Automation of Die Attach of Si onto Cu using BondFlow™

IMAPS New England 44th Annual Symposium & Expo
May 2, 2017

Jim Fraivillig
Fraivillig Technologies
Rich Koba & Kent Hutchings
Materion
Peter Cronin
MRSI Systems

Outline

- Summary of *BondFlow*
- Trends in Packaging of High Power Devices
- *BondFlow* experiment
- Results bonding to bare Al and to plated Cu
- Future investigations

BOTTOM LINE on TPI Bondflow™

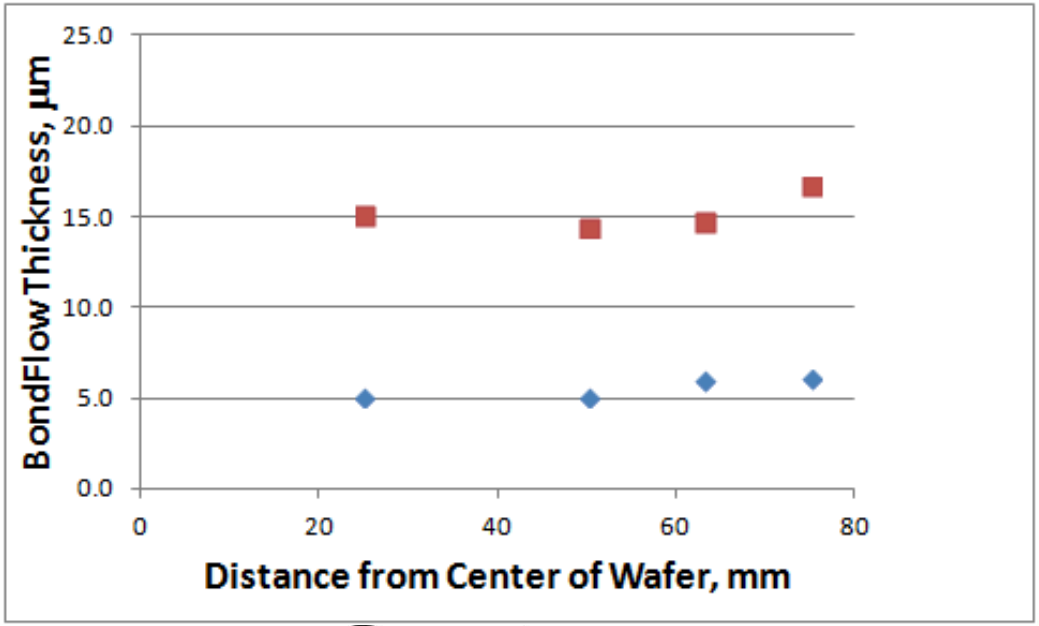
- Spin-coatable, backside die attach adhesive that bonds well to bare Al and to ENEPIG-plated Cu
- Durable bondlines between CTE-mismatched substrates, even Si-on-Al and Si-on-plated Cu
- Robust polyimide properties, including ductility (linear thermoplastic polymer vs cross-linked thermoset)
- Thin bondlines after cure (3 - 15 µm, with Ag-loading)
- Thermoplastic bonding process is very 'automatable', with short cycle times and high throughput
- B-staged BondFlow™ cures on a hot plate at 250˚C after only 2 seconds under pressure
- Electrical resistivity of <1E-4 Ω-cm.

MATERION

MRSI SYSTEMS

What is *BondFlow™*?

