MSE 5420
Flexible Electronics

Lecture 2
Tuesdays and Thursdays
11:40 am to 12:55 pm
Bard 140
Discussion

• What did video show?

• Showed chip processing in simple terms - then considered “packaging”

• Improvements will be needed to get higher performance

• Used to be considered less important, but now package is bottleneck in many electronics

• Advances in packaging are basis of new flexible electronics!
What Is Packaging?

Or What Do Electronic Devices Need To Do?

• Chip/Circuit Protection
  – Environmental, thermal, mechanical

• Communication
  – Maximize I/O

• Power

• Heat removal
  - Forced or natural convection
  - Wiring structure and power interconnects
Areas of Greatest Potential Impact

- Advanced medicine - Brain sensors
- Point-of-care medicine - remote wound monitoring
- Public health - Water purity monitoring
- Civil infrastructure - bridges
- Precision agriculture - improving wine production
Point of Care Medicine
Water Sensor

a) Sensor Sheet

b) Spiral Configuration

c) Monitoring

Large Sample Volume
≥ 1000 liters
EKG based Brain Computer Interface

- Miniaturization
- Flexible
- More electrodes
- On-board electronics
- Improved sensitivity & spatial resolution

Wolpaw, et al., Wadsworth Center
Accurate Brain Function Mapping

Retinal Implants

✓ Millions world-wide suffer severe visual impairment
  -- inborn visual deficits
  -- accident
  -- disease
    macular degeneration -- diabetes
    retinitis pigmentosa
    neovascular disease

✓ Must conform to surface geometry of eye

✓ Stimulate optic nerve
Retinal Implants

There is still a great deal to do

Implanted on retina

http://www.rehab.research.va.gov/cent/boston.htm
Precision Agriculture
Sensor Locations at Fox Run Vineyards, Penn Yan, NY
Concept - Embedded sensors in the vine trunks that can monitor the dynamic variations in water stress continuously.

Wireless reporting to provide real-time data in relation to environment and other factors is needed.
What do we need?

- Connection of different components
- Communication to and from device
- Power source
- Better interface to and protection from environment
- Sounds like packaging
Packaging vs. Microelectronics

• Rivals microelectronics in terms of industry size and complexity
• Critical bottleneck in device speed
• Sets size and capability of electronic device
• Determines cost of device
The Package

Each level needs to meet goals of package
Levels of Packaging

- 1\textsuperscript{st} Level – chip on substrate
- 2\textsuperscript{nd} Level – card
- 3\textsuperscript{rd} Level – card on board

- packaging getting as sophisticated as microcircuit
- how will we categorize package for flex?
# Packaging Technologies

<table>
<thead>
<tr>
<th>Technology Function</th>
<th>Technology Options</th>
<th>Typical Materials</th>
<th>Typical Process</th>
<th>Typical Process Temp °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connection to Chip</td>
<td>Wirebond</td>
<td>Gold, Aluminum, Pb–Sn, Copper, Gold, Aluminum, Polyimide</td>
<td>Wirebond</td>
<td>225</td>
</tr>
<tr>
<td></td>
<td>Solder Bond (C4) TAB</td>
<td>Reflow, Thermo-compression</td>
<td></td>
<td></td>
</tr>
<tr>
<td>First-Level Package</td>
<td>Ceramic</td>
<td>$Al_2O_3, SiC, BeO</td>
<td>Sintering</td>
<td>1,500–2,000</td>
</tr>
<tr>
<td></td>
<td>Plastic TAB</td>
<td>Epoxy, Cu on Kapton®</td>
<td>Molding</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adhesive-Bond</td>
<td></td>
<td></td>
</tr>
<tr>
<td>First-To-Second-Level Connection</td>
<td>Surface Mount Solder</td>
<td>Pb–Sn, Kovar, Pb/Sn, Kovar, Au/Sn</td>
<td>Reflow</td>
<td>220</td>
</tr>
<tr>
<td></td>
<td>Pin-In-Hole-Solder</td>
<td>Reflow</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pin-Braze</td>
<td>Braze</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Second-Level Package</td>
<td>Card</td>
<td>Epoxy–Glass, Glass on Steel, Invar, Cu on Kapton® Resin</td>
<td>Cure</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>Metal Carrier</td>
<td>Fuse</td>
<td></td>
<td>1,000</td>
</tr>
<tr>
<td></td>
<td>Flex</td>
<td>Adhesive-Bond</td>
<td></td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>Inj. Mold. Card</td>
<td>Molding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Third-Level Package</td>
<td>Board</td>
<td>Epoxy–Glass, Polyimide, Glass</td>
<td>Cure</td>
<td>175</td>
</tr>
<tr>
<td>Second-To-Third Level Connection</td>
<td>Connector</td>
<td>Cure</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cable</td>
<td>Cure</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Kapton is a trademark of Dupont Company.
New Technologies Needed for Flex

