Electronic Materials

Enabling Materials Technology for Multi-Die Integration

Dr. Jeffrey M. Calvert

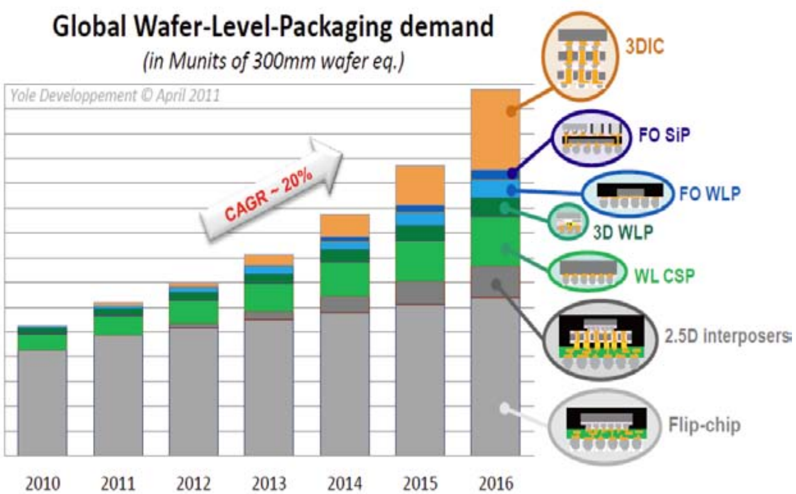
Global R&D Director, Advanced Packaging Technologies
Dow Electronic Materials
455 Forest St., Marlborough, MA 01752 USA
jcalvert@dow.com

Outline

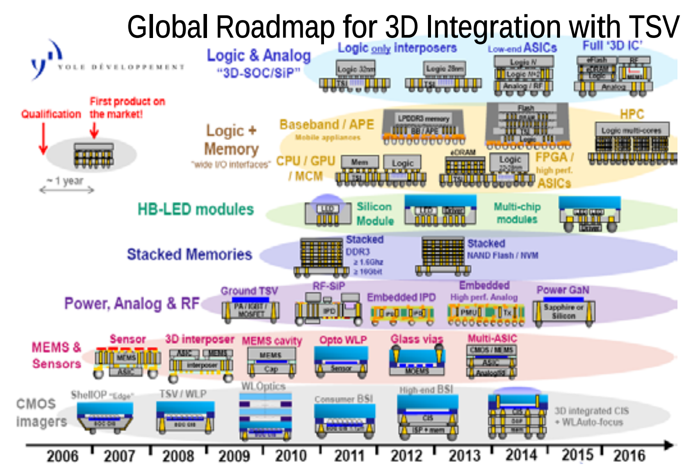
- Introduction
  - Key Materials Needs and Challenges
- Enabling Materials Solutions
  - Dielectrics
  - Temporary Wafer Bonding Adhesive
  - Non-Conductive Film
  - Cu TSV Filling
- Summary

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

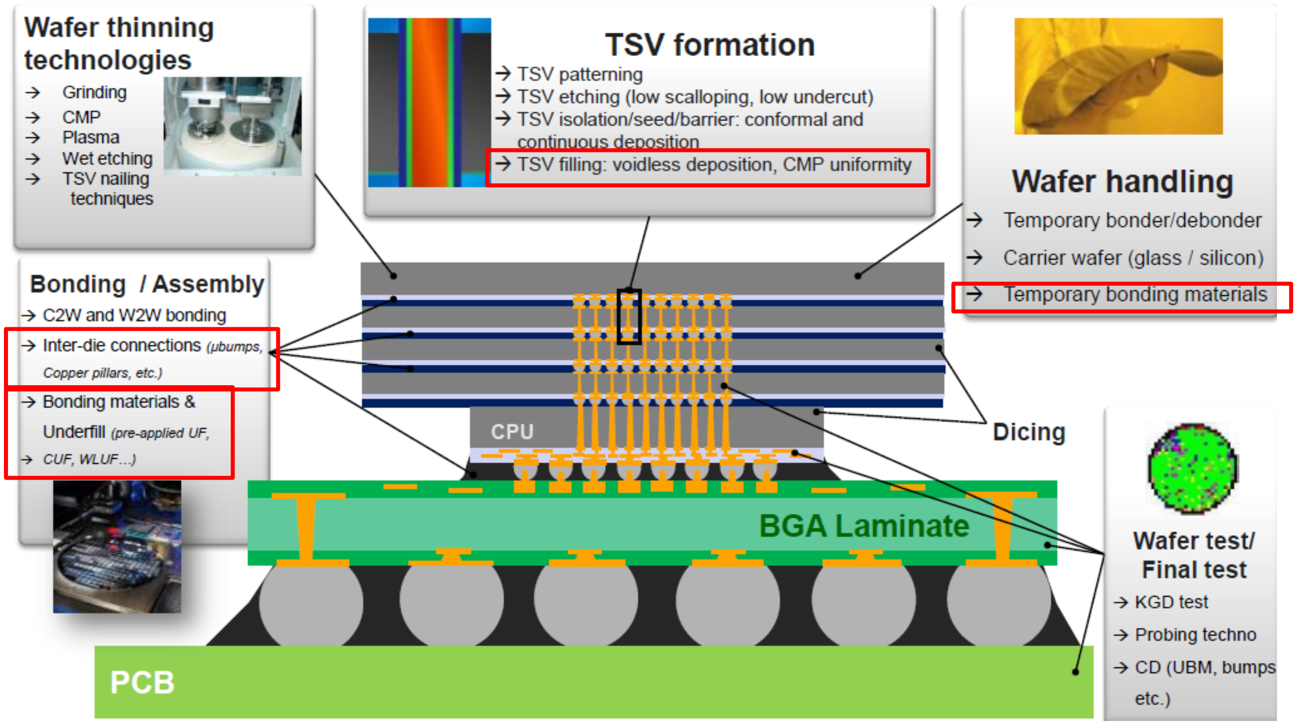


Graphic courtesy of Yole Developpement



Graphic courtesy of Yole Developpement

Key Material Challenges for 3D Packaging

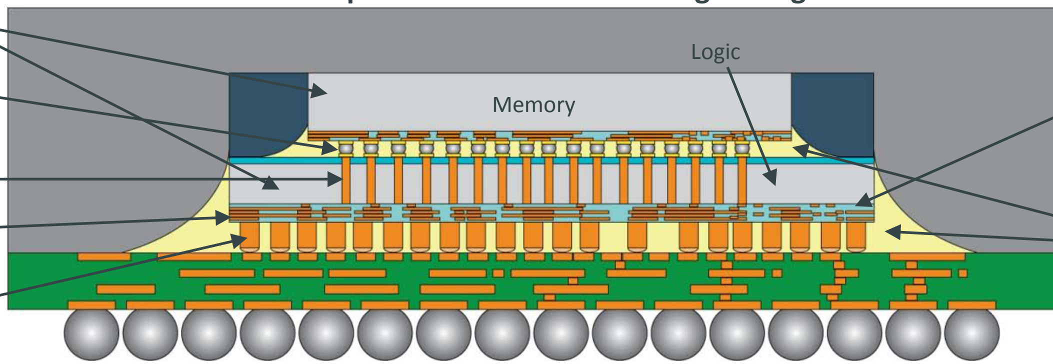


Graphic courtesy of Yole Developpement

- 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

ETNA 3D chip stack with DRAM and Logic integration



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

- **Metallization**
- **Bonding/ Assembly Materials**
- **Dielectrics/ Photoresists**

