micro and nanoelectronics
microsystems
ambient intelligence
image chain
biology and health

Si-based electronics

M. Brillouët

leti

cea

Outline

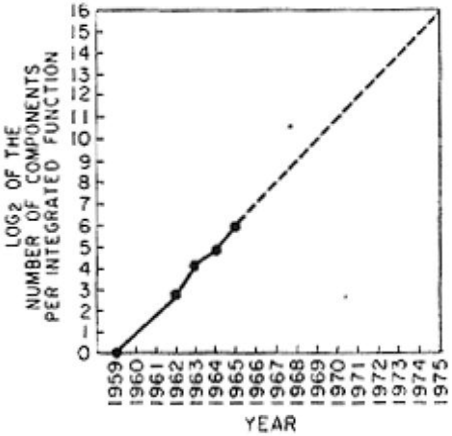
- Introduction
- Traditional scaling
  never say “impossible”
- Equivalent scaling
  the challenge of the introduction of new concepts
- Alternative concepts
  hypes and reality
- The economical challenge
  it is not rocket science, but…
- Design – technology interaction
  wishful thinking or real need?
- More-than-Moore
  the next frontier?
- Conclusion

What Gordon Moore actually said?

G. Moore - 1975

Higher integration density

nologies were first investigated in the late 1950's. The object was to miniaturize electronics equipment to include increasingly complex electronic functions in limited space with minimum weight. Several approaches evolved, including



Digital revolution

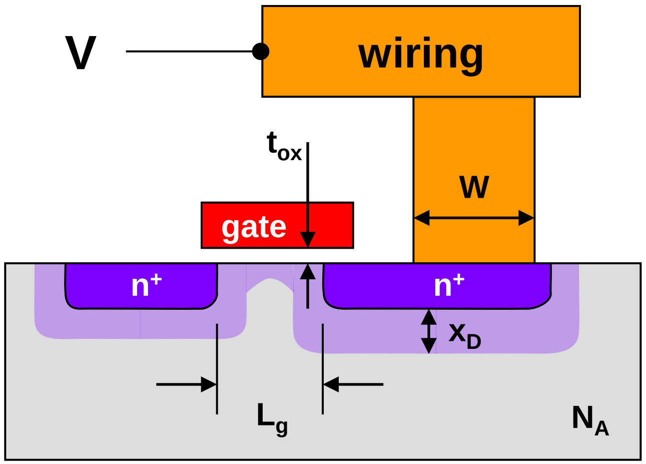
Integration will not change linear systems as radically as digital systems. Still, a considerable degree of integration

no reference to performance increase

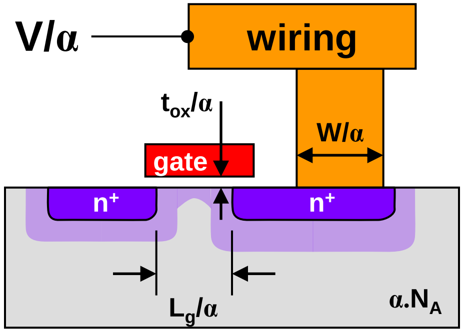
from G. Moore Electronics Vol.38 (8) April 19, 1965

The happy scaling

R. Dennard © IEEE



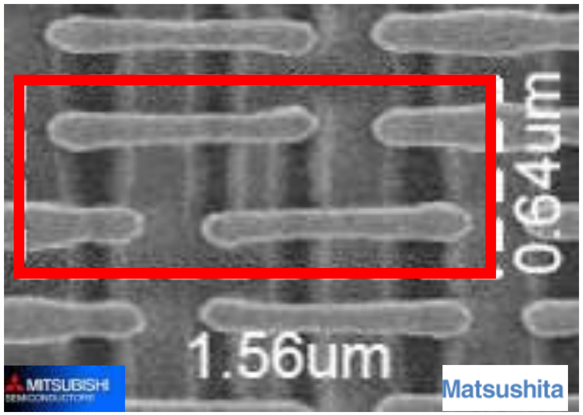
dimensions t_{ox}, L, W	**$1/\alpha$**
doping	**α**
voltage	**$1/\alpha$**
integration density	**α^2**
delay	**$1/\alpha$**
power dissipation/Tr	**$1/\alpha^2$**



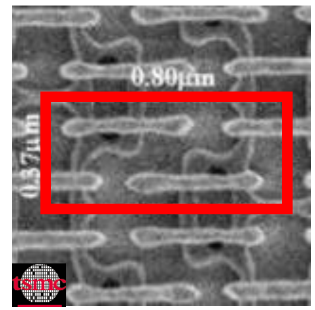
Traditional scaling

Never say “impossible”

Scaling is a reality



K. Tomita et al.
VLSI 2002 #2.2
0.998µm²



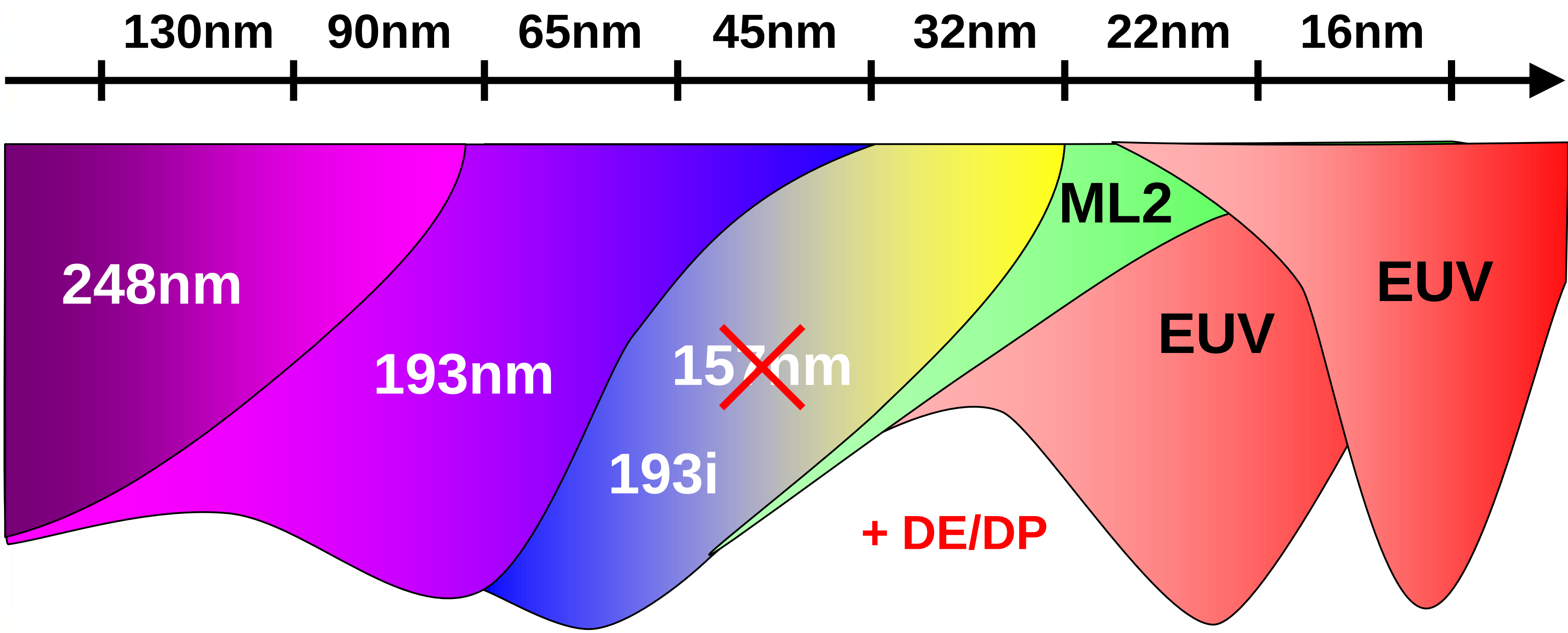
F.L. Yang et al.
VLSI 2004 #2.1
0.296 µm²

