
## What is Nanopackaging?

- Materials and processes at nanoscale for:
  - Interconnecting
  - Powering
  - Cooling
  - Protecting
    - Devices and Systems.

Leading to nano-packaged devices and nano-packaged systems with highest functionality at lowest cost in smallest size

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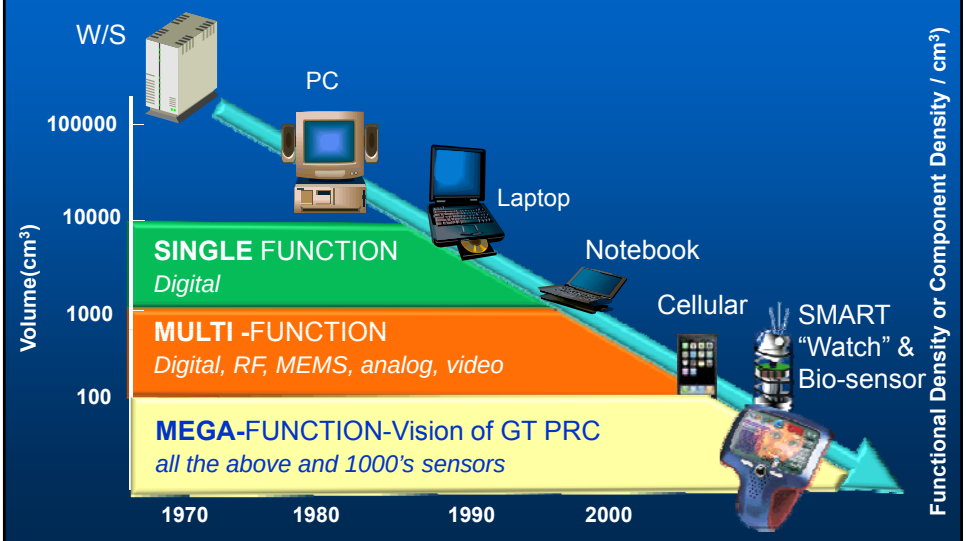
## Georgia Tech PRC Vision

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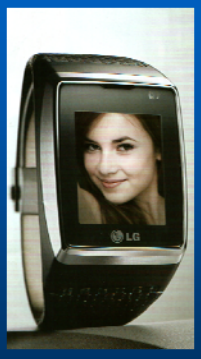
## Current Smart Systems

LG Video Phone Watch

- Featuring:
  - Full touch screen
  - Camera
  - Speaker
  - Bluetooth
- Bionic gadget can:
  - Play music
  - Take photos
  - Schedule appts
  - Read text messages
  - Make video calls



Apple's iPhone 4

- Featuring:
  - Multi-touch display
  - Dual cameras
  - Three-axis gyroscope
  - Camera and LED
- Bionic gadget can:
  - Play music, movies
  - Take photos
  - Record videos
  - Stream TV shows
  - Locate nearest Metro station in Paris
  - Over 200,000 applications

