Photo-Imageable Dielectrics Enabling Structured MEMS and 2.5D / 3D Bonding Systems

IMAPS 2022

David Danza, Colin Hayes, Kevin Wang, Greg Prokopowicz, Paul Berry, Masaki Kondo, and Michael Gallagher

DuPont Advanced Packaging Technologies

Agenda

- Introduction
- Dielectric Materials for Bonding Applications
- BCB Permeant Wafer Bonding
- Photo-patternable BCB Bonding
- Testing of Bonded Structures
- Future Work and Conclusion

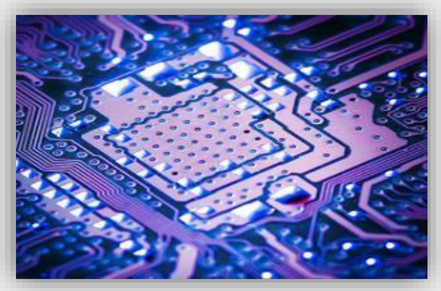
Electronics & Industrial: Our Businesses

Industrial Solutions

Specialty industrial materials, including flexographic and digital printing materials, OLED materials and display process chemicals, silicones for healthcare and industrial applications, and precision parts and elastomers for semiconductor, industrial and automotive applications

- Kalrez®
- MOLYKOTE®
- Cyrel®
- Vespel®
- Liveo™
- Artistri®

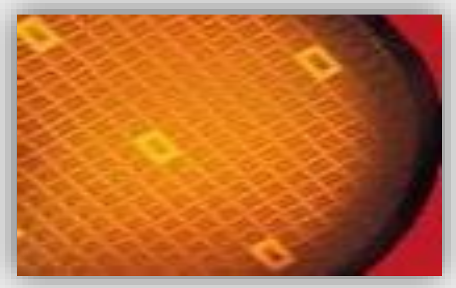
Interconnect Solutions



Metallization, imaging, surface treatments and films to enable smaller and multi-functional printed circuit boards

- Kapton®
- Riston®
- Pyralux®
- Microfill™

Semiconductor Technologies



Advanced materials for integrated chip fabrication and packaging to enable improved connectivity, power, functionality and performance

- Ikonic™
- Solderon™
- Intervia™
- EPIC™

A global technology leader with a unique depth and breadth of knowledge, applications and technical expertise, and product portfolio to address customers' most complex needs.

Photo-patternable Permanent Wafer Bonding

MEMS, HBM and Micro-optics (CMOS Image Sensors) are currently three of most important applications driving the need for permanent bonding materials.

Bonding Requirements for 2.5 / 3D-TSV Packaging

- High Bonding Strength
- High Throughput / High Accuracy
- High Yield / Low Cost

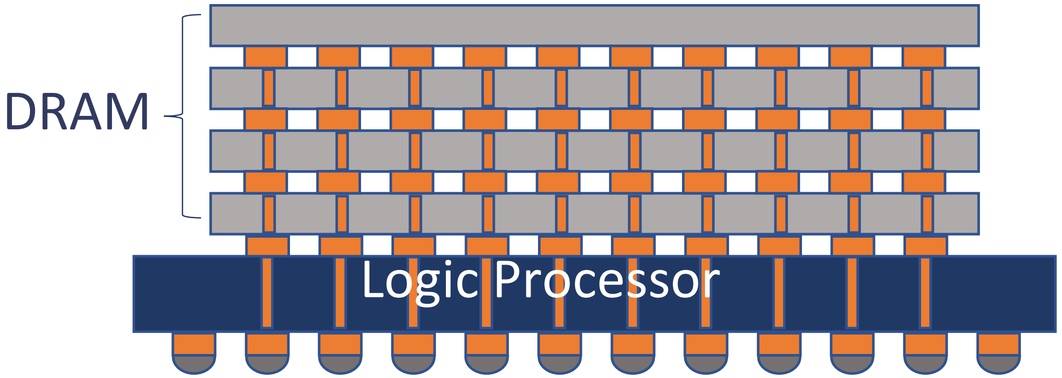
Types of Bonding Techniques

- Anodic / Si Direct / Eutectic / **Adhesive / Hybrid**

Advantages of Adhesive Bonding

- Low Bonding Temperature / High Bond Strength
- Low Cost / CMP / Reflow / Photo-patternable

3D-TSV Structure

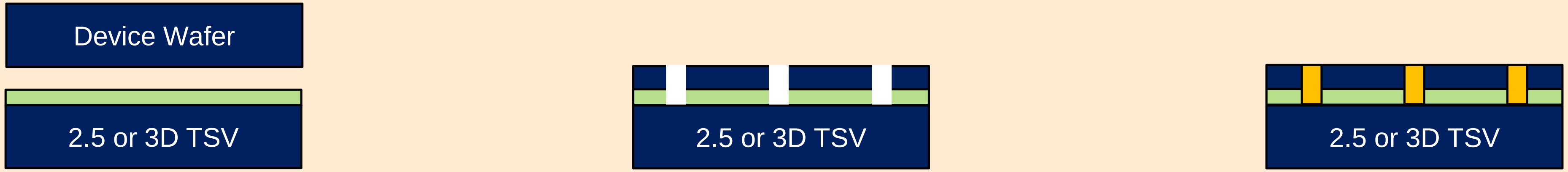


Dielectric Property Comparison

	CYCLOTENE™ 3022/402X Resin	**CYCLOTENE™ 6505**	**XP-5G-006**
Photo-patternable	Yes	Yes	Yes
Target Film Thickness Range	2.5-5 µm	3 -10 µm	5-15 µm
Tone	Negative	Positive	Negative
Viscosity cSt	192	190	
Via Resolution/Feature Size	<20 µm	≤5 µm	7.5 µm
Aspect ratio	1:4	>1:1	>1:1
Wall slope	45°	65-70°	>80°
Developer	DS2100 solvent type	0.26N TMAH aqueous base	PGMEA solvent type
Edge Bead / BSR Solvent	T1100	MMP, PGME or PGME/PGMEA	Cyclopentanone
Adhesion			
Lithographic post adhesion (1µm)	Not Tested	AP9000C → passes all tested	Self Priming →
Substrate (Cross hatch tape peel test)	AP3000 → passes all tested	AP9000C → passes all tested	passes Si, Cu, PI, SiN_x, self
Process Condition			
Build-Up Cure Temperature	210°C / 40min	200°C/100min	170°C/1hr
Material Properties			
Thermal Stability, <1wt% loss/hr	>300°C	290°C	>270°C
Shrinkage	9%	9%	10%
Residual Stress	28 MPa	29 MPa	20 MPa
Modulus	2.8 GPa	2.9 GPa	2.4GPa
CTE	42 ppm/°C	45 ppm/°C	95ppm/°C
Tensile Strength at break	90 MPa	121 MPa	84MPa
Elongation	8%	20%	28%
Dielectric Constant @ 100MHz	2.65	3.2	2.5→2.6 @ 20-60 GHz
Dielectric Loss @ 100MHz	0.0008	0.015	0.0028 → 0.0032 @ 20-60 GHz
Breakdown Voltage	5.3MV/cm	5.1MV/cm	TBD
Moisture Uptake 23C/45% RH	0.1%	1.1%	0.17%

Permanent Bonding Approaches with Polymer Adhesive

BCB Permanent Wafer Bonding – Via Last Process (SONY BSI)

