IBM Research and the Electronics Ecosystem

IBM Research
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Agenda

- Introduction to IBM Research
- Why is IBM involved in so much stuff?
- BRL
- Smarter Devices Group
- How does Nanotechnology fit in?
What is IBM Research?

- IBM Research is the world’s largest industrial research organization with 3400 employees at 11 labs worldwide including China, USA, Japan, Israel, Switzerland, India, and Brazil
- Number 1 in US patents in the last 18 years. $1.2B impact on IBM Business from IP, $6B in investments in R&D ($1.0B in R).
- IBM researchers include:
  - Approximately 1500 PhD’s
  - 5 Nobel laureates
  - 4 US National Medals of Technology
  - 3 US National Medals of Science
  - 19 US National Academy of Sciences members
  - 46 US National Academy of Engineering members
- Engagement mechanisms include JSA, JDA, ODIS, FOAK
IBM Research Overview

Famous for its science and technology and vital to IBM

- Almaden 1955
- Watson 1956
- Austin 1961
- Zurich 1972
- Haifa 1995
- India 1998
- Tokyo 1982
- Brazil Jun 2010
- Australia R&D Lab Oct 2010

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Globalization

Research in the Marketplace

Collaborative Innovation

Joint Programs

Centrally Funded

IBM Research has about 3000 Researchers in 10 Labs Worldwide

Each lab leads in selected areas, and collaborates closely with Researchers world-wide, leveraging top scientists at each lab.

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2011 US Patents Issued - 19 consecutive years of leadership

IBM

Microsoft
HP
Intel
Oracle/Sun
Apple
EMC
Accenture

6,180
2,312
1,308
1,244
918
676
275
127

76% Software and Services

>4X

>9X
Diversity of Disciplines at IBM Research

- Behavioral Sciences
- Chemistry
- Computer Science
- Electrical Engineering
- Materials Science
- Mathematical Sciences
- Physics
- Service Science, Management & Engineering

- Technology Innovation
- Business Innovation
- Social Innovation
- Demand Innovation
- Social & Cognitive Sciences
- Economics & Markets
Pioneering Materials for Making HP Chips (15 nm node)

HP processor chips require
• **photoresists** for lithographic processes to define the fine lines and
• **organic insulators** with low dielectric constants (“low-k” and “ULK” = ultra low-k) between Cu conductors

Both materials must be of **high purity** (ppb level) and of very **high performance**

IBM developed **nano-structured polymers** (“block-copolymers” which **self-assemble** to complex but designed patterns

IBM also defined **mechanisms** that exclude metal in the catalysts

This experience in chemistry and materials translates well to materials in healthcare, energy, and sustainability!
The Path to Membrane Technology

Polymer Research @ Almaden
Leverage strength in Chemistry, Polymers, Characterization and Computational Chemistry

Collaborative partnerships enable breakthroughs in technology and new adjacent areas

Core technology

Experiment

New Functional Materials

Computation

Lithography  Low-k dielectrics  Data storage

Energy  Catalysis/Green

Adjacent technologies

Nano-membranes  Bio-compatible Polymers

EUV Resist (20nm lines)  Nanomembranes  DSA w/ Block Copolymers  PET
**Nano-membranes**

Non-fouling, high performance nano-structured membrane architecture for anti-fouling coatings, wastewater treatment or desalination.

- *High salt rejection*
- *Higher throughput than conventional thin film membranes*
- *Effective in removing higher levels of difficult to remove elements such as Boron & Arsenic*

**Targeted Applications:**

- Antifouling coatings
- Reverse Osmosis membranes
- Nanofiltration membranes
Developing New Areas from Core Expertise
Developing New Areas from Core Expertise
**IBM Research - Brazil (BRL)**

- **Four Research areas**
  - SMARTER NATURAL RESOURCES: discovery, logistics, sustainability, safety
  - SMARTER HUMAN SYSTEMS: technologies for large-scale events
  - SMARTER DEVICES: advances in semiconductors & mtl
  - SERVICE SYSTEMS RESEARCH: service systems, technology, mgmt

- **How does it work**
  - Build local expertise in 4 areas
  - Access point for leveraging world-wide IBM Research technologies and expertise
  - Differentiation for customer engagements in Brazil and Latin America
Smarter Devices

Servers
Data Analytics
Services
etc.