B.S.Haram et al.
IEDM 2008, #27.1
0.100µm²

90nm → 45nm → 22nm

3x **3x**

Lithography: a key enabler



disruptive technologies?

ML2

from

niac

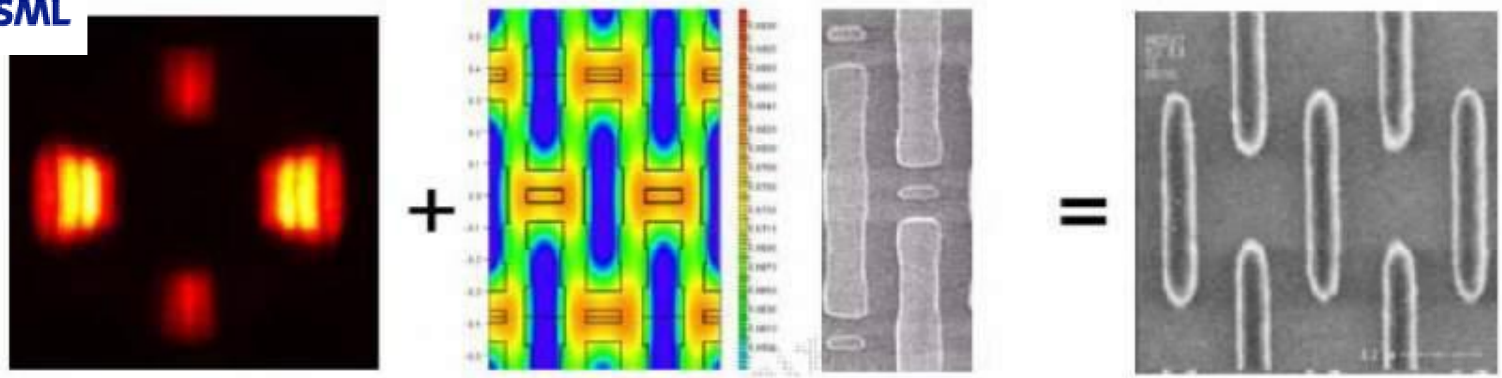
Strategic Research Agenda

Resolution Enhancement Techniques

$$R = k_1 \cdot \frac{\lambda}{NA}$$

RET illumination
phase
process

ASML



Exposing Illumination

Mask Feature

→ **cost of masks**

Top down SEM of Resultant Photoresist Structure

de Kim et al., SPIE 2005 & D.Flagello Albany Symposium 2005

Equivalent scaling

The challenge of the introduction of new concepts

Equivalent scaling

↑ mobility

$$\mu = \frac{q \cdot \tau}{m_c^*}$$

by strain

new materials

high k materials

SiO_2 limit

low EOT

classical scaling

lithography

$$I_{dsat} \approx \mu \cdot C_{ox} / L_g$$

short channel effect

new transistor architecture
better electrostatic control

out of equilibrium operation
use of quantum effects

What drives memory technologies?

Memory cell =	multiple stable & noise immune states which can be modified & read from outside

What drives the progress?

#1. Integration density → { Aggressive dimension scaling; Use of the 3rd dimension }

#2. Consumption (read, write & stand-by)

#2. Speed

#2. Non-volatility

#3. Correction of a defective information storage

The “universal” memory

Dense → **DRAM**
Fast → **SRAM**
Non volatile → **NAND, NOR**
‘Scalable’
Low power
Reliable