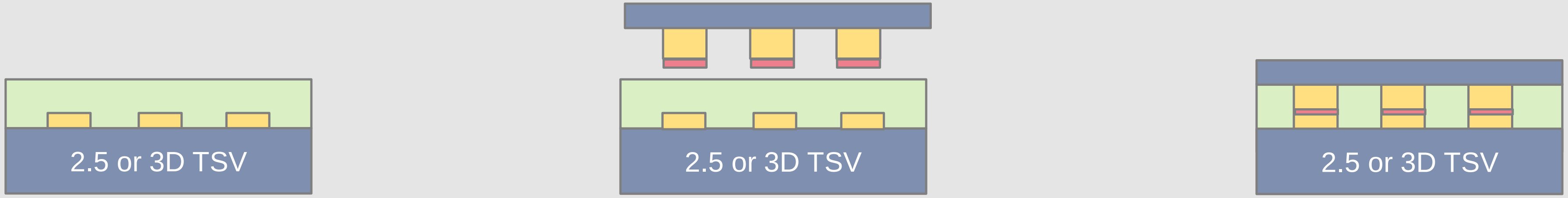


1) Coating and Bonding

2) Thin, Pattern, Etch

3) Cu Fill and CMP

Non-Patterned BCB Process

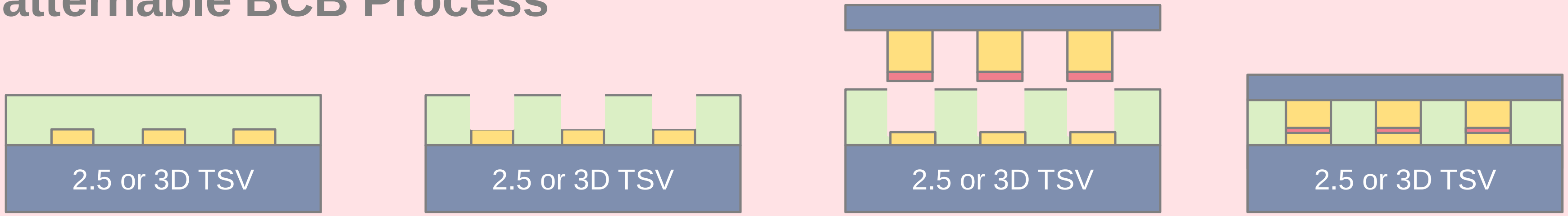


1) Coating

2) Alignment

3) Bonding

Photo-patternable BCB Process



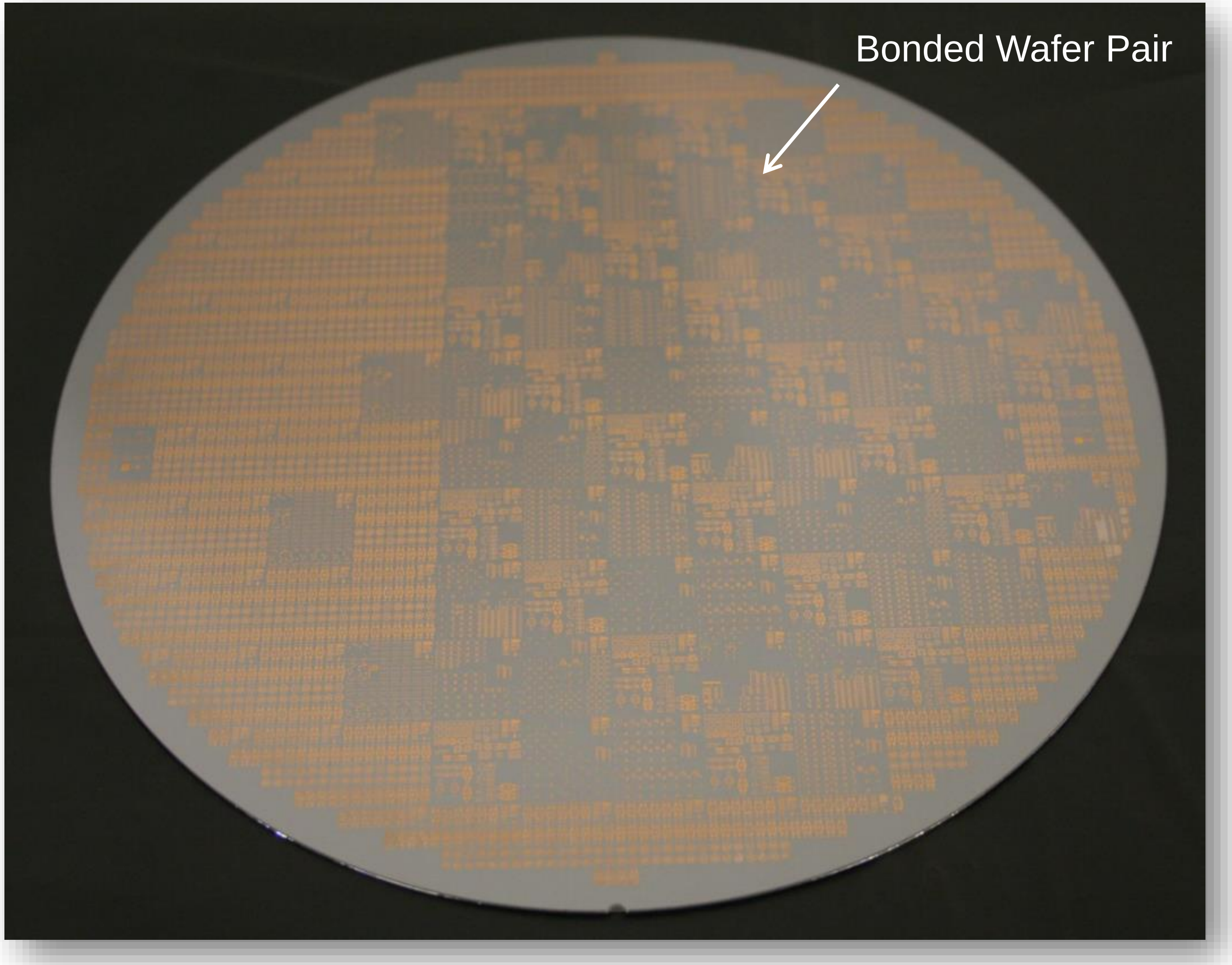
1) Coating

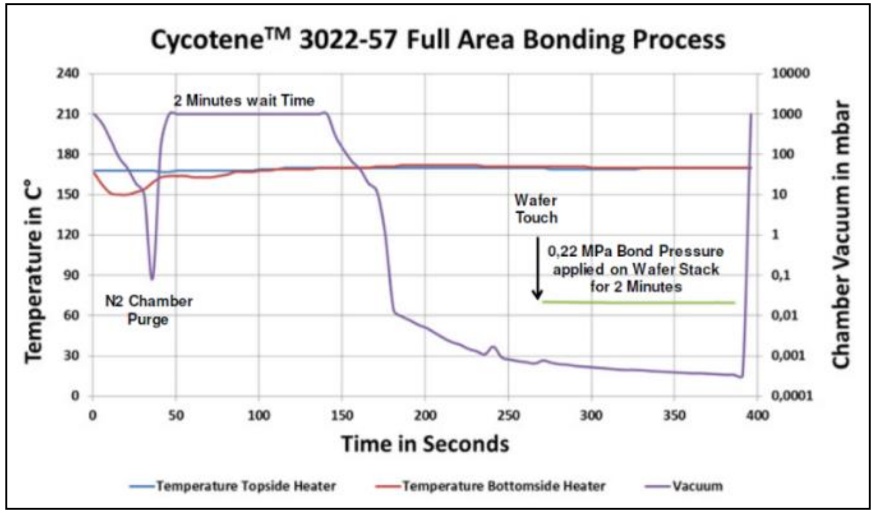
2) Photopattern BCB

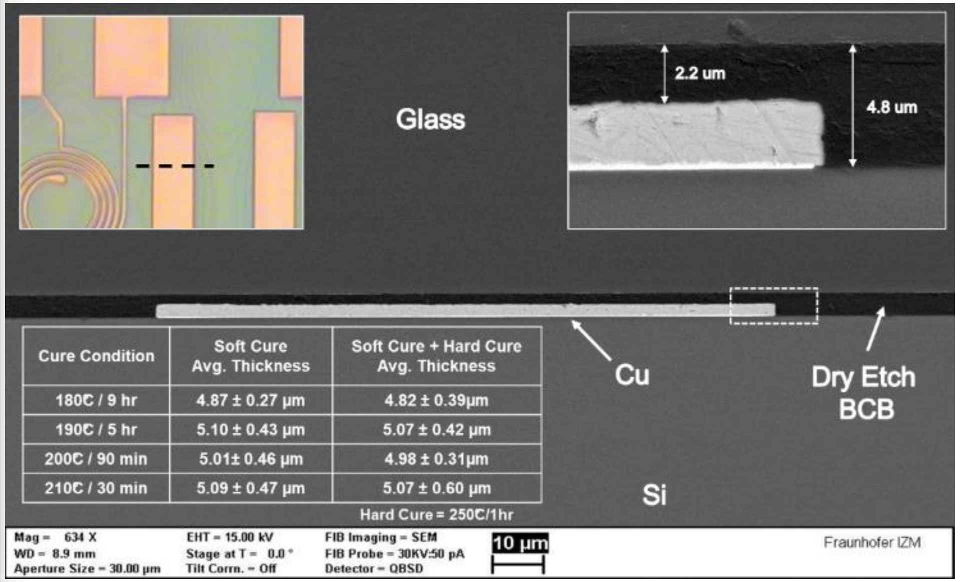
3) Plasma Clean

4) Align and Bond

Bonding Result – Cu Structured Si and Glass wafers





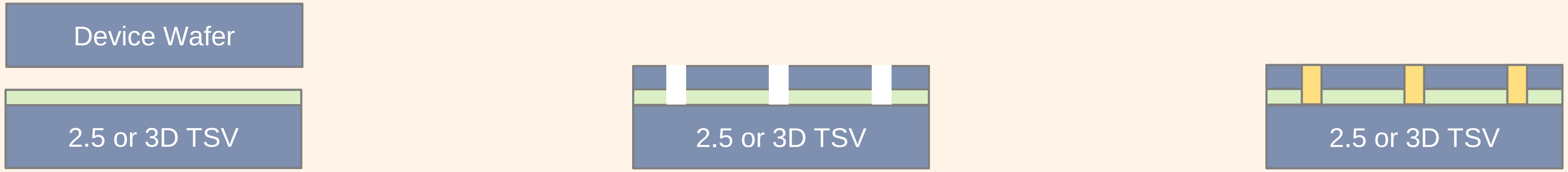


Cure Condition	Soft Cure Avg. Thickness	Soft Cure + Hard Cure Avg. Thickness
180C / 9 hr	4.87 ± 0.27 µm	4.82 ± 0.39µm
190C / 5 hr	5.10 ± 0.43 µm	5.07 ± 0.42 µm
200C / 90 min	5.01± 0.46 µm	4.98 ± 0.31µm
210C / 30 min	5.09 ± 0.47 µm	5.07 ± 0.60 µm

Hard Cure = 250C/1hr

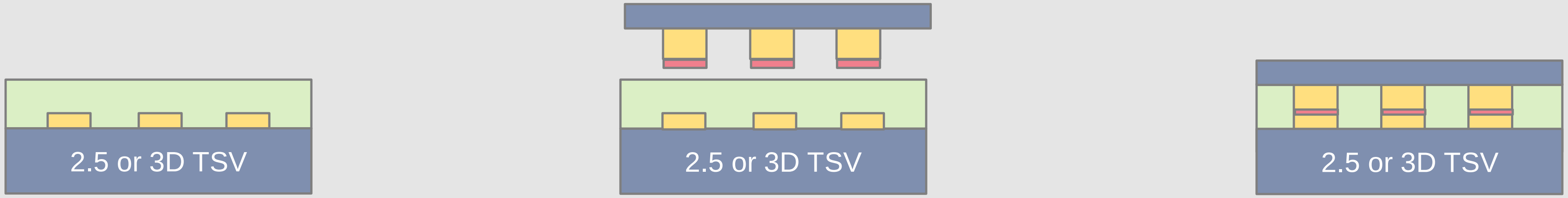
Permanent Bonding Approaches with Polymer Adhesive

BCB Permanent Wafer Bonding – Via Last Process (SONY BSI)



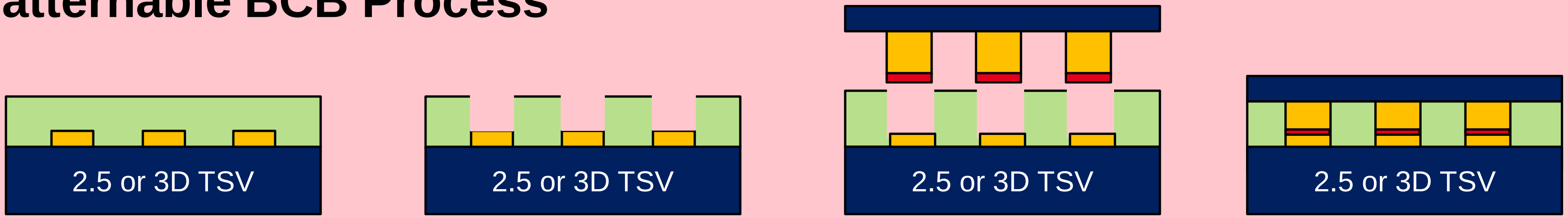
1) Coating and Bonding
2) Thin, Pattern, Etch
3) Cu Fill and CMP

Non-Patterned BCB Process



1) Coating
2) Alignment
3) Bonding

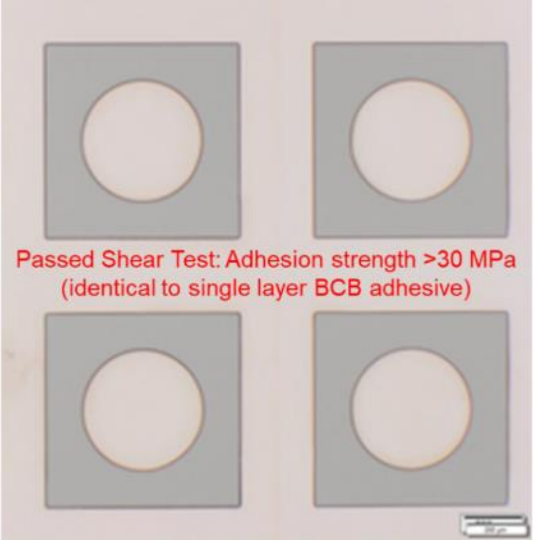
Photo-patternable BCB Process



1) Coating
2) Photopattern BCB
3) Plasma Clean
4) Align and Bond

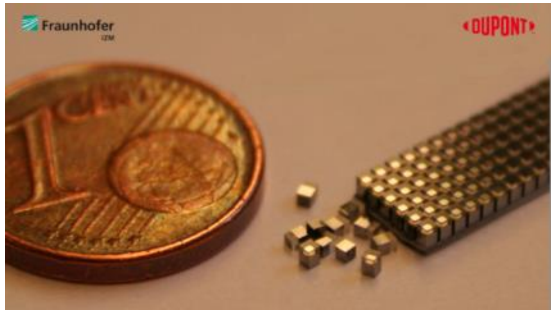
Photo-Patternable Bonding – No Voiding After Bonding or Curing

402X PID // Solvent Dev.

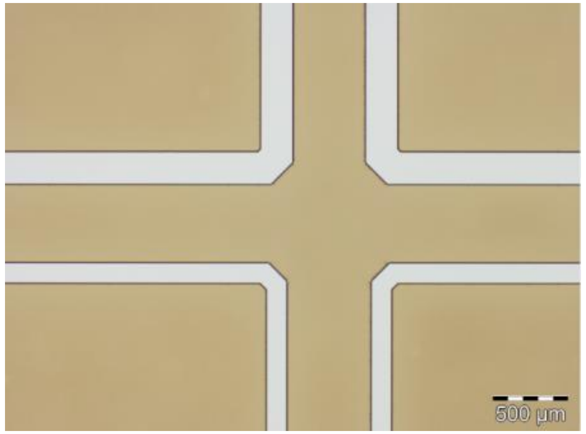


Passed Shear Test: Adhesion strength >30 MPa
(identical to single layer BCB adhesive)

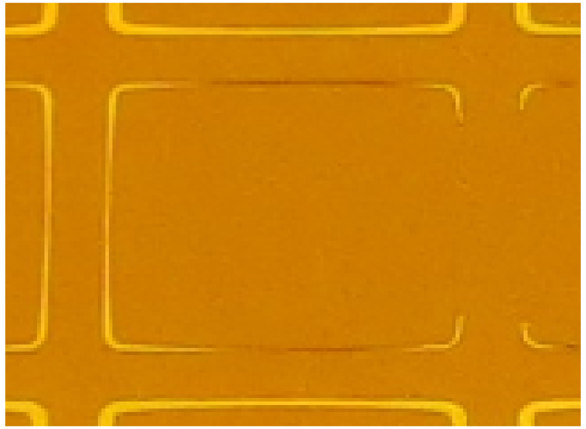
Images Courtesy of FhG IZM



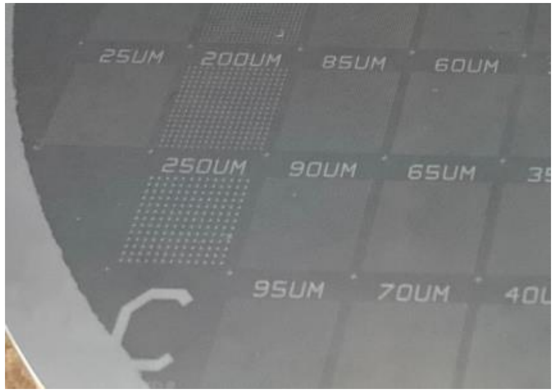
6505 PID // Aq. Dev.

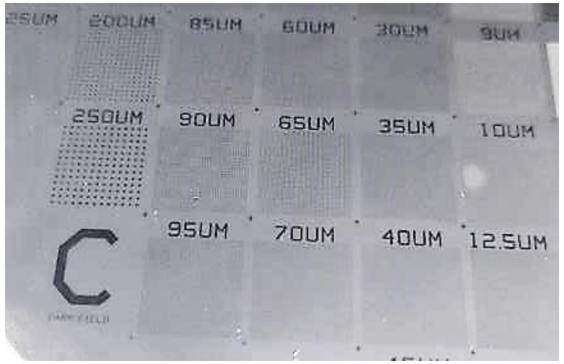


Images Courtesy of FhG IZM



XP-5G-006 // Solvent Dev.