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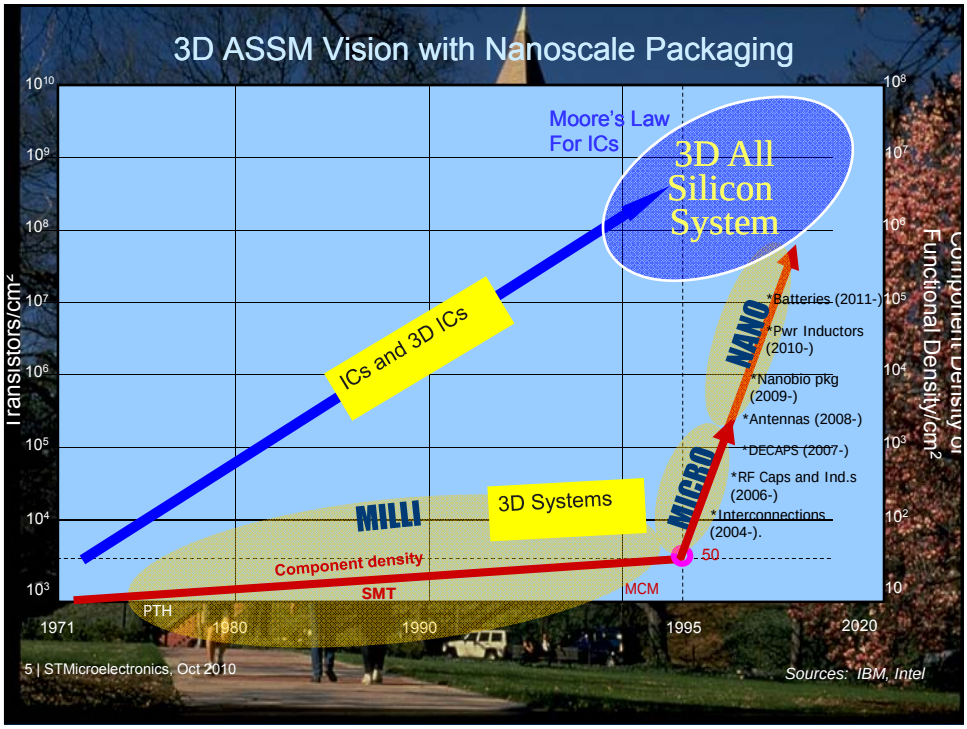
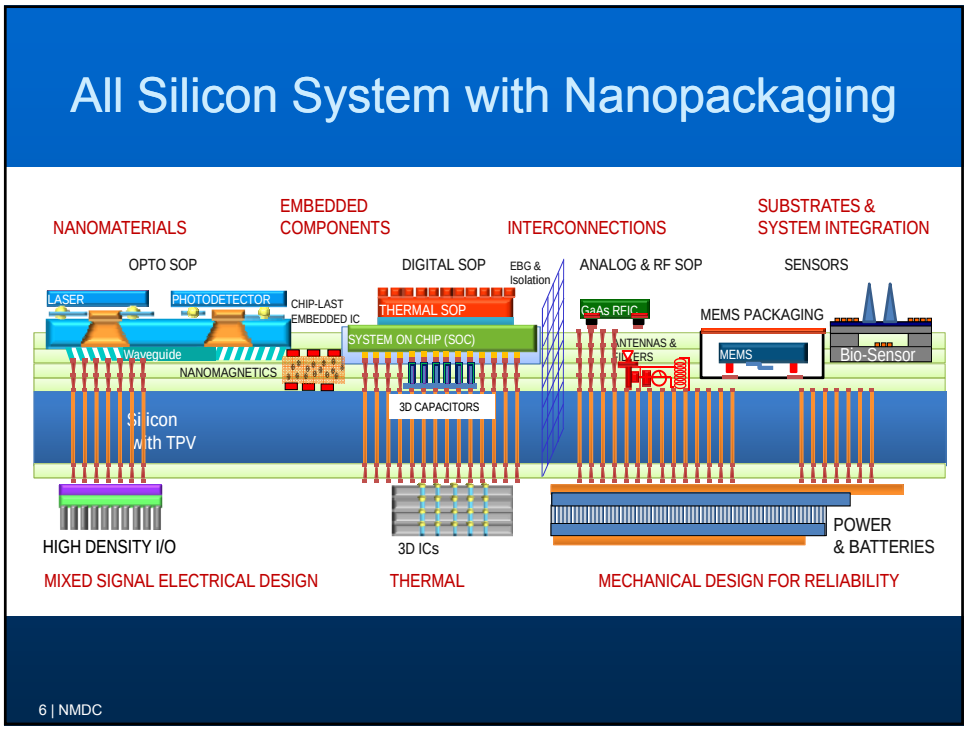

3D ASSM Vision with Nanoscale Packaging
Moore's Law For ICs
3D All Silicon System
ICs and 3D ICs
3D Systems
MILLI
MICRO
NANO
*Batteries (2011-)
*Pwr Inductors (2010-)
*Nanobio pkg (2009-)
*Antennas (2008-)
*DECAPS (2007-)
*RF Caps and Ind.s (2006-)
*Interconnections (2004-).
Component density
SMT
PTH
MCM
50
1971
1980
1990
1995
2020
Transistors/cm²
Component Density or Functional Density/cm²
5 | STMicroelectronics, Oct 2010
Sources: IBM, Intel


