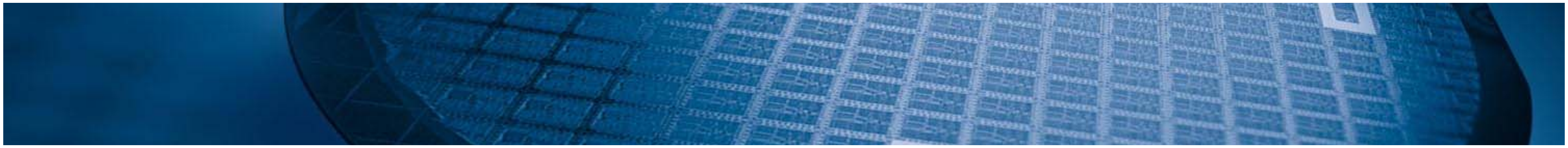



# FABRICATION AND RELIABILITY OF ULTRA-FINE RDL STRUCTURES IN ADVANCED PACKAGING BY EXCIMER LASER ABLATION

NCCAVS Joint Users Group Technical Symposium

San Jose, June 7th, 2017

Markus Arendt, SÜSS MicroTec Photonic Systems Inc.
Corona, CA 92880, USA

# OUTLINE

| | |
|---|---|
| 1 | **Advanced Packaging Trends** |
| 2 | **Excimer Laser Ablation Technology** |
| 3 | **Via and RDL Patterning in novel material** |
| 4 | **Reliability of Embedded Laser RDL Patterning for Advanced Packaging** |

# OPPORTUNITY & NEED FOR NEW INVESTMENTS IN RDL PATTERNING TECHNOLOGIES

**Laminate Panel Solid State Laser**

**BEOL Dual Damascene (DRIE)**

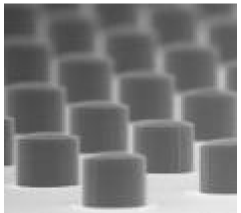

**Window of Growth**
**No dominant HVM solution available**

**Current Cost Effective Solutions Limited to 5um L/S and 10um Via Diameters**

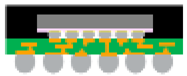
Source: Babak Sabi, Corporate VP Intel, 2016

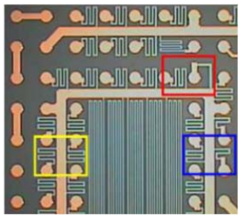
# COMMON REQUIREMENTS FOR ADVANCED PACKAGING

**Application:**

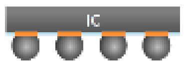


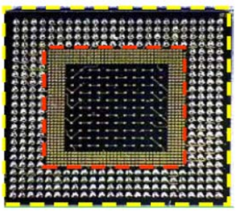
**Flip Chip: 200/300mm**
(Cu Pillar, Micro Bumping, Solder Bumping)



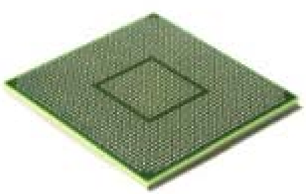


**WLCSP: 200/300mm**
(RDL, Integrated Passive Devices)

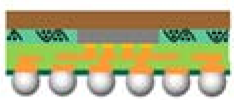


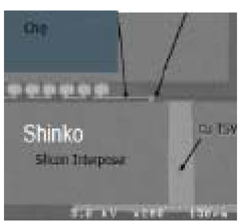



**Fan out WLP: >300mm**
(eWLB,RCP,other)

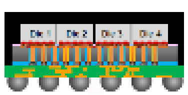


**Embedded IC: >300mm**
(FCBGA, FCCSP)






**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 (micro 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 (5G, AR, Automotive, …etc)
- Enhancements in Package Performance
  - Improved Material Choices: Thermal, Mechanical and Electrical Properties
  - Loss of pattern integrity through curing after patterning
  - CTE mismatch

## Alternative Patterning Solution: Excimer Laser Enabled RDL Formation

- Fine features: micro 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

# OUTLINE

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| 1 | Advanced Packaging Trends |
| 2 | **Excimer Laser Ablation Technology** |
| 3 | Via and RDL Patterning in novel material |
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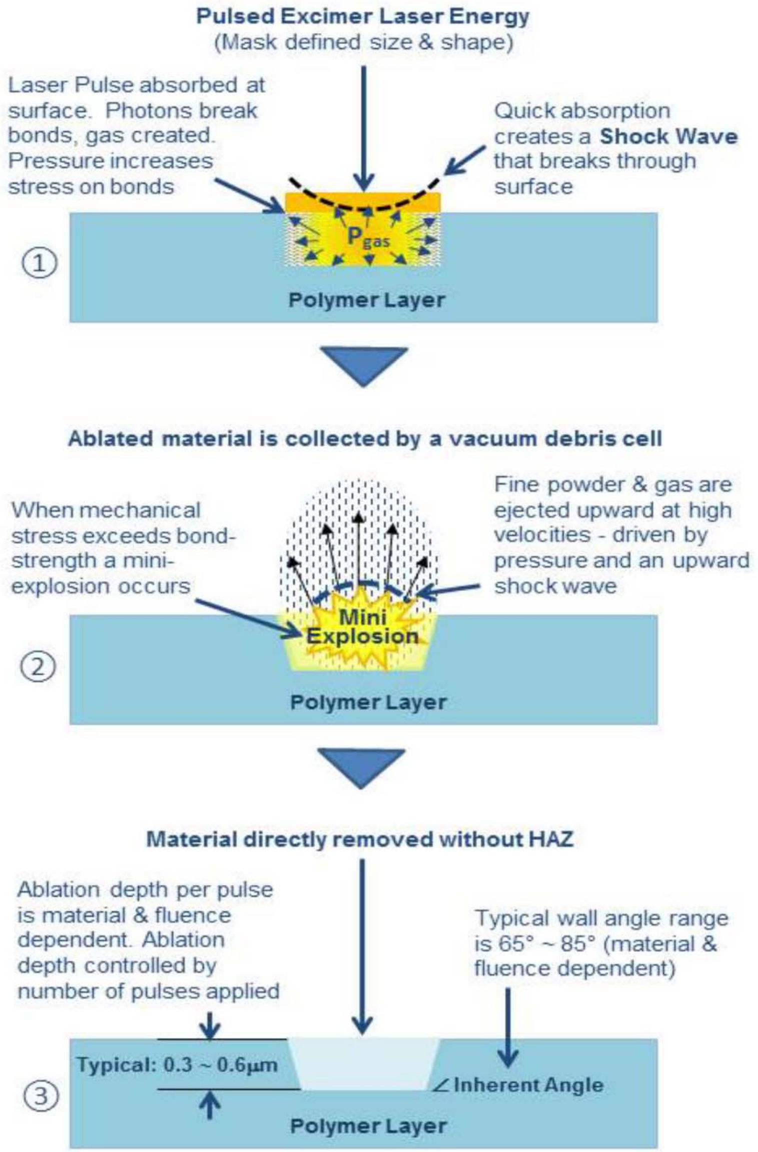
# EXCIMER LASER ABLATION TECHNOLOGY




- **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

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## + What is Laser ablation?

- Direct Material Removal by laser irradiation
- Common Laser Types: $CO_2$, DPSS (Diode Pumped Solid State), Excimer
- Various characteristics for different applications and purposes

| Laser | CO2 | DPSS (Solid State) | DPSS (Solid State) | Excimer | Excimer |
|---|---|---|---|---|---|
| **Wavelength** | 10.6mm (long) | 1.06um | 355nm | 308nm | 248nm (short) |
| **Photon Energy (eV)** | 0.12 | 1.7 | 3.5 | **4.08 Breaks Bonds** | **5 Breaks Bonds** |
| **Primary Ablation Mechanism** | Thermal | Thermal | Thermal | Photochemical | Photochemical |
| **Capable of Ablating or Cutting Matal Pads?** | **YES** | **YES** | **YES** | **NO** | **NO** |
| **Cu - Natural Stop Layer?** | **Yes** | **No** | **No** | **Yes** | **Yes** |
| **Relative Laser Heat Classification** | HOT ← | - - - - - | - - - - - | - - - → | COLD |
| **Heat Affected Zone (HAZ) & Recast** | Large | Moderate | Moderate | Small to none | Small to none |
| **In Production for Advanced Packaging?** | Yes – Large Vias | Yes – Med Vias | Yes – Med Vias | Yes – small vias | No - Qualifying |
| **Concerns of Pad/Dielectric Damage?** | No – even though Thermal | No – even though Thermal | No – even though Thermal | Logically No – Less Thermal + Cu stop layer | Logically No – Less Thermal + Cu stop layer |

# EXCIMER LASER STEPPER VS. SOLID STATE LASER

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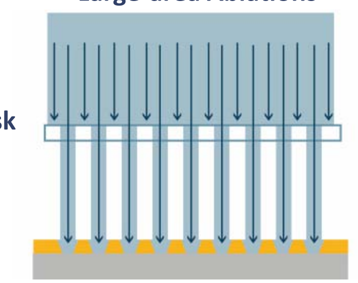
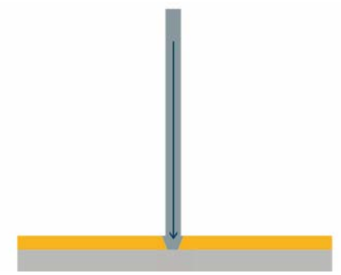
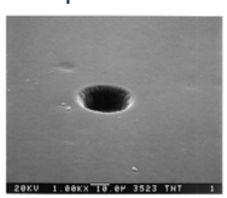
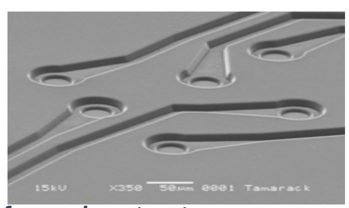
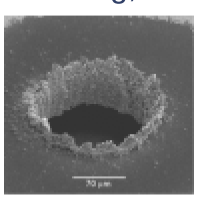
| | Excimer Laser Ablation | Solid State Laser Ablation |
|---|---|---|
| |  |  |
| ***Imaging Type*** | Mask based projection | Maskless, direct ablation |
| ***Patterning area*** | Field area, up to 50x50mm. 1000's of features at a time | Single spot |
| ***Patterning Mode*** | Direct bond breaking | 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:<br> <br>***Ablation of complex structures (i.e. RDL trench and vias)*** | Low density patterning, scribing, drilling:<br><br>***Laser drilling (i.e. through glass vias)*** |

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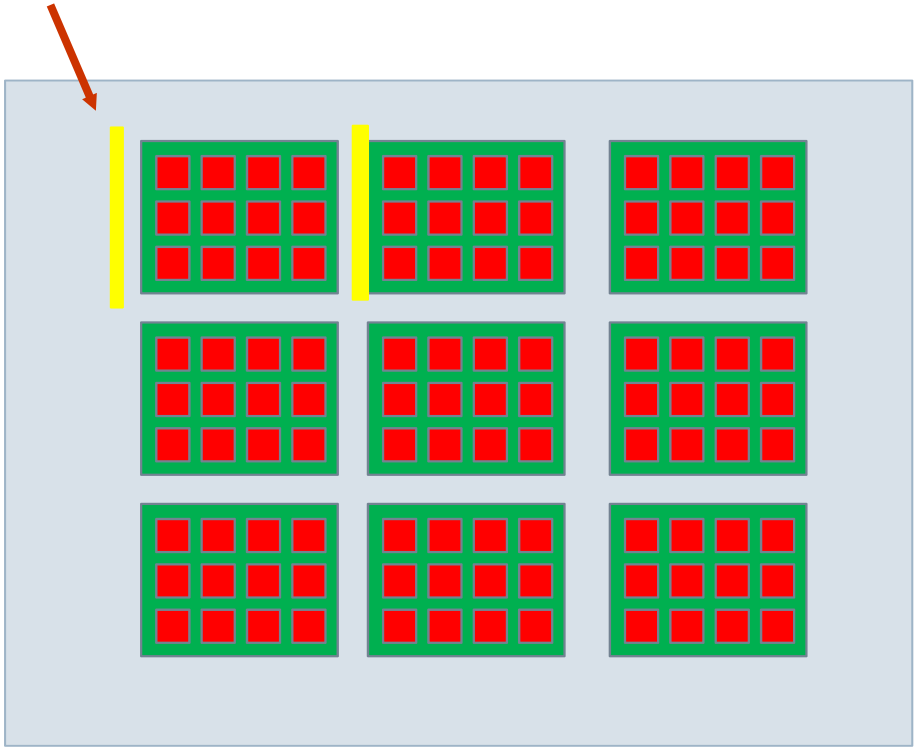
Scanning
Laser beam



