Applied Centura® RP Epi System for nMOS and pMOS Transistors

Schubert Chu, Ph.D.
Epitaxy Products
Transistor and Metallization Products

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Mobility Era Introduction
2000

PC era

Performance vs. power

~15%

2D Scaling

2013 and beyond

PC + MOBILITY era

Low Power with High Performance

3D Scaling

Higher Materials Intensity

3D FinFET
3D NAND
SOC
New materials

Transistor Performance Increase From Materials at each node

~90%

Images Source: Device manufacturers public announcements and conference publications; Data sources: IBM Microelectronics, IBM, IC Insights
Transistors are at the Heart of High Performance
Transistors are the Heart of High Performance

CMOS technology includes both nMOS and pMOS type of transistors each with their own optimization challenges.
Epitaxy Enhances Mobile Processor Performance

- **130nm**
  - nMOS Transistor
  - pMOS
  - Epi

- **90nm**
  - nMOS Transistor
  - pMOS
  - Epi

- **65nm**
  - nMOS Transistor
  - pMOS
  - Epi

- **45/40nm**
  - nMOS Transistor
  - pMOS
  - Epi

- **28/32nm**
  - nMOS Transistor
  - pMOS
  - Epi

- **22/20nm**
  - nMOS Transistor
  - pMOS
  - Epi

**FUTURE**
Next Gen Voice Recognition, Augmented Reality

**3rd GEN**
Voice Recognition, 1080p Video, More Multi-Tasking

**2nd GEN**
High-Res Display, Video Chat

**1st GEN**
Multi-Touch, Mobile Gaming

Drive Current ▶ SPEED
Evolution of the Transistor

Epitaxy plays a key role in transistor evolution
What is Epitaxy?
Why is it Needed?
What is Epitaxy?

Growing a monocrystalline film which takes on a lattice structure and orientation identical to the substrate. This enables a high-purity starting point for building a semiconductor device.
Strain Engineering with Epitaxy

Introduction of larger atoms during epitaxial deposition to induce strain

Larger Lattice Constant

Smaller Lattice Constant

SiGe Layer

Silicon Substrate

A Germanium lattice is 4% larger than that of Silicon

Silicon Atom

Germanium Atom
Close Up View of Strain Engineering

Key to enhancing channel mobility
Epitaxy Enhances Transistor Speed without Increasing Leakage

![Graph showing drive current improvement with epitaxy](image)

- >60% Drive Current Improvement
- 2X revenue in last 5 years with >80% share
- <25 to >500 systems (2002-2013F)

REFERENCE

SELECTIVE EPI
nMOS Epitaxy

THE FOCUS OF TODAY’S ANNOUNCEMENT
Helpful Strain in Transistors with Selective Material Deposition

Achieved by incorporating smaller P or C & P atoms

A Carbon atom size is 62% that of a Silicon atom
nMOS Transistor Boost by Selective Epitaxy

Epitaxy contributes 20% of nMOS mobility enhancement @ 20nm

Source: Device manufacturers public announcements and conference publications.
Benefits of Epitaxy in Advanced Transistors

- **PRECISION CHANNEL MATERIAL ENABLES GATE PERFORMANCE**
- **COMPRESSIVE STRAIN ON CHANNEL INCREASES DRIVE CURRENT**
- **RAISED SOURCE / DRAIN EPI KEEPS METAL CONTACT AWAY FROM CHANNEL**
Epitaxy Delivers Transistor Speed with Low Leakage

- New Epi materials will be key driver for transistor speed beyond 20nm
- Revenue doubled in last 5 years with >80% share
- >500 systems shipped and counting

4X INCREASE IN STEPS

<table>
<thead>
<tr>
<th>Epi Steps</th>
<th>45nm</th>
<th>32/28nm</th>
<th>22/20nm</th>
<th>16/14nm</th>
<th>10nm</th>
</tr>
</thead>
</table>

- Oxynitride
- Selective Epi
- High-k Metal Gate
- FinFET
Leadership in Epitaxy
What’s Next: New Materials Epitaxy

ATM Epi

pMOS
RP Epi
Si/SiGe

nMOS
RP Epi
SiP/SiCP

Siconi
Pre-Clean

Strain Engineering

Pure, Crystalline Films for Building Transistors

BLANKET EPI

SELECTIVE EPI

NEW MATERIALS EPI
High Mobility
Channel Engineering


ATM: Atmospheric pressure
RP: Reduced Pressure
### Market Driving for New Channel Materials

<table>
<thead>
<tr>
<th></th>
<th>GROUP IV</th>
<th>III – V MATERIALS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Si</strong></td>
<td>1500</td>
<td>GaAs</td>
</tr>
<tr>
<td><strong>Ge</strong></td>
<td>3900</td>
<td>InAs</td>
</tr>
<tr>
<td><strong>GaAs</strong></td>
<td>9200</td>
<td>InSb</td>
</tr>
<tr>
<td><strong>InAs</strong></td>
<td>40000</td>
<td></td>
</tr>
<tr>
<td><strong>InSb</strong></td>
<td>77000</td>
<td></td>
</tr>
</tbody>
</table>

**Electron Mobility**
- **Si**: 1500
- **Ge**: 3900
- **GaAs**: 9200
- **InAs**: 40000
- **InSb**: 77000

**Hole Mobility**
- **Si**: 430
- **Ge**: 1900

Higher electron mobility for nMOS

Higher hole mobility for pMOS

Higher speeds at lower power (lower supply voltage)
nMOS Epitaxy is essential for faster transistors inside next-gen mobile processors.

nMOS Epitaxy boosts transistor speed by the equivalent of half a device node without increasing off-state power consumption.

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