4th Workshop: Elaboration of Recommendations

Non-charge-based State Variables

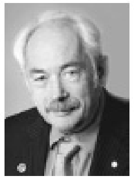
Rapporteurs:
Jouni Ahopelto (VTT) and Piotr Grabiec (ITE)

INPUTS FROM:

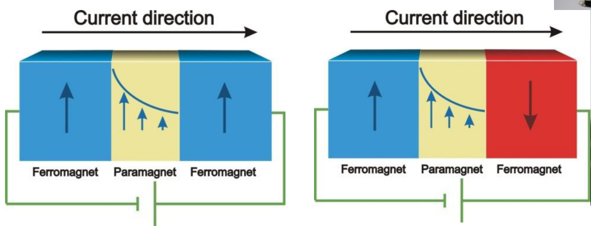
Speakers, Discussants, Rapporteurs: Spintronics

- Sergio Valenzuela (ICN, Spain), Speaker WS1
- Paolo Lugli (TU Munich, Germany) Discussant WS1
- Christian Pithan (FZ Jülich, Germany) Rapporteur WS1
- Johan Åkerman (U Gothenburg, Sweden) Speaker WS2
- Christian Pithan (FZ Jülich, Germany) Discussant WS2
- Mart Graef (TU Delft, The Netherlands) Rapporteur WS2
- Charles Gould (U Würzburg, Germany) Speaker WS3
- Thomas Swahn (Chalmers, Sweden) Discussant WS3
- Christian Pithan (FZ Jülich, Germany) Rapporteur WS3

Examples of Devices and Concepts: Spintronics

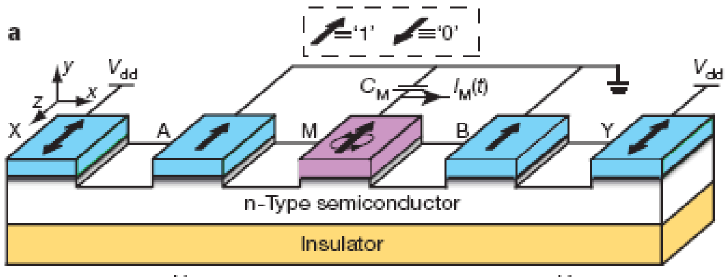
Fert, Grünberg. Nobel Prize 2007



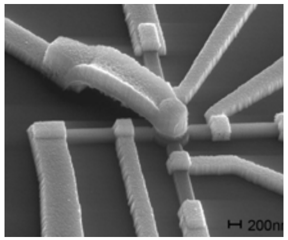
Current spintronic technologies: Spin valves

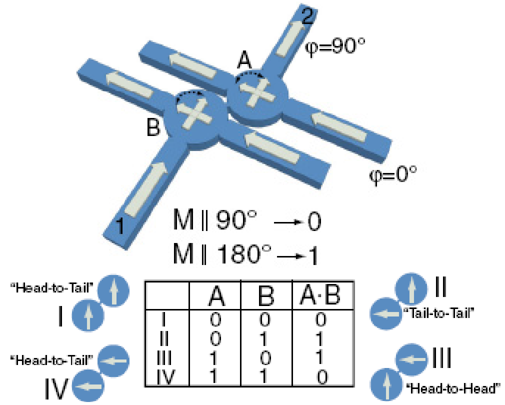
- **Giant magnetoresistance (GMR)**
- **Tunnel magnetoresistance (TMR)**
- **Memories, HDD (thermally assisted, bit patterned media, 2.5 Tbit/inch^2), MRAM**

Emerging topics: RF components, Spin Logics, Qubits and Quantum Computing, Spin Hall effects, Topological Insulators, Multiferroics, Spin Thermoelectronics…



Dery, Nature (2007)

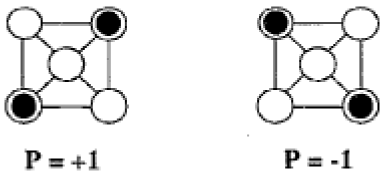




	A	B	A·B
I	0	0	0
II	0	1	1
III	1	0	1
IV	1	1	0

[S. Mark et. al., PRL 106, 057204 (2011)]