Process can be performed on wafers or substrates

Substrate moves under projection lens to ablate next unit site

# SCHEMATIC SETUP OF AN EXCIMER LASER STEPPER

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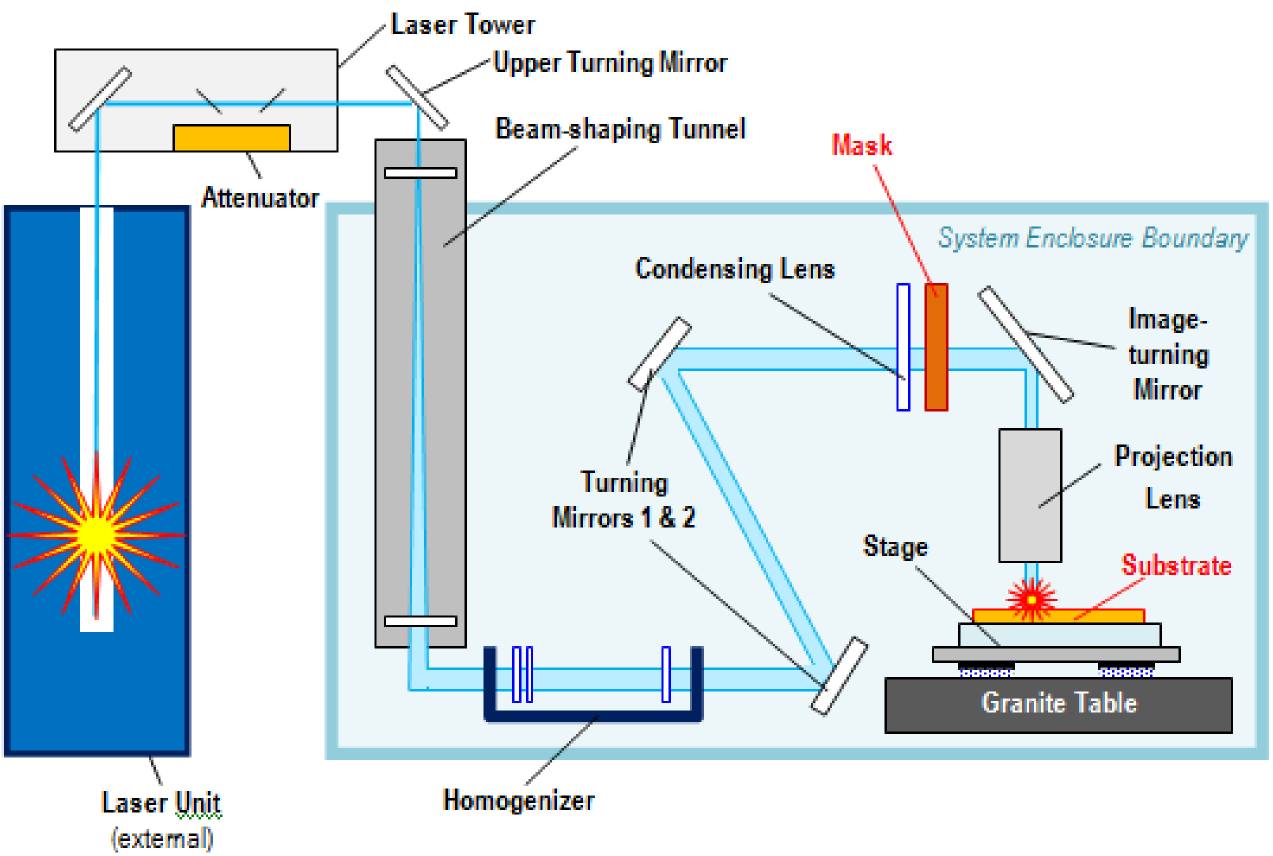
## + Typical setup of an Excimer Laser stepper:

- 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



# DEBRIS COLLECTION

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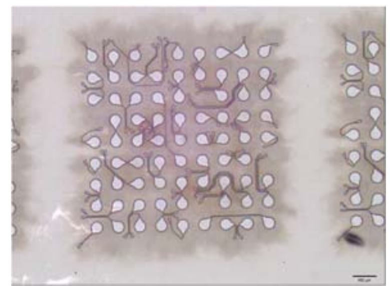
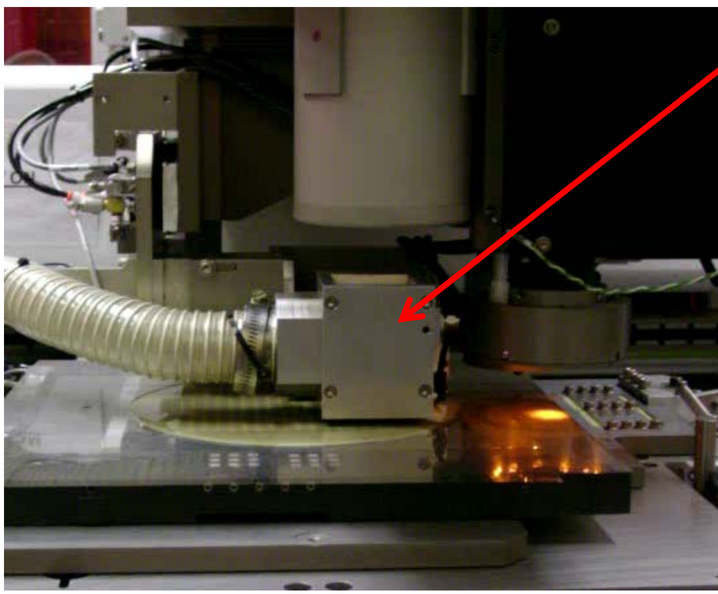
- Physical process of ablation is the generation of debris.
  - Process breaks down the material molecular structure and debris is generated, simulating dust.  To maximize debris removal, a Debris Cell is used.
    - Debris collection system sucks air around the ablation area
    - Debris exhausted out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

Precious metals can be reclaimed!



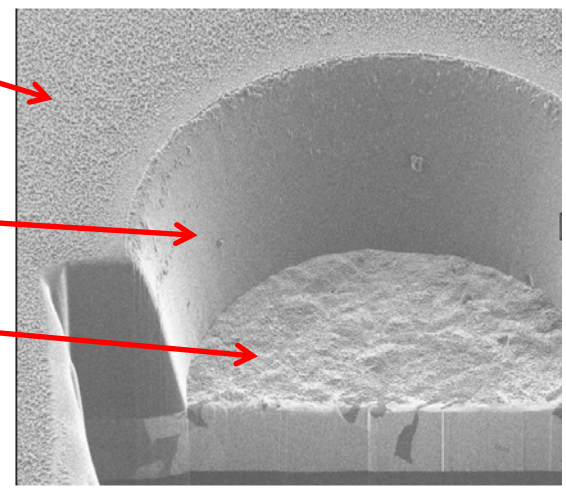


**Debris Cell**

Debris

PI (~7µm)

Cu Pad (~3µm)



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

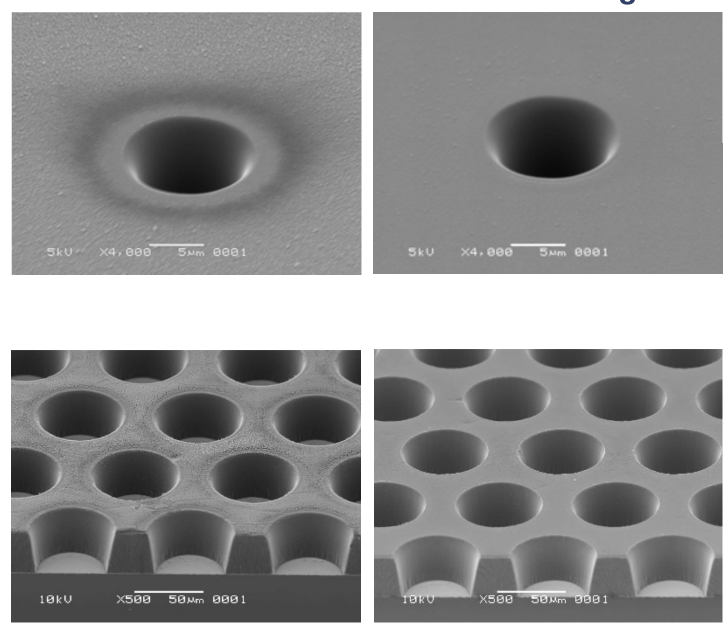
**O2 plasma cleaning: Recommended**

- Most common cleaning method
- Successful cleaning of wafer with PBO (HD8820)

**Sacrificial layer for debris removal:**

- Successful removal process shown for FCPi 2100 (Fuji Film) Sacrificial layer removed using high-pressure CO2 ionized water

Post Ablation | Post Cleaning



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# EXCIMER LASER APPLICATIONS IN ADVANCED PACKAGING

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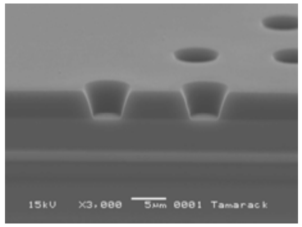
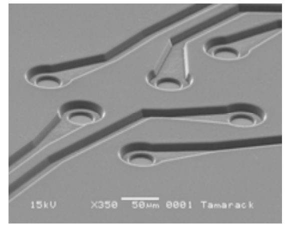
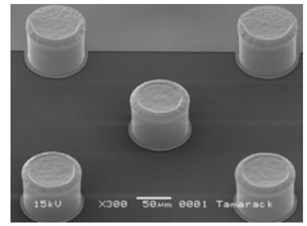
### Via Drilling



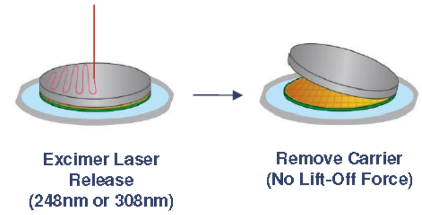
### RDL Trench

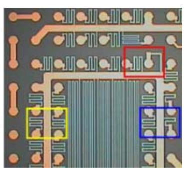


### Seed Layer Removal



### Debonding




| | 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

# EXCIMER ABLATION PROCESS CONTROL

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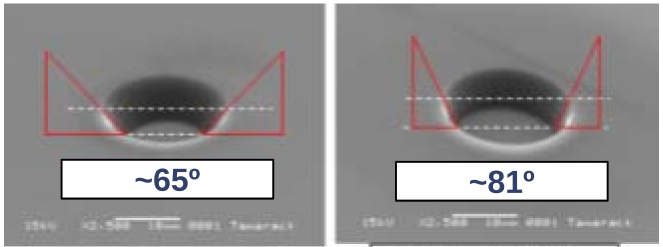
+ Excimer ablation allows us to control many things…

## Side-wall Angle Control (WPR5100):

- Higher fluence: Steeper wall-angle
- Lower fluence: Shallow wall-angle
- Wall angles to < 82º

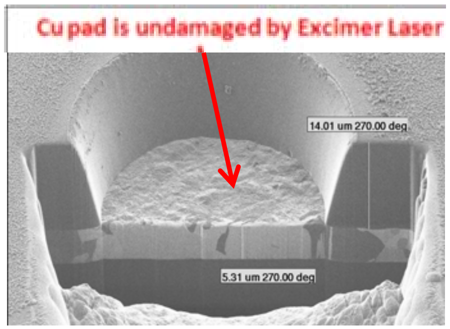



376mJ/cm² – 45 pulses

1200mJ/cm² – 12 pulses

## Selective Material Removal:

- Metal pads >1µm thick are a Stop Layer

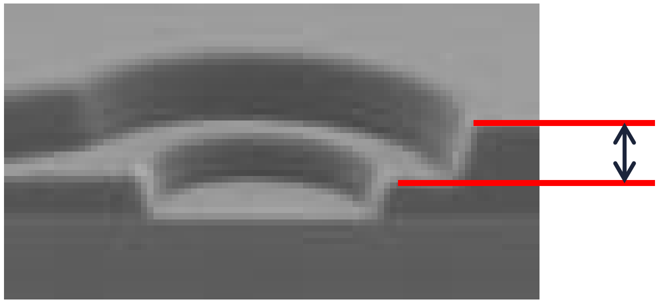



## Depth Control - by No. of Pulses:

- 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




- **Pulse Estimate Calculation:**

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

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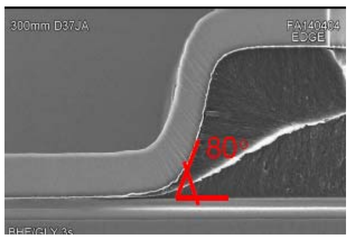
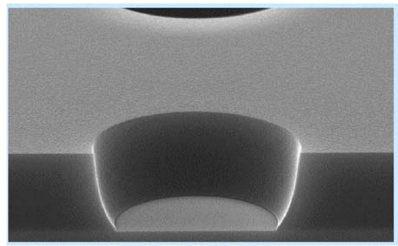
- Photolithography
  - Limited Pitch and Via Wall Angle Control (UV Imaging)
    - Flexibility desired to address tighter via pitches, wall angles for Cu sputtering or higher aspect ratios where thicker dielectrics are desired.