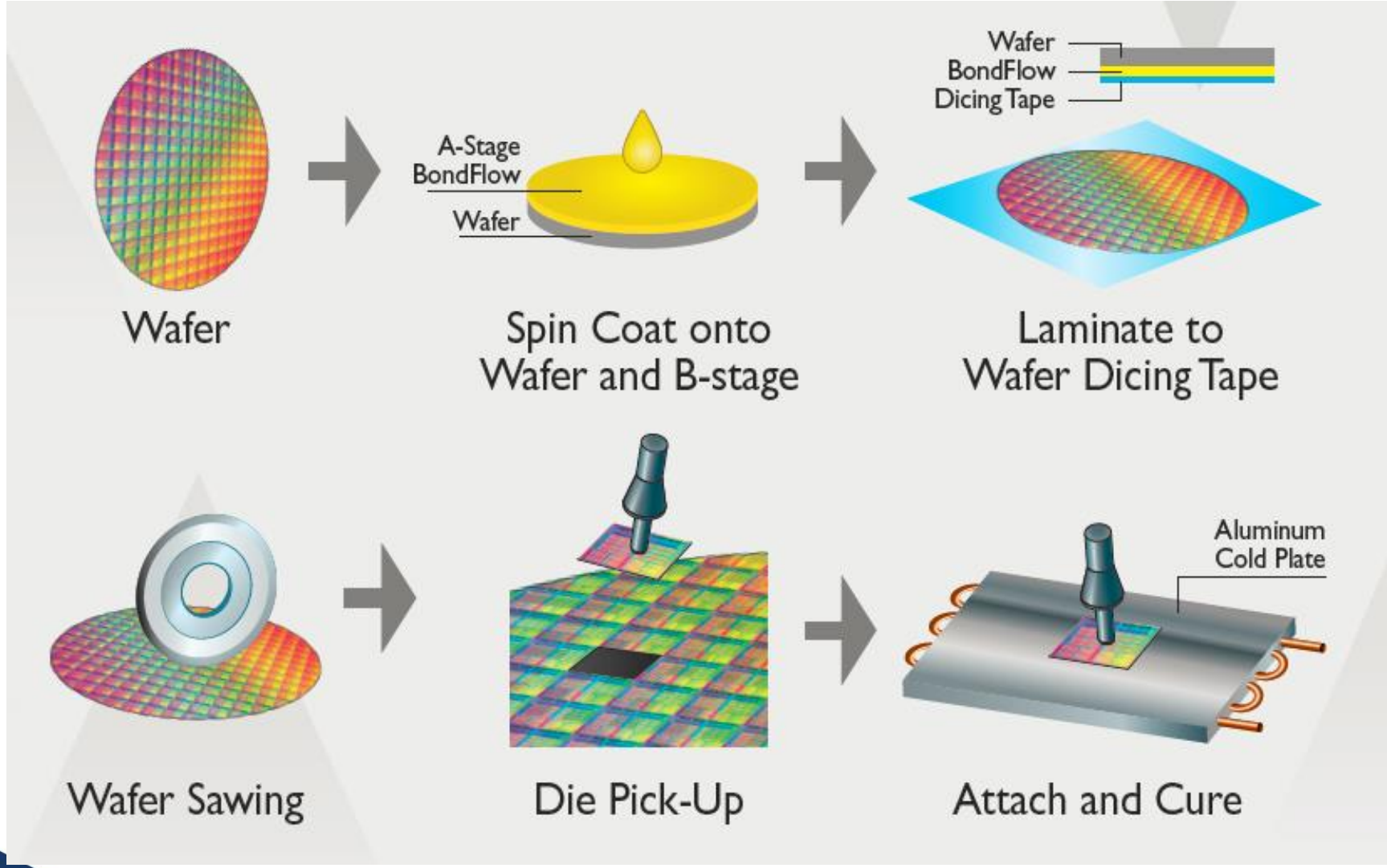
- BondFlow™ is A-Stage TPI filled with silver particles.
- BondFlow™ has a low enough viscosity to be deposited by spin coating or slot die coating.
- BondFlow™ can be B-staged into a non-tacky solid with a long shelf life at room temperature.
- BondFlow™ spin-coated coatings are very consistent



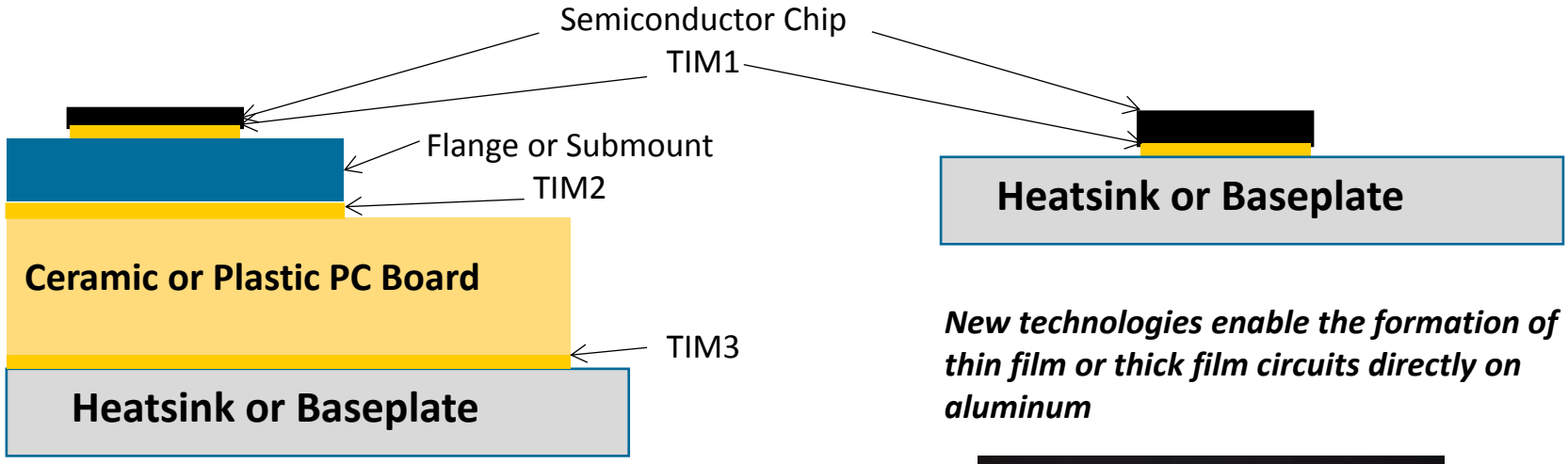
MATERION

MRSI SYSTEMS

Process Flow with BondFlow™



Trend in Packaging: Reduce the Number of Layers!