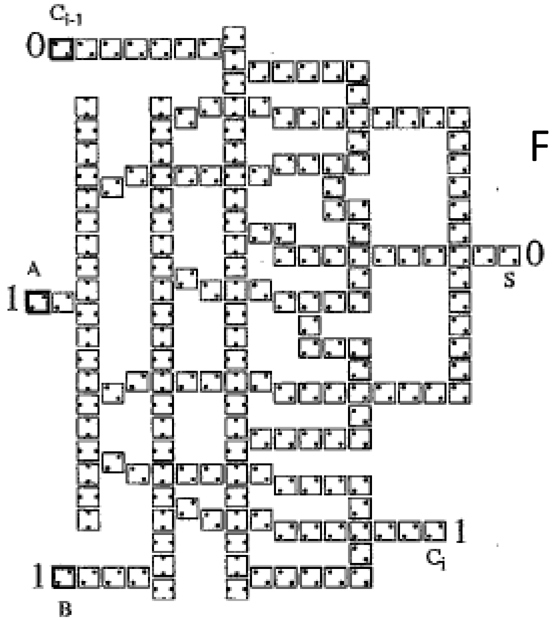
Examples of Devices and Concepts: Spintronics: Magnetic QCA



Nanotechnology 4 (1993) 49–57. Printed in the UK

Quantum cellular automata

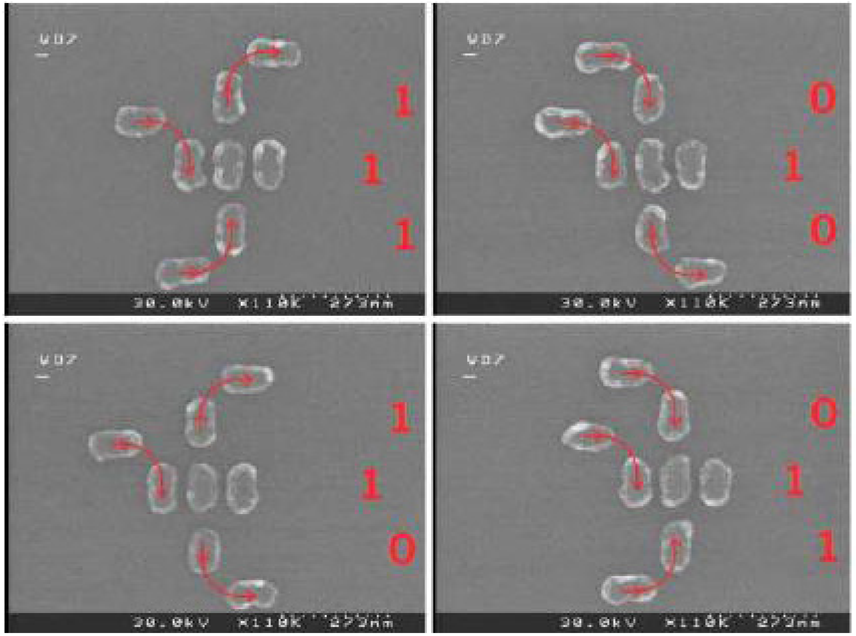
Craig S Lent, P Douglas Tougaw, Wolfgang Porod and Gary H Bernstein



Full adder

P. D. Tougaw and C. S. Lent J. Appl. Phys., Vol. 75, No. 3, 1 February 1994

Room temperature
Low power
Relatively fast (~GHz)



Cowburn Science (2000) Imre, Science (2006)

RECOMMENDATIONS

Memories

- Already commercial, strong industrial pull for new innovations

Logics

- Academic push
- Not mature
- Solid state
- Low power
- Design/Architecture: Boolean?
- Challenges: Spin injection, RT operation/spin flips, lifetime, stability, integration with CMOS…
- Still interesting new physics, topological insulators…
- Combination with charge?