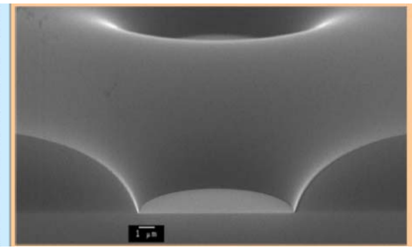
**Photolithography**



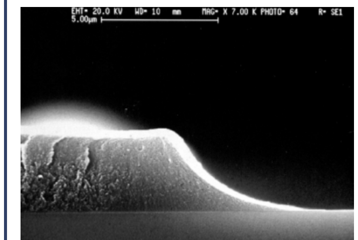

Wall to steep



BCB after UV expose



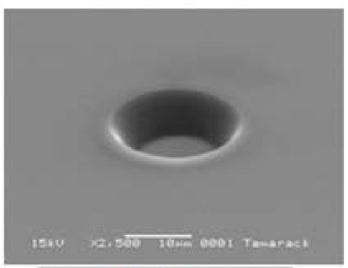
BCB after Cure



HD4000 – UV Imaged

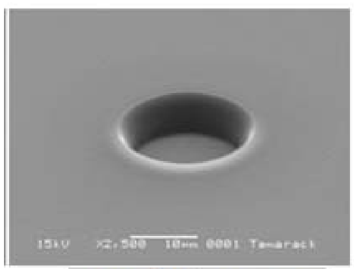
- Excimer Ablation
  - Ablation performed after cure. Provides ability to flexibly alter the wall angle to the desired requirement.

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



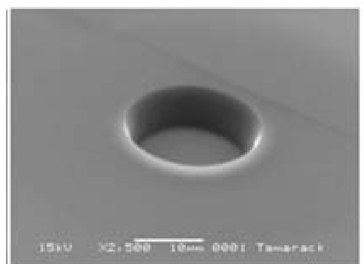
376mJ/cm² – 45 pulses

~65°



822mJ/cm² – 15 pulses

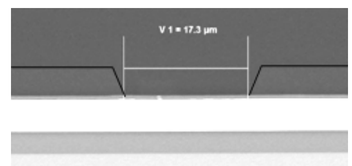
~74°



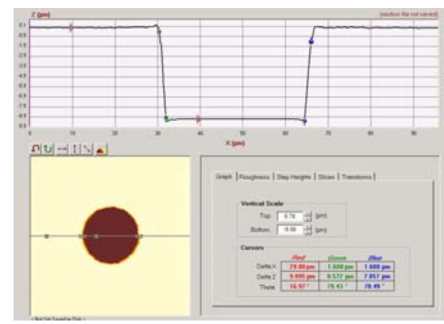
1200mJ/cm² – 12 pulses

~81°

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




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

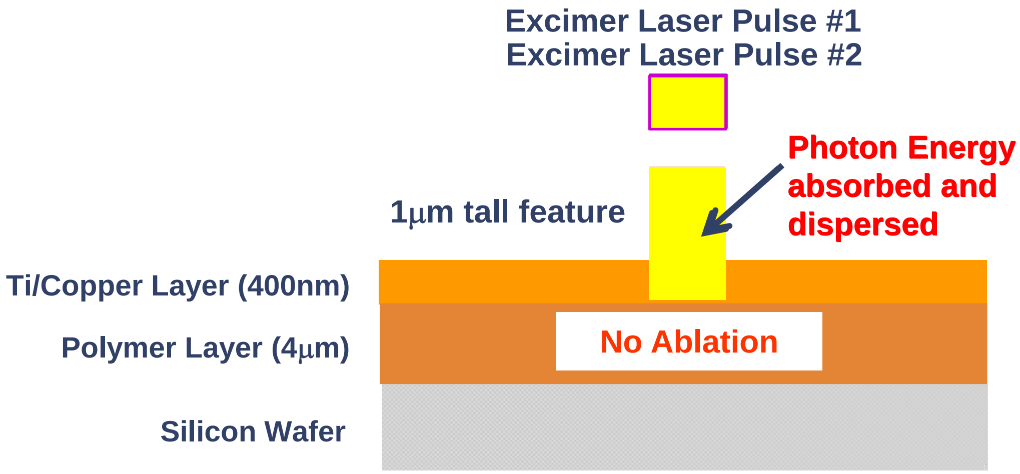


# EXCIMER LASER SLR – SELECTIVE FOR THIN METAL SEED LAYER REMOVAL

SUSS MicroTec

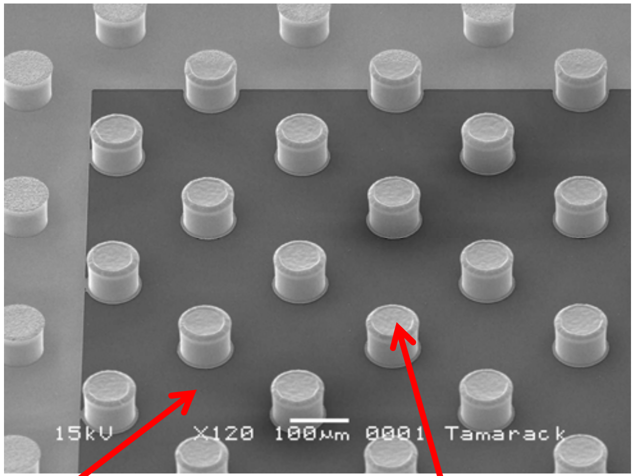
## Unique Characteristic of Excimer Laser Ablation:

- Thick (>1μm) Traces, Bumps & Pillars are Natural Stop Layers:
  - Consider the cross-section of the 1μm tall Cu feature, below.
  - The conductive metal immediately disperses the laser energy throughout the structure with its sea of free electrons
  - Any energy or heat that reached the Metal-Dielectric Interface is insufficient to break bonds via photochemical or thermal action – so No melting or Ablation takes place – even with multiple pulses




RDL Feature on Copper Seed Layer on Polymer Dielectric

**No Ablation or Damage to RDL Structures Thicker than 1μm - Readily apparent through Laser Seed Layer Removal Ablations**



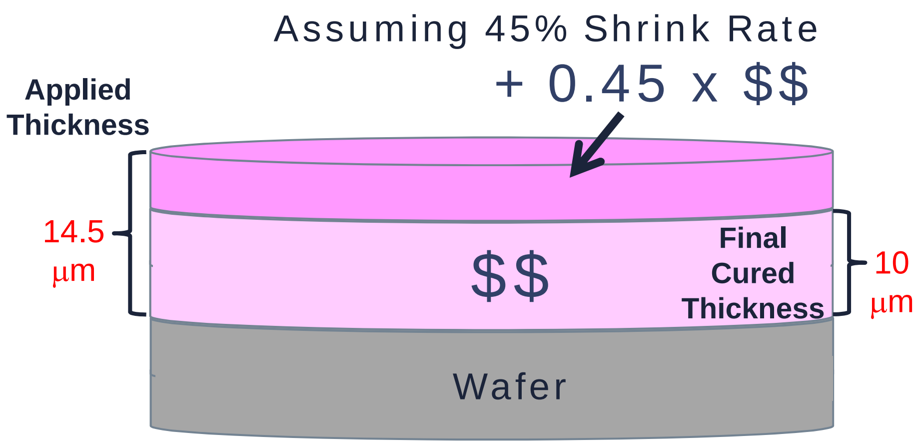

Thin Seed Layer ablated off of Polymer

Thick Cu Bumps Not Ablated or Damaged

## Photo vs. Non-Photo Dielectrics

- Non-Photo Dielectrics cost up to 50% LESS than Photo-Dielectrics
- Photo Dielectrics have a higher Shrinkage Rate – increased cost and less pattern fidelity
- Many Non-Photo Dielectrics have better thermal, mechanical and chemical properties
- Non-Photo Dielectrics increase the material choices => better CTE

**PHOTO DIELECTRIC**

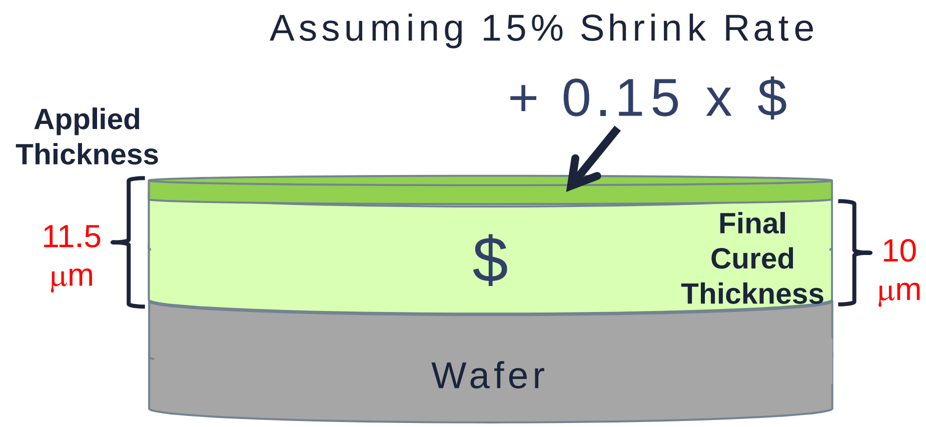



Total Cost = ~3.0 $

Almost 3X Cost

**NON-PHOTO DIELECTRIC**

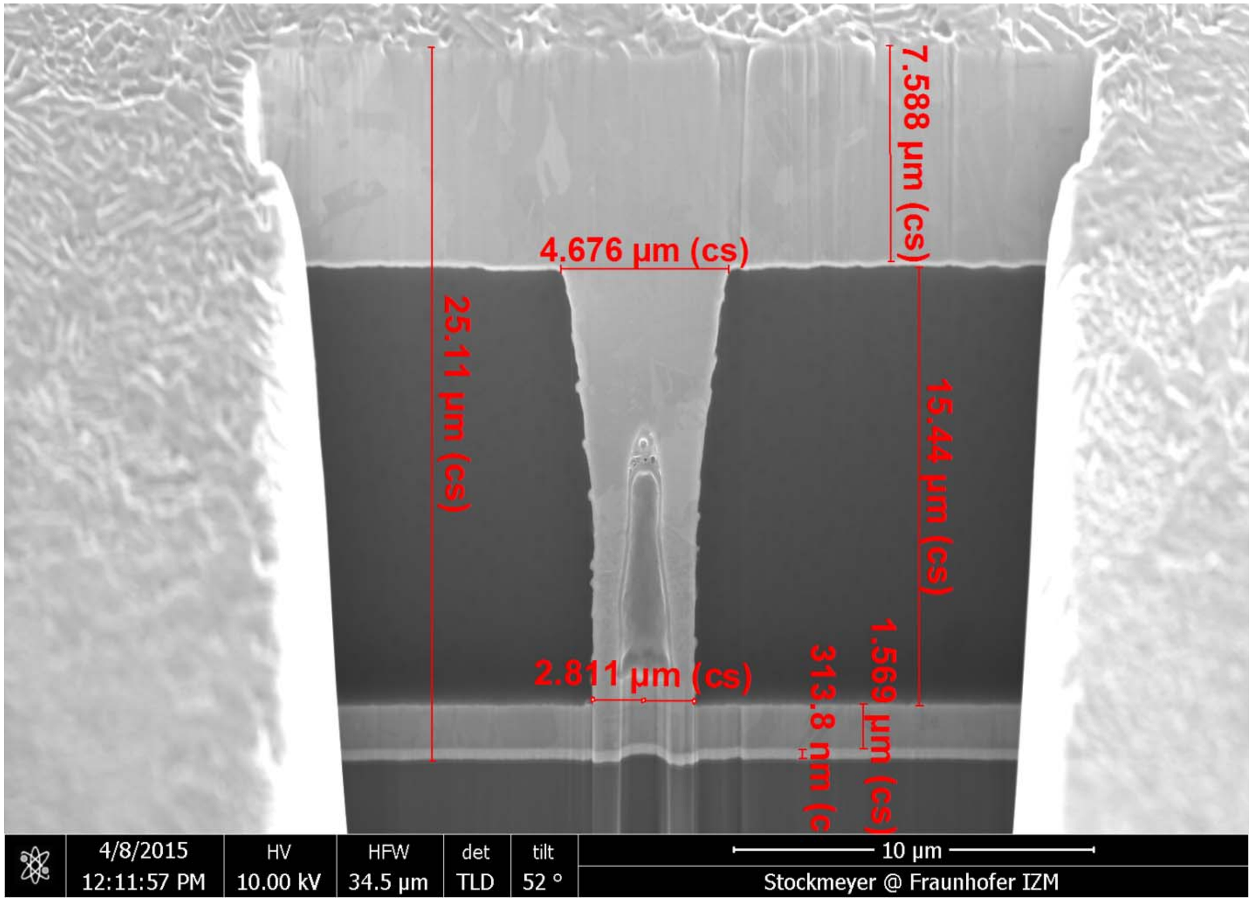
Some Non-Photo Dielectrics have 30% less Shrinkage vs. Photo

