Materials & Emerging Research Materials Chapter

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Chairman of Third Millennium Test Solutions

Dr. Bottoms received his Ph.D. from Tulane University and began his post graduate career in academia as a member of the EE faculty at Princeton University. He has worked in venture capital and as CEO of several companies both public and private.

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Materials & Emerging Research Materials TWG

The scope of the Chapter is focused on:

- Enabling disruptive changes in capability of emerging devices and systems such as quantum computers, Aerospace & defense, biomedical systems, IoT, etc through novel materials
- Expanding the range of properties available through new classes of composite materials combining novel matrix materials with nano-materials
- Supporting the HIR working groups with new materials required to meet the difficult challenges they identify.

Defining difficult challenges requires close collaboration with other TWGs both in and outside of HIR.

Scope of the Materials Sub-Chapter

The Materials Sub-chapter focus is on the evolution of materials providing a wider range of properties for conductors, semiconductors and insulators to meet demands for lower cost, reduced power, higher thermal density and higher performance. The Scope will address requirements identified by other HIR TWGS. The time horizon is for new materials that will be in production within 10 years. Supply chain requirements will be included in collaboration with the Supply Chain TWG.

Scope of the Emerging Research Materials Chapter

The Emerging Research Materials Sub-chapter focus is on the revolution in materials required for new device types, and disruptive improvements replacing the conductors, insulators, semiconductors and optical materials in current device architectures. The time horizon is for new materials that will be in volume production beyond 10 years and up to 25 years.

Heterogeneous Integration by Materials

HETEROGENEOUS INTEGRATION ROADMAP

Conductors

- Nanomaterials (CNT, graphene, nanowires)
- Metals (Cu, Al, W, Ag, Co, etc.)
- Composites

Dielectrics

- Oxides
- Polymers
- Porous materials
- Composites

Semiconductors

- Elemental (Si, Ge)
- Compounds (IIIV, IIVI, tertiary)
- Polymers

Materials Parameters must be compatible with each other for processing and operation:

- ✓ Cost
- ✓ CTE differential
- ✓ Thermal conductivity
- ✓ Fracture toughness
- ✓ Modulus
- ✓ Processing temperature
- ✓ Interfacial adhesion
- ✓ Operating temperature
- ✓ Breakdown field strength

Difficult Materials Challenges 2019-2029 (1)

	Identify integrated high k dielectrics with Equivalent Oxide Thickness <0.5nm, high breakdown field and low leakage
	Identify integrated contact structures that have ultralow contact resistance
	Achieving high hole mobility indirect band gap materials in FET structures
	Achieving high electron mobility in Ge with low contact resistance in FET structures
	Achieving a bandgap in graphene suitable for FET structures
	Multiferroic with Curie temperature >400K and high remnant magnetization to >400K
	Synthesis of single wall CNTs with tight distribution of bandgap and mobility
Achieving desired properties in integrated structures	Electrical control of the electron correlation, ex. Mott transition, Spin dynamics
	Simultaneously achieve package polymer CTE, modulus, electrical, thermal properties, with moisture and ion diffusion barriers for low stress packaging at use case temperature
	Thermal interface materials with low interface thermal resistance and high thermal conductivity with desired electrical and mechanical properties.
	Nanosolders compatible with <200C assembly, multiple reflows, high strength, high thermal [illegible] electrical conductivity and high electromigration resistance.
	[illegible] Inks that can be printed as die attach adhesives with required electrical, mechanical, [illegible]mal, interface,and reliability properties.
	[illegible] Inks that can be printed as conductors, via hole fillers, solders, or die attach adhesives with required electrical, mechanical, thermal, interface and reliability properties.

Achieving desired properties in integrated structures

Difficult Materials Challenges 2019-2029 (2)

Characterize and control coupled properties of embedded materials and their interfaces

Identifying manufacturable methodologies to enable deterministic fabrication with required property control

Characterize and control coupled properties of embedded materials and their interfaces	High mobility transition metal dichalcogenides TMD with unpinned Fermi level and low resistance ohmic contacts.
	High electron mobility in Ge with unpinned Fermi level and low resistance ohmic contacts.
	High mobility nanowires with unpinned Fermi level and low interface resistance.
	Graphene with a bandgap suitable for FET structures, high mobility, and unpinned Fermi level at dielectric interfaces.
	Complex metal oxides with unpinned Fermi levels
	Characterization of electrical properties of molecule / metal contact interfaces (i.e. Pentacene/Au)
	Characterization of electrical properties of embedded nano contact interfaces (i.e. CNT/Metal
	CNTs with low resistance contacts on both ends
	Characterization for density of dislocations and anti-phase boundary generating interface between Ge/III-V channel materials and Si.
Identifying manufacturable methodologies to enable deterministic fabrication with required property control	Dopant placement and activation i.e. deterministic doping with desired number at precise location for Vth control and S/D formation in Si as well as alternate materials.
	HVM compatible methods to place dopants in predetermined positions with minimal damage to the semiconductor.
	Manufacturing and purification methodologies of single wall CNTs to achieve required purity levels (pure semiconductor with bandgap)
	Identify DSA process simplification methodologies that can achieve required overlay requirements.
	Wafer scale growth of high quality graphene with desired process conditions (ex. Low temperature growth on metal or insulator)
	Controlling edge-termination / molecular absorption to graphene to achieve required bandga
	Synthesis or assembly of CNTs in predefined locations and directions with controlled diameters, chirality and site-density.
	III-V: Correlation between antiphase domains and electrical properties.
	Control defects in carbon nanotubes.
	Control defects in growth and processing of graphene.
	Control concentration and locations of cation and anion defects in complex metal oxides.
	Control precipitation in ferromagnetic semiconductors.
	Characterization for density of dislocations and anti-phase boundary generating interface between Ge/III-V channel materials and Si.

Example: Warpage For Ever Thinner Layers

Solutions for warpage are known and demonstrated but not integrated for production

- Reduced copper CTE (4.5 rather than 17)
- Low modulus dielectrics
- No underfill
- Direct interconnect bonding
- All joining processing done at or near use case temperature

Heterogeneous integration of materials and processes resolve a system problem

Plans For Materials Chapter 2020

- **Expanded coverage of 2D materials for electrical and thermal conductor, light emitters, insulators, barrier layers and semiconductor properties**
- **Expanded coverage of composite materials**
- **Update and expand the collaboration with other technical working groups both inside and outside HIR to identify needs and aspirations**
- **Update and expand tables to reflect the progression of new materials from research to production**
- **Recruit more participants from Europe and Asia**

Thank You For Your Attention