All Silicon System with Nanopackaging
NANOMATERIALS
EMBEDDED COMPONENTS
INTERCONNECTIONS
SUBSTRATES & SYSTEM INTEGRATION
OPTO SOP
DIGITAL SOP
EBG & Isolation
ANALOG & RF SOP
SENSORS
LASER
PHOTODETECTOR
CHIP-LAST EMBEDDED IC
THERMAL SOP
GaAs RFIC
MEMS PACKAGING
Waveguide
SYSTEM ON CHIP (SOC)
ANTENNAS & FILTERS
MEMS
Bio-Sensor
NANOMAGNETICS
3D CAPACITORS
Silicon with TPV
HIGH DENSITY I/O
3D ICs
POWER & BATTERIES
MIXED SIGNAL ELECTRICAL DESIGN
THERMAL
MECHANICAL DESIGN FOR RELIABILITY
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## Nano-Packaging Requirements

- Improved properties
- Miniaturization
- Low-temperature for organic packaging compatibility

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## 3D ASSM Strategy in Micro to Nanocomponents

- Power
  - High-density capacitors and inductors
  - Super-capacitors
  - Thin film batteries
- RF
  - Capacitors
  - Inductors
  - Antennas
- Digital
  - Capacitors
- Thermal
  - TIM (Thermal Interface Materials)
- Interconnections
  - Bonding layers: Adhesives and nanoparticle bonding layers
  - Nanoscale interconnections

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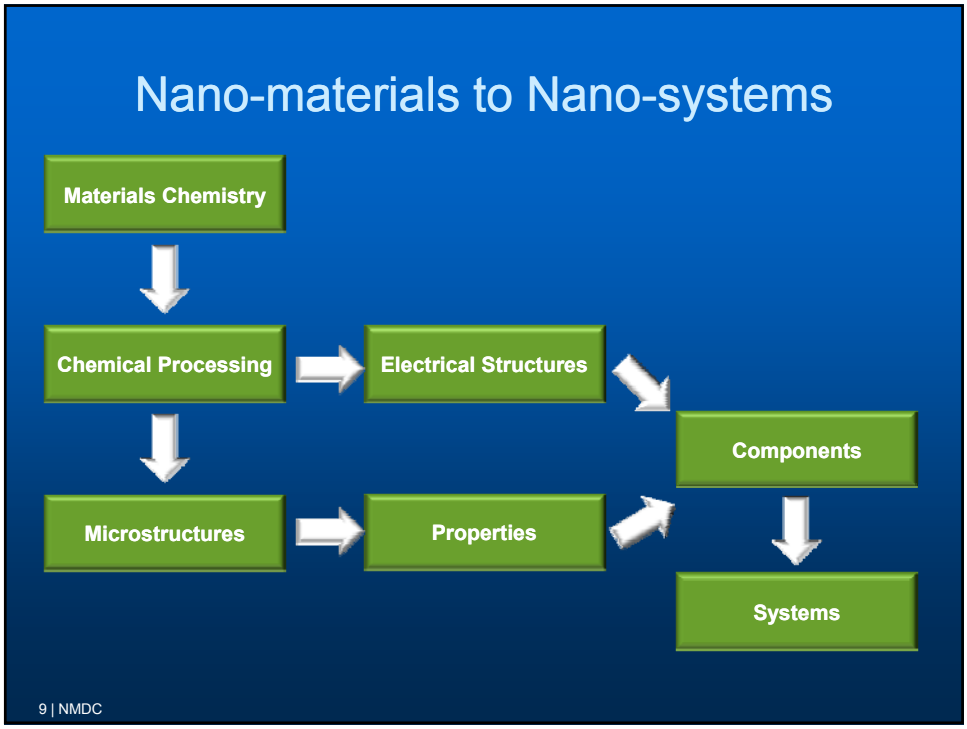


