NOVEL PROCESS OF RDL FORMATION FOR ADVANCED PACKAGING BY EXCIMER LASER ABLATION

NCCAVS Joint Users Group Technical Symposium

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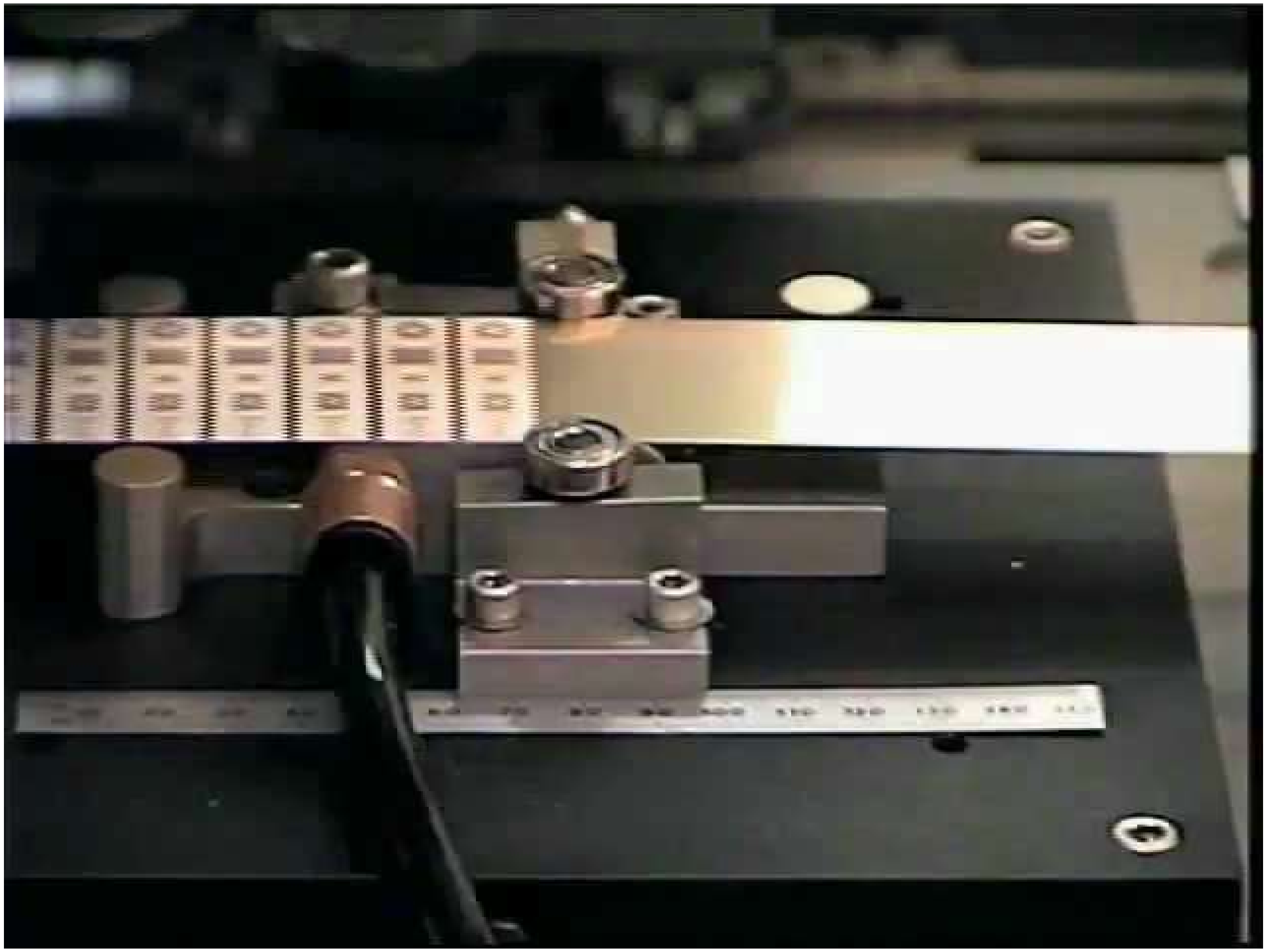
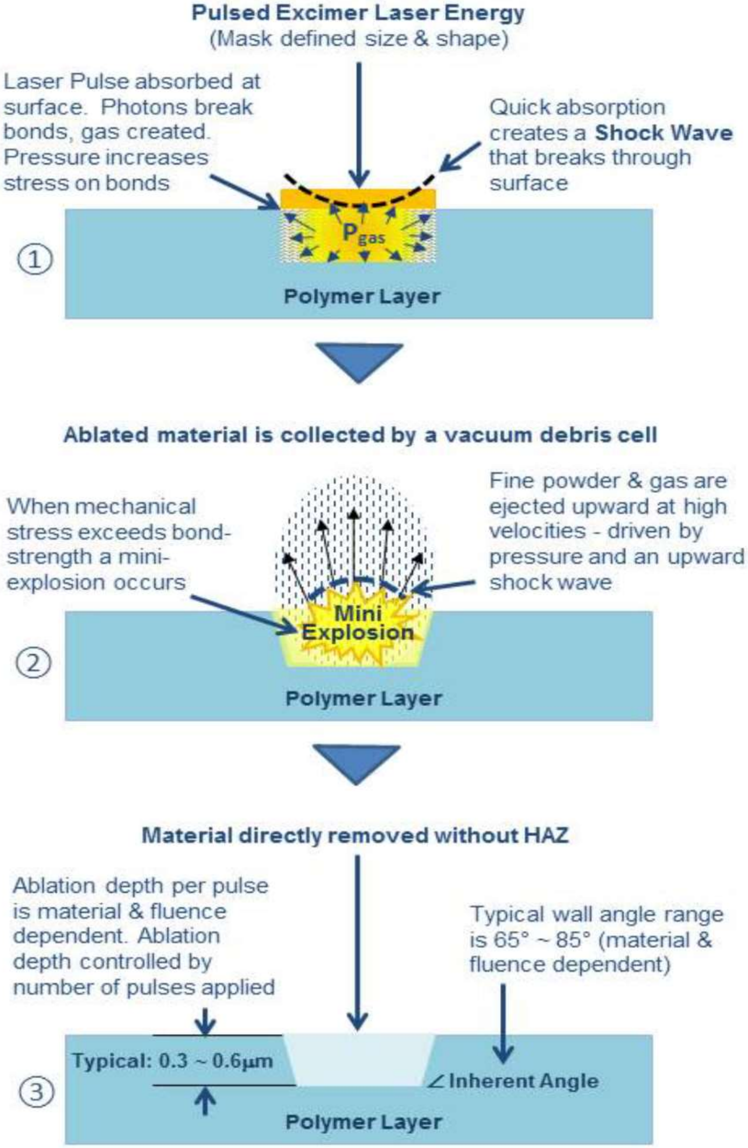
OUTLINE

How fast can Excimer laser processing really go…?

This is half speed …



EXCIMER LASER ABLATION TECHNOLOGY

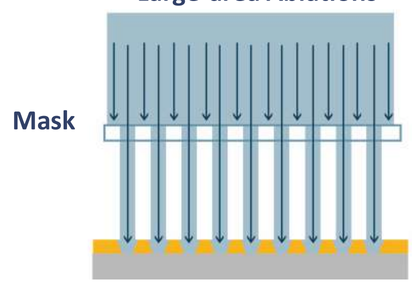
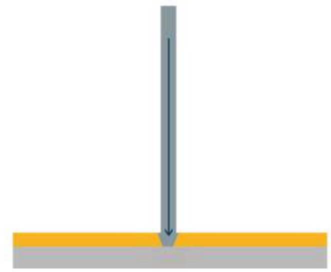
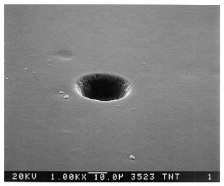
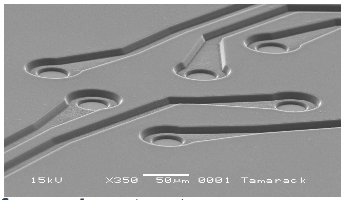
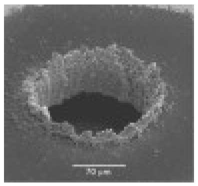


- **Laser ablation** is the process of removing material (subtractive process) from a solid surface by irradiating it with a laser beam.
- The ablation of polymer is a photo physical process: mixture of photo-chemical and photo-thermal processes.
- Rather than burning, enough energy is added to disrupt molecular bonds at the surface, disintegrating the broken material bonds into the air.
- Ablation occurs with almost no heating or change to the underlying material.

Materials suitable for Excimer ablation:

- Most organic materials
  - Polymers/Organic Dielectrics (PI, PBO's, BCB's, Epoxy etc…)
  - Epoxy Mold Compounds (EMC – filled and unfilled)
- Some in-organics
  - Dielectrics (SiNx - < 1µm thick with 248nm only)
  - Thin metals (Ti, TiW, TaN, Ta, Cu, Ag, Al, etc…); <600nm thick on organic material
  - Conductive materials (ITO, IZO, CNT); <1µm thick on organic material

EXCIMER LASER STEPPER VS. SOLID STATE LASER

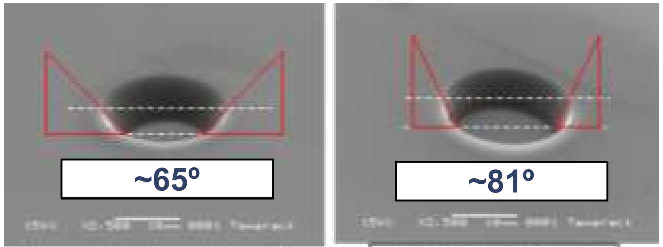
	Excimer Laser Ablation	Solid State Laser Ablation
	Excimer Laser **Large-area Ablations** 	**Solid State Laser** **Spot-area Ablations** 
Imaging Type	Mask based projection	Maskless, direct ablation
Patterning area	Field area, up to 50x50mm. 1000's of features at a time	Single spot
Patterning Mode	Direct bond breaking	Melting and evaporation
Available wavelength	(193nm), 248nm, 308nm	Various: 355nm, 532nm, 1064nm, etc…
Throughput	+++ (not dependent on pattern density)	- (pattern density and shape dependent)
Typical applications	Complex structures:   ***Ablation of complex structures*** ***(i.e. RDL trench and vias)***	Low density patterning, scribing, drilling:  ***Laser drilling*** ***(i.e. through glass vias)***

EXCIMER ABLATION PROCESS CONTROL

+ Excimer ablation allows us to control many things…

Side-wall Angle Control (WPR5100):

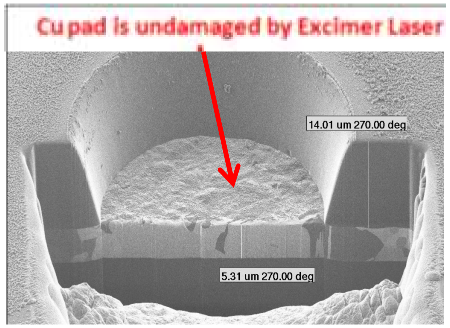
- Higher fluence: Steeper wall-angle
- Lower fluence: Shallow wall-angle
- Wall angles to < 85º



