Heterogeneous Integration: A Snapshot of Emerging Devices

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Emerging Research Devices Chapter Scope

Dimensional scaling is reaching its fundamental limit.

Continued enhancement of speed while lowering power consumption is difficult.

There is an urgent need to explore new devices for information processing and memory, new architectures and new approaches for heterogeneous integration for existing functions and emerging applications.

The scope of the Chapter includes:

Supporting the HIR working groups with new devices required to meet the difficult challenges they identify.

Assessing emerging research devices and technologies such as flexible electronics, neuromorphic devices, graphene/2D material electronics, CNT electronics, nanoscale vacuum electronics, plasmonics and others.

Defining the difficult challenges in ERD requires collaboration with Materials TWG and other Technical Working Groups both within and outside of HIR.

Emerging Research Devices

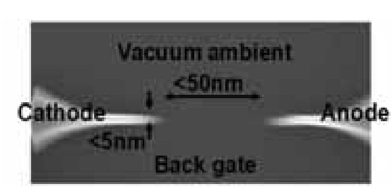
- Flexible electronics
- Nanoscale vacuum electronics
- Neuromorphic devices
- 3 dimensional stacked devices
- Plasmonic devices
- Quantum devices for information processing
- Spintronic devices
- Power electronics
- Electronics for harsh environment - automotive
- Electronics for harsh environment – space

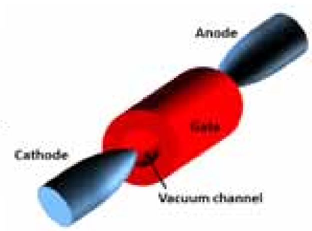
Emerging Research Devices (continued)

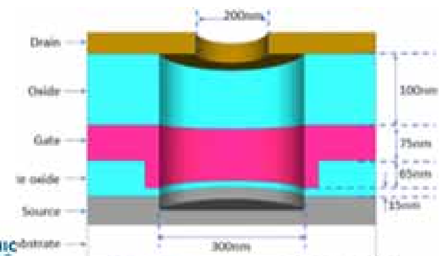
- - Sensor systems on a chip
- - Nanowire electronics
- - Carbon nanotube electronics
- - Graphene electronics
- - Phase change memory (both thin film and nanowire based)
- - Resistive random access memory (both thin film and nanowire based)
- - Ferroelectric memory
- - NEMS based memory
- - Molecular memory

Nanoscale Vacuum Electronics

- Advantages in speed, resistance to damage by extreme environment
- Recent efforts: reducing critical dimensions while using IC manufacturing techniques for wafer scale fabrication
- Limitations: low transconductance, ascribed to limited current density which is determined by work function and cathode electric field







Nanoscale Vacuum Electronics (continued)

- Difficult challenges and potential solutions:

Overcoming Child-Langmuir space charge limited channel current

- 1/ gap^2 dependence of channel current. In principle, gap can be in the tunneling regime (2 nm). Upper bound is still set by C-L limit.

Low voltage operation (1 V <) with enhanced channel current

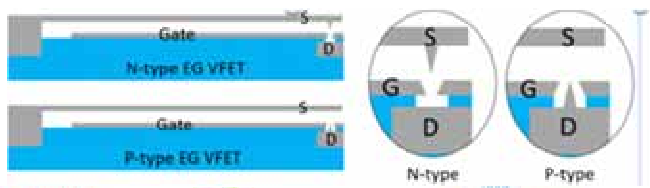
- surround gate helps with good electrostatic control and brings down the voltage

Availability of CMOS-like circuits for low standby power

Developing THz-range vacuum transistors and circuits

Complementary Devices in Vacuum Electronics

- Vacuum electronics is electron only, no p-type devices
- In the absence of holes, complementary operation is possible only if an external mechanism is combined with field emission. NEM-actuation of the gate to modulate the channel with the gate voltage is a possible mechanism.
- Recently proposed; complementary operation and circuits have been shown by simulation; fabrication pending.



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Flexible Electronics

Flexible/stretchable electronics is prime example of Heterogeneous Integration

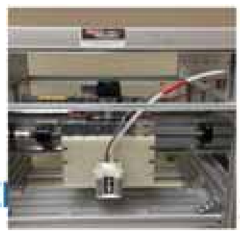
- Logic/memory electronics, sensors, actuators, antennas, RF devices integrated with data management capability and power supplies (potentially energy harvesters), energy storage devices and many others have been printed.
- Major advantages: very large functional devices; use and integration of extensive set of functional materials; wide range of substrates including flexible and stretchable; mass customization; rapid prototyping and iteration; low mass low cost devices.

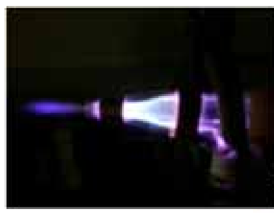
Flexible Electronics: Plasma Jet Printing

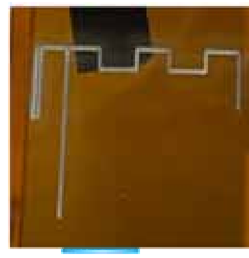
Challenges: Inkjet and Aerosol jet printing need annealing/sintering step to build up a consolidated thin film. Additional equipment, logistics, cost, print quality.

Plasma jet printing emerging as an alternative

- Does not need sintering; plasma enables "self-sintering" and gives films with good adhesion upon printing. Atmospheric pressure operation.
- When plasma is off, it is aerosol printing by default.

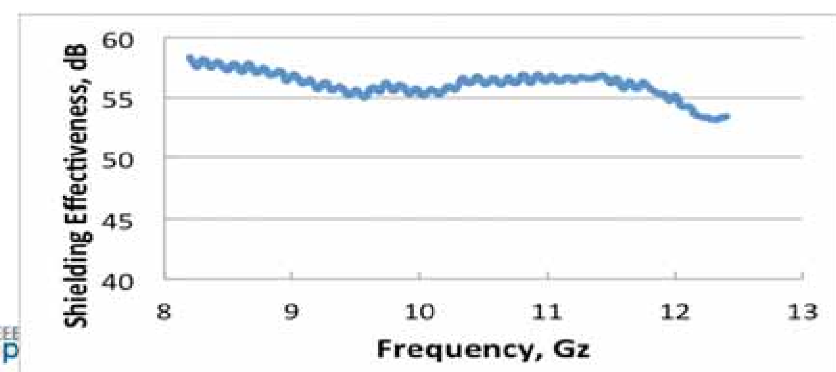






Printed Copper EMI Shield

- 3.75 µm printed copper film yields 56 dB average shielding effectiveness over the X-band.
- This gives an SSE of 1.67 x 10^4 dB cm^2/g
- Green Index is below 0.1, undesirable. Mixing with carbon materials can boost GI due to absorption mechanism.



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Flexible Electronics: Challenges

- Ink looks like the showstopper:

- **Very limited number of commercial inks**
- **Questionable quality, too many "unrevealed" ingredients and too much sintering trials to be done by customer for optimization**
- **Short shelf-life. Settles quickly in storage.**
- **Should become a commodity market soon to be cost effective**

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