

2009 ITRS

Emerging Research Materials [ERM]

December 16, 2009

Michael Garner – Intel
Daniel Herr – SRC



Work in Progress: Not for Distribution

2008 - 2009 ERM Participants

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Key Messages

In 2009, the ERM Working Group:

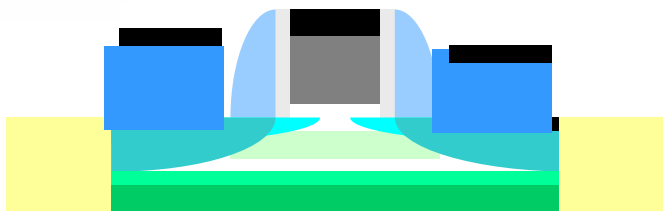
- Focused on ITWG identified application opportunities, in the following areas:
 - Emerging Research Devices
 - Lithography
 - Front End Processes and PIDS
 - Interconnects
 - Assembly and Packaging
- Established and launched a critical assessment process
 - Completed 1st assessment of Alternate Channel Materials



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Extending CMOS Alternate Channel Materials

MOS



Materials Assessments Include:

Material Quality/Performance

Gate Requirements

Contact Behavior

Interfaces

- Also identify related novel metrology and modeling needs

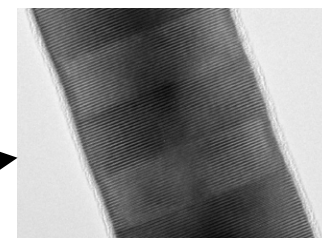
Alternate Channel Materials

- Ge and III-V Compounds

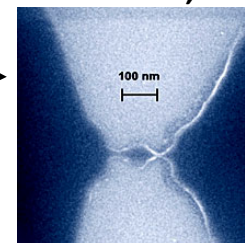
- Nanowires

- Graphene

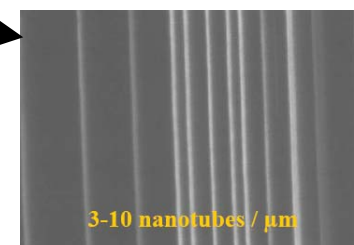
- Carbon Nanotubes



III-V Heterostructures
(L. Samuelson, Lund Univ.)



A. Geim, Manchester U.



C. Zhou, USC

Critical Review – Evaluation Scale

<p><i>Potential for the ERM Entry is projected to be significantly better than current materials (compared using the Material Relevance Criteria)</i> <i>(OPA \geq18)</i></p>	<p><i>Potential</i></p>
<p><i>Potential for the ERM Entry is projected to be equal to or slightly better than current materials (compared using the Material Relevance Criteria)</i> <i>(OPA >14-18)</i></p>	<p><i>Potential</i></p>
<p><i>Potential for the ERM Entry is unknown or is projected to be significantly less than current materials (compared using the Material Relevance Criteria)</i> <i>(OPA \leq 14)</i></p>	<p><i>Potential</i></p>

Overall Potential Assessment (OPA) = Potential Summed over the Eight Relevance Criteria for each Material Entry

Maximum Overall Potential Assessment (OPA) Sum = 24

Minimum Overall Potential Assessment (OPA) Sum = 8



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≤ 14 >14 -18 OPA >18

Alternate Channel Materials – Critical Assessment

N-8 Raters Research targets	Mobilities: Hole >5000 cm ² /V-s and/or electron >5000 cm ² /V-s	Performance Unpinned Fermi level, 10% thickness (1s), Dit <1E12/(eV- cm ²)	Material grown on Si wafers with low defect density	Contact resistivity <1E-8 W- cm ²	Property Control 10% (1s)	Demonstrate /understand controlled n and/or p channel & S/D doping, e.g. 10% (1s)	CMOS compatible catalyst, as needed, 10% of half pitch, vert. and/or horizontal	Understand formation mechanism, develop low defect density strategy	Integration Average (excluding mobility)
Ge [For p- channel devices] (2013-2018)	3	1.8	1.5	2	2	1.8	1.8	1.8	1.8
	2								
	1								
III-V Materials (2019+)	3	1.8	1.1	1.6	2	1.6	1.6	1.7	1.6
	2								
	1								
Homogeneous Nanowires [Group IV and III-V] (2019+)	3	2.6	1.8	1.6	1.3	1.8	1.8	1.6	1.7
	2								
	1								
Carbon Nanotubes (2019+)	3	1.8	1.3	1.4	1.3	1.3	1.4	1.3	1.4
	2								
	1								
Graphene (2019+)	3	2.9	1.7	1.3	1.4	1.4	1.4	1	1.4
	2								
	1								