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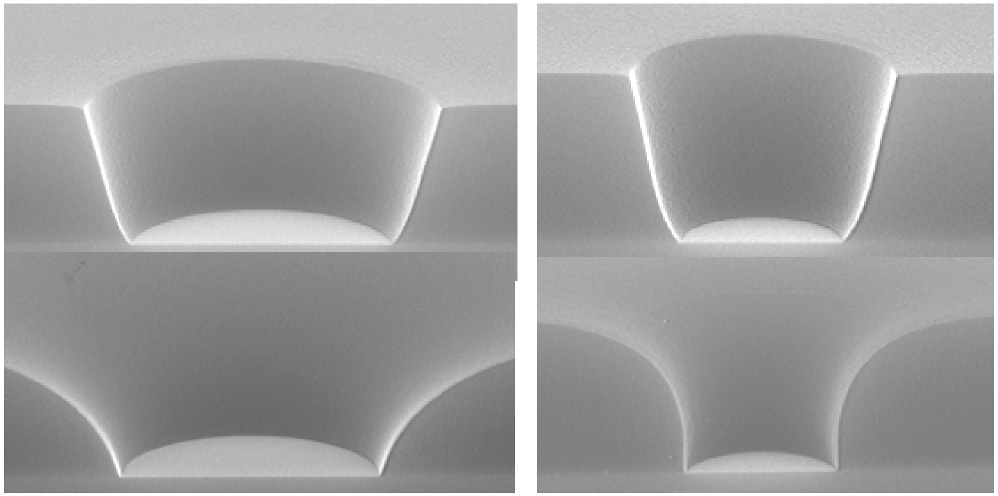
Dielectric Material Requirements

- 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

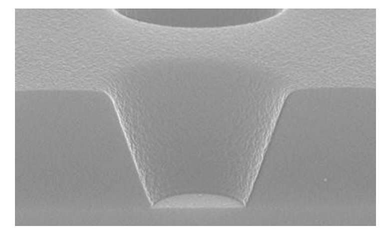
After 200°C Cure



10µm Via, 1:2 Pitch

5µm Via, 1:2 Pitch

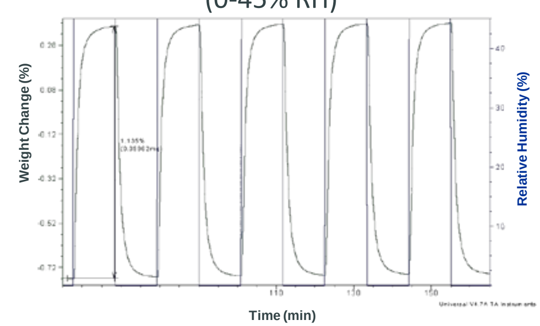
- FT: 6.5µm after SB (90°C/90s)
- Spin-apply, 1200 rpm
- i-line stepper, E_{size} @ 500mJ/cm^2
- 0.26N TMAH, 60sec, SSP
- Curing: 130℃/30min // 200℃/100min (<100ppm O_2)



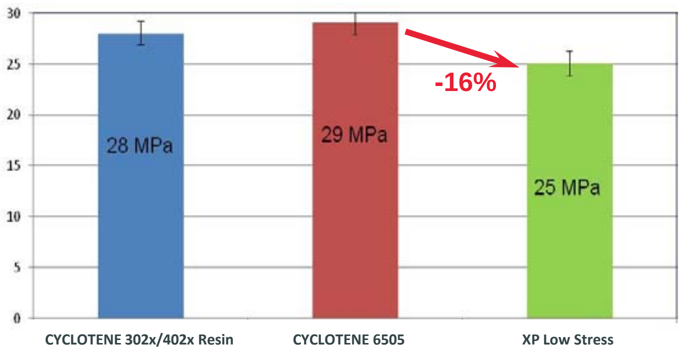
2µm Via, 1:2 Pitch (3.3µm FT)

- **CYCLOTENE^{TM} 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

Humidity cycling at 23℃ (0-45% RH)



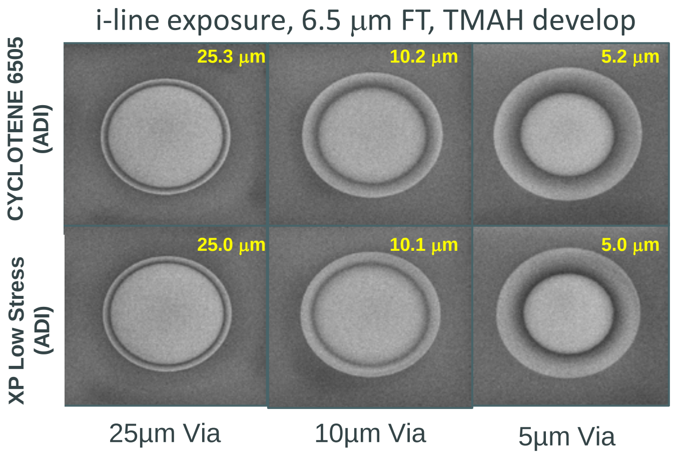
AD-BCB Dielectric Material (Stress Reduction)



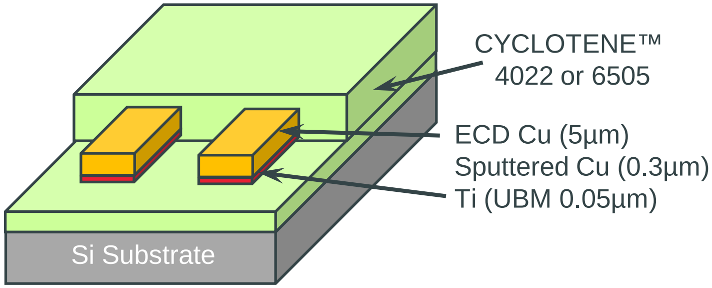
Film stress: Toho Flexus

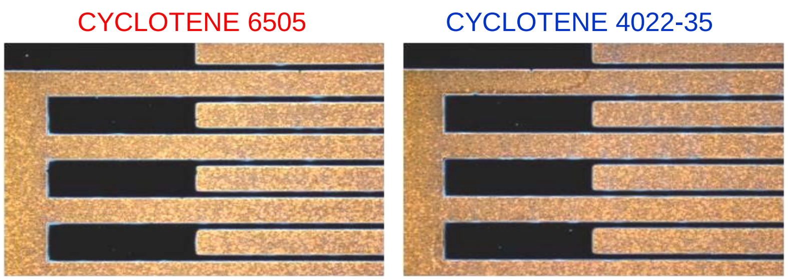
Wafer Bow: Optical Profilometry

- New XP Photodielectric has lower residual film stress vs. commercial CYCLOTENE™ products (BCB or AD-BCB-based materials)
- Lower stress → comparable reduction in wafer bow
- Litho performance of lower stress XP material similar to CYCLOTENE 6505 AD-BCB photodielectric

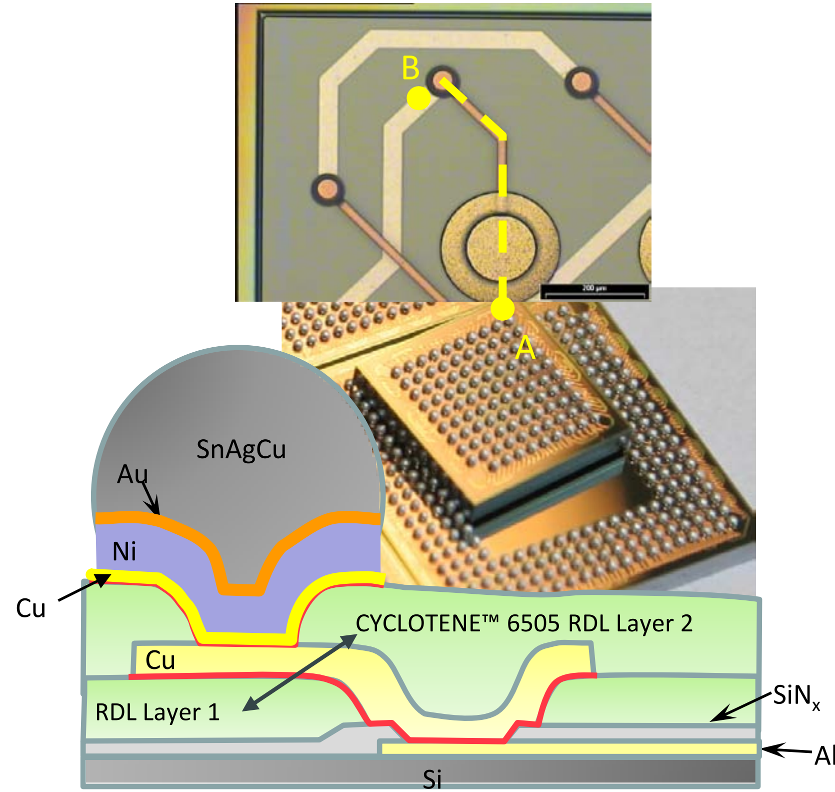


AD-BCB Dielectric Material (Reliability)