New technologies enable the formation of thin film or thick film circuits directly on aluminum

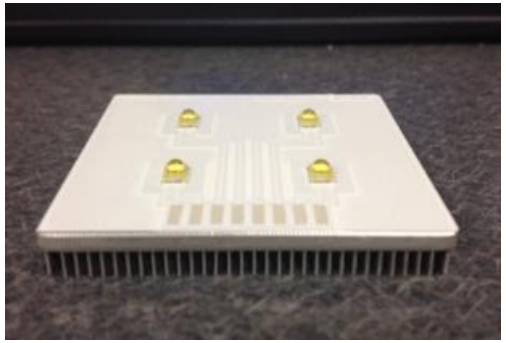
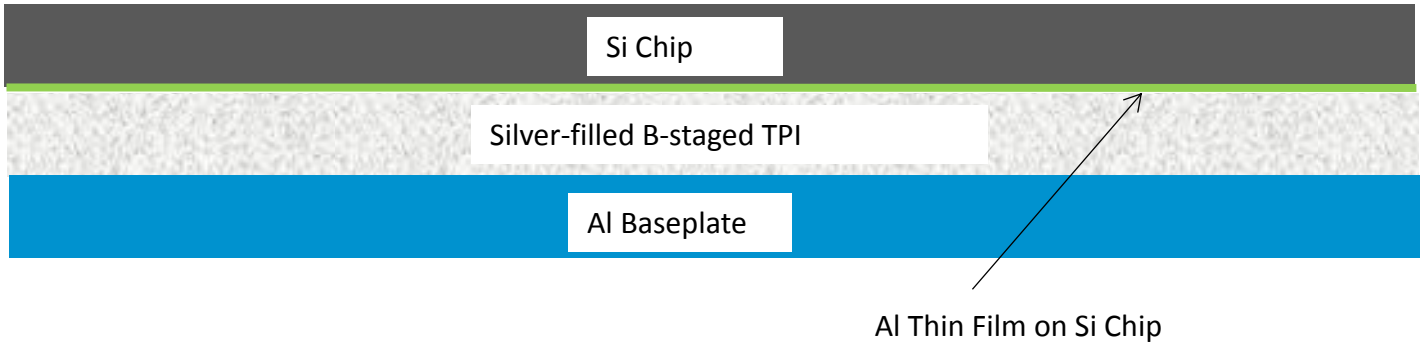


Image courtesy Heraeus *Celcion*

New TIM1 die attach materials must strongly adhere to both the semiconductor chip (Si) and baseplate (Al) despite the severe mismatch in CTE.

What is *BondFlow™*?



Schematic Cross Section (not to scale)

BondFlow can be tailored to the particular application by varying:

- viscosity
- thickness of B-staged coating
- weight % loading of silver particles in TPI

BondFlow™ can be Spun-On the Backside of a Wafer

1. Aluminum coated wafer backside
2. Spin on BondFlow
3. B-stage at 125-150˚C in air
   - *Not tacky after B-staging*
4. Dice with diamond saw
   - *B-staged TPI can contact the dicing tape*
5. Pick and place dice from tape onto substrate heated on a hot stage
6. Apply pressure to cure at 250˚C in air

Wafer Backside Spin Coating

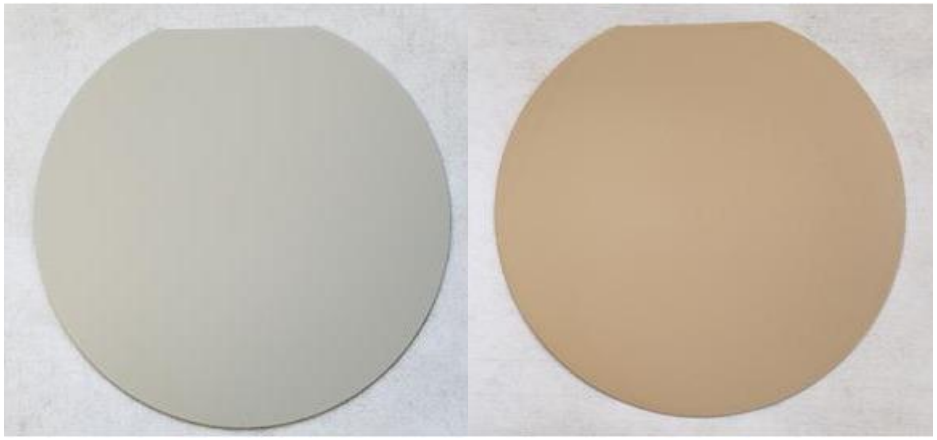
- Silicon 150 mm Ø x 680 μm wafer with Aluminum metallization
- Diced into 3.6mm x 3.6mm squares

Wafer #	Wt % Ag in C-stage	RPM on Spin Coater	B-Stage thickness by mass, μm
668022 "1B"	80%	1500	6.7
668023 "4B"	80%	500	19.4

Wet (A-stage) spun coating on wafer
(reflection of brick wall visible on coating)