## Nano-packaging Strategy

| Function | Component | Goal |
|---|---|---|
| **Power Components** | ▪ High density capacitors<br>▪ High density inductor<br>▪ Supercapacitors<br>▪ Batteries | ▪ High surface area<br>▪ Thinner dielectrics or electrolytes<br>▪ Low-loss and high-frequency magnetic materials |
| **RF Components** | ▪ Capacitors<br>▪ Inductors<br>▪ Antennas | ▪ High K and μ<br>▪ Low loss<br>▪ Low TCC |
| **Digital** | ▪ Decoupling capacitors | ▪ Thinner dielectrics<br>▪ High permittivity |
| **Interconnections** | ▪ Bump<br>▪ Bonding layers<br>▪ Barriers | ▪ Low melting point<br>▪ Enhanced strength and fatigue resistance |
| **Reliability** | ▪ Hermetic coatings<br>▪ Encapsulants<br>▪ Adhesives<br>▪ Molding compounds | ▪ Moisture resistance<br>▪ Biocompatibility<br>▪ Hermeticity |
| **Thermal Structure** | ▪ TIM | ▪ High thermal conductivity<br>▪ Low CTE |

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## Power Supply Components

- Capacitors
- Inductors
- Supercapacitors
- Thinfilm batteries

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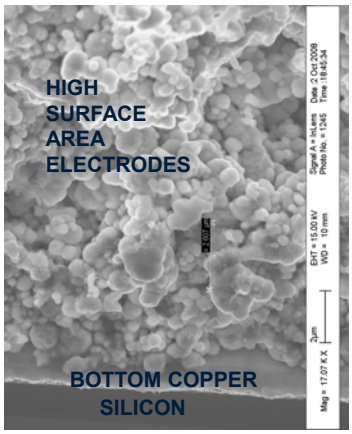
## Power Supply Capacitors

- Goal:
  - Voltage conversion:
    - Charge pumps
    - Linear regulators
  - Filtering power supply noise
  - DC blocking
- Approach:
  - High-surface-area electrodes
  - Conformal dielectrics
- Properties:
  - 50-100 uF/cm$^2$
  - 20 V
  - 1 uA/uF leakage
  - Integration in package




**Capacitance density: 30 uF/cm$^2$ ; Withstands 30 V;**
(GT-PRC)

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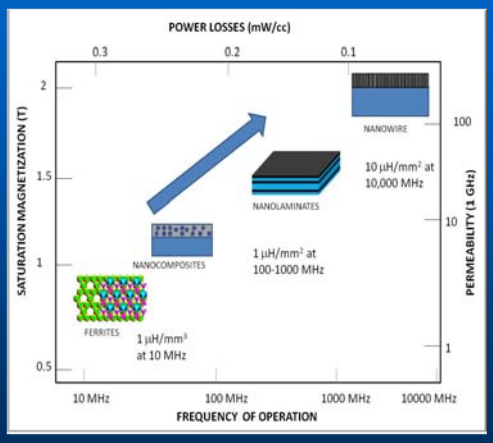
# Nanoscale Power Inductors

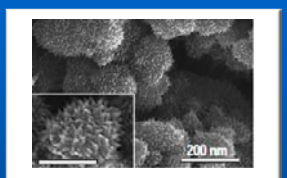
- Goal:
  - Inductors for Power convertors
- Approach:
  - Nano-layered or nanocomposite magnetic core for suppressed loses
  - Permalloy wires in polymer matrix
- Properties:
  - 1 mH/mm²
  - 50-100 micron device
  - 10-100 MHz



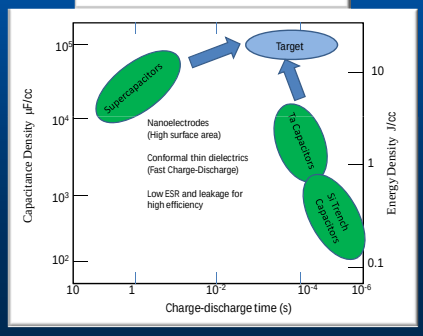



# Nanoscale Supercapacitors

- Goal:
  - Miniaturized components for:
    - Power boost in short duration
    - Power conversion
    - Pulsed power supply
- Approach:
  - High surface area oxide or CNT networks for volumetric efficiency
  - Novel designs and fabrication routes to eliminate the need for separator
  - Reduce the electrolyte thickness by 10-100X for faster charge and discharge
- Properties:
  - 500-1000 F/g
  - 100 mF/cm² for 100um thickness
  - Stable charge-discharge after 500,000 cycles