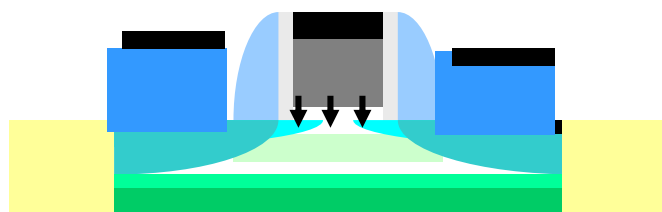
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Beyond CMOS Materials & Interfaces

Charge Based

Ferroelectric

Polarization



Negative Capacitance FET

States Other Than Charge Only

Individual or Collective

Spin State



Spin Devices

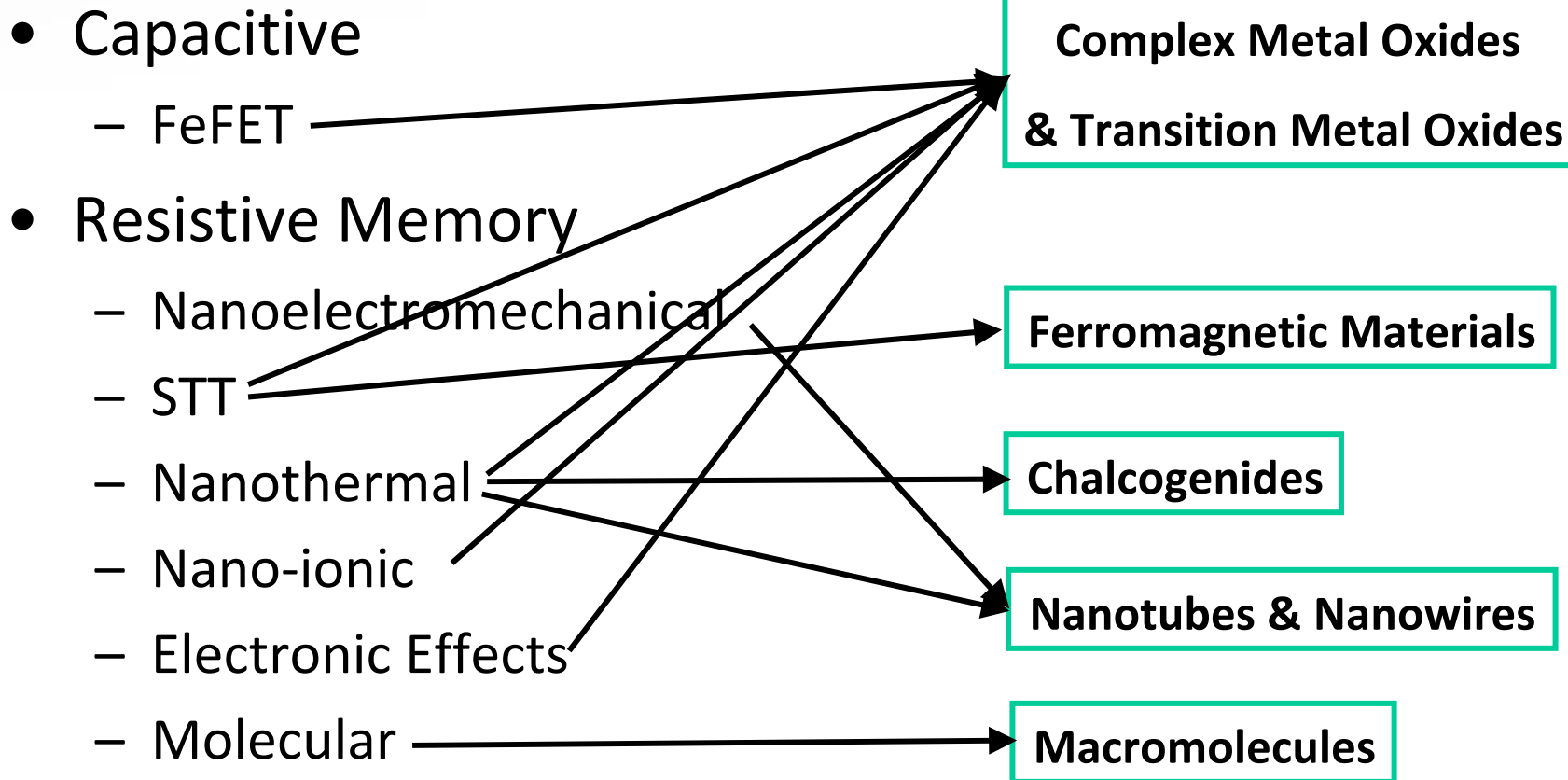
Assess:

