Advanced Material Solutions for Co-Packaged Optics

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Outline

• DuPont Electronics and Imaging Introduction

• High Speed Data Center challenges and Co-Packaged Optics

• Critical Materials for Next Gen data center
  • Polymer waveguide material
  • Low loss dielectric material
  • Index management material
  • Thermal management material
  • Others.

• Opportunity for faster development through material industry standards
DuPont Today: Our market-leading businesses delivering innovation in high growth markets

- **Nutrition & Biosciences**
  - Food & Beverage
  - Health & Biosciences
  - Pharma Solutions

- **Transportation & Industrial**
  - Mobility Solutions
  - Healthcare & Specialty
  - Industrial & Consumer

- **Safety & Construction**
  - Water Solutions
  - Shelter Solutions
  - Safety Solutions

- **Electronics & Imaging**
  - Semiconductor Technologies
  - Interconnect Solutions
  - Image Solutions

- **Non-core**
  - Biomaterials
  - Clean Technologies
  - Photovoltaics and Advanced Materials
  - DuPont Teijin Films JV
Electronics & Imaging

Transfer Chip Design to Wafer
Deposit Interconnects for Circuits, Packages & Boards
Planarize Each Chip Layer
Connect Chips to The Outside World
Connect Components, Packages & Systems
Electrical, Thermal & Mechanical Support
Thin, High Performance Display Materials

Enabling the entire value chain from transistor to system manufacturing

CMP Pads & Slurries • Cleaners • Microlithography • Photoresists • Laminates • Films • Dielectrics • Metallization • Imaging • Adhesives
Thermal Management • Films and Adhesives • Encapsulation • Permanent Bonding • Conductive Pastes • Ceramics • Display Materials
Material portfolio integration into electronic components

Front end of Line: Wafers [5nm and below] to Back end of line: PCB [mm]

DuPont Semiconductor business provides leading imaging and planarization technologies for FEOL and BEOL as well as Advanced Packaging solution for WLCSP, RDL, Fan-in, and Fan-out.

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High Speed Data Center Challenges and Co Packaged Optics
Efficiency challenges for next gen switch

- Data Center (DC) is reaching cooling and electrical power limits under expected bandwidth increase.
- Retrofits of existing DC are prohibitive in cost and downtime.
- Challenge is to define how they can increase capacity while maintaining switch power consumption flat.

>> Changing from conventional optical transceiver with Cu lines to co-packaged optics (CPO) will reduce the total SERDES power consumption up to 79%.

<table>
<thead>
<tr>
<th>Switch bandwidth (Tb/s)</th>
<th>Optical Ports / Speed</th>
<th>Target Chassis power (W)</th>
<th>Target Efficiency (pJ/b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.8</td>
<td>128/100GbE (25Gb/s 4 line)</td>
<td>&lt;1400 (actual)</td>
<td>&lt;100 (actual)</td>
</tr>
<tr>
<td>25.6</td>
<td>128/200GbE (50Gb/s x 4 line)</td>
<td>&lt;1600</td>
<td>&lt;34</td>
</tr>
<tr>
<td>102.4</td>
<td>128/800GbE</td>
<td>&lt;1750</td>
<td>&lt;17</td>
</tr>
</tbody>
</table>

Example case

<table>
<thead>
<tr>
<th>51Tb/s</th>
<th>Switch SERDES power (W)</th>
<th>Retimer SERDES Facing switch (W)</th>
<th>Retimer SERDES Facing pluggable (W)</th>
<th>Optical Modul Host Interface (W)</th>
<th>Total SERDES power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional switch</td>
<td>333</td>
<td>333</td>
<td>154</td>
<td>154</td>
<td>973</td>
</tr>
<tr>
<td>CPO</td>
<td>102</td>
<td>0</td>
<td>0</td>
<td>102</td>
<td>205</td>
</tr>
</tbody>
</table>

>5X efficiency needed

79% reduction

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1 James Stewart (Facebook), “Co-Packaged Optics Ecosystem for Hyperscale Data Center Applications”, OFC, 2020
Critical Materials for Next Gen Data Center
Novel material needs for next gen data center

- Novel materials are critical for designing next gen data center.
  