- Materials selection
- Circuits on substrate
- Processing conditions and limits
Conductors

<table>
<thead>
<tr>
<th>Metal</th>
<th>Melting Point °C</th>
<th>Electrical Resistivity $10^{-6} \Omega \cdot \text{cm}$</th>
<th>Thermal Expansion Coefficient $10^{-7}/\text{°C}$</th>
<th>Thermal Conductivity W/m$\cdot$K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>1083</td>
<td>1.7</td>
<td>170</td>
<td>393</td>
</tr>
<tr>
<td>Silver</td>
<td>960</td>
<td>1.6</td>
<td>197</td>
<td>418</td>
</tr>
<tr>
<td>Gold</td>
<td>1063</td>
<td>2.2</td>
<td>142</td>
<td>297</td>
</tr>
<tr>
<td>Tungsten</td>
<td>3415</td>
<td>5.5</td>
<td>45</td>
<td>200</td>
</tr>
<tr>
<td>Molybdenum</td>
<td></td>
<td>2.1</td>
<td>21</td>
<td>146</td>
</tr>
<tr>
<td>Platinum</td>
<td></td>
<td></td>
<td></td>
<td>71</td>
</tr>
<tr>
<td>Palladium</td>
<td></td>
<td></td>
<td></td>
<td>70</td>
</tr>
<tr>
<td>Nickel</td>
<td>1455</td>
<td>6.8</td>
<td>133</td>
<td>92</td>
</tr>
<tr>
<td>Chromium</td>
<td>1900</td>
<td>20</td>
<td>63</td>
<td>66</td>
</tr>
<tr>
<td>Invar</td>
<td>1500</td>
<td>46</td>
<td>15</td>
<td>11</td>
</tr>
<tr>
<td>Kovar</td>
<td>1450</td>
<td>50</td>
<td>53</td>
<td>17</td>
</tr>
<tr>
<td>Silver-Palladium</td>
<td>1145</td>
<td>20</td>
<td>140</td>
<td>150</td>
</tr>
<tr>
<td>Gold-Platinum</td>
<td>1350</td>
<td>30</td>
<td>100</td>
<td>130</td>
</tr>
<tr>
<td>Aluminum</td>
<td>660</td>
<td>4.3</td>
<td>230</td>
<td>240</td>
</tr>
<tr>
<td>Au-20% Sn</td>
<td>280</td>
<td>16</td>
<td>159</td>
<td>57</td>
</tr>
<tr>
<td>Pb-5% Sn</td>
<td>310</td>
<td>19</td>
<td>290</td>
<td>63</td>
</tr>
<tr>
<td>Cu-W(20%Cu)</td>
<td>1083</td>
<td>2.5</td>
<td>70</td>
<td>248</td>
</tr>
<tr>
<td>Cu-Mo(20%Cu)</td>
<td>1083</td>
<td>2.4</td>
<td>72</td>
<td>197</td>
</tr>
</tbody>
</table>

