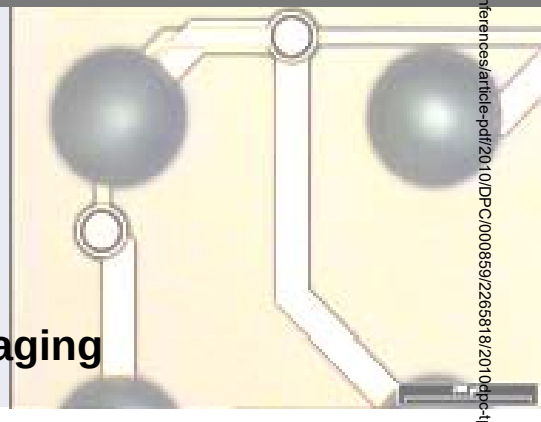
Using Permanent and Temporary Polyimide Adhesives in 3D-TSV Processing To Avoid Thin Wafer Handling

Presentation to
6th International Conference on Device Packaging
March 9, 2010



M. P. Zussman and C. Milasincic – HD MicroSystems
A. Rardin, S. Kirk and T. Itabashi – DuPont Wafer Level Packaging

HD MicroSystems
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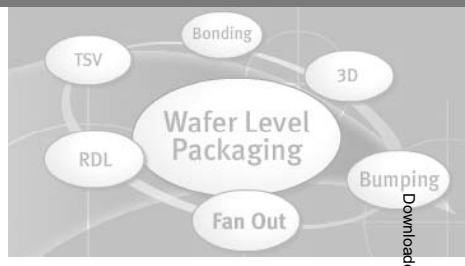
Acknowledgments



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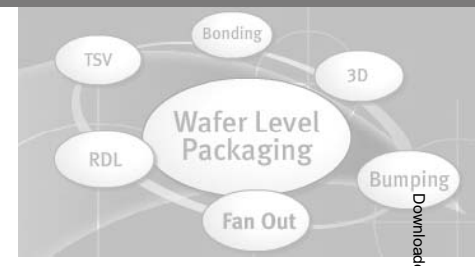
Development and characterization of polyimide adhesives is a global and multifunctional effort

Tamarack Scientific
- M. Souter
- M. Gingerella

DuPont Central Research
- B. Roeske
- S. McCracken
- J. Howe
- R. Pryor
- M. Lemmon

Süss MicroTec
- J. Hermanowski
- S. Sood
- Apps Team

Diversity in Architecture



3D Architectures will use a variety of designs, processes and materials

3D TSV Process Sequences – Applications for Adhesives

Process Type	"Step 1"	"Step 2"	"Step 3"
A - Vias first	TSV (FEOL, BEOL,PACK)	Handle (TA), thin, backside process	B2F Bond (Mtl)
B – Vias first	TSV (FEOL, BEOL,PACK)	F2F bond (Mtl)	Thin, backside process
C – Vias last	F2F bond (Mtl, SiO, PA)	Thin	TSV back, backside process
D – Vias first	Handle (TA), thin	TSV back, backside process	B2F bond (Mtl)
E – Vias last	Handle (TA), thin	B2F bond (PA)	TSV front, backside process

Table based on Refs. 1 & 2

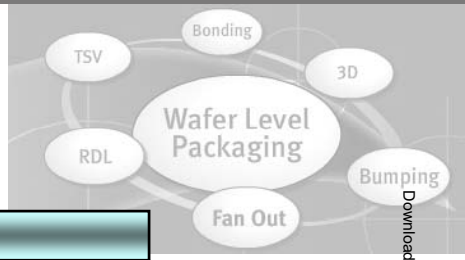
Mtl = metal to metal bonding
SiO = SiO_2 to SiO_2 bonding
TA = temporary adhesive bonding
PA = permanent adhesive bonding

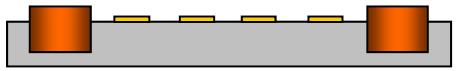
Temporary adhesives used in conjunction with handler or carrier wafers – HD-3007

Permanent adhesives complement Mtl bonding – HD-7010

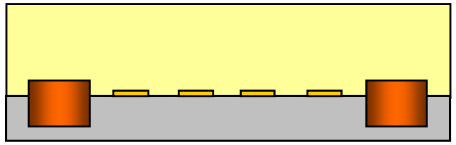
1. P.Garrou, "3D IC Integration: An Emerging System Level Integration Architecture", 3D Integration & Packaging Roadshow, 2008
2. J.-Q. Lu, "3-D Hyperintegration and Packaging Technologies for Micro-Nano Systems", Proc. IEEE 97(1), 2009

3D TSV Process Flow using Polyimide Adhesives to Avoid Thin Wafer Handling

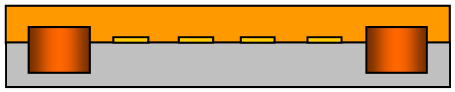




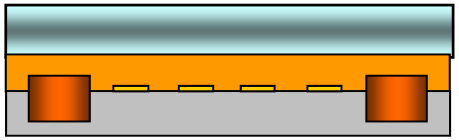
HD3007 Coat / Prebake



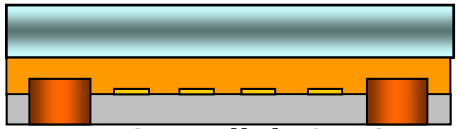
HD3007 Cure



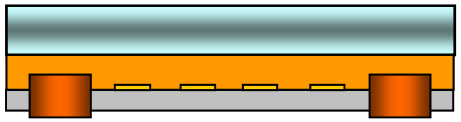
Thermo compression



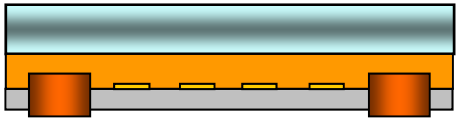
Back grinding



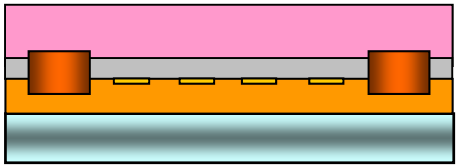
Cu polish & PCMP Clean: CoppeReady® &PCMP5510



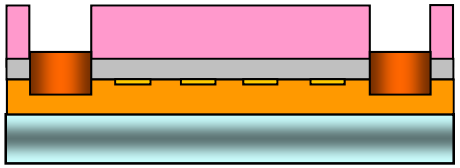
P-TEOS Depo & Etch.



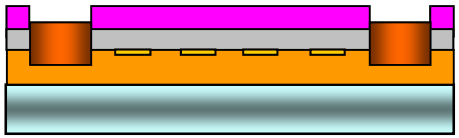
HD7010 Coat / Prebake



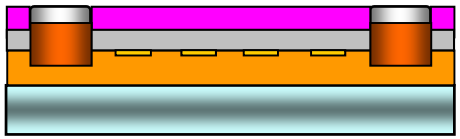
HD7010 patterning



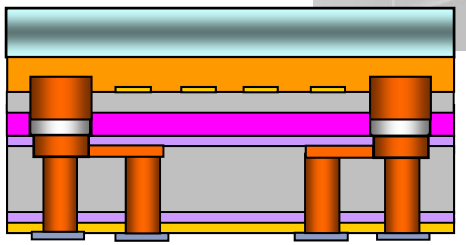
HD7010 Cure



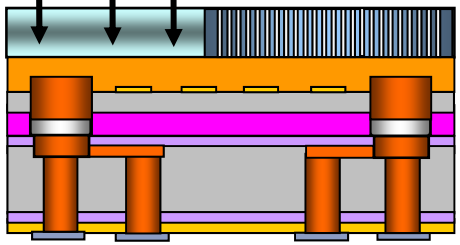
Sn Plating



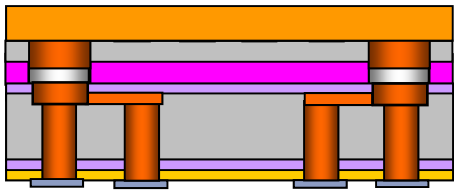
Thermo compression to Sub.



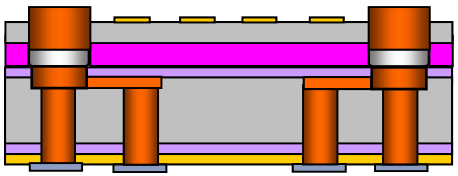
Laser Ablation or Solvent Release



Detach glass or perforated silicon



HD3007 Adhesive Removal



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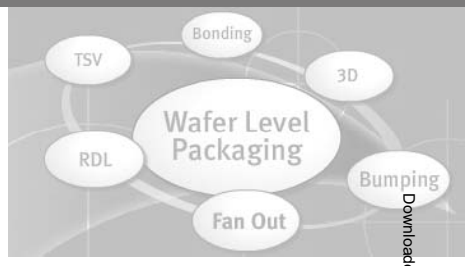
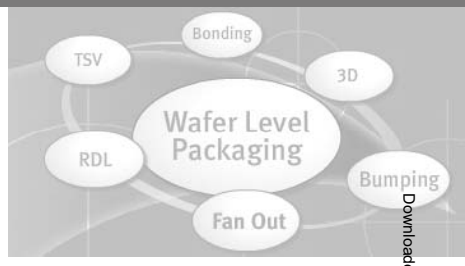


HD-3007 Temporary Adhesive

Introduction to HD-3007 Temporary Adhesive

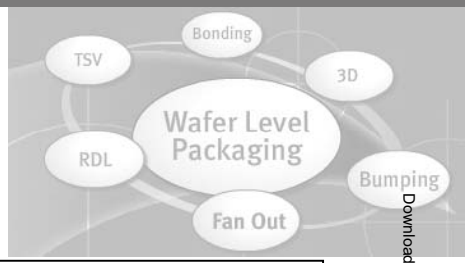


HD-3007 is a spin-applied liquid designed for use as a temporary adhesive

- Application: Wafer-to-wafer and die-to-wafer adhesive
- Thermal cure converts HD-3007 to a thermoplastic polyimide
- HD-3007 is not photosensitive
- Formulation in BLO/PGMEA (Note: formulation in NMP called HD-3003 X1)

