Enabling Materials Technology for Multi-Die Integration

Dr. Jeffrey M. Calvert

Global R&D Director, Advanced Packaging Technologies
Dow Electronic Materials
455 Forest St., Marlborough, MA 01752 USA
jcalvert@dow.com
Outline

- Introduction
  - Key Materials Needs and Challenges
- Enabling Materials Solutions
  - Dielectrics
  - Temporary Wafer Bonding Adhesive
  - Non-Conductive Film
  - Cu TSV Filling
- Summary
Drivers for Multi-Die Integration

- Flip-chip, wafer-level and 2.5D/3D packages are the market drivers for advanced packaging
- Key Drivers for 2.5D/3D Packaging
  - Cost and complexity of scaling (“More Moore”)
  - Demand for Increased Performance and Functionality (“More than Moore”)
- 3D Packaging is a complex landscape of many different package architectures, integration approaches ➔ diverse materials needs, uncertain insertion timing
Key Material Challenges for 3D Packaging

- High AR Cu via filling, planarization
- Fine pitch bump metallization (solder, Cu pillar)
- Low stress/low cure temperature dielectrics
- Improved bond/de-bond adhesives
- New underfill technology
- Thermal management
Dow’s Enabling Materials for 3D-TSV

- Metallization
- Bonding/Assembly Materials
- Dielectrics/Photoresists

ETNA 3D chip stack with DRAM and Logic integration

- Copper Damascene
- Pb-free Bump Plating
- Copper TSV
- Redistribution Copper
- Copper Pillars
- Photodielectric
- Underfill Material (CUF, NCF)

Process Chemicals
Bump Plating, Etching Photoresists
Ancillaries
(Developers, Removers, Adhesion Promoters)
Bonding Adhesive Layers
(Temporary, Permanent)
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Dielectric Material Requirements

- Dielectrics for fine-pitch RDL, FI/FOWLP, stress buffers, embedded architectures have increasingly demanding technical requirements
  - Low dielectric constant, Low dielectric loss
  - High thermal stability, Low-temperature cure processing
  - Fine geometry patterning
  - Process flexibility (coating, patterning, development)
  - Low moisture uptake
  - Robust mechanical properties and chemical stability
  - Tunable viscoelastic properties (planarization, gapfilling)
  - High reliability

- New dielectric material developments
  - High resolution, low stress, aqueous-developable (AD-BCB) dielectric
  - Toughened BCB-based dielectrics
    - Conventional photo or laser patternability
    - Spin-on or dry film coating
AD-BCB Dielectric Material (Litho Performance)

After Develop

After 200°C Cure

10µm Via, 1:2 Pitch
5µm Via, 1:2 Pitch

• FT: 6.5µm after SB (90°C/90s)
• Spin-apply, 1200 rpm
• i-line stepper, E_{size} @ 500mJ/cm²
• 0.26N TMAH, 60sec, SSP
• Curing: 130°C/30min // 200°C/100min (<100ppm O₂)

• CYCLOTENE™ 6505 AD-BCB Photodielectric
  - Positive-tone, Aqueous developable
  - High-resolution patterning with conventional litho
    • Extendible to 2µm patterning in 3.3µm FT
  - κ = 3.2, tan δ = 0.015, V_b > 5MV/cm
  - Rapid moisture desorption

2µm Via, 1:2 Pitch (3.3µm FT)

Humidity cycling at 23°C (0-45% RH)
AD-BCB Dielectric Material (Stress Reduction)

- New XP Photodielectric has lower residual film stress vs. commercial CYCLOTENE™ products (BCB or AD-BCB-based materials)
- Lower stress $\Rightarrow$ comparable reduction in wafer bow
- Litho performance of lower stress XP material similar to CYCLOTENE 6505 AD-BCB photodielectric
Highly accelerated stress testing (HAST) of CYCLOTENE™ 6505 AD-BCB photodielectric shows no evidence of dendrite formation or electromigration.

Underfilled flipchip package with CYCLOTENE 6505 photodielectric passes MSL-3, TCT >1000 cycles from -55°C to +125°C.
**Toughened BCB-based Dielectric Materials**

- Same BCB polymer resin as in CYCLOTENE 3000 and 4000 series dielectric materials
  - Same low dielectric and low loss properties (2.65, 0.0008)
  - Same low curing temp w/o outgassing
  - Same low moisture uptake
  - Same high thermal and chemical stability
  - Dry etch or negative tone/solvent developable

- Modified BCB formulations offer new/improved features:
  - Coating by spin-apply or lamination (dry film)
    - Film thickness to >100µm
  - Tunable mechanical properties
    - High elongation to break (to >35%)
  - Dry etch or neg. tone/solvent developable or laser patternable
  - Long pot life: $E_{gel}$ unchanged after 30 days at RT