B-staged ~7 μm Coating

B-staged ~19 μm Coating



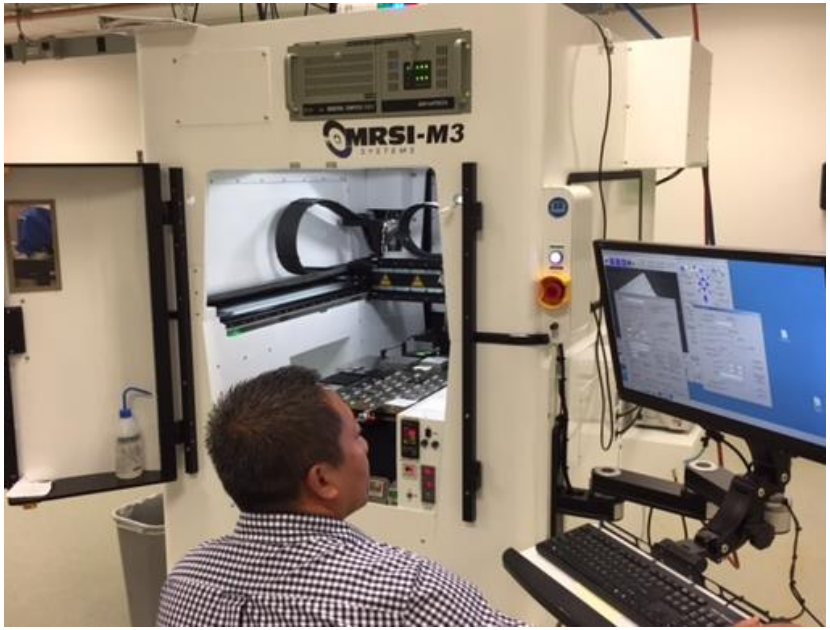
MATERION

MRSI SYSTEMS

MRSI Systems *M-3* Automatic Die-Attach System

Capabilities

- Hot stage up to 500˚C
- Pick and place to ±3µm
- Collet control
  - Programmable load
  - Scrub Option
- High speed, automatic operation
- Options:
  - Lift dice off the dicing tape
  - Tape-and-reel pick up and placement



MATERION

MRSI SYSTEMS

BondFlow Automated Die Attach Investigation

Ø150mm Si wafer 680 µm (0.027”) thick

- Backside coated with 100nm Al
- Backside spun coat with Ag-filled BondFlow at 1500 and 500 RPM to produce 2 thicknesses
- B-staged in air at 150˚C; 10 min. for thinnest and 20 min. for thickest coating
- Diced into 3.6mm x 3.6mm squares

BondFlow:

- 80 wt% Ag
- Two grades of Ag evaluated
- Viscosity = 9800 cP at 24˚C with a Thixotropic index of 2

Substrate:

- Al 6061 plates 1” x 0.7” x 0.125” (Surface R_a = 0.05 µm)
- Surface prep: wiped with isopropanol

Die attached & Cure in the MRSI M-3 Die or 705 Attach System

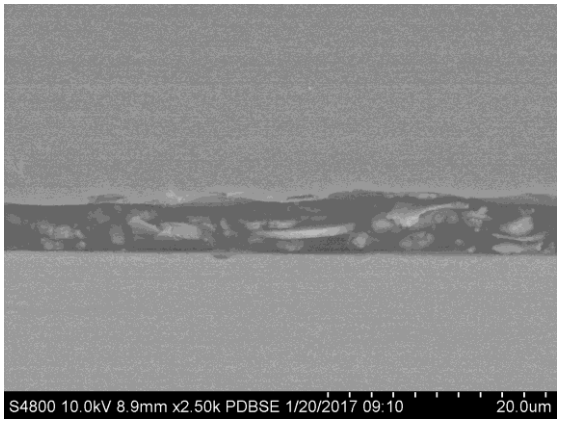
- Four dice per substrate
- Heat substrate on hot plate at 250˚C for 20 – 85 seconds
- Bond each die under pressure for 2 seconds
- Pressure of 188, 376, 750 or 1128 kPa (250, 500, 1000 and 1500 gf)

MATERION

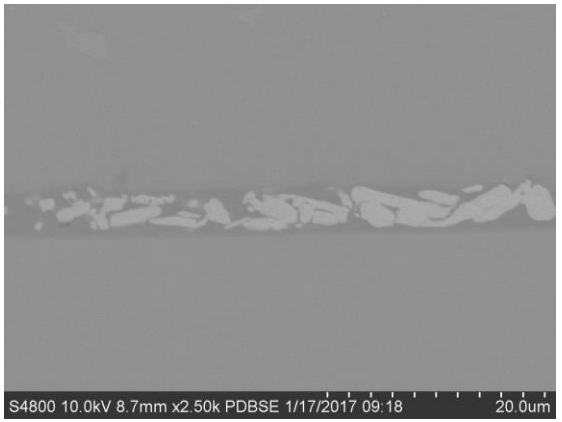
MRSI SYSTEMS

BondFlow Cross-Section Micrographs

Thin Bondline

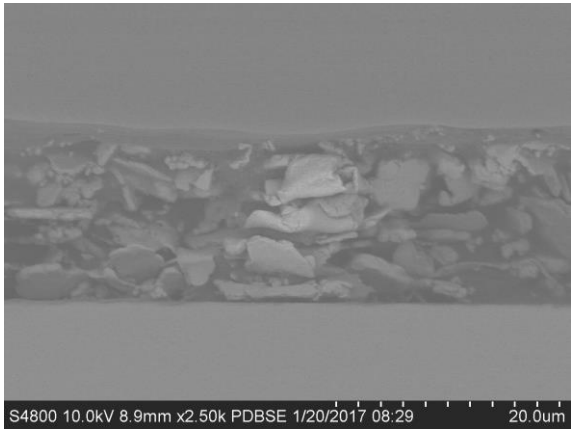


SEM of as-sawn cross-section of B-staged BondFlow on Si die.

