1.8 Mrad
GaAs N15 and N16 irradiated by gammas

- γ source: $^{60}\text{Co}$, $E_\gamma = 1.25$ MeV
- Dose rate 96 Krad/hour
- Absorbed dose 5 Mrad

NOTE: Unfortunately, no curves obtained before irradiation
GaAs: Cr 1cm•1cm detectors at gamma irradiation (Jan. 2004)

The detectors were exposed to γ source with the gamma energy 1.25 MeV. The absorbed doses ranged from 5 to 51 Mrad. The figures show the full tolerance of GaAs to the gamma fluxes within this load range.
GaAs Prospects for LC particle ID

- Vertex detectors
- Forward detectors
- Forward calorimetry
- Luminosity monitors
GaAs for TESLA tracking

- Vertex Detector
- Intermediate Tracking System
GaAs:Cr for ECAL

LAT = Low Angle Tagger
TDR: 63 planes of W (2.6mm) and silicon (0.5mm)
GaAs alternative: a few front planes with GaAs diodes.

LCAL = LumiCAL
TDR: LAT-like W+Si design
GaAs alternative: full GaAs replacement of silicon
О.П. Толбанов говорит:

**Вывод 3**: В GaAs вдвое выше плотность ионизации, втрое выше быстродействие и в 5 раз выше амплитуда импульсов наведённого тока.

**Вывод 4**: GaAs в сравнении с Si имеет радиационную стойкость более, чем на 2 порядка выше.

**GaAs detectors provide:**

- Stronger signal:
- Higher radiation hardness:
- Tolerant leakage currents (no refrigeration)
- New high-tech opportunities in HEP instrumentation
- Applied science and interdisciplinary studies
We continue to work...

It would be nice:

- to **continue studies** in hadron beams up to a final conclusive step regarding GaAs vs Silicon.

- to irradiate in **neutron** beams.

- to involve **interested parties**.

- to get **support**.