Void-free bonding and
no outgassing after cure + 3X reflow

Positive Tone Photo-patternable Bonding

CYCLOTENE™ 6505 Process Conditions

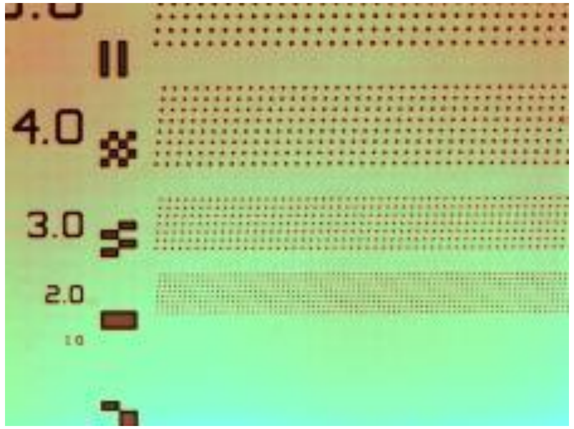
Materials

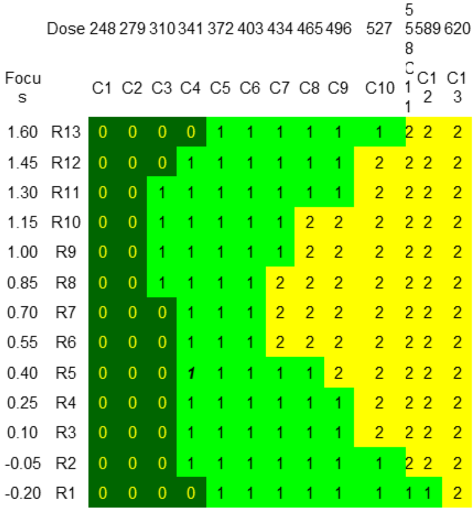
- Substrate: 200mm Silicon
- Adhesion Promoter: AP9000C
- Dielectric: CYCLOTENE^{TM} 6505 Dielectric (positive tone)

Bonding Evaluation

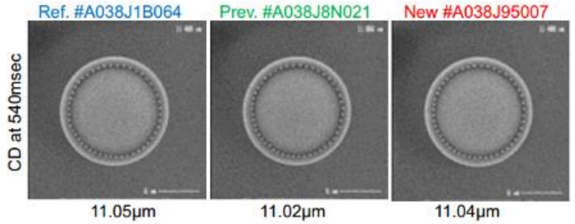
1) Priming with AP9000C: 200mm Wafer Track
   - 2000rpm spin coat, 150˚C/60sec
2) Spin Coat: 200 mm Wafer Track
   - 1250 rpm/45 sec targeting 5.5 um after development
   - 90˚C/90 sec
3) Exposure tool:Mask Aligner
   - ABCD Mask Square Post (1-300 um features)
   - 20 um proximity gap
4) Post Exposure Delay: ~15 minutes
5) Development: 200mm Wafer Track
   - No prewet, MF CD-26 (0.26*N* TMAH), single puddle 1x60 sec
   - DI water rinse for 60 sec
6) Bonding: Commercial 200mm Wafer Bonder
   - Temperature 80-120˚C
   - Force: 4-30kN
7) Hard Cure: Blue M Oven
   - Nitrogen-purged convection oven
   - 130 ˚C/15 min → 250˚C/60min

Lithographic Post Adhesion Test



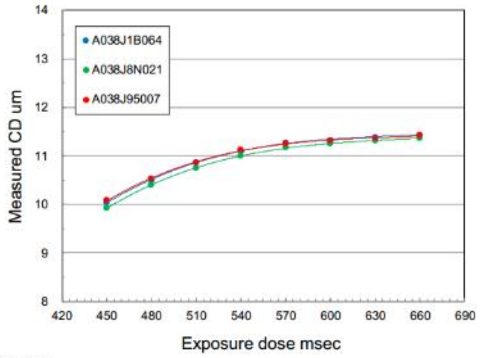


Dose		248	279	310	341	372	403	434	465	496	527	558	589	620
Focus		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
1.60	R13	0	0	0	0	1	1	1	1	1	1	2	2	2
1.45	R12	0	0	0	1	1	1	1	1	1	2	2	2	2
1.30	R11	0	0	1	1	1	1	1	1	1	2	2	2	2
1.15	R10	0	0	1	1	1	1	1	2	2	2	2	2	2
1.00	R9	0	0	1	1	1	1	1	2	2	2	2	2	2
0.85	R8	0	0	1	1	1	1	2	2	2	2	2	2	2
0.70	R7	0	0	0	1	1	1	2	2	2	2	2	2	2
0.55	R6	0	0	0	1	1	1	2	2	2	2	2	2	2
0.40	R5	0	0	0	1	1	1	1	1	2	2	2	2	2
0.25	R4	0	0	0	1	1	1	1	1	1	2	2	2	2
0.10	R3	0	0	0	1	1	1	1	1	1	2	2	2	2
-0.05	R2	0	0	0	1	1	1	1	1	1	1	2	2	2
-0.20	R1	0	0	0	0	1	1	1	1	1	1	1	1	2



Dose msec	Measured CD um		
	Reference A038J1B064	Previous A038J8N021	New A038J95007
450	10.04	9.92	10.08
480	10.50	10.40	10.53
510	10.86	10.75	10.86
540	11.11	11.00	11.13
570	11.27	11.17	11.26
600	11.33	11.25	11.32
630	11.39	11.31	11.36
660	11.44	11.37	11.42

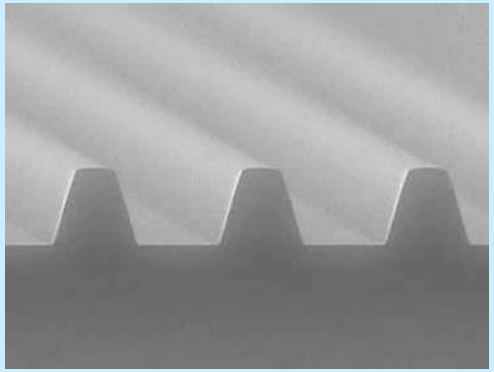
Substrate: 6inch bare Si
Test mask:
Duty 1:2.0 10μm Contact hole
Focus setting: 0μm



CD and via openings on the new lot are well equivalent to the reference.

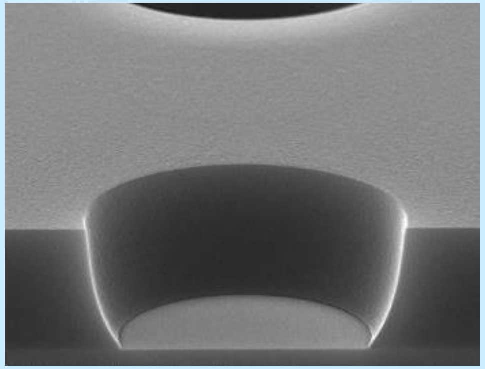
Process Scheme for Patterned Permanent Bonding

After Cure



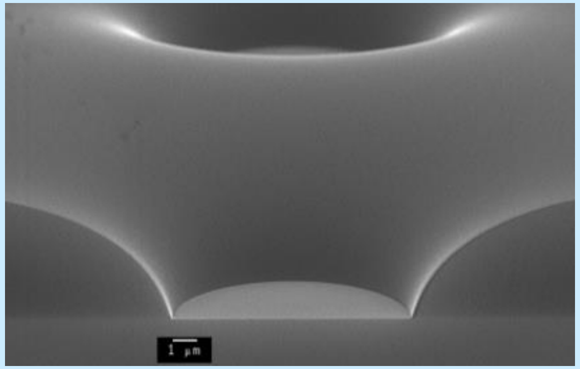
CD: 8µm L/S Dose: 500 mJ/cm^2

ADI



CD: 10µm 1:2 Dose: 532 mJ/cm

Standard Cure



CD: 10µm 1:2 Dose: 532 mJ/cm
Wall Angle 45°

Photopatternable 6505

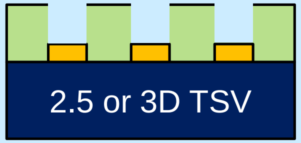
Target opening to pillar size

Sidewall angle: 45-72°

Wall angle dependent on cure process

TMAH Develop: 60s SP

Cross section image showing side wall after development



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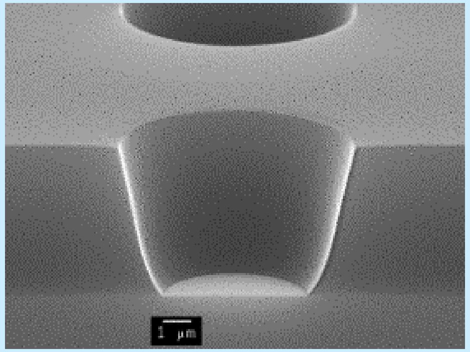
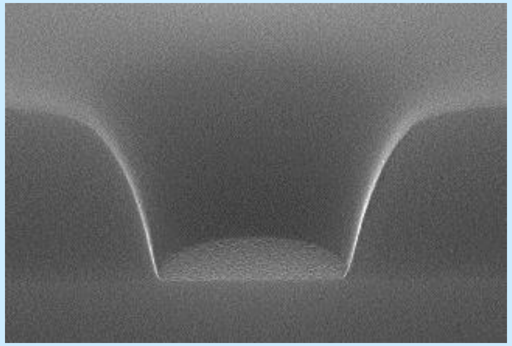
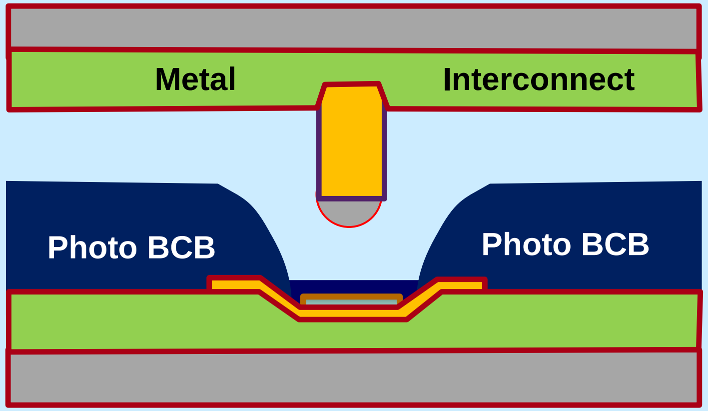


CD: 5µm 1:2 Dose: 532 mJ/cm

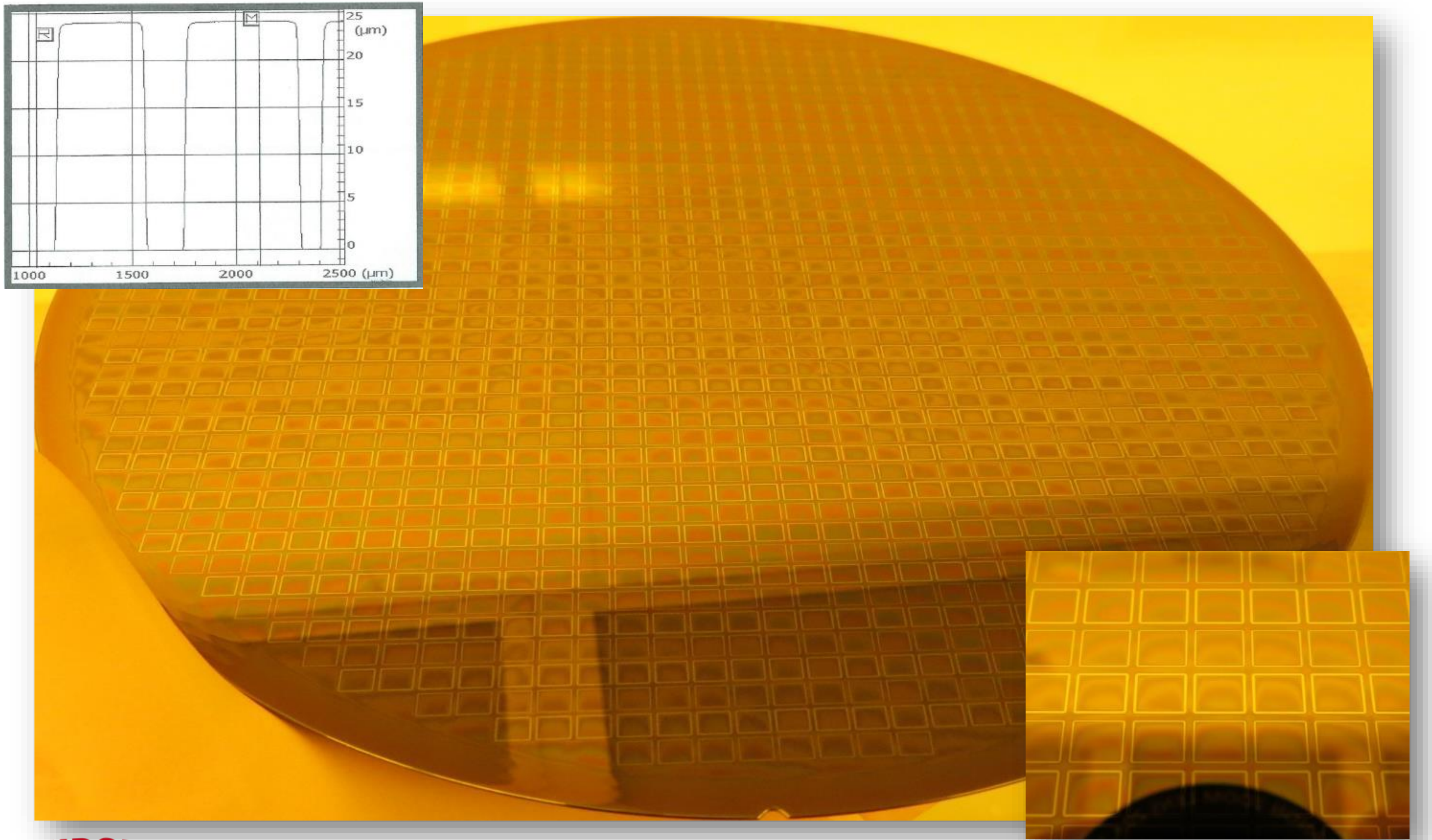
Alternate Cure



CD: 5µm 1:2 Dose: 532 mJ/cm
Wall Angle 72°



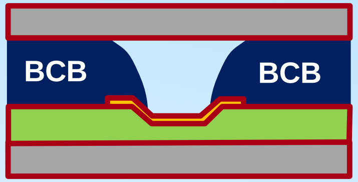
Patterned Wafer – 30µm double coat 6505 PID + 6X puddle

