# Materials Integration for CHIPS

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Henry Samueli School of
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Birthplace of the Internet



# Materials Science and Engineering: Research and Future Directions

### **Top Tier Efforts in:**

– 21<sup>st</sup> Century Society Challenges:

### **Energy and Infrastructure: New Solutions through Novel Materials**

DOE EFRC Molecularly Engineered Energy Materials; Perovskite and polymer solar cell, Integrated solar cells, porous media, nanocatalysts, hydrogen storage, computational materials, biofuel cells, 3-D batteries

### Electronics and Information Technology: Materials Beyond the Roadmap

Interconnects and packaging, quantum wires, heterogeneous materials integration, graphene, nanodots, dielectrics, nanomagnetic materials, polymer memory

### **Bio-inspired Materials: Nano-Engineering with Nature**

Virus-based nanoarchitecture assembly, biomolecular and bio-hybrid materials, electroelastomer muscles...

ArchaeoMaterials

Conservation, ancient materials and societies

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## Materials Science and Engineering

2015 QS World University Rankings: 16<sup>th</sup>



2007 – 2013
Research Funding Expenditures

2006 - 2007	\$5,089,711
2007 - 2008	\$6,210,320
2008 - 2009	\$5,523,285
2009 - 2010	\$6,252,166
2010 - 2011	\$7,746,634
2011 - 2012	\$7,015,862
2012 - 2013	<b>\$7,886,133</b>
Total	\$45,724,110



# UCLA CHIPS

#### Applications & Architecture

Heterogeneous Systems
Fault Tolerance
Supply chain Integrity
Security
Memory Subsystems
Processing in Memory
DFT
Network on Board

#### Design Infrastructure

Thermo-Mechanical Electrical Tools

#### **Tier 1 Equipment Partners**

New Tool Concepts Tool Development Scale-Up

### Integration

A processing facility for Interconnect Fabric (IF)

- ·Silicon processing
- ·Glass
- Flexible substrates
- Additive manufacturing
- •Thermal compression bonding •Wafer thinning

### Devices/Components

Fine Pitch Interconnect

Substrate Materials

Warpage, Stress

Flexible Materials

Thermal solutions

Mfg. Reliability

Materials for Additive

Materials

Novel witches
New memory
MEMS
Sensors
Passives, antennae
Medical devices

### **Tier 1 Foundry Partners**

Si, Compound Semis,

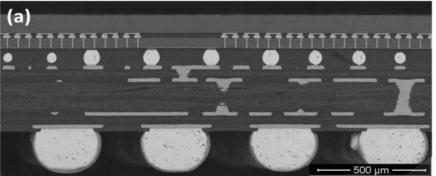
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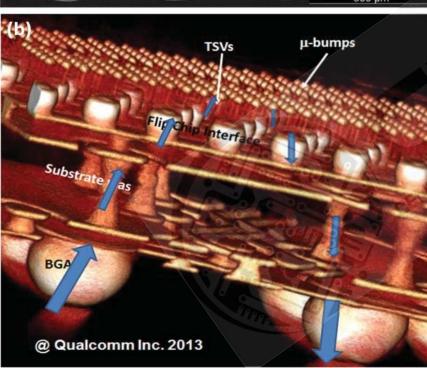
## 3D IC Packaging Reliability Research K. N. Tu, Dept. MSE, UCLA



(a) SEM image of cross-section of a stacking of two Si chips, on the top side.

The lower Si interposer chip has TSV.

There are three levels of solder joints; BGA, C-4 joint, and  $\mu$ -bump.



(b) Synchrotron radiation tomography of the 2.5D IC structure shown in (a).

The blue arrows indicate the path of applied current in electromigration study.

Yingxia Liu, et al, "Synergistic effect of electromigration and Joule heating on system level weak-link failure in 2.5D integrated circuits," J. Appl. Phys., **118**, 135304 (2015).

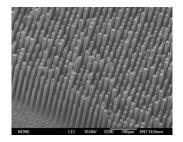
ECTC 2015 Intel best student paper: Yaodong Wang "Size Effect on Ductile-to-Brittle Transition in Cu-Solder-Cu Micro-Joints"



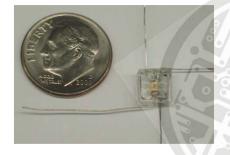
### 3-D Batteries: A New Direction for Portable Power

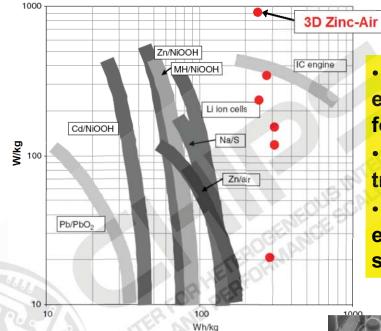
Bruce Dunn, MSE, UCLA

High aspect ratio Zn arrays



3-D Zinc-air microbattery



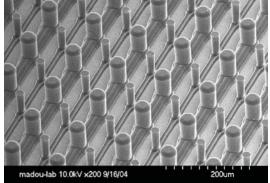


3-D battery architectures

- Maximize power and energy density in small footprint area
- Maintain short ion transport distances
- Micromachined electrodes for precise spatial control

