Some Trends and Impacts of Micro/Nanoelectronics

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Philips today
Sales per sector, as % of total

1998
100%= EUR 30.5 B

2003
100%= EUR 29.0 B

<table>
<thead>
<tr>
<th>Sector</th>
<th>1998</th>
<th>2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>15%</td>
<td>16%</td>
</tr>
<tr>
<td>CE</td>
<td>36%</td>
<td>31%</td>
</tr>
<tr>
<td>DAP</td>
<td>4%</td>
<td>8%</td>
</tr>
<tr>
<td>Components</td>
<td>8%</td>
<td>7%</td>
</tr>
<tr>
<td>Semiconductors</td>
<td>11%</td>
<td>21%</td>
</tr>
<tr>
<td>Medical</td>
<td>14%</td>
<td>17%</td>
</tr>
<tr>
<td>Misc.</td>
<td>6%</td>
<td>1%</td>
</tr>
<tr>
<td>Unallocated</td>
<td>6%</td>
<td>8%</td>
</tr>
</tbody>
</table>

Legend:
- Lighting
- CE
- DAP
- Components
- Semiconductors
- Medical
- Misc.
- Unallocated
Packaging is a Bridge from IC to System

It Controls:
- >90% size
- Performance
- Cost
- Reliability
Definition

- A means of “protecting, powering, cooling and interconnecting an integrated circuit”

- An integrated circuit form factor conversion providing compatibility with mainstream second level assembly and multi-functionality

IC (Die)      Encapsulation
Glue        Wire

Ultra-thin BGA package
(9x9 mm, 300 um thick)
Electrical Interconnect

Component Carrier & Construction Part

- Single Sided
- Double Sided
- Multilayer
- Build-up Multilayer
Wafer → Single IC → Package

Source: Motorola
Some Trends and Impacts of Micro/Nanoelectronics

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Outline

1. Development trends
2. Characteristics and Consequences
3. Challenges
4. Eniac /7FP
5. Concluding remarks
1. Development trends
Scientists from RAND Corporation have created this model to illustrate how a “home computer” could look like in the year 2004.

However the needed technology will not be economically feasible for the average home. Also the scientists readily admit that the computer will require not yet invented technology to actually work, but 50 years from now scientific progress is expected to solve these problems.

With teletype interface and the Fortran language, the computer will be easy to use.
Revolutions in lighting

Open fire  Tamed fire  more efficient  glass bulb

Vac. Tube  Digital (Solid State Lighting)
Ambient Intelligence

Environments that are sensitive and responsive to the need and presence of people

Embedded
Context aware
Personalized
Adaptive
Anticipatory

Many invisible distributed devices throughout the environment, that know about their situational state, that can be tailored towards your needs and can recognize you, that can change in response to you and your environment, that anticipate your desires without conscious mediation.
Consumer wishes
Smaller, smarter, lighter, faster, cheaper, more flexible, more convenient, more reliable and functionalities.

Tech development trends
• Moore’s law
• More than Moore
Moore’s law

The chip circuitry will double every 18 months!
CMOS090 baseline cross section Cu-SiOC interconnect (Crolles2 300mm pilot line)
Packaging & assembly

- Wire diameter < 10 microns
- Interconnect pitch of NLWSP < 20 microns
- Thickness of copper film/PCB < 5 microns
- Microvia diameter < 20 microns
- Wafer thickness < 40 microns

Not only the wafer technology, packaging and assembly are also going beyond visualization!
Is the Roadmap Going to End?
Let’s see some famous forecasts

I think there is a world market for maybe five computers
*Thomas Watson, Chairman of IBM, 1943*

Computers in the future may weigh no more than 1.5 tons
*Popular Mechanics Magazine, 1949*

“640K ought to be enough for anybody”
*Bill Gates, 1981*
Beyond CMOS

(1) THE OPTICAL COMPUTER
Instead of using the flow of electrons to carry data, this device uses photons, which can pass by one another without interference.

(2) THE DNA COMPUTER
The double-stranded DNA molecule becomes a biological computer: bases and solutions are carried in the sequence of bases on the strands.

(3) MOLECULAR/DOT COMPUTERS
In these designs, silicon transistors are replaced by molecules or electrons, respectively, which then act as tiny logic gates and switches.

(4) THE QUANTUM COMPUTER
The ultimate in miniaturization, this design uses the direction of the axis (spin up or down) to encode information.
• Technologies/products (based upon or derived from Semiconductors) that enable functions equivalent as the eyes, ears, noses, arms, and legs of human-being, while microprocessor and memory functioning as the brain.