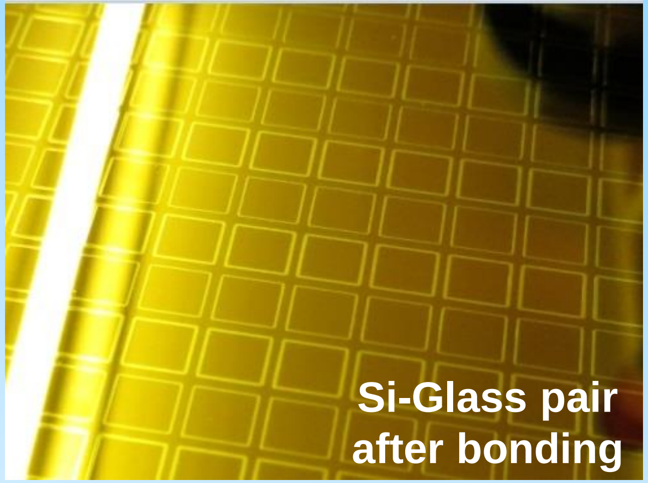


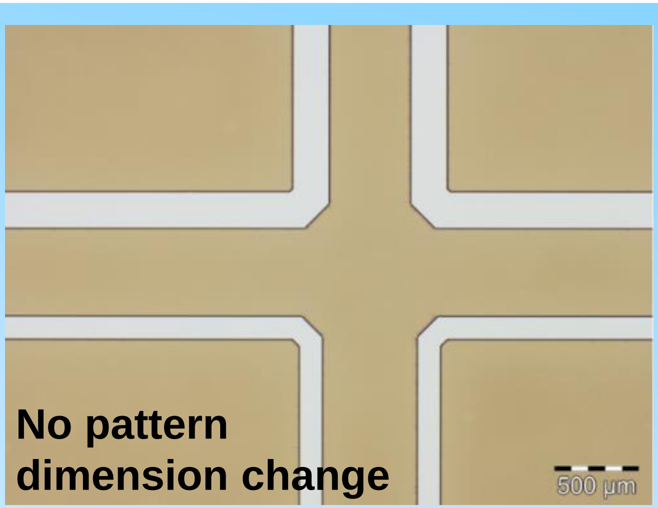
Bonding Process – Impact on BCB Reflow

Bonding
(no reflow)

80°C / 60 kN
5 min



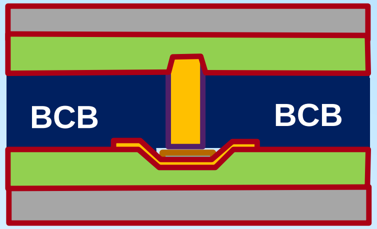

Si-Glass pair after bonding

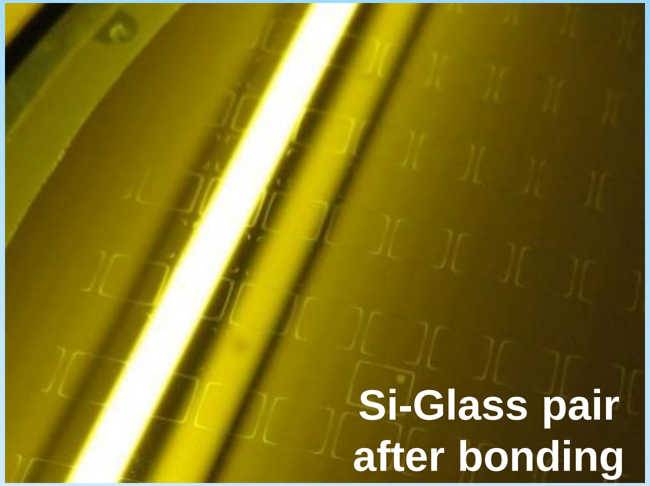

No pattern dimension change

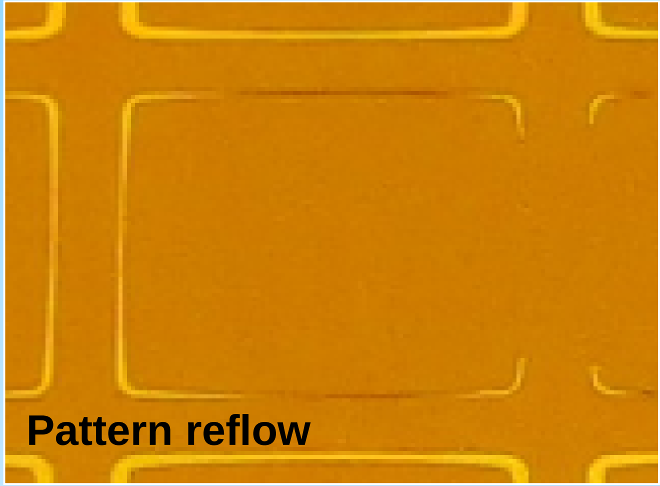
Images Courtesy of FhG IZM

Bonding
(reflow)

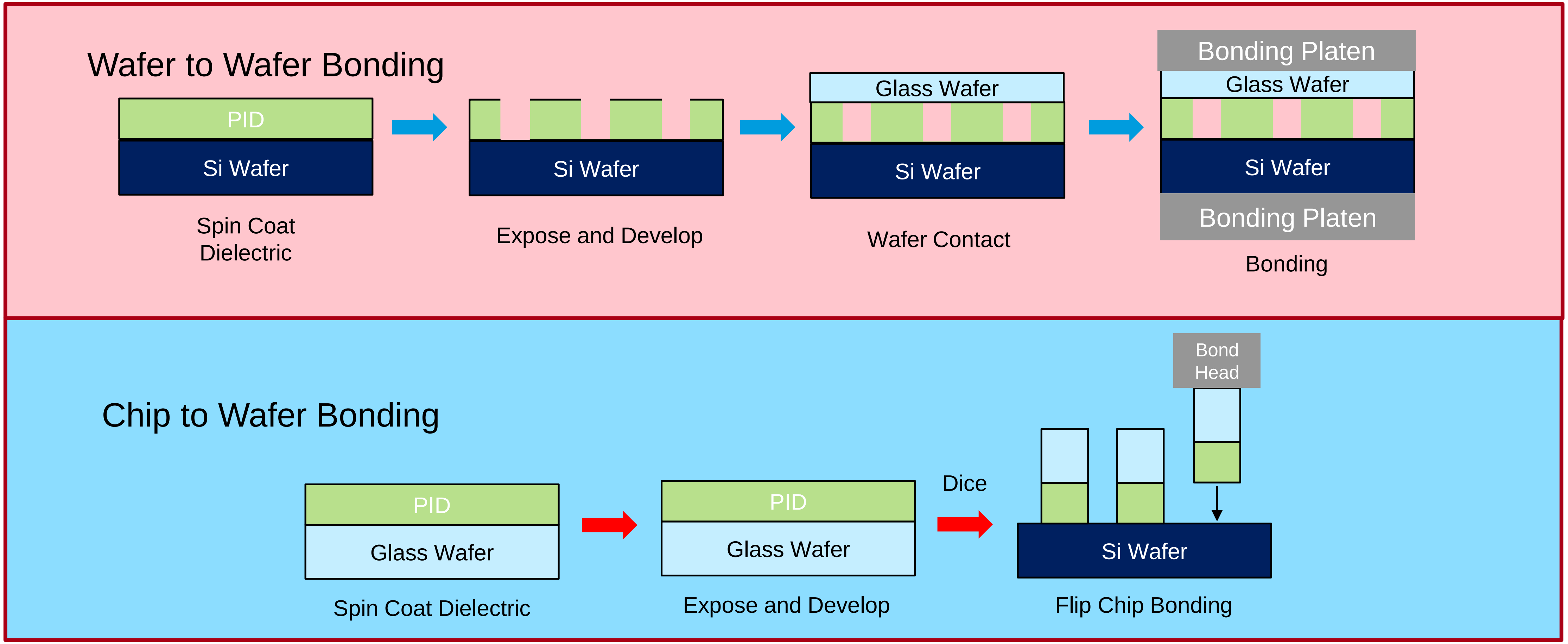
100°C / 60kN
3 min



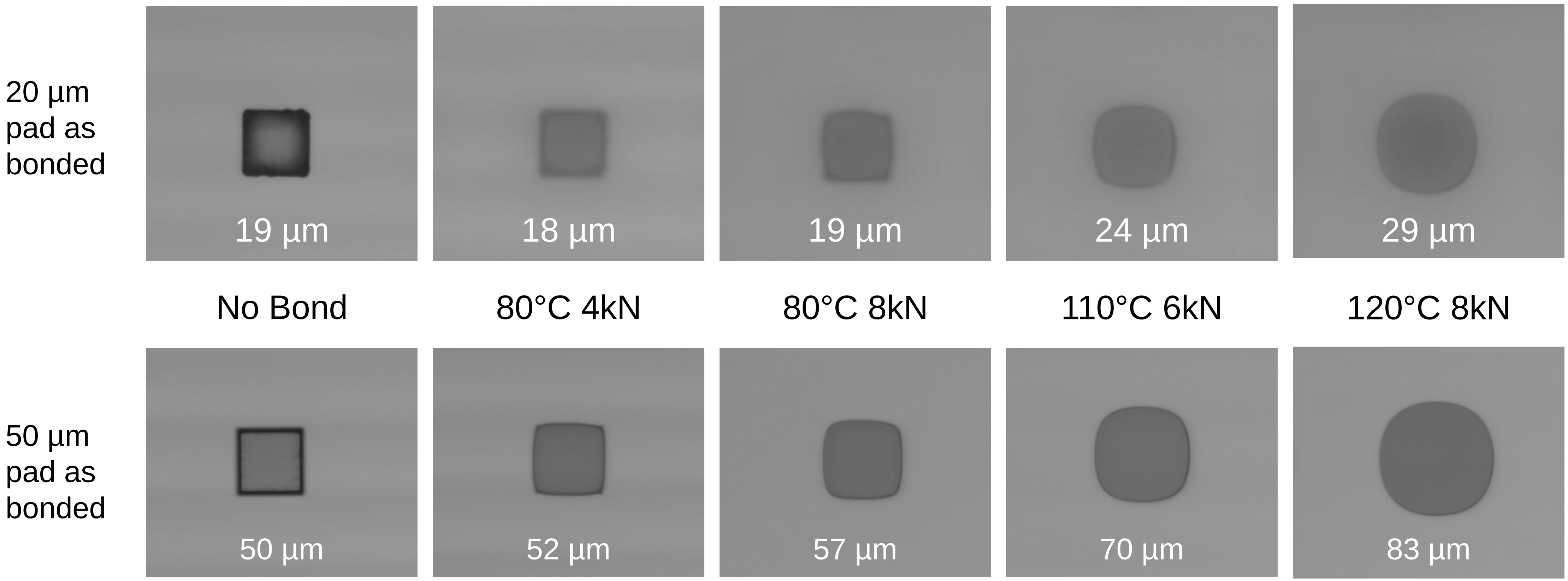

Si-Glass pair after bonding


Pattern reflow

Bonding Process Flow



CYCLOTENE™ 6505 Bonding Performance (Bonded)