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Elongation >35% achievable

Flexible, transparent ~75µm thick freestanding toughened BCB film
Toughened BCB-based Dielectric Materials (Litho)

- **Spin-on Version**
  - Spincoat AP9000S Adh. Promoter, SB 90°C/90s
  - Spincoat toughened BCB Photodielectric, SB 90°C/90s
  - i-line or BB exposure
  - PEB 90°C/90s
  - Solvent develop (DS-2100), Single puddle 15s
  - PDB, SB 90°C/30s
  - Std. low O₂ BCB curing process

- **Lithographic performance (FT = 6.5µm)**

- **Dry Film Version**
  - Nominal 10µm FT Dielectric on PET backsheet
  - Vacuum or Hot roll lamination onto Si or glass
  - i-line or BB exposure
  - PEB 90°C/90s
  - Solvent develop (DS-2100), Triple puddle 30s
  - PDB, SB 90°C/60s
  - Std. low O₂ BCB curing process

- **Lithographic performance (FT = 10µm)**
Toughened BCB-based Dielectric Materials (Laser)

- XP toughened BCB photodielectric coated onto 330mm PET backing w/ PE cover sheet
- Exposures performed using Süß MicroTec Photonics Systems - 248nm Laser System
- Pattern resolution to 7µm L/S demonstrated in 10µm thick dielectric film
- Laser ablation residue is cleanly removed using standard 0.26N TMAH developer

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Dielectric Materials Summary

- **CYCLOTENE 6505 Photodielectric product**
  - High resolution, positive-tone litho
  - Compatibility with aqueous track processing (TMAH develop)
  - High reliability performance, typical of BCB-based dielectric materials

- **XP Low Stress Photodielectric**
  - High resolution patterning and aqueous processability
  - ~15% lower residual stress, leading to reduced wafer bow

- **XP Toughened BCB-based dielectrics**
  - Retain desirable electrical, thermal and other material properties of BCB
  - **Plus** much improved mechanical properties
  - **And** greater process flexibility
    - Spin-on or dry film coating
    - Conventional litho or laser patternability
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  - Non-Conductive Film
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Temporary Wafer Bonding (TWB) Adhesive

- **XP-130215 TWB Adhesive**
  - Based on Dow’s benzocyclobutene (BCB) resin technology; BCB is well-established in manufacturing as a permanent bonding adhesive material
  - Designed for bond-debond applications ranging from planar/low topography structures to C4 bumps
  - Coating thicknesses to >100 µm.
  - Rapid, low temperature curing process
  - Cured film has high thermal (300°C) and chemical stability
  - Room temperature, mechanical debonding
  - Compatible with wafer thinning and backside integration processes
TWB Overall Process Flow

1. Full Thickness Bumped Device Wafer
2. Spin-on Temporary Bonding Adhesive
3. High-Throughput Bonding
4. Thinning and Backside Processing
5. RT Mechanical Lift-off from Device Wafer
6. Thinned TSV Device Wafer
7. Carrier_Wafer
8. Spin-on Adhesion Promoter
9. Tape-Peel Adhesive from Carrier
10. Reclaimed Carrier

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TWB Adhesive Application Process

- **Device Wafer**
  - Spin Coat Thermoset Adhesive
  - Soft Bake & Pre-Cure
    - 120°C, 2 min
    - 180-210°C, 2-5 min
  - Flip Wafer

- **Carrier Wafer**
  - Spin Coat Adhesion Promoter
  - Soft Bake Adhesion Promoter
    - 120°C, 1 min

- **Process Flow diagram courtesy of Süss MicroTec**

- **Thermocompression Bond**
  - 100°C, 10 kN, 30 sec
  - Post-Bond Cure
    - (N₂ atmosphere)
    - 210°C
    - 2 ~ 4 min

- **Total process time in bonding chamber: <2min**
- Enables high wafer throughput
TWB Adhesive Performance (Coating, TTV)

- Low TTV after coating, bonding and thinning – flat Si or over topography
TWB Adhesive Performance (After Debonding)

- Clean, mechanical debonding from bumped die (Cu Pillar, C4 bump, µbump) at room temp
- TWB adhesive removed from carrier by tape peeling

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TWB Adhesive Summary

- **XP-130215 TWB Adhesive**: New TWB product developed for room temperature, mechanical debonding

- Tunable film thickness, low TTV for surfaces ranging from low topography to Cu Pillars to C4 bumps → extendibility to fine pitch/TSV applications

- Short cycle time for TWB adhesive deposition/curing, rapid, simple, clean mechanical debonding process → lower CoO

- Compatible with backside integration process steps – demonstrated with 300mm test vehicles → high reliability/yield

- Customer evaluations ongoing
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Non-Conductive Film (NCF)