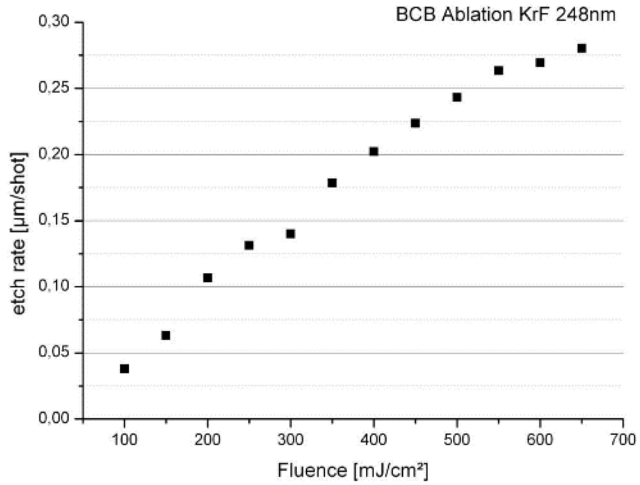


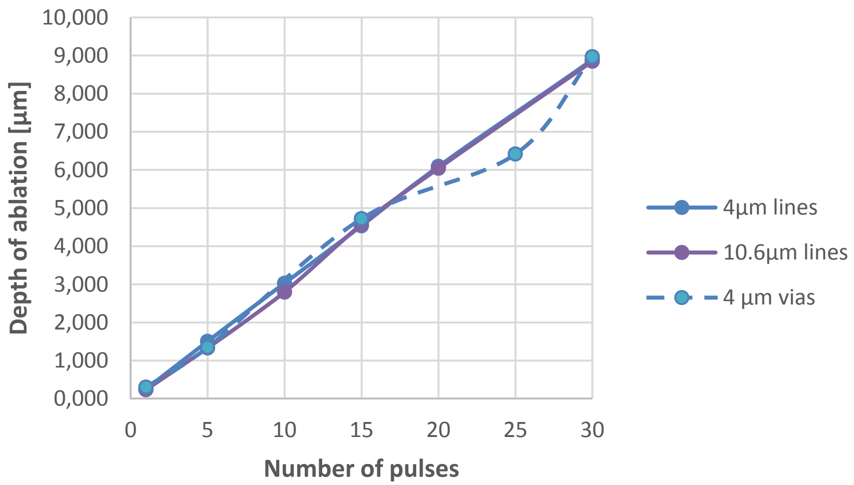

Total Cost = ~1.15 $

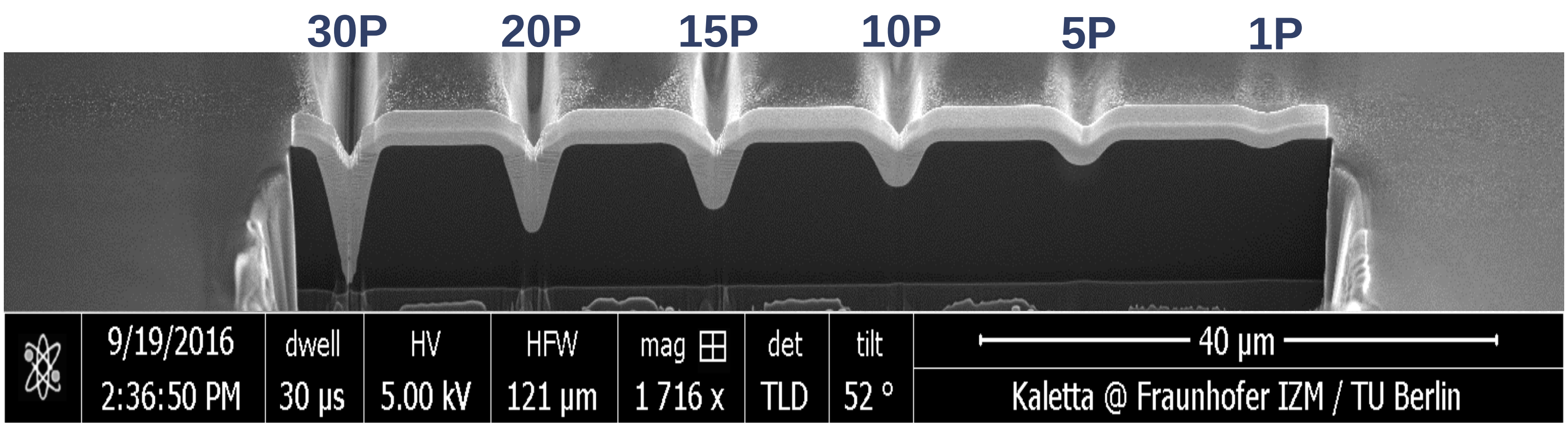
## Excimer Ablated 5µm Via in 15 thick BCB:

- Result: 4.7µm top and 2.8µm bottom
- Aspect Ratio: 4~5

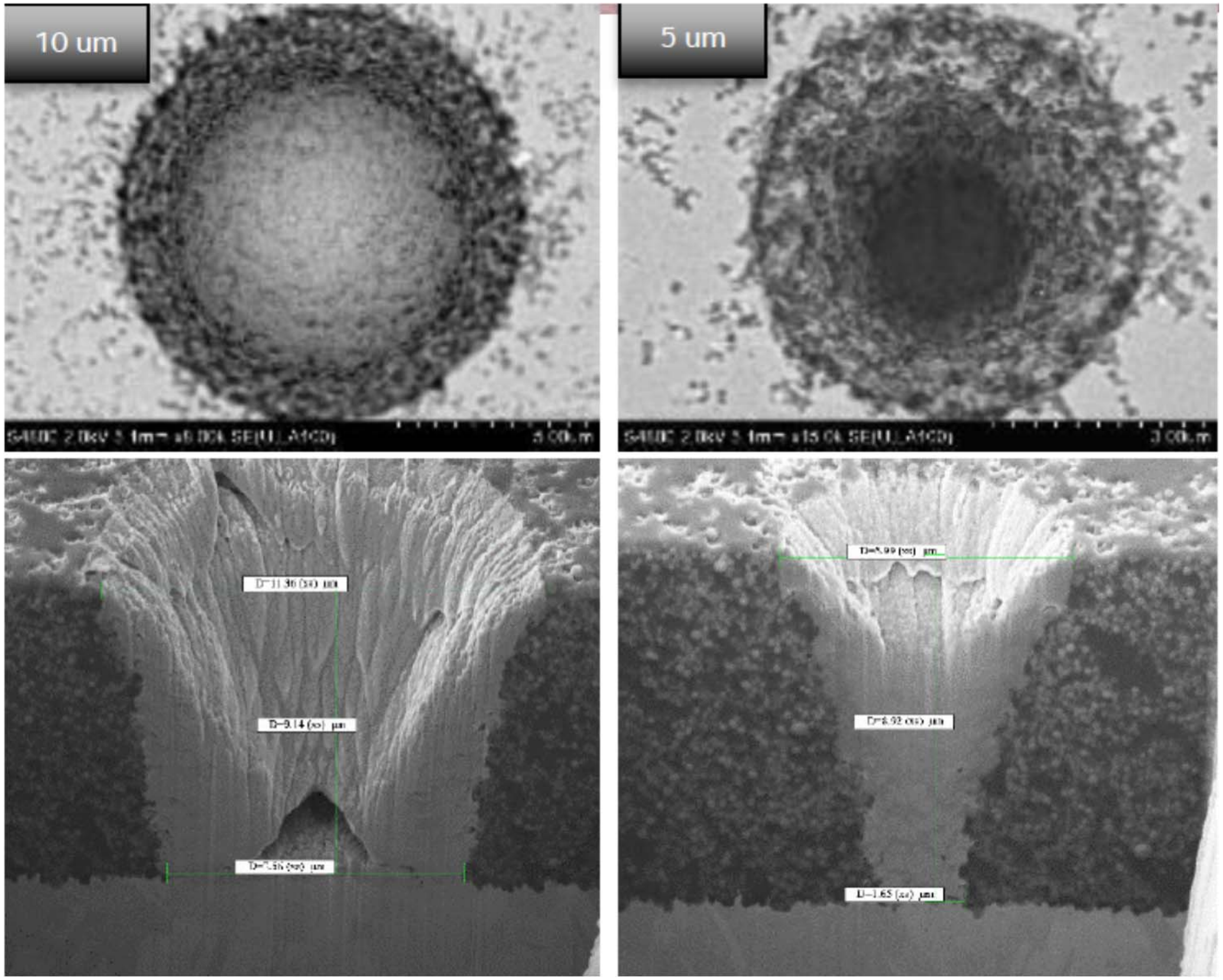



BCB Ablation KrF 248nm
etch rate [µm/shot]
Fluence [mJ/cm²]
0,00
0,05
0,10
0,15
0,20
0,25
0,30
100
200
300
400
500
600
700


Depth of ablation [µm]
Number of pulses
0,000
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000
0
5
10
15
20
25
30
4µm lines
10.6µm lines
4 µm vias

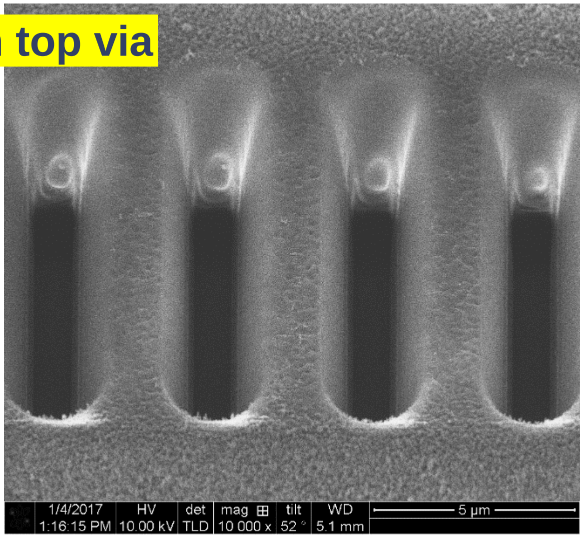

30P
20P
15P
10P
5P
1P
9/19/2016
2:36:50 PM
dwell
30 µs
HV
5.00 kV
HFW
121 µm
mag
1 716 x
det
TLD
tilt
52 °
40 µm
Kaletta @ Fraunhofer IZM / TU Berlin

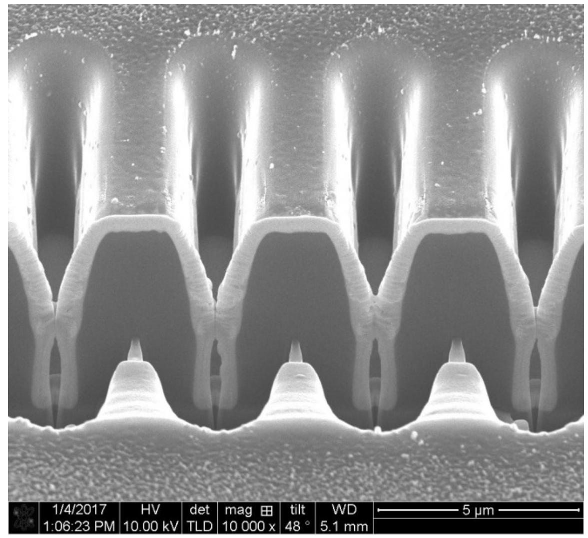
# 5UM AND 10UM VIAS IN 9UM THICK NON-PHOTO ABF MATERIAL