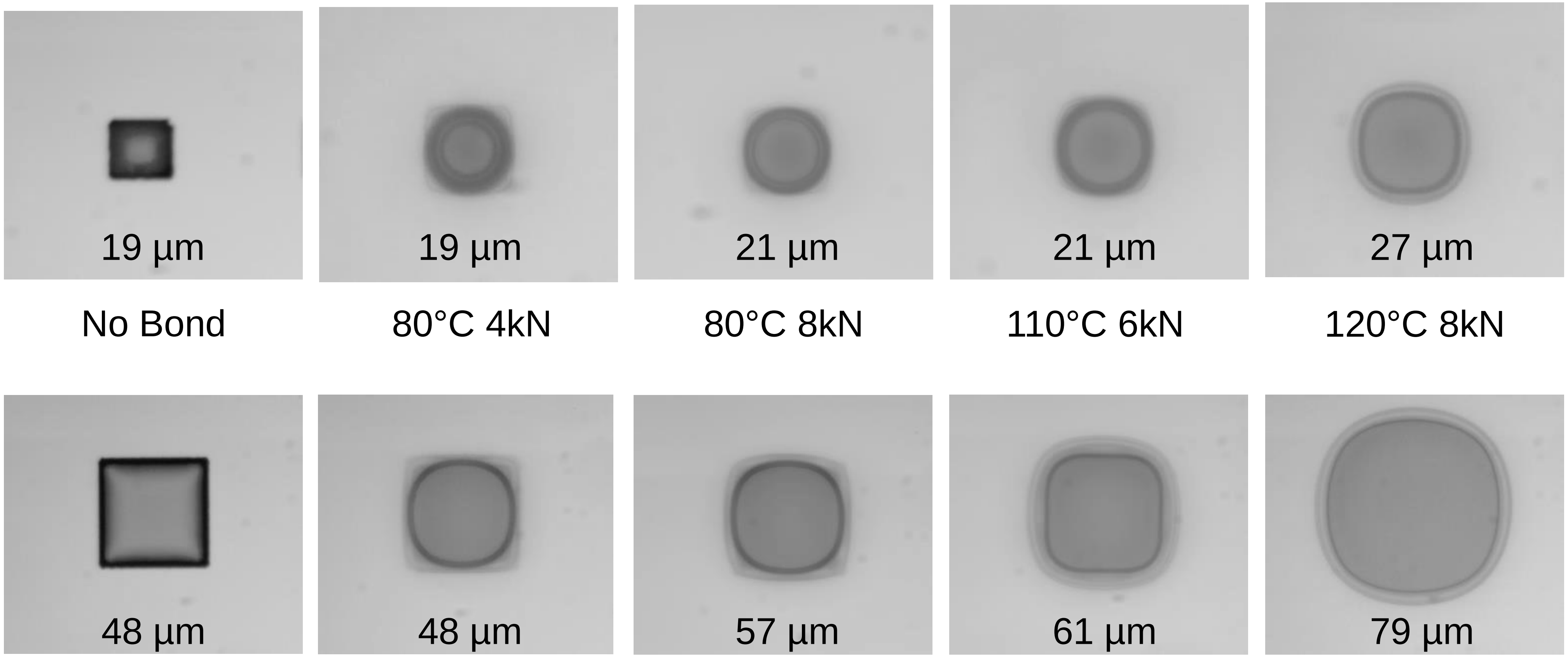


Increased Bonding Temperature and Pressure
Large impact on feature shape

CYCLOTENE™ 6505 Bonding Performance (Cured)

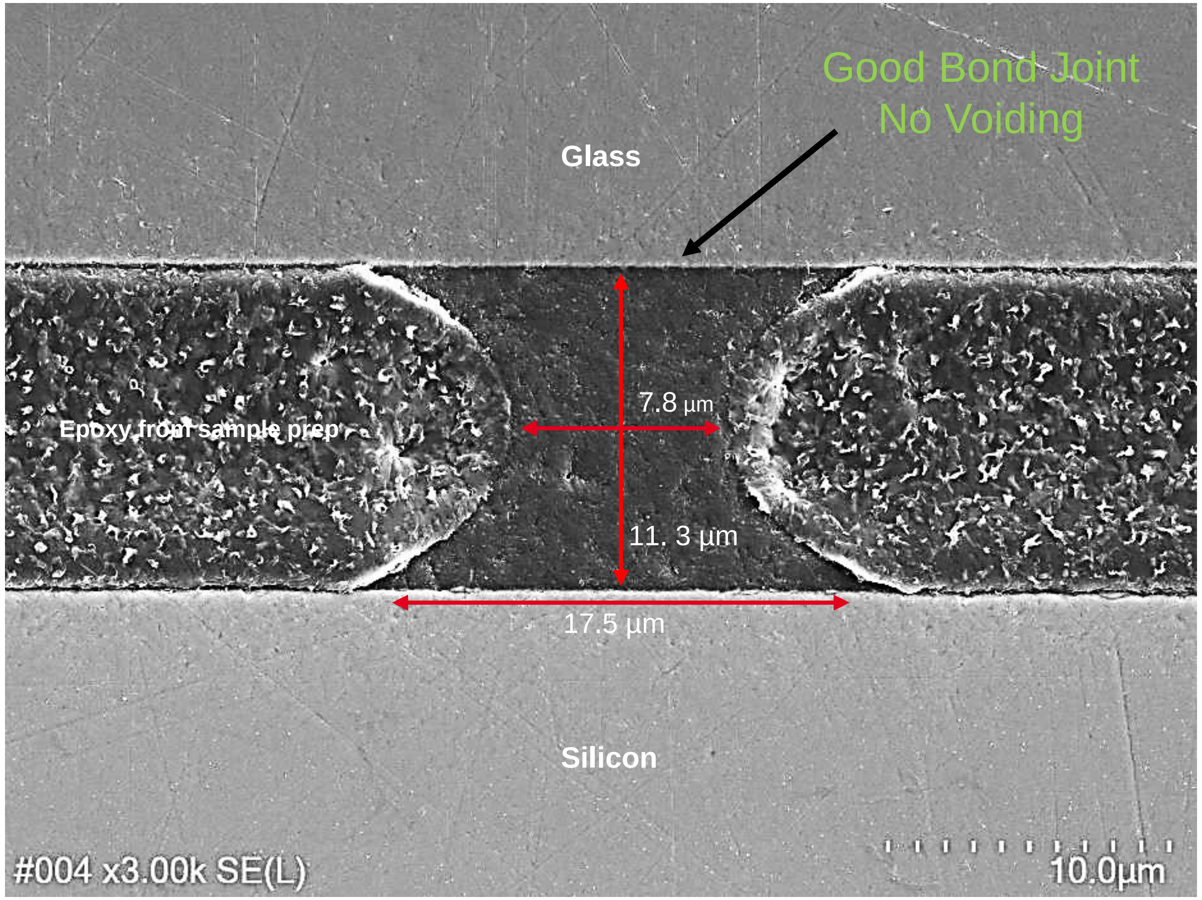
20 µm
pad as
cured

50 µm
pad as
cured

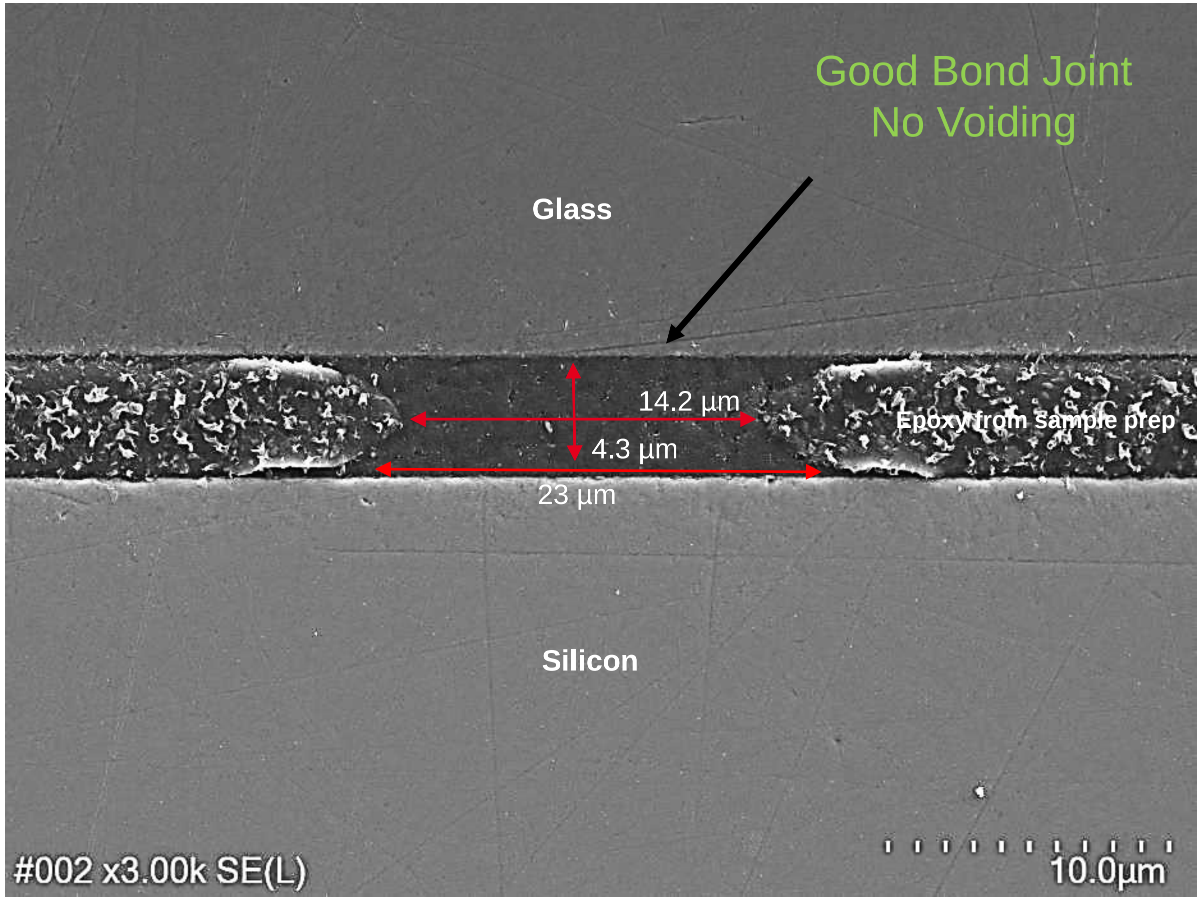


Increased Bonding Temperature and Pressure
Large impact on feature shape

CYCLOTENE™ 6505 Cross Section After Bonding 20 um Pillar



80ºC 4kN

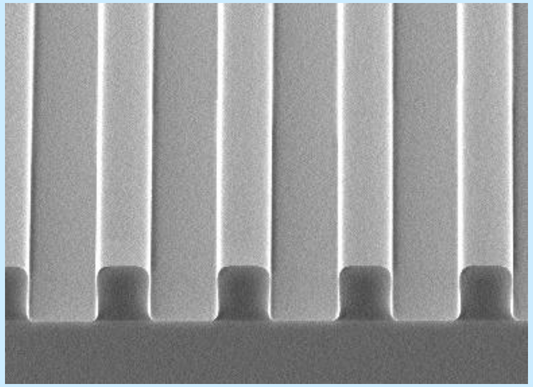


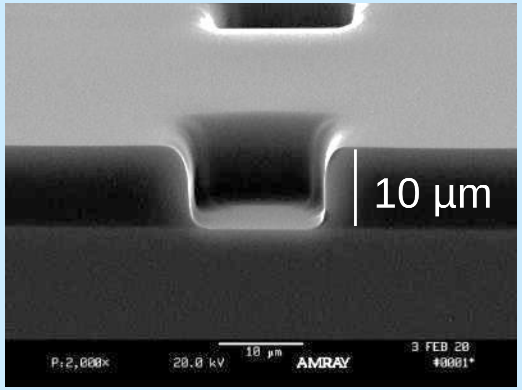
120ºC 4kN

Negative Tone Photo-patternable Bonding

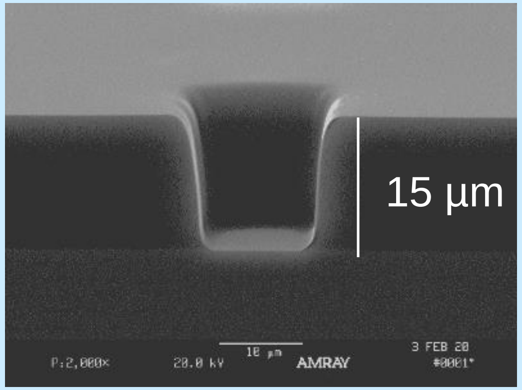
Process Scheme for Patterned Permanent Bonding