RECOMMENDATIONS

Spintronics Recommendations :

- **Short term, application oriented research:**
  - **RF components:** Increase power output. Demonstration of phase-locking of tens of oscillators needed. Understanding of nonlinearities
  - **Spin Logics:** Material and design developments; improvement of nonlocal devices based on semiconducting and metallic materials. Magnetization switching with pure spin currents. Pure spin currents generation.
- **Long term research (more fundamental science based)**
  - **Spin Hall effects and Topological Insulators:** extreme fundamental as well application interest. Focus on materials and device design needed.
  - **Spin Thermoelectronics** – Fundamental research needed to understand phenomenology.
  - **Spin Qubits:** Coupling between more than 2 qubits. Limit decoherence from nuclei, molecular spin clusters, quantum control improvement, error correction, Application of new materials.

Issues to be addressed in all above research: interconnects and connecting nanoscale objects, variability, reliability and temperature stability.

INPUTS FROM:

Speakers, Discussants, Rapporteurs (MEMS):

- Lina Sarro, DIMES, Delft Univ. of Technology; speaker at workshop 2 (S2:MEMS)
- Piotr Grabiec, ITE Warsaw, discussant at workshop 2 (S2:MEMS)
- Danilo de Marchi, POLITO, Turin, rapporteur at workshop 2 (S2:MEMS)
- Michael Gaitan, NIST, Gaithensburg, MD,USA, Speaker at workshop 3 (S6:MEMS)
- Lars Hedrich, Univ. of Frankfurt, discussant at workshop 3 (S6:MEMS)
- Androula Nassiopoulou, NCSR „Democritos" – IMEL, Athens, rapporteur at workshop 3 (S6:MEMS)

MEMS/NEMS Examples of Devices and Concepts:

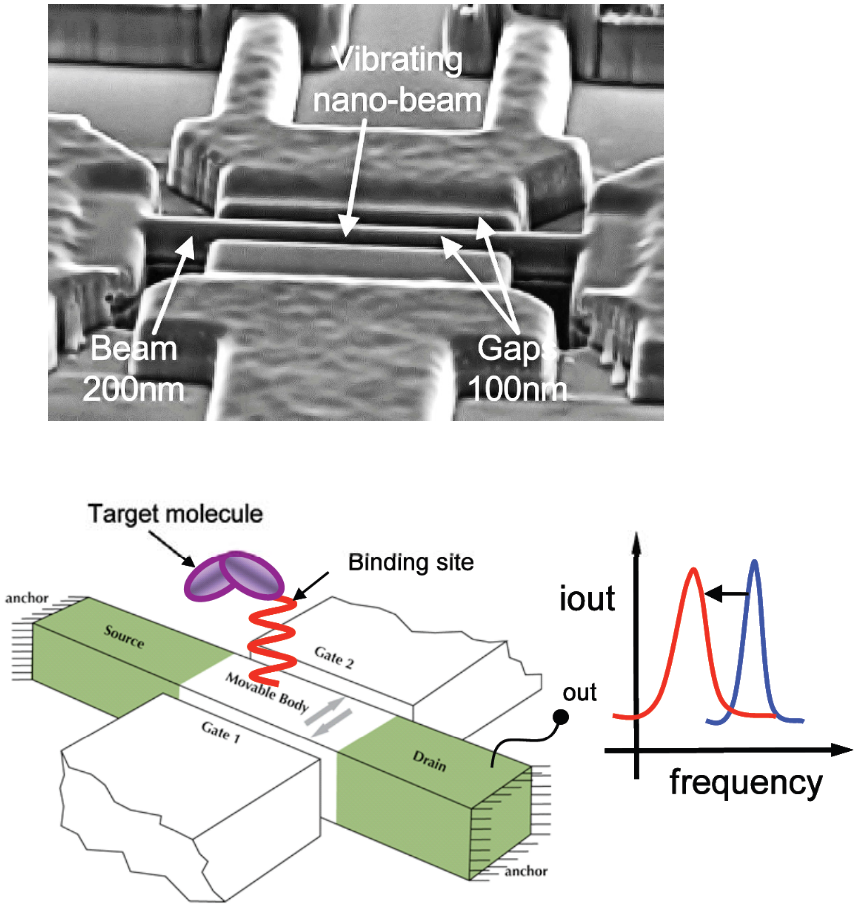
MEMS/NEMS devices are based on the CMOS technology development supplemented by MEMS specific processes. They differs from CMOS by putting the main focus on integrating diverse functions per chip. Nowadays, deep miniaturization and increasing diversity exist in this technology contributing not only to More than Moore but also to the Beyond CMOS domains.