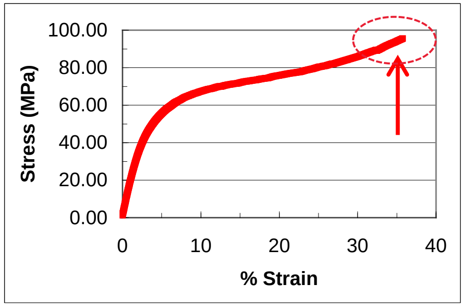
Optical microscopy after HAST (30µm dielectric linewidth)
Electrical resistivity >1E+12 Ω-cm, unchanged after 96hrs
@ 130ºC / 85% RH / 5V bias



- 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℃ to +125℃

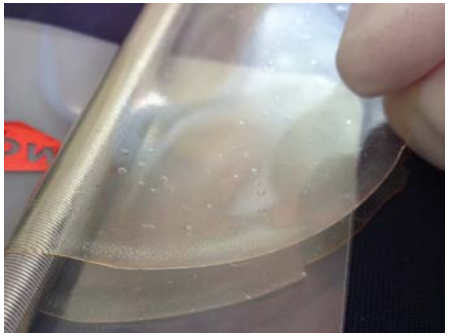
Toughened BCB-based Dielectric Materials

- 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



Elongation >35% achievable

- 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 <u>or</u> neg. tone/solvent developable <u>or</u> laser patternable
  - Long pot life: E_{gel} unchanged after 30 days at RT



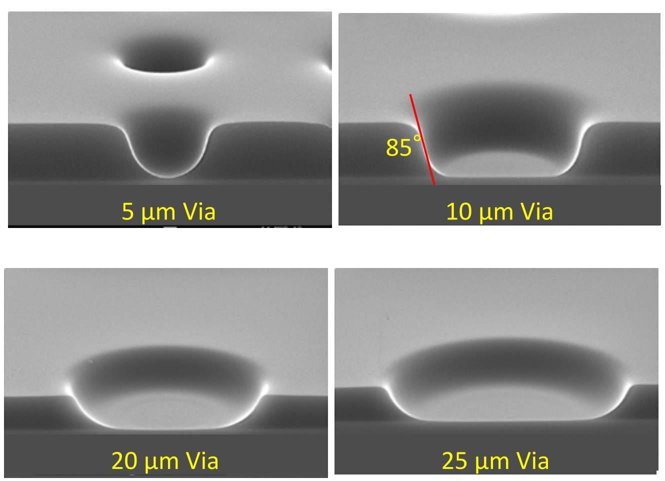
Flexible, transparent ~75μm thick freestanding toughened BCB film

Toughened BCB-based Dielectric Materials (Litho)

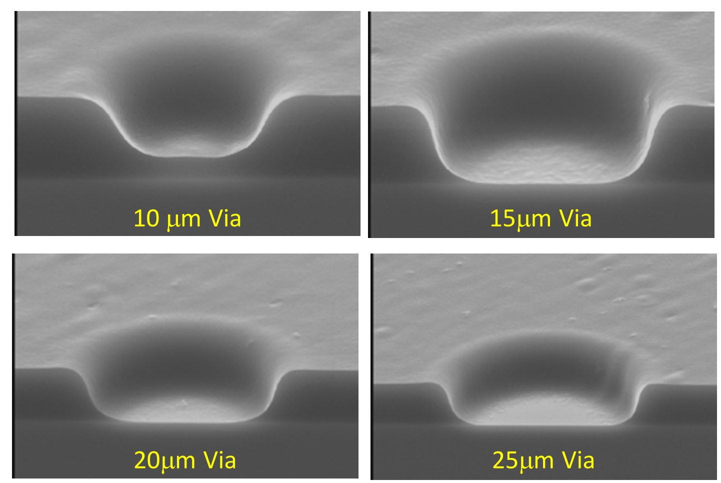
- Spin-on Version
  - Spincoat AP9000S Adh. Promoter, SB 90°C/90s
  - Spincoat toughened BCB Photodielectric, SB 90°C/90s
  - i-line or BB exposure
  - PEB 90°C/90s
  - Solvent develop (DS-2100), Single puddle 15s
  - PDB , SB 90°C/30s
  - Std. low O_2 BCB curing process

- 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 O_2 BCB curing process

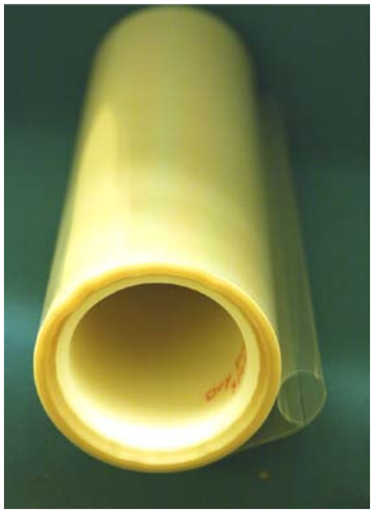
- Lithographic performance (FT = 6.5μm)



- Lithographic performance (FT = 10μm)

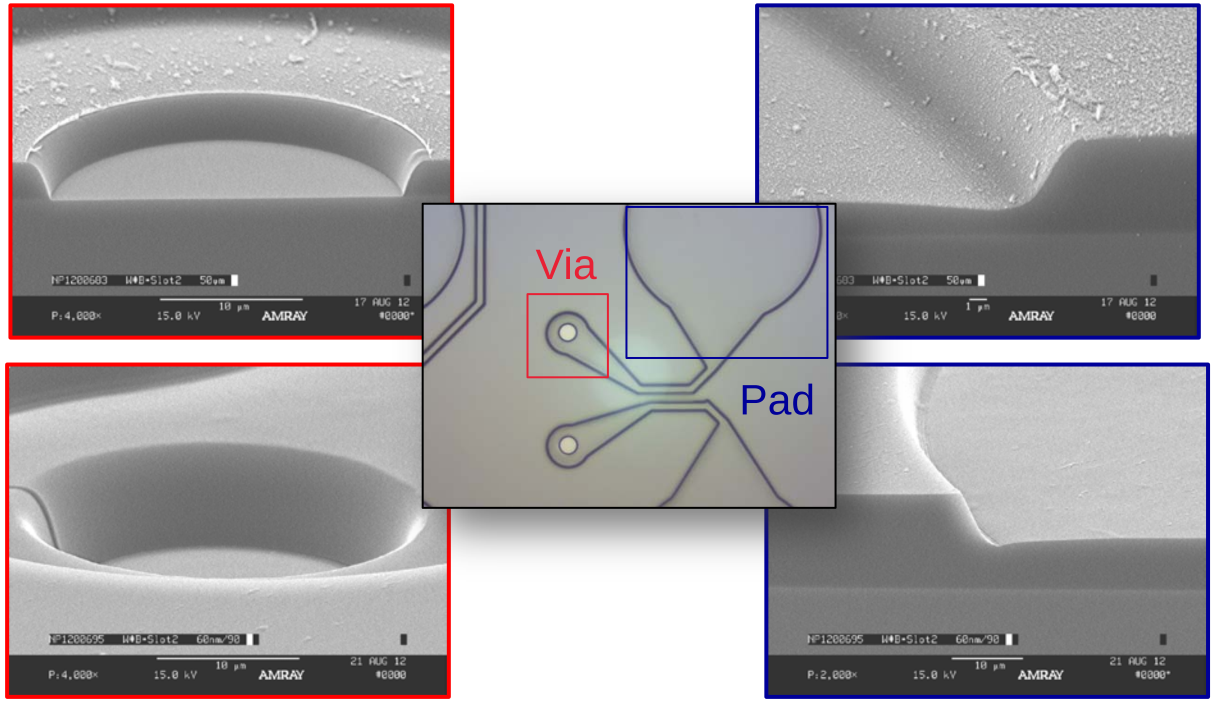


Toughened BCB-based Dielectric Materials (Laser)



