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First radiation test results of the SiGe Technology SGB25V of IHP

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Overview radiation test

- Baseline: Characterization of the IHP SiGe SGB25VD BiCMOS process regarding its sensitivity to a radiation environment.
- Goal: Derive inputs for the design of the local oscillator and future applications.

Test program:
- Total dose tests (7 samples biased, 3 samples unbiased, 1 reference sample)
  - High dose rate
  - Low dose rate
- SEE tests (2 samples, 1 reference sample)
  - Single Event Effects
  - Latch-up
- Displacement damage tests (4 samples, 1 reference sample)
  - Degradation
## Overview SGB25V technology

### Bipolar Section

<table>
<thead>
<tr>
<th>Parameter</th>
<th>High Performance</th>
<th>Standard</th>
<th>High Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_E$</td>
<td>0.42 $\times$ 0.84 $\mu$m$^2$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak $f_{\text{max}}$</td>
<td>95 GHz</td>
<td>90 GHz</td>
<td>70 GHz</td>
</tr>
<tr>
<td>Peak $f_T$</td>
<td>75 GHz</td>
<td>45 GHz</td>
<td>25 GHz</td>
</tr>
<tr>
<td>$BV_{CE0}$</td>
<td>2.4 V</td>
<td>4 V</td>
<td>7 V</td>
</tr>
<tr>
<td>$BV_{CB0}$</td>
<td>$&gt;7$ V</td>
<td>$&gt;15$ V</td>
<td>$&gt;20$ V</td>
</tr>
<tr>
<td>$V_A$</td>
<td>$&gt;50$ V</td>
<td>$&gt;80$ V</td>
<td>$&gt;100$ V</td>
</tr>
<tr>
<td>$\beta$</td>
<td>190</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### CMOS Section (0.25 $\mu$m)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SGB25VD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core Supply Voltage</td>
<td>2.5 V</td>
</tr>
<tr>
<td>nMOS $V_{\text{th}}$</td>
<td>0.6 V</td>
</tr>
<tr>
<td>nMOS $I_{\text{DSat}}$</td>
<td>570 $\mu$A/$\mu$m</td>
</tr>
<tr>
<td>nMOS $I_{\text{off}}$</td>
<td>3 pA/$\mu$m</td>
</tr>
<tr>
<td>pMOS $V_{\text{th}}$</td>
<td>-0.51 V</td>
</tr>
<tr>
<td>pMOS $I_{\text{DSat}}$</td>
<td>290 $\mu$A/$\mu$m</td>
</tr>
<tr>
<td>pMOS $I_{\text{off}}$</td>
<td>3 pA/$\mu$m</td>
</tr>
</tbody>
</table>
Test samples (1)

Each chip with test structures included:

- 3 bipolar NPN transistors of type npnVh (standard)
- 3 bipolar NPN transistors of type npnVp (increased $V_{CE}$ breakthrough voltage)
- 3 bipolar NPN transistors of type npnVs (speed optimized)
- 1 NMOS transistor 25 x 0.24µm² (W x L), 1 NMOS transistor 25 x 25µm² (W x L) >>> common gate and common source
- 1 PMOS transistor 25 x 0.24µm² (W x L), 1 PMOS transistor 25 x 25µm² (W x L) >>> common gate and common source
- 1 CMOS ring oscillator (CRO) with 100 inverters plus 1 NAND logic (transistors: 0.24 x 0.48µm²)
- 1 bipolar ring oscillator (BRO) with 53 CML circuits (transistors: type npnVp)
- 1 CMOS shift register (SR) with 10 blocks of 100 D-FF plus 1 inverter (transistors: 0.24 x 0.48µm² and 0.24 x 1.1µm²)

Each structure is protected by guard rings which are all connected to power GND.
Test samples (2)

Chips are wire bonded to a 64 CQFP carrier with open lid.

PMOS Transistors
NPN Transistors
CMOS Shift Register
CMOS Ring Oscillator
Bipolar Ring Oscillator

FLIPFLOPPAD

RINGOSZI1V/PAD
R016_FINAL

S732J_H
Test board TID (1)

- Up to 8 samples could be installed and tested at the same time.
- Test sockets were used to take up the test samples.
- Unbiased samples were placed on conductive foam in between the two rows of biased ones.
- The distance between biased and unbiased samples to the board was equalized.
- SMB connectors were used to get access to the outputs of the CMOS ring oscillators and shift registers.
- The area to be irradiated was about 15 x 10 cm².
Test board TID (2)

- Charged particle equilibrium was ensured by an aluminum plate of 2 mm in front of the samples.