Fewer conductors to choose from
### Insulators

<table>
<thead>
<tr>
<th></th>
<th>Dielectric Constant</th>
<th>Thermal Expansion Coefficient $10^{-7} / ^\circ C$</th>
<th>Thermal Conductivity W/m-K$^\circ$</th>
<th>Approximate Processing Temperature $^\circ$ C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Non-organics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>92% Alumina</td>
<td>9.2</td>
<td>60</td>
<td>18</td>
<td>1500</td>
</tr>
<tr>
<td>96% Alumina</td>
<td>9.4</td>
<td>66</td>
<td>20</td>
<td>1600</td>
</tr>
<tr>
<td>$Si_3N_4$</td>
<td>7</td>
<td>23</td>
<td>30</td>
<td>1600</td>
</tr>
<tr>
<td>$SiC$</td>
<td>42</td>
<td>37</td>
<td>270</td>
<td>2000</td>
</tr>
<tr>
<td>$AlN$</td>
<td>8.8</td>
<td>33</td>
<td>230</td>
<td>1900</td>
</tr>
<tr>
<td>BeO</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BN</td>
<td></td>
<td></td>
<td></td>
<td>&gt;2000</td>
</tr>
<tr>
<td><strong>Organics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Epoxy-Kevlar(x-y)</td>
<td>3.6</td>
<td>60</td>
<td>0.2</td>
<td>200</td>
</tr>
<tr>
<td>(60%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polyimide-Quartz (x-axis)</td>
<td>4.0</td>
<td>118</td>
<td>0.35</td>
<td>200</td>
</tr>
<tr>
<td>Fr-4(x-y plane)</td>
<td>4.7</td>
<td>158</td>
<td>0.2</td>
<td>175</td>
</tr>
<tr>
<td>Polyimide</td>
<td>3.5</td>
<td>500</td>
<td>0.2</td>
<td>350</td>
</tr>
<tr>
<td>Benzocyclobutene</td>
<td>2.6</td>
<td>350–600</td>
<td>0.2</td>
<td>240</td>
</tr>
<tr>
<td>Teflon®</td>
<td>2.2</td>
<td>200</td>
<td>0.1</td>
<td>400</td>
</tr>
</tbody>
</table>

*Teeflon is a trademark of Dupont Company.*

Largely organics
## 2nd-Level Packages

*(How would they function for flex?)*

<table>
<thead>
<tr>
<th>Insulator Material</th>
<th>Organic Card</th>
<th>Organic Board</th>
<th>Inorganic Board</th>
<th>Coated Metal</th>
<th>Flexible Carrier</th>
<th>Inj. Mold Card</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Epoxy Glass</td>
<td>Epoxy Glass</td>
<td>Alumina</td>
<td>Glass or Polyimide</td>
<td>Polyimide</td>
<td>Resin</td>
</tr>
<tr>
<td>Conductor Materials</td>
<td>Cu</td>
<td>Cu</td>
<td>Mo or W</td>
<td>Ag/Pd or Cu</td>
<td>Cu</td>
<td>Cu</td>
</tr>
<tr>
<td>Number of Layers</td>
<td>8</td>
<td>&gt;42</td>
<td>&gt;33</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Coefficient of Thermal Expansion (RT* - 100°C) x 10^-7/°C</td>
<td>150</td>
<td>150</td>
<td>66</td>
<td>30–70</td>
<td>200</td>
<td>300</td>
</tr>
<tr>
<td>Dielectric Constant</td>
<td>4.0</td>
<td>4.0</td>
<td>9.5</td>
<td>3.5–6.0</td>
<td>3.5</td>
<td>4</td>
</tr>
<tr>
<td>Thermal Conductivity (W/m·K)</td>
<td>0.2</td>
<td>0.2</td>
<td>20</td>
<td>150</td>
<td>5</td>
<td>0.1</td>
</tr>
</tbody>
</table>

*Room temperature*
Single Chip Packages

- Ceramic Capacitors
- SO (Small Outline)
- PLCC (Plastic Leaded Chip Carrier)
- QFP (Quad Flat Pack)
- CLCC (Ceramic Leaded Chip Carrier 0.5 mm)
- C-PGA (Ceramic Pin Grid Array 1.27 mm)
- PAD GA (Pad Grid Array 0.75 mm)
- LCC (Leadless Chip Carrier)
- TAB (Tape Automated Bonding)