Q ↓

flash

FeRAM

R ↘

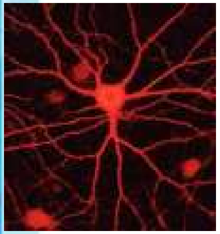
PCRAM

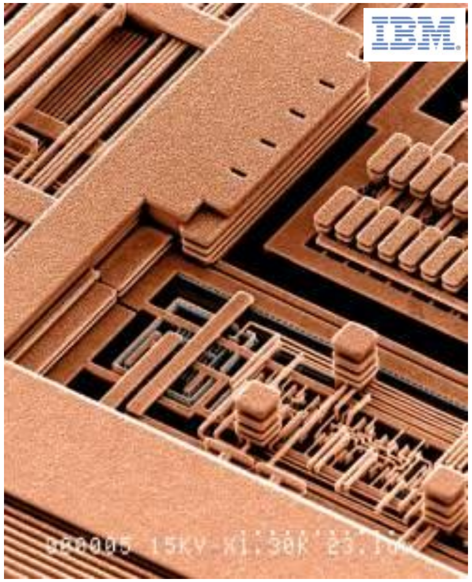
MRAM

RRAM

…

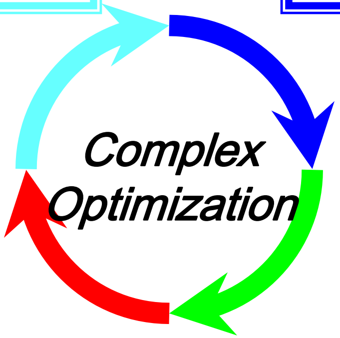
Interconnection: a major challenge





Connectivity

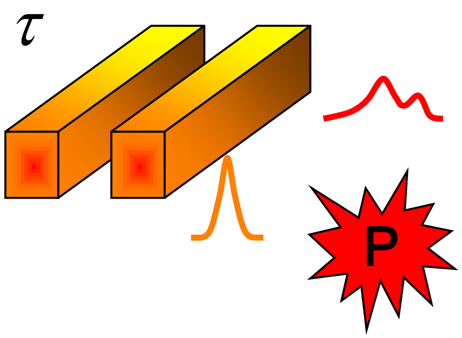
Density

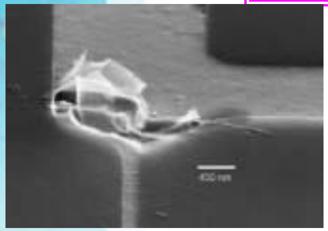


Reliability

Performance

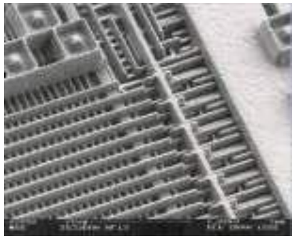
Signal integrity





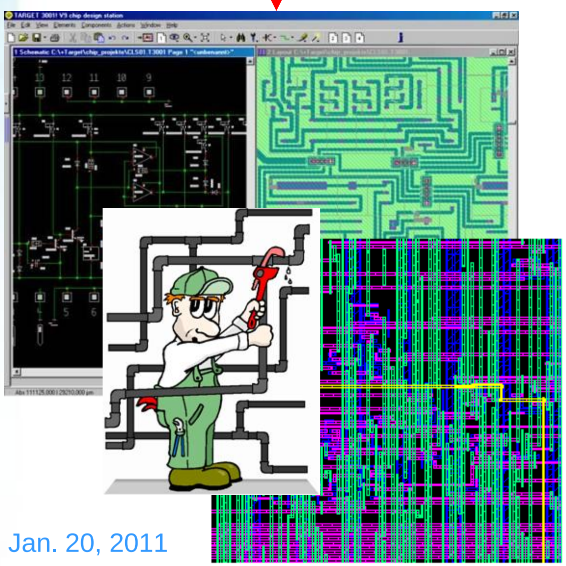
fromH Wendrock et al., ME 82 660 (2005)

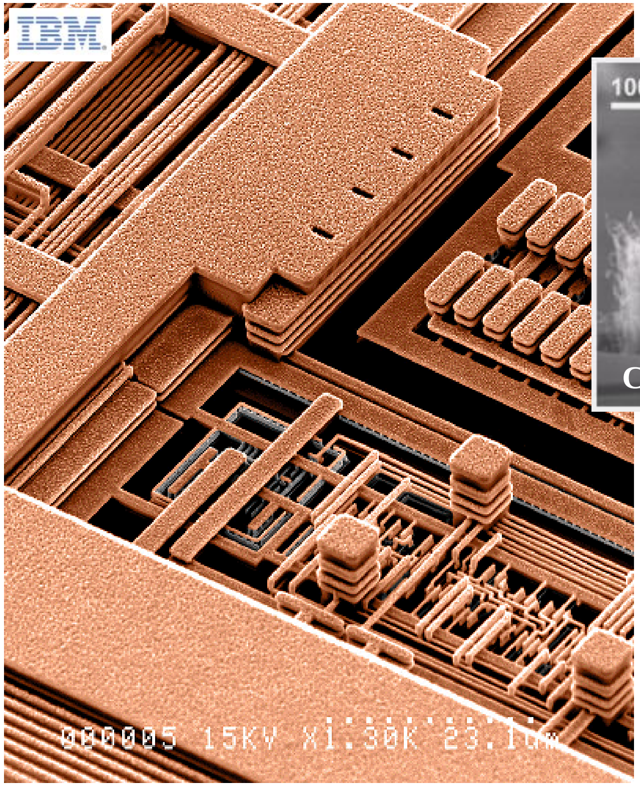
Yield & cost

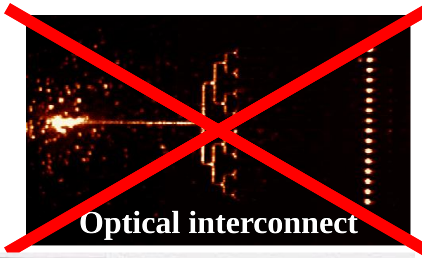


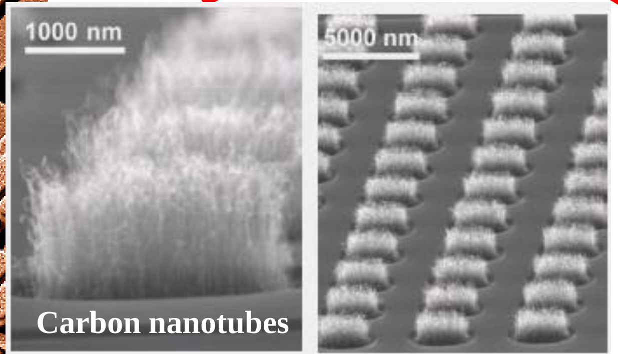
Interconnection in the short term

Don't dream any technological breakthrough









from S.Sato et al. IITC 2006 Paper #12.4

Find design & manufacturing solutions!

Alternative concepts

Hypes and reality

Physical limits?

"I am not convinced that there is any such thing as an **"ultimate" limit**.
In fact, finding ways to surmount those obstacles that, at the present, seem to be the limits is what technology is all about"

R.W. Keyes, IEEE Spectrum, vol. 6, pp.36-45 (1969)