Via Pattern

Pad Pattern



- 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

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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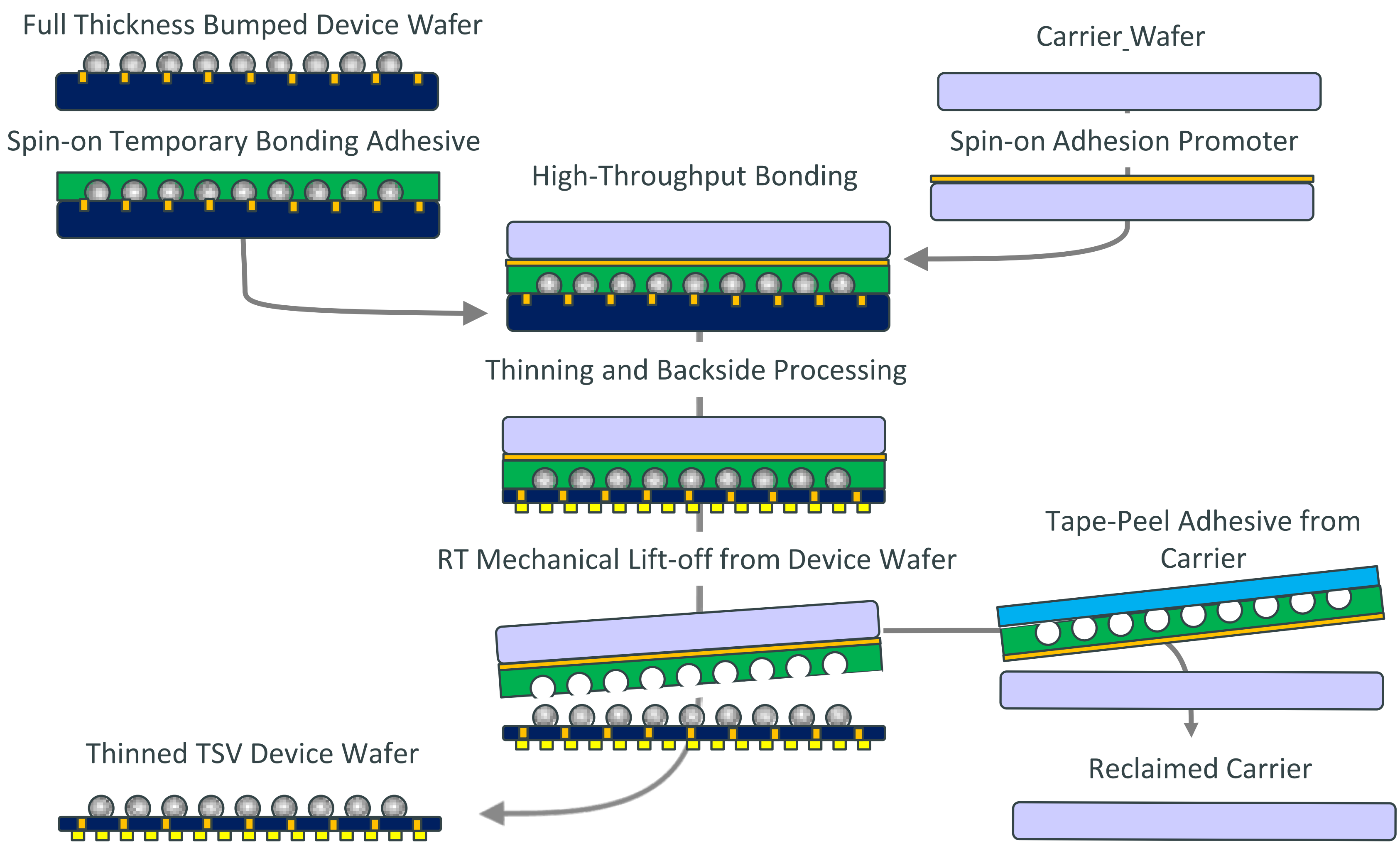
Temporary Wafer Bonding (TWB) Adhesive

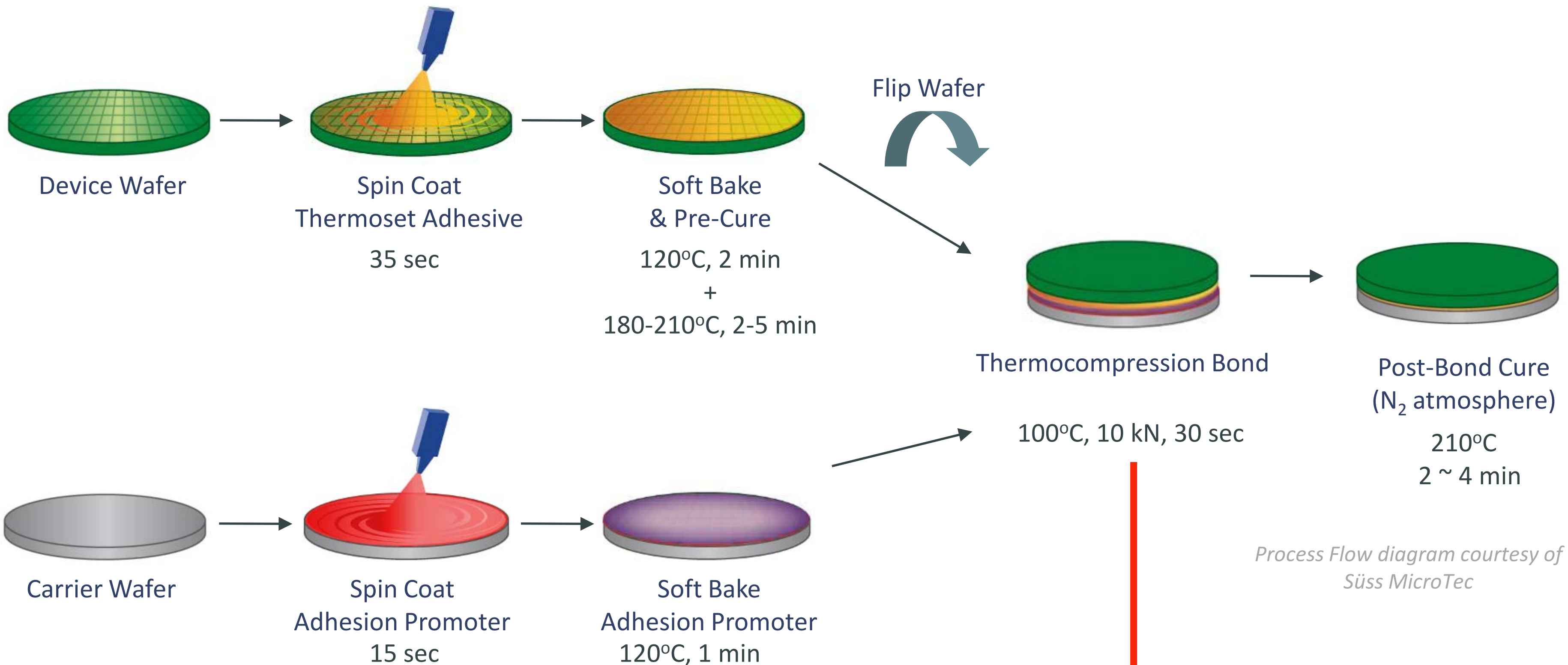
- **XP-130215 TWB Adhesive**

- 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 >100μm.
- Rapid, low temperature curing process
- Cured film has high thermal (300^{o}C) and chemical stability
- Room temperature, mechanical debonding
- Compatible with wafer thinning and backside integration processes

TWB Overall Process Flow



TWB Adhesive Application Process

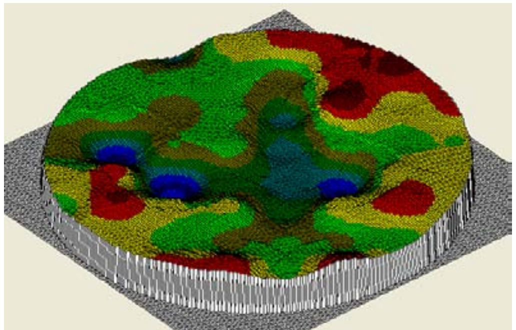


Process Flow diagram courtesy of Süss MicroTec

- Total process time in bonding chamber: ≤2min
- Enables high wafer throughput

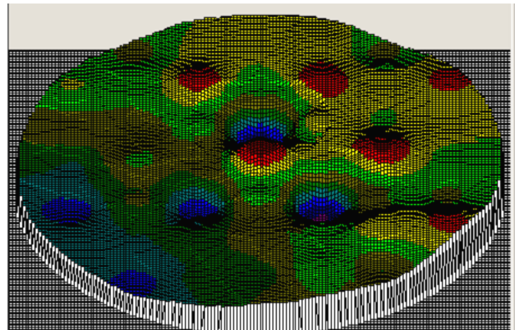
TWB Adhesive Performance (Coating, TTV)