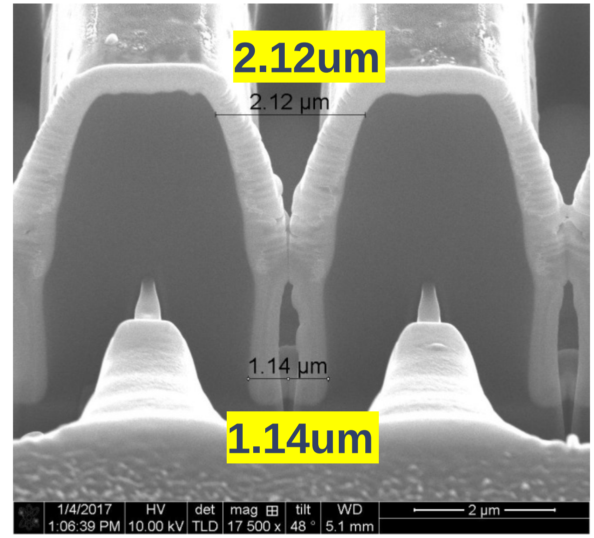


# FINE TRENCHES IN 5.6UM THICK HD4100: 2.0UM AND 2.5UM TOP OPENING

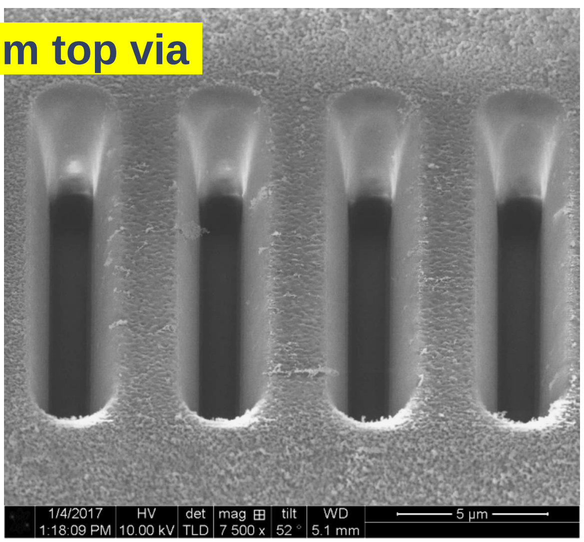
2um top via

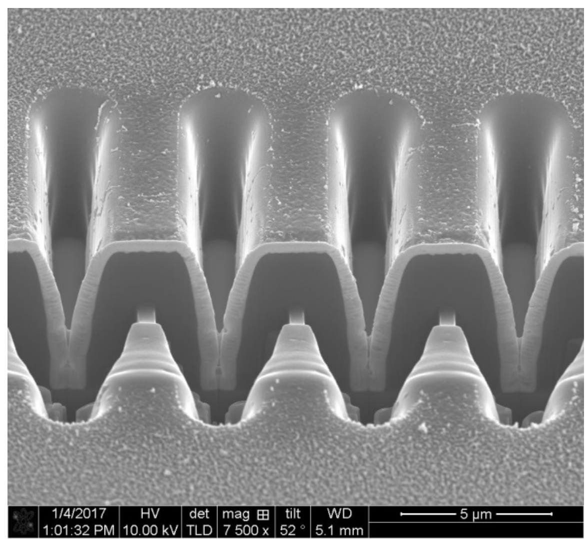


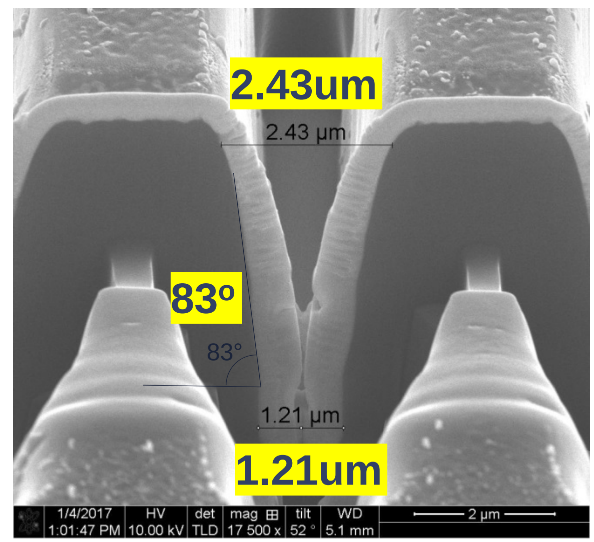




2.5um top via



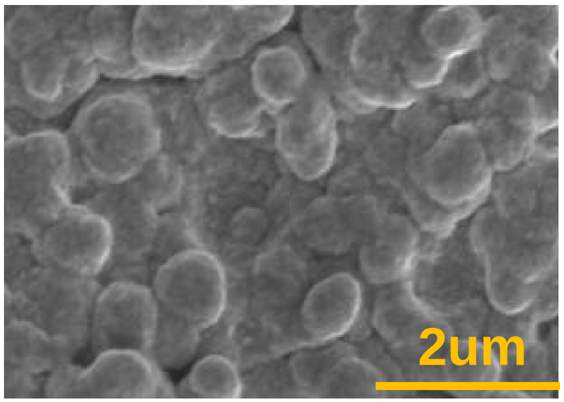



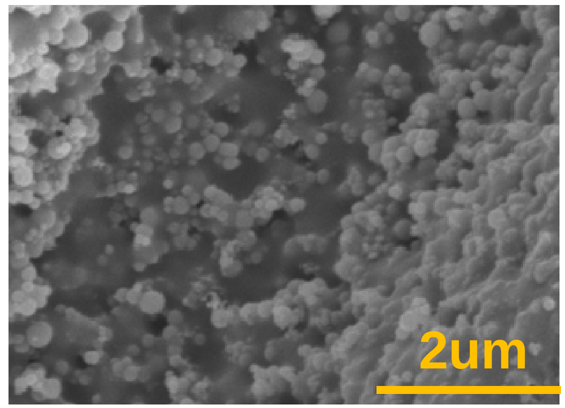



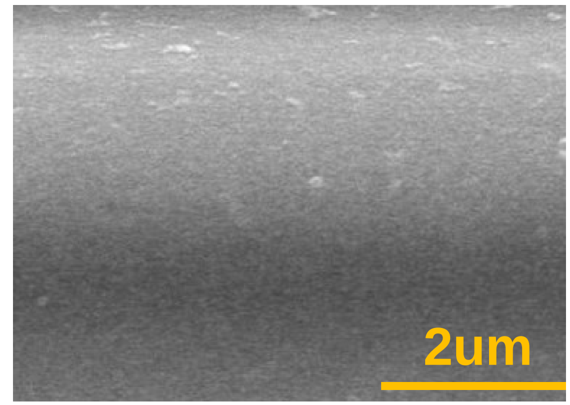
# EFFECT OF FILLER SIZE ON FINE PITCH TRENCH FORMATION

| | ABF GX92 | ABF GY50 | Fujifilm Polyimide |
|---|---|---|---|
| | Large filler | Small filler | No filler |

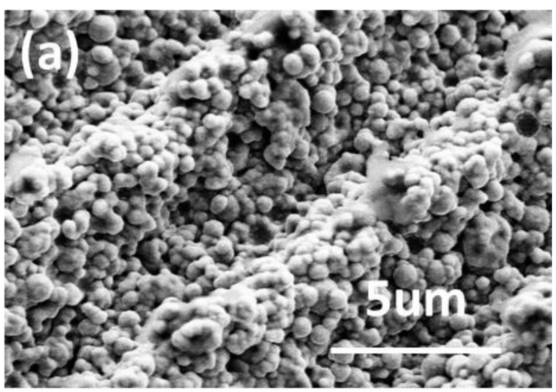
**surface topology**

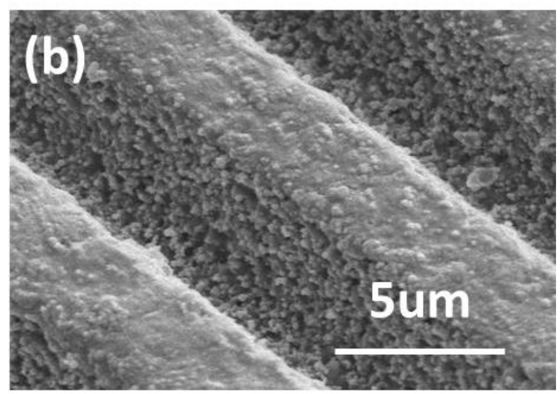


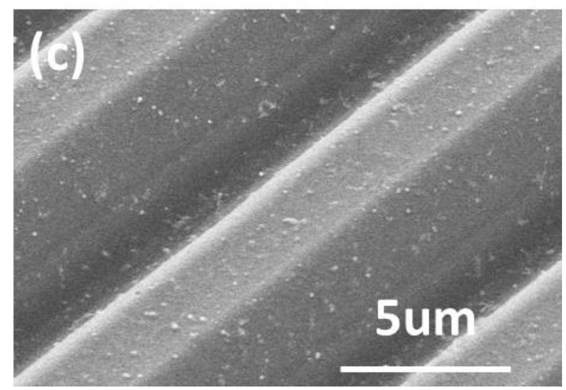




**4µm L/S trench**



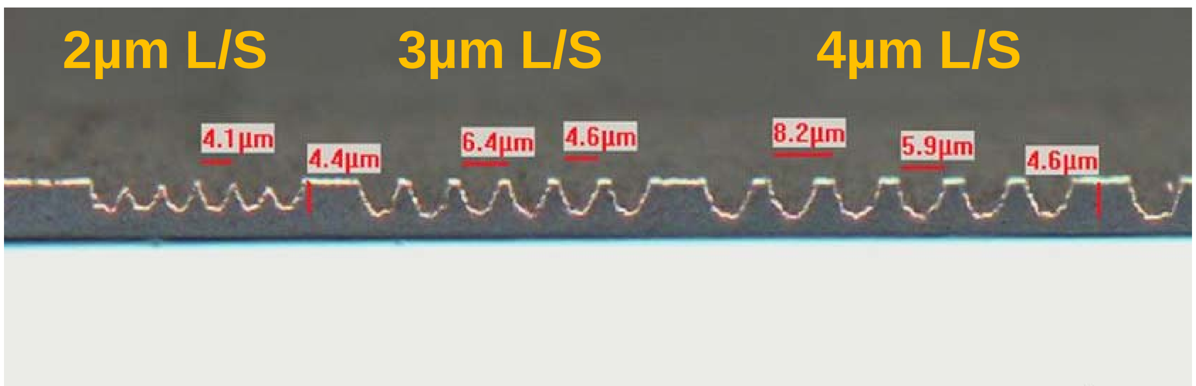

- Large filler in polymer dielectrics leads to side erosion
- Small/ no filler material enables high resolution trench formation

# 2UM L/S FINE RDL TRENCH BY EXCIMER LASER

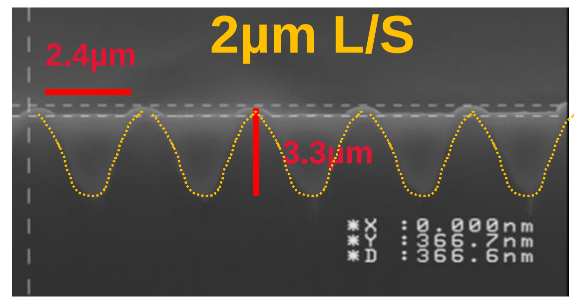
SUSS MicroTec

- Material: ABF GY50, Fujifilm Polyimide
- Target: 4.5µm depth
- Mask: 2µm – 4µm line and space

**ABF GY50 (small filler)**




**Fujifilm Polyimide (non filled)**

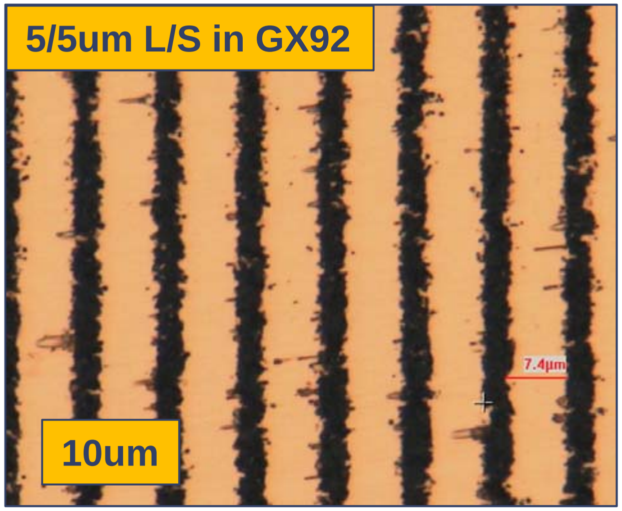


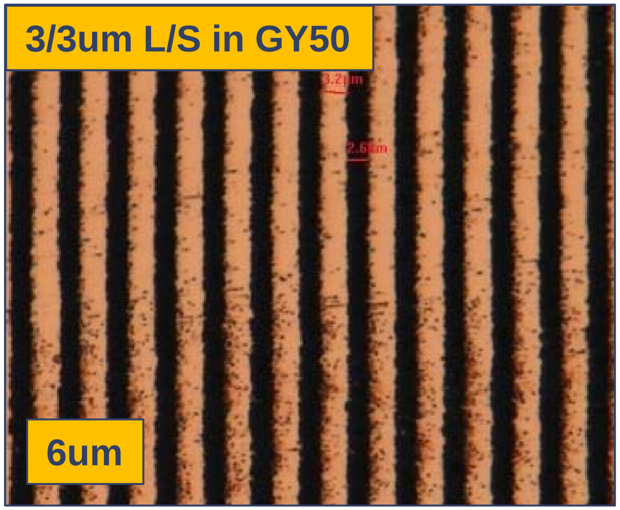

- **Aspect ratio of trench ~ 1:1 for small filler ABF, 1:1.5 for non-filled**
- **SUSS R&D project to develop new projection optics for higher resolution and aspect ratio**