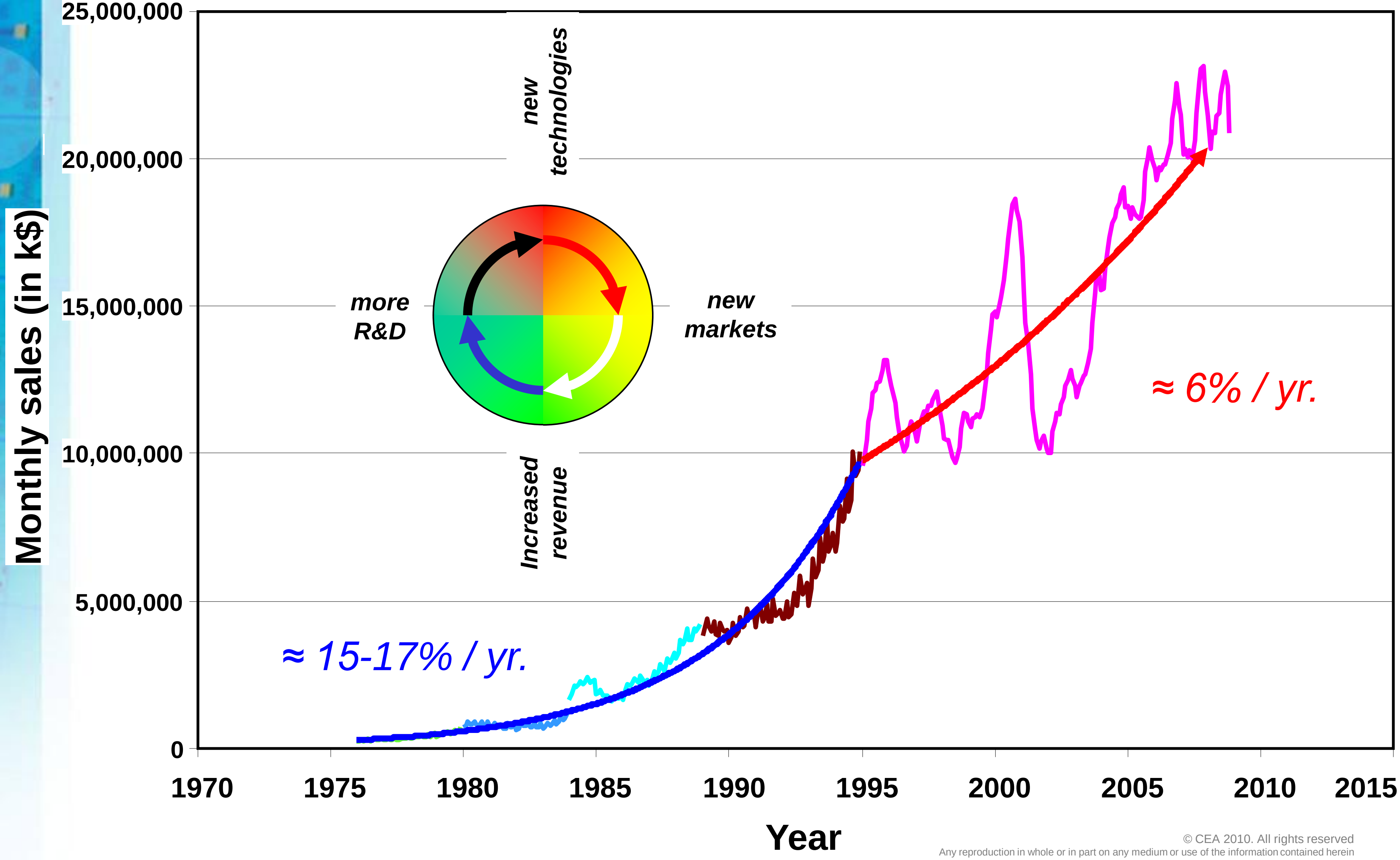
Some examples

- RTD (resonant tunneling diodes) [’80s]
  - said to allow multi-valued logic
  - sensitive to thicknesses (tunnel effect!)
  - never achieved high complexity circuits
  - it was better to wait for the next CMOS node
- SET (single electron transistor) [90’s]
  - the “ultimate” charge-based device
  - room temperature operation challenging
  - CD is critical
  - sensitive to background charges (?)
  - convincing demonstration only on “specialty” devices of lesser complexity (e.g. noise generation)

The economical challenge

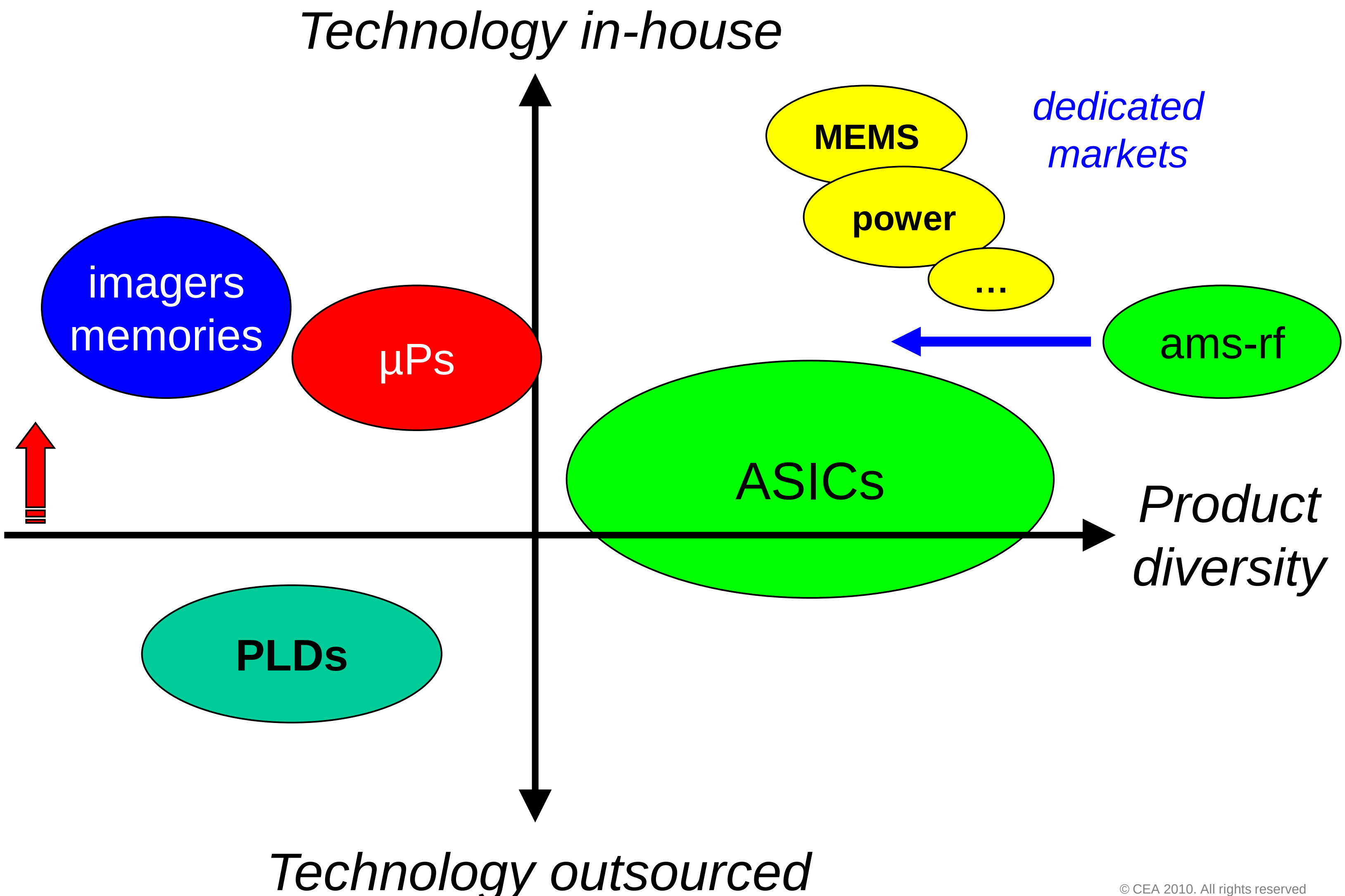
It is not rocket science, but…

The microelectronic virtuous circle



©SIA ; 3-months average

Evolution of the technology landscape



What future for the European “More Moore”?

E&M

IDM

EDA

“fablite”

“asset-smart”

“fabless”

specialty markets

leader

diversification

3D integration

etc.