376mJ/cm² – 45 pulses | 1200mJ/cm² – 12 pulses

Selective Material Removal:

- Metal pads >1µm thick are a Stop Layer

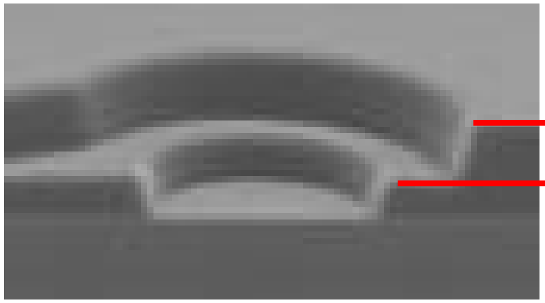


Depth Control - by No. of Pulses:

- Each pulse removes a certain amount of material
  + Etch-rate = material removed/pulse
- With a known etch-rate – the number of pulses to reach a desired depth can be predicted and controlled

Example:

- Assume Typical Polyimide Etch-rate = ~0.30µm / pulse
- Desired Depth for Trench & Pad Pattern = ~5µm



5µm Depth Desired

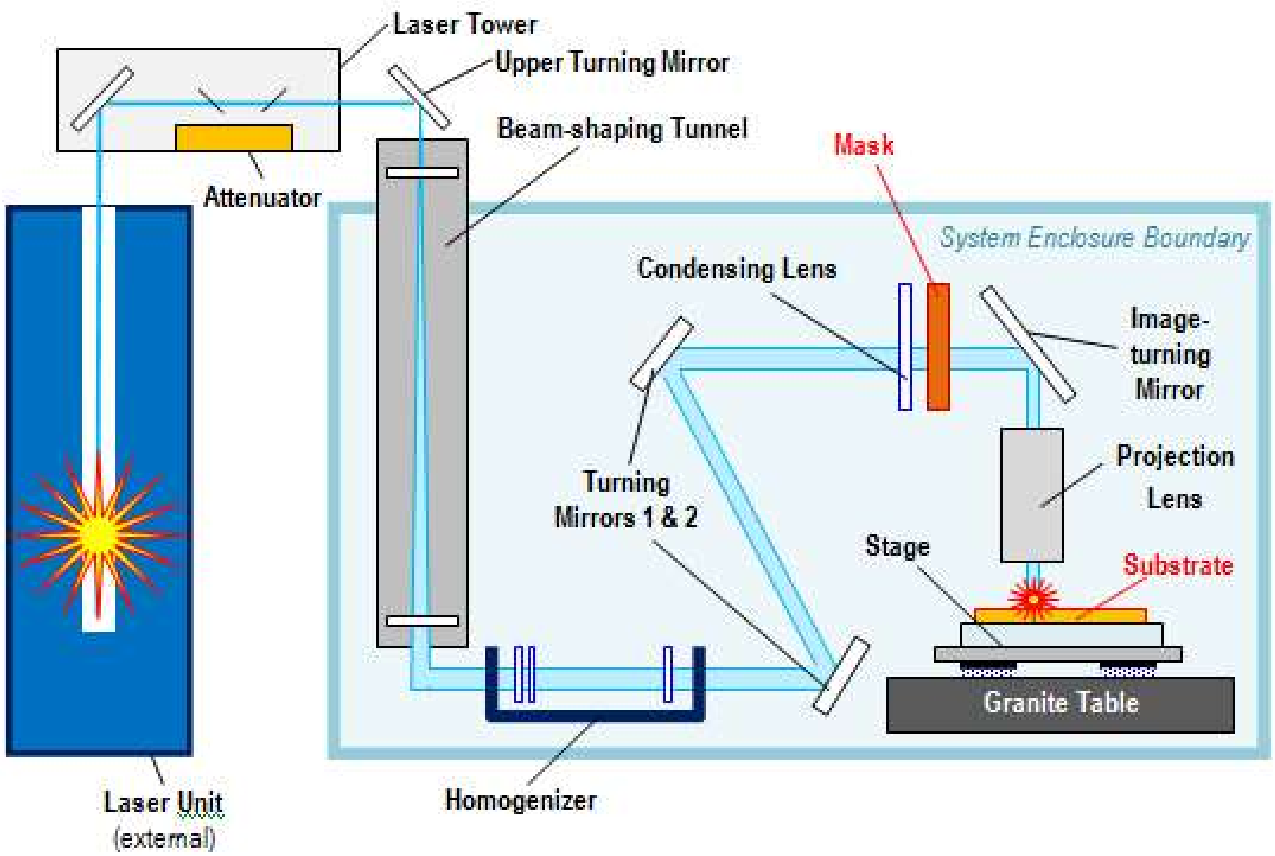
- **Pulse Estimate Calculation:**

5µm Depth / 0.30µm Etch-Rate = 16.667 = **~17 pulses**

SCHEMATIC SETUP OF AN EXCIMER LASER STEPPER

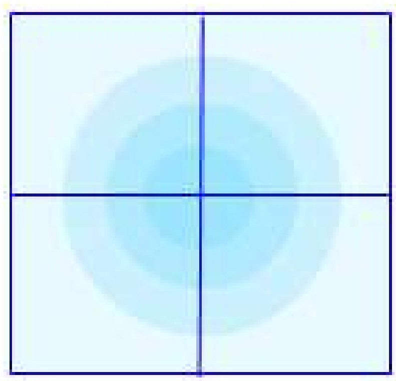
Typical setup of an Excimer Laser stepper:

- Laser beam is made uniform and shaped through the optics train
- The laser beam hits the mask, and the resulting image is projected through a reduction projection optics on the substrate
- The system operates like a normal stepper, with a laser source instead of a UV lamp

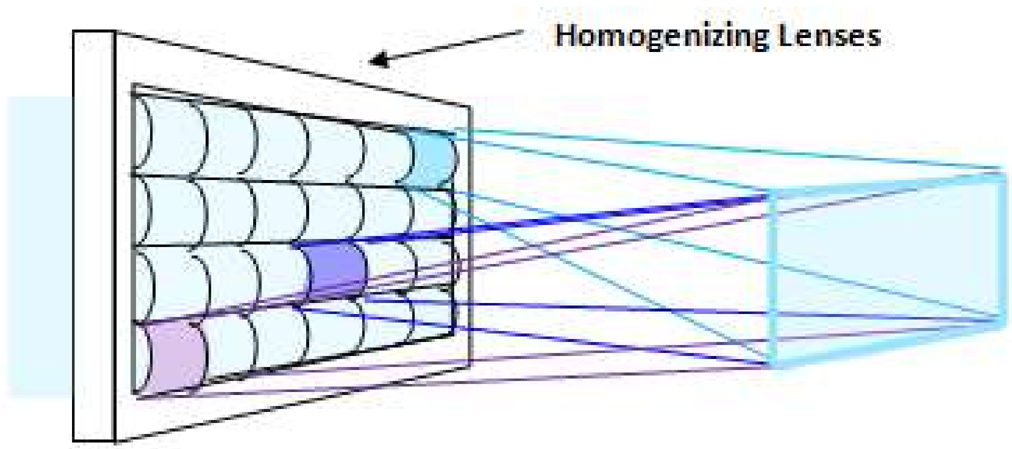


Optical Path – Homogenizer:

- Purpose: To transform the incoming laser beam from being uniform in shape – to also being uniform in light distribution:
  - The homogenizer is a series of lenses that break-up and recombine the laser light in small portions (e.g., 6 x 7 mm) to create a very uniform laser beam at its exit side



Light entering the homogenizer



Light leaving the homogenizer

EXCIMER LASER PROJECTION LENS

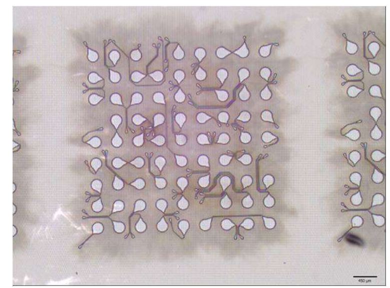
- Projection optics are one of the most critical aspects of an Excimer laser system. The ELP lens is designed so…
  - No need for lens cooling.
    - Optics are designed such that focal points are located as far from the optic as possible, thus enhancing optic life. This also means no auxiliary projection lens cooling required.
- Projection lens (reduction lens) produces a projected image of the mask pattern to be ablated on the substrate.
  - Beam Uniformity < +/- 5%
  - Standard Lens
    - 2.5X (50mm diameter ablation field); 248 or 308nm
      - < 3µm resolution (material dependent)
  - Projection Lenses available (308nm and 248nm):
    - 2.0X (100mm diameter ablation field); 308nm only
    - 5.0X (25 & 20mm diameter ablation field); 248 or 308nm

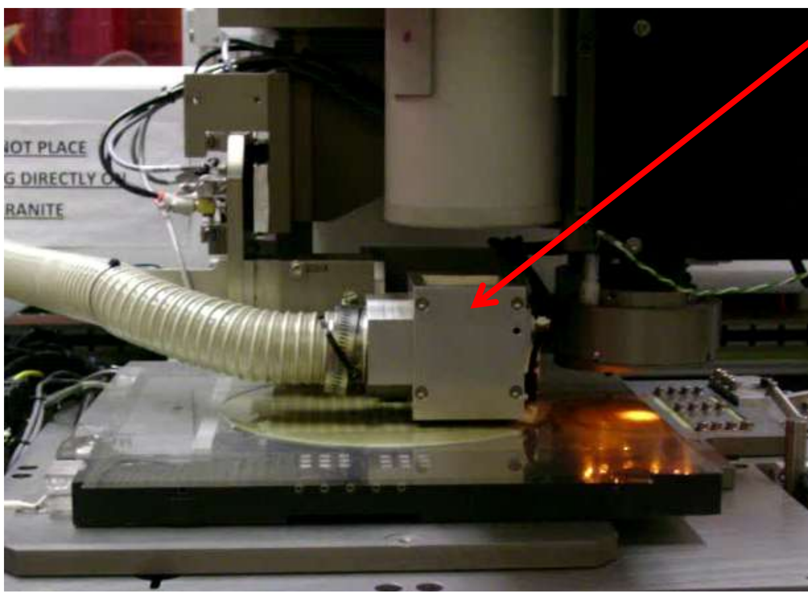
Protection window against debris

DEBRIS COLLECTION

- Physical process of ablation is the generation of debris.
  - Process breaks down the material molecular structure and debris is generated, simulating dust. To maximize debris removal, a Debris Cell is used.
    - debris collection system sucks air around the ablation area
    - debris exhausted out of the building or through a filter
    - laminar flow of HEPA filtered air across the substrate.

Precious metals can be reclaimed!