General process sequence for HD-3007

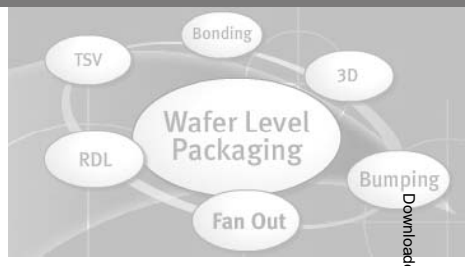
- Apply to substrate wafer by spin coating, soft-bake to dry film
- Cure (oven or hotplate)
- Bond to carrier wafer
- Process wafer for TSV (backgrinding, via formation, other backside processing, bonding, etc)
- De-bond carrier wafer from product and clean residual HD-3007



HD-3007 Typical properties and process

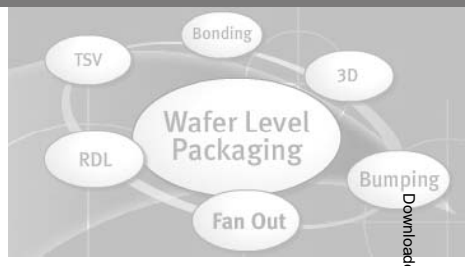
Property/Condition	Units	HD-3007
Liquid Viscosity	Ps	9-11
Non-volatile Contents	%	24-26
Cure Temp Range	°C	250-350
Bonding Temp Range	°C	300-350
Bonding Pressure	N/cm^2	>14-22
Contact time	minutes	1-10*
Cured Dielectric Thickness	µm	2-10
Glass Transition Temp (Tg)	°C	180
Weight loss @ 350C	%	0.2
CTE	ppm/ °C	50
Dielectric Constant	z	3.4
Tensile Strength	MPa	130
Modulus	GPa	3.3

* Bond times dependent on bonding temperature and adhesive thicknesses used
- Thicker adhesive layers will bond faster
- Thinner adhesive layers will bond slower



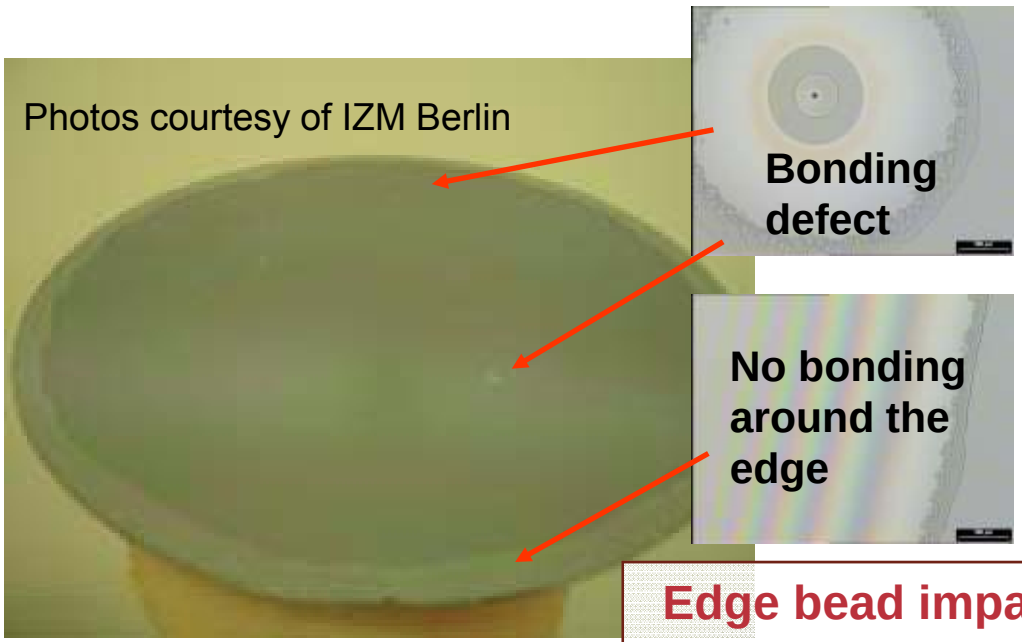
HD-3007 Temporary Adhesive : Wafer-to-Wafer Bonding

W2W Bonding of HD3007 – Process Definition



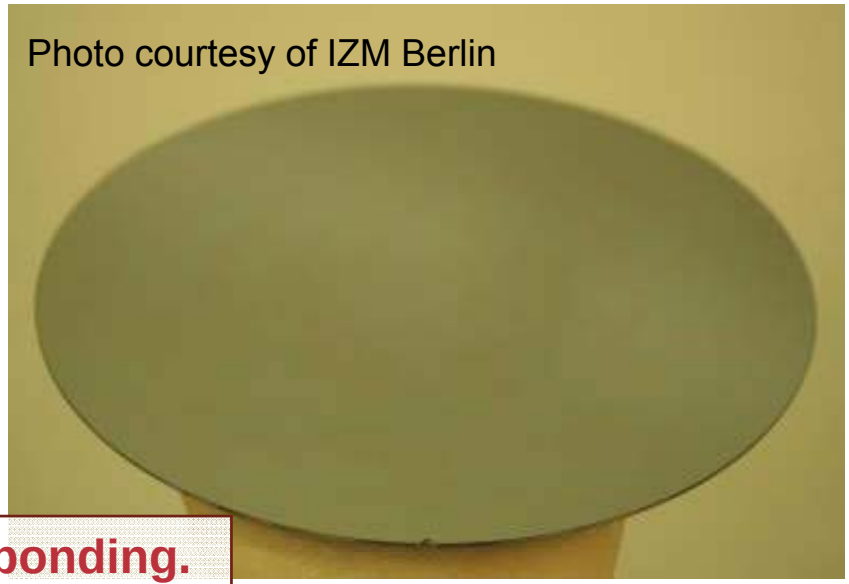
Poor Result

- **Cure Temp:** 350 °C
- **Adhesive thickness:** 4 µm
- **Bond Temp:** 200 °C
- **Pressure:** 14.5 N/cm^2
- **Bonding Time:** 35 min



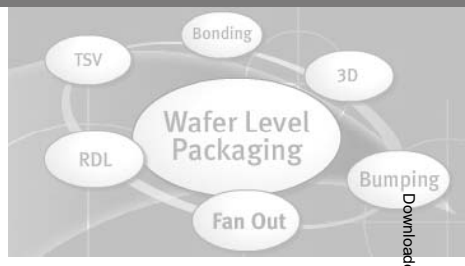
Good Result

- **Cure Temp:** 350 °C
- **Adhesive thickness:** 8 µm
- **Bond Temp:** 300 °C
- **Pressure:** 22 N/cm^2
- **Bonding Time:** 1 min



Edge bead impairs bonding.

Flow required for good result



W2W Bonding Requires Adhesive Flow

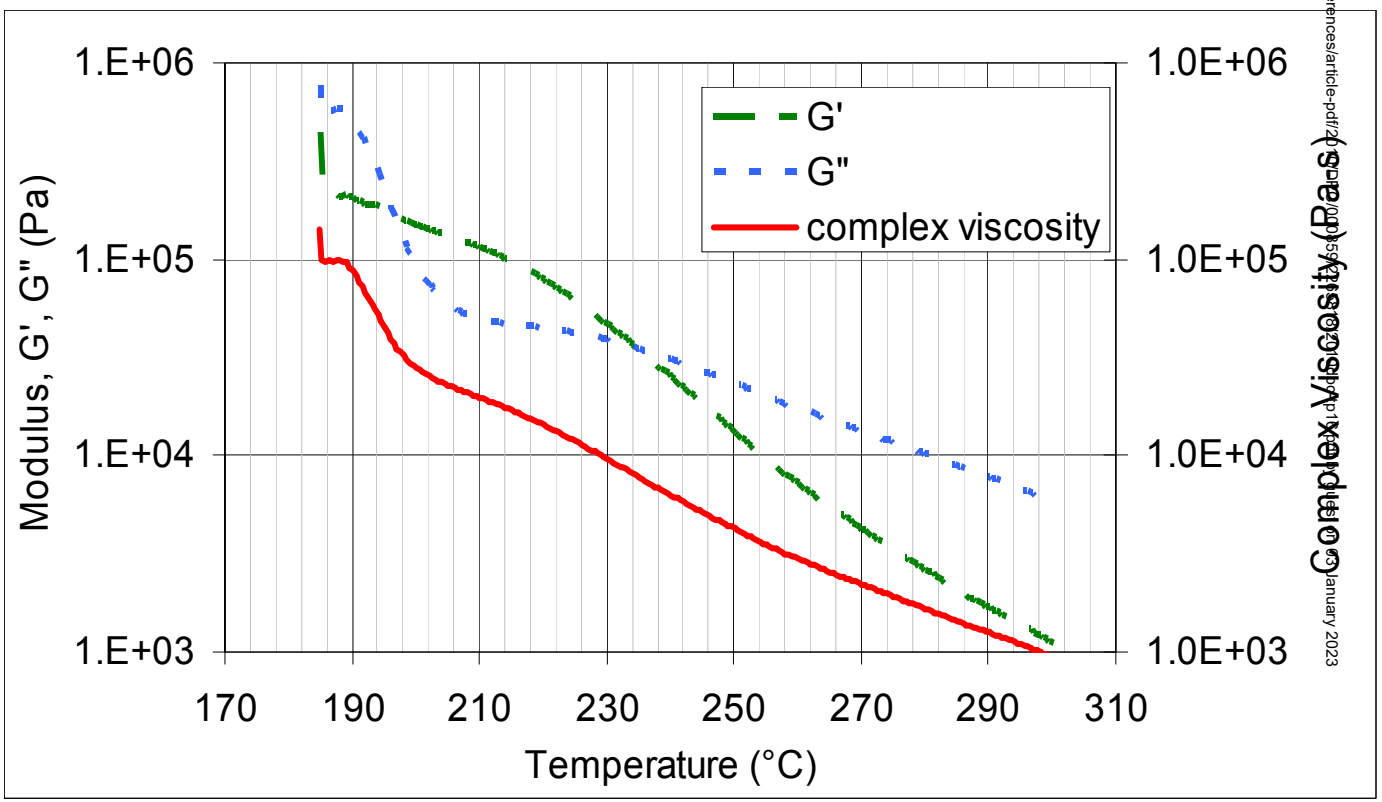
Flow determined by the rheology of the adhesive under bonding conditions