ST

ASML

intel

GLOBALFOUNDRIES

austriamicrosystems

LFoundry

ARM

BOSCH

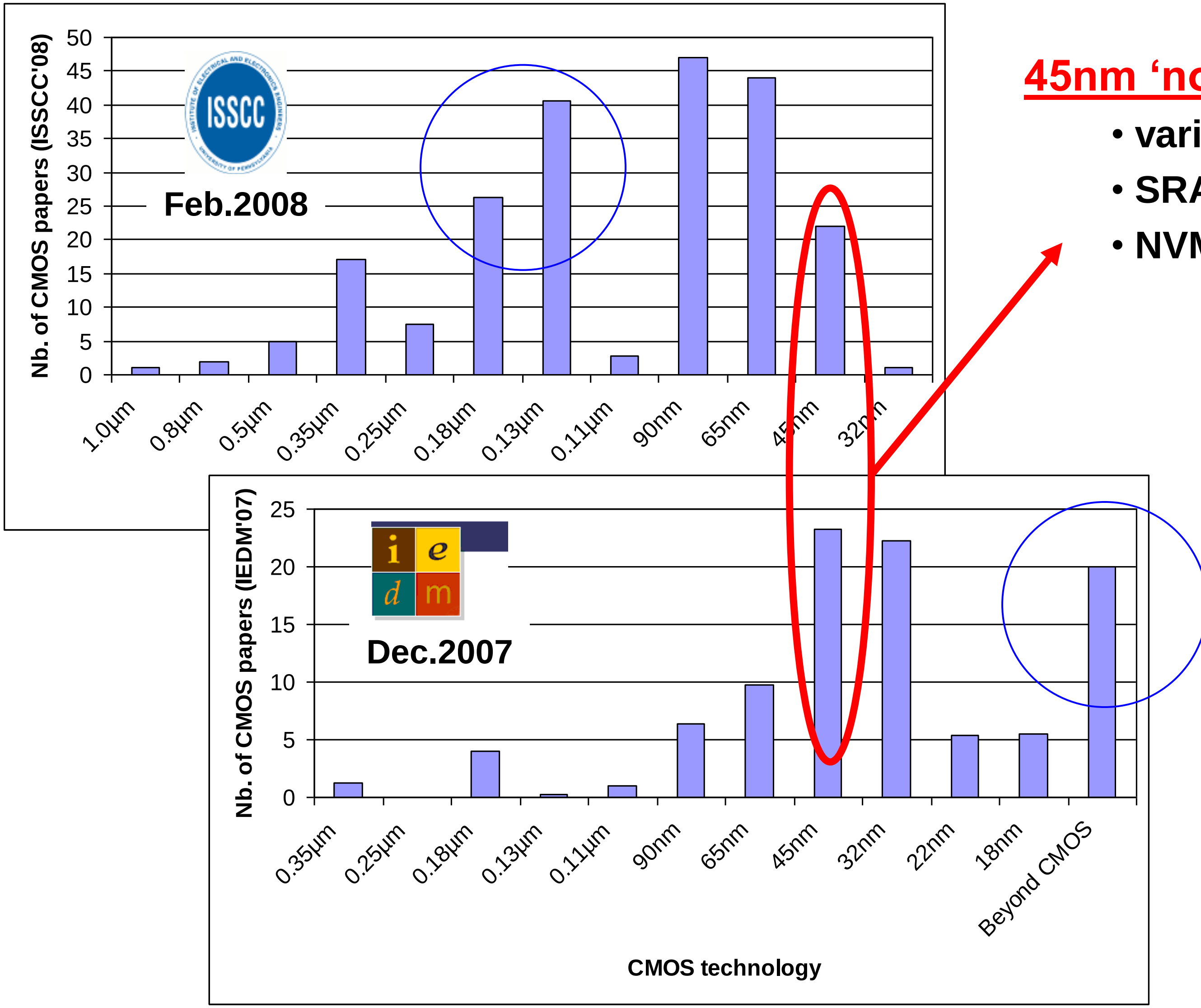
Infineon technologies

NXP founded by Philips

Design – technology interaction

Wishful thinking or real need?

What drives researchers?



45nm 'node'

- **variabililty (?)**
- **SRAM**
- **NVM**

from M. Brillouët, ICICDT 2008

What is new?

- Circuits are more sensitive to technology characteristics (e.g. SRAM)
- C:OS integration development is left to a few IDMs (Intel…) & Alliances (IBM..)
- The foundry – fabless model is dominating the minds
- Major fabless companies (Qualcomm...)
  - need to know in advance the details of future technologies
  - intend to drive the technology

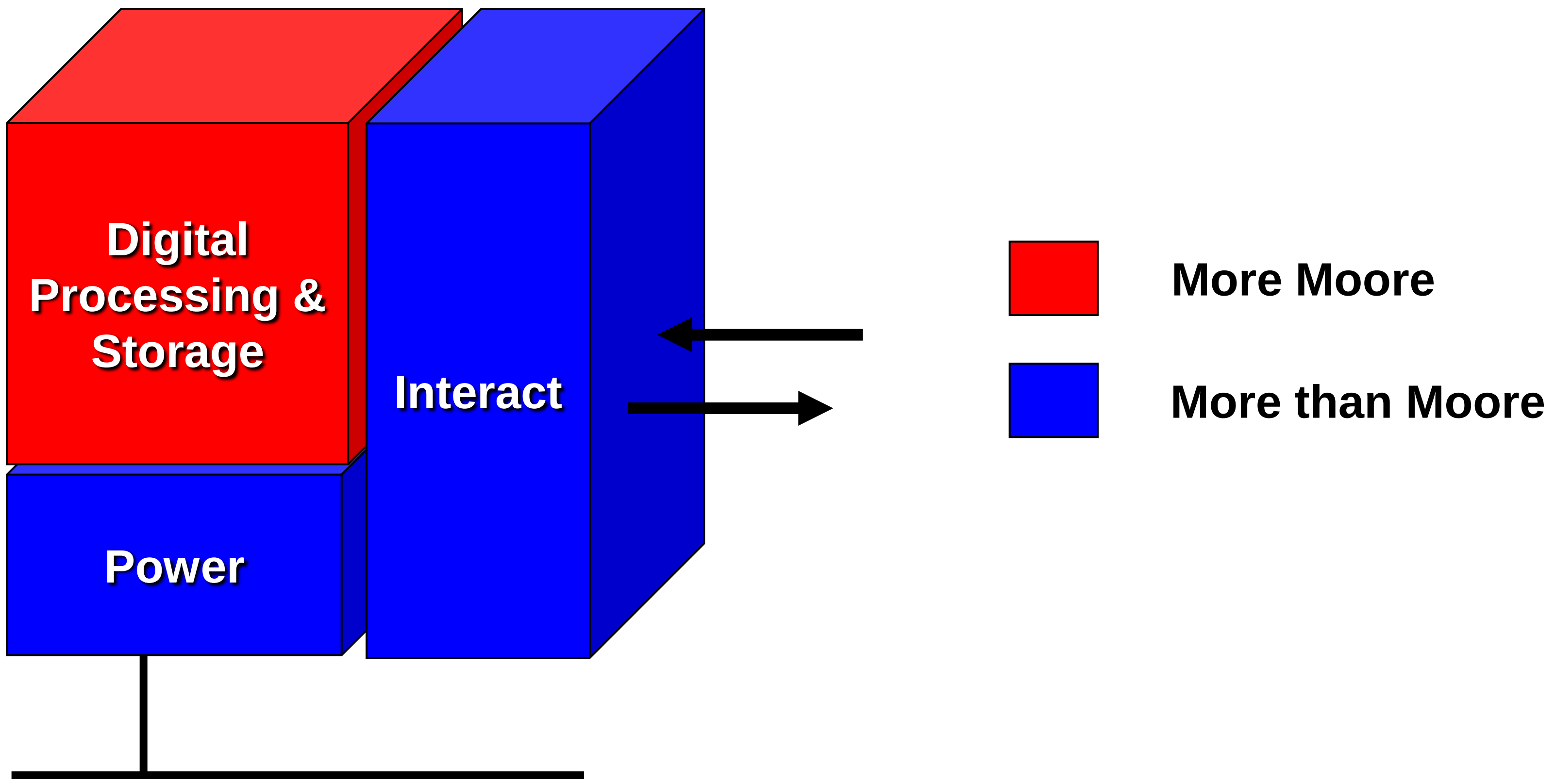
⇒ design – technology interaction is a must