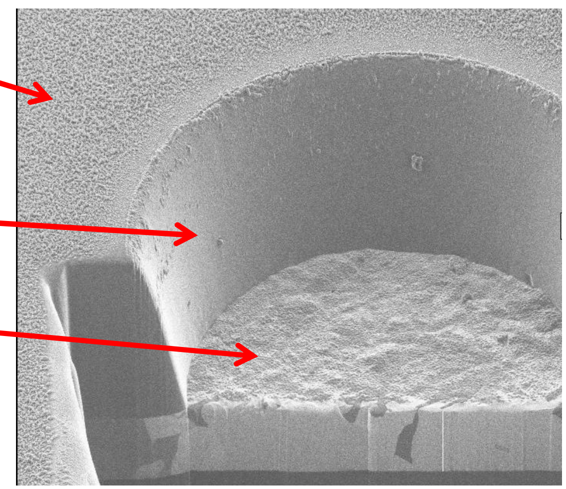


Debris Cell

Debris

PI (~7μm)

Cu Pad (~3μm)

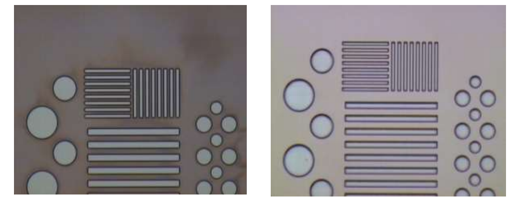


POST LASER ABLATION CLEANING

- In addition to the debris cell, post-laser ablation cleaning is needed.
- Depending on the ablated material, several options are available:

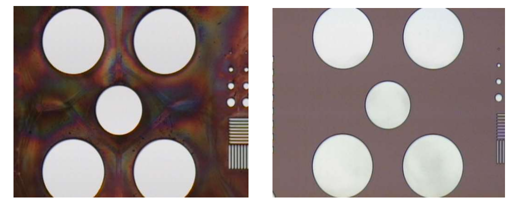
O2 plasma cleaning:

- Most common cleaning method
- Successful cleaning of wafer with PBO, BCB, HD2611, HD4110



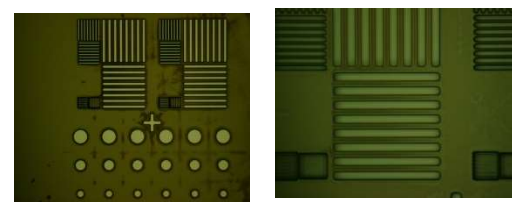
Sacrificial layer for debris removal:

- Successful removal process shown for HD4104
- Sacrificial layer removed using high-pressure CO2 ionized water



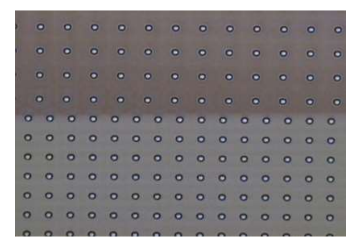
CO2 snow cleaning

- Successfully cleaned PBO with most aggressive CO2 snow without damaging features
- Short-term access to CO2 snow cleaning tool available



DPSS Cleaning

- Successfully cleaned debris post PBO (HD8820) ablation using pico Second DPSS Laser (532)nm)
- In house tool available to perform this cleaning method



- There is no „one“ single cleaning recipe that fits all requirements
- Optimum post-laser ablation cleaning is dependent on the individual process conditions, and recipe must be developed individually

OUTLINE

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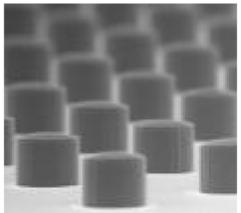
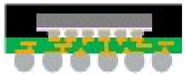
1. Excimer Laser Ablation - Technology and Tool
2. **Excimer Laser to Pattern Vias and RDL for Advanced Packaging**
3. Dual Damascene RDL Process Enabled By Excimer Ablation

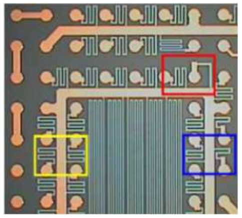
COMMON REQUIREMENTS FOR ADVANCED PACKAGING

Application:

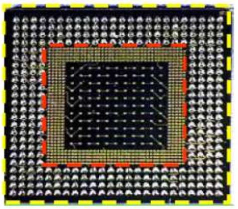


Flip Chip: 200/300mm
(Cu Pillar, Micro Bumping, Solder Bumping)

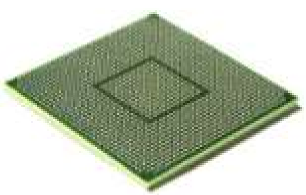




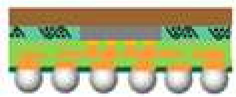
WLCSP: 200/300mm
(RDL, Integrated Passive Devices)



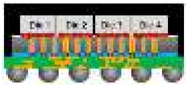
Fan out WLP: >300mm
(eWLB,RCP,other)



Embedded IC: >300mm
(FCBGA, FCCSP)



2.5D Interposer, 3DIC: (200)/300mm



+ Challenges Facing RDL Patterning Process

- New package designs to meet the changing market requirements
  - + Small Thin Light Form Factor (5um via's, 2/2um L/S RDL) and Higher I/Os
- Seed Layer Etch is difficult due to fine pitch of RDL traces
- Fine RDL traces becoming unstable
- Consumer electronic devices driving the need for process cost reductions
- Enhancements in Package Performance
  - + Improved Material Choices: Thermal, Mechanical and Electrical Properties
  - + Loss of pattern integrity through curing after patterning
  - + CTE mismatch

+ SOLUTION: Innovative RDL Process Integration with Excimer Laser Ablation

- Fine features: 5um vias and 2/2um L/S RDL
- RDL structure is embedded; Seed Layer Removal and RDL trace stability not a concern anymore
- Direct Laser Patterning (dry etching) with curing before patterning – maintain pattern integrity
- More Dielectric Material Choices through use of non-photo dielectrics
- Significant Reduction of Cost of Ownership

LASER PATTERNING IN ADVANCED PACKAGING

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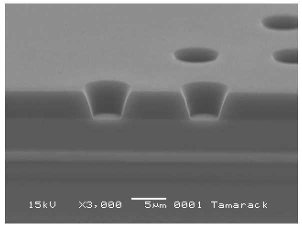
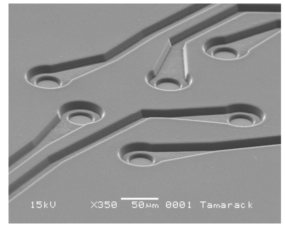
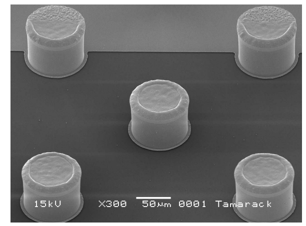
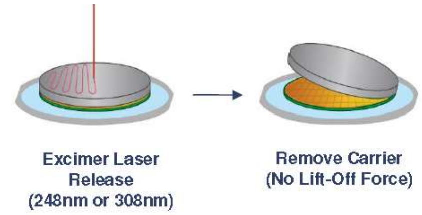
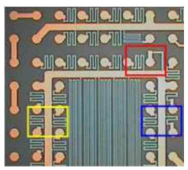
	Via Drilling	RDL Trench	Seed Layer Removal	Debonding
				
Wafer 	✓	✓	✓	✓
Substrate 	✓	✓	✓	

Trends:
- Small Vias: 5um
- Cost Reduction
- New materials
- Photolith & mtl limits
- DPSS limits

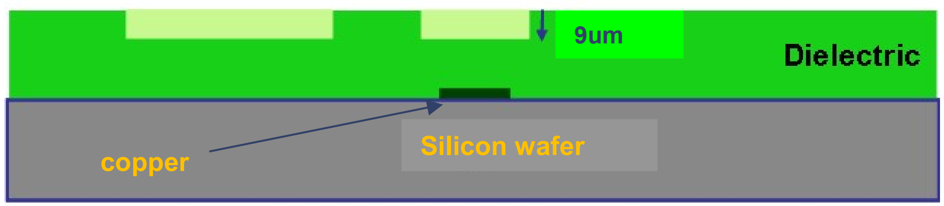
Trends:
- Smaller RDL 2/2um
- Better PI's
- Cost Reduction
- Photolithography resolution limits

Trends:
- Tighter Cu pitch
- Smaller RDL < 5um
- Wet process limits

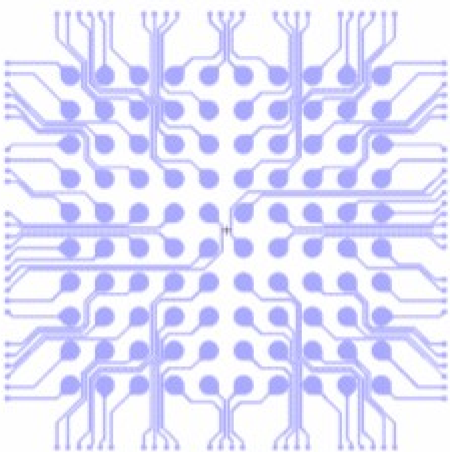
Trends:
- No mechanical stress
- No thermal stress
- High throughput

TRENCHING RDL AND DRILLING VIAS USING EXCIMER LASER

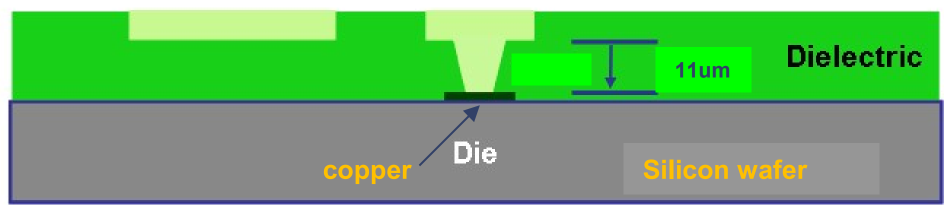
1st Step Ablation

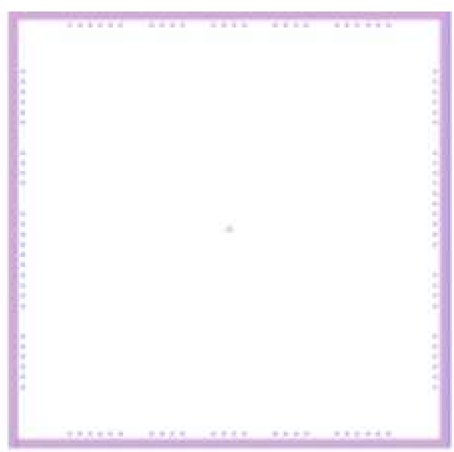


- 1st Step
  - **Alignment**
  - **Ablate trench**



2nd Step Ablation

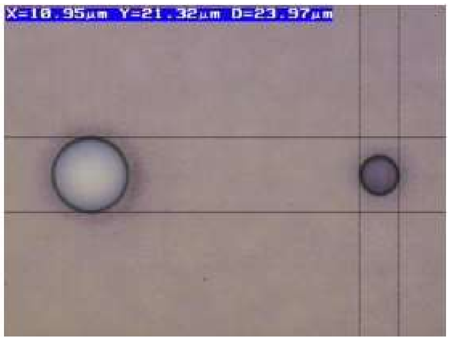


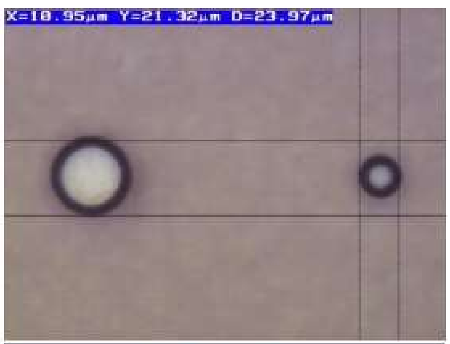


- 2nd Step
  - **Ablate via down to Al, or Cu metal pads to form Dual Damascene Structure**

