Outline

• VTT in brief
• Facilities and process resources
• 3D detector process
• Edgeless detector prototypes on 6” SOI Wafer
  • Wafer layout, fabrication process & motivation
  • Different designs: p-on-n and n-on-n
  • Handle wafer removal and packaging
• Detector characterization
  • Strip detectors: CV, IV and Breakdown voltage
  • Pixel detector: IV, X-ray source and tube images
• VTT’s process capabilities for advanced detectors
• Summary
VTT in brief

Customer sectors
- Biotechnology, pharmaceutical and food industries
- Electronics
- Energy
- ICT
- Real estate and construction
- Machines and vehicles
- Services and logistics
- Forest industry
- Process industry and environment

Focus areas of research
- Applied materials
- Bio- and chemical processes
- Energy
- Information and communication technologies
- Industrial systems management
- Microtechnologies and electronics
- Technology in the community
- Business research

VTT’s operations
Research and Development ■ Strategic Research ■ Business Solutions ■ Ventures ■ Expert Services ■ Corporate Services

- Turnover 245 M€
- Personnel 2,700
- 77% with higher academic degree
- 6,200 customers
- Established 1942
- VTT has been granted ISO9001:2000 certificate.
Public decision makers, financiers and R&D performers

Parliament of Finland

Council of State

Research and Innovation Council

Ministry of Education

Ministry of Employment and the Economy

Other ministries and research institutes

Academy of Finland

Sitra, the Finnish Innovation Fund

Universities

Finnvera

VTT

Finnpro

Finpro

Finnish Industry Investment Ltd

TE-Centres
TECHNOLOGY PARTNERSHIP
Create business from technology

TECHNOLOGY AND INNOVATION MANAGEMENT
Leverage the technology benefits more effectively

TECHNOLOGY AND MARKET FORESIGHT
See the future

STRATEGIC RESEARCH
Be a forerunner

PRODUCT AND SERVICE DEVELOPMENT
Acquire competitiveness

IPR AND LICENSING
Exploit turnkey technologies

ASSESSMENTS, TESTING, INSPECTION, CERTIFICATION
Ensure your competitive edge

2 November 2009
J. Kalliopuska
Edgeless Detectors for High Energy Physics Applications
### MICRONOVA CLEANROOMS

**Main Cleanroom Characteristics**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Area</td>
<td>2 600 m²</td>
</tr>
<tr>
<td>Cleanroom Classification</td>
<td>ISO 4…ISO 6 (in clean bays) (10…1000)</td>
</tr>
<tr>
<td>Temperature</td>
<td>21 °C ± 0,5 °C</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>45 % ± 5%</td>
</tr>
</tbody>
</table>

**Labs with built-in Cleanrooms**

- Micropackaging lab - dicing saws, wire bonding
- SubTech lab - Ion implantation, CMP, backgrinder, wafer bonder

- Process equipment is mainly for 150 mm wafer size, but some processes can be performed also on 200 mm wafers

**Clean bay - Service chase type**
- Ventilation based on filter fan units
- Raised perforated floor
- Subfab with technical support areas

*Image of cleanroom with people working in the background.*
Equipments

**Furnace:**
- oxidation, LTO, TEOS, Nitride, doped and undoped polysilicon
- 2 Centrotherm furnace stacks

**Lithography:**
- Contact aligners – MA150 and MA6 (bottom side alignment), MA200
- E-beam writing – Zeiss LEO 1560
- Step and Stamp Imprint Lithography – Suss MicroTec NPS 300
- i-line stepper, Canon FPA 2500i3
- Resist/development tracks, Suss ACS 200 and AIO Duna 700

**Dry etching**
- Etchers for silicon oxide, nitride, metals - LAM 4520/4420/9600
- Deep silicon etching - Aviza Omega i2L and STS ASE
- Silicon oxide ICP etching – STS AOE
- RIE – Oxford 80Plus
- Plasma stripers (PRS 800/801), microwave asher (Aura 1000), wet ozone stripping