  **Optical materials**
  - Ultra low loss waveguide
  - Tunable index (lens) material
  - Optical adhesive for assembly

  **Dielectric materials**
  - Low loss photopatternable dielectric
  - Low loss laminate / substrate

  **Thermal management materials**
  - Heat dissipation solutions

  And more..
Co-Packaged Optics – Integration options

Co-Packaging Optics using v-groove fiber attach

- Passive alignment (high throughput, scalable)
- Low profile vs. grating coupling
- Low assembly complexity

Co-Packaging Optics using polymer waveguide interface

- Passive alignment
- Polymer waveguide allows optical fiber fan-out (denser pitch at chip interface)
- No need for wet etch (v-groove)

1Alexander Janta-Polczynski, “Silicon Photonics Co-Packaging,” COBO webcast, Sep 2020
Photonics – Material use cases in optical transceiver

- Waveguide Materials
- Index Management Materials
- Optical Adhesive Materials
- Thermal Interface Materials
- Interconnect Materials
- Dielectric Materials
Polymer Waveguide (Polymer link for OBO/CPO)

Main criteria for Waveguide: optical insertion loss

Insertion Loss (IL) = Coupling loss (CL) + Propagation loss (PL)

- CL = refractive index (material property) + end face profile
- PL = absorption (material property) + scattering (pattern shape) + bend (waveguide design)

Key Material Parameters

- Low absorption at 1310nm (SM) / 850nm (MM)
- Tunable refractive index
- Accurate photo patternability
- Reliability under high T, high humidity

- Molecular vibration (C-H, C-O, OH)
- Aromatic structure
- Crosslinking density
- Water uptake
Polymer Waveguide (Polymer link for OBO/CPO)

Enabling next generation Switch ASIC & Data center high speed communication

Core Material Competency
- BCB materials have excellent reliability for optical use
- Photo patternable materials CYCOLTENE™ 6505, achieves loss value of ~0.5dB/cm (single mode) on Silicon wafer
- Core-Clad delta RI tunable from 0.004 to 0.010

Targeted Material Design meeting Application CTQs
- Waveguide material has stable Δdn/dT and loss values under reliability testing
- Novel Ultra Low Loss (<0.3dB/cm) waveguide material development is underway

Modeling of Single Mode WG to support Technical path
- Model SMWG transmission and optimal performance:
  - Waveguide Geometry
  - Cut off RI delta for SG vs MM
  - Loss for linear vs around bend
  - Transmission via polymer / Glass

Waveguide Fabrication and Testing
- DuPont has capability to fabricate waveguides at three R&D sites for screening and prototyping.
Low loss photo dielectric (chip packaging, board)

**Main criteria for dielectric: transmission loss**

Trans Loss (TL) = Conductor loss ($\alpha_c$) + Dielectric loss ($\alpha_d$)

- $\alpha_c = K_{sr,drum} \frac{9.48\sqrt{f}}{(w+t)Z_0} + K_{sr,matte} \frac{22.12\sqrt{f}}{(w+t)Z_0}$
  - Proportional to Cu/dielectric roughness, $\sqrt{f}$

- $\alpha_d = 2.32\sqrt{D_k D_f f}$
  - Proportional to $D_k$ & $D_f$ ($\tan(\delta)$) (material property)

**Key Material Parameters**

- Low dielectric constant ($D_k$) and dissipation factor ($D_f$)
- Good mechanical (Tensile) properties
- Lithography (resolution, photospeed, aspect ratio)
- Low temp curing (<200°C/1hr), low water uptake

- ArylAlkyl Thermoset polymers (DuPont CYCLOTENE™ products)
  
  - Redesign of polymer backbone and photo switchable chemistry
Low loss photo dielectric (chip packaging, board)

Enabling high speed high frequency applications

Core Material Competency (BCB chemistry)

Benzocyclobutene (BCB) resin shows:
- Excellent Cu barrier and electrical properties
- Good thermal stability (up to 300°C) and chemical resistance
- Low T cure, no outgassing
- Multilayer build capability

Wide processing window
- Novel chemical structure leads to low curing temperature.
- No effect on Df vs. curing extent, unlike acyl-epoxy or photo-PI due to diene chemistry.