Lead Spacing:
- 1.27 mm
- 0.64 mm
- 0.5-1.27 mm
- <0.5 mm

Years:
- 1980
- 1985
- 1990
Chip Package

- Die attach
- Wire bonding & Plating
- Encapsulation - molding compound
- Package types
  - Quad flat pack
  - PLCC
  - PGA
  - BGA
  - C4
Multichip Modules

- Combine several chips in one package
- Reduces signal delay time
- Heat dissipation
- Stress relief
- Substrate is high signal density layer

Types
- MCM-L
- MCM-C
- TCM
Tape Automated Bonding (TAB)

- Attach chip to plastic carrier with metallization
- Looks like 35 mm film
- Speeds up production
- Usually polyimide & copper
- Flex circuits use similar technology
PCB or PWB

- Composite - often epoxy/glass
- Parallel process
  - Screen printing
  - Lamination
- Multilayer crossed by vias
  - Capacitance, inductance and resistance
- Pick and place
- Solder & reflow
- Thermal issues
Common Themes
(Flex will have to achieve this)

- Maximize I/O
- Minimize thermal issues
  - Heat dissipation
  - Thermal stress
- Environmental protection and encapsulation
- Lowest cost needed to get results
- Drive to continuously reduce size and power
Microelectronics Advanced Interconnections
Semiconductors versus Package
Smallest features: “parallel paths” for how long?

Laser via / thin film / z-interconnect based interconnect technology needed to reduce the IC to PWB interconnect gap

HyperBGA® Interconnect technology
Reduced Interconnect Gap

HyperBGA is a registered trademark of Endicott Interconnect Technologies, Inc.
Flexible Electronics: Enabling Materials

- Flexible substrates
- Barrier layers
- Inorganic conducting layers and mechanical properties
- Organic conducting layers and mechanical properties
- Optical coatings
- Thin film transistors
- Electro-optic materials
Enabling Processes

- Patterning Methods
- Printed organic electronics
- Rollable materials
- All plastic systems
Flexibility

- Flexibility creates potential problems as the multilayer film is flexed
- Different E
- Different CTE

Figure 6.2 Strain distribution in a bend film

Figure 6.3 The durability of thin film/polymer layered composites is determined by the internal stress (coating and interfacial region), the coating cohesive strength and related crack onset strain, and the coating/substrate adhesion.
Stress Cracking

Modulus mismatch leads to stress cracking
# Mechanical Properties of Layer Components

<table>
<thead>
<tr>
<th>Material</th>
<th>Young’s modulus, E (GPa)</th>
<th>Coefficient of Thermal Expansion, CTE (ppm/K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardcoat</td>
<td>6.0 ± 0.5</td>
<td>61 ± 1</td>
</tr>
<tr>
<td>Base polymer</td>
<td>2.9</td>
<td>~65</td>
</tr>
<tr>
<td>Gas Barrier</td>
<td>150</td>
<td>10</td>
</tr>
<tr>
<td>ITO</td>
<td>119 ± 5</td>
<td>7.6</td>
</tr>
</tbody>
</table>
Organic Substrates

Flexible plastics are not as thermally stable as glass or metal.
Polymers can be used as semiconductors and even doped to be conductors.
TFT’s on flexible substrates can be produced from polymeric or inorganic semiconductors using printing methods.
Barrier layers are needed to protect the various components from the environment.
New Patterning Methods

- New processing is enabled by new materials

**Figure 12.15** Advantages of printing organic electronics. The first column depicts a typical lithographic process. Subject material is deposited on the substrate. Photoresist is applied, exposed, and developed. The subject material is etched and the photoresist is stripped. The second column depicts a subtractive printing process. Subject material is deposited on the substrate. A mask is printed and the subject material is etched. The resist is then stripped. The third column depicts an additive printing process in which an ink carrying the subject material is printed only where necessary.
Future Prospects