- Ferromagnetic Materials, Dilute Magnetic Semiconductors
- Complex Metal Oxides
- Strongly Correlated Electron State Materials (FE, FM, FE & FM)
- Macromolecules
- Interfaces



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Memory



**Complex Metal Oxides
& Transition Metal Oxides**

Ferromagnetic Materials

Chalcogenides

Nanotubes & Nanowires

Macromolecules



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Lithography

Evolutionary Resist Design

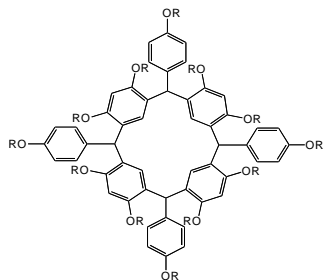
Positive Resist

New Applications of Old Resist

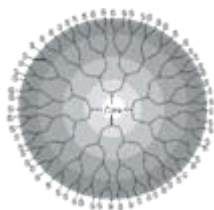
Non-Chemically Amplified (193nm)

Negative Resist (EUV)

Novel Molecular Resist Components



Molecular Glasses
Ober, Cornell

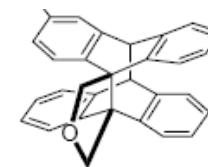


Dendrimers,
Frechet, UC-B

Novel Molecules for Double Exposure



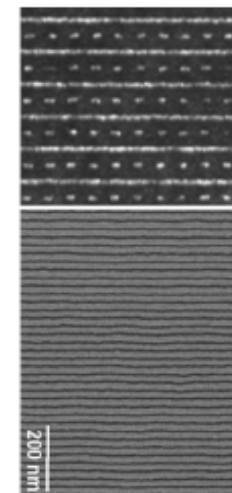
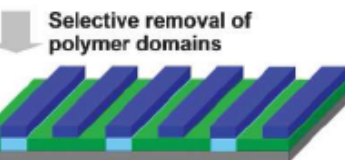
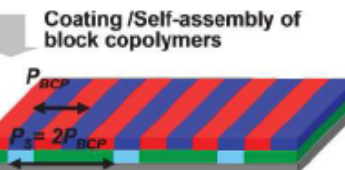
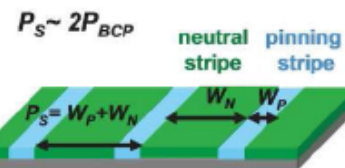
Intermediate State



