300mm RFSOI Development toward IoT Era

SOI Workshop 2016 Tokyo
Jan. 21st, 2016

TowerJazz & TPSCo team for RFSOI
Contents

1. RF related semiconductor industry

2. 300mm benefit & Development using TCAD

3. Achievement

4. Advanced IoT technology in 300mm fab

5. Summary
Market Growth Driven by 4G/-LTE Enabled Handsets
The Future is Bright for RF: Internet of Things

While individual forecasts vary, there is a unanimous consensus: IoT will have a massive economic impact. RF Technology will be the key driver for IoT.

<table>
<thead>
<tr>
<th>Source</th>
<th>Date</th>
<th>CAGR 2014–'20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cisco</td>
<td>2013</td>
<td>23%</td>
</tr>
<tr>
<td>Ericsson</td>
<td>2010</td>
<td>-</td>
</tr>
<tr>
<td>Gartner</td>
<td>2013</td>
<td>23%</td>
</tr>
<tr>
<td>IDC</td>
<td>2014</td>
<td>17%</td>
</tr>
<tr>
<td>ABi Research</td>
<td>2014</td>
<td>29%</td>
</tr>
<tr>
<td>Harbor Research</td>
<td>2014</td>
<td>21%</td>
</tr>
<tr>
<td>Global Insight</td>
<td>2014</td>
<td>14%</td>
</tr>
</tbody>
</table>

Note: Some forecasts only for specific years, in that case all other years in between are extrapolated based on the corresponding growth rate; Ericsson does not specify today’s number of connected devices – therefore: Average of all other studies assumed as starting point in 2014

1. CAGR = Compound annual growth rate
2. Connected devices includes all autonomous connected things (every forecaster has own definition) - does NOT include computers, mobile devices, tablets

Sources: Cisco, Ericsson, ABI Research, Gartner, IHS, IDC, Harbor Research, IoT-Analytics.com
Wireless FEM content in iPhone 6

FEM content from ifixit teardown:

- Skyworks 77802-23 Low Band LTE PAD
- Skyworks 77803-20 Mid Band LTE PAD
- Skyworks 77356-8 Mid Band PAD
- Avago A8020 High Band PAD
- Avago A8010 Ultra High Band PA + FBARs
- RF Micro Devices RF5159 Antenna Switch Module
- Murata 339S0228 Wi-Fi Module
- Qualcomm QFE1000 Envelope Tracking IC

TowerJazz Solutions

- RF SOI Switches, tuners
- SiGe Power Amplifiers
- RF CMOS PA Control and Envelope Tracking
RF-SOI for RF Switching

# of RFSW ports has increased dramatically from 2G (6) -> 3G (9) -> 4G (30).

RF-SOI has taken over this market from GaAs pHEMT.
- Reduction in high-res substrate parasitics
- Switch FET device performance improvements
- Supports integration w/ other FEM functions, digital, etc.
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Benefit of 300mm Technology

- 300mm wafer for RFSOI is now available
- Leading Edge Technologies and Tools can be used
- Well Calibrated Tools and TCAD environment
- Well Controlled Manufacturing Capabilities (VM-APC)
- Cost will be competitive in case of high volume mass production

Source: “Device and Technology Implications of the Internet of Things” / ARM(VLSI2014)
Development Methodology

Early Success in 300mm RFSOI

- Relatively high Mask Price
- Relatively high Wafer Price
- Customer Proven 200mm RFSOI technologies - CS18QTx Family
- Accumulated 300mm Technologies - World First 65nm consumer LSI - World First 45nm LSI - World First GF-HKMG 32nm LSI
- Well-Calibrated TCAD Technology - Proven in 65nm/45nm/32nm - Proven in Imager and analog LSI
Heritage from historical development

Well-Developed TCAD can shorten RFSOI development duration

1) Well described Structure

2) Well Matched Profile

3) Well Matched Electrical Characteristics

4) Well Matched ET – RTA relationship
Demonstration of high accuracy TCAD simulation

- **Process/Device simulation**
  - Tr-Coff, Tr-Ron, AC-BV

- **Wiring simulation**
  - Wire-Coff, parasitic Ron

- **RF-switch design**
  - Device and layout optimization to minimize FOM (Ron x Coff)

**High accuracy TCAD** (Error of FOM < 5%)

[Graph showing Coff, Ron, and FOM]
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RF-SOI Technology Figure of Merit for a Switch

Ron x Coff (fs)

200mm

300mm

2012 2013 2014 2015
TowerJazz and TPSCo Announce Breakthrough RF Technology for Next-Generation 4G LTE Enabled Smartphones and IoT Applications

Begin sampling best-in-class sub-90fs Ron-Coff RF switch technology from TPSCo’s 300mm factory

MIGDAL HAEMEK, Israel, and UOZU, Japan September 2, 2015 — TowerJazz, the global specially foundry leader and TowerJazz Panasonic Semiconductor Co. (TPSCo), the leading analog foundry in Japan, today announced breakthrough RF technology for next-generation 4G LTE smartphones and IoT devices. Through a collaborative effort, TowerJazz and its majority owned subsidiary, TPSCo, have developed a new 300mm RF SOI process that can reduce losses in an RF switch by as much as 30% relative to current technology, improving battery life and boosting data rates. The technology achieves a record Ron-Coff figure of merit of sub-90fs and is now being sampled to a lead customer.

Development duration < 200 days

Demonstrating 300mm RF-SOI has room to run.
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Virtual Metrology: Methodology

- Tool data is collected and analyzed with statistical method and physical mechanism.
- Even Gox thickness can be virtually measured by this technology.

Big Data

- Data Analysis
- Tools
  - Parameter($X_{11}$)
  - Parameter($X_{21}$)

Virtual Metrology

- Depo Rate
- Polish Rate

Virtual PCM

- Tr Vt
- Resistance

Yield Prediction

Industry 4.0 cycle

Real World

Sensor

Analog Circuit

Digital Circuit

Digital Data

Information/Knowledge/Wisdom
Virtual Metrology for Gox

- Virtual Metrology technology is implemented in Gox
- NPW measurement and VM measurement are well matched.

Reference: Satoshi Yasuda AEC/APC Asia 2009
Virtual Metrology (VM) in CMP tools

- Conventional APC using physical thickness check was not enough for stable manufacturing.
- Virtual Metrology can accurately predict its removal rate, which greatly reduces its variability.

Feedback (spend long-time) vs. Feedback (Real Time)

Inspection (sampling) vs. VM prediction (100% coverage)

Conventional APC vs. VM APC

C_{pk} = 0.92
C_{pk} = 1.52

Removal rate = a_1 x_1 + a_2 x_2 + \cdots + a_i x_i

Date

Predict the processing result at real time!
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Summary

1) RF technology will grow rapidly in accordance with IoT growth. Currently RF-SOI is the typical RF technology and high growth is expected.

2) 300mm technology is beneficial for further RF-SOI improvement in terms of:
   - Higher technical capabilities using 300mm tools and technologies
   - Well calibrated tools and TCAD environment

3) TPSCo’s TCAD technology can predict FOM with 5% accuracy

4) FOM of < 90fs was achieved utilizing 300mm technologies and TCAD with < 200 days development. Limited PDK is now available. Further FOM reduction can be expected.

5) This technology is supported in 300mm fab with advanced IoT technology, which promises higher yield and stability