Positioning More than Moore Characterization Needs and Methods within the ITRS

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May 26, 2011

2011 International Conference on Frontiers of Characterization and Metrology for Nanoelectronics
Overview

• Miniaturization
• The ITRS roadmapping process
• New territory: More than Moore
• Characterizing More than Moore
Miniaturization
“Reduced cost is one of the big attractions of integrated electronics, and the cost advantage continues to increase as the technology evolves toward the production of larger and larger circuit functions on a single semiconductor substrate.”

Electronics, Volume 38, Number 8, April 19, 1965
CMOS Transistor Scaling

Scaling $S = \frac{1}{2}\sqrt{2} \approx 0.7$/cycle
(0.5x per 2 technology cycles)

Critical dimension (half pitch, gate length) [nm]:

250 → 180 → 130 → 90 → 65 → 45 → 32 → 22 → 16

Moore’s Law: Miniaturization

![Diagram showing the miniaturization of critical dimensions over time, from 100 μm in 1960 to 1 nm in 2040. Key points include 1k bits in 1970, 1M bits in 1980, 1G bits in 2000, and 1T bits in 2040.](image-url)
Scaling and Lithography

Minimum dimension

10 µm

1 µm

436 nm Hg (g)

365 nm Hg (i)

100 nm

248 nm KrF

193 nm ArF immersion

10 nm

13 nm EUV

1 nm

λ source
Typical Interconnect Stack

- Global
- Intermediate
- Metal 1

- Wire
- Via
- Pre-Metal Dielectric
- Tungsten Contact Plug
- Passivation
- Dielectric
- Etch Stop Layer
- Dielectric Capping Layer
- Copper Conductor with Barrier/Nucleation Layer

Metal 1 Pitch
The ITRS roadmapping process
Why create a roadmap?
Cooperation:
The concept of ‘pre-competitive’ technology research
International Technology Roadmap for Semiconductors (ITRS) 1998 - now

http://www.itrs.net
ITRS Objective

- Provide guidance to the semiconductor industry by predicting technology trends in the industry, spanning 15 years (near-term 1-6 yrs; long-term 7-15 yrs)
Organization and implementation

• Organization
  – International Roadmap Committee (IRC)
  – 16 international technology working groups (ITWG)

• ITRS release every 2 years
  – 16 chapters, ~1000 pages, >200 tables
  – >300 contributors, representing >50 companies
  – Update of tables every other year

• 3 Workshops/year
  – Europe (spring / Semicon Europa)
  – USA (summer / Semicon West)
  – Asia (winter / Semicon Japan)

• 2 Public symposia/year (incl. press conference)
  – ~130 participants
Technology Working Groups

1. System Drivers
2. Design
3. Test & Test Equipment
4. Process Integration, Devices & Structures
5. RF and Analog/Mixed Signal
6. Emerging Research Devices
7. Emerging Research Materials
8. Front End Processes
9. Lithography
10. Interconnect
11. Factory Integration
12. Assembly & Packaging
13. Environment, Safety & Health
14. Yield Enhancement
15. Metrology
16. Modeling & Simulation
Impact of the ITRS

- Provides a benchmark for the semiconductor industry
- Identifies technology challenges
- Generates industrial research agenda
- Can be (mis)used for marketing purposes
When will the roadmap end?
The end of lithography?
The roadmap of the roadmap

(John Sturtevant, Motorola)
Lithography requirements

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“The Red Brick Wall”
More Moore: Increasing complexity

Cumulative Interdependent Challenges

Area  Speed  Power  Yield

Man...
Reaching dimension/complexity limits

Complexity in # of devices

1  1000  1M  1G  1T

10 mm

100 μm

1 μm

10 nm

1 Å

1947  1958

MOS Devices

Quantum devices
Nanotubes
Molecular electronics

2011

2020

Beyond CMOS?

Validated concept

Source: STMicroelectronics
New territory:
More than Moore
Roadmap at the crossroads

ITRS 2005
“More Moore” & “More than Moore”
Smart microsystems: More Moore & More than Moore
Smart microsystems: More Moore & More than Moore

Data Processing & Storage

Radio

Power

Sensor & Actuator

More Moore

More than Moore

Heterogeneous Integration
Technology Framework
Technology-Application Framework

Application

MEMS

Nano-electronics

System integration
Example: healthcare domain

Radiotracer- & fluorescence-guided surgery, biopsy, diagnostics

Single-photon sensitive Si photon detectors

Time stamping electronics

Compact probe

Courtesy Edoardo Charbon, TUDelft
Characterizing More than Moore
Why a More than Moore roadmap?