Tethered Anthracene
Bristol, Intel

Directed Self Assembly

Sparse Chemical Pattern



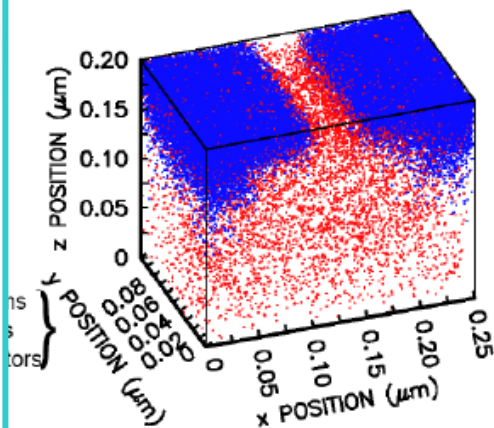
Sparse Patterns
Hinsberg, IBM

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Front End Processing & PIDS Materials

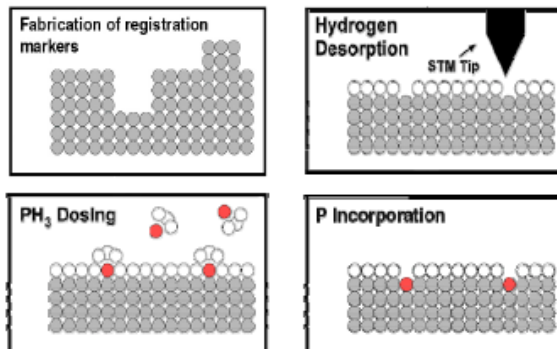
Deterministic Doping Options



D. Frank, ISSCC 2004

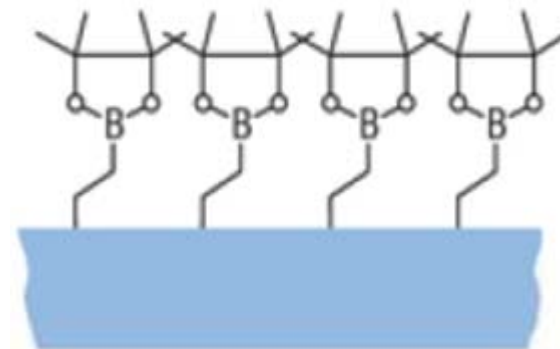
V_t set by the number of dopant atoms at the interfaces and the channel depletion regions

STM Dopant Placement



Simmons, UNSW

Monolayer Doping



Javey, UCB

Proposals for massively parallel precision implants

Directed Self Assembly for selective:

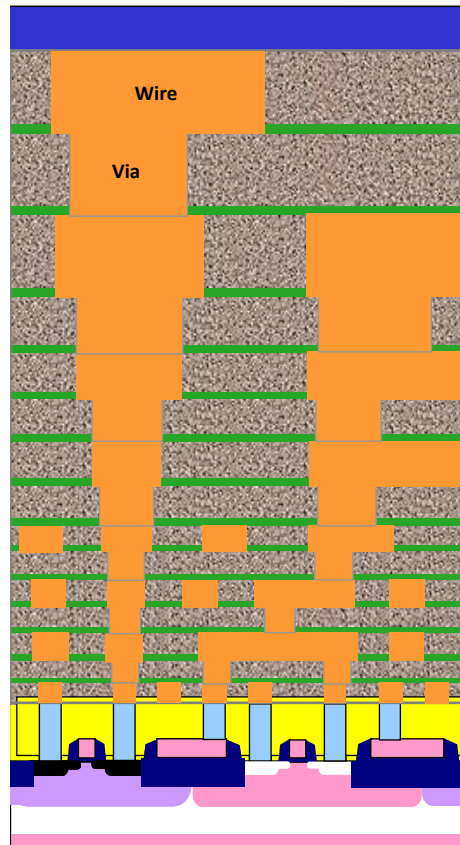
- Etch
- Deposition
- Protection in clean operations



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Interconnect Materials

Interconnects



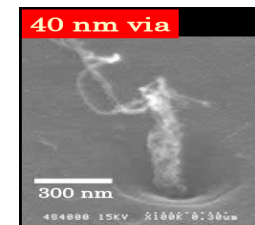
Ultra-thin Barrier Layers

- Transition Nitride (ZrN, HfN, ZrGeN,...)
- Direct Plate (Ir, Os, Rh, ...)
- SAM