Smarter Planet
• consumer
• mobile
• IoT

Growth markets

Global markets
Smarter Devices

- Support Brazilian government’s focus on growing a microelectronics ecosystem: *semiconductor manufacturing capacity being built*

- Work with Brazilian key industries in various hardware and materials areas where IBM has expertise: **Focus on sensors with Brazilian and international partners with aim to support ecosystem integration.**

- Work with IBM labs worldwide to leverage expertise.
Smarter Devices - Status

- Support Brazilian government’s focus on growing a microelectronics ecosystem: **semiconductor manufacturing capacity being built**
- Work with Brazilian key industries in various hardware and materials areas where IBM has expertise: **Focus on sensors with Brazilian and international partners with aim to support ecosystem integration.**
- Work with IBM labs worldwide to leverage expertise.
- Building up personnel resources (since April)
- Setting up collaborative research projects
  - with commercial entities
    - in Brazil and
    - in rest of the world
  - with academia
- Projects with short and long term commercialization prospects
A Functioning Microelectronics Ecosystem

Each circle describes an industry or sub-industry component.

Ecosystem is connected by supply chain built on standards and a common roadmap.
The Brazilian Microelectronics Ecosystem

A subjective view of the ecosystem.

Over the past years improvements in
• Semiconductors
• Packaging
• Design

Areas that require attention:
• Teaching & Research in:
  - Packaging
  - Assembly
• Administrative barriers to supply chain
Ecosystem

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- **Projects with short and long term commercialization prospects**
Making High Performance Chips (15 and 10nm nodes and beyond)

10/15 nm nodes require

- **photoresists** that define gates in the semiconductor and fine metal lines at the nano-scale in the

- **low dielectric constant semi-organic interlayer dielectric (ILD).**

- Materials must be of extremely high **purity** (ppb level)

Issues w/10/15 nm nodes

- At small size scale doping levels in semiconductor become non-uniform

- Quantum effects play an increasingly important effect leading to large leakage currents requiring Å thick liners

Silicon will have to be replaced in order to miniaturize further!
Why do we need to go Beyond Silicon?

- Approaching atomistic and quantum-mechanical boundaries
- Atoms don’t scale

Major transistor innovation is becoming mandatory at every new generation
**One Option Beyond Silicon: CNTFET**

- **Local bottom gate geometry**

  - Pd source/drain
  - 3 nm HfO₂ (EOT ~ 0.65 nm)
  - W embedded gate

**Energy efficiency** is the most significant challenge standing in the way of continued miniaturization of electronic systems,

- **Miniaturization** is the principal driver of the semiconductor industry.

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Ion at Vdd 0.5V and Lg ~ 10nm
- ET ~ 41 μA/μm
- Fin ~ 138 μA/μm at 20nm Fin pitch
- Wire ~ 300 μA/μm at 20nm Wire pitch
- CNT ~ 630 μA/μm at 5nm CNT pitch
CNTFET Material Challenges: Separation

- What is needed?
  - Single-walled CNTs can be metallic or semiconducting
    Statistically: \( \sim 66\% \) semiconducting
    \( \sim 33\% \) metallic
  - Example high-density integration scenario:
    1 billion transistors on chip
    \[ \times 3 \text{ CNTs per transistor} \]
    \[ 3 \times 10^9 \text{ CNTs/chip} \]
    Ideally less than 1 metallic in \( 1 \times 10^9 \) semiconducting CNTs
    \( \rightarrow \) Many 9’s purity needed: \( > 99.9999 \% \)

- Why is this difficult?
  - Bundling
  - Very high purity needed
CNTFET Material Challenges: Placement

- What is needed?
  - Dense arrays of CNTs
  - 100-200 CNTs/μm
  - Consistent pitch
  - Parallel

Comparison to projected minimum finFET pitch:
CNTFET Material Challenges: Placement

Why is this difficult?
- Bundling
  - Strong Van der Waals interactions
  - Must wrap CNTs with something else to keep from bundling
- Selectivity
  - Depends strongly on solution CNTs are dispersed in
- Rigidity
  - CNTs are non-rigid (like al dente pasta noodles)

Target:
- 5-10 nm
- 100-200 CNTs/μm
Nano-science in other Electronics Areas

- Nano-technology used not only in device research

- Some facts
  - Since 2002: Chip performance has stopped to drive systems performance; packaging has picked up that role
  - Since 28nm bulk Si: Chip – Package Interaction (CPI) dominating ability to use chips

- What is the (electronic) package?
What is Electronic Packaging?