• Physical enabler for Ambient Intelligence of broad applications with a plethora of functions
Intelligent systems incorporate ‘More Moore’ and ‘More than Moore’
Scope and functionality

- **baseline CMOS memory**
- **RF Power passives**
- **sensors actuators**
- **bio, fluidics**

`More Moore` vs `More than Moore`

- **Compute/storage**
  - Digital content
    - Complex Design (SoC)
    - Lots of software

- **Interact with user and environment**
  - Non-digital content
    - Hetero Integration
    - Lots of processes
Intelligence applied: personal comfort

- Personal Health Monitor
  - Heart activity
  - Blood pressure
  - Glucose level

- Gaming
- Mouse
- Identification

- Personal Weather Station
  - Humidity
  - Pressure
  - Ozone
  - UV exposure

- Decibel Meter

- Personal Map
  - Compass
  - GPS
  - Altitude
### System-in-Package

<table>
<thead>
<tr>
<th>SiP 1: Evolutionary</th>
<th>SiP 2: Innovative</th>
<th>SiP 3: Breakthrough</th>
</tr>
</thead>
<tbody>
<tr>
<td>More than One IC</td>
<td>More than IC Processing</td>
<td>More than Electronics</td>
</tr>
</tbody>
</table>

- **SiP 1: Evolutionary**
  - Multi-chip package: video processor
  - Philips

- **SiP 2: Innovative**
  - Passive integration: GSM radio
  - Philips

- **SiP 3: Breakthrough**
  - MEMS module: pressure sensor
  - Bosch
SiP vs SoC

Complementing, not competing

**SoC** – Programmable monolithic IC – More Moore
- Advanced baseline CMOS,
- Maximize utilization of (expensive) mask sets
- Diversification is in the software & embedded IP mix

**SiP** – Multi-technology module – More than Moore
- Mature and/or advanced wafer processes, advanced packaging
- Maximize utilization of dedicated option fabs
- Diversification is in the components & technology mix
- Creating more values via integrating traditional and non-traditional functionality in one package
The Nanoelectronics Landscape: Moore’s Law & More than Moore

More than Moore: Diversification

- Analog/RF
- Passives
- HV Power
- Sensors
- Actuators
- Biochips

More Moore: Miniaturization

Baseline CMOS: CPU, Memory, Logic

- 130nm
- 90nm
- 65nm
- 45nm
- 32nm
- 22nm
- ...

Information Processing

- Digital content System-on-chip (SoC)

Interacting with people and environment

Non-digital content System-in-package (SiP)

Beyond CMOS
Rationale of More than Moore

• Increased social needs for high level system integration including non-digital functions

• The necessity to speed up product innovation and to create new product portfolio of fabs in Europe (sustainability and employability)

• The limiting factors of cost and time-to-market of SoC development

• MtM adds value to society on top of and beyond advanced CMOS and conventional packaging, with fast increasing marketing opportunities and huge business potentials
2. Characteristics and Consequences
Much more than miniaturization:

- multi-application/market/requirements,
- multi-organization,
- multi-supply chain,
- multi-infrastructure,

- multi-functionality,
- multi-discipline,
- multi-scale (in both geometry and time),
- multi-technology,
- multi-process,
- multi-material/interface,
- multi-damage and failure mode,
- multi-variability.

**Strong Nonlinear Multi Interaction!**
IC - package
WLP, NSWLP

Package - board
Embedded, MCM

Waferfab

System

IC - Board
Total signal integrity

M+M
Nanoelectronics
High level SiP
Dramatically increased design complexity

Linking Giga-Scale Dreams to Nano-Scale Realities

Giga-Scale Complexity

Nanoscale Realities

Architectural gap
Nanoscale design tolerance and process windows
Device variability impacts predictability and yield
No co-designing theories, methods and tools
Dramatically increased chance and consequences of failures
Overstress

- Cracks (die, plastic, wirebond, etc.)
- Delamination
- Pop-corn
- Buckling
- Yields (ball shear, pattern shift, etc.)
- Warpage
- Large deformation
- Electro/thermal/stress migration
- Voiding
- ......

Wear out

- Fatigues
- Creep
- Wear
- ......