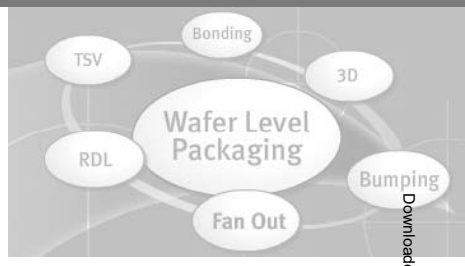
Melt viscosity has strong temperature dependence

- Viscosity falls 2 orders of magnitude from 190 to 300°C

- G' – Storage modulus: in-phase response
- G'' – Loss modulus: out-of-phase response
- Complex Viscosity :

$$\eta^* = \sqrt{\left(\frac{G}{\omega}\right)^2 + \left(\frac{G'}{\omega}\right)^2}$$

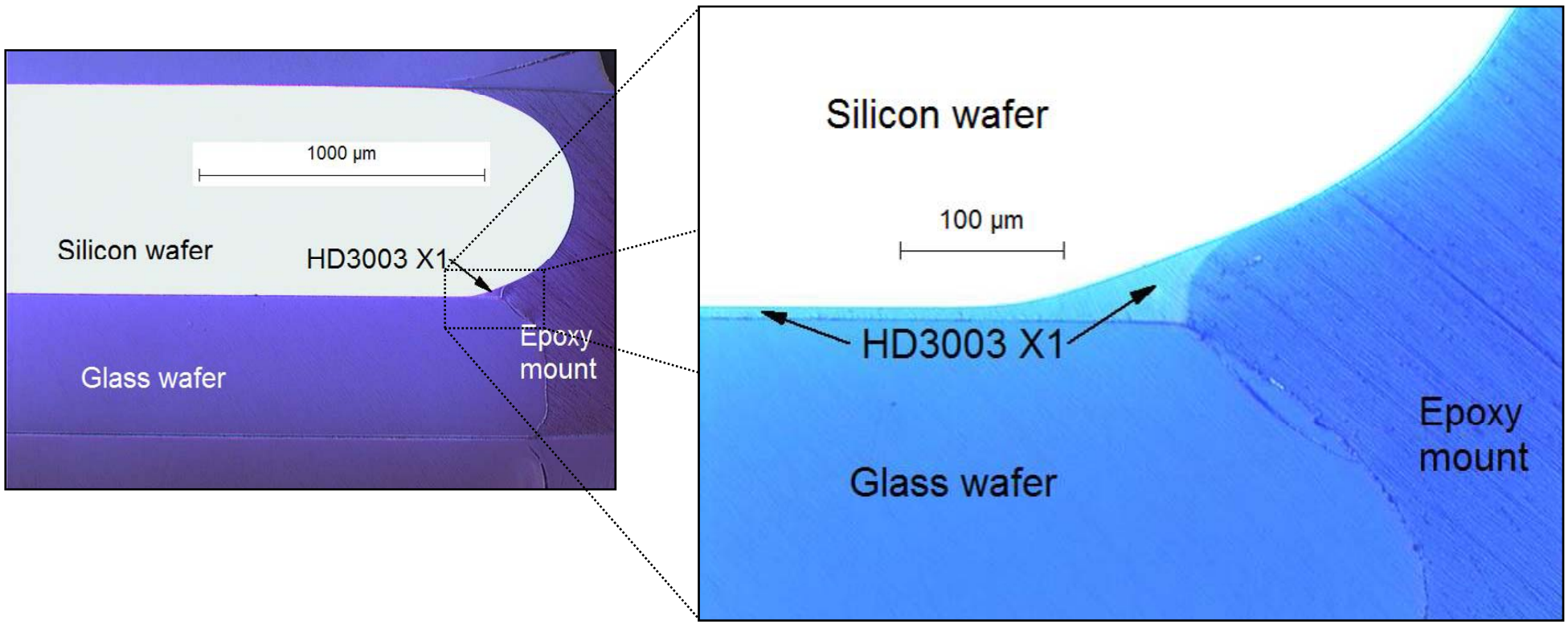




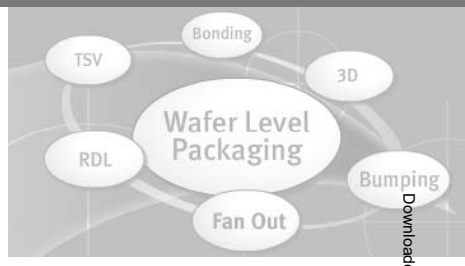
Adhesive Characterization – Edge Flow

Flow during bonding is needed to coat over topography, and bond the edge bead region

Flow at wafer edge is also critical to protect wafer during back-grinding

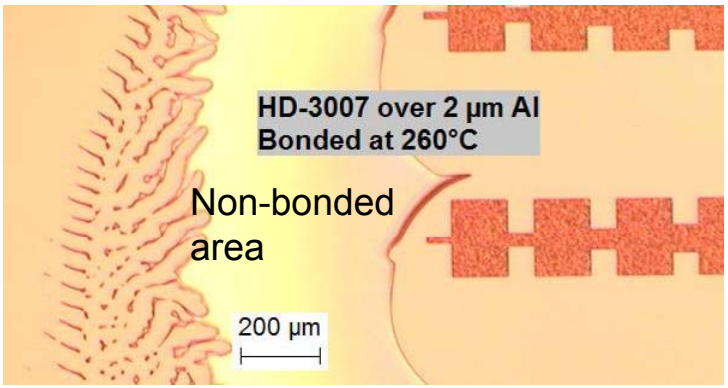


Bonding of HD-3007 Coated over Topography



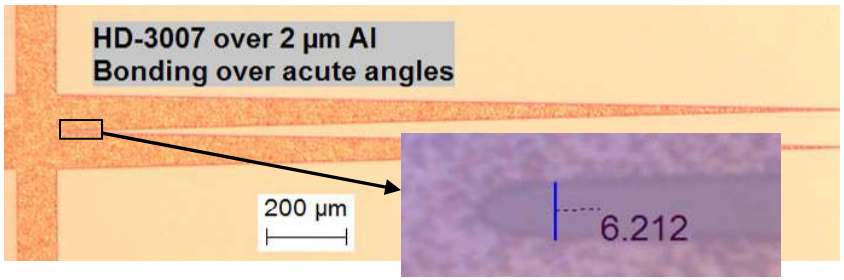
HD-3007 coated over 2 µm Aluminum topography, then cured @290°C

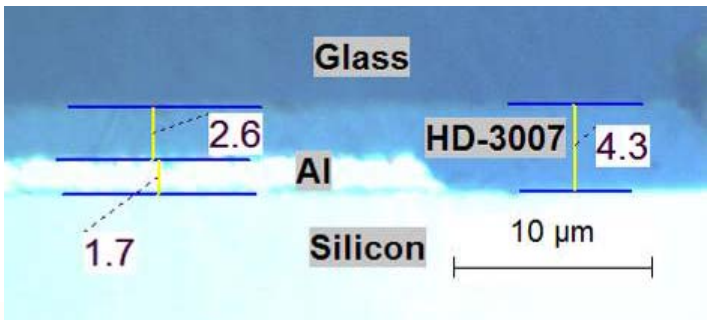
Bonding at 260°C is incomplete – non bonded areas adjacent to patterned areas

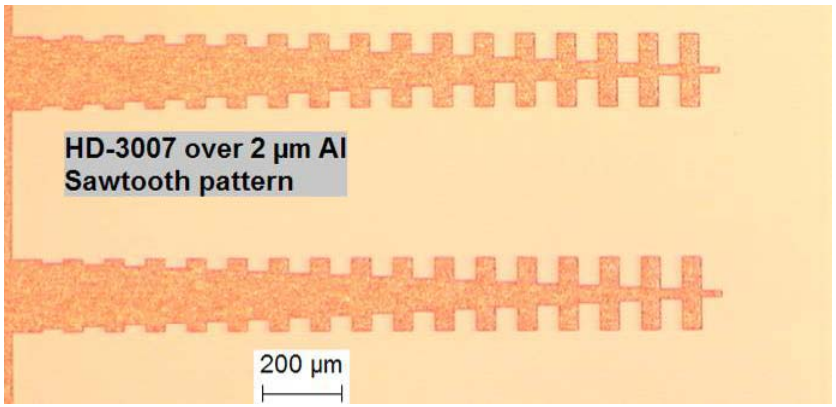


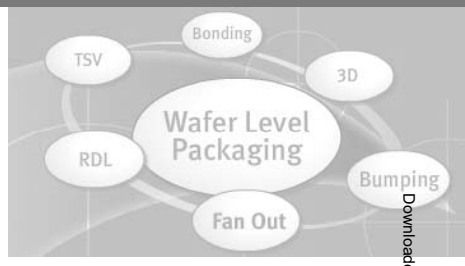
Bonding at 350°C is complete

- No voids seen when bonding over fine features
- Cross-section shows conformal coating over topography