Ultra low-K ILD

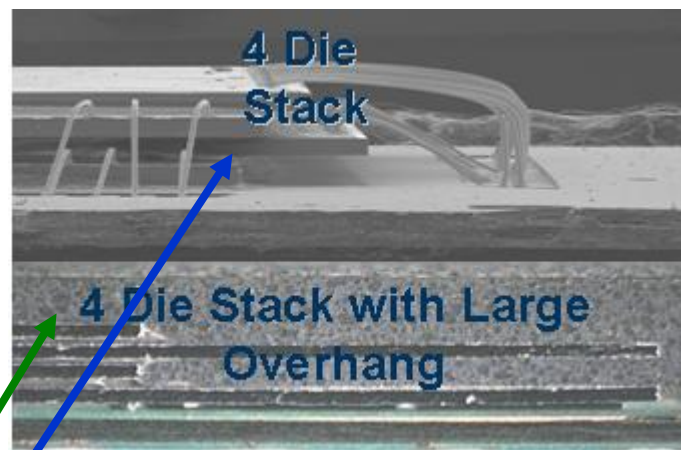
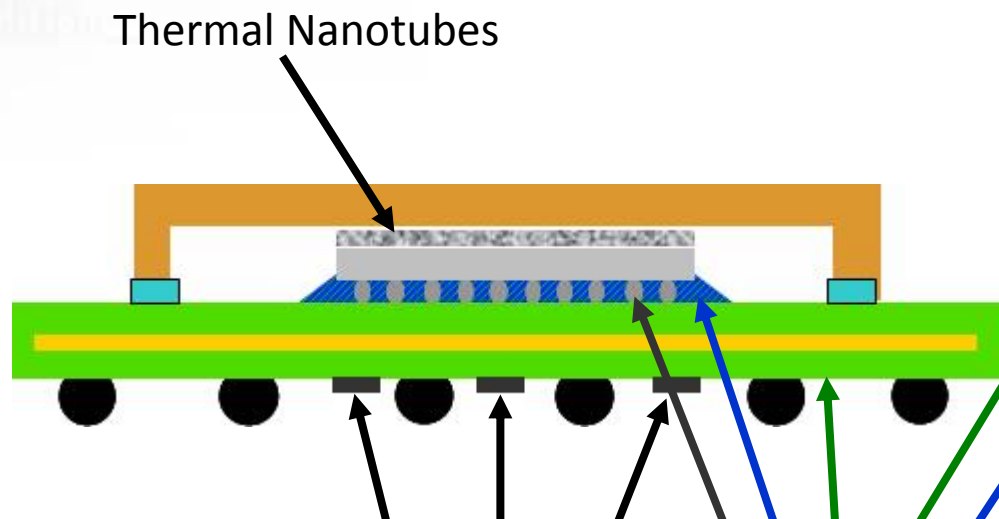
Novel Interconnects & Vias

- Carbon Nanotubes
- Graphene
- Single Crystal Metal Nanowires



Y. Awano, Fujitsu

Emerging Packaging Applications



High Density Power Delivery Capacitors

Package Thermo-Mechanical

- Dielectrics: High- κ
- Self Assembly
- Interconnects: Nanotubes or Nanowires

- Substrate: Nanoparticles, Macromolecules
- Adhesives: Macromolecules, Nanoparticles
- Chip Interconnect: Nanoparticles
- Polymers: Nanoparticles & Macromolecules