The main role of MEMS/NEMS in ICT is seen as integrating functionalities with strong emphasize on applications, however NEMS technology may be used also to fabricate ULP switches with extremely high Ion/Ioff ratio.

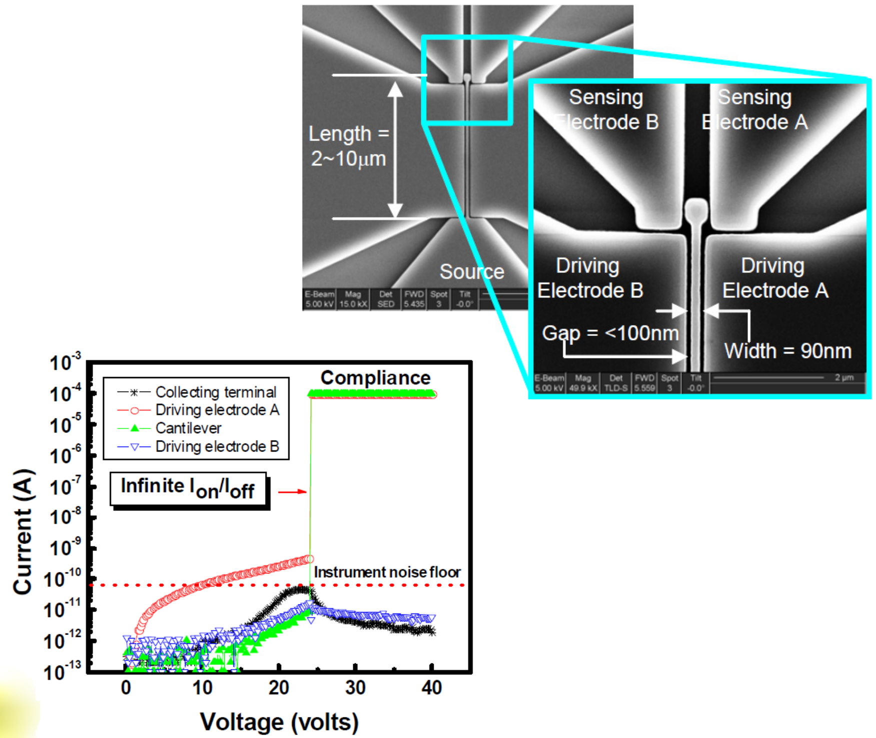
The use of the third dimension is one of the most important characteristics allowing to: (i) integrate specific functions, (ii) enhance performances, (iii) miniaturize a complete system.

Important feature of the MEMS/NEMS devices is also utilization of not only electronic but also other specific properties of the materials: mechanical, chemical, optical etc.

