OVERVIEW OF OPTICAL LITHOGRAPHY AT LETI: CAPABILITIES AND ACHIEVEMENTS

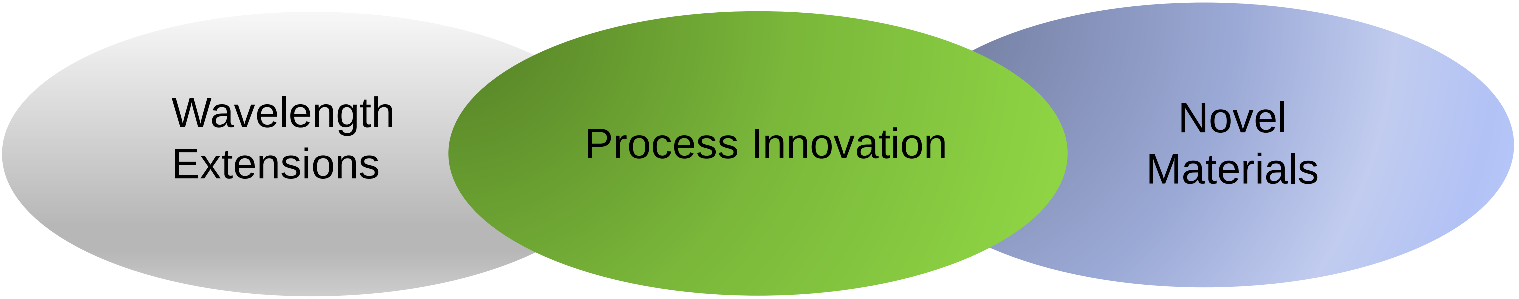
Leti litho workshop | ALLOUTI Nacima | 6 July 2018

OUTLINE

- **Overview of CEA-LETI 300mm Optical lithography capabilities**
- **300mm Optical lithography alternative capabilities & achievements**
- **Conclusion**

Overview of CEA-LETI 300mm Optical lithography capabilities

PATTERNING ADVANCES



- **Progress in lithography has been the result of many advances**
  - Better lenses, resists, chemical-mechanical polishing, resists, chemical-mechanical polishing (CMP) etc.

- **The largest impacts have been made by changes in wavelength**

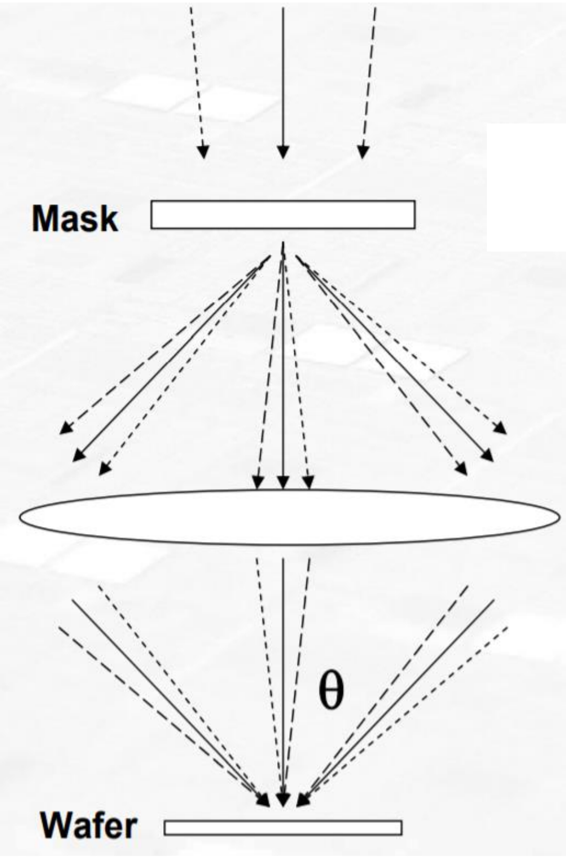
g-line → i-line → KrF → ArF → F_2

436 nm → 365 nm → 248 nm → 193 nm → 157 nm

1 µm ⟶ 360 nm

OPTICAL LITHOGRAPHY RESOLUTION

$$R = k\frac{\lambda}{NA}$$




Lord Rayleigh
(John Strutt)