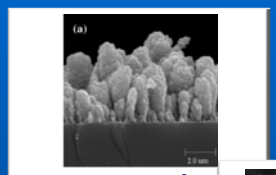



**Nanocomposite electrodes**
(Yushin, GT)

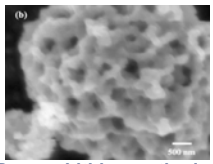


## Batteries

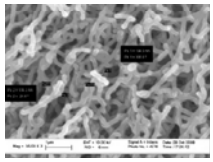
- Goal:
  - Thin film power source integrated in the package
- Approach:
  - Lithium intercalation with higher active surface area for fast electrode kinetics
  - Shorter diffusion lengths for rapid transport with Advanced electrolytes
  - Thin film packaging compatible for battery integration
- Properties:
  - Thin film and nano-batteries with 1 mAhr/cm² mm at 3 V (equivalent to 30,000 W hr/liter)
  - 1000-2000 mAhr/g



**Nano $SnO^2$**
(Meilin Liu, GT-PRC)



**Porous Lithium cathodes**
(Meilin Liu, GT-PRC)



**Si-decorated CNT**
(Jud Ready, GTRI – GT)

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## RF Components

- Capacitors
- Inductors
- Antennas

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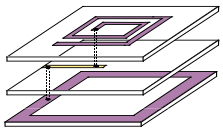
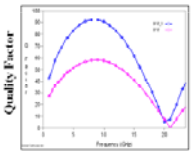
# RF Inductors

- Goal:
  - High Q and high-density inductors for:
    - RF filters
    - Oscillators
    - Matching networks
- Approach:
  - Multilayered design for high Q
  - Materials: Low loss dielectrics
  - Low-Cost Multilayered processes
  - Low-cost drilling, wet metallization
  - Thin form factors
- Properties:
  - 10-100 nH/mm$^2$ (50 microns)
  - Q of above 100
  - Frequency: 1-10 GHz



Inductor design

Inductor demo.




Q >100 of RF inductors

GT-PRC

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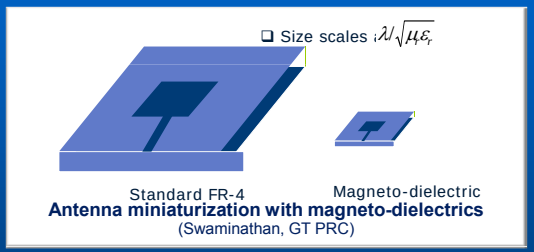
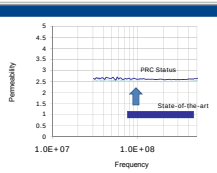
# Nanoscale Magneto-Dielectric Antennas

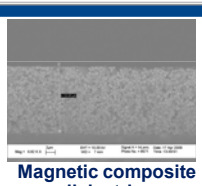
- Goals:
  - 1-10 GHz (ex. WiFi and WiMAX)
  - Size reduction by 10X
  - Enhance bandwidth and gain
- Approach:
  - Nanoscale magnetic composites
- Properties:
  - Frequency: 1-10 GHz
  - Permeability: 10-100
  - Permittivity: 5-15




**Antenna miniaturization with magneto-dielectrics**
(Swaminathan, GT PRC)




**GHz permeability demo. with polymer composites**
(GT PRC))



**Magnetic composite dielectrics**

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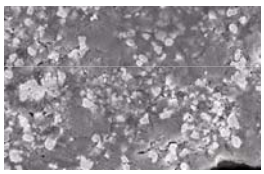
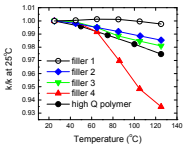
# RF Capacitors: Nano and Micro-polymer Composites

- Goal:
  - Components for RF
    - 10-100 nF/cm²
    - Q>200
    - Tolerance within 5%
- Approach:
  - Nanocomposite dielectrics
  - Oxides in Polymer matrix
  - Polymer (5-10) um and inorganic (1um)
  - Precision tolerance for size and thickness
-

| | Ferroelec | LTCC and Traditional RF dielec. | Nanocomp. |
|---|---|---|---|
| TCC ppm/C | 2000 | 50 | 50 |
| Perm. | 500-1000 | 2.5-8 | 10-80 |
| Loss | 0.08 | 0.001 | 0.001 |



