DOTSEVEN
Towards 0.7 THz SiGe
Rudolf Lachner, Project Coordinator, Nov. 14, 2012
Some Results from Predecessor DOTFIVE

DOTSEVEN
- In a Nutshell
- Objectives
- Challenges

Summary
### Results of the DOTFIVE Project

DOTFIVE: February 2008 – August 2011

<table>
<thead>
<tr>
<th></th>
<th>IHP</th>
<th>IMEC</th>
<th>ST</th>
<th>IFX</th>
</tr>
</thead>
<tbody>
<tr>
<td>$w_E$ (nm)</td>
<td>120</td>
<td>75</td>
<td>100</td>
<td>130</td>
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<tr>
<td>$f_T$ (GHz)</td>
<td>300</td>
<td>245</td>
<td>290</td>
<td>240</td>
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<tr>
<td>$f_{\text{max}}$ (GHz)</td>
<td>500</td>
<td>460</td>
<td>430</td>
<td>380</td>
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<tr>
<td>$BV_{\text{CE0}}$(V)</td>
<td>1.6</td>
<td>1.7</td>
<td>1.5</td>
<td>1.5</td>
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<tr>
<td>$t_{\text{CML}}$ (ps)</td>
<td>1.9</td>
<td>N A</td>
<td>[1.9]</td>
<td>2.4</td>
</tr>
</tbody>
</table>
DOTFIVE: IHP’s Record 500 GHz SiGe HBT

- Sacrificial layer
- Spacer
- Emitter
- SiGe
- Collector window
- STI
- Elevated extrinsic base
- Collector contact
- Heavily-doped collector

Graph:
- Extrapolation Frequency (GHz)
- $f_T$, $f_{max}$
- 8 Single Devices
- Multi-Emitter Device
- 0 20 40 60 80 100 Extrapolation Frequency (GHz)
DOTFIVE: Infineon‘s and ST‘s 400 GHz SiGe HBTs

IFX: $f_T = 250$ GHz; $f_{\text{max}} = 400$ GHz

STM: $f_T = 300$ GHz; $f_{\text{max}} = 400$ GHz
Latest Results of Infineon‘s Scaled SiGe HBT

\[ A_E = 0.11 \times 4.9 \, \mu m^2 \]
\[ f_T = 240 \, (BEBC) \sim 250 \, GHz \, (BEC) \]
\[ f_{\text{max}} = 400 \, GHz \]
\[ \tau_d = 2.38 \, ps \, ; \, \sigma = 1 \% \, \text{over wafer} \]
Fabrication of DPSA SEG SiGe Emitter / Base Module

Fabrication Steps of E/B Module

Cross Section of SiGe HBT
Parasitics of the DPSA SEG E/B Structure

\[ f_T = \frac{1}{(2\pi \cdot \tau_{EC})} = \frac{1}{2\pi \left[ kT(C_{EB} + C_{BC})/qI_C + \tau_B + \tau_E + W_{CB}/(2v_{sat}) + R_C C_{BC} \right]} \]

\[ f_{MAX} \approx (f_T/(8\pi \cdot R_B \cdot C_{BC}))^{1/2} \]

- Base link dominates \( R_B \)
- Difficult to minimize in DPSA SEG structure
- Temperature budget for link anneal limited by base widening effects

\[ \Rightarrow \text{ new E/B architecture required (DOTSEVEN)} \]
DOTSEVEN in a Nutshell

- Development of Silicon-Germanium Bipolar Technology with $f_{\text{max}} = 700$ GHz
- 14 Partners from 6 EU countries
- Project coordinator: IFX
- Budget: 12.3 M€
- EC contribution: 8.6 M€
DOTSEVEN Partners are from all over Europe!
### Project Partners

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Short Name</th>
<th>Country</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Infineon Technologies AG</td>
<td>IFX</td>
<td>Germany</td>
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<tr>
<td>2</td>
<td>IHP GmbH / Innovations for High Performance Microelectronics</td>
<td>IHP</td>
<td>Germany</td>
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<tr>
<td>3</td>
<td>Universita di Napoli</td>
<td>UN</td>
<td>Italy</td>
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<td>4</td>
<td>RWTH Aachen</td>
<td>RWTH</td>
<td>Germany</td>
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<td>5</td>
<td>Technische Universitaet Dresden</td>
<td>TUD</td>
<td>Germany</td>
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<tr>
<td>6</td>
<td>Université de Bordeaux</td>
<td>UB1</td>
<td>France</td>
</tr>
<tr>
<td>7</td>
<td>XMOD technologies</td>
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<td>France</td>
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<td>8</td>
<td>University of Wuppertal</td>
<td>BUW</td>
<td>Germany</td>
</tr>
<tr>
<td>9</td>
<td>Johannes Kepler University of Linz</td>
<td>JKU</td>
<td>Austria</td>
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<td>SiversIMA</td>
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<td>Trebax</td>
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<td>Delft University of Technology</td>
<td>TUDelft</td>
<td>Netherlands</td>
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<td>Dice GmbH &amp; Co KG</td>
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<tr>
<td>14</td>
<td>ALMA</td>
<td>ALMA</td>
<td>France</td>
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</table>
In What League Will We Play?
Main Objectives of DOTSEVEN