**Ion Implantation**
- Medium current, 200 keV, P, As, B – Eaton NV8200-P
Equipments

Sputtering: AlSi, Mo, TiW, Si - Provac LLS 801

PECVD: Silicon oxide and nitride, incl. TEOS-process

Electroplating:
  • Ni, Cu, SnAg, SnPb and SnBi – RENA and home-built plating systems

Flip-chip bonding: 2 Suss MicroTec FC150 bonders

Dicing: Disco DFD 651 and Loadpoint uAce-352

Fusion wafer bonding: EVG 5201S and EV 801 (non-IC materials)

Backgrinding (wafer thinning): Strasbaugh 7AF

Polishing and planarization: Strasbaugh 6DS-SP
VTT’s 3D DETECTORS

**Pixel element of a strip detector**

**PROPERTIES**

• GOOD SPATIAL RESOLUTION
• TUNABILITY OF THE VERTICAL DOPING PROFILES
• SMALL DEPLETION VOLTAGE
• LARGE AREA STRIP AND PIXEL DETECTORS DEMONSTRATED (~10 cm²)
• SAME TECHNOLOGY FOR VERTICAL I/O’s & EDGELESS DETECTORS

**Pixel of a 3D strip detector and X-ray image taken with a 3D detector coupled to the Medipix2**
EDGELESS DETECTORS on 6” (150 mm) SOI WAFER

**Main edgeless strip detectors**
- 5 x 5 cm²
- DC & FOXFET
- 50 μm edge distance

**Medipix 2 edgeless pixels**
- 1,4 x 1,4 cm²
- 20 & 50 μm edge distance

**Baby edgeless strip detectors**
- 1 x 1 cm²
- DC, PT & FOXFET
- 20, 50 & 100 μm edge distance
VTT’s edgeless fabrication process

Poly process, p-on-n

Edge implantation, p-on-n
Poly process

6 um inactive polysilicon

500 nm oxide

Edge implantation
3D PROCESSING WITH POLYSILICON FILLING

- Filling of the trenches is a slow process
- ~50% of total process equipment time in furnace
- Bowing of 6” wafers due to the polysilicon growth (~0.5 mm)
- Difficulties in lithography, planarization and ion implantation
- Wafers brittle -> increased possibility of wafer cracking
- Slow planarization process required
- Detector edge cracking after the support removal
- Physical inactive edge region ~5-10 μm

3D PROCESSING WITH ALTERNATIVE PROCESS

- No need for polysilicon filling, planarization and separate ICP dicing
- Fast process and no bowing of the wafer
- Detector edges sustain handling – no edge cracking
- Physical inactive edge region <1 μm
- Requires non-planar lithography -> readiness available at VTT
Handle wafer removal
Edgeless strip detectors
DC-coupled strip designs & n-on-n layout
Edgeless strip detectors
Strip leakage current: p-on-n implantation vs. poly

- Low leakage currents for both process approaches
- Very early breakdown voltages for poly filling
- Leakage current depends on the active edge distance
Leakage current and breakdown: p-on-n and n-on-n

- p-on-n: 50 - 70 nA/cm² & breakdown at 145 - (>200 V)
- n-on-n: 116 - 118 nA/cm² & breakdown at 75 - 95 V
Strip capacitance and depletion: p-on-n and n-on-n

- Front-to-backplane depletion 7 V (p-on-n) and 4 V (n-on-n)
- p-on-n: 550 – 700 pF/cm² and full depletion 25 - 40 V
- n-on-n: 800 – 960 pF/cm² and full depletion 13 - 25 V
**Characteristics of 150 um thick edgeless strip detectors**