**ε > 10, TCC 50 ppm/C; Loss 0.005**




**Filler chemistry selection to balance dielectric constant, Q and thermal stability**
(jin Hwang, Georgia Tech)

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# Digital Components

- Decoupling Capacitors

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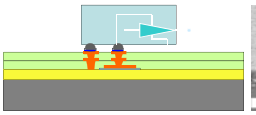
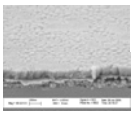
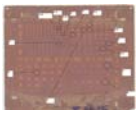
# Decoupling Capacitors

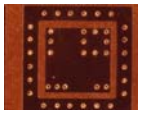
- Goals:
  - Noise-free power supply
  - Support high power ICs (higher current demands)
  - Support high bandwidth I/Os
- Approach:
  - Thin film capacitors integrated in organic build-up layers
  - Silicon integration with trench structures and conformal coatings
  - Design for low impedance
  - Design to route high-density I/Os
- Properties:
  - High capacitance density> 2 mF/cm$^2$
  - Low impedance (high Self-Resonance) in the GHz frequencies
  - BDV>20 V





**High K on Silicon; 100-200 nm** (GTPRC)





**High K on organic packages;**
**300-400 nm,** DuPont (left) and GTPRC (right)

**Trench capacitors in silicon**
**5 micron trench; 30-50 nm dielectric**

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# Printed Nanometal Wiring

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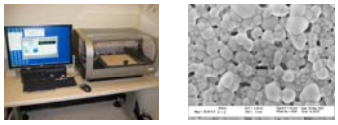
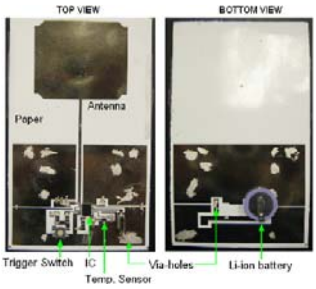
# Printed Nano-metal Wiring

- Goals:
  - Metal wiring with low-cost printing technologies on flex and roll-to-roll process
  - Organic compatible processing
- Approach:
  - Suspensions of nanosilver (5-50 nm)
  - Ink jet printing of nanosilver ink
  - Sintering at organic or paper compatible temperatures
- Properties:
  - T < 250°C
  - Conductivity close to bulk metal



**Silver sintered at 200°C**




**Ink-jet printed antenna on low-cost LCP and PET Flex** (Tentzeris, Georgia Tech)

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# Interconnections

- Conductive Adhesives
- Nanoscale Interconnections
- Nanoparticle Bonding

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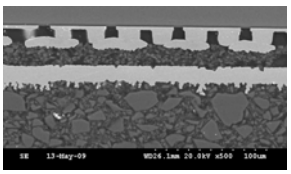
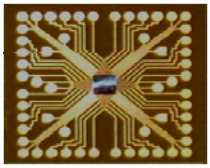
# Fine-pitch Interconnections with NCF & n-ACF

- Goals
  - Fine Pitch (30 micron) interconnections using NCF
  - 10X reduction in pitch compared to flipchip
  - 150 C assembly
  - Embedding in organic packages
- Approach:
  - Copper bumps
  - Bonding with NCF
- Properties:
  - Contact resistance < 10 milliohms
  - Reliable interconnections:
    - 1400 cycles TST (-55 to 125)
    - 175 C, 72 hours HTS
    - 192 hrs, HAST



IC Embedding with Cu bump and Chip-Last; Cross-section



IC Embedding, Top View

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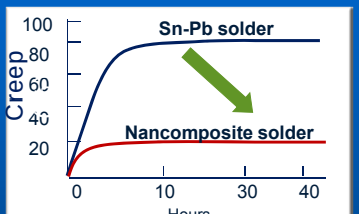
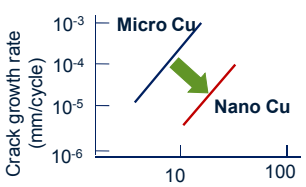
# Nanoscale Interconnection Materials