⇒ the way it will happen is not settled

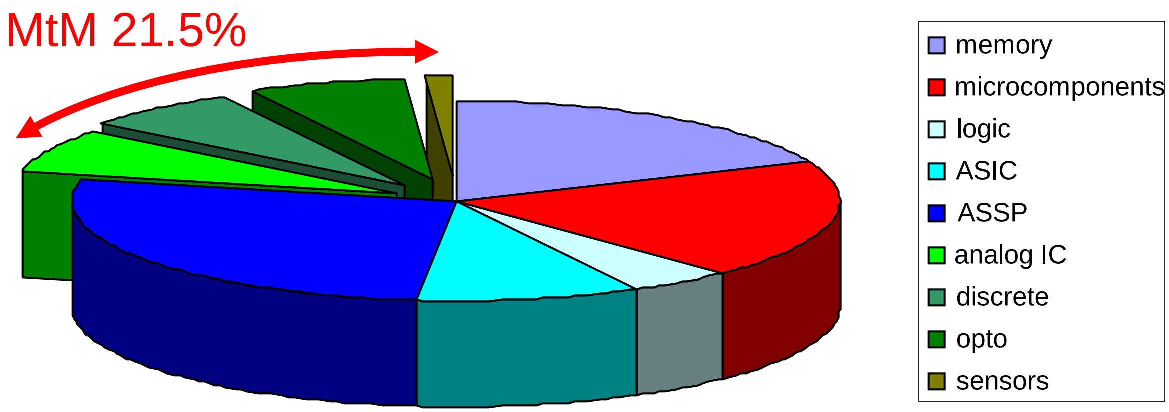
“More-than-Moore”

The next frontier?

What is More-than-Moore?



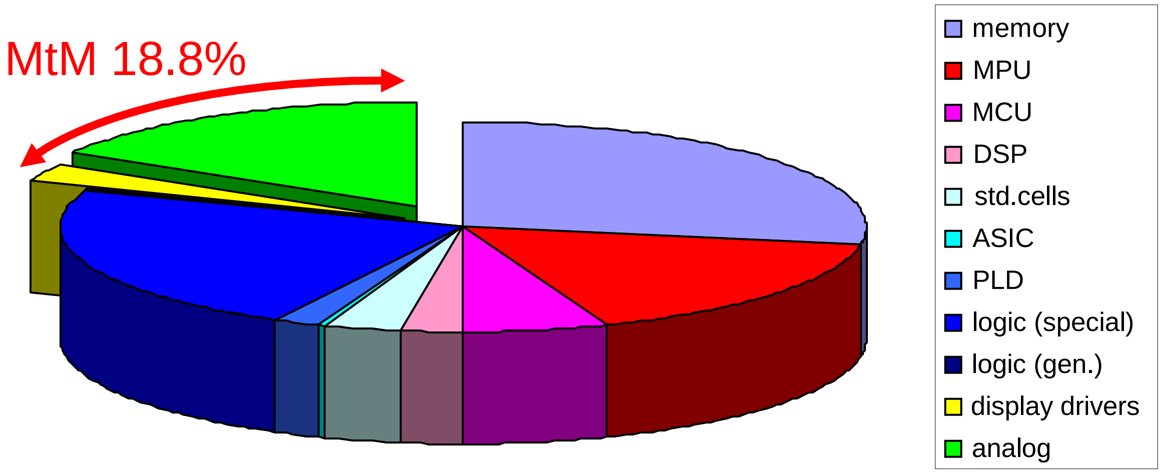
MM vs. MtM markets



2008

$255B market

Source: Gartner Dataquest (03-2009)