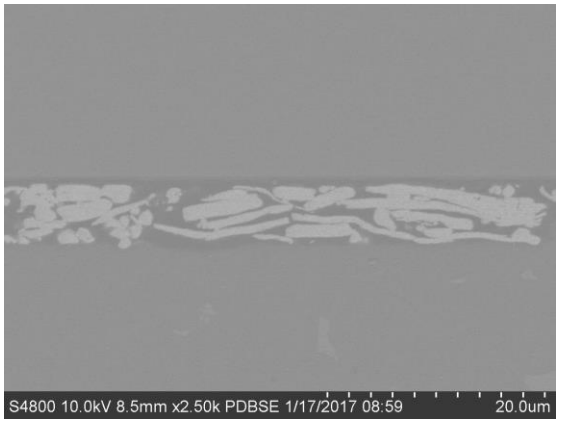


SEM of polished cross-section of cured BondFlow bonding Si to Al

Thick Bondline



SEM of as-sawn cross-section of B-staged BondFlow on Si die.



SEM of polished cross-section of cured BondFlow bonding Si to Al

MATERION

MRSI SYSTEMS

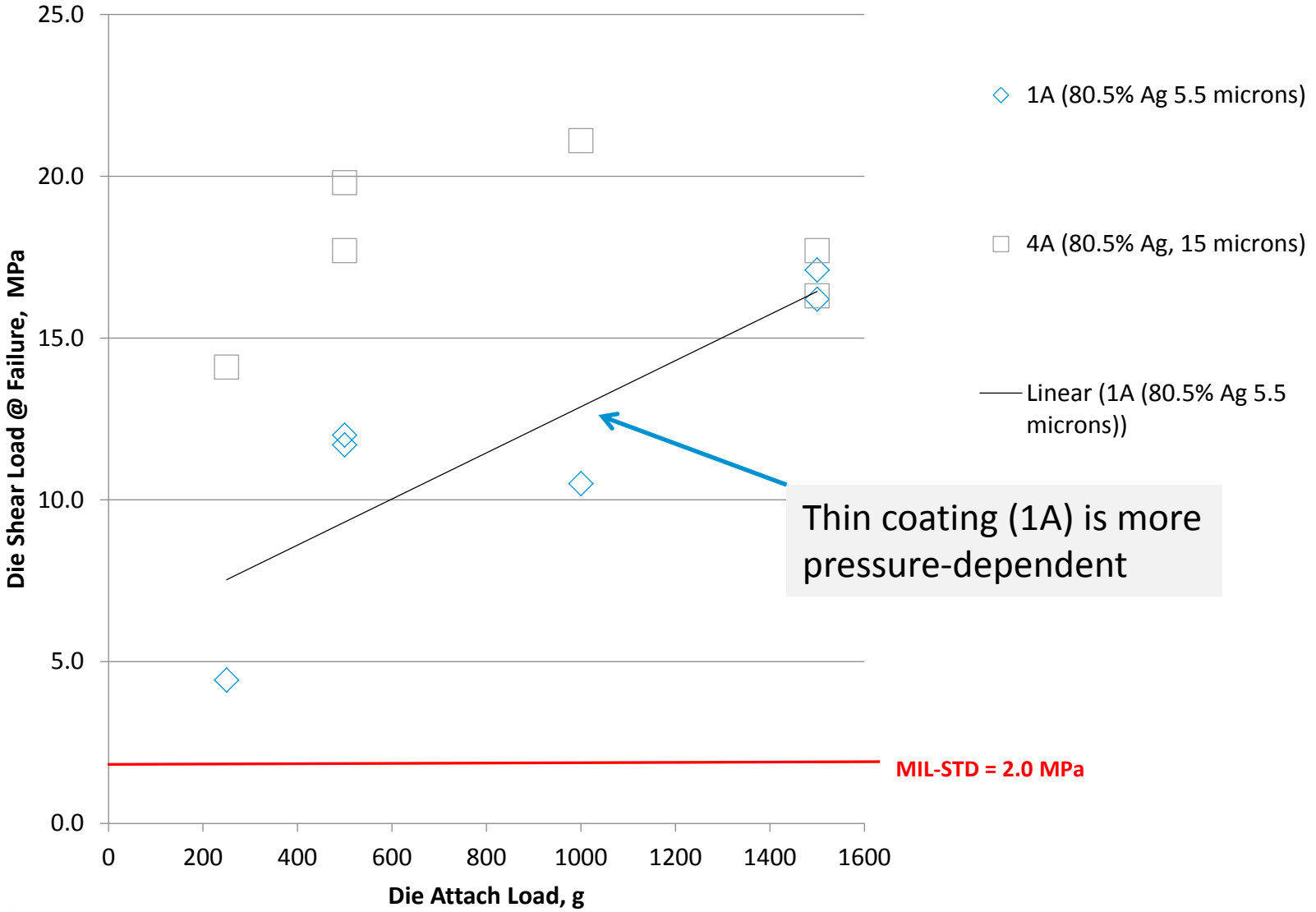
Summary of Coating Conditions

- Aluminum metallized Silicon wafers
- Each die under pressure for 2 seconds: 250, 500, 1000 or 1500 gf (27, 54, 108 and 162 psi or 188, 376, 750 and 1128 kPa.)
- Thickness measured after B-stage: ~5 µm and ~15 µm
- Thickness measured after cure: 4.7 µm and 6.2 µm
- Reduction in thickness after cure was greater for the thicker B-staged layer