- Future applications not even imagined do not appear here

*Figure 25.3* Flexible display value by application, 2005–10
The Air Force has announced a complementary program using OLED on SS

Source: John Pellegrino (ARL) and Darrel Hopper (AFRL)
Flexible Display Center @ ASU

Flexible Display Center of Excellence

- (6) Manufacturing Integration
- (5) Monolithic encapsulation / Barrier coatings
- (4) Electro-optic devices - display imaging technology (e.g. multi-layer OLED, RGB pixels)
- (3) Backplane Electronics
- (2) Flexible Substrates
- (1) Barrier coatings

Technology into Center

Limited Quantities of Display Demos

Technology subsets from the Center (i.e. backplanes)

UNIVERSITIES

INDUSTRY

GOVERNMENT LABS/RDECs

United States Army
Roll-to-Roll Manufacturing R&D
Motivation and Purpose

A proposed means to lower the cost of producing flexible displays in a high-volume manufacturing environment by taking advantage of a unique attribute of flexible substrates relative to the traditional thick glass substrate used in LC displays.

Such a manufacturing paradigm, compared to the traditional batch process (cluster tools and cassette transport), generally does not enable any enhanced product performance characteristics.
What is Roll-to-Roll (R2R)?

- Substrate is a Flexible format
- \( L >> W >> T \)
- Can be stored in coils (\( D < 1 \text{m} \))
- Handled in Rolls:
  - Unwind – process - Windup
Converging interests from other developing industries

Opportunity: pool resources and knowledge

- Flex Circuit Packaging
  - Reduce L/S < 15um
  - Embedded actives, passives
  - Integrated passives, active

- Thin Film Photovoltaics
  - Reduce cost
  - Improve yield

- Large Area Solid State Lighting
  - Low cost production of OLED panels

- Low Cost RFID
  - New TFT technologies

High precision R2R electronics manufacturing
Challenges & Opportunities for R2R

Engineering

- Need to develop R2R equipment to operate at IC-industry specifications

  - Existing hurdles:
    - Damage due to handling
    - Particle generation
    - Impurity due to contact
    - Yield management
    - Linear processing

- Financial
  - A fully integrated facility
  - Lower capital cost
  - Lower labor costs
Why R2R Manufacturing?

Because it may be essential to enable the high volume applications of flexible electronic products and systems and it is highly compatible with organic electronics & solution processing!

- Flexible
- Formable
- Weight
- Ruggedness
- Low Cost

- Many customers will not pay a premium for these.
- However, a premium is inevitable for new technology.
- Customers have come to expect lower cost!

Roll-to-Roll Production?
Roll-to-Roll Manufacturing
What it is NOT in the context of the FDI!

- Not an essential capability to produce flexible displays

- Does not satisfy a gating Army need (volume, application variability)

- Not a near term capability (either from an ability to accomplish or a market demand point of view)

- Does not meet the Army timeline

- Not appropriate for a display technology development environment
USDC CONCLUSIONS & GUIDANCE
Roll-2-Roll Manufacturing – A Companion Initiative

Supporting Factors

- There is insufficient funding in the Army program to do both initiatives
  ► spend the “marginal” funding on the important and essential display component deliverables at the FDC

- Keep the ASU team focused on displays and backplanes to meet the Army’s objectives for the FDC

- Core competencies very different for addressing flexible displays and R-2-R manufacturing technology ► different industries [tool & process development expertise] and very different academic R&D expertise

- Commission someone else with the responsibility to secure additional funding and support
  • Other funding avenues, e.g., state, federal, industry
  • Industry partners from outside the display community

- Efforts can run more concurrently [although not essential to meeting Army flexible display objectives] without dissipating focus and funding
New effort in U.S.: CAMM (Center for Advanced Microelectronics Manufacturing)

- Located at Binghamton University (New York State)
  - Launched in January 2005
  - Develop and demonstrate advanced integrated R2R manufacture of microelectronics
- Test site for USDC R2R projects
- Facilities provided by Endicott Interconnect Technologies

If there is interest, we can visit!!