Lithium-ion secondary battery

- Interdigitated design
- Alternate rows of carbon and polypyrrole rods





## Thermocompression Bonding: Cu and Au

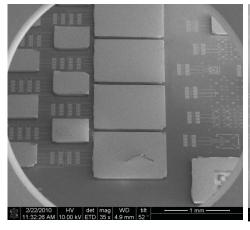
 Grain evolution, bonding and electrical integrity



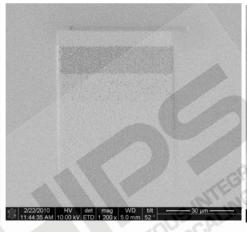


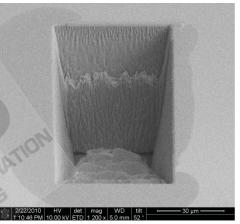


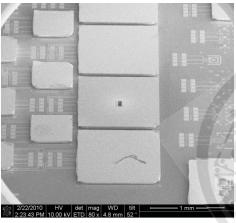
## FIB / Microscopy of interfaces

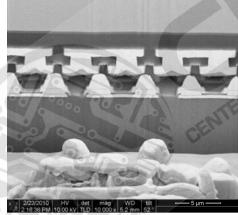


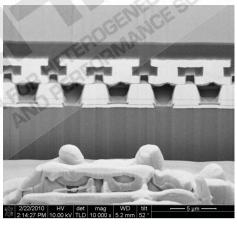


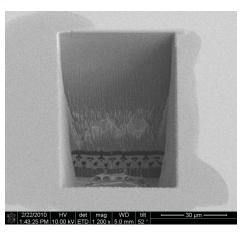






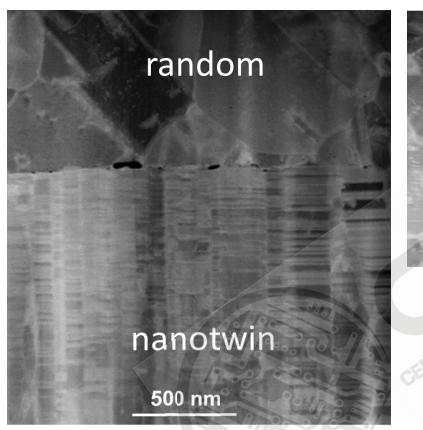


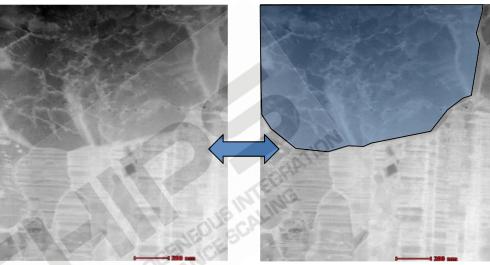


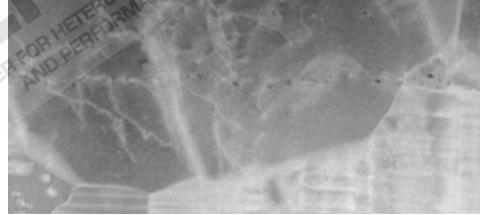




### TEM of Bonded Interfaces: Nanotwin



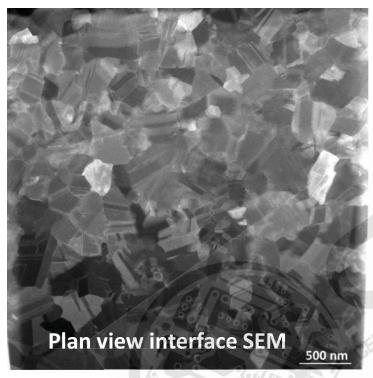


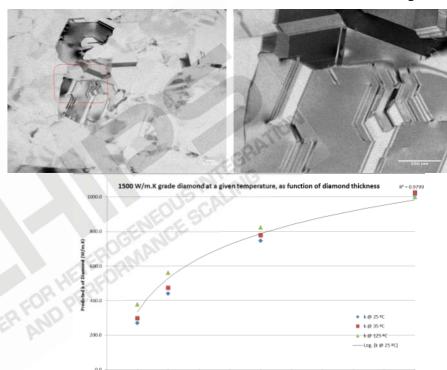


 Conditions for nanotwin transformation: Grain orientation



# Novel Diamond Materials for Fundamental Thermal Understanding and Round Robin Measurement Study





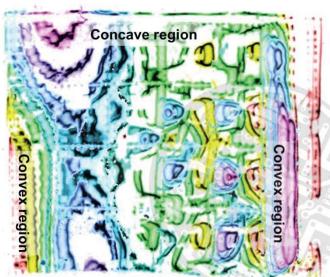
 Role of nucleation layer, grain size, dislocations unknown for thermal performance



### Warpage / Stress Assessment & Thinning

X-ray diffraction imaging Quantify strain / stress through imaging techniques to determine strain in bonded chips

-300" -150" 0" +100" +150" +200" +300" +400"



Wafer grinding
Cracks, breakage
Etching

Stress introduced in thinning procedure

Importance of damage-removal etch
Diffraction imaging and HRXRD to assess
effectiveness of grind & etch

TEM showing grinding damage in thinned chip

2mm





### **MSE Summary**

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#### Materials

Fine Pitch Interconnect Substrate Materials Warpage, Stress Flexible Materials Thermal solutions Materials for Additive Mfg. Reliability

#### Devices/Components

Novel switches
New memory
MEMS
Sensors
Passives, antennae
Medical devices

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