- Goal:
  - Flipchip assembly for next-generation nano and 3D ICs
- Approach:
  - Nanocopper bump
  - Nanocomposite solders
  - Advanced Barriers
- Properties:
  - Current handling 106 Amp/cm$^2$
  - Enhanced creep and fatigue resistance
  - Enhanced strength
  - Fine pitch capability with WLP: 50-100 microns




creep resistance for traditional solder vs nanocomposite solder




Fatigue resistance for micro and nanocopper

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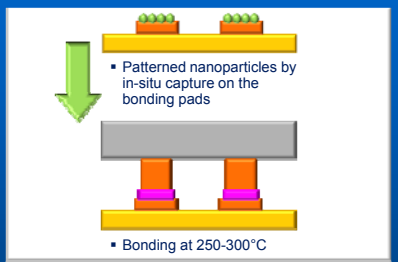
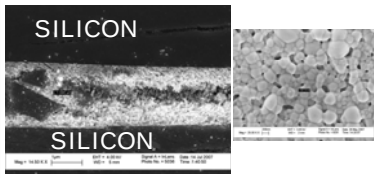
# Nanoscale Bonding Layer

- Goal:
  - 3D IC assembly and interconnections with:
    - Pitch less than 20 microns
    - T < 250 C
    - Solder-free for reliability, fine-pitch and low-cost process
- Approach
  - Patterning nanoparticles
  - Low-temperature Cu pad-to-pad bonding
- Properties:
  - Sintering at T < 250°C
  - Conductivity approaching that of bulk metals
  - Flipchip infrastructure compatibility




- Direct capturing of nanoparticles on bonding pads
- Bonding at low temperatures with gold, silver and copper nanoparticles

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# Thermal Interfaces

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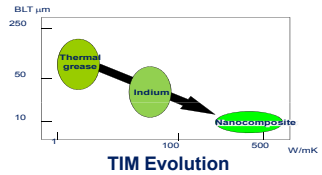
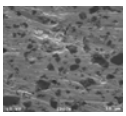
# Nano-materials for TIM

- Goal:
  - Thermal management in:
    - High-power PCs and workstations
    - Miniaturized 3D mobile systems
- Approach
  - Advanced thermal adhesives with nanoflakes
    - Metal nanocomposites as TIM
    - CNT-based TIM
- Properties:
  - Thermal resistance less than 0.01°C cm²/W
  - Reliability with thin layers (<10 microns)
  - CTE compatibility with Si and heat sink




**TIM Evolution**



**Indium-graphite composites**
(Reddy et al., GT-PRC)

**CNT Transfer** (CP Wong, GT)

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# Reliability

- Nano-composite for Electronics
- Packaging for Biocompatibility
- Nanomaterials for Bioelectronics

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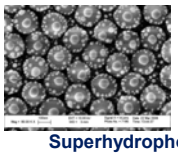
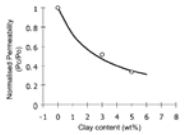
# Nanocomposites for Reliability

- Goal:
  - Enhance polymer composite properties for:
    - Adhesives
    - Underfills
    - Molding compounds, Encapsulants
    - Coatings
- Approach:
  - Hybrid organic-inorganic materials for improving CTE, Tg and modulus (thermomechanical properties)
  - Nanocomposites for low moisture permeability
  - Surface modification for hydrophobicity for low moisture permeability
- Properties:
  - Process compatibility for 5-10 micron clearance and pitch
  - CTE: 10-20 ppm/C; TG>250 C;
  - Contact angle > 160°
  - Low moisture permeability



**Superhydrophobic Surfaces**
**Contact angle > 160 ° ; Low adhesion**
**Nanostructured morphology**
(C P Wong, GT PRC)


**Clay–polymer nano-composites**
(Azom.com)



**Water permeability as function of filler content**
(Chugang Hu, Jang-kyo kim, HUST)

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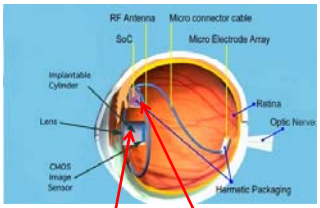
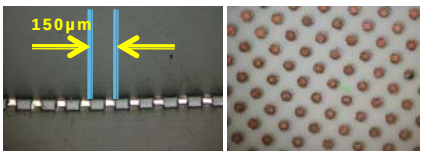
# Bio-compatible and Hermetic Packaging