<table>
<thead>
<tr>
<th>Edge distance</th>
<th>20 µm</th>
<th>50 µm</th>
<th>100 µm</th>
</tr>
</thead>
<tbody>
<tr>
<td>polarity</td>
<td>p-on-n</td>
<td>n-on-n</td>
<td>p-on-n</td>
</tr>
<tr>
<td>Full depletion voltage</td>
<td>~25 V</td>
<td>~13 V</td>
<td>~35 V</td>
</tr>
<tr>
<td>IV @ 40 V (nA/cm²)</td>
<td>50-59</td>
<td>118</td>
<td>58-68</td>
</tr>
<tr>
<td>CV @ 40 V (pF/cm²)</td>
<td>580-620 940-960</td>
<td>652-665 930-950</td>
<td>650-655 937-955</td>
</tr>
<tr>
<td>Breakdown voltage</td>
<td>~145 V</td>
<td>~75 V</td>
<td>~180 V</td>
</tr>
</tbody>
</table>
Edgeless pixel detectors
Medipix2 pixel design & n-on-n layout

- Pixel pitch of 55 μm
- Active edge distances 20 and 50 μm
- UBM service available from subcontractor
Flip-chip bonding to Medipix2
Medipix2 n-on-n pixel detector: leakage current

- Detector biased from backside
- Active edge distances of 20 and 50 μm
- Leakage currents: 88 nA/cm² and 90 nA/cm²
- No breakdown observed below 70 V
Medipix2 n-on-n pixel detector: radiation source images

- Good flip-chip bonding yield
- Fe55 ($\gamma$), Cd109 ($\gamma$) and Sr90 (e$^-$) for 300 s at -15V bias
- Second to the edge row has highest count rate
Medipix2 n-on-n pixel detector: X-ray tube images

- 20 \(\mu\)m active edge distance detector at -15V bias
- W-tube with 30 keV, 10 mA and 2.2 mm Al filtering
- Flat band correction improves the image at the edge

Uncorrected image

Flat-field corrected

2 November 2009  J.Kalliopuska  Edgeless Detectors for High Energy Physics Applications
VTT’s process capabilities for advanced detectors

- Operator time 48-54% of the equipment time -> parallel batch processing
- Delivery time includes possible UBM process and handle wafer removal
- Add 1 month to the delivery time for the prototype process

<table>
<thead>
<tr>
<th>Process Time (h)</th>
<th>DC STRIP (realized)</th>
<th>EDGELESS POLY (realized)</th>
<th>EDGELESS IMPLANTATION (realized)</th>
<th>NEW EDGELESS IMPLANTATION (estimate)</th>
<th>FULL 3D EDGELESS POLY (estimate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>108 (2-3 WEEKS)</td>
<td>511 (10-11 WEEKS)</td>
<td>305 (6-7 WEEKS)</td>
<td>276 (5-6 WEEKS)</td>
<td>356 (7-8 WEEKS)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Process Steps</th>
<th>59</th>
<th>118</th>
<th>119</th>
<th>109</th>
<th>152</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Bottle Necks (% of the Process Time)</th>
<th>LITHOGRAPHY 23% FURNACE 20%</th>
<th>FURNACE 46% DRY ETCH 13% PLANARIZATION 12%</th>
<th>LITHOGRAPHY 23% FURNACE 20%</th>
<th>FURNACE 21% LITHOGRAPHY 18%</th>
<th>FURNACE 27% DRY ETCH 20%</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Delivery Time</th>
<th>1 MONTH</th>
<th>3-4 MONTHS</th>
<th>2-3 MONTHS</th>
<th>2 MONTHS</th>
<th>3 MONTHS</th>
</tr>
</thead>
</table>
Summary

➢ First prototypes p-on-n and n-on-n edgeless detectors have been fabricated
  • Breakdown and depletion voltage increase with the active edge distance
  • Leakage current increases with the active edge distance
  • Capacitance increases for the p-on-n with the active edge distance but decreases for the strip closest to the edge
  • For the n-on-n the capacitance is almost independent on the edge design
  • Good uniformity observed within the strips and pixels
  • Second to the edge pixels collect more charge
  • Physical edge activity of ~1 μm and no edge cracking

➢ VTT has capability to produce and deliver edgeless and full 3D edgeless detectors in 2-4 months.
   ➢ Three edgeless prototype processes done (1 poly & 2 edge implantation)
   ➢ Good understanding of the edgeless 3D process and non-planar lithography

➢ Further work in edgeless detector characterization: radiation hardness, edge activity determination and beam tests.
VTT creates business from technology