After Coating (Flat Si)



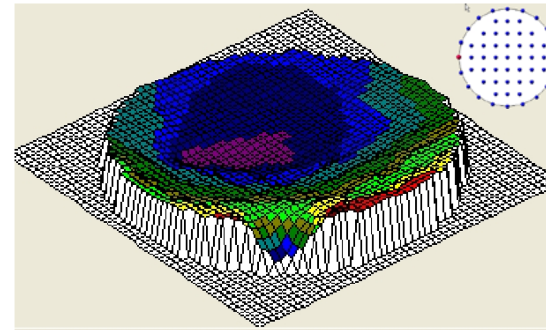
25.6 µm FT; TTV = 0.36µm

After Bonding (Flat Si)



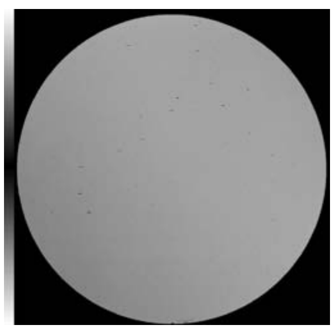
25.6 µm FT; TTV = 3.2µm

After Thinning (Flat Si)



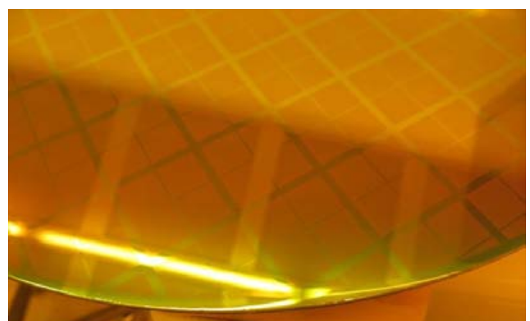
Thinned (50mm) Wafer; TTV = 2.3 µm

After Bonding (Flat Si)



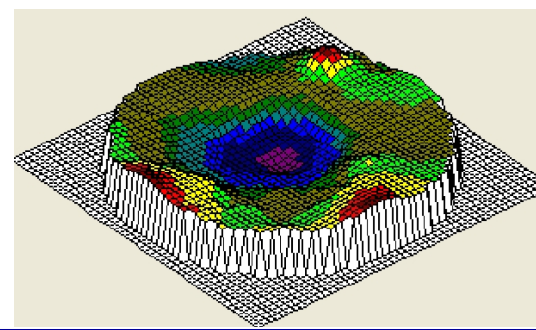
CSAM: Void-Free

After Coating (Cu Pillar)



Defect-Free Coating , 25mm Cu Pillar

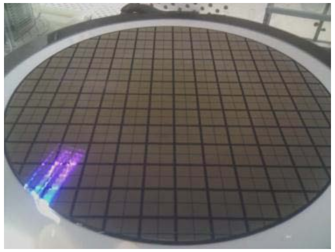
After Thinning (Cu Pillar)



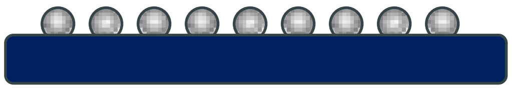
Thinned (50mm) Wafer; TTV = 3.6 µm

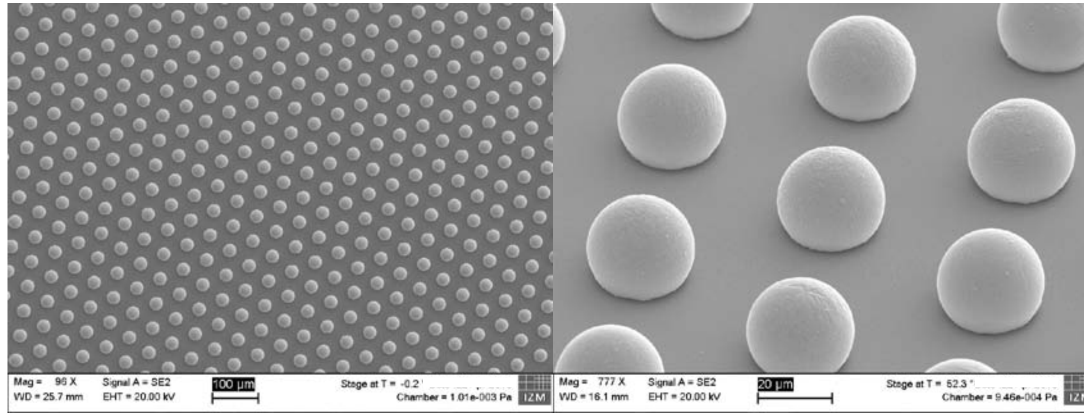
- Low TTV after coating, bonding and thinning – flat Si or over topography

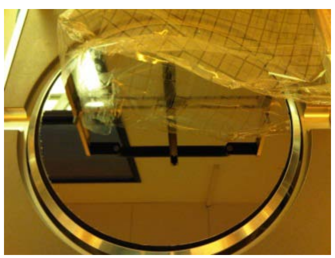
TWB Adhesive Performance (After Debonding)



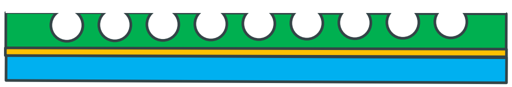
Debonded Device Wafer

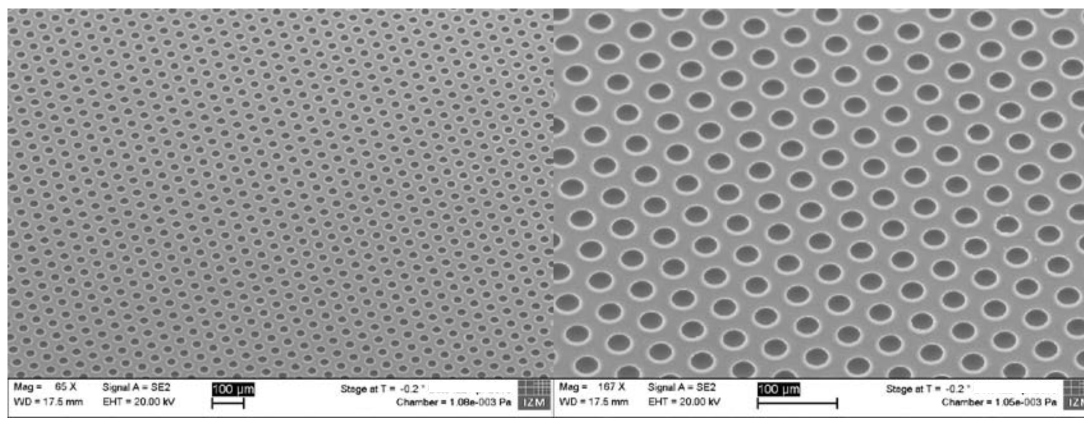






Peeled-off Adhesive Layer





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

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)