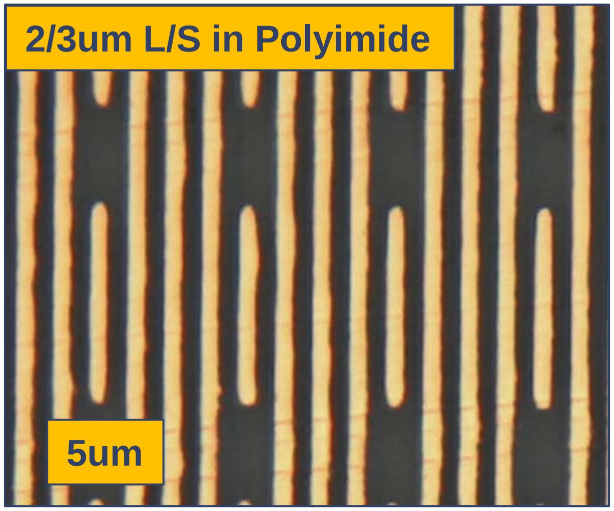
Georgia Tech PACKAGING RESEARCH CENTER

## Fine pitch embedded RDL trench wiring by Excimer Laser ablation

| ABF GX92 | ABF GY50 | Fujifilm Polyimide |
|---|---|---|
| Large filler | Small filler | No filler |



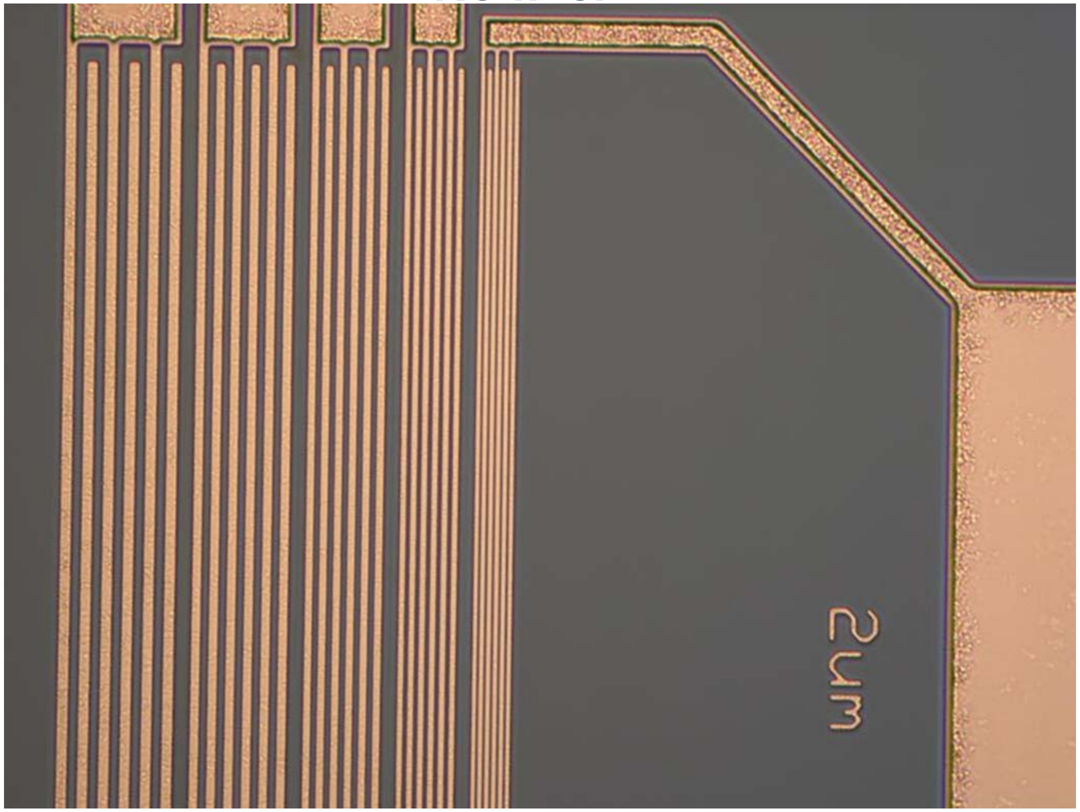




**10µm pitch in GX92, 6µm pitch in GY50 and 5µm pitch in PI demonstrated**

## Fine pitch embedded RDL trench wiring by Excimer Laser ablation

# Fujifilm Polyimide (FFEM)

No filler




**6/6, 5/5, 4/4, 3/3, and 2/2um L/S in PI demonstrated**

# OUTLINE

1 Advanced Packaging Trends

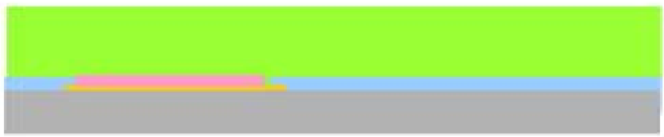
2 Excimer Laser Ablation Technology

3 Via and RDL Patterning in novel material

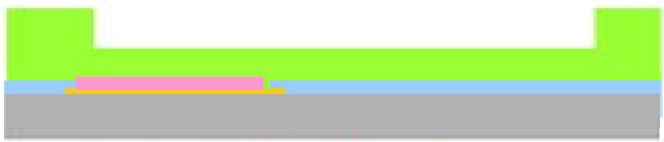
4 **Reliability of Embedded Laser RDL Patterning for Advanced Packaging**

# EMBEDDED LASER RDL FORMATION SCHEME

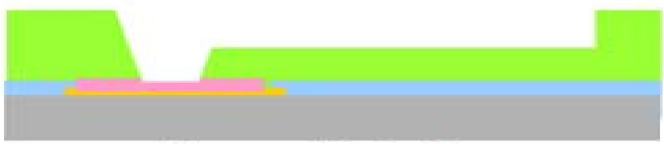
Starting substrate



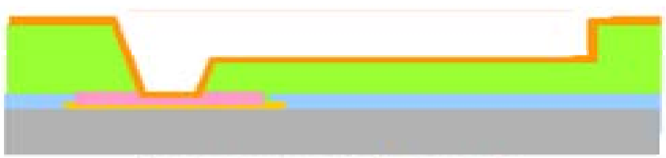
Coat and cure polymer



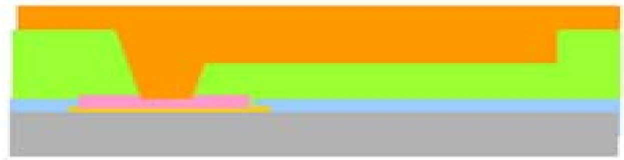
Laser ablate RDL trenches



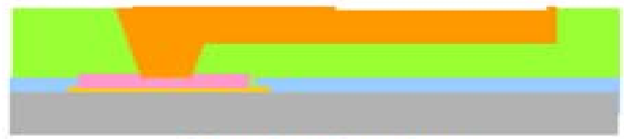
Laser ablate Vias



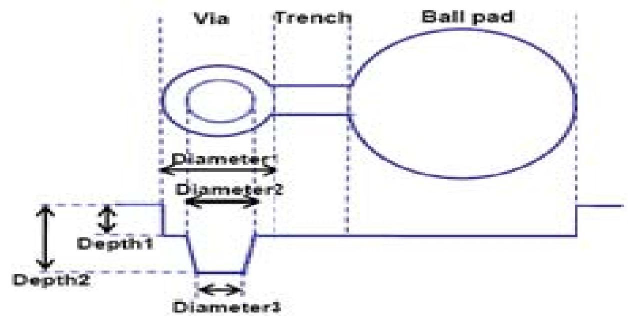
Sputter seed metals



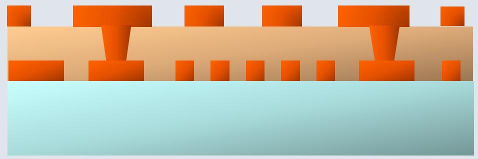
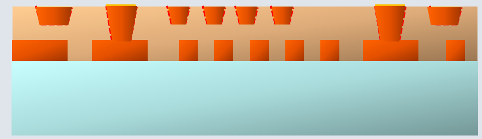
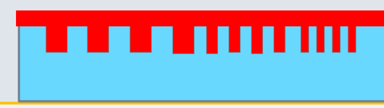
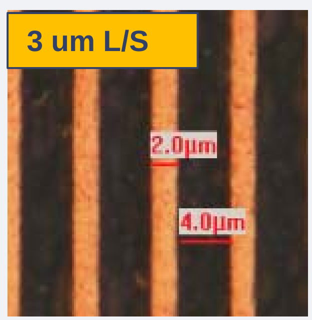
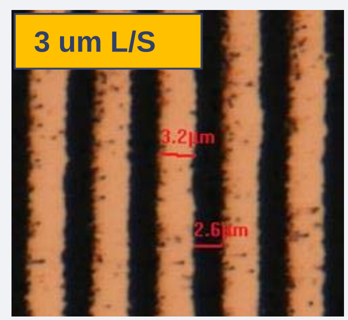
Overplate Cu



Metal reduction

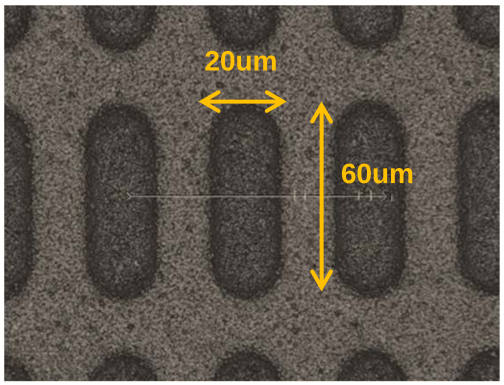



# EMBEDDED LASER RDL FORMATION VS. CURRENT PROCESS

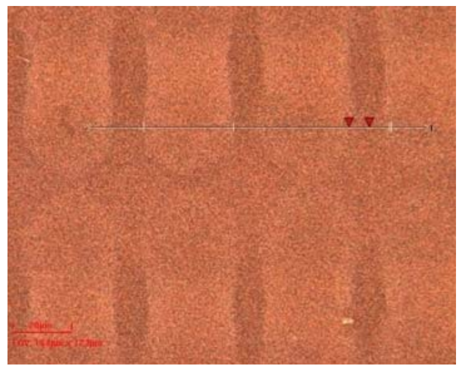
| | Semi-additive | Embedded trench |
|---|---|---|
| Cross section |  |  |
| Advantage | - Current POR in industry<br>- Lots of industry development | - No photo-lithography material required<br>- Line & via formation in one Step<br>- No wet seed removal required<br>- Via pattern integrity |
| Challenge | - RDL Undercut and erosion during seed etch<br>- Surface non-planarity<br><br> | - Planarization of Cu overburden<br> |
| Fine line | - Erosion of the Cu during seed layer removal<br><br> | - No Cu erosion<br><br> |

# SURFACE PLANARIZATION

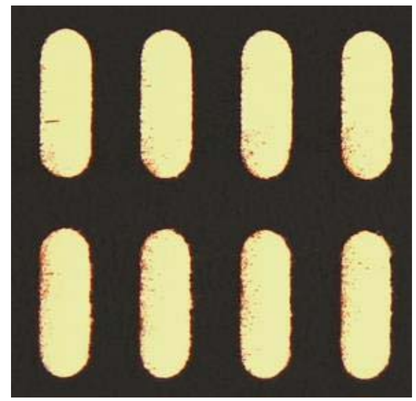
**Trench formation by excimer laser**

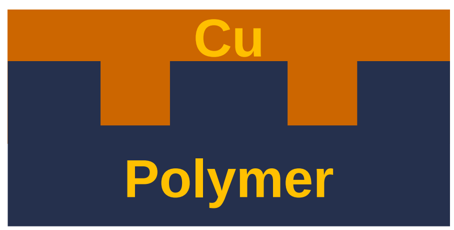



**Trench filling by Cu plating**



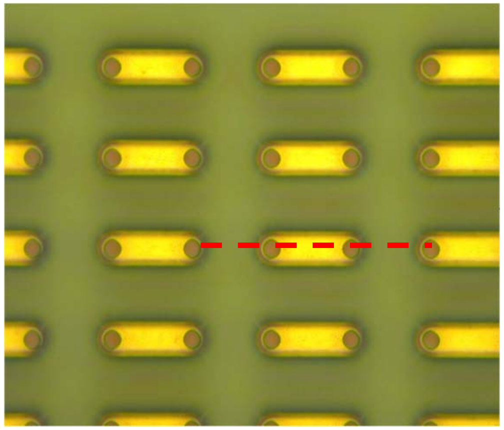
**Cu overburden removal by surface planarization**