INTRODUCTION

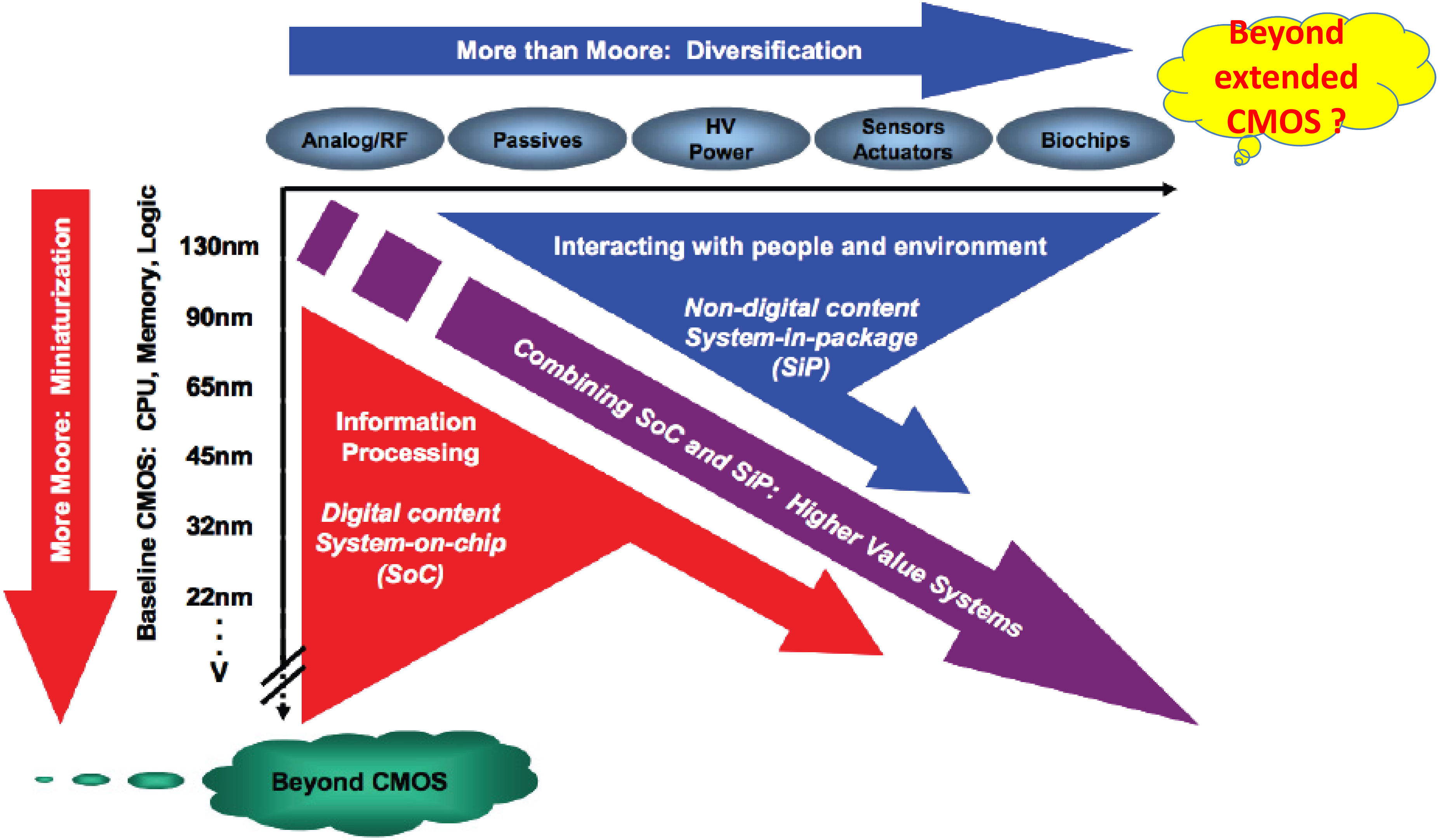


NEMS Sensor: Transistor with suspended laterally vibrating gate
(CEA LETI) *NEMSIC FP7 project web page*