ADI


CD: 15.3 µm L/S Dose: 200 mj/cm^2



CD: 11.88 µm - Dose: 117 mj/cm



CD: 10.16 µm - Dose: 150 mJ/cm

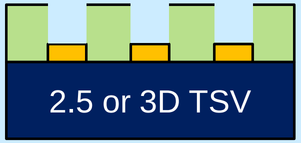
<u>Photopatternable XP-5G-006</u>

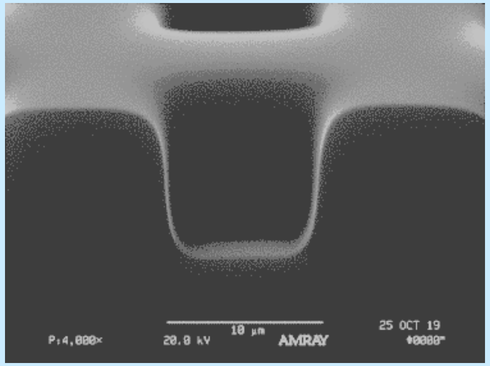
Target opening to pillar size

Sidewall angle: 85°

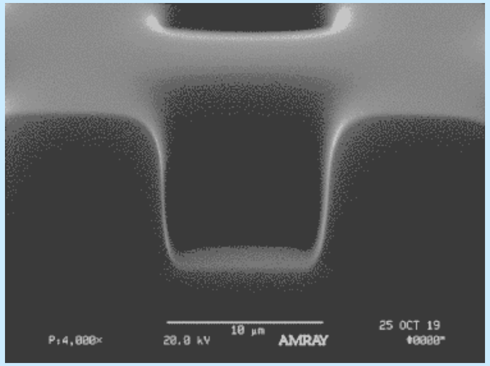
PGMEA Develop: 2x30 SP

Cross section image showing side wall after development

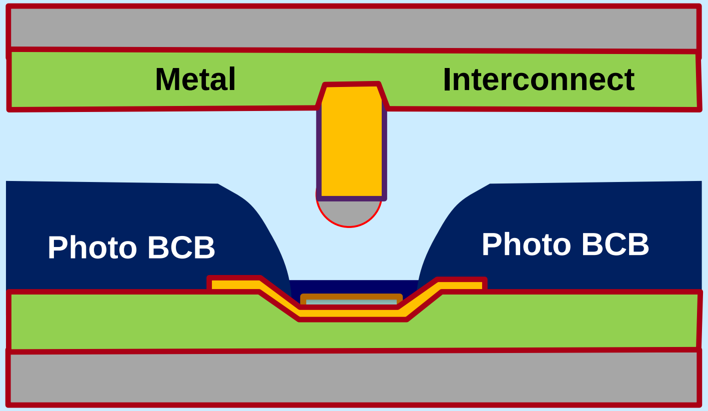




ADI



After Cure+Descum



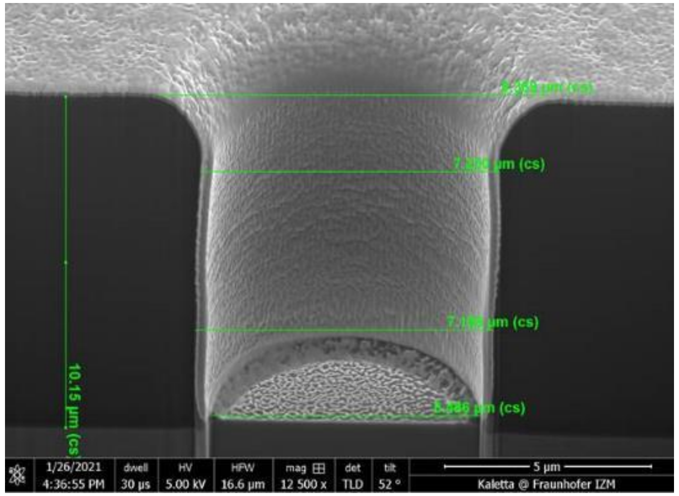
XP-5G-006 Process Conditions

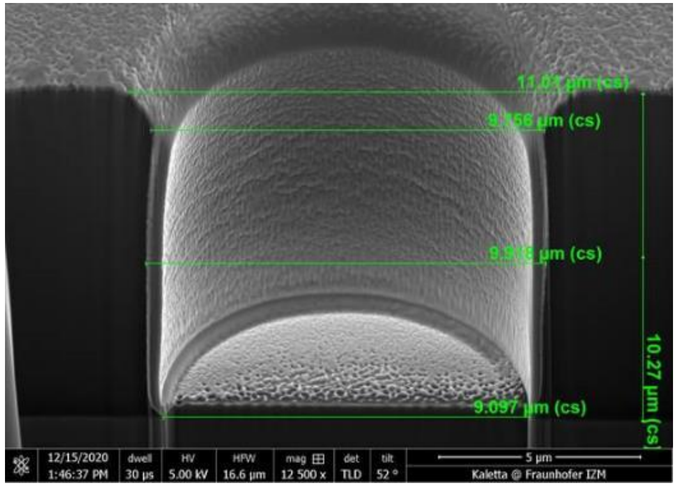
Materials

- Substrate: 200mm Silicon
- Dielectric: XP-5G-006 Photoimageable Dielectric (negative tone)

Bonding Evaluation

1) Spin Coat: 200mm Wafer Track
    - 2500 rpm/45 sec at 5 um thickness as developed
    - 100˚C/180 sec
2) Exposure tool: i-line Mask Aligner
    - ABCD Mask Square Post (1-300 um features)
    - 20 um proximity gap
    - PEB 65˚C/90 sec
4) Development: 200mm Wafer Track
    - No prewet, PGMEA develop, double puddle 2x30 sec
    - PGMEA rinse for 30 sec
5) Bonding: Commercial Wafer Bonder
    - Temperature 80-120˚C
    - Force: 4-30kN
6) Hard Cure: Blue M Oven
    - Nitrogen-purged convection oven
    - 130 ˚C/15 min → 200˚C/60min





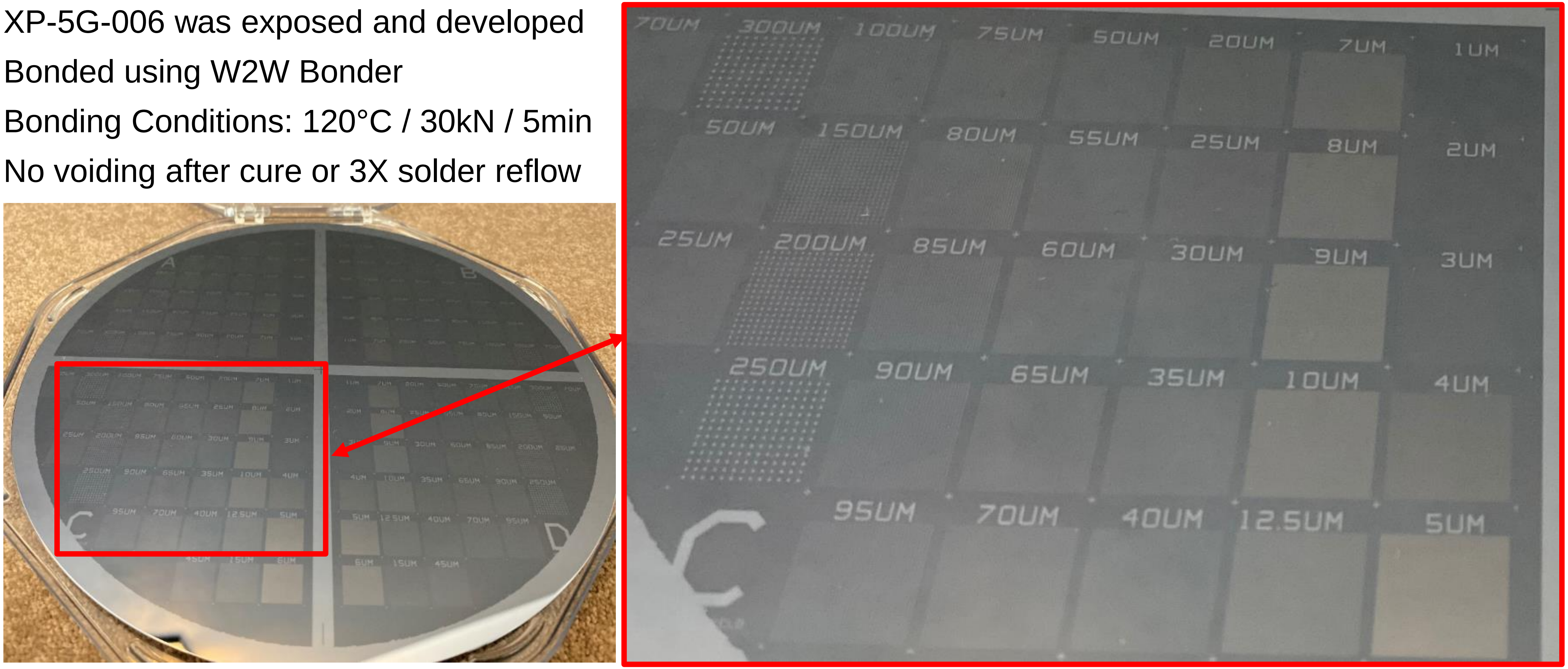
Patterned Bonding of XP-5G-006

XP-5G-006 was exposed and developed

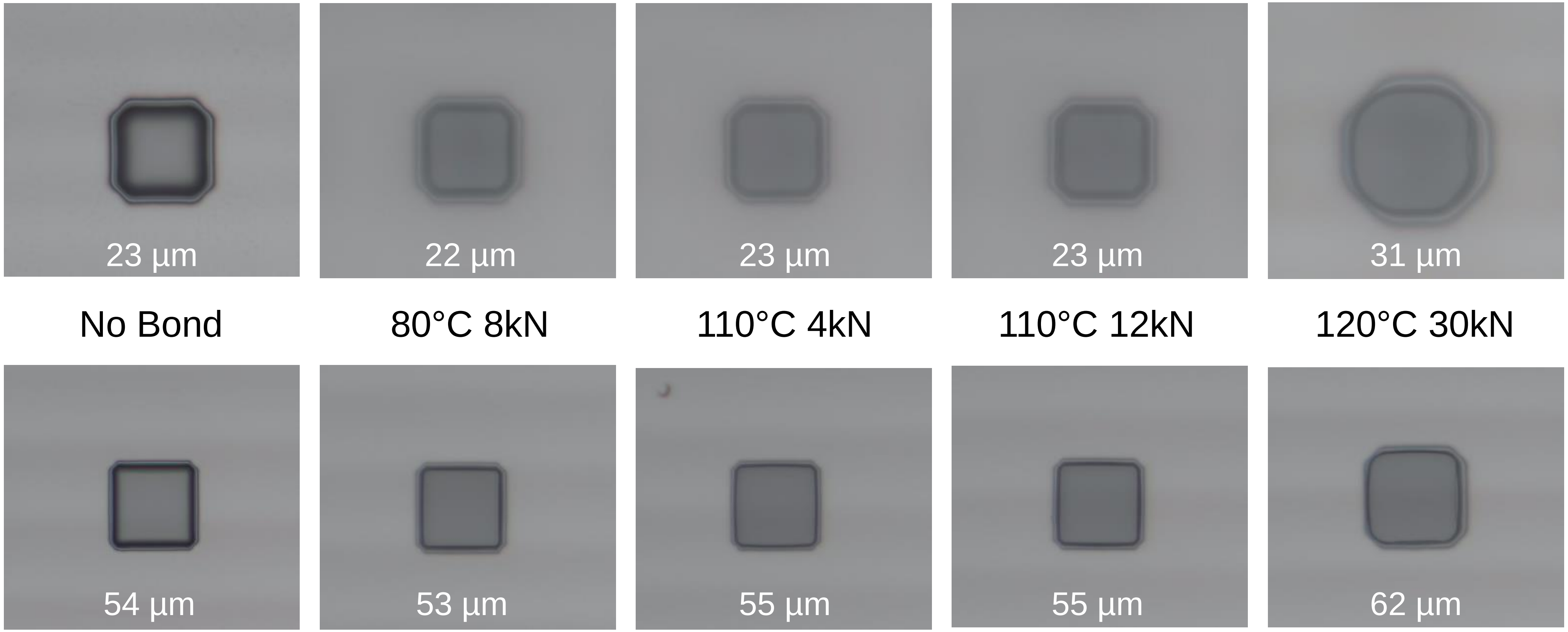
Bonded using W2W Bonder

Bonding Conditions: 120°C / 30kN / 5min

No voiding after cure or 3X solder reflow



XP-5G-006 Bonding Performance (Bonded)