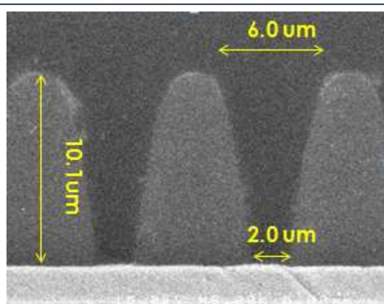
RDL AND VIA PATTERNING USING EXCIMER LASER

EMC material – 10μm thick
undisclosed (Japan)

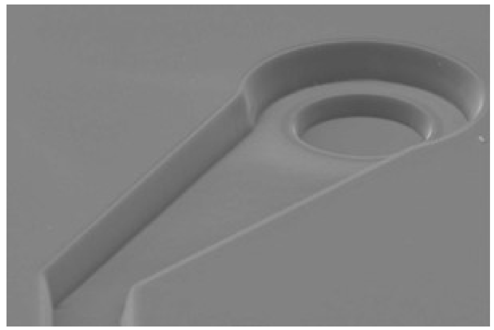


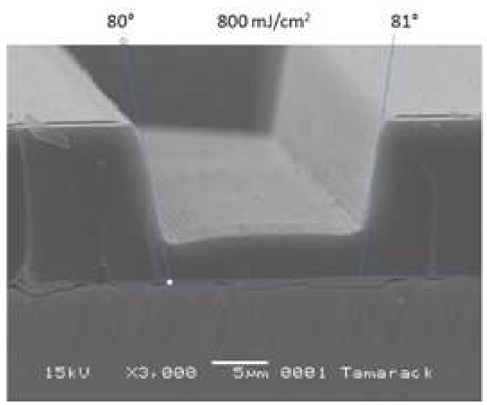


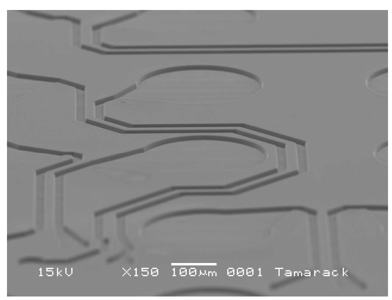
ϕ10,20um vias



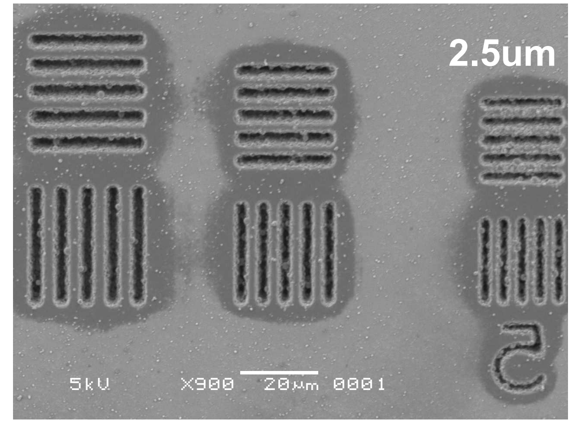
HD8930 PBO - 13μm thick



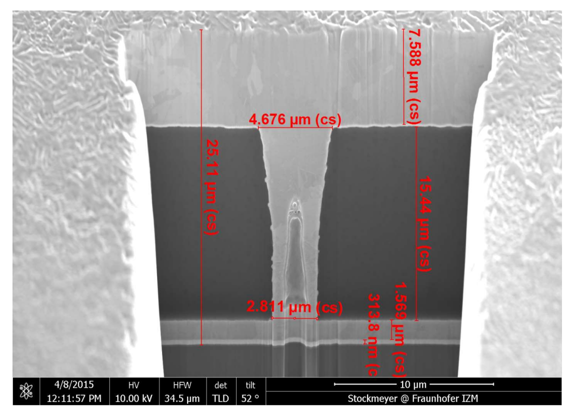




ABF GX92 with 2.5μm lines

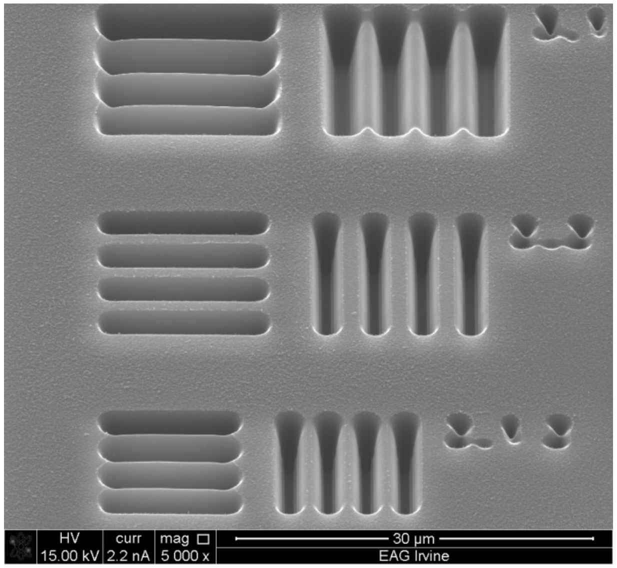


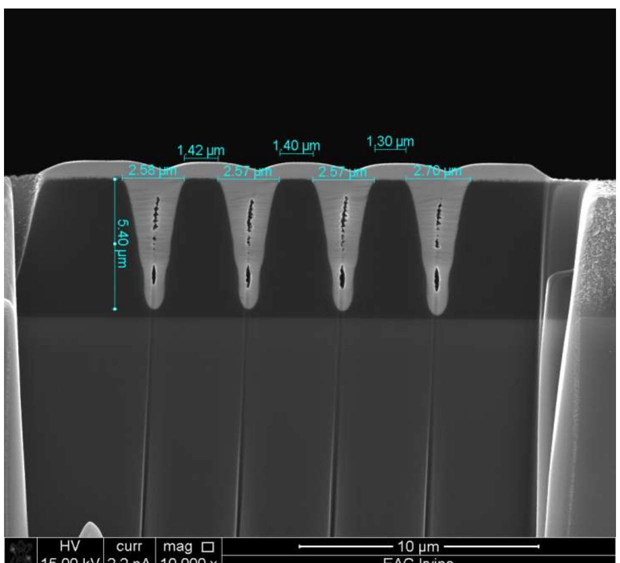
Dry Film BCB, 15μm thick
Via hole with 2.8μm bottom dia.
Aspect Ratio 5:1



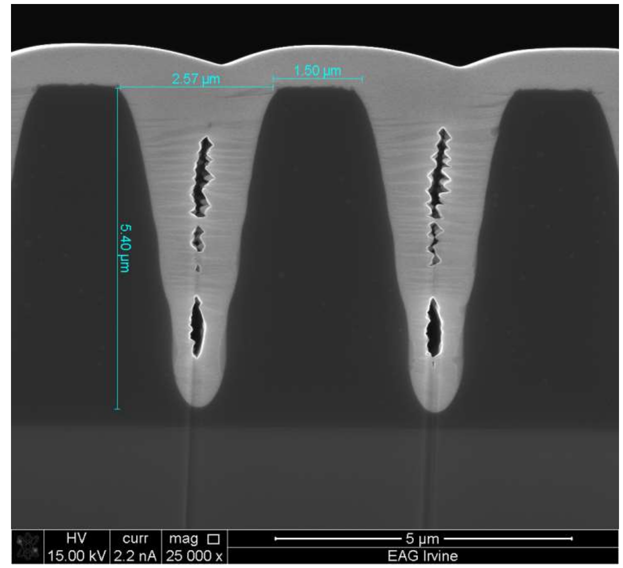
ABLATION OF HD4100: TARGET ASPECT RATIO OF 2:1 (DEPTH TO CD) - (SI/6UM HD4100)

