Performance comparison of Hall Effect Sensors obtained by regular bulk or SOI CMOS technology

Dr. Maria-Alexandra PAUN

Visiting Researcher
High Voltage Microelectronics and Sensors (HVMS) Group, Department of Engineering, University of Cambridge, United Kingdom

Secretary, IEEE Switzerland ExCom
Chair, IEEE WIE Switzerland
Different Hall cells have been integrated in both bulk and SOI CMOS technology and analyzed in terms of their specific parameters.

The first one is XFAB regular bulk CMOS XH 0.35 µm and the second one is XFAB SOI XI10 1 µm non-fully depleted.

Geometry plays an important role in Hall cells performance. The focus of this work is on the XL Hall cell.

The most important parameters of a specific Hall cell, based on both regular bulk and SOI structures, are evaluated through three-dimensional physical simulations.
Hall Effect Sensors

- low-power applications
- current sensing
- position detection & contactless switching

\[ V_{HALL} = S_A B \] (1)

\[ S_A = \frac{G r_H}{n q t} I_{bias} \] (2)
Hall Cells Design Selection

- Different 3D Hall sensors were integrated in both regular bulk and SOI CMOS.

- They are all symmetrical and orthogonal structures.

- The geometry plays an important role in the sensors performance.

\[
G \approx 1 - \frac{16}{\pi^2} \exp \left( - \frac{\pi}{2} \frac{L}{W} \right) \left[ 1 - \frac{8}{9} \exp \left( - \frac{\pi}{2} \frac{L}{W} \right) \right] \left[ 1 - \frac{\theta_H^2}{3} \right]
\]

valid if \( 0.85 \leq L/W < \infty \) and \( 0 \leq \theta_H \leq 0.45 \)
Hall Effect Sensors Measurements

- Measurements results on nine different Hall Effect sensors in regular bulk CMOS
- Similar results expected soon for the SOI counterparts

**Objectives:** offset @ T=300 K < ±30 μT & offset drift < ±0.3 μT/°C

<table>
<thead>
<tr>
<th>Geometry Type</th>
<th>Basic</th>
<th>Low-doped</th>
<th>L</th>
<th>XL</th>
<th>45 Deg</th>
<th>Narrow Contacts</th>
<th>Borderless</th>
<th>Square</th>
<th>Optimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated Shape (CMOS 0.35 μm)</td>
<td><img src="image" alt="Integrated Shape" /></td>
<td><img src="image" alt="Integrated Shape" /></td>
<td><img src="image" alt="Integrated Shape" /></td>
<td><img src="image" alt="Integrated Shape" /></td>
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<td><img src="image" alt="Integrated Shape" /></td>
<td><img src="image" alt="Integrated Shape" /></td>
</tr>
<tr>
<td>$R_0$ (kΩ) @ T=300 K, B=0 T</td>
<td>2.3</td>
<td>5.6</td>
<td>2.2</td>
<td>2.2</td>
<td>2.1</td>
<td>2.5</td>
<td>1.3</td>
<td>4.9</td>
<td>1.5</td>
</tr>
<tr>
<td>$S_A$ (V/T) @ $I_{bias}$=1 mA</td>
<td>0.0807</td>
<td>0.3392</td>
<td>0.0804</td>
<td>0.0806</td>
<td>0.0807</td>
<td>0.0822</td>
<td>0.0325</td>
<td>0.0884</td>
<td>0.0635</td>
</tr>
<tr>
<td>Offset drift (μT/°C) (4-phase current spinning)</td>
<td>0.409</td>
<td>0.067</td>
<td>0.264</td>
<td>0.039</td>
<td>0.373</td>
<td>0.344</td>
<td>0.526</td>
<td>0.082</td>
<td>0.328</td>
</tr>
<tr>
<td>$L$, $W$ (μm) of the Active Area (N-well)</td>
<td>$L=21.6$</td>
<td>$L=21.6$</td>
<td>$L=32.4$</td>
<td>$L=43.2$</td>
<td>$L=21.64$</td>
<td>$L=21.6$</td>
<td>$L=50$</td>
<td>$L=20$</td>
<td>$L=54$</td>
</tr>
<tr>
<td>$W$</td>
<td>$W=11.8$</td>
<td>$W=11.8$</td>
<td>$W=17.8$</td>
<td>$W=22.6$</td>
<td>$W=11.8$</td>
<td>$W=9.5$</td>
<td>$W=50$</td>
<td>$W=20$</td>
<td>$W=54$</td>
</tr>
<tr>
<td>$L/W$</td>
<td>1.83</td>
<td>1.83</td>
<td>1.82</td>
<td>1.91</td>
<td>1.83</td>
<td>2.27</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$s$ (μm) for Sensing Contacts</td>
<td>11</td>
<td>11</td>
<td>16</td>
<td>20.7</td>
<td>11</td>
<td>1.5</td>
<td>2.3</td>
<td>2.3</td>
<td>5.4</td>
</tr>
<tr>
<td>Geometrical Correction Factor ($G$)</td>
<td>0.913</td>
<td>0.913</td>
<td>0.912</td>
<td>0.924</td>
<td>0.913</td>
<td>0.87</td>
<td>0.76</td>
<td>0.73</td>
<td>0.74</td>
</tr>
</tbody>
</table>
Single Phase and Residual Offset