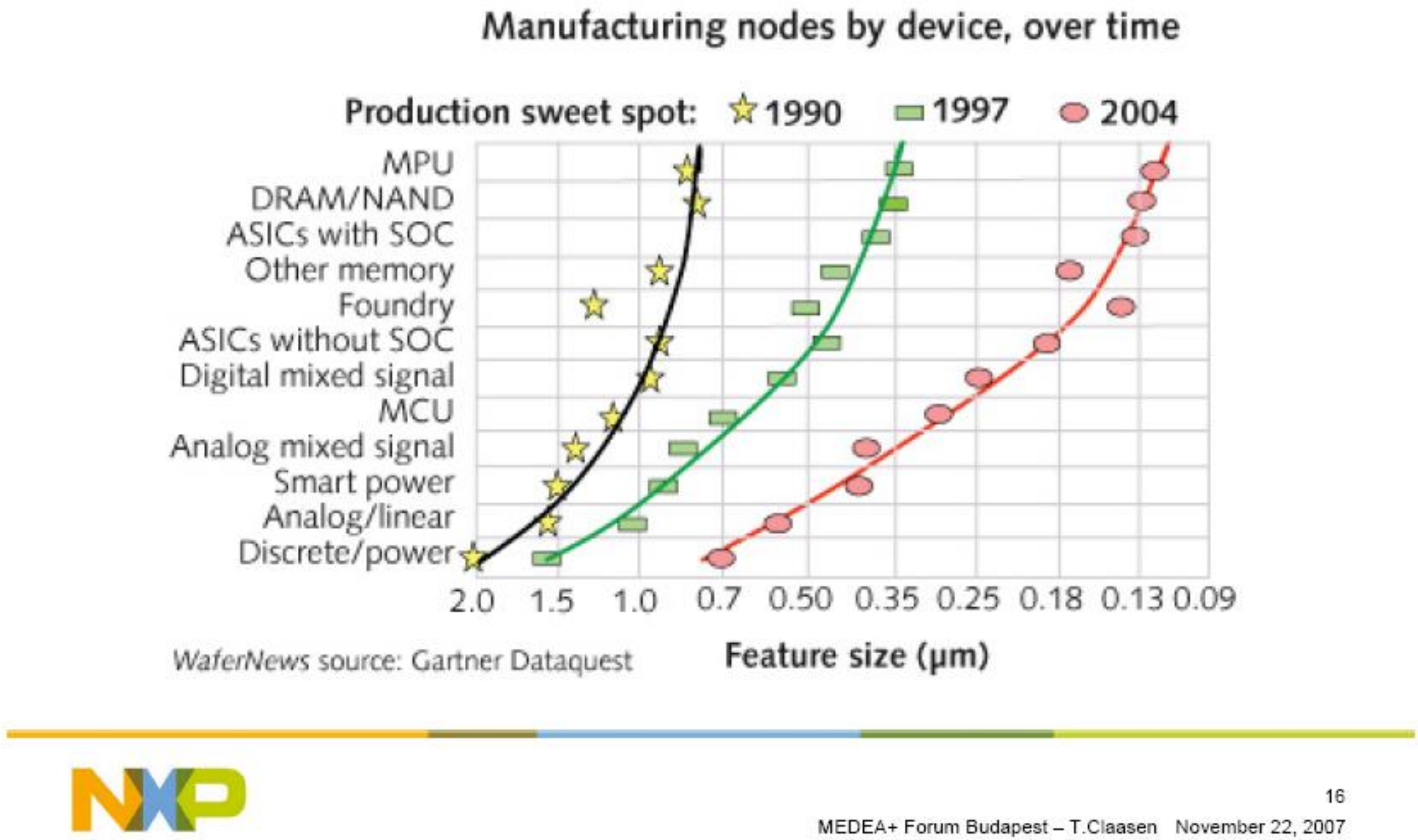


Forecast 2010

$244B market

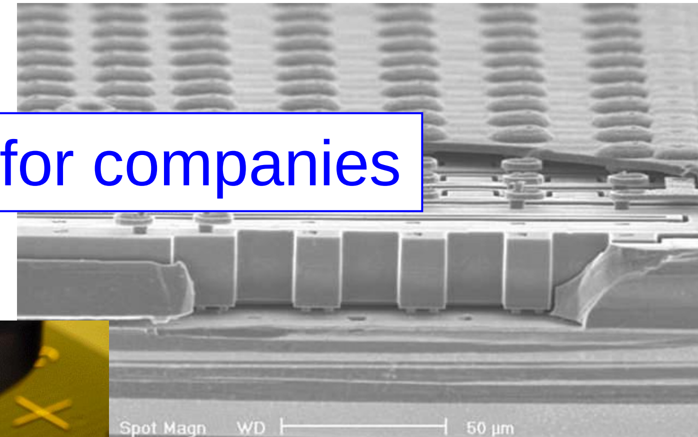
Source: IBS (Q2/2010)

More-than-Moore dimensions are lagging

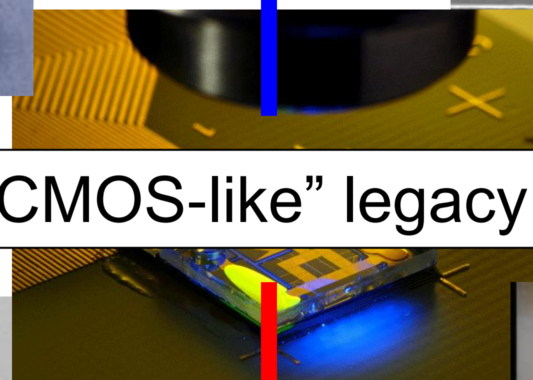


from T. Claasen, MEDEA+ Forum 2007

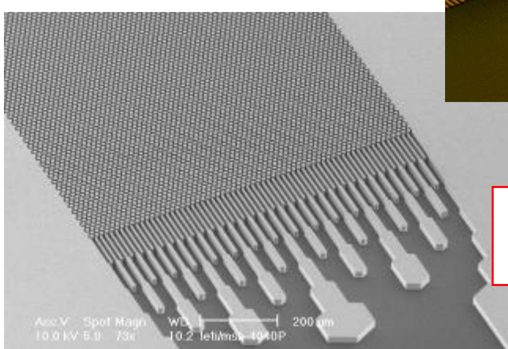
A wide diversity of new products

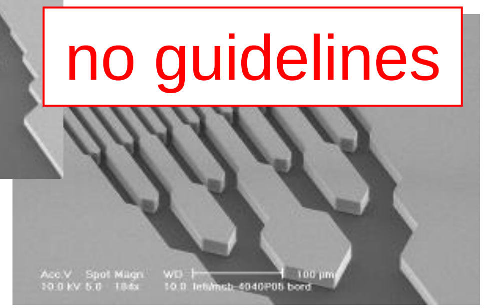


opportunities in R&D and for companies

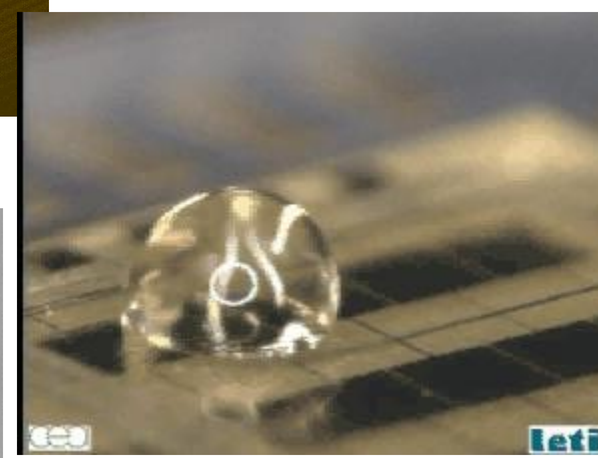


no established “CMOS-like” legacy process / device





no guidelines



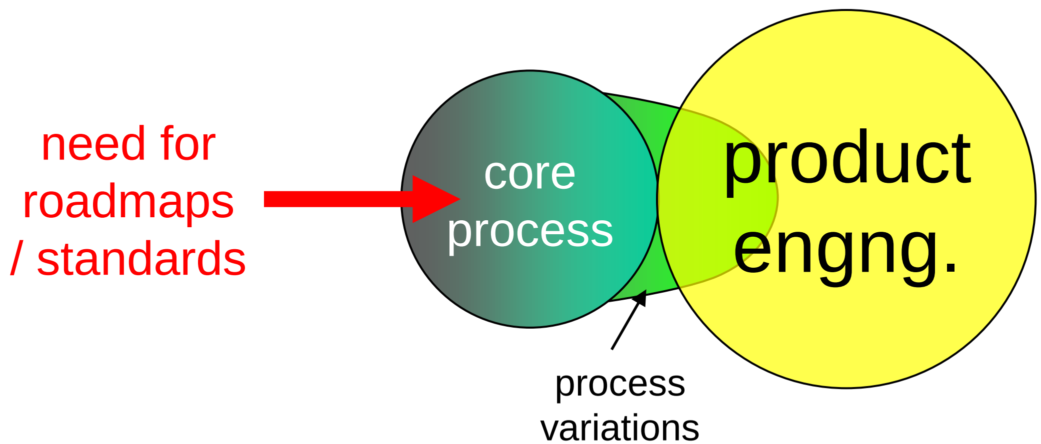
Economics of differentiated products

~~1 product = 1 process~~

1 product = 1 process variation

- **[mostly] low volume / product or process**
- **high NRE / product (design, test…)**
- **high entry barrier (system knowledge)**
- **process control & yield difficult**