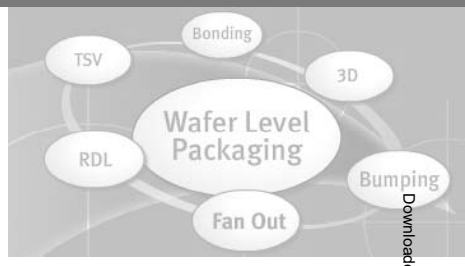








HD-3007 Temporary Adhesive : Thermal Performance



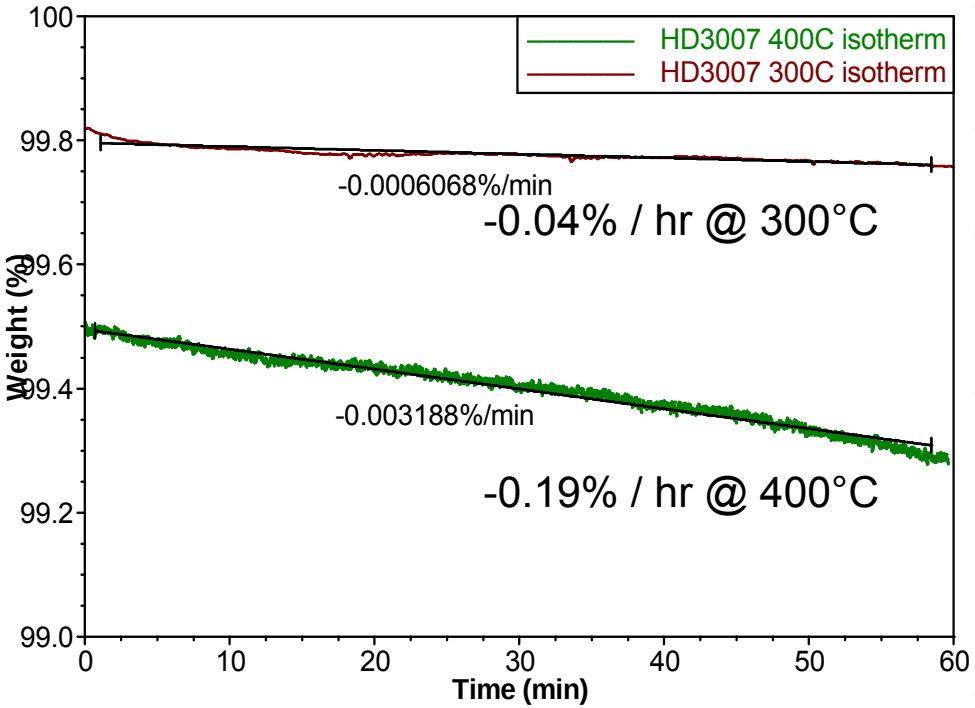
HD-3007 Polyimide has High Thermal Stability

1% Weight loss temperature is >520°C (@10°C/min, in air or N_2)

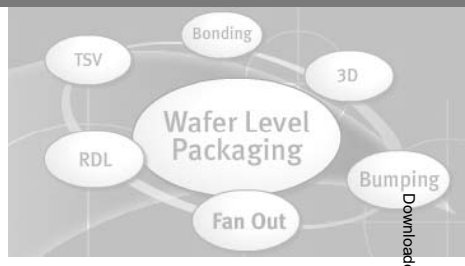
Isothermal weight loss is slow, linear process

Thermal stability of HD-3007 higher than reported values for BCB, epoxy, and other polyimide adhesives (Ref. 4,5,6)

Use of HD-3007 is compatible with processes up to 400°C – e.g. M2M bonding, annealing, PI for RDL, etc.

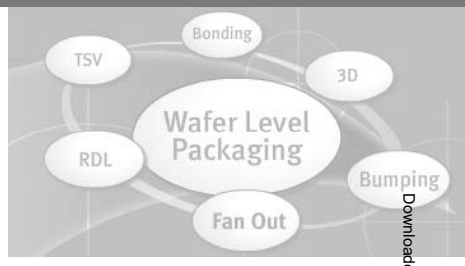


4. http://www.dow.com/PublishedLiterature/dh_0055/0901b803800550e7.pdf?filepath=cyclotene/pdfs/noreg/618-00200.pdf&fromPage=GetDoc
5. http://www.microchem.com/products/pdf/SU-8-table-of-properties.pdf
6. J. Hermanowski, “Thin wafer handling - Study of temporary wafer bonding materials and processes”, 2009 IEEE International Conference on 3D System Integration, 3DIC 2009 , art. no. 5306550



HD-3007 Temporary Adhesive: Release Methods

Laser Release of HD-3007



Laser release demonstrated with 248 and 308 nm excimer lasers

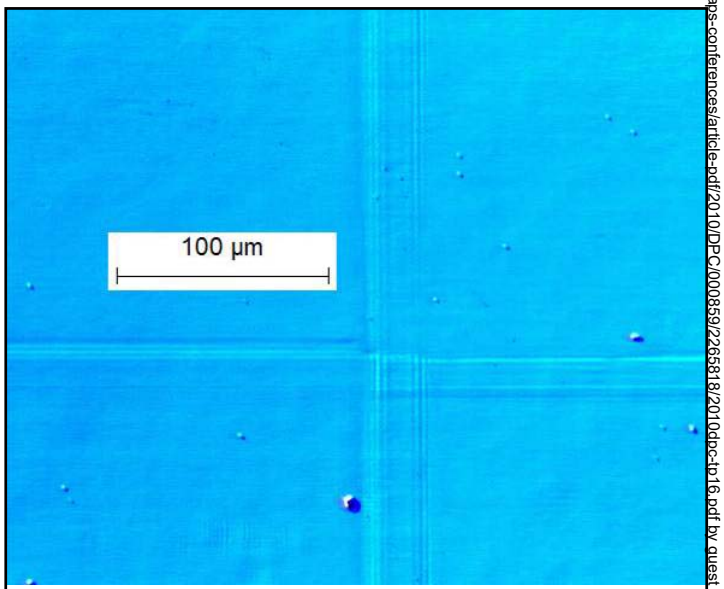
Irradiation @ 248 nm through glass carrier ablates HD-3007 within 0.2 µm of the glass surface

- 500 µm thick, Borofloat glass carrier wafers
- Slight residue remains on glass carrier
- Most of the HD-3007 remains on the silicon wafer

De-bonding occurs with a single pulse

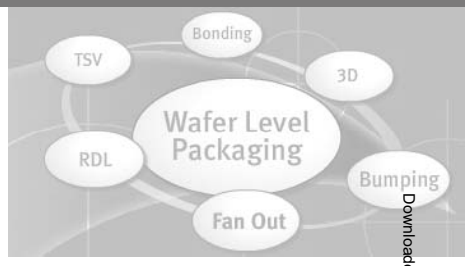
- Throughput depends on beam size and pulse frequency
- De-bonding fluence is affected by carrier thickness due to light absorbed by the carrier
- Commercial laser de-bonders are under development

HD-3007 residue on carrier after laser de-bonding



De-bonding with a 248 nm laser, 6.5 mm^2 spot size. Residue on the carrier from overlap of step-and-repeat laser pulsing

Laser de-bonding of Thinned Wafer from Glass Carrier



De-bonded glass carrier and 50 µm thinned silicon wafer

Laser de-bonding performed at Tamarack Scientific

- De-bonded at 248 nm, single pass, 30 s de-bond time
- Very little residue on glass wafer

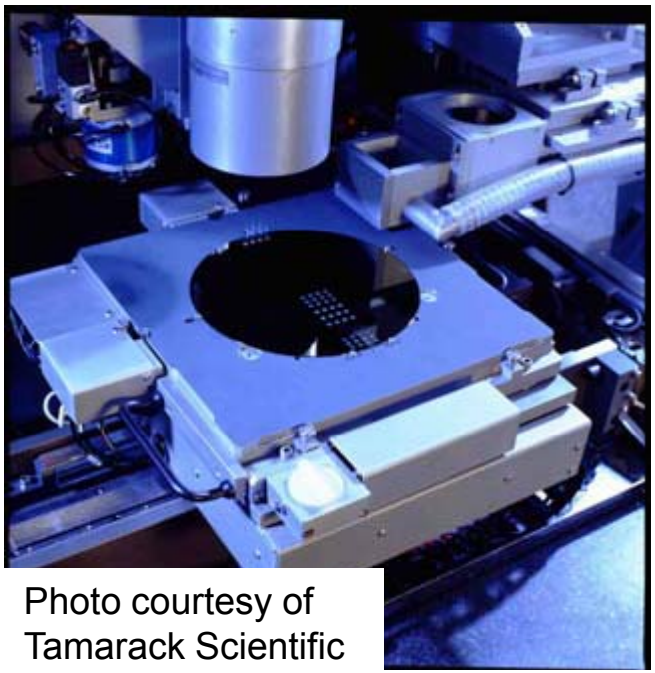
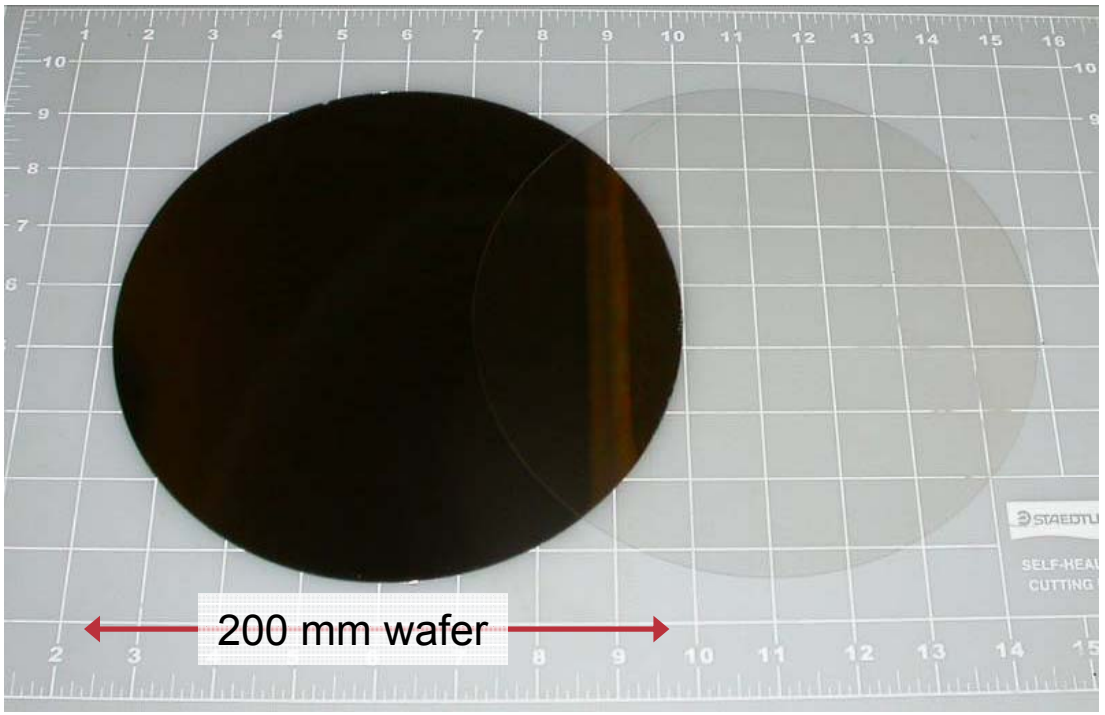
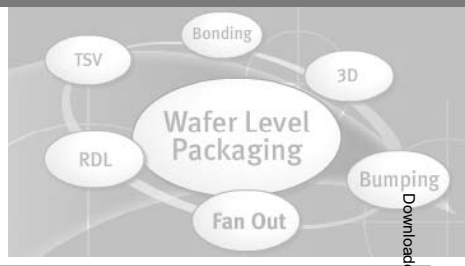