Finer resolution can be achieved by:

1 – Shorter wavelength (436 nm… 365 nm …248 nm…193 nm…13.5 nm)

2 – Reduced process factor : k

- Improved masks (CD control, Phase Shift masks)
- Improved lenses (aberrations)
- Better photoresists
- Better process controls
- Resolution Enhancement Techniques (RET)

– Increased numerical aperture
Immersion with NA>1

3 – Alternative patterning process integrations:

- Double patterning /Etch trimming / DSA etc.
- Lithography Tool technology Mix and match

OPTICAL 300MM @ LETI

Size

1X Mask Aligner 365nm

TAKATORI Dry film Vaccum laminator

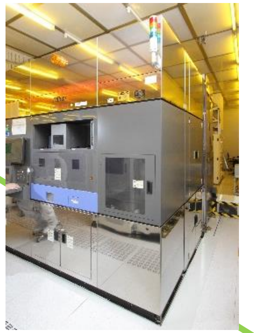
Suss ACS300 Track

3D Stepper 365nm

Cluster CANON FPA-5510iZ + TEL LITHIUS Track

300mm Leti Pilot Line

Scanner 193nm



Cluster Scanner ArF dry Nikon S307E (NA=0.85) + Sokudo RF3 Track

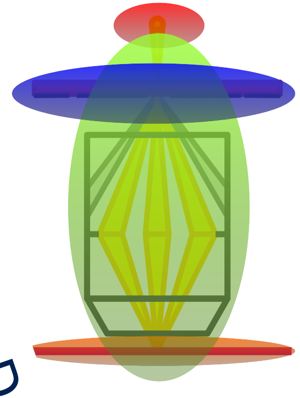
Immersion 193nm

Cluster Scanner NXT:1970Ci + Sokudo DUO DT3000 Track

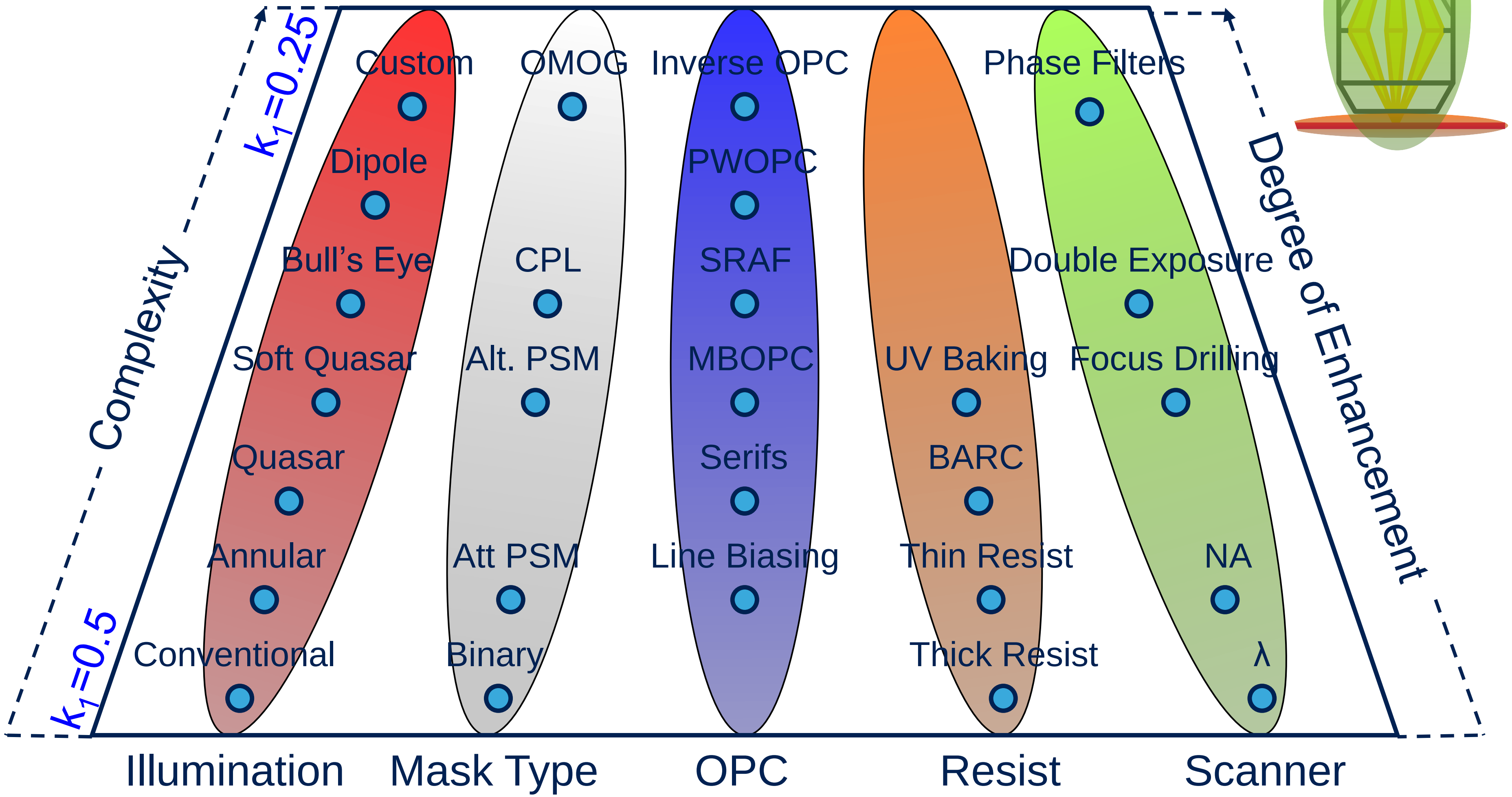
Performance

Optical Lithography resolution : Ways to reduce k_1

Existing Resolution Enhancement Techniques

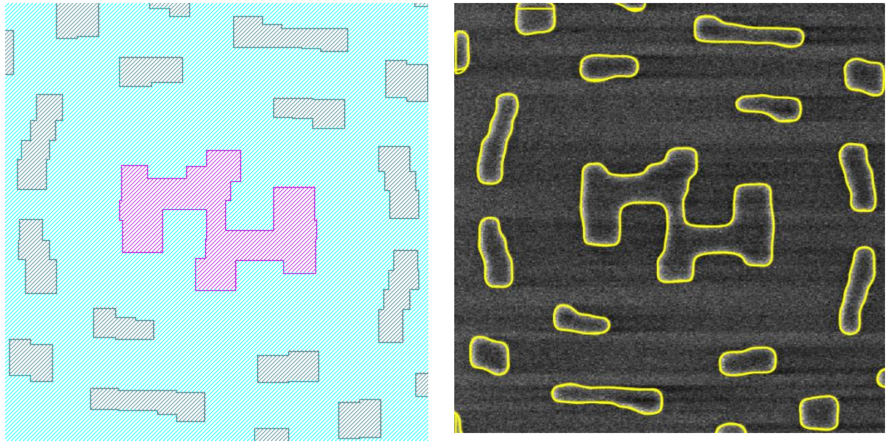


$CD = k_1 * \lambda/NA$



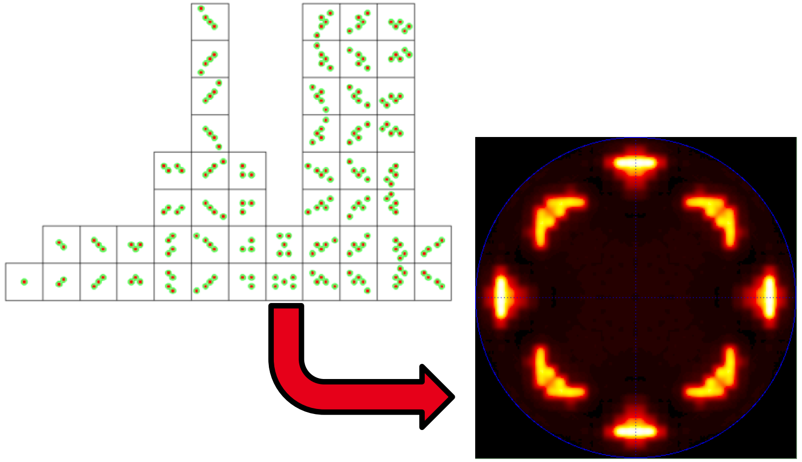
Optical Lithography resolution : reducing k_1 by mask data prep