- The distance to the samples was minimized but determined by the RF connectors.
Test board SEE

- The board was designed to fit to a sample board holder as defined in ECSS 25100.
- Test sockets were used to take up 2 test samples.
- For online measurement of output signals, level shifter and line driver were installed close to shift registers and oscillators.
- Only one sample was irradiated, biased, and verified at a time.
- Transistors were not biased during irradiation.
- For verification of all structures after irradiation the TID sample board and unit tester were used.
Test board DD

- A dedicated board was designed to take up 4 passive samples on test sockets.

- The area was limited to 5 x 5cm² to ensure a uniform proton density across the samples.
Test equipment

Unit tester:

- Laptop
  - Control, data storage
- Measurement equipment
  - Biasing, data acquisition
- Signal conditioning electronics
  - Filters, buffers

Interfaces:

- Laptop – rack: LAN (30m)
- Rack – signal conditioner: about 2.5m
- Signal conditioner – sample board: about 1m

Monitoring of measurements via VPN tool
**TID verification (1)**

**Measured parameters**
- **Shift registers:** time delay, power supply current
- **Ring oscillators:** frequency, power supply current
- **Transistors:** see tables below

### Verification of NPN-Transistors

<table>
<thead>
<tr>
<th>Modes</th>
<th>Basic</th>
<th>“Gummel - 0V”</th>
<th>“Gummel - 1V”</th>
<th>“Break Through”</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U_{CE}$</td>
<td>1V</td>
<td>0V</td>
<td>1V</td>
<td>open</td>
</tr>
<tr>
<td>$U_{BE}$</td>
<td>0.7V</td>
<td>0…1V in steps of 0,1V</td>
<td>0…1V in steps of 0,1V</td>
<td>0…5V in steps of 0,1V</td>
</tr>
<tr>
<td><strong>Measured Parameters</strong></td>
<td>$U_{CE}$, $U_{BE}$, $I_C$, $I_B$</td>
<td>$U_{CE}$, $U_{BE}$, $I_C$, $I_B$</td>
<td>$U_{CE}$, $U_{BE}$, $I_C$, $I_B$</td>
<td></td>
</tr>
<tr>
<td><strong>Plots</strong></td>
<td>$I_C$ and $I_B$ over $U_{BE}$ @ different TID levels</td>
<td>$I_C$ and $I_B$ over $U_{BE}$ @ different TID levels</td>
<td>$I_B$ over $U_{BE}$ @ different TID levels</td>
<td></td>
</tr>
</tbody>
</table>

### Verification of P-/NMOS-Transistors

<table>
<thead>
<tr>
<th>Modes</th>
<th>Basic</th>
<th>“Threshold”</th>
<th>“Saturation”</th>
<th>“Leakage”</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U_{DS}$</td>
<td>-0,1V / 0,1V</td>
<td>-0,1V / 0,1V</td>
<td>-2,5V / +2,5V</td>
<td>-2,5V / +2,5V</td>
</tr>
<tr>
<td>$U_{GS}$</td>
<td>-2V / 2V</td>
<td>0…-2,5 / +2,5V in steps of 0,25V</td>
<td>0…-2,5 / +2,5V in steps of 0,25V</td>
<td>0V</td>
</tr>
<tr>
<td><strong>Measured Parameters</strong></td>
<td>$U_{GS}$, $U_{DS}$, $I_D$</td>
<td>$U_{GS}$, $U_{DS}$, $I_D$</td>
<td>$U_{GS}$, $U_{DS}$, $I_D$</td>
<td></td>
</tr>
<tr>
<td><strong>Plots</strong></td>
<td>$I_D$ over $U_{GS}$ @ different TID levels</td>
<td>$I_D$ over $U_{GS}$ @ different TID levels</td>
<td>$I_D$ @ different TID levels</td>
<td></td>
</tr>
</tbody>
</table>
TID verification (2)

- Test facility: GSF, Neuherberg/München
- Test program:
  - High dose rate – 200krad @ 2rad/s
  - 24h annealing @ ambient temperature
  - 168h annealing @ 100°C
  - Low dose rate – 20krad @ 0.02rad/s
  - 24h annealing @ ambient temperature
  - 168h annealing @ ambient temperature

- Summary of test results:
  - All structures passed the irradiation tests.
  - No distinct ELDR effects were seen.
  - Only low drifts were detected on transistor elements as well as on complex structures.
TID verification (3)

Low Dose Rate Tests (biased)
Plots of NPN-T3 transistors with no degradation after annealing (yellow and blue curves)

High Dose rate tests (unbiased)
Plots of NPN-T1 Transistors
TID verification (4)

High Dose Rate Tests
Plots of N-MOS T2-transistors
(Threshold measurements)

High Dose Rate Tests
Plots of P-MOS T2-transistors
(Threshold measurements)
SEE verification (1)

- Test facility: RADEF, Jyvaskyla/Finland
- Test program:
  - Determination of the cross-section in the LET range of 1.8 to 85MeV/mg/cm²
  - Verification of latch-up sensitivity at elevated temperature (about 60°C)
  - Test of dynamic and static mode of shift registers
  - Check for transients at oscillator outputs.