20 µm
pad

No Bond

80°C 8kN

110°C 4kN

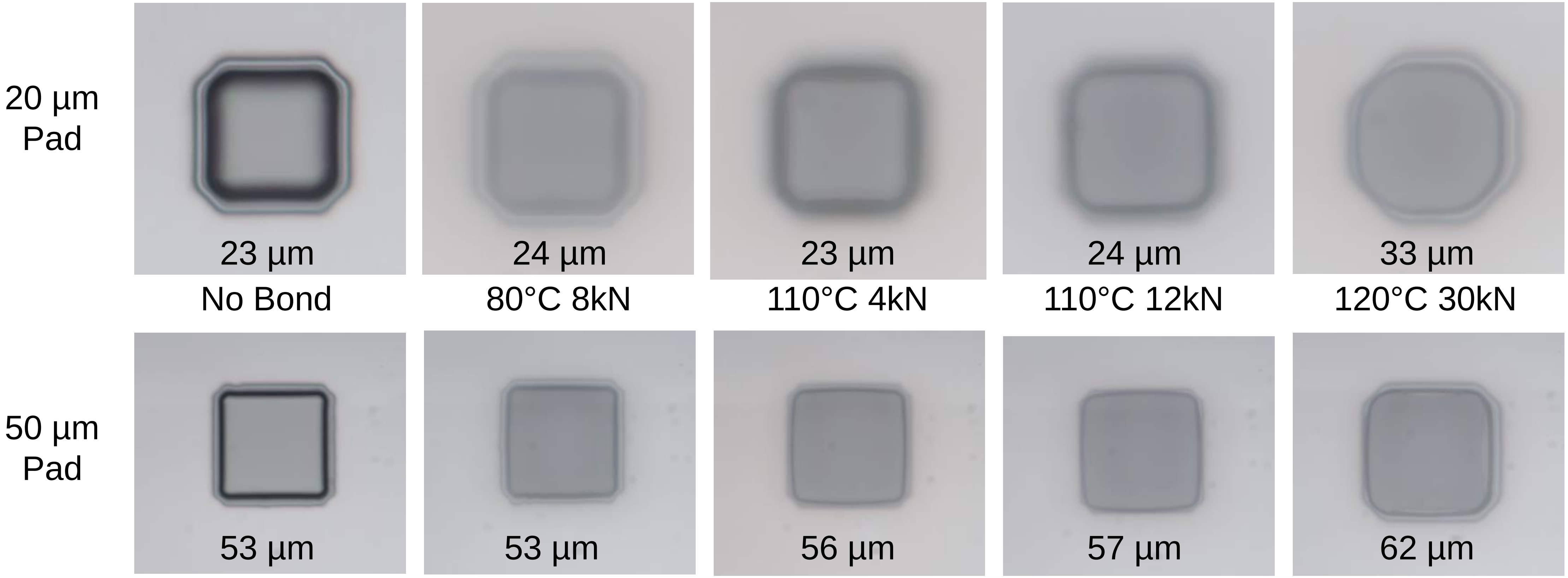
110°C 12kN

120°C 30kN

50 µm
pad

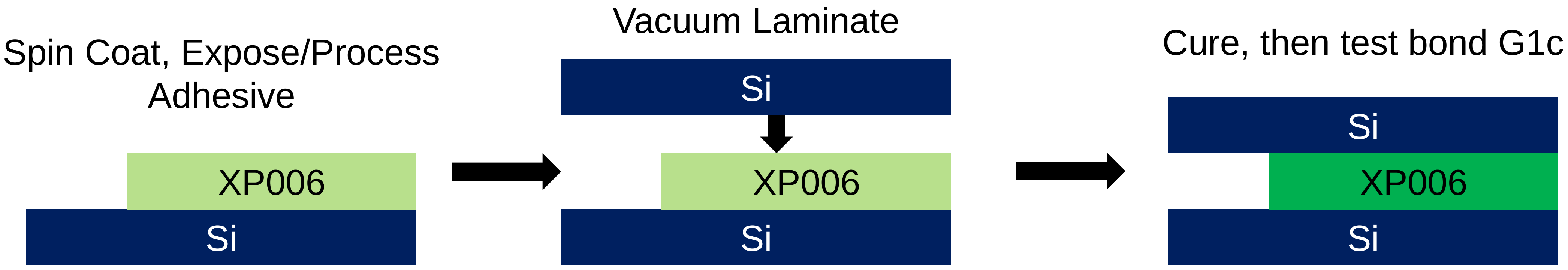
Increased Bonding Temperature and Pressure
No Feature Reflow Seen

XP-5G-006 Bonding Performance (Cured)



Increased Bonding Temperature and Pressure
No Feature Reflow Seen

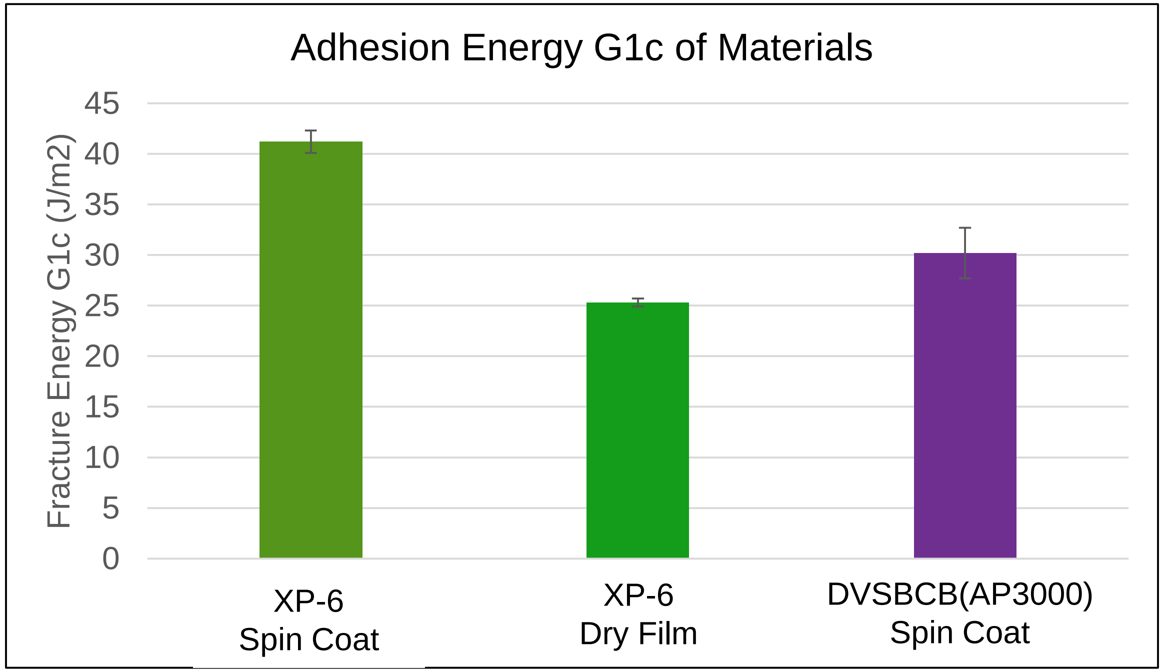
Adhesion to Bonded Surface (Silicon test) G1c Fracture Energy