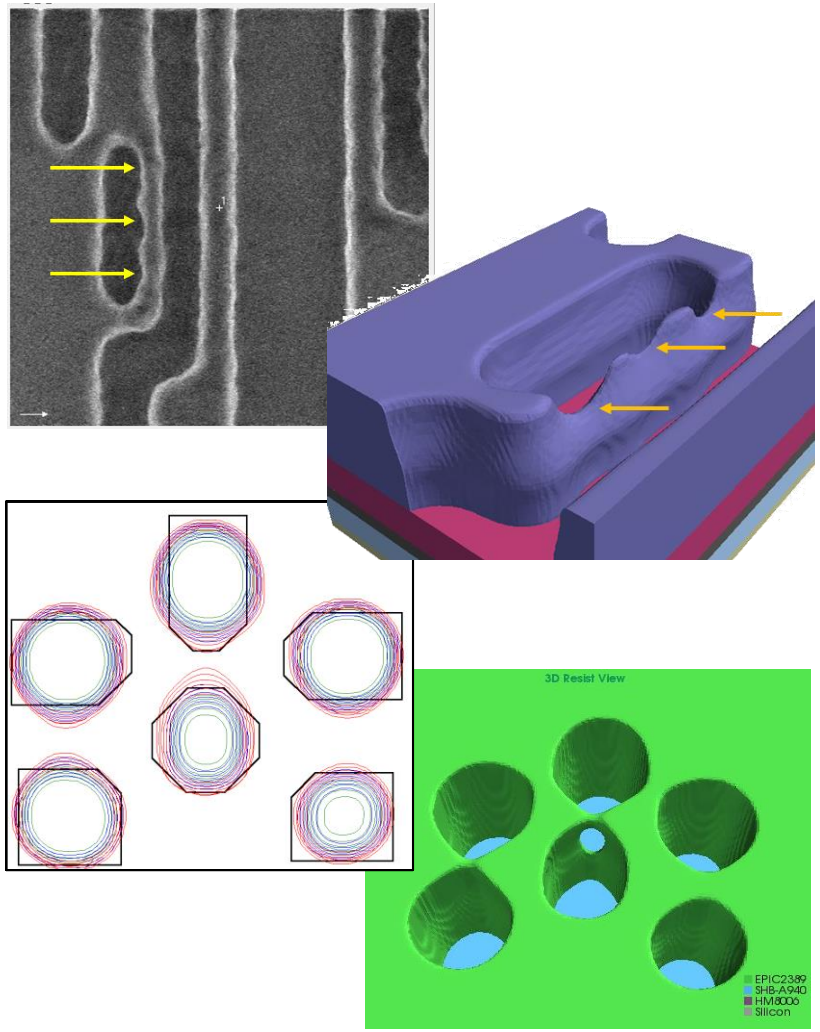
Leti dedicated Data-Prep Team



Advanced OPC, ILT, mask analysis

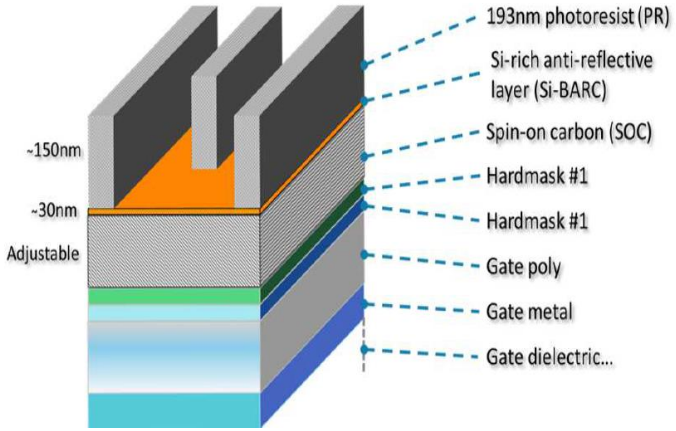
Source Mask co-Optimization

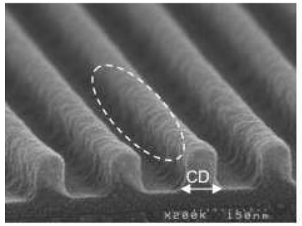


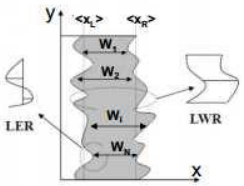


Hotspots failure prediction / analysis

OPTICAL 300MM LITHOGRAPHY RESOLUTION
MATERIAL BENCHMARKING & LWR IMPROVEMENT







- Line Width Roughness

$$LWR = 3\sigma_{CD} = 3\sqrt{\frac{1}{N}\sum_{i=1}^{N}(W_i - \langle W \rangle_N)^2}$$

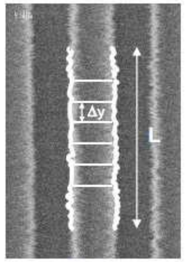
- Line Edge Roughness

$$LER_{Left} = 3\sigma_L = 3\sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_{L,i} - \langle x_L \rangle_N)^2}$$

Two method used for LWR:

1. Mean LWR measured on MEB CD KLA CG4000
2. Power Spectral Density method with roughness spectral measurement

CD-SEM line segments (N*)



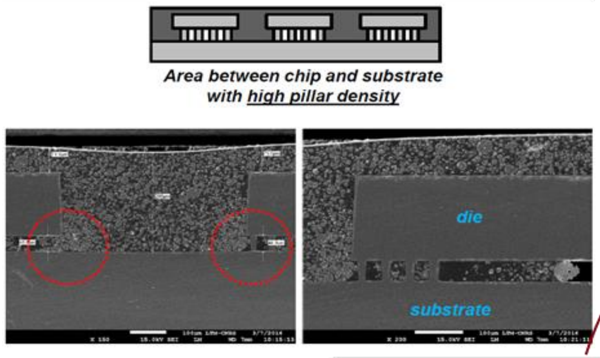
N*>200
L=2154nm; Δy=5.4nm

SOC + SiArc	Resist	motif	POST CD mean	POST LER (nm)	POST LWR (nm)	POST 3σ (nm)	POST ETCH CD mean	POST ETCH LER (nm)	POST ETCH LWR (nm)	POST ETCH 3σ (nm)
JSR HM8102 + ISX412	AR1682J	isolé	80	5,7	7,9	2	34	6	5	2
		dense	75	8,4	9	2	29	7	5,5	2
JSR HM8102 + ISX412	AIM9541N	isolé	85	5,4	7,3	2,6	35	6	4	3
		dense	75	7,6	8,1	2,3	23	6	4,8	2,9
JSR HM8102 + ShinEtsu SOC	AIM9541N	isolé		6,7	9,5	6,3		10	5,5	3,2
		dense		9,8	11,1	4,5		10	9,3	4
Brewer SoC110D + HM825	AIM9541N	isolé	86	4,5	6,1	2,5	36	6	3,7	3
		dense	77	7,5	7,6	3	25	6,8	4,2	2,8