MATERION

MRSI SYSTEMS

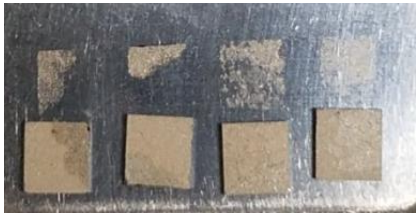
BondFlow Die Shear Results



MATERION

MRSI SYSTEMS

BondFlow Die Shear Images

High Ag Loading (~80 wt%)	Thin BondFlow (~5 μm)	Thick BondFlow (~15 μm)
	High Bond Load (1500 g) Shear 16.2 ±3.7 MPa 	High Bond Load (1500 g) Shear 17.6 ± 7.8 MPa 
	Low Bond Load (250 g) Shear 14.4 ± 2.7 MPa 	Low Bond Load (250 g) Shear 14.1 ± 5.2 MPa 

Next Experiments:
Investigate Effects of Ag Loading and Substrate Material

Substrates

- Al-coated Si
- Alumina
- BondFlow B-staged onto the Substrate
- Diced into 3.6 mm x 3.6 mm squares

BondFlow:

- 80 wt% Ag
- Two grades of Ag evaluated
- Viscosity = 9800 cP at 24˚C with a Thixotropic index of 2

Substrate:

- Eless Ni + Eless Pd + Immersion Au plated copper 1” x 0.7” x 0.06”
- Al 6061 plates 1” x 0.7” x 0.125” (Surface R_a = 0.05 μm)
- Surface prep: wiped with isopropanol

Die attached & Cure in Manual Hydraulic Press

- 100 psi (690 kPa) per die
- 3 - 5 minutes at 250˚C

BondFlow Formulation & Characterization

BondFlow Formulation: 80 wt% Ag lot 667960-2 NP-771-17-2

Composition checked by LOI at 800C wt% Ag = 80.8 wt % (80.2% target)

Viscosity measured using Brookfield RVT viscometer with Spindle RV3

Adhesion Strength measured by bonding Al_2O_3 dice (3.6mm x 3.6 mm x 1 mm) to ENEPIG plated Cu coated with 667960-2 BondFlow (MIL-STD-883 Method 2019.7)

Volume electrical resistivity measured by Four Point Probe (MIL STD 883 Method 5011.4)