• Loading sources/levels/gradients/steps increased;
• Test coverage and efficiency reduced;
• Strongly non-linear, stochastic, time and process dependence response
No appropriate design method
•Experience and Trial-error based
•Empirical, phenomenological, case dependent,
•Sub-optimal product/process
•High development costs

No appropriate qualification method
•Time and money consuming
•Unclear correlation between application profiles with spec. and accelerated testing
•No guarantee for extrapolating to outside of the spec.
•No satisfied coverage for quality, robustness and reliability
Increased gap between technology advance and fundamental knowledge
3. Challenges
- Predictive modeling
Geometry (median value/distribution/tolerance/defect)
Material (type/property/interface)
Loading (history and gradients, manufacturing/assembly/functionality testing/reliability qualification)

Determining:
- Life time and performance of product/process

Reliable inputs

All statistic in nature

Inputs must be reliable
Predictive modeling capability

• Algorithms, solvers and tools for
  ➢ Non-continuum (atomistic/nanoscale)
  ➢ Multi-scale (bridging gaps)
  ➢ Multi-physics
  ➢ Both deterministic and stochastic
  ➢ Multi-failure mode and interaction
  ➢ Process history
  ➢ Nonlinear
  ➢ 3D applications

• Accurate, Robust and Efficient
Novel experimental Techniques

• **Methods and tools for modeling inputs**
  - Material/interface characterization
  - Failure analysis (mode/location/evolution/mechanisms/probability)

• **Methods and tool for modeling verification**
  - Representative sample preparation
  - Modeling validity for the whole design space

• **General requirements**
  - Multi-scale, from nano to macro
  - Both deterministic and stochastic
  - Multi-physics
  - Multi-failure mode and interaction
  - Process history
  - Accurate, robust and efficient
ENIAC: European’s Nanoelectronics Strategic Research Agenda

Modeling, simulation, optimization and design

1 Integrated multiscale (from atomistic to macro, including the strong size and surface effect), multiphysics (electrical, mechanical, thermal, physics, chemical, etc.), multidamage (cracks, delamination, fatigues, electromigration, voids, creep, degradations, etc.) and multi-process (wafer, micromachining, packaging, assembly, qualification and application profile) modeling incorporating the important loading history in order to understand and predict the performance and reliability. Herein, new algorithms and simulation tools are needed.

2 Innovative experimental methods and techniques to extract material/interface and total system behavior, in order to provide inputs for modeling and simulation, and to verify the modeling results and design rules, covering both nano and macro scales.

3 Efficient optimization methods for design rule development of nonlinear, stochastic and multiparameter process/product responses.
4. Eniac

European Nanoelectronics Initiative
Advisory Council

European Technology Platform
Preparing for the future of nanoelectronics in EU

The Strategic Research Agenda (2004-2005) - Revision every 2 years -


Vision 2020

SRA

Stakeholders

Research Programmes

Research Projects

Strategic Partnership between Public (EU, National, EUREKA) and Private (Industry)
ENIAC: Society Needs and Applications

Health
- ‘The Doctor in your Pocket’
- Real-Time Diagnostics
- Bio-Chips / Body-Sensors

Mobility / Transport
- 100% Safety on the Road
- Integrated Transport Systems
- Prevention of Pollution

Security
- Personal Emergency Systems
- Protection against Crime and Terrorism
- Secure Home Environment

Communication
- Seamless Wired / Wireless Access
- Mobile Services without Compromise
- Protection of Privacy

Education / Entertainment
- Learning Anywhere, Anytime
- Content with Best Quality (e.g. HDTV)
- Content Protection
Six enabling technology domains

Society Needs

Application Domains

Design Automation

Beyond CMOS

‘More Moore’

‘More than Moore’

Equipment and Materials

Heterogeneous Integration
5. Concluding remark
Any intelligent fool can make things bigger, more complex and more violent. It takes a touch of genius and a lot of courage to move in the opposite direction.

- A. Einstein

Technological progress has merely provided us with more efficient means for going backwards
Enhancing industry and academia partnerships

- Reducing the gaps
- Increasing the return on R&D
  - Leverage infrastructure, knowledge/capability and other resources
  - Industrialization/commercialization

Managing the complexity of innovation

- Soaring complexity and cost:
  - New technology, short time to market, many emerging applications, high risks
  - HW and SW complexity

- Solution: Open Innovation
  - Technology partnerships
  - Public-private research partnerships
  - Sharing infrastructure, services, knowledge and resource
“… firms that can harness outside ideas to advance their own business while leveraging their internal ideas outside their current operations will likely thrive in this new era of open innovation”
Thanks for your attention!

Questions?