193NM LITHOGRAPHY TRILAYER BENCHMARKING

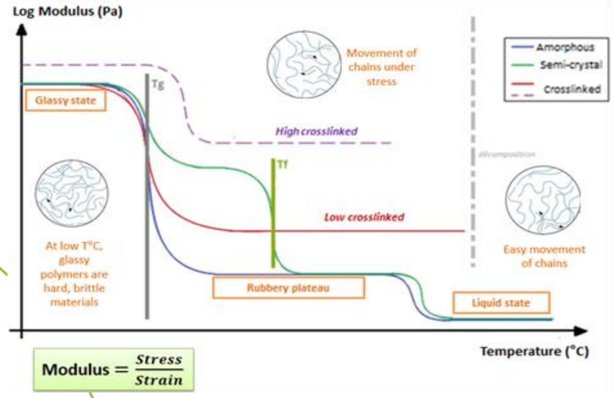
OPTICAL 300MM LITHOGRAPHY RESOLUTION MATERIAL CHARACTERISATION PLATFORM

More than 100 m² dedicated to characterization



Thermal analysis

ATG, DMA & DSC

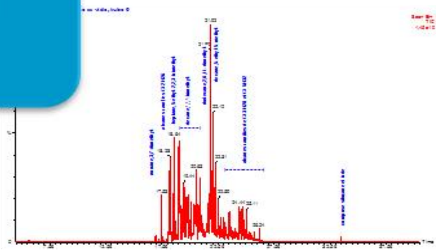


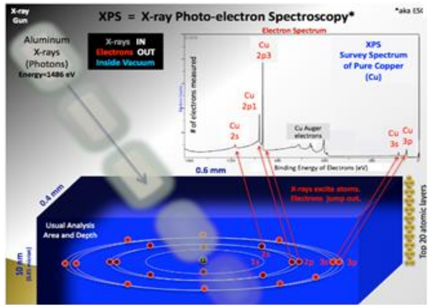
Morphological analysis

MEB, FIB, TEM

Resist outgassing

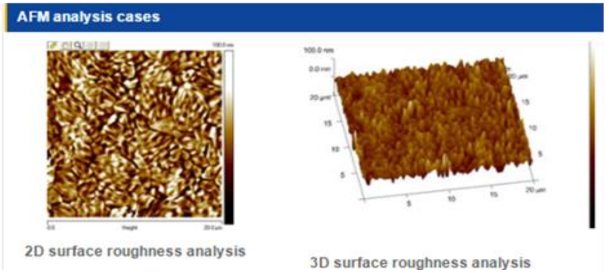
ATD GCMS





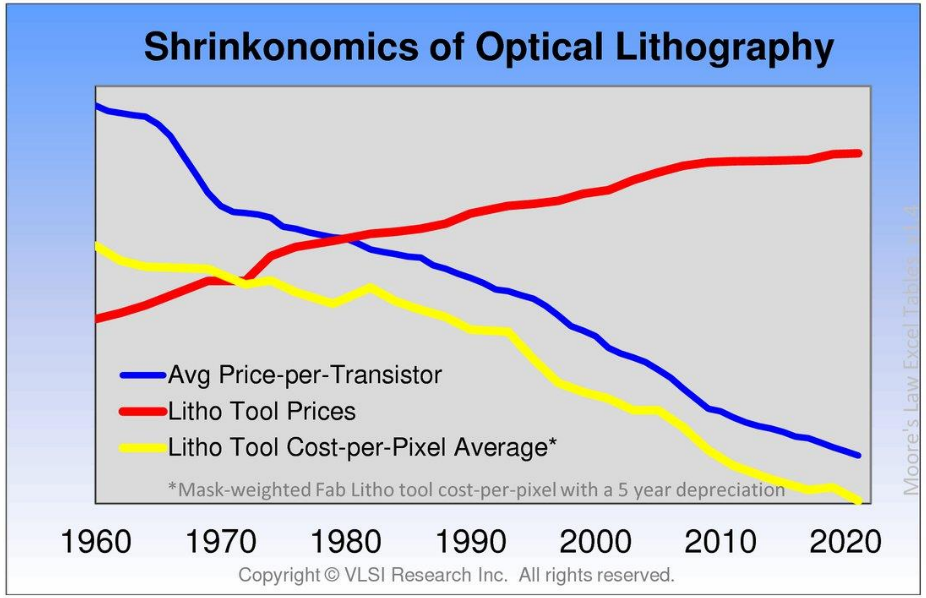
Atomic surface analysis

ICPMS, FTIR, XPS, AFM
Fluorescence X, XRD ..