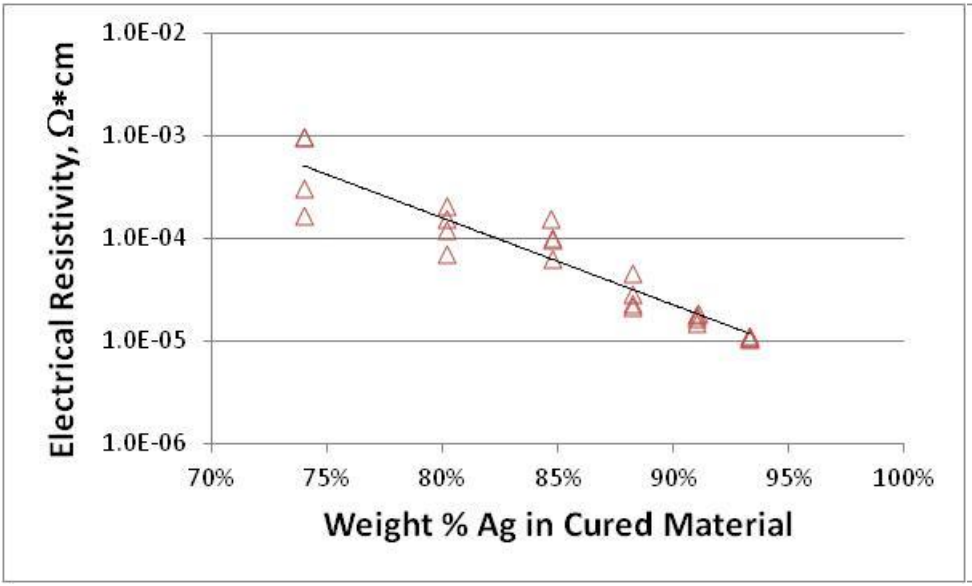
667960-2 80 wt% Ag BondFlow

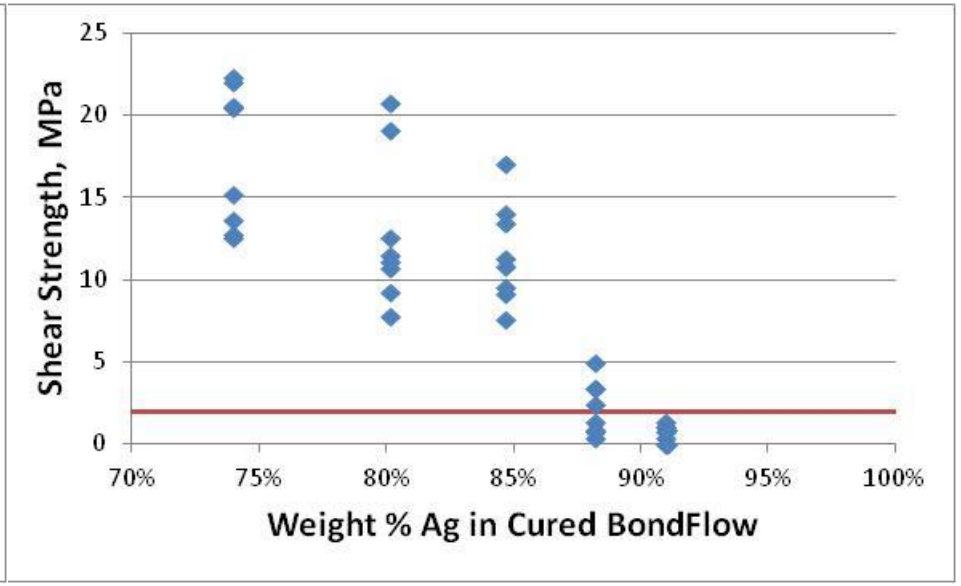
RPM	Viscosity, cP
1	14,200
2.5	10,000
5	8,140
10	6,900
Average	9,810
Thixotropic Index	2.06
Temperature, °C	24

RVT Viscometer Measurement: BondFlow is Thixotropic

Resistivity and Adhesion Strength vs Ag %

- Electrical resistivity decreases with increasing Ag
- Bond strength is acceptable until > 85 wt% Ag where a drop in strength is observed





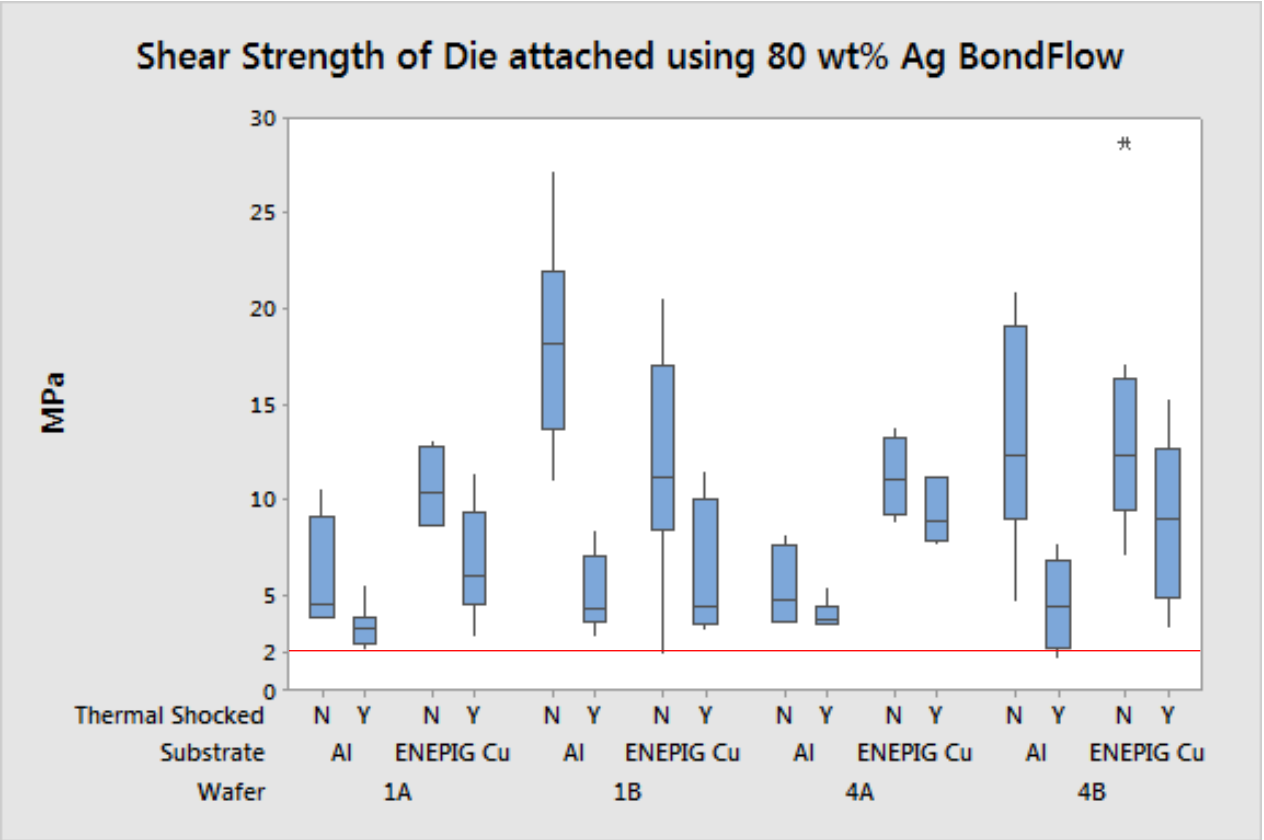
Die-Shear Strength

- Manual Die attach using laboratory heated platen press
- Bonding of 3.6mm x 3.6mm Silicon die coated with BondFlow

Wafer	Thickness, μm	Ag Grade
1A	5	A
1B	7	B
4A	15	A
4B	19	B

Bonded @ 250°C for 3 minutes

Thermal Shock Process:
Remove from 250°C hot platen and place on RT Aluminum Block with water on top; quickly cools to RT.
Repeated10X



Conclusions: Adhesion strength to ENEPIG Cu retains its strength better after thermal Shock than adhesion strength to Aluminum; likely due to lower CTE mismatch.