- **added value → process optimization**
- **long-lived products**



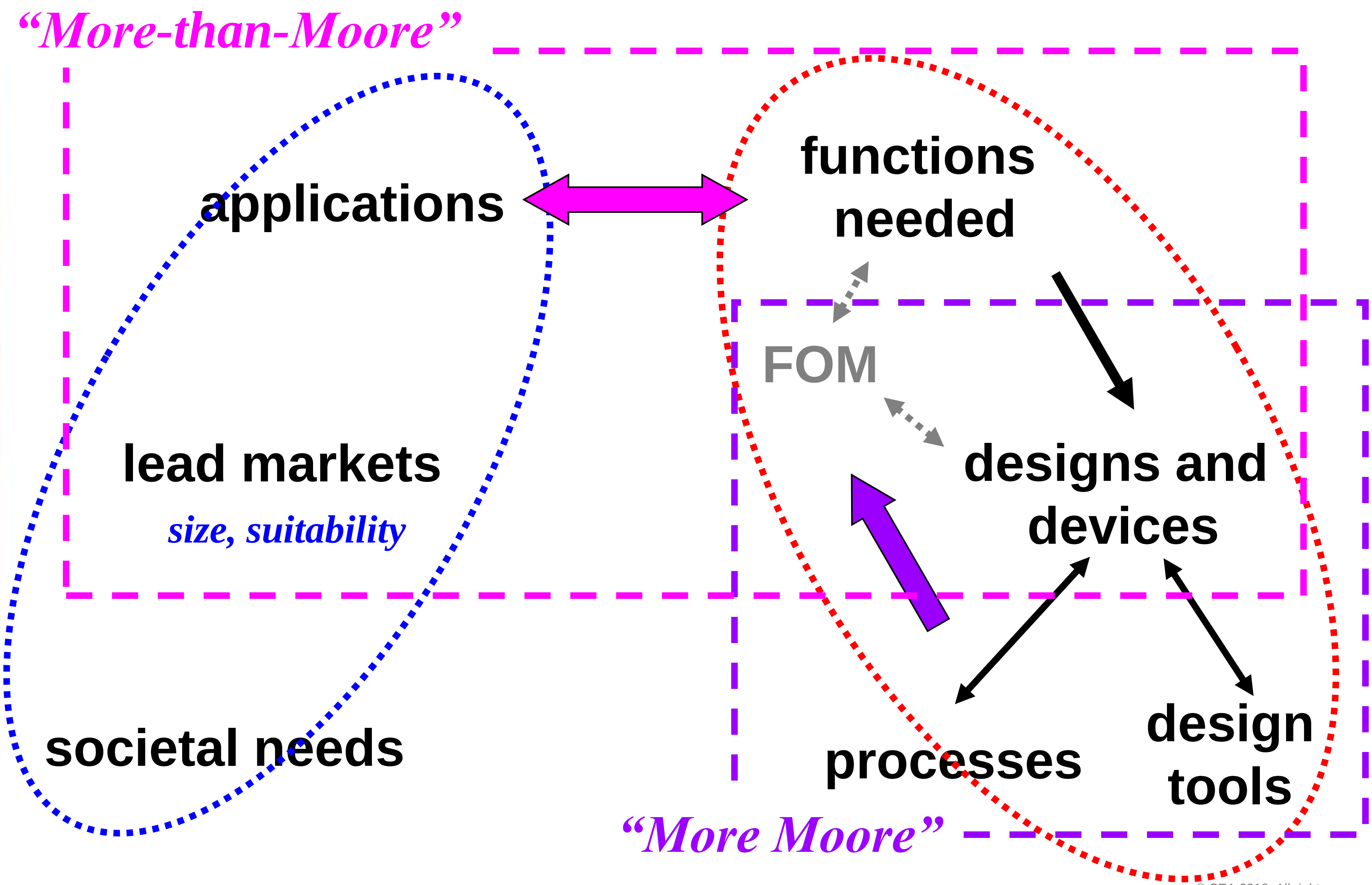
after P. Pflüger, IEF 2009

Roadmapping?

- preconditions
  - FOM = Figure Of Merit
  - LEP = Law of Expected Progress
  - WAT = Wide Applicability of Technology
  - ECO = Existing COmmunity
  - SHR = Willingness to SHaRe information
- effort started:
  - in ITRS (White Paper) + iNEMI
  - in the CATRENE Scientific Committee

There will not be an exhaustive roadmap for the MtM domain

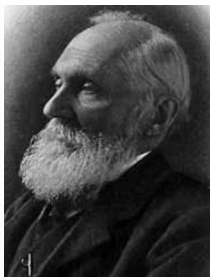
Application – Function – Technology interplay



Conclusion

Be modest in predicting potential **futures**

*"**Prediction is always difficult, above all of the future.**"*
Niels Bohr



*"Heavier-than-air flying machines are **impossible**"*
Lord Kelvin, president, Royal Society, 1890-1895

*"This 'telephone' has **too many shortcomings** to be seriously considered as a means of communication."*
Western Union memo, 1876

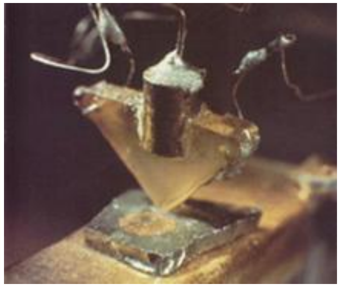
*"That is the biggest fool thing we have ever done [research on]… The bomb **will never** go off. I speak as an **expert** in explosives."*
Admiral William D. Leahy, U.S. Atomic Bomb Project, 1944

Don’t be too **pessimistic** about microelectronics

“The rumors of my death have been greatly exaggerated”

Mark Twain (1897)

Don’t dream too much, but dream right

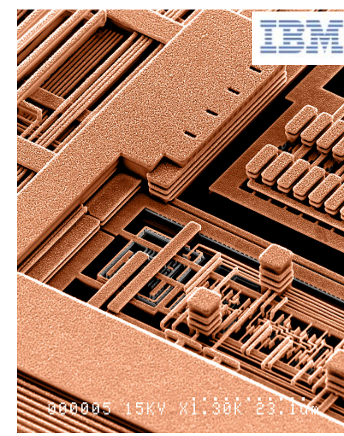


It is not just a new switch

You should never underestimate
the real complexity
of building an information processing system

…innovation will arise more and more
by combining

- materials (physics, chemistry)
- devices
- system (mathematics…)
- and ‘soft’ sciences



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Innovation for industry

Loyalty
Entrepreneurship
Team work
Innovation

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