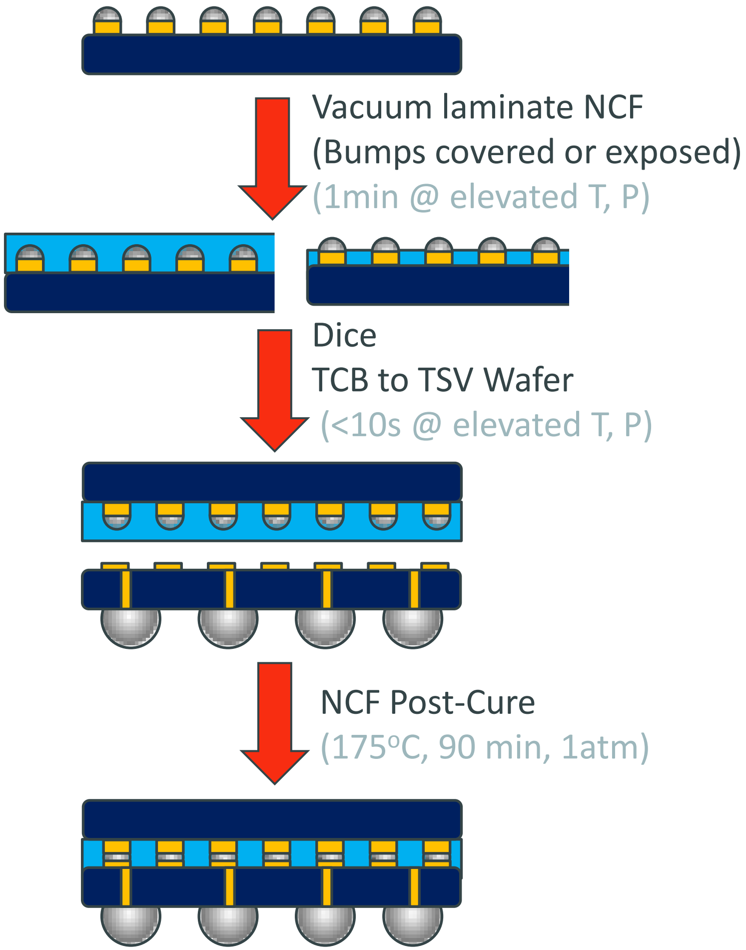
- **XP-130576A NCF***

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

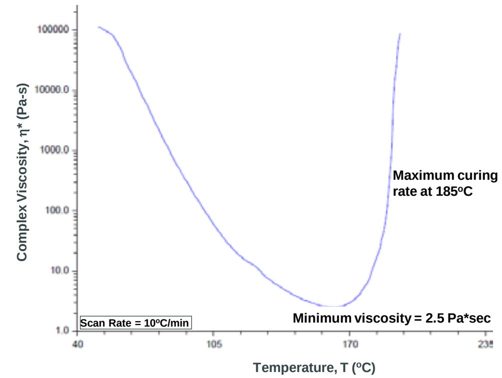
- Silica-filled epoxy based film designed for vacuum lamination application
  - Available in dual-use format with backgrinding tape
- High uniformity coating over topography (Cu pillar/solder cap)
- Good bump and fiducial visibility for dicing and alignment
- Self-fluxing, fast film curing during thermocompression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

NCF Process Overview

Thinned Wafer, Cu μPillar/SnAg Cap



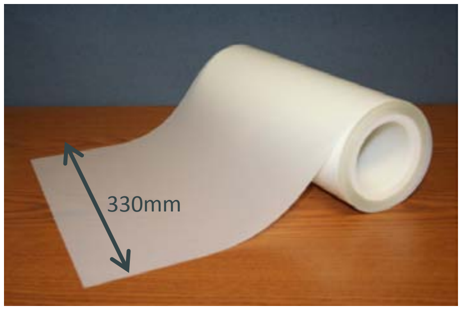
NCF Dynamic Rheology Profile



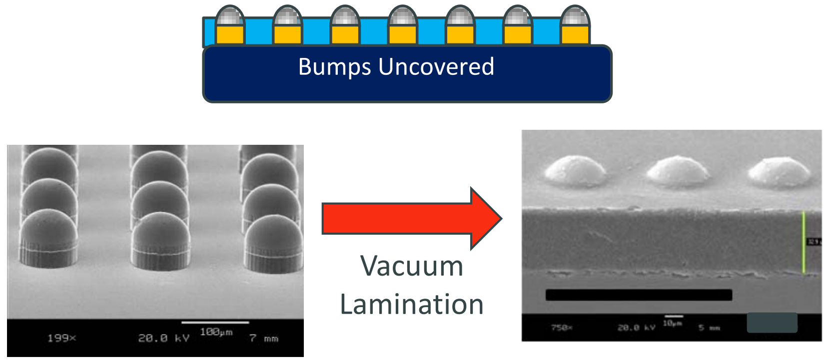
– Representative profile - minimum viscosity and maximum curing rate are tunable

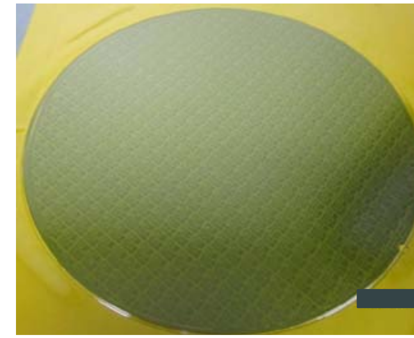
- Key Properties of Cured NCF
  – T_g (TMA): 170ºC
  – CTE (a_1): 25ppm/ºC
  – E: 6.5 GPa

NCF Performance (Coating)

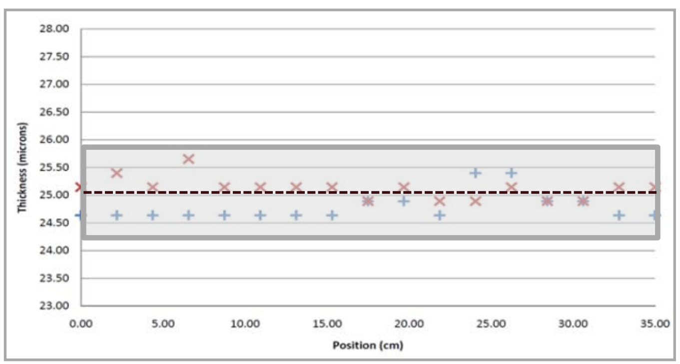


NCF Laminate Film Roll
Film thickness (FT): 20-40µm

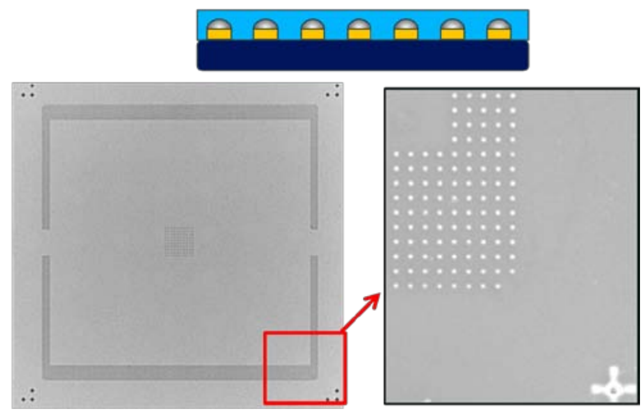




NCF Laminated Wafer
300mm

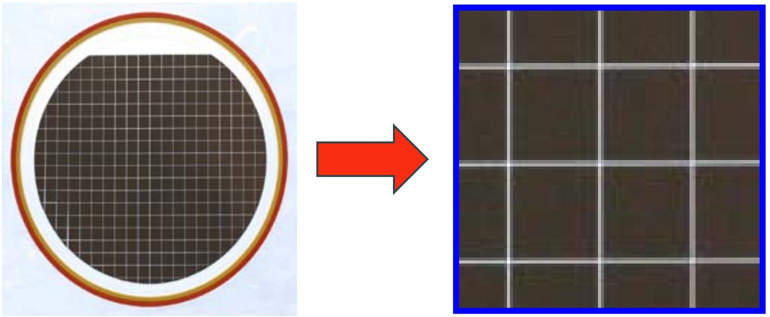


Film Thickness Uniformity
(across 330mm wide roll)
FT: 25 ± 0.5µm (±2%)

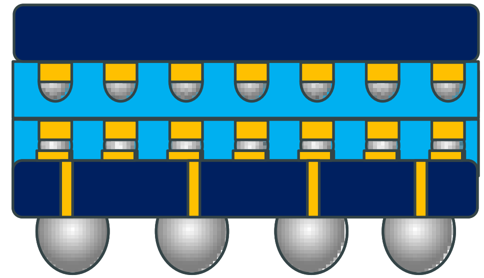


Good Bump Visibility (Covered Bumps)
Viewed through TCB camera
FT: 23µm

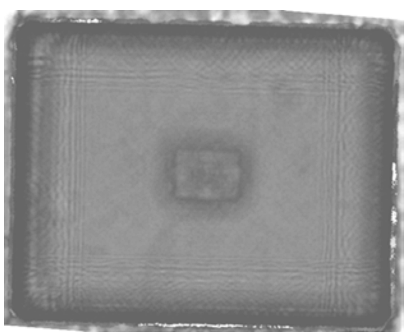
NCF Performance (Bonding)