Bond Strength Retention after Severe Thermal Shocks

*250°C => 25°C in 1 second…**10X***

Die-shear loss with Thermal Shock		
	------ Substrate ------	
Coating	ENEPIG Cu	Al
1A	38%	43%
1B	50%	72%
4A	17%	26%
4B	33%	66%

RESULT: ***Plated copper retains die-shear strength more than aluminum, likely due to lower CTE-mismatch.***

MATERION

MRSI SYSTEMS

Electrical Resistivity of a 80 wt% Cured BondFlow with Silver Particles

Measured by 4-Point Probe per MIL-STD 883 Method 5011

Volume resistivity ρ < 1E-4 Ω-cm

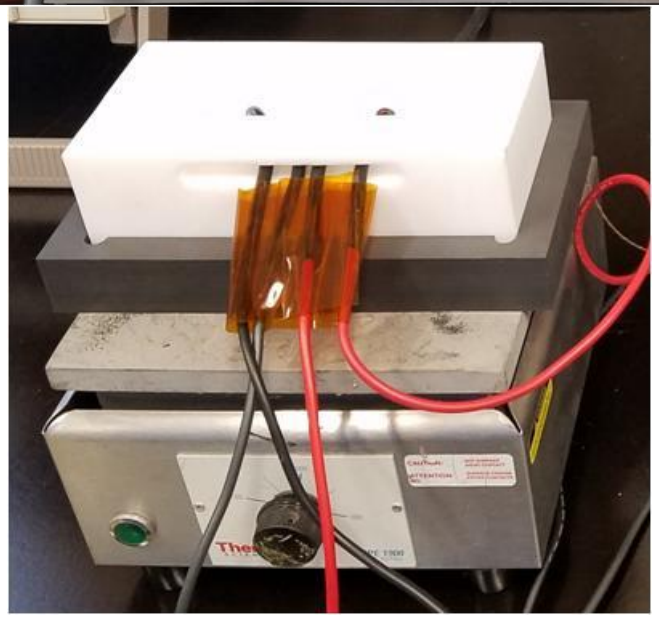
This volume resistivity is similar to most silver-filled die-attach epoxies

MATERION

MRSI SYSTEMS

Volume Resistivity Measurement Setup

- 4 wire (4 point) mode. Average of at least 100 data points.



Discussion

- BondFlow is a user-friendly adhesive that can be spin- coated onto Al metallized Si wafers and then B-staged.

- Since B-staged BondFlow is not tacky, it can be placed onto dicing tape to enable automated die attach. Shelf life of B-staged film at room temperature is several years.

- Curing can be achieved onto a Al substrate heated to 250°C after only 2 seconds under pressure. Curing is complete on the hot stage; no need to pass the part through a curing oven.

- All samples examined exceeded the MIL-STD die shear specification of 5.5 lbs (2 MPa or 289 psi) despite the large CTE difference between Si and Al, and between Si and Cu.

- Degradation of shear strength after thermal shock was less for Si-on-Cu than for Si-on-Al.

Dielectric BondFlow Also Available

- Filled with thermally conductive ceramic particles
- Can be spin-coated
- Die shear strength exceeds MIL-STD-883 Method 2019.7
- Thermal conductivity ~1 W/m-K
- Dielectric strength 140 V/µm
  - By comparison, dielectric strength of 96% alumina is 8.3 V/µm

Potential Applications

- Die attach of high power Si, GaAs or SiC dice to
  - Al or Cu heatsinks
  - Ceramic heatsinks
  - Diamond
  - Metal matrix composites
- High-temperature electronics
- Stacked dice, System In Package (SIP)
- TIM2 applications: e.g., LED submounts onto Al heatsinks

- *Any others??*

Future Investigations

- Measure thermal conductivity
- Additional temperature cycle air-to-air per MIL-STD-883 1010.8 (-65˚C to +150˚C)
- C-SAM imaging of bondline

Please provide your suggestions!

Special Thanks to:

- Jack Inocencio, Julius Ortega, John Hayes, Jon Medernach and Michael Chalsen

  MRSI Systems

- Kazoua Lor, Dennis Hoefs and Jayne Spanos

  Materion

Future Investigations

- Measure thermal conductivity
- Additional temperature cycle air-to-air per MIL-STD-883 1010.8 (-65˚C to +150˚C)
- Thermal soak at 175˚C for 1000 hrs.

Please provide your suggestions!

Thank you!

Jim Fraivillig
Fraivillig Technologies
145 Pinckney Street, Unit 401
Boston, MA 02114
Phone: 512-784-5698; Email: jim@fraivillig.com

Rich Koba and Kent Hutchings
Materion Advanced Materials Group
407 North 13th Street
Milwaukee, WI 53233
Phone 978-478-8739; email Richard.Koba@materion.com

Peter Cronin
MRSI Systems
101 Billerica Avenue
North Billerica, MA 01862
Phone 978-667-9449; email: Peter.Cronin@mrsisystems.com