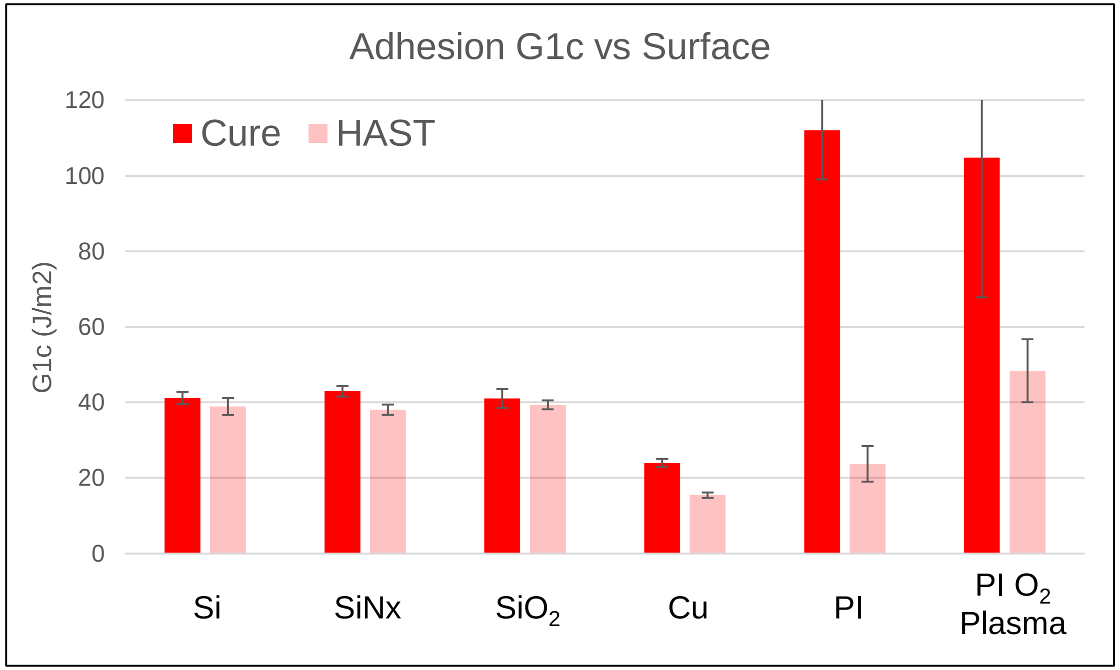
Spin Coat, Expose/Process Adhesive

Vacuum Laminate

Cure, then test bond G1c

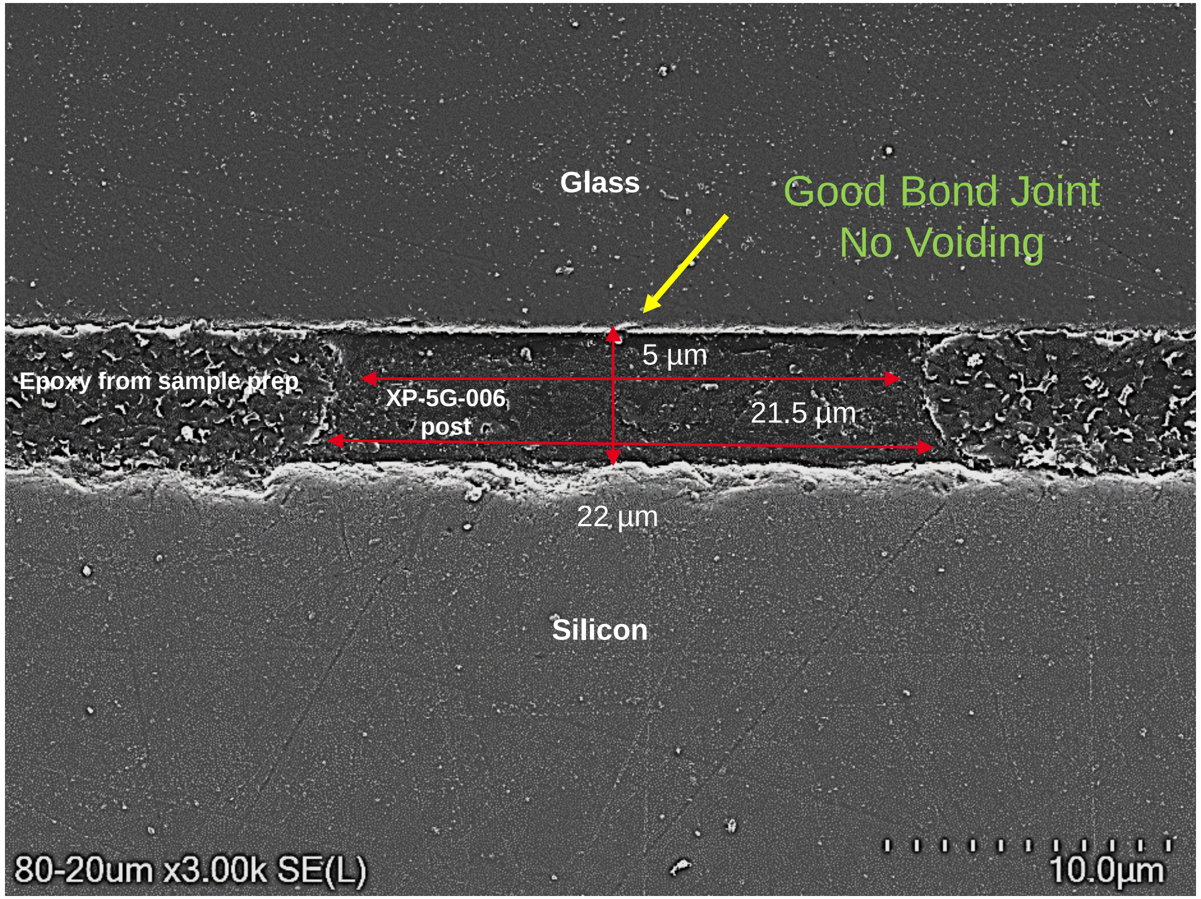


Adhesion Energy G1c of Materials

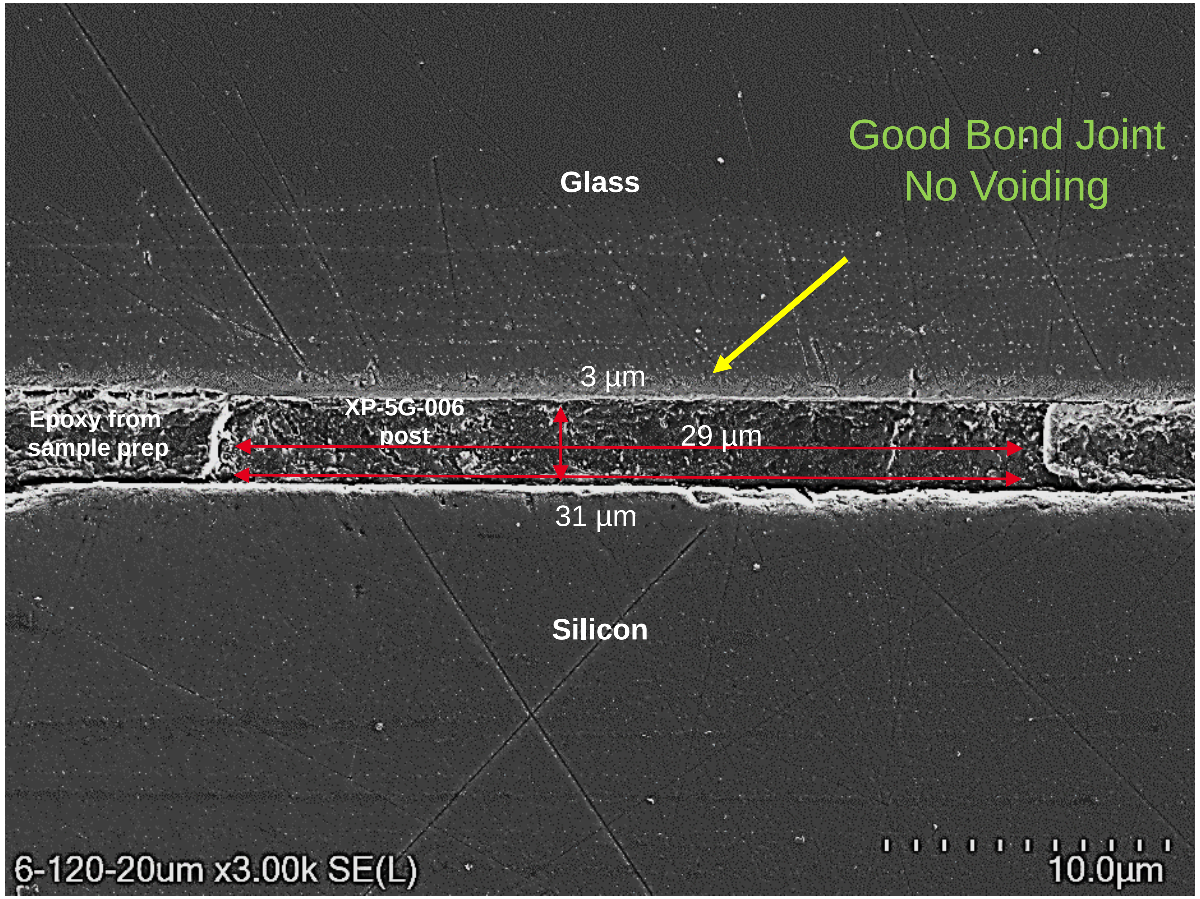


Adhesion G1c vs Surface

Cross-sectional SEM images of 20-µm pillars of XP-5G-006



80ºC 8 kN



120ºC 30 kN

Testing of Bonded Substrates

Chemical Resistance of Photopatternable Dielectrics

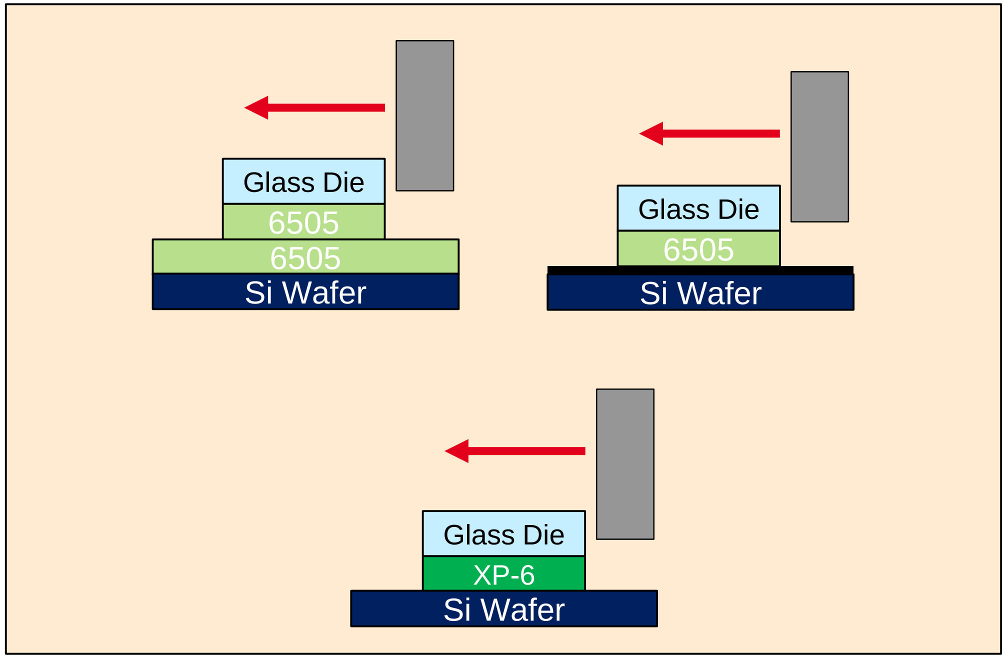
	Solvent/Stripper/Plating Chemical	CYCLOTENE 6505 PID		XP-5G-006 PID	
Temp	Cure Condition → 30 min exposure↓	Soft Cure 200°C/100min	Hard Cure 250°C/60min	Soft Cure 170°C/100min	Hard Cure 200°C/60min
RT	Cu Plating Solution pH8.5	Pass	Pass	Pass	Pass
50°C	PGME	Pass	Pass	Pass	Pass
	PGMEA	Pass	Pass	Pass	Pass
	NMP	ΔFT <3% *	Pass	Pass	Pass
	DMSO	ΔFT <3% *	Pass	Pass	Pass
	2.38% TMAH	Pass	Pass	Pass	Pass
	20% H_3PO_4 / 5% H_2O_2	Pass	Pass	Pass	Pass
	Ni Plating Solution pH4	Pass	Pass	Pass	Pass
	2%HF	Pass	Pass	Pass	Pass
	Ni Plating Solution pH4	Pass	Pass	Pass	Pass
70°C	DMSO/KOH	-	Pass	-	Pass
90°C	DMSO/KOH / 60min	-	Pass	-	Pass

Pass = no change in color, <1% change in film thickness. * For NMP & DMSO swelling occurs but can be removed by soft bake

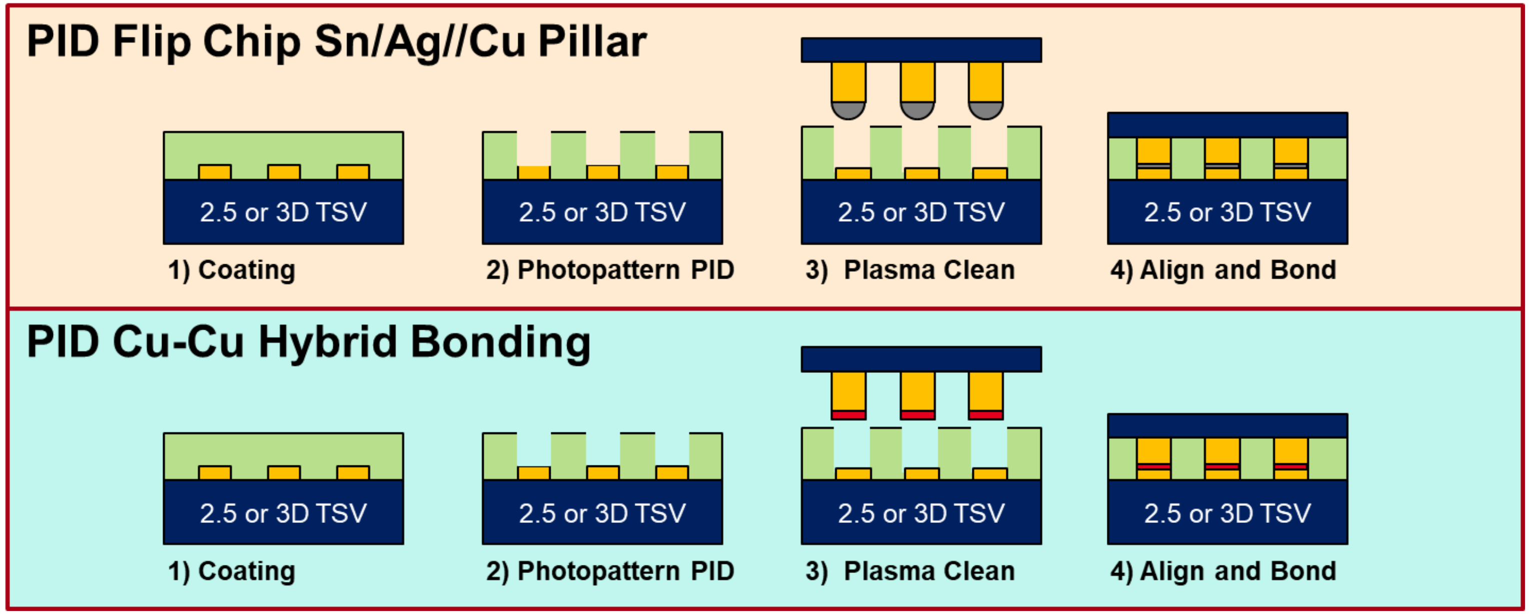
Die Shear Results

Dielectric	Substrate	Temperature	Force	Shear Strength (N/mm2)
CYCLOTENE 6505	Si + AP9000	90°C	100N	8.16
		100°C		18.88
		110°C		23.50
	6505	90 °C		15.03
		100°C		9.75
		110°C		8.44
XP-5G-006	Si	100°C	150N	20.25
		110°C		15.5
		120°C		13.75
	XP-5G-006	100°C		Work in Progress
		110°C		
		120°C		

Die Shear Conditions	
Tool	Bond tester
Max load	100KG or 1000N
Shear tool	9 mm wide flat tip
Test type	Destructive
Shear speed	75 µm/s
Land speed	500 µm/s
Shear height	20 µm
Max shear distance	4000 µm



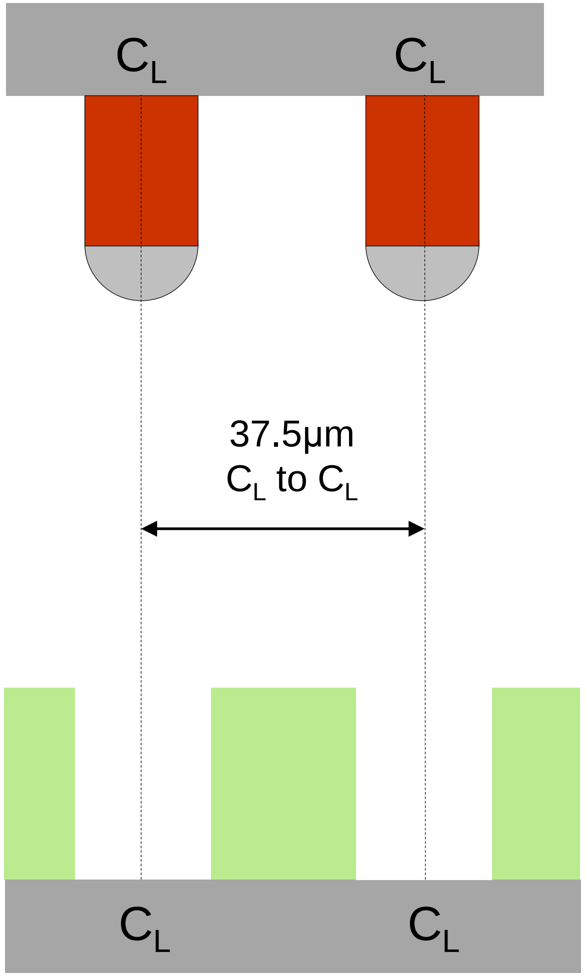
Future Work on Flip Chip and Hybrid Bonding


PID Flip Chip Sn/Ag//Cu Pillar

1) Coating
2) Photopattern PID
3) Plasma Clean
4) Align and Bond

PID Cu-Cu Hybrid Bonding

1) Coating
2) Photopattern PID
3) Plasma Clean
4) Align and Bond


15µm ϕ Sn/Ag capped Cu pillar

37.5µm
C_L to C_L

18µm ϕ PID opening

Conclusions and Next Steps

Void free patterned bonding demonstrated for both positive and negative tone PID materials

	CYCLOTENE™ 6505 PID	XP-5G-006 PID
Photopatternable	Positive tone (TMAH)	Negative Tone (PGMEA)
Cure temperature	220°C/3hr	200°C/1hr
Adhesion promoter	AP9000C	Self Priming
Bonding temperature	80-110°C	80-110°C
Bonding force	4kN-8kN	4kN-12kN
Bonding time	≤10min	≤10min
Voiding or offgasing	No	No
Reflow	Yes	No

Sn/Ag capped copper pillars will be plated at a variety of pitches

C2W and W2W bonding are planned for Q2 with reliability testing to follow

Special thanks to Shekhar Subramoney, Keith Warrington, David Fleming, Christine Hatter, Paul Morganelli, Hua Dong, Peggy Wu, Monita Pau, Shashi Gupta, and Kirk Thompson