- ITRS has demonstrated value of roadmapping for CMOS
  - Identify pre-competitive research domains, enabling cooperation between industries, institutes and universities.
    - Sharing of R&D efforts
    - Increase resource efficiency through focus
    - Reduction of development costs and time
  - Synchronization of the equipment & materials community with the semiconductor manufacturing community
- More than Moore roadmapping offers a similar but more challenging opportunity
  - Need to propose a roadmapping methodology
    - White paper
More than Moore White Paper
Roadmapping Methodology

“More-than-Moore”

White Paper

Published by the ITRS in 2010
http://www.itrs.net/papers.html
Necessary conditions for an industry-wide technical roadmap effort

- Restricted set of figures of merits (FOM)
- Convergence of opinion among a majority of the key players on the progress trends that these figures of merit are expected to follow (LEP)
- Potential market of significant size inducing a wide applicability of the roadmap (WAT)
- Willingness to share information (SHR)
- Existence of a community of players (ECO)
# MtM Technology Assessment

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<th>LEP Law of expected progress</th>
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<th>WAT Wide applicability</th>
<th>ECO Existing community</th>
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From applications to functions to devices

Applications
- Power metering
  - $A_2$

Functions
- ADC
  - $f_2$
  - $f_3$
- Gas detector
  - Fluid detector
  - $f_5$
- PLC

Devices
- Transistor
  - $d_2$
- Capacitor
- Cantilever MEMS
  - $d_5$
  - $d_6$
  - $d_7$
- Inductor

From applications to functions to devices
1st More than Moore Workshop
April 13, 2011 Potsdam

MtM ITRS Workshop
Agenda

08:30 – 08:50 ITRS White Paper & on-going actions M. Graef
08:50 – 10:15 Update ITRS ITWG activities on MtM
  Wireless J. Pekarik (20mn)
  A&P B. Bottoms (20mn)
  MEMS (+iNEMI MtM roadmap) M. Gaitan (20mn)
  CATRENE WG summary M. Brillouët (25mn)
10:15 – 10:30 break
10:30 – 12:00 Parallel sessions:
  Automotive (chair: P. Cogez)
  Energy / Integr. power (chairs: M. Graef & B. Huizing)
  Lighting (chairs: M. Brillouët & R. Mahnkopf)
12:00 – 13:00 lunch
13:00 – 13:30 Overview sensors for security & healthcare M. Brillouët
13:30 – 14:00 3x10’ summary of the discussion rapporteurs
14:00 – 14:10 Wrap-up M. Brillouët

ITRS TWGs
- Wireless
- Assembly & Packaging
- MEMS

Application domains
- Automotive
- Energy & Power
- Lighting
- Security
- Healthcare
What we talk about when we talk about ‘More than Moore’

• **System-in-Package:**
Integration of digital and non-digital functions in one module
  – Power, RF, passives, sensors, fluidics, lighting,…
  – Packaging is a functional element

• **High diversity of technologies:**
Heterogeneity of materials and designs
  – Modular platforms in a structured design environment
  – Integration of new materials: interfaces!

• **Builds on existing CMOS infrastructure**
  – Lithographic scaling capability controls Moore’s law
Testing 3D Devices

- Multiple die system
  - Sub-systems designed to operate and be assembled together
  - Process optimized for contents of each die
    - Logic, DRAM, NVM, Analog
  - Connection by potentially 1000s of TSVs

- Design, interconnect, assembly and test problem

- Design for Test requirements
  - Testability of each die
  - Via continuity checks
    - For signal and non-signal vias
    - 3-5 μm via cannot be probed! ESD!
  - N+ die test methodology as die added
  - Final “system” test

Source: Roger Barth, ITRS 2009
Testing System in Package (SiP)

- Challenges
  - High yield with low test cost
  - Standardized test strategy for mini-systems

- Potential test solutions
  - Design for die, debug and system test
  - Per die built in system test (BIST)
  - ‘Known good die’ (KGD) with minimal post test

Source: Roger Barth, ITRS 2009
Characterization needs for More than Moore: Key terms

- **Multidisciplinarity**
  - Multifunctionality: device characterization requires methodologies from electrical engineering plus… (micro)mechanics, thermomechanics, materials science, optics, chemistry, biology, medical science,…

- **Heterogeneity**
  - 3D structures, multiscale characterization, new interfaces

- **Complexity**
  - Multi-variability
  - Merging of subsystems (new ‘middle end’)

- **Reliability**
  - Packaging is enabling functional component
From Microelectronics to Nanoelectronics

Moore’s Law → More of Moore
More than Moore → More of everything

Social environment
Physical interface
Signal processing

From miniaturization... to function integration
Thank you!

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