SiGe Technology and Devices

Nanqi Liu
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Introduction

- SiGe is a semiconductor alloy, meaning a mixture of two elements, silicon and germanium.

<table>
<thead>
<tr>
<th>Energy bandgap at 300K</th>
<th>Si</th>
<th>Ge</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.12 eV</td>
<td></td>
<td>0.66 eV</td>
</tr>
</tbody>
</table>

- The main characteristics of the SiGe material with respect to silicon are its lower energy bandgap and the possibility to control it by varying the germanium content.

- In SiGe alloy, bandgap reduces approximately 75 meV for each 10% of Ge introduced.
Usages in semiconductor processes:

- Strain-inducing layer for CMOS transistors
  - The strained layer will have higher carrier mobility than unstrained Si.
- Base region of a BJT to form a heterojunction bipolar transistor (HBT)
  - The heterojunction bipolar transistor (HBT) is a type of BJT which uses differing semiconductor materials for the emitter and base regions, creating a heterojunction.
  - Heterojunction bipolar transistors have higher forward gain and higher peak frequency $f_T$ than traditional homojunction bipolar transistors.
History

- The first functional SiGe HBT was demonstrated by IBM in December of 1987.
- In 1990, a SiGe HBT grown by ultra-high vacuum / chemical vapor deposition (UHV/CVD) was demonstrated with fT of 75GHz.

From Silicon-Germanium Heterojunction Bipolar Transistors (2002) by John D. Cressler
Comparison of the band diagrams of a SiGe HBT (solid line) and a Si bipolar transistor (dashed line)
Graded germanium

A gradient in the conduction band, which acts as a built-in electric field, accelerating electrons from the emitter to collector
First generation SiGe HBT

Schematic cross section of a representative first generation SiGe HBT, drawn through first metal.
Doping profile

Measured doping profile of a representative first generation SiGe HBT.
Cross sectional SEM

Cross sectional SEM of a representative second generation SiGe HBT
Advantages over other III-V compound semiconductors

- Gallium arsenide (GaAs) is the best technology to build power amplifiers, but expensive.
- SiGe can be processed on equipment nearly the same as used for ordinary CMOS.
- Compared to gallium arsenide (GaAs), it doesn't lack a native oxide (important for forming MOS structures) and doesn't suffer from mechanical fragility that limits the wafer size of GaAs.
Schematic process flow for a BAG second generation SiGe HBT BiCMOS technology
## Comparisons of Technologies for RFICs

<table>
<thead>
<tr>
<th>Performance Metric</th>
<th>SiGe HBT</th>
<th>Si BJT</th>
<th>Si CMOS</th>
<th>III-V MESFET</th>
<th>III-V HBT</th>
<th>III-V HEMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency response</td>
<td>++</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>1/f and phase noise</td>
<td>++</td>
<td>+</td>
<td>-</td>
<td>--</td>
<td>0</td>
<td>--</td>
</tr>
<tr>
<td>Broadband Noise</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Linearity</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Output conductance</td>
<td>++</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>++</td>
<td>-</td>
</tr>
<tr>
<td>Transconductance/area</td>
<td>++</td>
<td>++</td>
<td>--</td>
<td>-</td>
<td>++</td>
<td>-</td>
</tr>
<tr>
<td>Power dissipation</td>
<td>++</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>CMOS integration</td>
<td>++</td>
<td>++</td>
<td>N/A</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>IC cost</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

(Excellent: ++; Very good: +; Good: 0; Fair: -; Poor: --)
Summary of SiGe BiCMOS and RF CMOS technology

From IBM
Rich RF Portfolio

Addresses performance, complexity and cost demands

World-leading LNA and switch built in RF SOI, control function integration for RF FEM, phase arrays, mmWave beam forming

SiGe PA for Wi-Fi and cellular power amplifiers, displacing GaAs

Advanced and mainstream technologies for TRX, automotive radar, IoT

High-Performance SiGe for base stations, automotive radar

From GF website
Summary

- SiGe HBTs offer better frequency response, noise figure, and linearity than both Si BJTs and Si CMOS.
- SiGe HBTs have comparable performance to GaAs HPTs, but a much lower cost.
- The SiGe BiCMOS technologies provide high performance SiGe HBTs combined with advanced CMOS technology and a variety of passive devices critical for realizing an integrated mixed-signal system-on-a-chip (SoC).
References

- Foundation of rf CMOS and SiGe BiCMOS technologies, IBM Journal of Research and Development
- Silicon-Germanium Heterojunction Bipolar Transistors (2002) by John D. Cressler
- Current status and future trends of SiGe BiCMOS technology, IEEE Transactions on Electron Devices
Thank You!