Measurement results of IHEP-IMEv1 low gain avalanche devices and IHEP-IMEv2 sensor design for ATLAS HGTD

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Abstracts

Low Gain Avalanche Detector (LGAD) with time resolution better than 50ps has been chosen as the sensors for HGTD project and has so far been developed by several institutes. This poster will show the measurement results about 50um thick HHEP-IMEv1 LGAD sensors designed by the Institute of High Energy Physics (IHEP) and fabricated by Institute of Microelectronics (IME). Beta source measurement results show that the time resolution of IHEP-IMEv1 sensors are better than 40ps and the collected charges are larger than 200e before irradiation. The properties of IHEP-IMEv1 sensors fulfill the required specifications of sensors before irradiation for ATLAS HGTD project. Performance of the sensors after irradiation will also be shown. Furthermore, this poster will show the second version of sensor design for 15X15 sensor arrays, especially simulation results of process parameters for gain layer implantation which will be optimized for the sensors to meet irradiation requirements of the project.

Devices physics Structure

- The most important part of LGAD sensor is the charge multiplication in the so called gain layer which is formed by a heavily doped 1-2um thick p+ layer sandwiched between the n++ implant and the p substrate.
- While other structures as HTE (Junction Termination Extension), is implanted to avoid early breakdown at the edge.
- The thickness of the p-substrate are as thin as ~50um for superior time resolution of about 35ps per detector layer.
- The negative anode voltages are applied from backside electrode to make sure the sensor work at the voltage before breakdown and with Gain >10 for effectively charge collection, while the signals of each sensor be collected and analyzed by the top cathode electrode.

Devices Fabrication

- Substrates: 8 inch boron doped (100)-oriented p-type silicon wafers with 50um thick EPI layer which has resistivity of 1kΩcm.
- 3 wafers with different process parameters were taped out.
- For each wafer having four quadrants, four different dose for p+ layer were implanted into different quadrants of one wafer.
- The implantation parameters of p+ layer and n++ layer for different wafers and quadrants are listed in the follow table.

<table>
<thead>
<tr>
<th>Process parameters</th>
<th>W1</th>
<th>W2</th>
<th>W3</th>
<th>W4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon implantation</td>
<td>W1</td>
<td>W2</td>
<td>W3</td>
<td>W4</td>
</tr>
<tr>
<td>EPI thickness (μm)</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>p+ layer dose/cm²</td>
<td>h</td>
<td>h</td>
<td>h</td>
<td>h</td>
</tr>
<tr>
<td>n++ layer dose/cm²</td>
<td>h</td>
<td>h</td>
<td>h</td>
<td>h</td>
</tr>
<tr>
<td>Energy/kΩ</td>
<td>800</td>
<td>800</td>
<td>800</td>
<td>800</td>
</tr>
<tr>
<td>etch depth (μm)</td>
<td>600</td>
<td>600</td>
<td>600</td>
<td>600</td>
</tr>
</tbody>
</table>

- Leakage Current-Voltage characteristics

leakage current-voltage characteristics

Charge collection and time resolution

- All IHEP-IMEv1 LGAD sensors have a collected charge larger than 150e before irradiation, some of them can reach to 300e, which satisfy the requirement of the ATLAS HGTD project (>150e before irradiation).
- After 2.5x10⁴μm²/μm², sensors have a collected charge larger than 4F at about 700V, which satisfy the requirement of the ATLAS HGTD project (>4F after irradiation).
- The time resolution of sensors W1-IV, W7-IV, and W8-IV, which have p+ layer dose up to 2.5±12μm² can be lower than 40ps at ~370V.
- After 2.5±1μm²/μm², the sensors can reach time resolution lower than 50ps.
- Those three sensors have the potential to satisfy the ATLAS physics requirement in HGTD project (<35 ps before irradiation), <70ps after irradiation.

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For IHEP-IMEv2 run, IHEP and IME will add large area sensors(15X15), optimizing the doping of gain layer and condition of carbon injection to improve the performance of charge collection after irradiation.

5 wafers have been taped out. Measurement will be done soon.

IHEP-IMEv2 design and fabrication

Capacitance-voltage characteristic

Capacitance-voltage characteristic

Gain layer depletion voltage (Vgd) increase with p+ layer dose up.

The trends of the capacitance properties also fit with TCAD simulation results, while Vgd from testing results are about 3-5V higher than simulation results.

Compared with wafer 7, sensors form wafer 8 with higher n++ implantation energy shows lower Vgd.

The capacitance properties of LGAD sensors designed by the Institute of Microelectronics, Chinese Academy of Sciences, Beijing 100029, China.