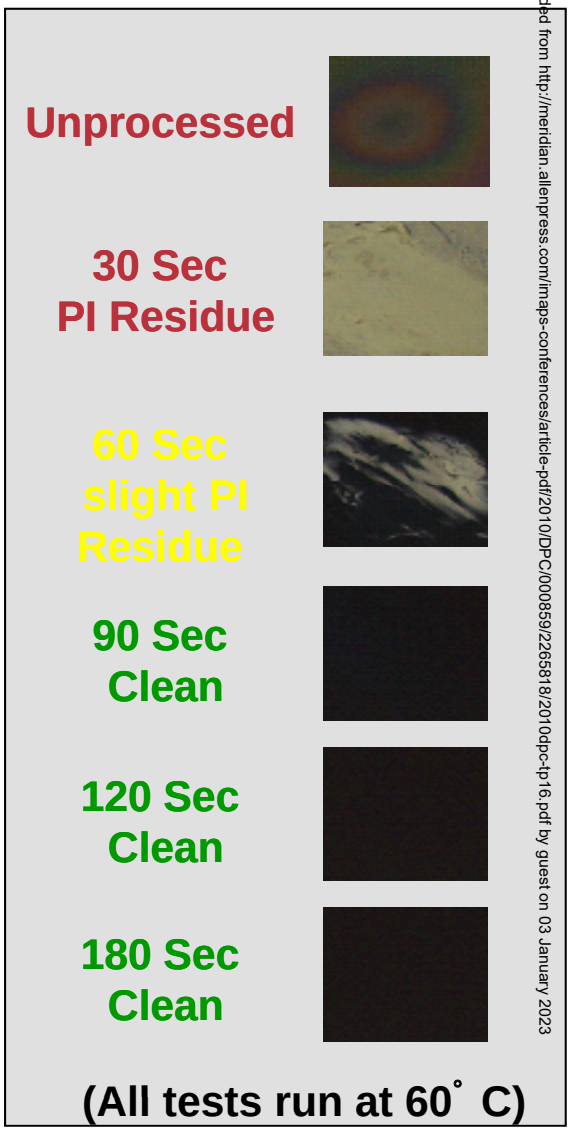
Photo courtesy of Tamarack Scientific



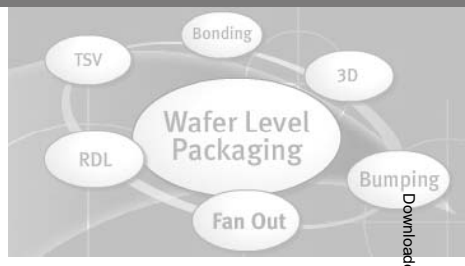
Solvent Cleaning: EKC865™ Selective Adhesive Remover for HD-3007



- **Test Wafer Process Conditions**
  - HD-3007 thickness = 8µm (4µm standard thickness)
  - Cured at 290˚ C, bonded at 300˚ C
  - De-bonded via laser ablation
  - Additional pieces of silicon wafer coated with HD-4100 (blanket and patterned) and cured at 350˚ C were also tested for compatibility
- **Cleaning Results**
  - Rapid Cleaning at 60˚ C for a time of 60 -180 seconds
  - Compatible with HD-4100 cured at 350˚ C
    - Tested at 60˚ C for 30min with no attack to HD-4001
  - Excellent Compatibility to Sensitive Metal Films
    - Aluminum, Copper, Titanium, Nickel, Chrome, Tungsten, & other Metal Alloys
- **Chemistry can be re-circulated in a closed loop system**
- **Water rinse-able**
- **Can be utilized in both automated and manual wet cleaning equipment platforms**



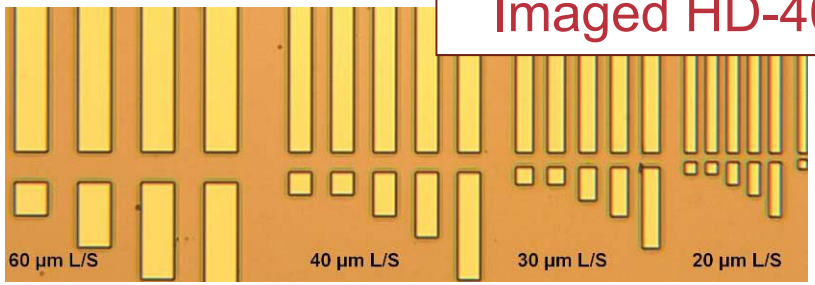
Cleaning of HD-3007 over Topography

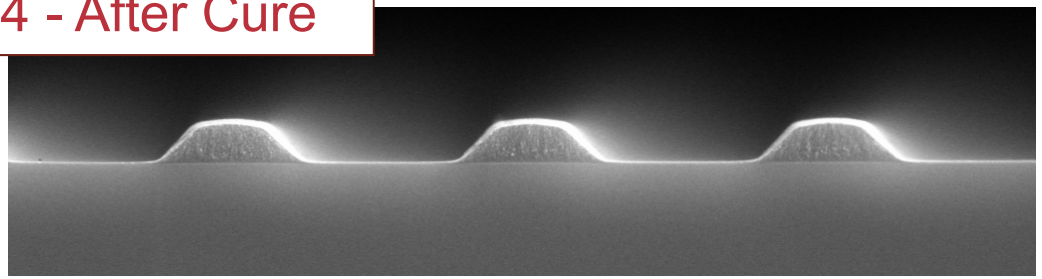


Top View - 60, 40, 30 & 20 µm L/S

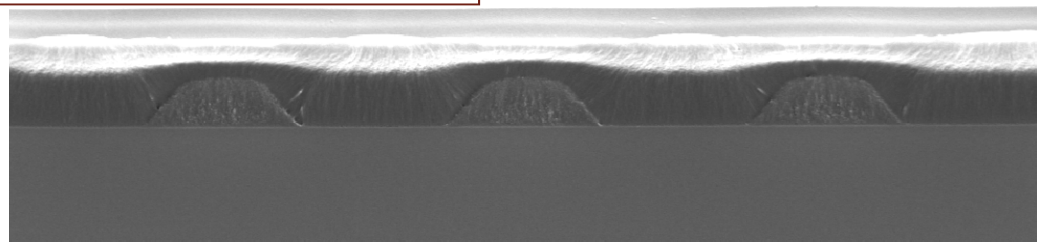
Cross-Section – 6 µm L/S

Imaged HD-4004 - After Cure

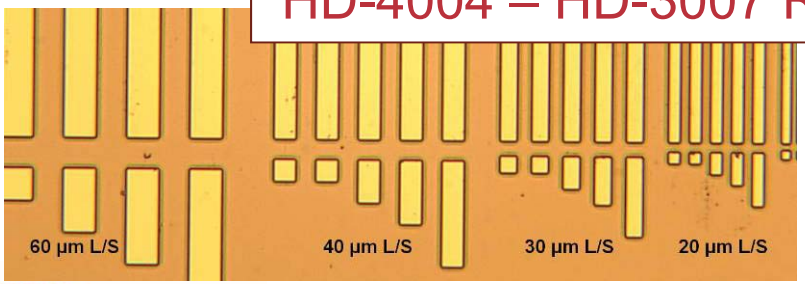


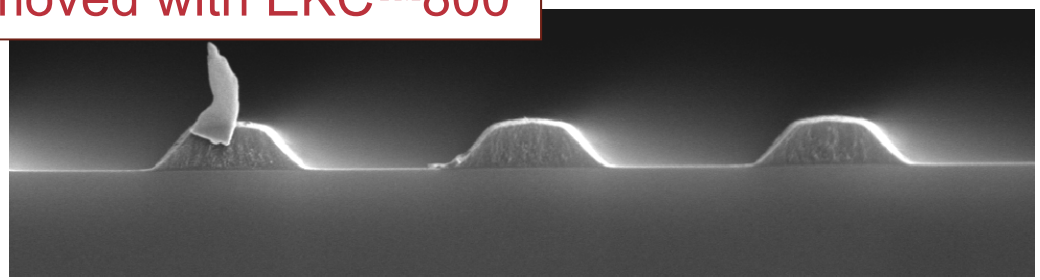


HD-3007 Coated Over Imaged HD-4004

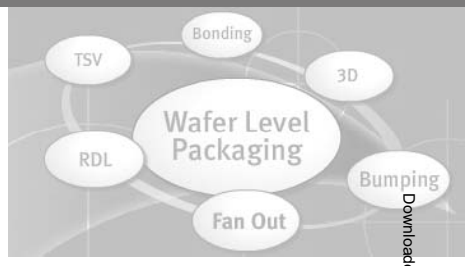


HD-4004 – HD-3007 Removed with EKC™800





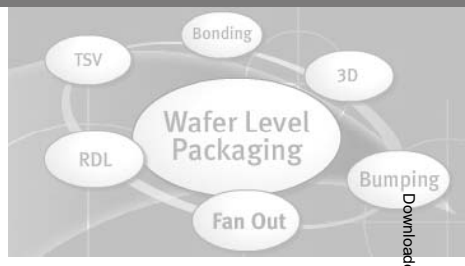
Solvent De-Bonding of HD-3007



Since HD-3007 after cure and bonding is still soluble in selected solvents, solvent de-bonding is possible