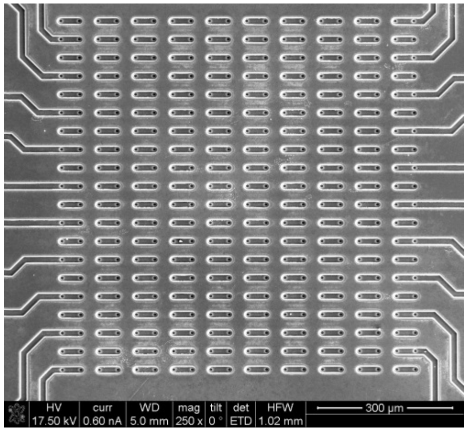



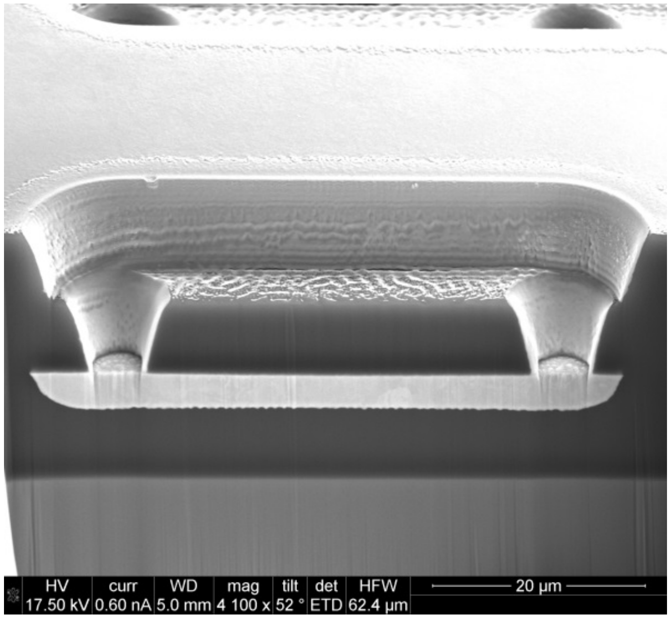

# XSEM OF EMBEDDED RDL STRUCTURE IN FCPI 2100 (FUJI FILM)

**Courtesy of Fujifilm US**

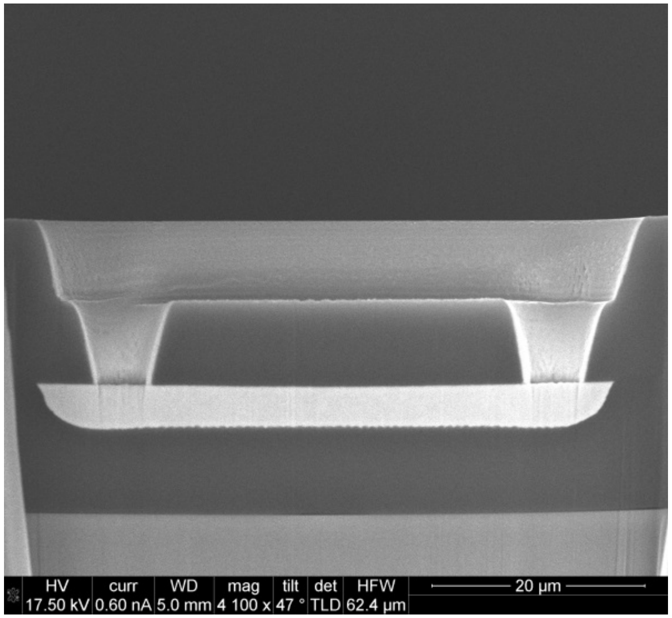


15/15/8um



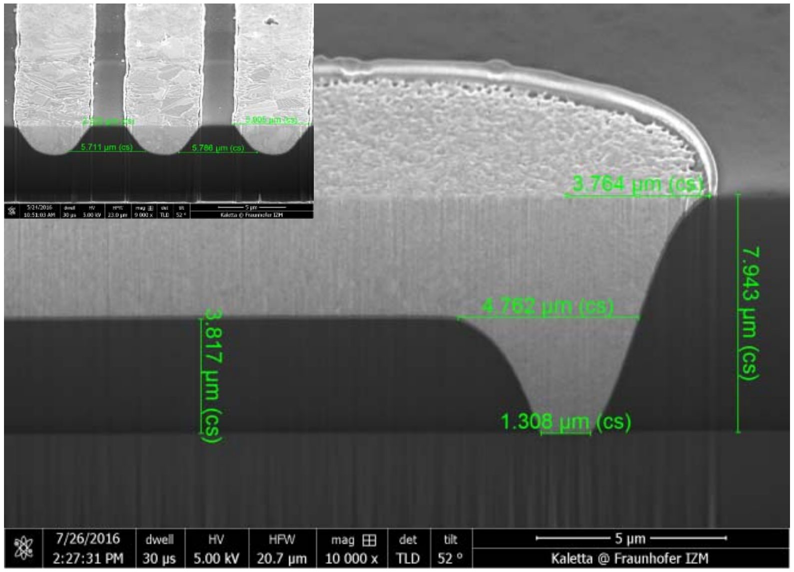



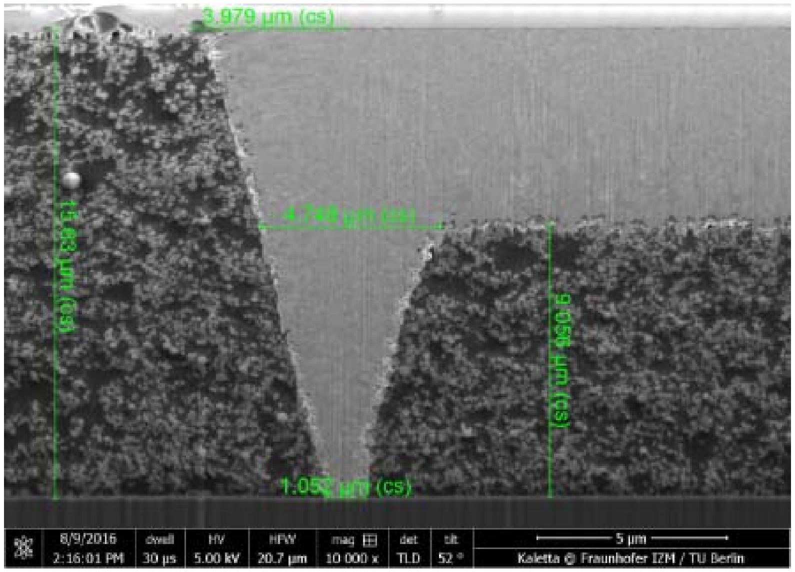

40 micron pitch 52° tilt after FIB




40 micron pitch 90° tilt after FIB, high resolution detector

# XSEM OF EMBEDDED LASER RDL IN PHOTO AND NON-PHOTO MATERIALS (VIA FIRST PROCESS)



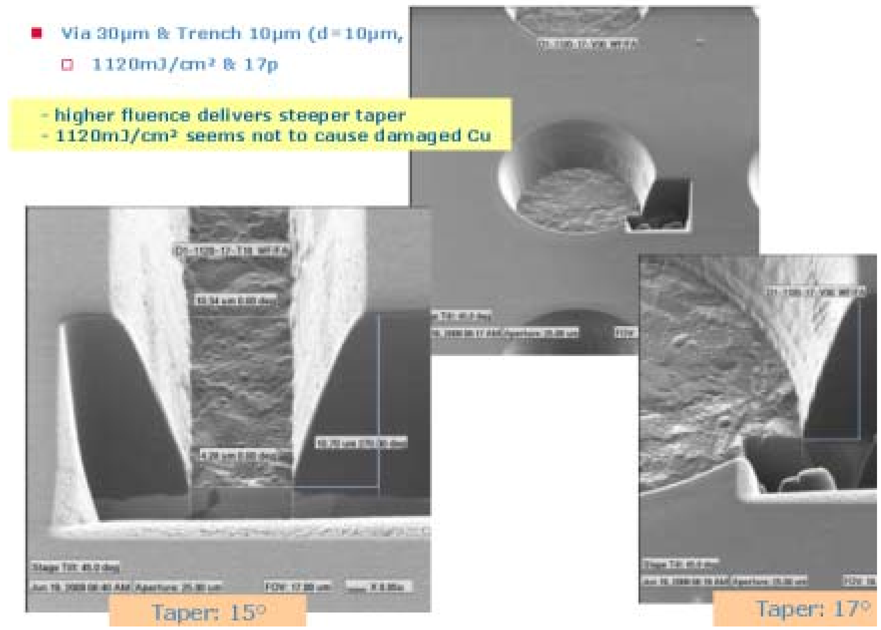

- Material: LTC9320 low T cure (Fujifilm)
- 4/4/4um L/S/via
- Sputtering seed: 100nm Ti 600nm Cu
- Cu Plating 4.7µm overburden
- CMP for planarization (stop on seed layer)
- Seed layer removal using Excimer Laser
- No leakage observed post seed layer removal
- No plating voids in via!

- Material: ABF GY50 (Ajinomoto)
- 6/6/6um L/S/via
- Sputtering seed: 100nm Ti 600nm Cu
- Cu Plating 4.7µm overburden
- CMP for planarization for Cu, seed layer and stop on ABF
- No leakage observed post CMP
- No plating voids in via!

Courtesy of IZM Fraunhofer

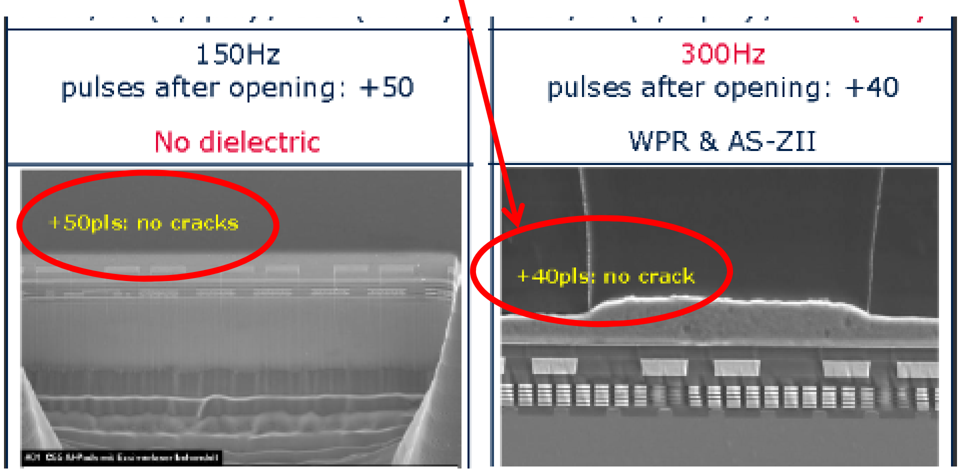
## + Excimer ablation over Cu and Al pads:

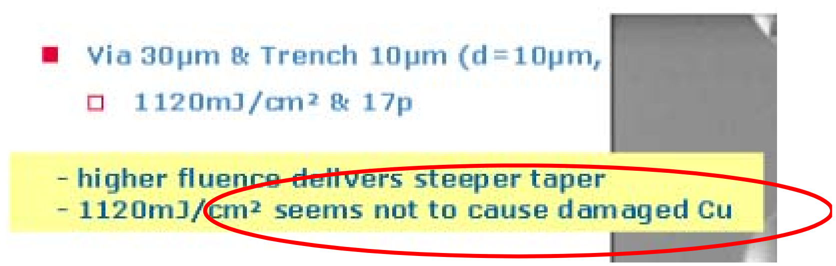
- 3rd party tests have been performed showing no damage to the underlying materials
- **Case study:**
  - Si/SiOx/SiNx/TiTiN/AlCu(1.4um)/ dielectric(8.5um)
  - Over pulsed 40 and 50 with no damage to the low k dielectrics




**3rd party confirmation of no damage to Cu pads**

- **Summary: No increase of crack rates after laser impact**



CONFIDENTIAL

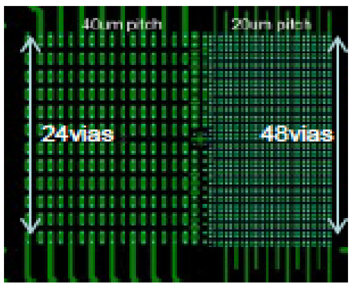
# Excimer Laser Micro-via Reliability

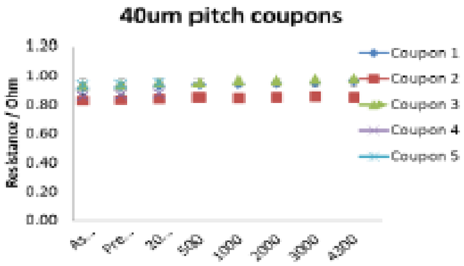
## – Build-up + excimer +Eless seed SAP –