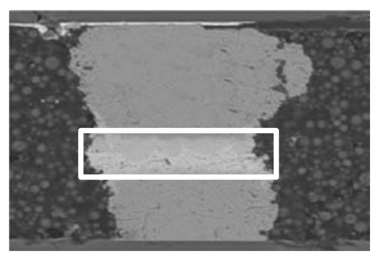
Compatible with Dicing (Mechanical or Stealth)
No cracking, chipping, “hinging” of laminated NCF



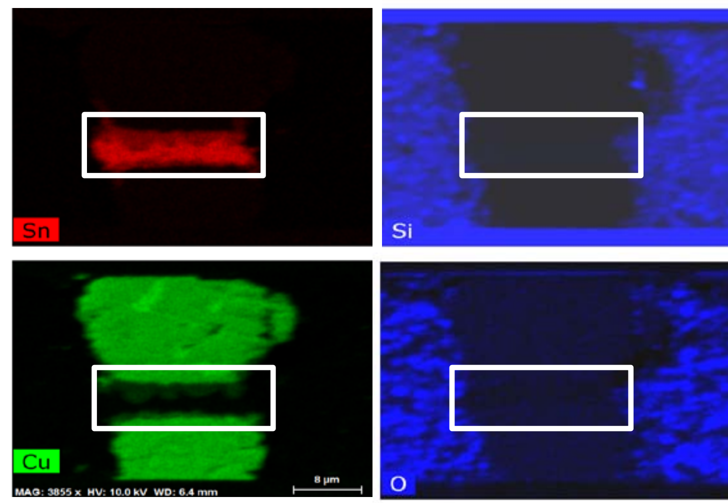
Thermocompression Bonding



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



Good Joint Formation
SEM x-section

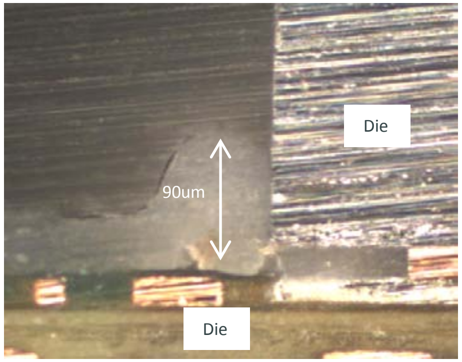


No Filler Entrapment Observed
SEM/EDX analysis

NCF Performance (Reliability)

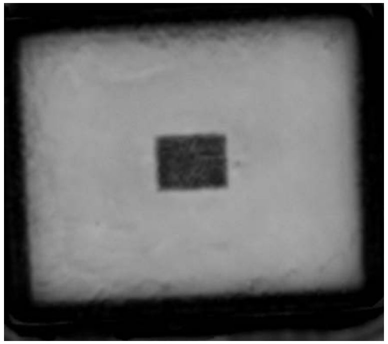
Fillet

Good coverage along die sidewall



MSL3 Test

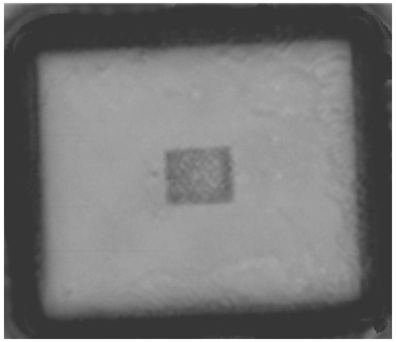
1 week at 30°C/60% RH
+ 3X solder reflow - Pass



Mechanical test structure
- Passed with no delamination or voiding

Thermal Cycle Test

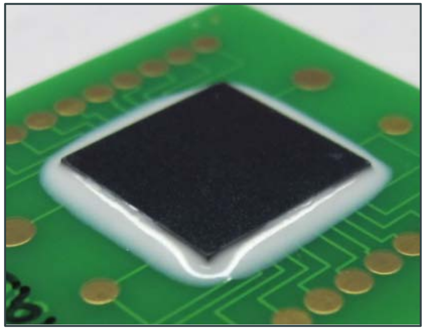
-55 to +125°C, 2000 cycles - Pass



Mechanical test structure
- Passed 2000 cycles with no voiding or delamination

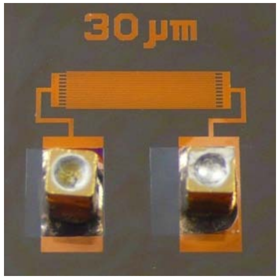
Electrical Testing

Testing in progress (electrically-testable die)



Biased HAST

130°C, 85%RH, 96 hrs - Pass



SIR test structure
- Surface Insulation Resistance unchanged

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

Outline

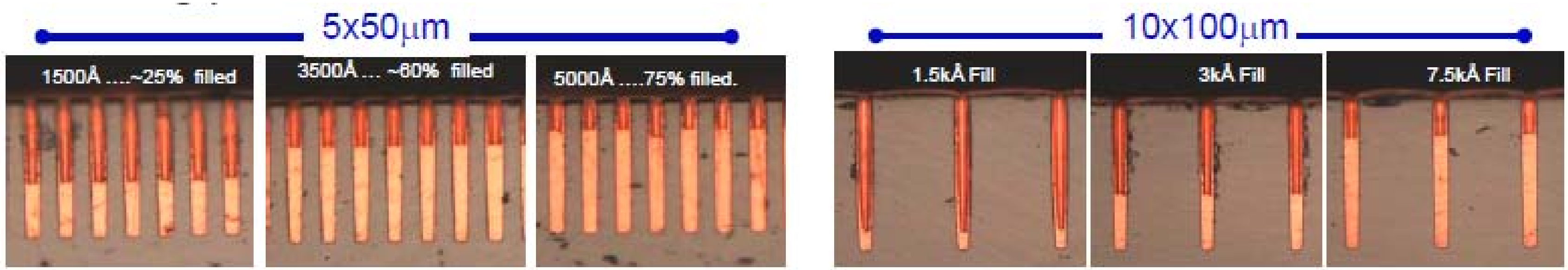
- Introduction
  - Key Materials Needs and Challenges
- Enabling Materials Solutions
  - Dielectrics
  - Temporary Wafer Bonding Adhesive
  - Non-Conductive Film
  - Cu TSV Filling
- Summary

Cu TSV Plating Chemistry

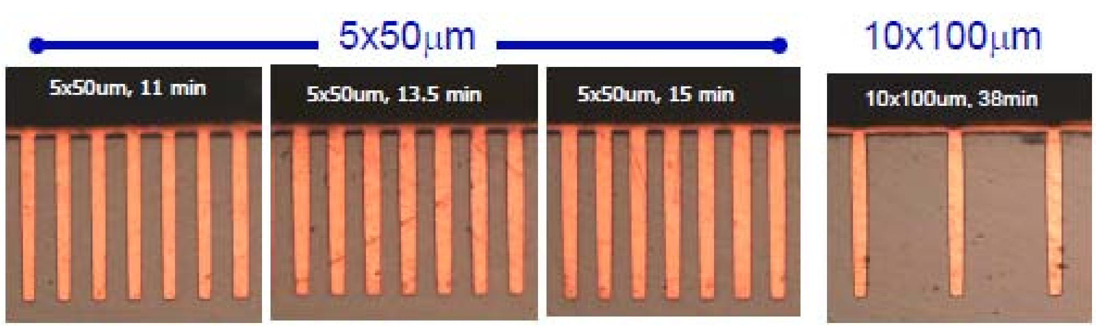
- **INTERLINK™ Cu TSV Chemistry**
- Designed for Interposer and Via Middle TSV Applications
- Bath Components
  - Sulfuric Acid-Based Copper Electrolyte
  - 3 Part Additive System
    - Accelerator: Electrocatalyst for bottom-up filling
    - Suppressor: Suppresses deposition in field, along sidewalls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

Cu TSV Plating Performance (Deposition)

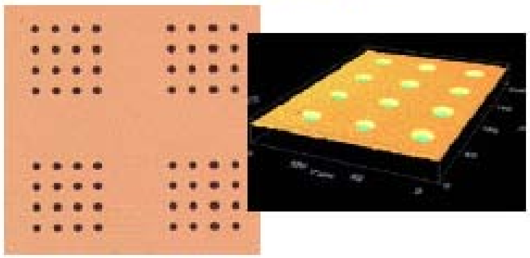
- Partial Filling Sequences: Strong polarization at via opening → ideal filling profile