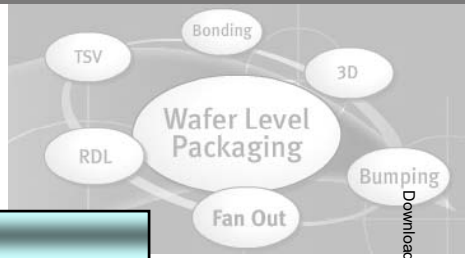
Perforated carrier is required so solvent can attack the bond

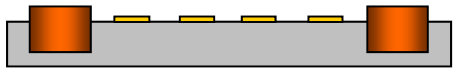
Experiments are underway to define a solvent de-bonding process



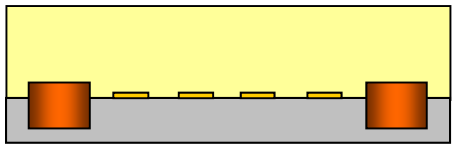
Permanent Polyimide Adhesive: HD-7010

3D TSV Process Flow using Polyimide Adhesives to Avoid Thin Wafer Handling

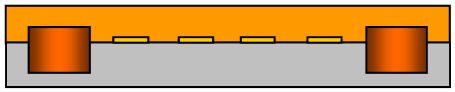




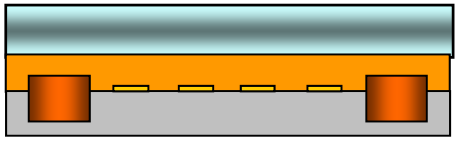
HD3007 Coat / Prebake



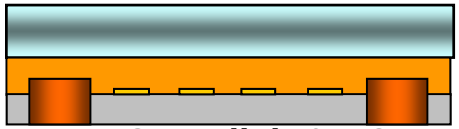
HD3007 Cure



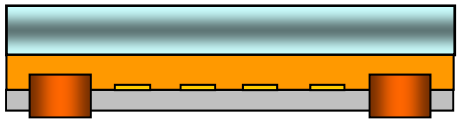
Thermo compression



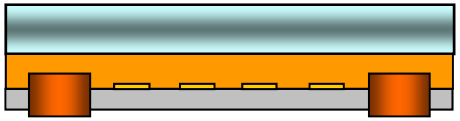
Back grinding



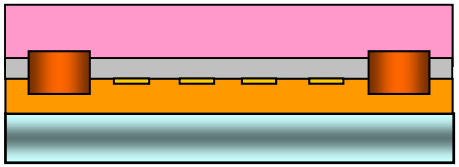
Cu polish & PCMP Clean: CoppeReady® &PCMP5510



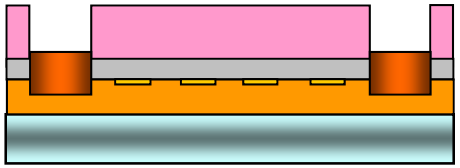
P-TEOS Depo & Etch.



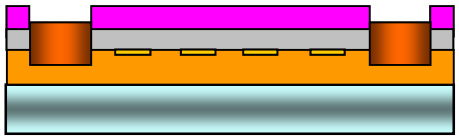
HD7010 Coat / Prebake



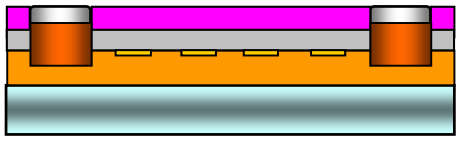
HD7010 patterning



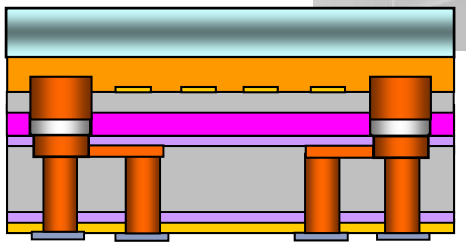
HD7010 Cure



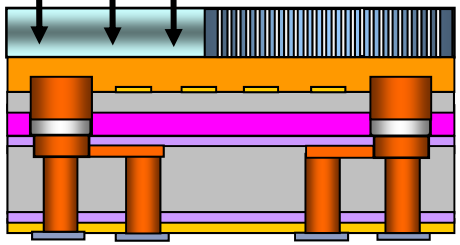
Sn Plating



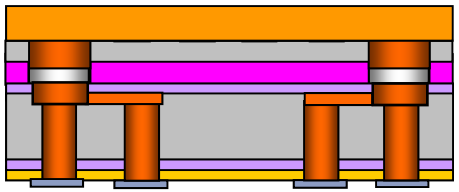
Thermo compression to Sub.



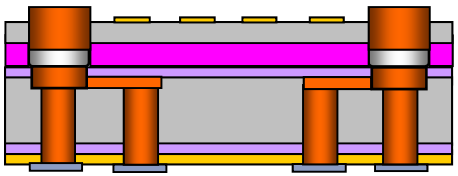
Laser Ablation or Solvent Release



Detach glass or perforated silicon



HD3007 Adhesive Removal



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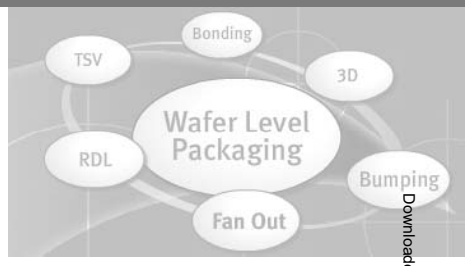
HD MicroSystems

Introduction to HD-7010 Permanent Adhesive



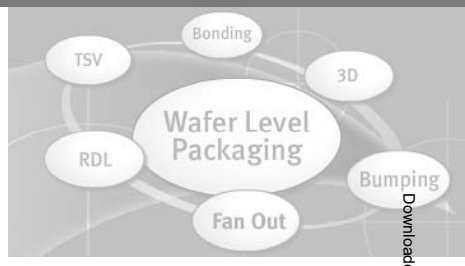
HD-7010 is a spin-applied liquid designed for use as a permanent adhesive and for RDL

- Solvent developed, negative tone photodefinable polyimide precursor
- Application: Die-to-die, die-to-wafer and wafer-to-wafer bonding
- HD-7010 is copper compatible – no corrosion when cured over Cu features

General process sequence for HD-7010

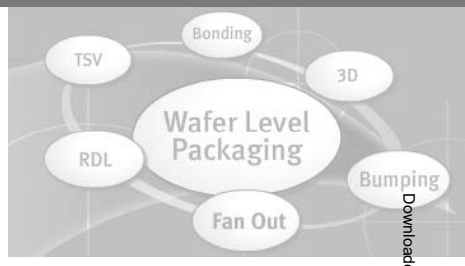
- Apply to wafer by spin coating, soft-bake to dry film
- UV expose, then remove un-exposed film with solvent developer
- Cure (oven cure recommended)
- Bond to second substrate (die or wafer)
- Repeat process to complete 3D build

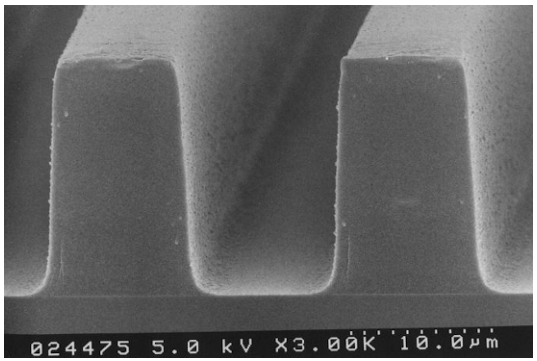
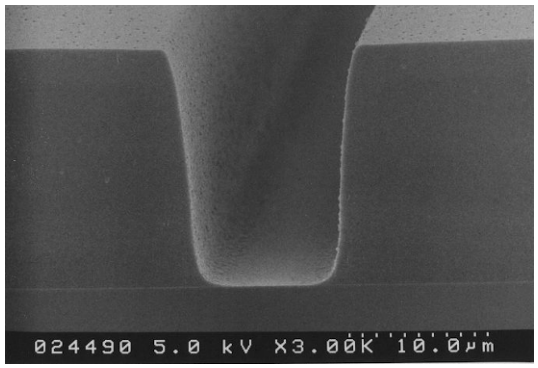
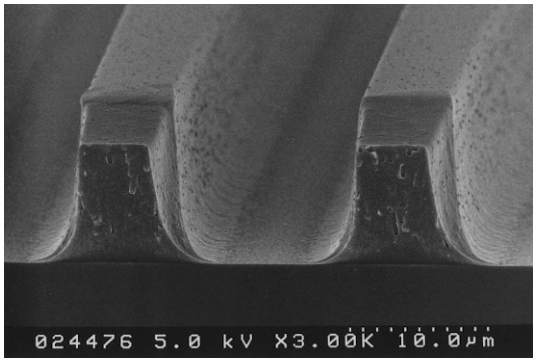
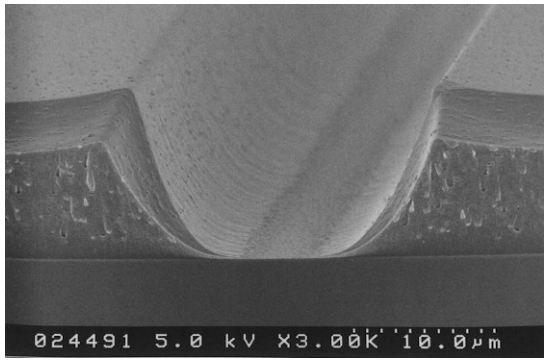
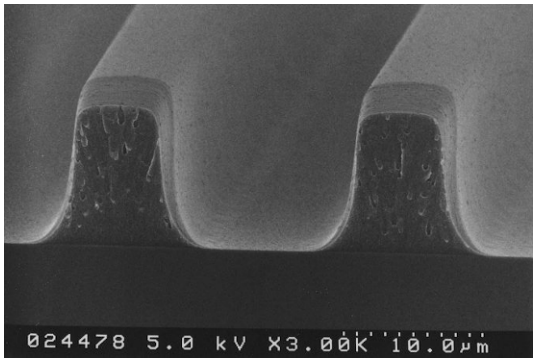
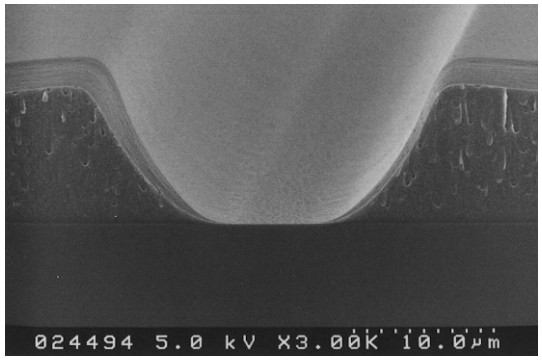
HD-7010 : Typical properties and process