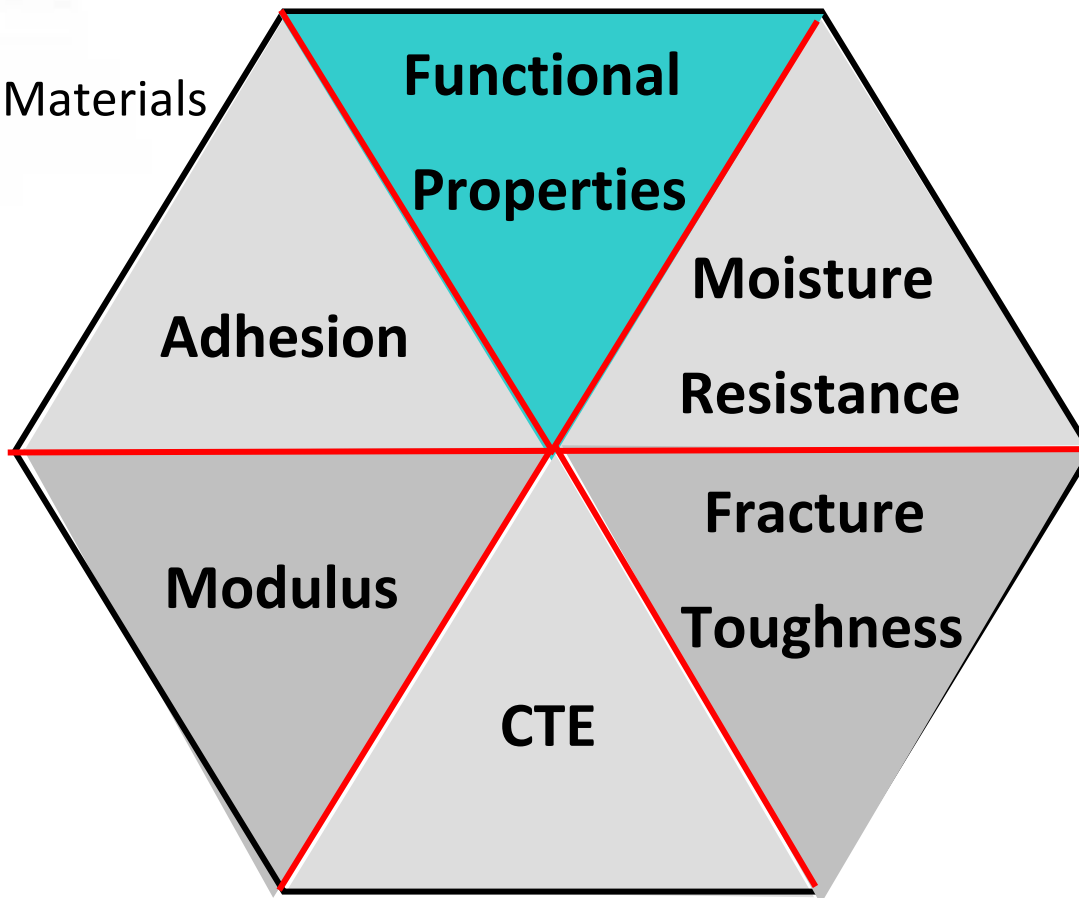


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Hexagon of Assembly Material Requirements

Examples:

Thermal Interface Materials
Mold Compounds
Underfills
Adhesives
Epoxies



Highly coupled material properties

Apply novel materials to achieve optimal performance



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ESH Challenges

Materials needed to overcome significant technical challenges:

- Few materials could meet projected performance requirements
- Materials have known or uncharacterized EHS properties
- Stimulate ESH research in uncharacterized materials
- Encourage development of best known methods for materials EHS in research, development and high volume manufacturing
- Efficient use of materials and resources
- Manufacturing in highly controlled environments



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Emerging Metrology and Modeling Needs

□ Metrology

- Chemical and structural imaging and dimensional accuracy at the atomic and nanometer scales
- Low dimensional material properties (Mapping)
- Nondestructive nanoscale embedded interface characterization
- Simultaneous dynamic spin and electrical properties
- Nanometer scale characterization of vacancies and defects and their effects on electronic properties

□ Modeling Materials and Interfaces

- Low dimensional materials synthesis and properties
- Spin material properties
- Strongly correlated electron material properties
- Effects of anion and cation vacancies on electronic properties
- Integrated metrology and modeling tools to de-convolve nanometer scale metrology signals

□ Metrology and modeling must be able characterize and predict performance and reliability



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ERM Summary

In 2009, ERM identified, monitored, and assessed selected families materials in consideration as potential solutions for ITWG identified applications

The 2009 ERM Ge and III-V assessment supports ERD's recommendations

Significant technical material challenges must be addressed for other Emerging Research Materials to warrant transition consideration to the ITWGs



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