2007 ITRS

Emerging Research Materials [ERM]

December 5, 2007

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2006 - 2007 ERM Participants

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HP
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Macromolecular Scale Devices are on the ITRS Horizon

Outline

• ERM Goals and Scope
• Emerging Research Device Examples
• Lithography Example
• FEP Example
• Interconnect Example
• Assembly & packaging Example
• Environment Safety & Health
• ERM Metrology & Modeling Needs
• Summary
Emerging Research Materials [ERM]

- New Cross-cutting ERM Chapter
  - Goal: Identify critical ERM technical and timing requirements for ITWG identified applications
  - Align ERM requirements with ITWG needs
    - ERM with potential value to ITWG Gaps
    - Difficult challenges that must be overcome
  - Consolidate materials research requirements for:
    - University and government researchers
      - Chemists, materials scientists, etc.
    - Industry Researchers
      - Semiconductor
      - Chemical, material, and equipment suppliers
## ERM Potential ITWG Applications

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<th>Materials</th>
<th>ERD Memory</th>
<th>ERD Logic</th>
<th>Lithography</th>
<th>FEP</th>
<th>Interconnects</th>
<th>Assembly and Package</th>
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<td>Complex Metal Oxides</td>
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<td>Interfaces &amp; Heterointerfaces</td>
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Potential Applications Identified
ERM for Emerging Research Devices
Examples
Emerging Research Device Applications

**Device State***
- 1D Charge State
- Molecular State
- Spin State
- Phase State
- Memory
  - Fuse/anti-fuse, Ferroelectric FET, etc.

**Emerging Materials**
- (Low Dimensional Materials)
- (Macromolecules)
- (Spin Materials and CMO**)
- (CMO** and Heterointerfaces)

*All Devices have critical interface requirements*

*Representative Device Applications

**CMO = Complex Metal Oxides**
1D Charge State

Group IV & III-V Nanowires Grow in 111 Orientation Catalyst determines location (T. Kamins, el. Al., HP)

Atomically smooth Heterostructures (L. Samuelson, Lund Univ.)

Nanotube Challenges
• Control of Location & Orientation
• Control of Bandgap
• Contact Resistance

Graphene & Graphitic Carbon

Advantage: Patternable
Challenge: Deposition, Edge Passivation

Quantum Dot

Source Intel

Carrier doping & control is challenging for low dimensional materials
Molecular State

High contact energy barriers may be masking potential molecular switching!!

- Need more research on contact formation
- Novel lower potential barrier contacts…
Room temperature ferromagnetic semiconductors (T_{curie})

- Reports of high Curie temperature FM semiconductors
  - GeMn Nanocolumns >400K
  - SiMn >400K
  - (InMn)P ~300K
  - Need verification & more study

**Spin State**

Maximum Curie Temperature

- Doped Oxides
- (III.Mn)V

Carrier mediated exchange
Complex Metal Oxides

- Complex Metal Oxides
  - MgO, Pb(Zr$_{1-x}$Ti$_x$)O$_3$, La$_{1-x}$Sr$_x$MnO$_3$, BiFeO$_3$
- Memory
  - FeFET (Ferroelectric polarization)
  - Fuse-antifuse (Resistance change, etc.)
- Logic
  - Spin Tunnel Barriers
  - Novel Logic Heterostructures (Coupling charge to magnetic properties & alignment)
- Challenges
  - Control of Vacancies
  - Contact stability
    - Hydrogen degradation
  - Electric field & environmental stability
  - Control of stress & crystal structure
Strongly Correlated Electron State

- Materials exhibit complex phase relationships
  - Structure, Strain, Spin, Charge, Orbital Ordering
- Goal: Determine whether complex phases and coupled dynamic and static properties have any potential to enable alternate state logic devices
  - Example: Mott transition or other coupled states

Can these materials enable new device functions?
Novel Properties at Hetero-interfaces

SrTiO3-LaAlO3

Hetero-interfaces may enable novel coupling of properties!!

J. Mannhart et. al. 2006
Augsburg Univ.
ERM for Lithography
Examples
Emerging Lithography Applications

- **Resist: Unique Properties**
  - Immersion: Low leaching and low surface energy
  - EUV: Low outgassing, high speed and flare tolerant

- **Imprint Materials**
  - Low viscosity
  - Easy release

- **Directed Self-Assembly**
  - Resolution, LER, density, defects, required shapes, throughput, registration and alignment

Macromolecular Architectures

- Molecular Glasses and PAGS, Ober, Cornell
- Polymer Design, R. Allen, IBM

Sublithographic resolution and registration, Ross, MIT
Design Pattern Requirements for Directed Self-Assembly
ERM for Front End Processing Example
Emerging FEP Applications

- **Deterministic Doping**
  - Conductance variability reduced from 63% to 13% by controlling dopant numbers and roughly ordered arrays;
  - Conductance due to implant positional variability within circular implant regions of the ordered array ~13%.


- **Selective Processes/Cleans**
  - Macromolecules
  - Self-assembling materials and processes
ERM for Interconnects
Examples
Emerging Interconnect Applications

- **Vias**
  - Multi-wall CNT
  - Higher density
  - Contact Resistance
  - Adhesion

- **Interconnects**
  - Metallic
  - Alignment
  - Contact Resistance

- **Dielectrics**
  - Novel Polymer ILDs

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ERMs Must Have Lower Resistivity

- Y. Awano, Fujitsu

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Quartz Crystal Step Alignment

- H. Dai, Stanford Univ.

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Ref. 2005 ITRS, INT TWG, p. 22
ERM for Assembly & Packaging Examples
Emerging Packaging Applications

- Thermal Nanotubes
- High Density Power Delivery Capacitors
  - Dielectrics: High K
  - Self Assembly
  - Interconnects: Nanotubes or Nanowires

Package Thermo-Mechanical
- Substrate: Nanoparticles, Macromolecules
- Adhesives: Macromolecules, Nanoparticles
- Chip Interconnect: Nanoparticles

4 Die Stack
4 Die Stack with Large Overhang
Environment, Safety, and Health

- Metrology needed to detect the presence of nanoparticles
- Research needed on potential undesirable bio-interactions of nanoparticles
- Need Hierarchical Risk/Hazard assessment protocol
  - Research, Development, Commercialization

➢ Leverage Existing Research and Standards Activities
Emerging Metrology and Modeling Needs

- **Metrology**
  - Chemical and structural imaging and dimensional accuracy at the nm scale
  - Low dimensional material properties (Mapping)
  - Nano-interface characterization (carbon)
  - Simultaneous spin and electrical properties
  - nm scale characterization of vacancies and defects

- **Modeling Materials and Interfaces**
  - Low dimensional material synthesis & properties
  - Spin material properties
  - Strongly correlated electron material properties
    - Long range and dynamic
  - Integrated models and metrology (de-convolution of nm scale metrology signals)

- **Metrology and modeling must be able characterize and predict performance and reliability**
Summary

- ERM identifies materials with desirable properties that may enable potential solutions for ITWG applications

- Significant challenges must be addressed for these materials to be viable for transfer to the ITWGs

Future:
- Refine and update ERM requirements
- Assess ERM progress toward meeting identified application requirements
- Identify new ITWG application opportunities for ERM
- Identify new families of Emerging Research Materials