- Summary of test results:
  - All structures passed the irradiation tests
  - The upset threshold is rather low. Upsets could already be detected at 3.6MeV/mg/cm²
  - No latch-up occurred up to 85MeV/mg/cm²
  - Error rates of static and dynamic modes correspond
  - No transients were detected on oscillator output signals with the given set-up (limited resolution).
## SEE verification (2)

### ARTES 30/20: Cross Section Shift Registers (Early Structures)

<table>
<thead>
<tr>
<th>Particles</th>
<th>LET</th>
<th>Angle</th>
<th>Fluence</th>
<th>Dose</th>
<th>Upsets</th>
<th>Cross Section</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>1.8</td>
<td>0</td>
<td>1.00E+07</td>
<td>288.396</td>
<td>1</td>
<td>1.00E-10</td>
<td></td>
</tr>
<tr>
<td>Ne</td>
<td>3.6</td>
<td>0</td>
<td>1.00E+07</td>
<td>576.792</td>
<td>11</td>
<td>1.10E-09</td>
<td></td>
</tr>
<tr>
<td>Ne</td>
<td>5</td>
<td>45</td>
<td>1.00E+07</td>
<td>801.1</td>
<td>99</td>
<td>9.90E-09</td>
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<tr>
<td>Ar</td>
<td>10.1</td>
<td>0</td>
<td>5.00E+06</td>
<td>809.111</td>
<td>156</td>
<td>3.12E-08</td>
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<tr>
<td>Ar</td>
<td>14.1</td>
<td>45</td>
<td>5.00E+08</td>
<td>1129.551</td>
<td>203</td>
<td>4.06E-08</td>
<td></td>
</tr>
<tr>
<td>Fe</td>
<td>18</td>
<td>0</td>
<td>2.00E+06</td>
<td>576.792</td>
<td>67</td>
<td>3.35E-08</td>
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<tr>
<td>Fe</td>
<td>18</td>
<td>0</td>
<td>1.00E+07</td>
<td>2883.96</td>
<td>422</td>
<td>4.22E-08</td>
<td>Control Measurement</td>
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<tr>
<td>Fe mean</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.79E-08</td>
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</tr>
<tr>
<td>Kr</td>
<td>32.1</td>
<td>0</td>
<td>1.00E+07</td>
<td>5143.062</td>
<td>648</td>
<td>6.48E-08</td>
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</tr>
<tr>
<td>Kr</td>
<td>45</td>
<td>45</td>
<td>1.00E+06</td>
<td>720.99</td>
<td>108</td>
<td>1.08E-07</td>
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</tr>
<tr>
<td>Kr mean</td>
<td>45</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.15E-07</td>
<td>Control Measurement</td>
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<tr>
<td>Xe</td>
<td>60</td>
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<td>1.10E+07</td>
<td>10574.52</td>
<td>1338</td>
<td>1.22E-07</td>
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</tr>
<tr>
<td>Xe</td>
<td>85</td>
<td>45</td>
<td>1.00E+07</td>
<td>13618.7</td>
<td>1804</td>
<td>1.80E-07</td>
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<tr>
<td>TID</td>
<td>krad</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>37843.964</td>
<td></td>
</tr>
</tbody>
</table>

Here is a graph illustrating the cross section vs. LET (Mev/mg/cm²) for different particles. The table shows the cross section for particles N, Ne, Ar, Fe, Kr, and Xe at various LET values and fluences. The cross sections are given in units of particles per bit per particle. The remarks column indicates control measurements for some entries.
Displacement damage verification (1)

- Test facility: RADEF, Jyvaskyla/Finland
- Test program:
  - Determination of degradation after $1E+11$, $2E+11$, $5E+11$ and $1E+12$ protons
  - Application of protons of 30MeV
  - Applied flux was about $1E+8$ particles/cm$^2$/s.

- Summary of test results:
  - All structures passed the irradiation tests
  - No distinct degradation effects could be identified.

Test setup
Displacement damage verification (2)

Plots of NPN-T1 transistors
(Breakthrough measurements)

Plots of NPN-T2 transistors
(Breakthrough measurements)
Displacement damage verification (3)

Plots of NMOS-2 transistors
(Threshold measurements)

Plots of PMOS-2 transistors
(Threshold measurements)
Conclusion

- **TID**
  - The technology only shows minor degradation up to the maximum tested level of 200 krad.
  - No distinct ELDR effects were detected.

- **SEE**
  - No latch-up occurred up to the tested value of 85 MeV/mg/cm².
  - The technology is sensitive to bit-flips. The SEU threshold is below 3.6 MeV/mg/cm².

- **DD**
  - The technology only shows negligible degradation effects up to the tested value of 1E+12 protons/cm².