Property/Condition	Units	HD-7010
Liquid Viscosity	Ps	27 - 33
Non-volatile Contents	%	35 - 40
Exposure	mJ/cm2, BB	130 - 150
Developer / Rinse		CP / PGMEA
Cure Temp Range	°C	250 - 400
Bonding Temp Range	°C	250 - 350
Bonding Press	N/cm2	14 - 22
Contact time	minutes	5 - 10
Cured Dielectric Thickness	microns	8 - 20
Glass Transition Temp	°C	250
5% Weight loss Temp.	°C	395
CTE	ppm	74
Dielectric Constant	z	3.3
Tensile Strength	Mpa	173
Modulus	Gpa	2.6
Elongation	%	70

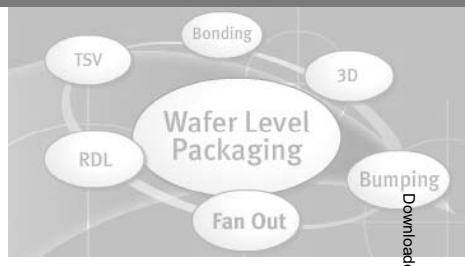
Photopatterning of HD-7010: Exposure with I-line Stepper



	L/S=10um/10um	L/S=40um/10um
Pattern After Dev. Dev.=PA400D Rinse=PA400R		
350deg.C Cured		
400deg.C Cured		

Film thickness: 10µm cured

000884



HD-7010 : Effect of Cure Temperature on Mechanical and Thermal Properties

Cure Condition	Tensile Strength (MPa)	Elongation (%)	Modulus (GPa)	Residual Stress (MPa)	CTE (ppm/°C)	Tg (°C)	5% Loss (°C)
350C / 1 hr	173	67	2.60	29.8	74	252	398
320 C / 1 hr	175	79	2.47	27.6	97	234	344
300 C / 1 hr	209	73	2.55	28.4	99	232	335
250 C / 2 hr	174	69	2.33	-	132	216	330
250 C / 1.5 hr	159	62	2.44	-	182	213	325
250 C / 1 hr	143	66	2.37	24.5	245	207	326

Mechanical properties show little dependence on cure temperature
Thermal properties and CTE are cure temperature dependent

W2W Bonding of HD7010 at Lower Temperature and Pressure

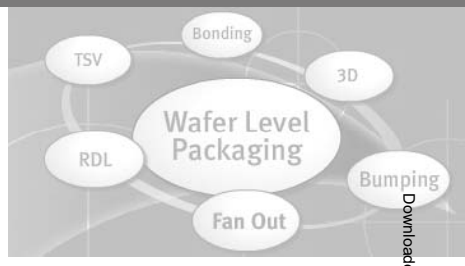


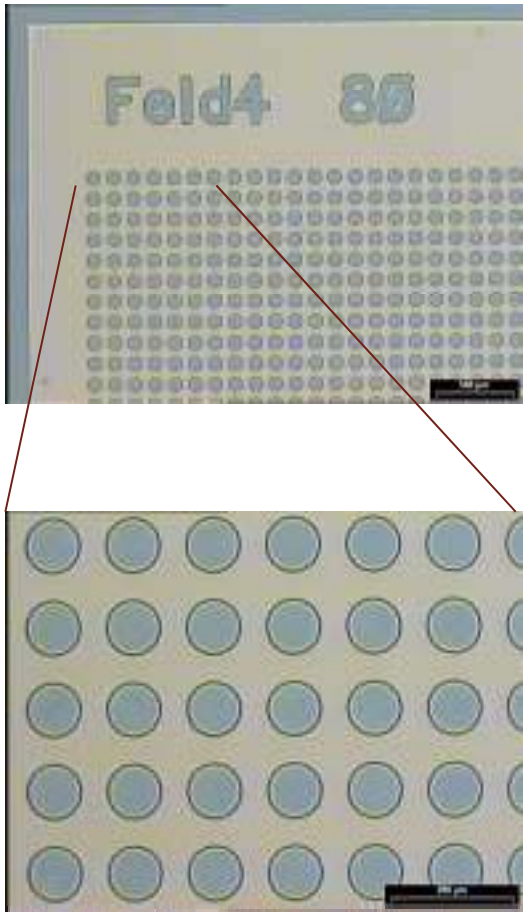
Photo-patterned HD-7010 has crowning around features

Recommended process for low pressure bonding:

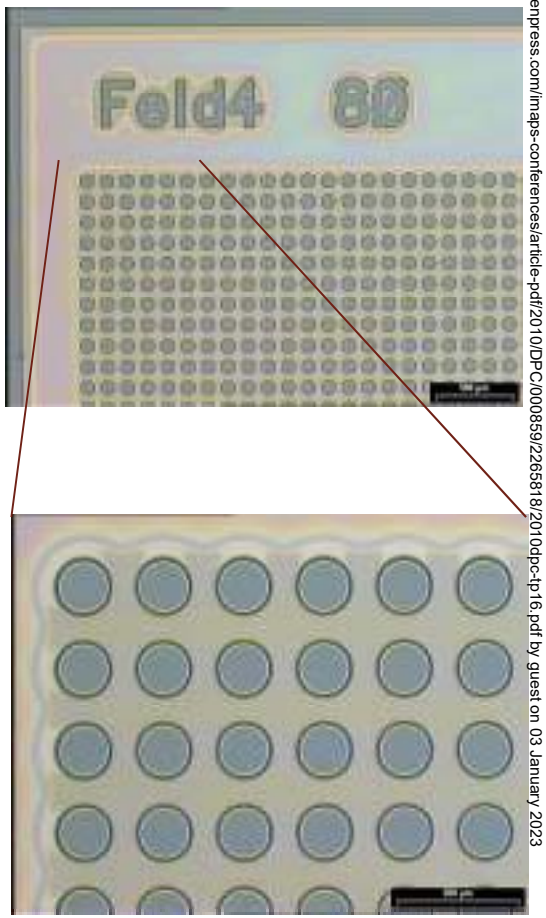
- Cure at 250°C
- Planarize surface (remove crowning) by CMP
- Bond at 250 – 300°C
- Pressure ≥22 N/cm^2

HD-7010 has low flow after cure

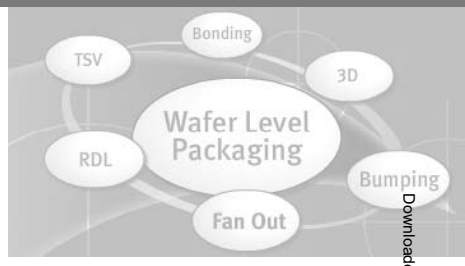
CMP before bond



No CMP before bond



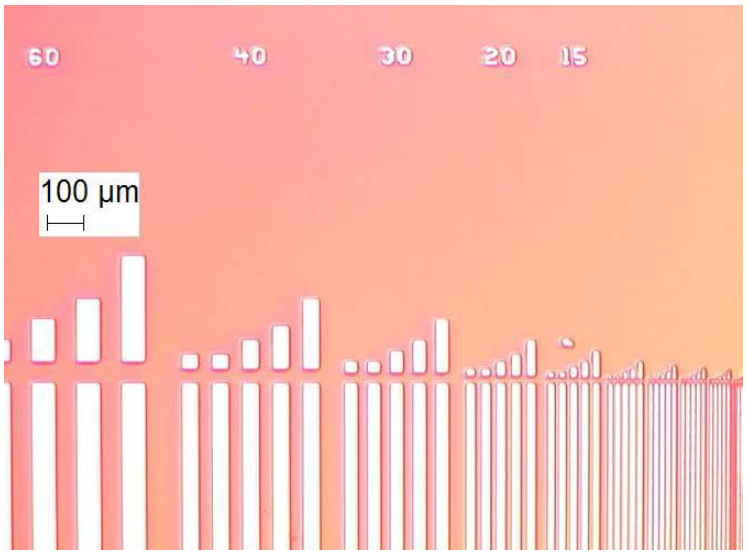
Bonding of HD-7010 at Higher Pressure and Temperature

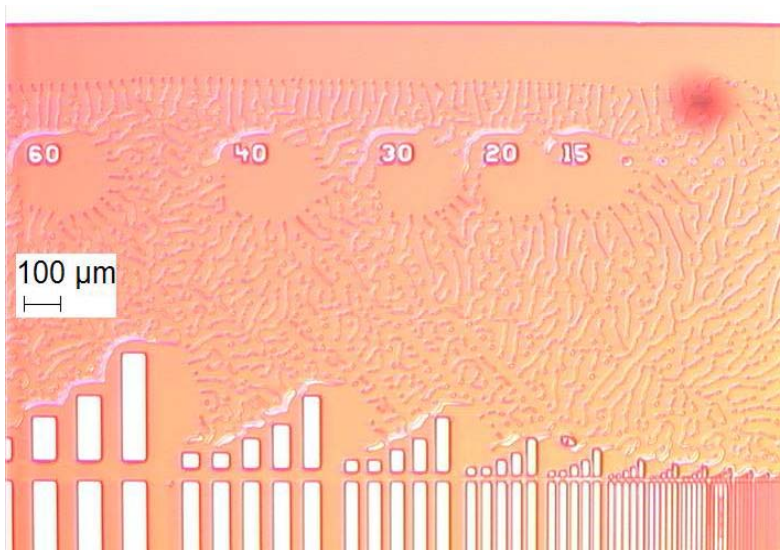


Imaged HD-7010 films on 200 mm wafers

Wafers were bonded to glass carriers at Süss MicroTec

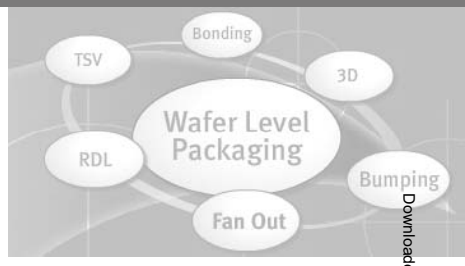
- Bonded at 350°C, 30 kN, 10 min contact time (no CMP)
- Most of the HD-7010 was bonded well to the glass carrier