- Goals:
  - Hermeticity in water or saline environment
  - Biocompatibility with tissue interface
- Approach:
  - Biocompatible polymers such as LCP and paralyne
  - High-density packaging with hermetic metal-polymer interfaces
  - Hermetic coatings
- Properties:
  - Sealing with low leak rates
  - 1000 feedthroughs in 5 mm x 5 mm




**Intraocular Camera** **Retinal Prosthesis**




**1000 Channel Feedthrough Array with <$10^{-9}$ leak rates**

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## Summary

- 3D ASSM is about highest functionality at lowest cost in smallest- size system, enabled by
  - Silicon for devices, packages and boards
  - Components at nanoscale
- Silicon interposers and packages underway to enable this vision with low cost panel-based Si
- Nanoscale component research is underway for
  - Digital
  - RF
  - Power
  - Thermal
  - Encapsulation

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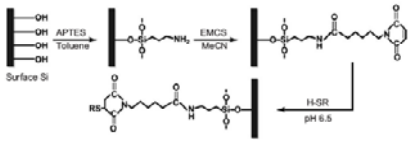
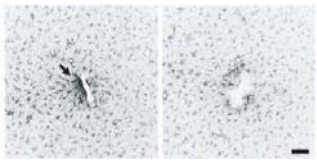
# Nanocoatings for Neural Interface Compatibility

- Goal:
  - Enhance stability of implanted electrodes to improve reliability and life-time
- Approach:
  - Immobilize anti-inflammatory coatings on the electrode surface
  - Coat with molecules which enable tissue integration
- Properties:
  - Suppress inflammation and tissue scar formation at the interfaces




**Anti-inflammatory Coating on silicon electrodes** (Ravi Bellamkonda, GT )



**Modulated Neural Interfaces**
**Modulation of scarring around implanted electrodes using coating**

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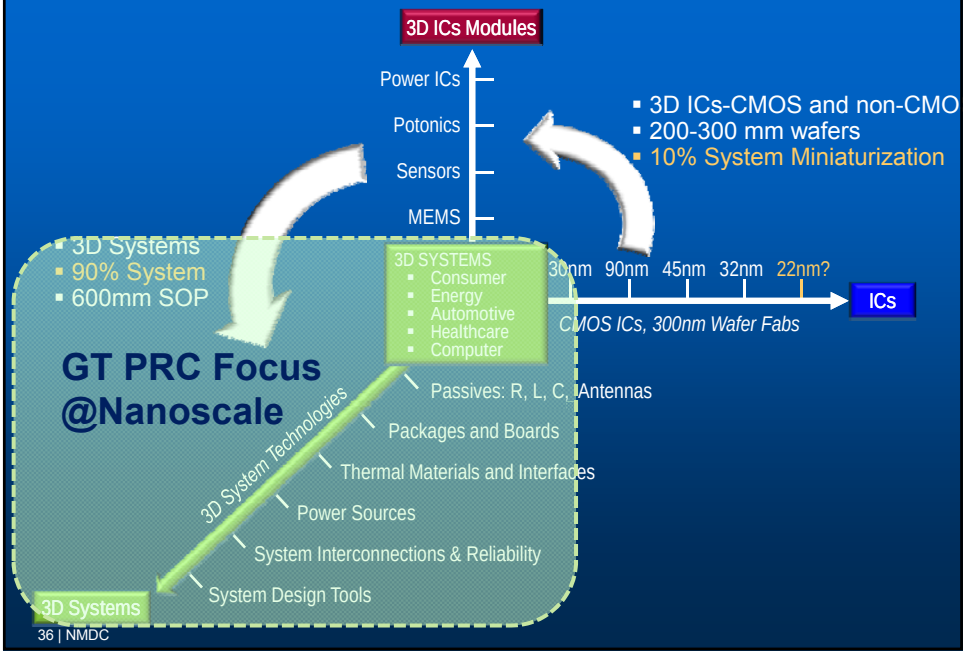
# Georgia Tech-PRC Vision of 3D Systems

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