- XP-130576A NCF*
  *Also referred to as Wafer-Level Underfill (WLUF) or Pre-Applied Underfill (PAUF)

- Silica-filled epoxy based film designed for vacuum lamination application
  - Available in dual-use format with backgrinding tape
- High uniformity coating over topography (Cu pillar/solder cap)
- Good bump and fiducial visibility for dicing and alignment
- Self-fluxing, fast film curing during thermocompression bonding (TCB)
- Good joining without filler entrapment
- Void-free film after bonding
- Passes reliability testing
NCF Process Overview

- Thinned Wafer, Cu μPillar/SnAg Cap
- Dice
- TCB to TSV Wafer (<10s @ elevated T, P)
- Vacuum laminate NCF (Bumps covered or exposed) (1min @ elevated T, P)
- NCF Post-Cure (175°C, 90 min, 1atm)

NCF Dynamic Rheology Profile

- Representative profile - minimum viscosity and maximum curing rate are tunable

Key Properties of Cured NCF

- $T_g$ (TMA): 170°C
- CTE ($a_1$): 25ppm/°C
- $E$: 6.5 GPa
**NCF Performance (Coating)**

- **NCF Laminate Film Roll**
  - Film thickness (FT): 20-40µm

- **NCF Laminate Film Roll**
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- **NCF Laminated Wafer**
  - 300mm

**Film Thickness Uniformity**
- (across 330mm wide roll)
  - FT: 25 ± 0.5µm (+2%)

**Good Bump Visibility**
- (Covered Bumps)
  - Viewed through TCB camera
  - FT: 23µm

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NCF Performance (Bonding)

Compatible with Dicing (Mechanical or Stealth)
No cracking, chipping, “hinging” of laminated NCF

Void-Free Adhesive Bonding
C-SAM inspection of cured film

Good Joint Formation
SEM x-section

No Filler Entrapment Observed
SEM/EDX analysis

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NCF Performance (Reliability)

**Fillet**
Good coverage along die sidewall

**MSL3 Test**
1 week at 30°C/60% RH + 3X solder reflow - Pass

**Thermal Cycle Test**
-55 to +125°C, 2000 cycles - Pass

**Electrical Testing**
Testing in progress (electrically-testable die)

**Biased HAST**
130°C, 85%RH, 96 hrs - Pass

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NCF Summary

- **XP-130576A NCF**: New Non-Conductive Film developmental product
- Designed for fine pitch, narrow gap Cu Pillar/TSV applications
- Highly uniform laminated film over topography, TCB snap curing ➔ high throughput, lower CoO
- Void-free bonding, good joint formation, no filler entrapment ➔ high reliability/yield
- Customer evaluations ongoing
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Cu TSV Plating Chemistry

- **INTERLINK™ Cu TSV Chemistry**
- Designed for Interposer and Via Middle TSV Applications
- **Bath Components**
  - Sulfuric Acid-Based Copper Electrolyte
  - 3 Part Additive System
    - Accelerator: Electrocatalyst for bottom-up filling
    - Suppressor: Suppresses deposition in field, along sidewalls
    - Leveler: Enhances planarization over feature arrays
Cu TSV Plating Performance (Deposition)

- Partial Filling Sequences: Strong polarization at via opening ➔ ideal filling profile

- Via filling speed tests: Rapid filling capability
  - Cycle times <15min (5x50µm), <40min (10x100µm) demonstrated (Wafer type, seed layer dependent)

- Low overburden thickness, smooth deposits

Test Vehicle source: Applied Materials
- Consistent via filling across 300 mm wafer in production toolset
- Cu TSVs annealed at 400°C for 30 min
- Annealed film is void-free with large full-width Cu grains
- High purity Cu deposit (<50ppm organics by SIMS)
Cu TSV Plating Performance (Aging)

- 10x100µm TSV aging study, 38min cycle time, 1.4µm overburden
- Continuous plating, 8% bleed/feed, daily additive dosing
- No voids in as-plated or annealed deposit, no polarization loss during aging study to 13.8 AHR/L

Test Vehicle source: Applied Materials
Cu TSV Plating Summary

- **INTERLINK™ Cu TSV CHEMISTRY**: New product developed for Cu TSV interposer and via middle applications
- Fast filling times and low overburden ➔ lower CoO
- Void-free filling, low defects, high purity deposit ➔ high reliability/yield
- Online bath metrology available
- Customer evaluations ongoing
Summary

- 2.5D/3D-TSV is a complex landscape with many different materials requirements
- Dow has successfully developed enabling new products that are tailored for these applications
  - New Dielectrics, Temporary Wafer Bonding Adhesive, Non-Conductive Film, TSV Cu filling
  - Fast, simple processes ➔ high throughput, reduce CoO
Thank You