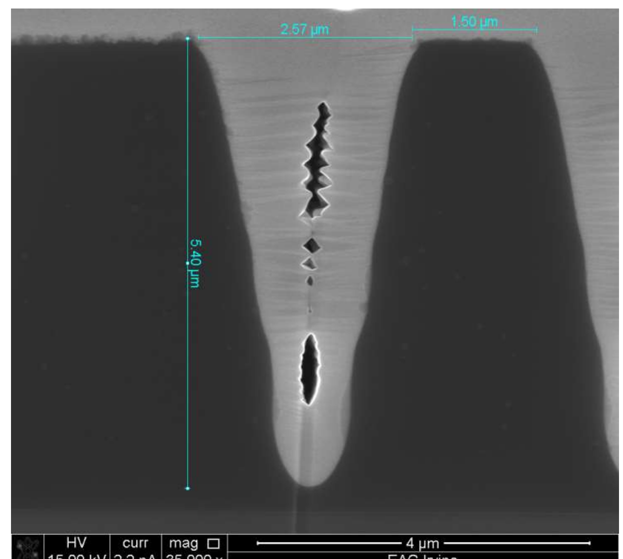
Top view with angle





FIB XSEM images
at different magnification





RELIABILITY DATA (1/3): CROSS SETION IMAGES OF DUAL DAMASCENE STRUCTURES OF 10/10 UM RDL

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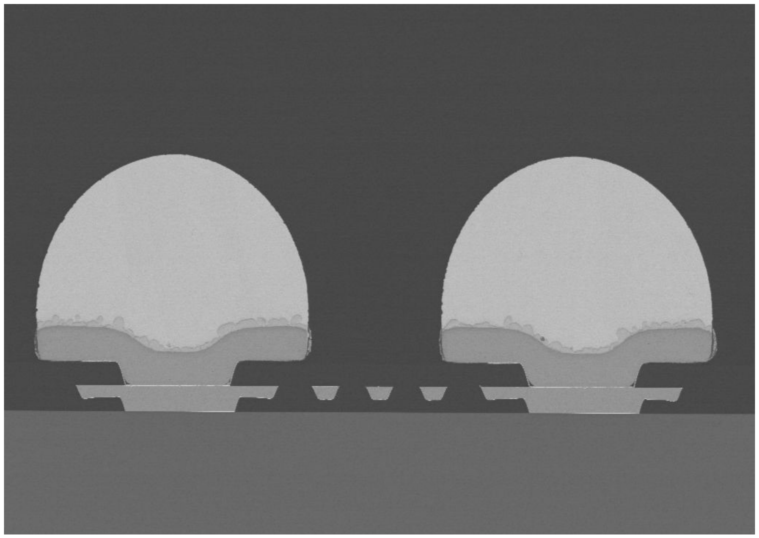
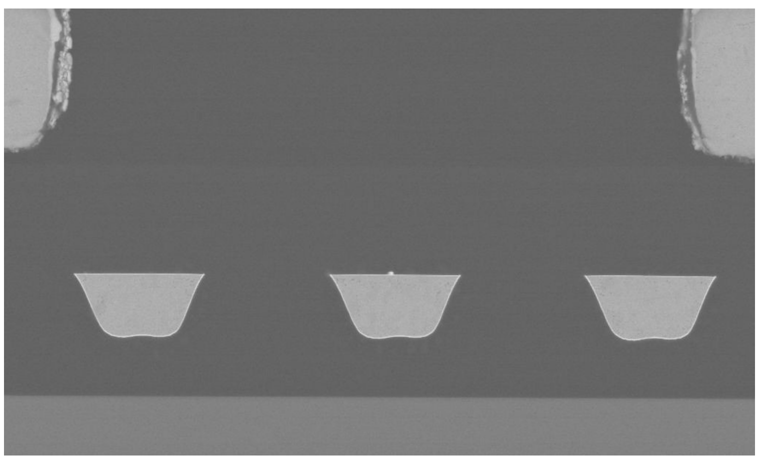
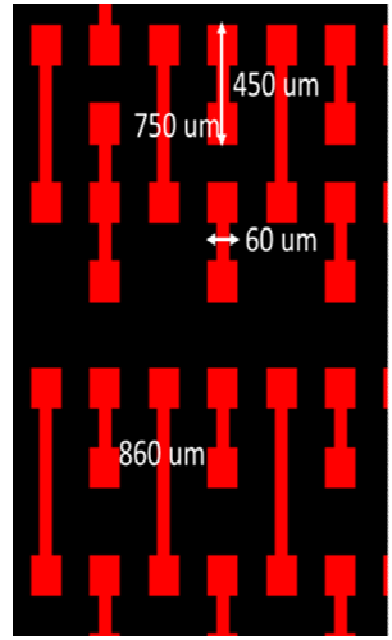
Material: HD1801 X2 (non-photo dielectric)





Courtesy of IBM

Probe Current	100mA
Short Dog Bone	
Measured V (mV)	R (ohm)
2.74	0.0274
4.73	0.0473
3.19	0.0319
3.25	0.0325
3.06	0.0306
3.21	0.0321
3.12	0.0312
3.86	0.0386
3.07	0.0307
3.58	0.0358
Average	0.0338
STD	0.0056



C4s connected to chip wiring, have a range of resistance that is generally 15-30 milliohm

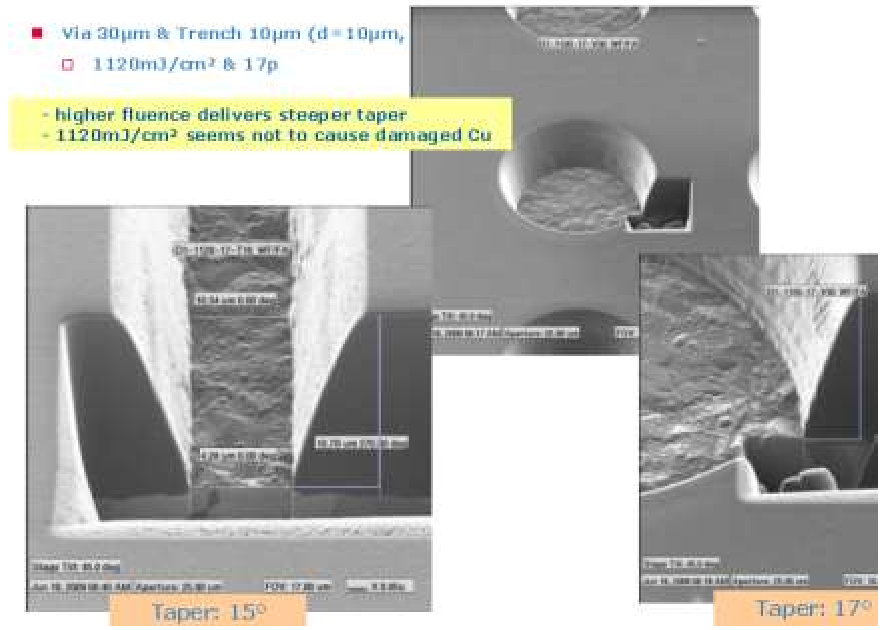
Electrical results equivalent to PoR (photolithography), but with the advantages of Excimer laser ablation:
- **No CTE mismatch**
- **Direct embedding (no resist stripping)**
- **Cost saving through reduced process steps**

RELIABILITY DATA (2/3): EFFECT OF ABLATION ON METAL PAD/UNDERLYING METAL

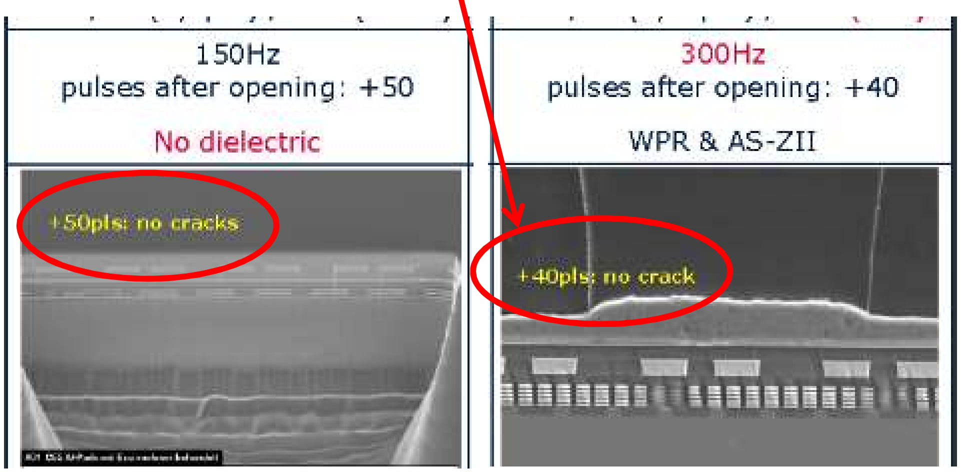
SUSS MicroTec

+ Excimer ablation over Cu and Al pads:

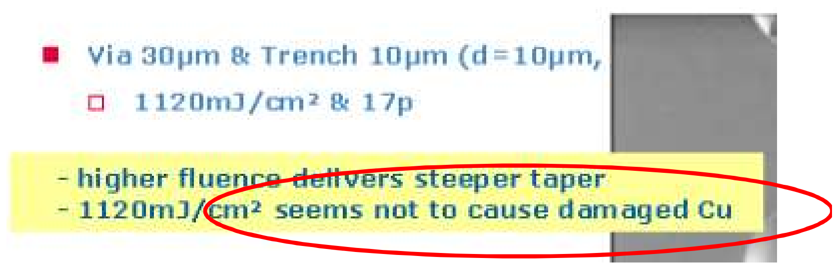
- 3rd party tests have been performed showing no damage to the underlying materials
- **Case study:**
  - Si/SiOx/SiNx/TiTiN/AlCu(1.4um)/ dielectric(8.5um)
  - Over pulsed 40 and 50 with no damage to the low k dielectrics



Summary: No increase of crack rates after laser impact



3rd party confirmation of no damage to Cu pads



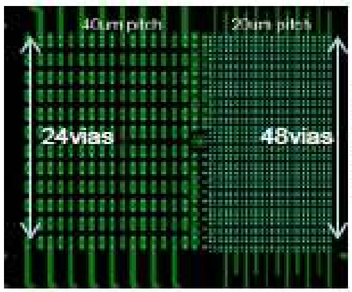
Excimer Laser Micro-via Reliability

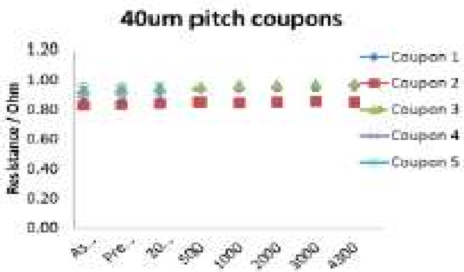
– Build-up + excimer +Eless seed SAP –

GT-PRC team: Yuya

- 8µm diameter, 20/40µm pitch micro-vias in 10µm build-up layer with excimer laser
- Coupon number: 6 coupons in one panel
- 8 daisy-chain lines in a coupon for 40µm pitch, 6 lines for 20µm pitch

Thermal cycle

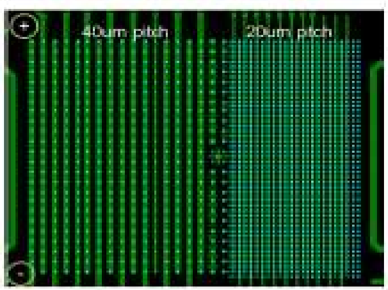


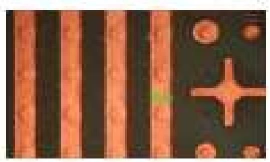


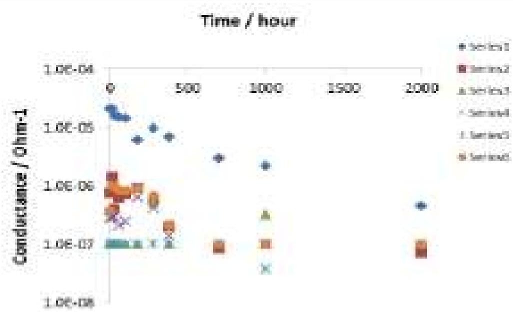
Preconditioning: MSL3
TCT condition:
-55°C,15min ↔ 125°C,15min

No resistance increase for 4300cycles

bHAST







B-HAST condition:
130°C, 85%RH, 5.0V

No Conductance increase for 2000hr

No reliability failures observed with single layer micro-via chains

OUTLINE

1. Excimer Laser Ablation - Technology and Tool
2. Excimer Laser to Pattern Vias and RDL for Advanced Packaging
3. **Dual Damascene RDL Process Enabled By Excimer Ablation**

EXCIMER ABLATION ENABLED DUAL DAMASCENE SCHEME

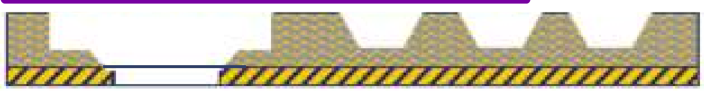
SUSS MicroTec

+ Integration of RDL Stacking using Excimer Laser Ablation:

Apply/Cure 1st Polymer Layer

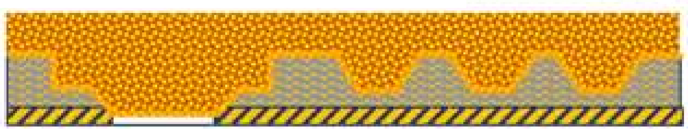
Create RDL Pattern using Laser

Open Vias using Laser

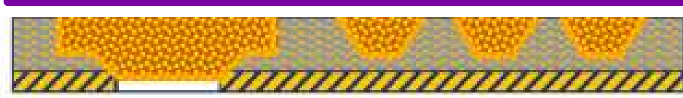


Sputter down Seed Layer

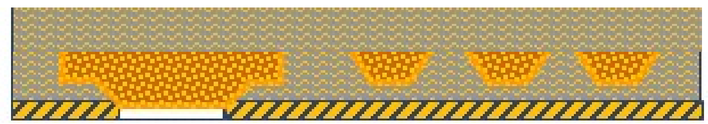
Damascene Plate Cu



CMP + SLR Process



Apply/Cure 2nd Polymer Layer



Excimer Laser process Step

- **More RDL layers can be added by repeating the process.**

SOLVES CURRENT BARRIERS WITH LITHO-BASED INTEGRATION FLOW

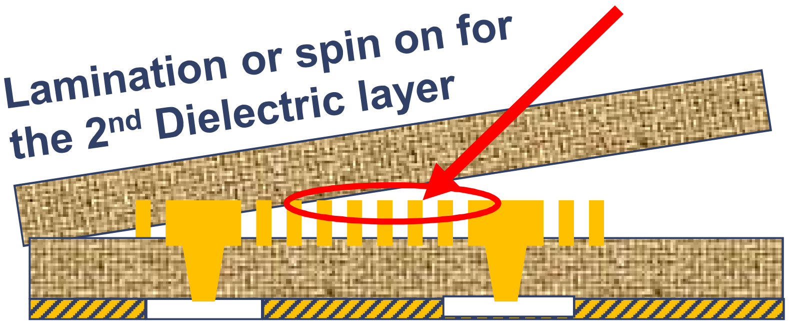
SUSS MicroTec

+ Current Barriers with Litho-Based Integration Flow:

- Gap Filling issues with smaller spacing
- Topography issues post lamination

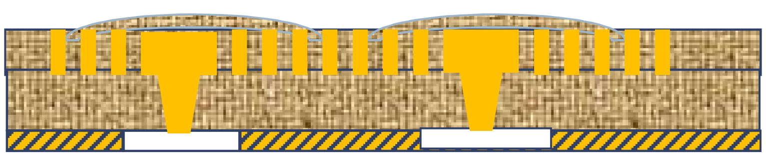
BARRIER-1

Gap filling with smaller spacing



BARRIER-2

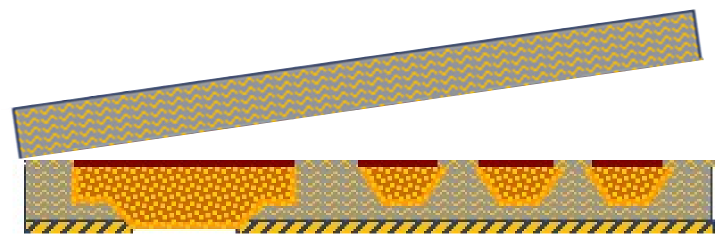
Topography post lamination or spin on process of second dielectric layer



BARRIERS SOLVED

SUSS Planarized Layer Process:

- No Gaps to Fill
- No Topography to Distort



SOLVES CURRENT BARRIERS WITH LITHO-BASED INTEGRATION FLOW

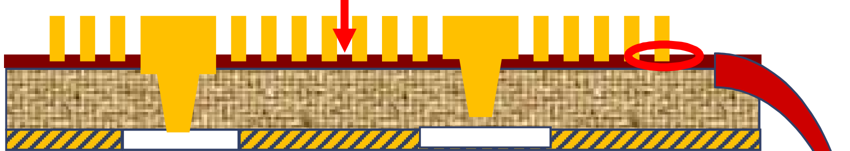
SUSS MicroTec

Current Barriers with Litho-Based Integration Flow:

- Seed Layer Removal in smaller spacing
- Undercutting of RDL features
- Erosion of top metal for RDL traces

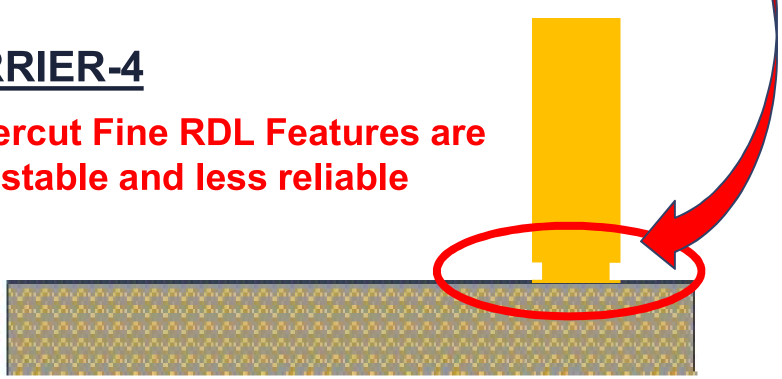
BARRIER-3

Seed Layer removal in fine pitch is challenging and also results in RDL undercutting with Wet-clean



BARRIER-4

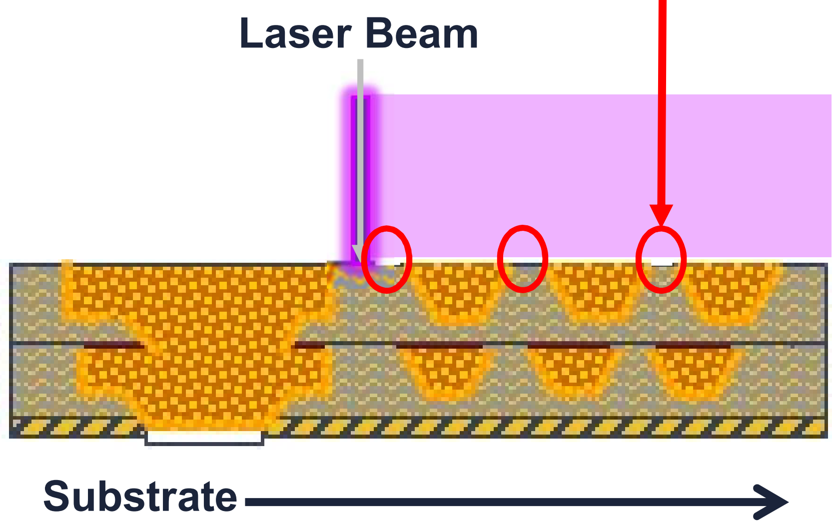
Undercut Fine RDL Features are less stable and less reliable



BARRIER SOLVED

SUSS Process with Excimer Laser SLR or Wet-Clean Removal:

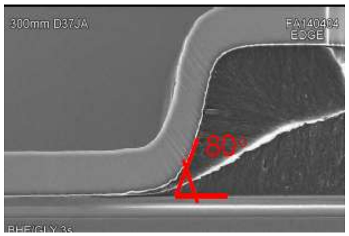
- No Tight Spaces
- **For Laser SLR: Seed Layer Removed over Organic Dielectric, but not over RDL features**



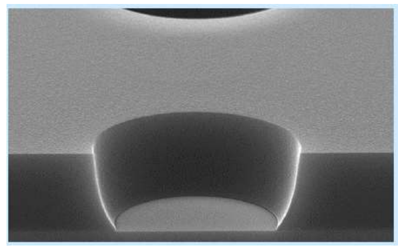
Photolithography

- Limited Pitch and Via Wall Angle Control (UV Imaging)
  - Flexibility desired to address tighter via pitches, wall angles for Cu sputtering or higher aspect ratios where thicker dielectrics are desired.

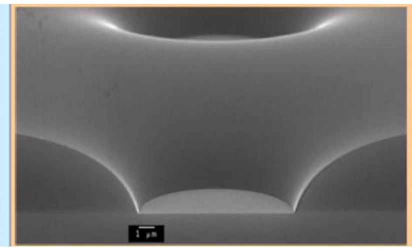
Photolithography



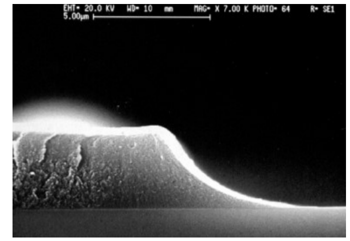
Wall to steep



BCB after UV expose



BCB after Cure

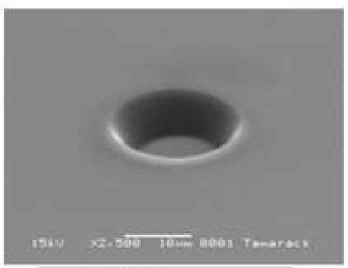


HD4000 – UV Imaged

Excimer Ablation

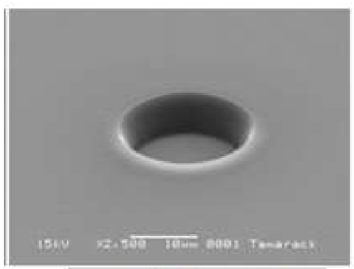
- Ablation performed after cure. Provides ability to flexibly alter the wall angle to the desired requirement.

Demonstration of via wall angle control: WPR5100 (7µm). Wall angle altered with fluence change



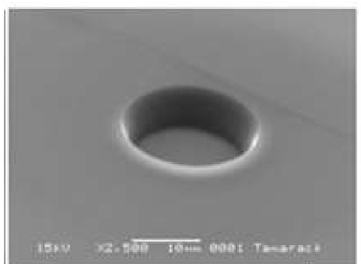
376mJ/cm² – 45 pulses

~65°



822mJ/cm² – 15 pulses

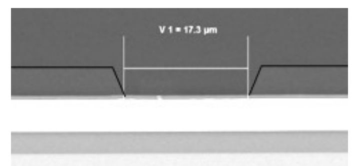
~74°



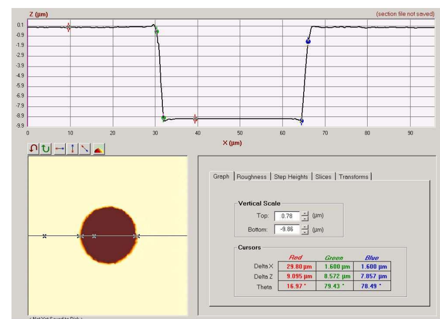
1200mJ/cm² – 12 pulses

~81°

9µm thick HD4000. Via wall angle 45 & 78 degrees



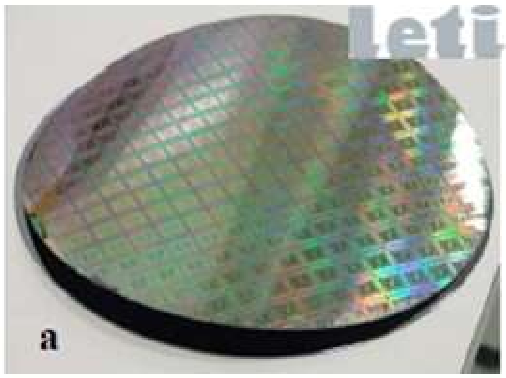
9µm thick HD4000 & 17µm via. Wall angle ~45 degrees



