4th Workshop: Elaboration of Recommendations

Non-charge-based State Variables

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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.

RECOMMENDATIONS

Spintronics Recommendations :

Memories

Already commercial, strong industrial pull for new innovations

Logics

Is characterized by mostly academic push, not mature, interesting new physics.

- Advantages for CMOS replacement should be identified. Spintronics offers reduced power dissipation and to large extent could re-use most of existing design architecture, it is also a good candidate to implement a 4-level logic, however a critical fundamental and technology related viabilities have to be clarified:
  - pure spin propagation in wires, without charge propagation
  - spin injectors and spin-sensing transistors (CMOS transistor size)
  - other spintronic architectures? Other carriers - Phonons should also be considered.
- Design investigation for multi-level logic can be studied independently from spintronic feasibility

RECOMMENDATIONS

Spintronics Recommendations :

Spintronics, did not show the whole potential yet. Many new phenomena have to be investigated with clear application perspectives.

- Spin Transfer Torque (STT) oscillators (STO) offers very interesting perspectives for systematic generation, manipulation and detection of spin waves (magnonics).
- STT is also able to move domains around – enabling very interesting opportunities for spintronic memristors.
- Spin Hall Effect may generate a pure spin current w/o a charge current which, via STT may generate a spin vawes with very little energy losses.

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.

RECOMMENDATIONS

MEMS/NEMS recommendations:

- The NEMS switches cannot replace CMOS for high density computing, however they can replace CMOS in some interesting and important niche applications e.g. operation in noisy (electromagnetic) enviroment or to simplify technology when logic operations have to be integrated with NEMS resonators for RF or sensor applications.
- NEMS introduce additional functionalities, extending CMOS applications.
- New applications using phonons and phonon confinement in nanostructures (e.g. porous Si) are investigated with prospective applications including on-chip cooling and thermal devices.

RECOMMENDATIONS

MEMS/NEMS recommendations:

- MEMS/NEMS have to be considered as functionality enablers in broader sense, thus a term „(heterogeneous) micro/nano-systems" has to be used.
- Nanoelectromechanical devices are expected to be suitable building blocks for creating RF components (oscillators, antennas, interconnects) offering better perfonmance operation, (low RF losses, non-linear operation, opto-mechanical actuation, combination with phonon engineering, etc). For the RF applications, NEMS research should be focused on exploitation of nano-scale phenomena, new materials and on integration with CMOS (from technological and design point of views).
- Nano-scale NEMS resonators provide a versatile tool for many innovating sensing appplications.
- MEMS/NEMS technology has to be considered as a provider of tools for instrumentation necessary for measurement and diagnostics on advanced micro/nano-technology based products (devices, materials, systems)

RECOMMENDATIONS

MEMS/NEMS & Spintronics recommendations:

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