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



Overburden

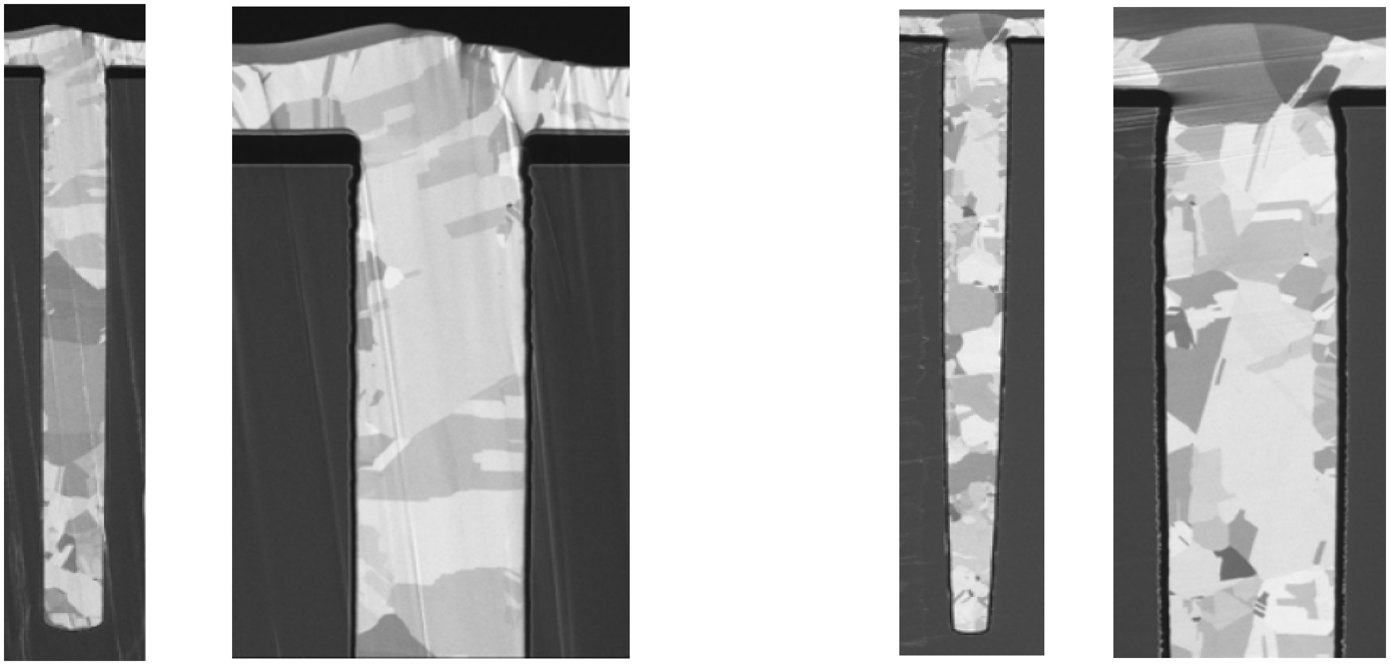


0.80µm OB for 1.5µm Cu deposit
$R_a \leq 10$nm

Test Vehicle source: Applied Materials

Cu TSV Plating Performance (Annealing)

5x50μm

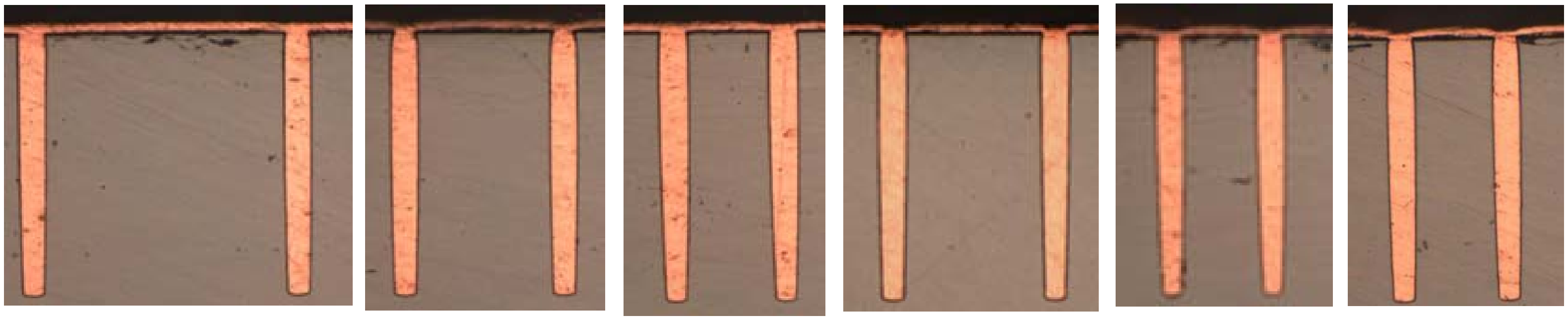


10x100μm

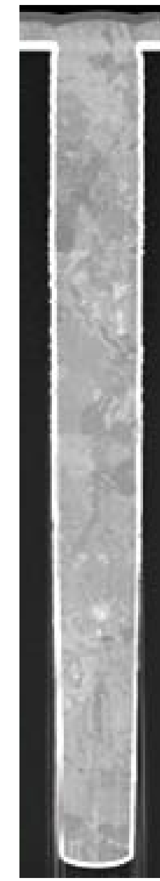
Test Vehicle source: Applied Materials

- Consistent via filling across 300 mm wafer in production toolset
- Cu TSVs annealed at 400^{o}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)



Fresh Bath | 1.7Ahr/L | 3.5Ahr/L | 6.8Ahr/L | 11.1Ahr/L | 13.8Ahr/L (aging study stopped)



After Annealing

- 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

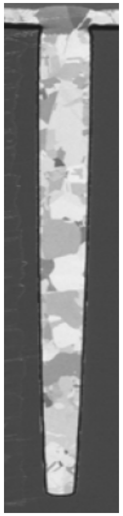
Test Vehicle source: Applied Materials

Cu TSV Plating Summary

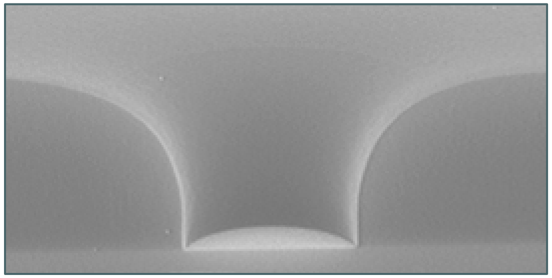
- **INTERLINK^{TM} Cu TSV CHEMISTRY:** New product developed for Cu TSV interposer and via middle applications
- Fast filling times and low overburden → lower CoO
- Void-free filling, low defects, high purity deposit → high reliability/yield
- Online bath metrology available
- Customer evaluations ongoing

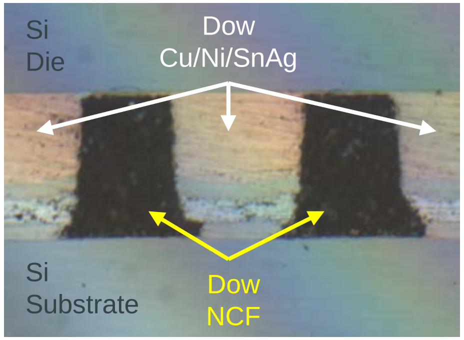
Summary

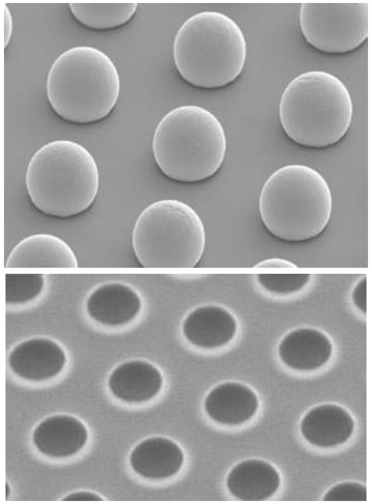
- 2.5D/3D-TSV is a complex landscape with many different materials requirements
- Dow has successfully developed enabling new products that are tailored for these applications
  - New Dielectrics, Temporary Wafer Bonding Adhesive, Non-Conductive Film, TSV Cu filling
  - Fast, simple processes → high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



Test Vehicle source: Applied Materials







Thank You