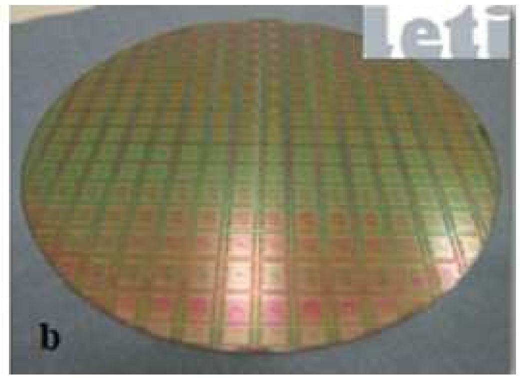
SOLVE WAFER WARPAGE: WIDER MATERIAL CHOICES

SÜSS MicroTec

	Young modulus (GPa)	CTE (10^{-6}/°C)	Residual stress (MPa)
Polymer 1	2.1	65	23
Polymer 2	0.1	180	<5



Polymer 1



Polymer 2

+ Excimer laser open up a multitude of material choices:
  photo and non photo material that offers best required mechanical properties
  - Improved yield and reliability
  - Robust packaging
  - Cost saving

NON-PHOTO DIELECTRICS

SÜSS MicroTec

The Pro's and Con's of Non-Photo Dielectrics:

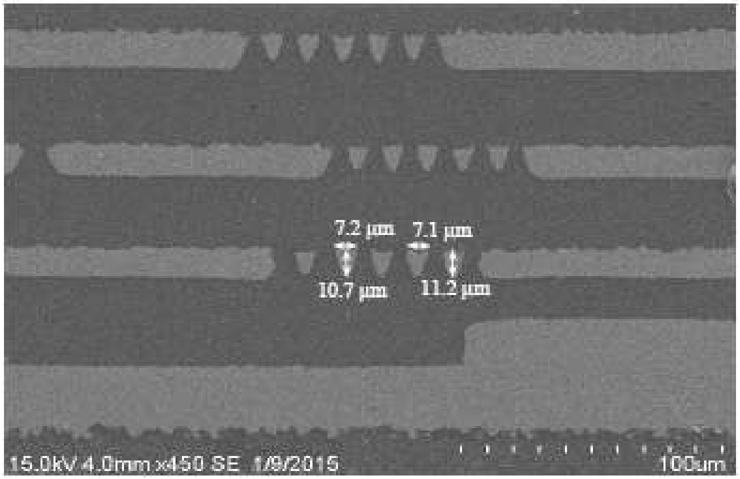
- **Pro's:**
  - Well Proven in Industry prior to advent of Photo-definable Dielectrics
  - Historically have Superior Thermal & Mechanical Performance over Photo Dielectrics
  - Estimated Total Material Cost Savings of ~3X:
    - Per Leading Dielectric Manufacturers - Non-Photo Dielectrics cost 50% Less
    - Due to Lower Shrinkage Rates - ~30% Less Dielectric is used per wafer
  - Can be Laser Patterned after curing without feature size/shape change
- **Con's:**
  - Some Non-Photo formulations require Adhesion Promoter
  - Many Non-Photo formulations are Non Copper-Compatible (need Cu Barrier)
  - Some Non-Photo formulations are only for thin-layers (< 10 um)

Sample Dielectrics Comparison for Low CTE & Low Residual Stress

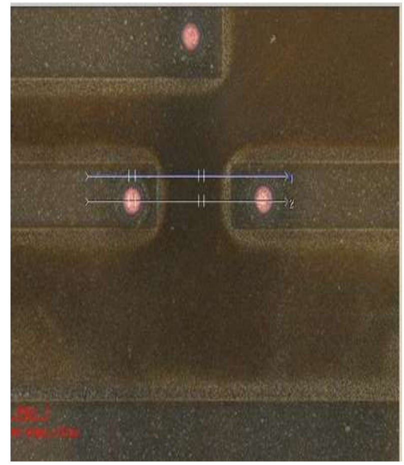
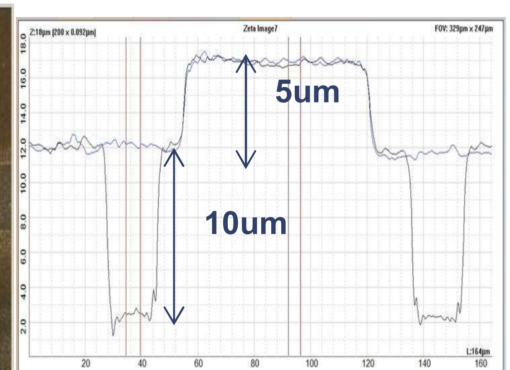
Lower Numbers are Better

Maker	Model	Type	Definable	CTE (ppm/°C)	Residual Stress (Mpa)
HD Micro	**PI-2610**	PI	NON-Photo	3	2
HD Micro	**PI-2611**	PI	NON-Photo	3	2
Fujifilm	**7005**	PI	Photo	27	?
Fujifilm	**7020**	PI	Photo	27	?
HD Micro	**HD-4100**	PI	Photo	35	34

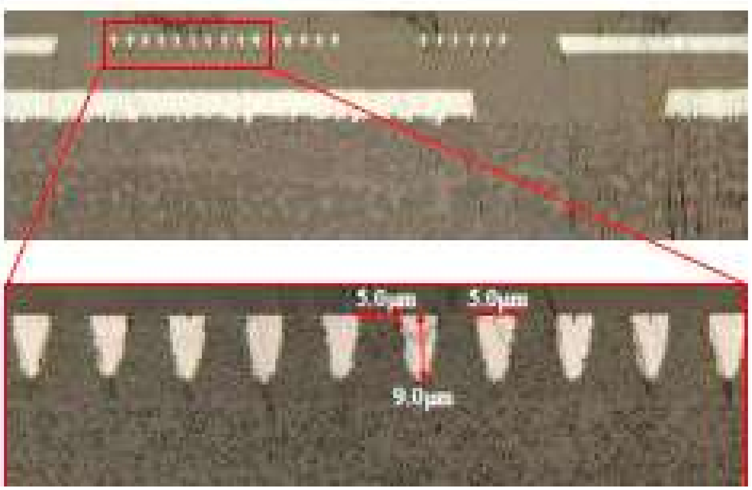
DEMONSTRATED DUAL DAMASCENE RDL PATTERNING USING EXCIMER LASER



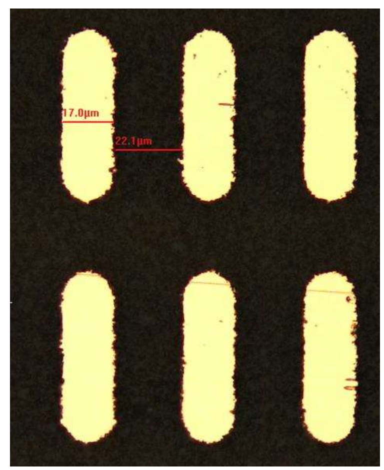
Laser embedded circuit pattern and Xsection for 7/7um*

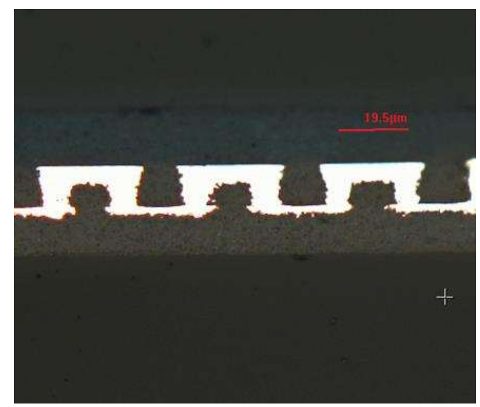



Vias (10um depth) and trenches (5um depth) in 15um ABF**



Laser embedded circuit pattern and Xsection for 5/5um*





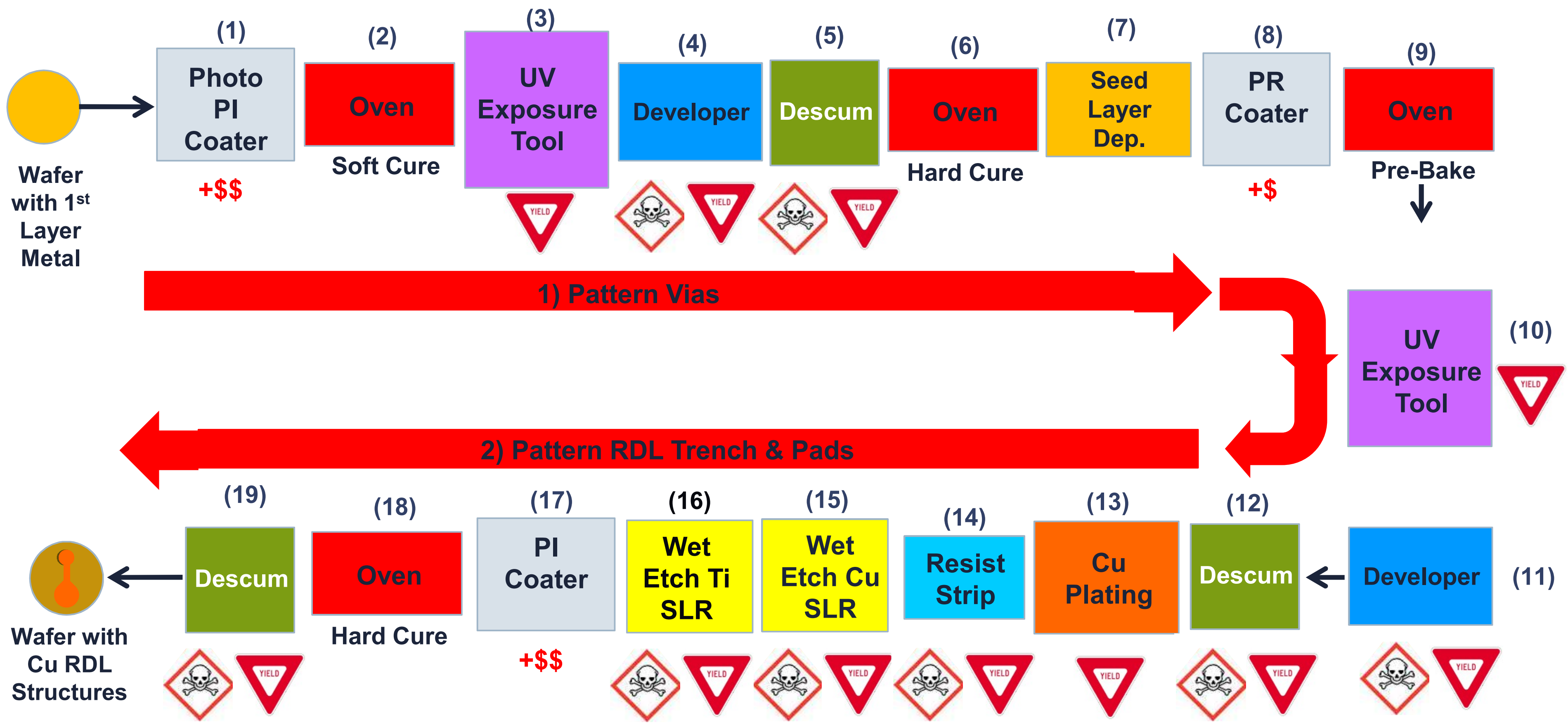
Two metal RDL layer (trench 5um depth, connection through 10um deep via) in 15um ABF**