Excellent photo patterning properties
- Developmental Photodielectric good 1:1 aspect ratio, 5um feature lithography performance (i-line stepper, mask aligner)

Custom material design
- Novel Aryl-Alkyl based thermoset based formulation shows very promising electrical performance.
- Developmental effort (XP-5G-B)* Df=0.0028@28GHz

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Applications for Photo Patternable Dielectric Materials

Electro-optical transceiver on glass interposer connected to single-mode optical fiber I/O
(Single mode, 1310 or 1550nm)

Optical Lens (6505)

Turning Mirror/Cladding (6505/Dry Film)

Dielectric Dry Film Filled Via

Thickness (μm)

10 5
140 140
10 5
230

Corning SOW3

Dielectric Dry Film Cu RDL

Stack-up

SnAg

PWB (FR4)

Simulated E/O performance shows 3x reduction in signal loss using Dielectric Lens/Mirror/Cladding structures


*Collaboration with Georgia Tech is a registered Trademark of the Board of Regents of The University System of Georgia.
Index Management Materials – light coupling

- Active program to serve next generation image sensor and data center applications.
- DuPont has developed an Index Management Materials with tunable RI.

**Key Industry Challenges**

- Optical devices always have loss between light source and guided materials at the interface.
- Material with tunable refractive index will minimize light loss and increase overall energy efficiency.

**DuPont strategy**

- Product contains no metal oxide particles (filler free) and deliver adjustable RI.
- Available for slot-die or spin coat to furnish films with excellent thermal performance, patternability, and optical durability.
  - High (1.66-1.73)
  - Mid (1.63-1.65)
  - Low (1.28-1.35)

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Thermal Management Materials (heat dissipation)

- Developing next generation material for data center and high speed communication infrastructure
- DuPont has developed a Thermal Interface Materials 1 (TIM1) that meets 6W/mK.
- Scouting technology for >10W/mK material development.

### Key Industry Challenges

- Heat dissipation
- Warpage control

### Features & benefits (Si-based TIMs)

- High thermal conductivity
- Low thermal resistance, TR
- Excellent die coverage
- Low modulus
- Moderate elongation

### Product offering

- TIM1 (Gel & Adhesive)
  - Thermal dissipation
  - Stress relief
  - Coverage and delamination prevention are critical
- Lid Seal Adhesive
  - Bond the lid on the substrate
  - Warpage control is challenging

### Signature Offering

- Award-winning TC-3040 TIM1 Gel
- Industry standard. SE-4450 & DA-6534 TIM1 adhesive
Material Specification/Standard Example

Opportunities for bridging gaps between material supplier and OEMs
The USB standard defines performance requirements and even makes design suggestions. Implementing those designs in a reliable and manufacturable way is defined in the IPC standards.

Material suppliers develop materials to meet performance standards for fabricators and designers.

PCB materials must meet the mechanical and electrical performance requirements consistently and reliably to satisfy the dielectric and foil performance specifications.

Fabricators use the IPC standards and IPC listed materials to construct the boards that meet performance requirements.
IEEE specifications define performance requirements but don’t dictate “how” to build the assemblies at the manufacturing level of detail.

IPC-0040 defines the Optoelectronic and Packaging Technology Standards on how to build a robust optical system but is not as robust as the listing of PCB standards and is a single standard document versus many documents for standard PCB.

Material suppliers need to know mechanical, electrical and optical properties to make a manufacturable and high performing part for optical assemblies.

Fabricators can avoid mistakes and make a higher performing more reliable part if provided a design standard that’s more robust.

COBO or CPO consortium can take a leadership role in defining material performance parameters and creating standards that help us meet performance, processing and reliability goals.
Conclusion

- Co-Package Optics (CPO) will drive Next Gen high bandwidth switch.

- System level performance advancement requires **new materials with novel optical and electrical properties**

- DuPont is actively developing multiple optical material solutions that are critical for CPO adoption.

- Establishment of **materials standards** can help accelerate material discovery and fabrication in the near future.
Thank you