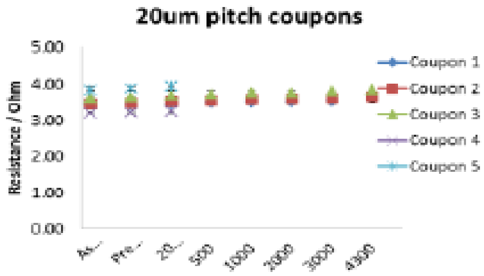
GT-PRC team: Yuya

- 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



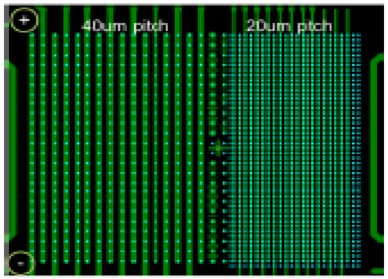



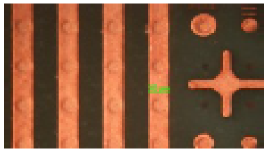



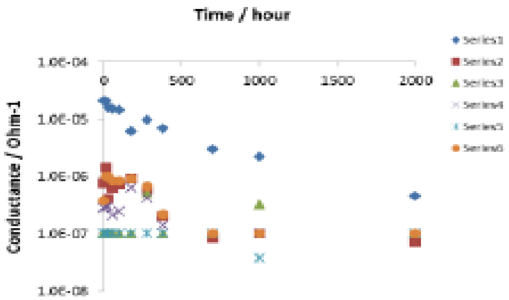

Preconditioning: MSL3
TCT condition:
-55ºC,15min ↔ 125ºC,15min

No resistance increase for 4300cycles

### bHAST






B-HAST condition:
130ºC, 85%RH, 5.0V

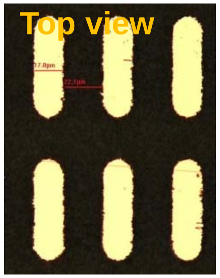
No Conductance increase for 2000hr

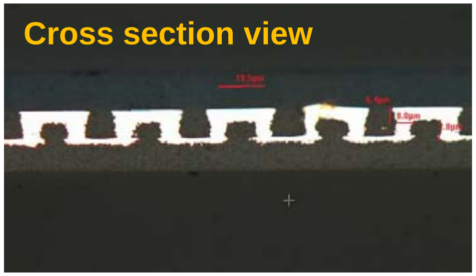
**No reliability failures observed with single layer micro-via chains**

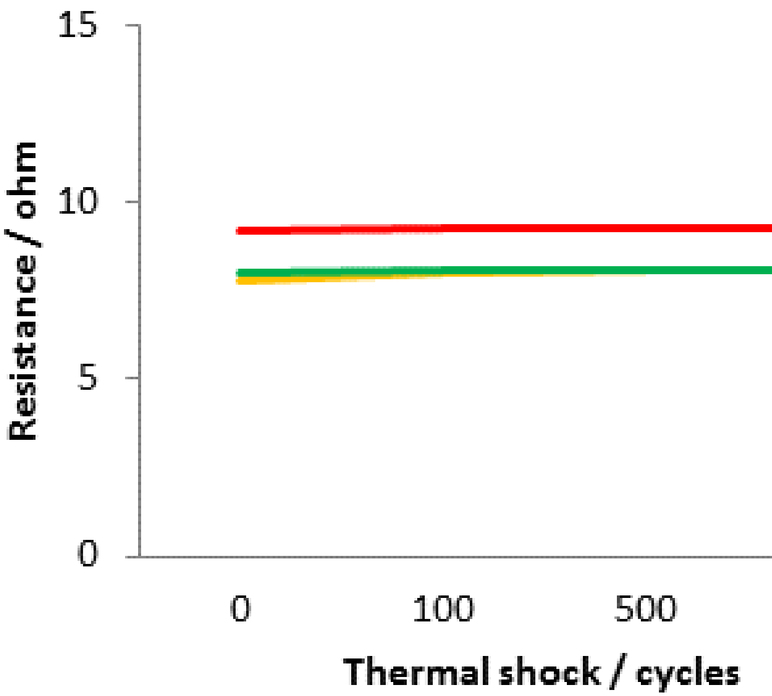
# RELIABILITY OF EMBEDDED TRENCH (5/5UM)

Courtesy of GIT-PRC

**Multilayer RDL structure in ABF GX92 with 8um via diameter**
**20, 30 and 40um pitch daisy chain structure**
**Thermal shock test**
**liquid to liquid: 125°C 1min and -55°C 1min**

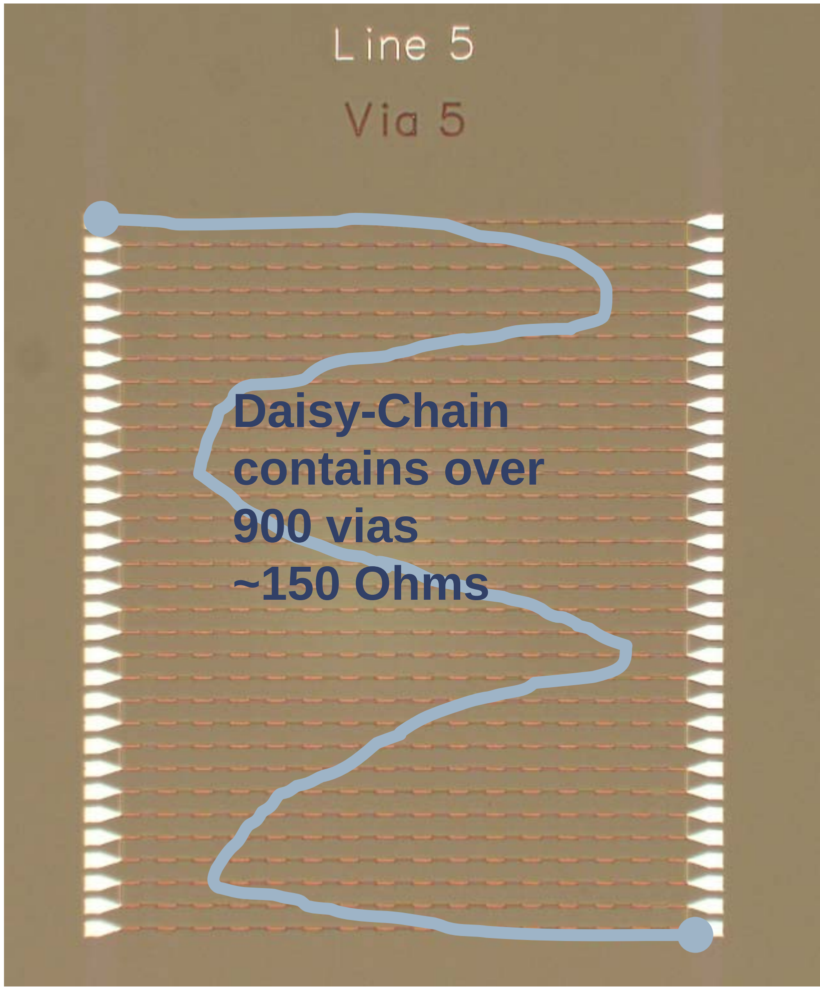


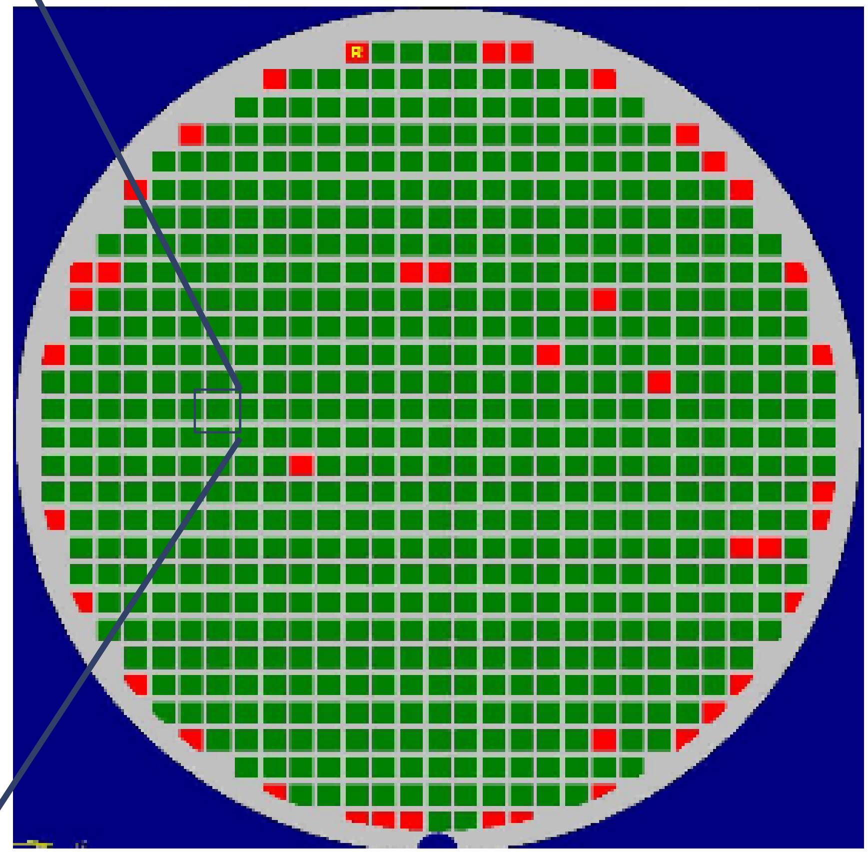




**No failure observed after 1000 cycle of thermal shock test**

# QUALITY CHECK OF LASER DUAL DAMASCENE RDL




**Low temperature polyimid (Fujifilm LTC 9320)**



# PROCESS COST COMPARISON

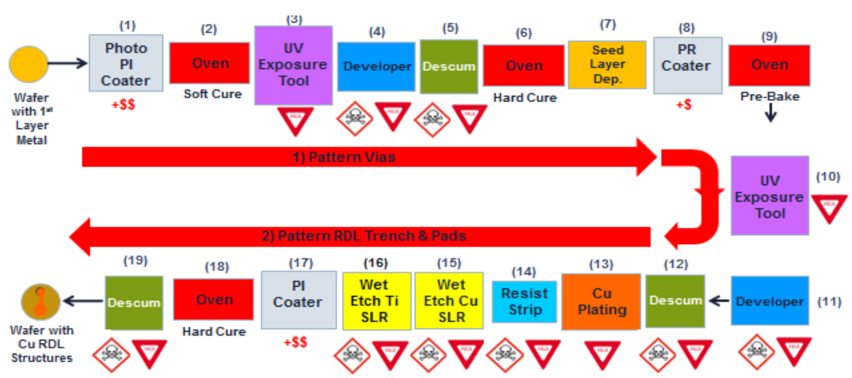
## 14x14mm package (10x10mm die), 10um via in 20um dielectric, 10/10um L/S RDL*

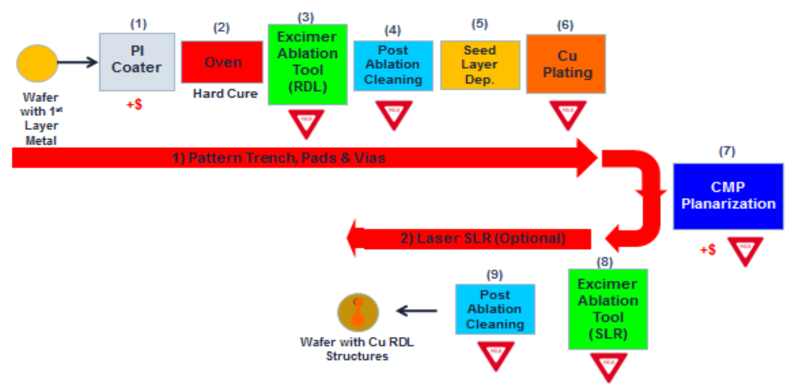
| | Photolithography Process | |
|---|---|---|
| | Cost/wafer ($USD) | % of Total |
| Capital | 44.64 | 60% |
| Labor | 1.37 | 2% |
| Material | 27.93 | 38% |
| **Total** | **73.93** | **100%** |

| | 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

# 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

### Next GEN Device Patterning Challenges

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

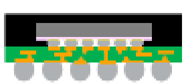
- Excimer Laser Ablation

SOLUTIONS

- Photolithography Limitations
- UV Lasers Limitations

BARRIERS

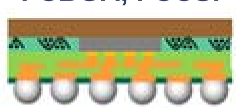
Cu Pillar, Micro Bump, Solder Bump



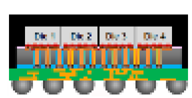
RDL, Integrated Passives


Fan-Out WLP

FCBGA, FCCSP



2.5D Interposer, 3DIC




SUSS MicroTec Photonic Systems, Inc.
220 Klug Circle
Corona, CA 92880-5409
USA