*Courtesy of Unimicron - ICEP Japan 2015

**Courtesy of Georgia Tech – April 2016

Litho RDL Patterning of Photo Dielectrics and Trace Build-up Processes:

- **Requires (2) Complete Litho Processes per RDL Layer:**
  - (19) Step Process:
    - (8) Steps with Wet-Chemical Consumables, Handling/Storage/Disposal Costs
    - (1) Step with PR Consumable Costs
    - (11) Steps that can contribute to Total Yield Loss

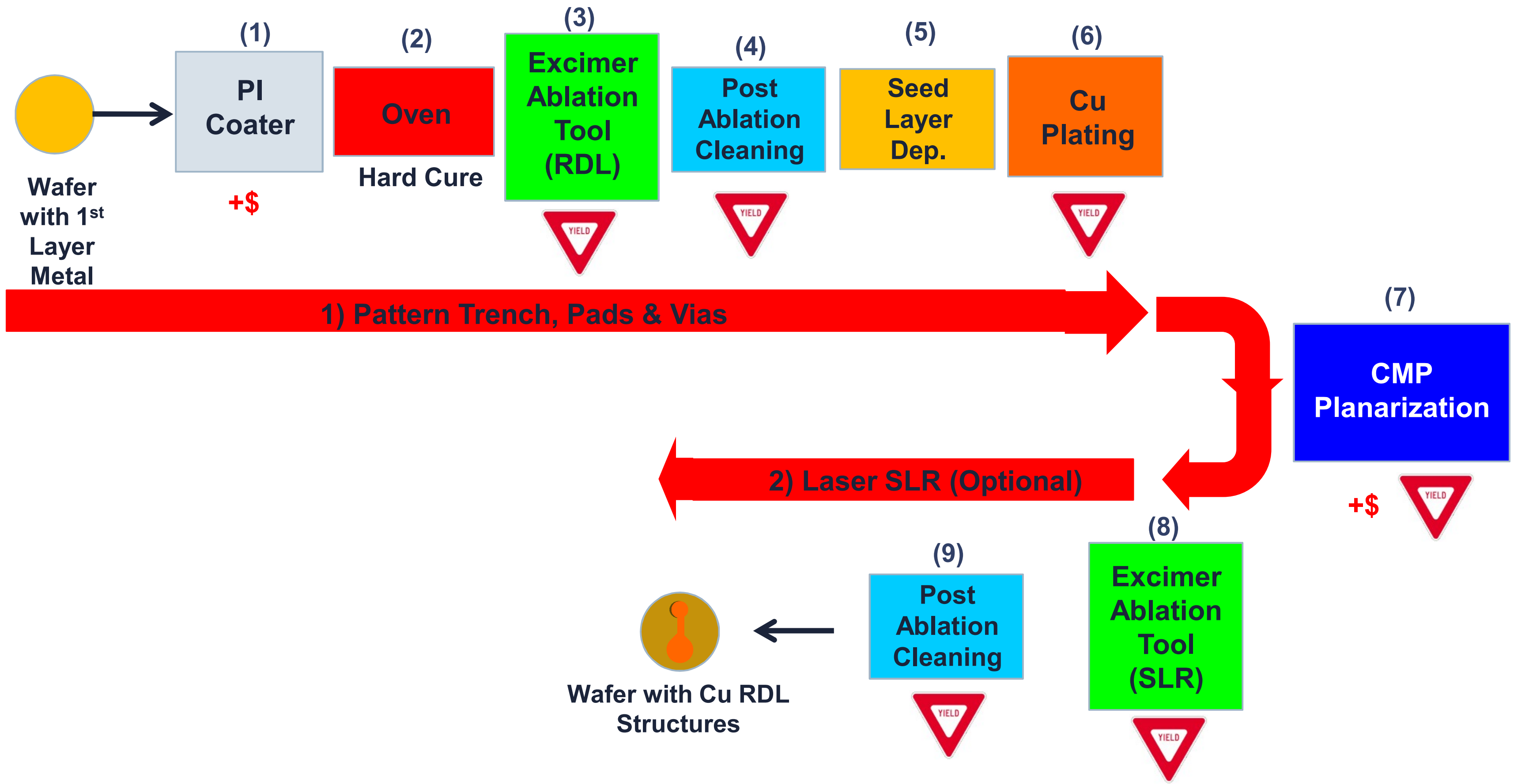


PHOTOLITHOGRAPHY VS. EXCIMER LASER ABLATION

SÜSS MicroTec

RDL Trench & Via Formation with Excimer Laser Ablation:

- **Requires (1) Shorter Processes per RDL Layer:**
  - (9) Step Process:
    - (0) Steps with Wet-Chemical Consumables, Handling/Storage/Disposal Costs
    - (0) Step with PR Consumable Costs
    - (6) Steps that can contribute to Total Yield Loss



Process Comparison Summary:

- **Net Excimer Ablation Process Saving**

Category	Photodefinable Litho Process	Excimer Laser Process	Net Process Saving
No. of Process Steps	24 Steps	14 Steps	Saves 10 Process Steps
No. Steps with Wet-Chem Consumables, Handling, Storage and Disposal Costs	8 Steps	0 Steps	Eliminates 8 Steps of Wet-Chem Related Costs (SAVES $$)
No. Steps with PR Consumable Costs	1	0	Eliminates 1 Step of PR Consumable Costs (SAVES $)
No. Steps contributing to Possible Yield Loss	11	6	Cuts Yield Loss Steps by almost 50%

Category	Photodefinable Litho Process	Excimer Laser Process	Net Process Saving
Relative Dielectric Material Costs	2X	1X	SAVES >50% over Photodefinable Dielectrics

PROCESS COST COMPARISON

SUSS MicroTec

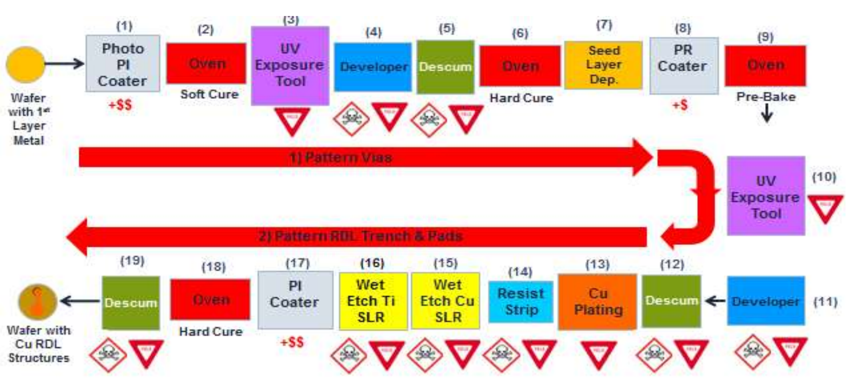
14x14mm package (10x10mm die), 10um via in 20um dielectric, 10/10um L/S RDL*

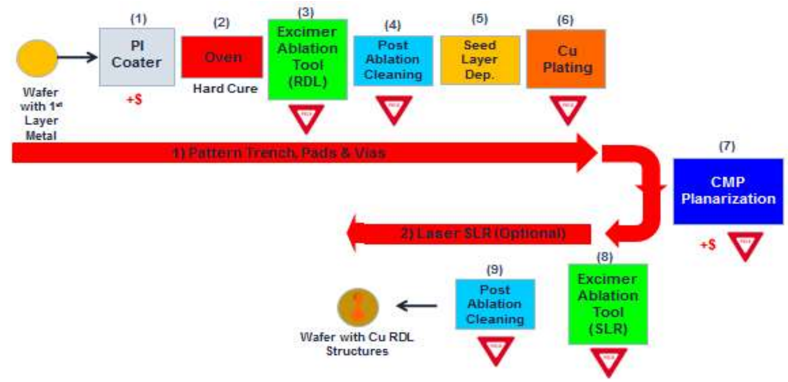
	Photolithography Process	
	Cost/wafer ($USD)	% of Total
Capital	44.64	60%
Labor	1.37	2%
Material	27.93	38%
Total	**73.93**	**100%**

	Excimer Laser Process	
	Cost/wafer ($USD)	% of Total
Capital	35.39	68%
Labor	0.86	2%
Material (non-photo dielectric)	15.45	30%
Total	**51.70**	**100%**
Savings	**30%**	

	Photolithography Process
Cycle Time	5.80 hours

	Excimer Laser Process
Cycle Time	2.38 hours
Savings	**59%**





*Collaboration with SavanSys

An Innovative RDL Process Integration:

- Process Cost Reduction → **>30% Cost & >50% Time Saving**
- Reduced Process Steps & Cycle Time → **9 Steps vs. 19 steps**
- Process Improvement → **Overcomes Litho Process Barriers**
- Increased Material Choices → **Photo and Non-Photo Dielectrics**
- Greener Process → **Reduces Wet Chemical Steps**

To sum it up...

EXCIMER ABLATION – AN ENABLING TECHNOLOGY

SÜSS MicroTec

Excimer Laser Ablation is a Valuable Enabling Technology:

- Enables Finer Resolution Patterning in Photo-Polymers (Dielectrics)
- Enables Direct Dry-Etch Patterning of Non-Photo Polymers
- Enables Higher-Density Via Drilling
- Enables Multilayer RDL integration at lower cost
- Enables Complex Patterns, More Uniform Feature Shape, Placement and Quality on thin metal surfaces
- Enables Selective Dry-Etch Thin Seed-Layer Removal
- Enables Cost-Effective Patterning of Large Surfaces
- Enables non-contact Debonding

Next GEN Device Patterning Challenges

1. Fine Photo-Dielectric Patterning
2. Direct Non-Photo Dielectric Patterning
3. More Complex – Higher-Density Laser Patterning

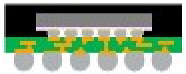
- SUSS Excimer Laser Ablation

SOLUTIONS

- Photolithography Limitations
- UV Lasers Limitations

BARRIERS

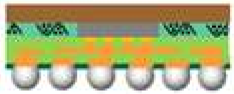
Cu Pillar, Micro Bump, Solder Bump



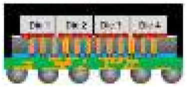
RDL, Integrated Passives

Fan-Out WLP

FCBGA, FCCSP



2.5D Interposer, 3DIC



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