Basic HW Elements / Components

Supply chain important to advance device nodes but also to advance packaging
What is Electronic Packaging?

Interconnect Materials

- BGA (organic)
- Pins (ceramic)
- LGA
- TIM2
- Flip-Chip
- Underfill (UF)
- TIM1
- C4s: solder balls
- Substrate
- Printed Circuit Board
What is Electronic Packaging?

Function of the Package

- Signal to / from chip
- Power supply
- Space translation
- Cooling
- Reliability / robustness (Chip-Package Interaction (CPI))
Chip-Package Interaction

Stress Generation in Organic Packages
Origin of CPI Problem

Flexibility of substrate

- Thick core FCPBGA
- Ceramic
- Oxide
- Low k
- ULK
- ELK

Cohesive strength of the dielectric (ILD)

C4 Stiffness

- Thin core FCPBGA
- Pb Free
- Pb

Feature size decreases

Time / Technology Node

Coreless

end
Consequences of CPI Stress

- Highest stress in corners leads to BEOL delamination and / or UF delamination and / or white (ghost) bumps
Managing CPI Stresses using Underfills (UFs)

- UFss are complex composites of epoxy with near theoretical maximum filler content with sizes from ~ 5 um to 100 nm.
- Once UF fails package / device fails
- Stress in UF calculated using FEM (finite element modeling):
  - State of stress around C4s can not be modeled except for individual solder balls
- Can we experimentally access the strain in UFss?
  - Benefits:
    - Validation of FEM would allow “virtual” qualifications saving much money ($ millions!)
    - Experimental data would allow to improve models
The stress environment of carbon nanotubes (CNTs) can be quantified from shifts in the second order disorder band detected through Raman spectroscopy.
Challenge: Dispersion of CNTs

Poor CNT/Epoxy Dispersion
- Large van der Waals forces hinder dispersion

Leads to sparse CNT Raman signal and noise
- non-uniform strain map
- Raman signal correlates poorly to local strain

Non-Covalent Functionalization

SWCNT Bundles, Polymer and Solvent
High Energy Sonication
Polymer Wrapped SWCNT Dispersion

Good CNT/Epoxy Dispersion
Challenge: Homogenously Distributed CNTs under Chip

Non-uniform

Uniform

Rheology: Bingham Plastic

< critical stress = solid

>> critical stress = Newtonian

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Results

- Qualitative agreement with FEM
- Magnitude of FEM strain is lower than CNT measured strain – some UF properties differ

FEM Data

Empirical Data

Organic Package

Diagonal Cross-section

- Tensile, ~Symmetric, $\sigma_{yy}$ $\sim$ $\sigma_{xx}$

Center $\%\epsilon_{xx}$ and $\%\epsilon_{yy}$
- Tensile and $\sigma_{yy} \sim \sigma_{xx}$

Lateral Distribution
- $\%\epsilon_{xx}$
  - Tensile and ~Symmetric
High Resolution Raman Mapping Captures Local C4 Stress

- **FEM**
  - Stresses Approximately the Same Throughout Underfill Region ~0.18%
    - Deviations ~300μm from Edge (see inset)
- **Raman**
  - Average Tensile Strain in Corner Region ~0.6% (Qualitative Agreement w/ FEM)
    - Same as Center (Previous Slide ~0.6%)
    - Strain Decreases Near Edge
  - Concentration of Stress Around C4 Region
    - FEM Does Not Account for C4s

![Raman Map](image)

- Optical Micrograph 50x
- Percent $\varepsilon_{yy}$ Strain Map
- Percent $\varepsilon_{xx}$ Strain Map
- $\%\varepsilon_{xx}$ ~2x Res

1/4 Symmetry

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Summary

- Micro- and nano-electronics is an exciting field for basic and applied research
- To support a healthy ecosystem for Brazil many areas need to be addressed
- BRL is involved in addressing some of these topics
- BRL is undergoing rapid growth in our key areas of technology, data analytics, and service science based on
  - world-wide collaboration
  - flexible collaboration arrangements
  - proven technology
  - world-class innovation
- IBM Research is always looking for synergies with key partners
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