- Some areas of the wafer showed incomplete bonding
- Follow-up experiments required to improve uniformity

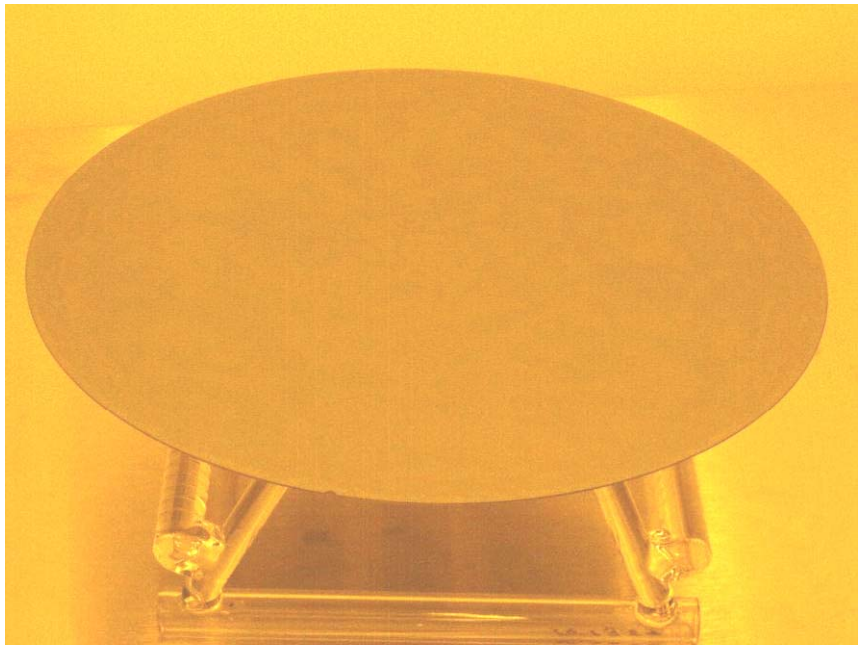
Process Integration: HD-7010 on Thin Silicon



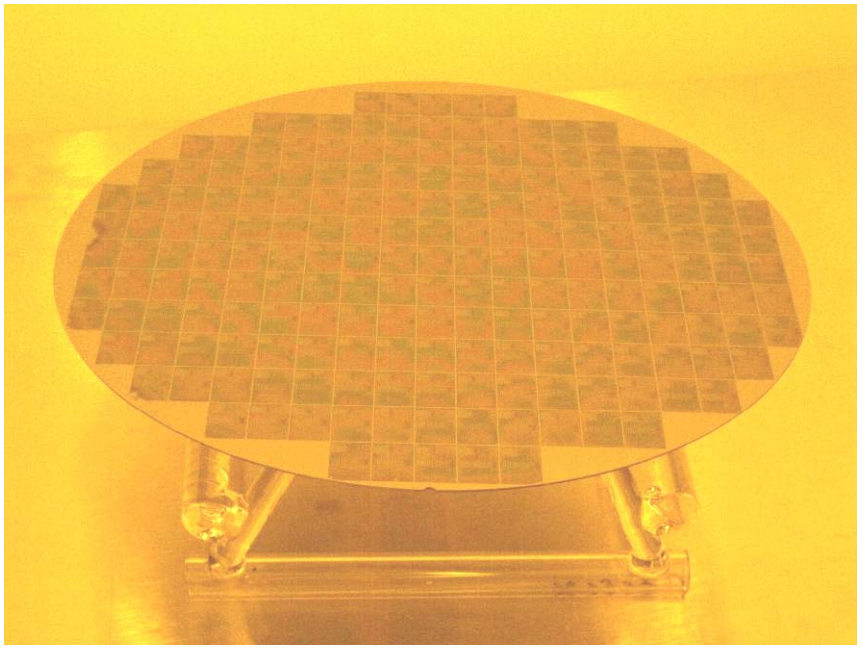
Substrate: 50 µm wafer bonded with HD-3007 to glass carrier

HD-7010 was coated onto backside, imaged and cured at 350°C

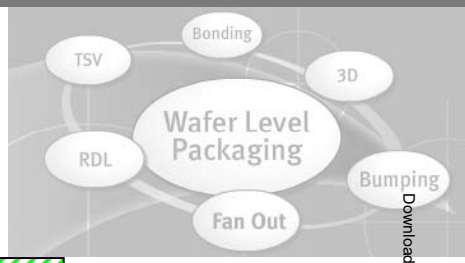
Frontside view: glass carrier bonded with HD-3007

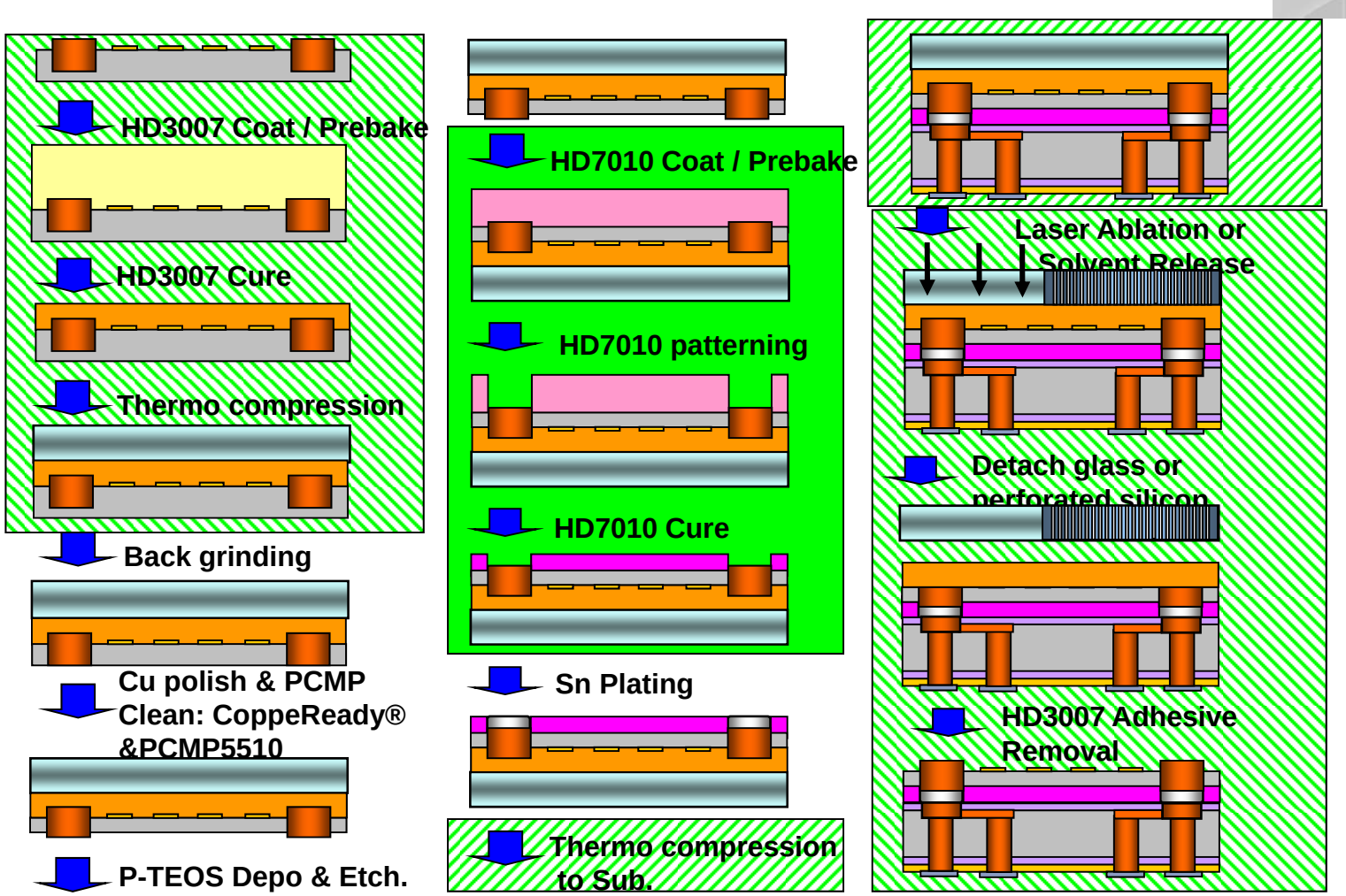


Backside view: imaged HD-7010 on thin wafer

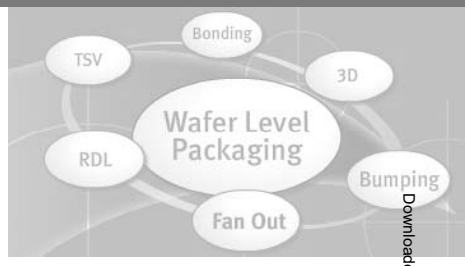


Summary of Demonstrated Process Steps





Key: HD-3007 only | HD-7010 only | HD-3007 with HD-7010



Conclusions

HD-3007 Temporary adhesive

- Superior thermal stability
- Excellent mechanical properties and adhesion
- Rapidly de-bonded with laser irradiation
- Soluble after cure in selective solvents

HD-7010 Permanent adhesive

- Photo-imageable polyimide adhesive
- Compatible with Cu and other metallurgy
- Bonding characterized by high adhesion and low flow

Future work focused on process integration

- Demonstrate compatibility of polyimide adhesives throughout the TSV assembly process
- Work with other parts of the supply chain to provide a system solution

Thank you for your attention!