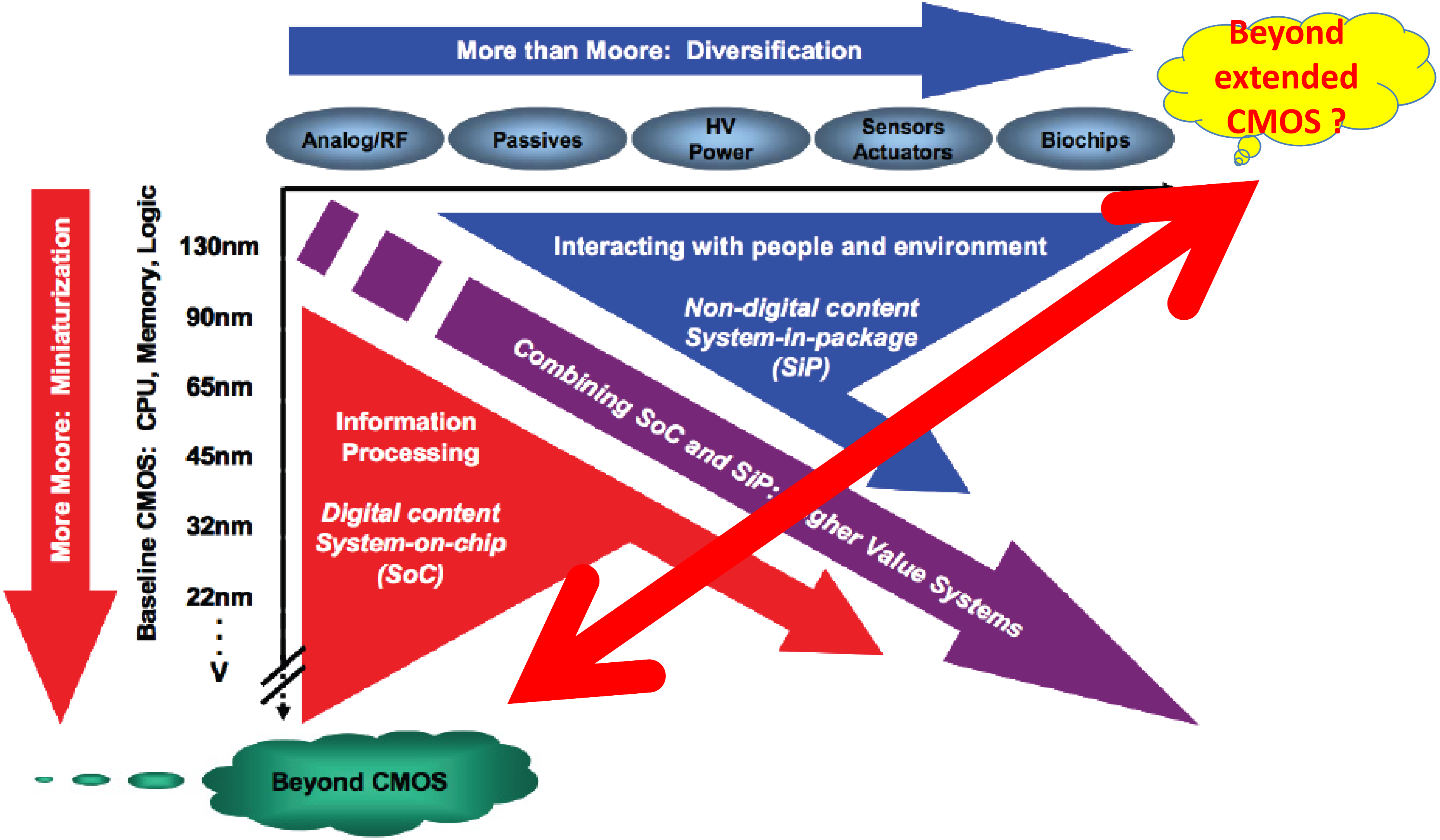


NEMS Switch allows for extremely high Ion/Ioff ratio.
after Raj Jammy, SEMATECH,
SEMATECH/ISMI symp. Sept.11. 2009.

INTRODUCTION



INTRODUCTION



RECOMMENDATIONS

MEMS/NEMS Recommendations:

- **Towards Beyond CMOS (NEMS switches):**

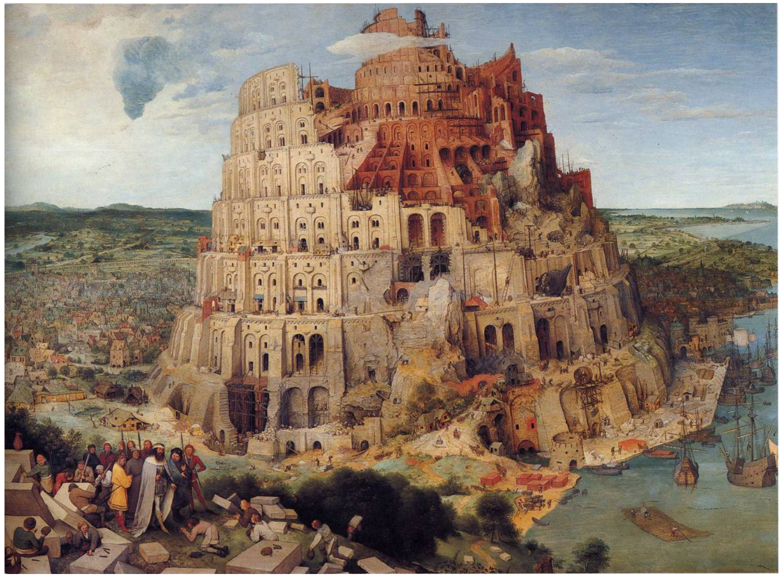
NEMS switches with stable, high performance are necessary for relay-based ICs. The on-state contact resistance should be as low as possible with reliability exceeding 10^{14} on/off cycles. Reliability issues for NEMS switches include permanent stiction (nano-scale physics), contact wear and plastic deformation, and environmental effects. Understanding of contact physics, friction, and wear at the nano-scale is essential for development of active power management, and logic applications.

- **Towards More-than-Moore:**
  - Deep miniaturization – technology development followed by upgrading of design & simulation tools to include the nano-scale multi-physics.
  - Complexity (monolithic vs. heterogeneous solutions) must be considered with regard to new, extended functionalities, performance, reliability, volume & cost.
  - Multidisciplinary fundamental research towards application of new materials and new functionalities in MEMS/NEMS devices and systems.

DESIGN FACTORS

Challenges in design of this set of device technologies:

- technology development should be followed by upgrading of design & simulation tools to include the nano-scale multi-discipline phenomena. Multi-directional collaboration between technology, physic, chemistry, simulation and design experts is needed.



- ……..
- ……..


Thank you
for your attention

INTRODUCTION

[ONE DEVICE, eg nanowires, PER SLIDE WITH NICE GRAPHICS INDICATING THE CRUCIAL FACTORS, ETC]

Examples of Devices and Concepts:

- Spintronics
- Main characteristics
- Principle of operation
- Context of B CMOS

[ONE DEVICE, eg nanowires, PER SLIDE WITH NICE GRAPHICS INDICATING THE CRUCIAL FACTORS, ETC]

Examples of Devices and Concepts:

- MEMS switches
- Main characteristics
- Principle of operation
- Context of B CMOS

INTRODUCTION

[ONE DEVICE, eg nanowires, PER SLIDE WITH NICE GRAPHICS INDICATING THE CRUCIAL FACTORS, ETC]

Examples of Devices and Concepts:

- Molecular electronics/Conformal changes
- Main characteristics
- Principle of operation
- Context of B CMOS

INTRODUCTION

Examples of Devices and Concepts:

- Non-charge based technologies not tackled in NANO-TEC
- QCA etc ..
- Main characteristics
- Principle of operation
- Context of B CMOS

INPUTS FROM:

Speakers, Discussants, Rapporteurs: (of the 3 workshops before)

- Molecular Electronics
- Speaker: Dominique Vuillaume - CNRS, Lille, France (35 minutes)
- Discussant: Clivia M Sotomayor Torres - Catalan Institute of Nanotechnology,Barcelona, Spain (5 minutes)
- Rapporteur: Jouni Ahopelto - VTT Technical Research Centre of Finland,

- Discussant: Paolo Lugli, Technische Universität München.

- Rapporteur: Christian Pithan, Forschungszentrum Juelich GmbH.

- Prof Dr A . N. Other (affiliation, role)
- Principle of operation

DESIGN FACTORS

IDEA HERE IS TO INCLUDE POINTS TO BE REINFORCED IN THE DESIGN-TECHNOLOGY SECTION
SEE DRAFT RECS

Challenges in design of this set of device technologies:

- Xxxx
- Xxxx
- Xxxx