- Cell polarization and the corresponding phases

![Greek-cross cell polarization](image)

<table>
<thead>
<tr>
<th>Phases</th>
<th>Ibias</th>
<th>$V_{\text{HALL}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1</td>
<td>a to c</td>
<td>b to d</td>
</tr>
<tr>
<td>Phase 2</td>
<td>d to b</td>
<td>a to c</td>
</tr>
<tr>
<td>Phase 3</td>
<td>c to a</td>
<td>d to b</td>
</tr>
<tr>
<td>Phase 4</td>
<td>b to d</td>
<td>c to a</td>
</tr>
</tbody>
</table>

- Single phase offset and residual offset

\[
V_{\text{out}} = V_{\text{HALL}} (B) + V_{\text{offset}}
\]  

\[
\text{Offset}_{\text{residual}} (4 \text{ phase}) = \frac{V_{P1} - V_{P2} + V_{P3} - V_{P4}}{4}
\]
Offset measurements

- Measured for XL regular bulk CMOS, results expected soon for XL SOI

![Graphs showing offset measurements](image-url)
Regular bulk vs. SOI CMOS technology

The sensors fabricated in SOI (Silicon On Insulator) technology have obvious benefits, with respect to the bulk Hall sensors.

- higher magnetic sensitivity
- less noise generation
- possibility to use lower biasing voltage
- smaller leakage current through the dielectric
- enhanced radiation resistance etc.
The 3D Simulation of regular bulk Hall Cells

- The XL structure follows the XFAB XH 0.35 fabrication process.

- **active n-well region**: Arsenic doping
  - ✅ Gauss profile implantation
  - ✅ $1.5 \times 10^{17}$ cm$^{-3}$

- **p-substrate**: Boron doping concentration of $10^{15}$ cm$^{-3}$

### Parameter Table

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>L (µm)</td>
<td>43.2</td>
</tr>
<tr>
<td>W (µm)</td>
<td>19</td>
</tr>
<tr>
<td>Contacts dimension s (µm)</td>
<td>18.3</td>
</tr>
</tbody>
</table>
The stacking of the layers, according to a SOI Xfab XI10 fabrication process.

The active silicon layer is found on top of the dielectric buried silicon oxide ($\text{SiO}_2$) layer, which is in its turn found on the silicon substrate, or handle wafer.

### DOPING CONCENTRATIONS IN THE SOI HALL CELL FABRICATION

<table>
<thead>
<tr>
<th>Layer</th>
<th>Type</th>
<th>Numerical value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wafer (handle) substrate</td>
<td>Si, p-doped (Boron)</td>
<td>6.5 E+14 cm$^{-3}$</td>
</tr>
<tr>
<td>Dielectric</td>
<td>Buried Silicon Oxide, $\text{SiO}_2$</td>
<td></td>
</tr>
<tr>
<td>p-substrate in active Silicon layer</td>
<td>Si, p-doped (Boron)</td>
<td>1E+15 cm$^{-3}$</td>
</tr>
<tr>
<td>n-well in active Silicon layer</td>
<td>Si, n-doped (Arsenic)</td>
<td>5E+16 cm$^{-3}$</td>
</tr>
</tbody>
</table>
3D Simulations results (II)

SOI XL cell:
- I-V characteristics
- $V_{\text{HALL}}$ estimation
- Sensitivity numerical estimation

![Graph 1](image1.png)

Hall voltage vs. biasing voltage, SOI XL

![Graph 2](image2.png)

Sensitivity vs. biasing voltage, SOI XL

V-I characteristics, SOI XL, $R_{\text{input}} = 42\ \text{k}\Omega$
**3D Simulations results (III)**

**Regular bulk XL:**
- I-V characteristics
- $V_{\text{HALL}}$ estimation
- Sensitivity numerical estimation

**V-I characteristics, regular bulk XL, $R_{\text{input}}=2.2$ kΩ**

$$y = 0.019x + 0.0002$$

**$V_{\text{HALL}}$ vs. biasing voltage, regular bulk XL**

$$y = 0.038x + 0.0003$$

**$S_A$ vs. biasing voltage, regular bulk XL**
Conclusions

- This work was intended to analyze the behaviour of the XL Hall cell in both regular bulk and SOI CMOS fabrication process, by performing three-dimensional physical simulations.

- The Hall voltage, absolute sensitivity and input resistance were extracted through simulations.

- With respect to equivalent devices fabricated in regular bulk, the Hall devices built in SOI technology offer higher absolute sensitivity.
References (selective list)

Acknowledgements:

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Thank you for your attention!