- Development of a SiGe HBT technology with cut-off frequency \( f_{\text{max}} \) around 700 GHz (0.7 THz).
- Demonstration of manufacturability and integratability with CMOS
- Demonstration of capabilities and benefits of 0.7 THz SiGe HBT technology by benchmark circuits and system applications in the 0.1 to 1 THz range

- Strengthening and advancing Europe’s leading edge position in SiGe HBT technology, modelling and millimeter wave applications
## DOTSEVEN Performance Targets

<table>
<thead>
<tr>
<th>Target (PDK)</th>
<th>Target Details</th>
<th>Month</th>
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<tbody>
<tr>
<td>SiGe HBT 1 (PDK1)</td>
<td>IHP: $f_{\text{max}} / t_d = 500 \text{ GHz} / 2.0 \text{ ps}$&lt;br&gt;IFAG: $f_{\text{max}} / t_d = 400 \text{ GHz} / 2.5 \text{ ps}$</td>
<td>7</td>
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<tr>
<td>SiGe HBT 2</td>
<td>$f_{\text{max}} / t_d = 600 \text{ GHz} / 1.7 \text{ ps}$</td>
<td>21</td>
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<tr>
<td>SiGe HBT 3</td>
<td>$f_{\text{max}} / t_d = 600 \text{ GHz} / 1.7 \text{ ps}$</td>
<td>41</td>
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<tr>
<td>Demonstrators (run 2)</td>
<td>Fundamental Operating Frequency: 240 GHz&lt;br&gt;240 GHz Radar Demonstrator&lt;br&gt;Communication Demonstrator: Towards 100 Gbps</td>
<td>41</td>
</tr>
<tr>
<td>Benefits of 0.7 THz SiGe</td>
<td></td>
<td></td>
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<td>-------------------------</td>
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<tr>
<td>Enables fundamentally operated circuits up to 240 GHz</td>
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<tr>
<td>Enables sub-harmonically operated circuits up to 1.4 THz</td>
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<tr>
<td>Improved energy efficiency (PAE) at lower $f_{\text{op}}$</td>
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<td>Higher integration capability</td>
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<td>Low cost due to depreciated CMOS litho</td>
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<tr>
<td>„More than Moore“, „Beyond (and ahead) of CMOS“</td>
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</tbody>
</table>
Adressed Applications Fields

**High-speed Communication**
- Wireless:
  - Personal and Local Area Networks (PANs/LANs)
  - Consumer electronic devices
  - Consumer electronic devices
  - Wireless backhaul
  - Inter-building communication, E-band (71-76, 81-86GHz)
  - Secure links and surveillance
  - Space and inter-satellite communication
- Digital:
  - High-speed interconnects
  - Data switches (Mux/DeMux)
  - Analog to Digital Conversion (ADC/DAC)

**Radar Applications**
- Automotive:
  - Long Range Radar (LRR)
    - Collision avoidance, automated cruise control (77GHz)
  - Short Range Radar (SSR)
    - Pre-crash detection, stop-and-go, lane change assistant (77-81GHz)
  - Road condition detection
- Space:
  - Aviation safety in extremely poor visibility (94GHz)
  - Airport ground control (94GHz)

**mmWave, THz Imaging and Sensing**
- Security:
  - Non-invasive imaging
  - Drug and explosive detection
- Sensing:
  - Earth sensing and climate control
  - Industrial process control
  - Astronomy, microwave background
- Biotechnology:
  - Medical imaging, tumor recognition
  - Genetic screening
Power Savings with Higher $F_{\text{max}}$

\[\text{PDP}_{\text{rel}} = \text{relative power*delay product} \sim V_{\text{cc}} \ast I / f_{\text{max}}\]

- **B11C**: 400 GHz
  - $PDP_{\text{rel}} = 0.62$
  - $W_e = 0.12 \mu m, L_e = 2.0 \mu m$

- **B7HF**: 250 GHz
  - $PDP_{\text{rel}} = 1.00$
  - $W_e = 0.18 \mu m, L_e = 2.7 \mu m$

Improved performance @ same current / power consumption

Lower current / power consumption @ same performance
Competition to Advanced CMOS

**ITRS RF&AMS Roadmap (Edition 2011)**

- DOT7 will redefine the ITRS roadmap of SiGe
- Although CMOS makes rapid progress with respect to *intrinsic* $f_t/f_{max}$, its AMS properties will be inferior to SiGe in actual circuits:
  - Higher 1/f noise
  - Lower PAE / $P_{out}$
  - Higher Noise Figure due to inferior passives & interconnects
  - Lower Linearity
  - Worse Matching
  - Lower Reliability
Moderate Litho Requirements of SiGe HBTs

- ITRS RF&AMS Roadmap (Edition 2011)

- Lithographic and tool/fab requirements are much higher for advanced CMOS
- ...therefore cost of advanced CMOS will be extremely high for low to medium volume products (mask set several million US $)
Main Challenges

- **Reliability**
  - Yield (leakage currents) of very thin SiGe base layers
  - Excessive selfheating
  - (performance degradation / electro migration)
  - Extremely high emitter / collector current density (electro migration)
  - Degradation effects under mixed mode stress
  - ESD protection

- **Compatibility with CMOS processing at the 130 / 90 nm node**
Summary

- DOTSEVEN will significantly expand the successful work of DOTFIVE
- DOTSEVEN Paves The Road Towards 0.7 THz SiGe HBT Technology
- It will strengthen Europe’s leading edge position in SiGe technology, modeling and applications