OPTICAL LITHOGRAPHY FUTURE

- Introducing new lithographic technologies will be hard
  and expensive



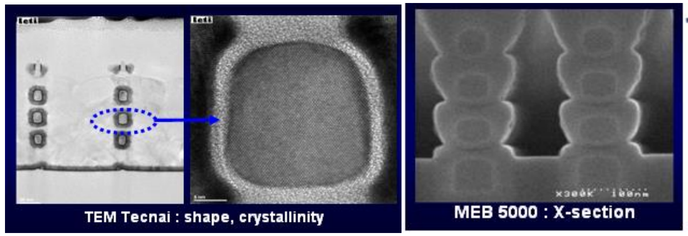
- The End of optical lithography is finally approaching…
  But not immediately!

- Alternatives lithography integrations may enable the semiconductor industry to continue to produce higher performance device for cheaper cost ?

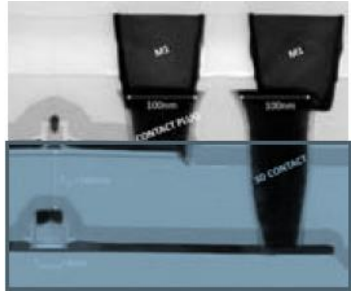
300 optical lithography alternative capabilities & achievements

OPTICAL LITHOGRAPHY KEY ACTIVITY

- **CMOS**
  - Focus on FDSOI for sub 28nm TN
  - Si nanowire for 10 nm TN (nano sheet T.ernst)
  - 3D stacked devices



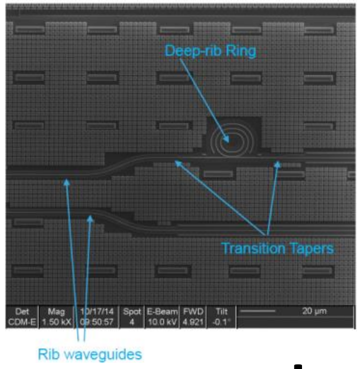
- **3D Integration**
  - Si interposer
  - High density TSV, TSV Mid/Last etc..



P.Batude: TEM cross section of 3DSI with 200nm contact and 3D contact pitch

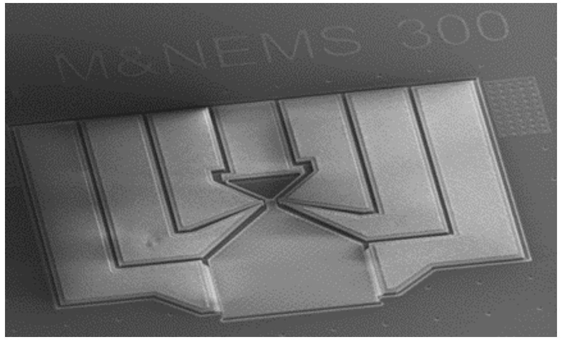
- **Memories**
  - Embedded non volatile memories
  - Focus on resistive memories (PCM, CBRAM, OXRAM and MRAM) for speed, consumption, reliability

- **Silicon Photonic**
  - Optical waveguide
  - Far Back End Optics



B.Szellag: Photonic guide

A.Berthelot: M&NEMS 300mm accelerometer



- **Microsystems and Advanced components**
  - MEMS, NEMS, actuator, RF components, Power devices

SPECIFIC 3D LITHOGRAPHY ACTIVITIES

Litho process
- RDL: CDmi
- Passivation
- Bump/µpilla
- TSV: CDmir
- UBM: resist
- Damascene

possibilities:
FAV/FAR, IR

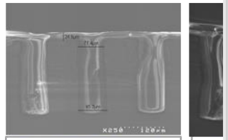
rect bonding

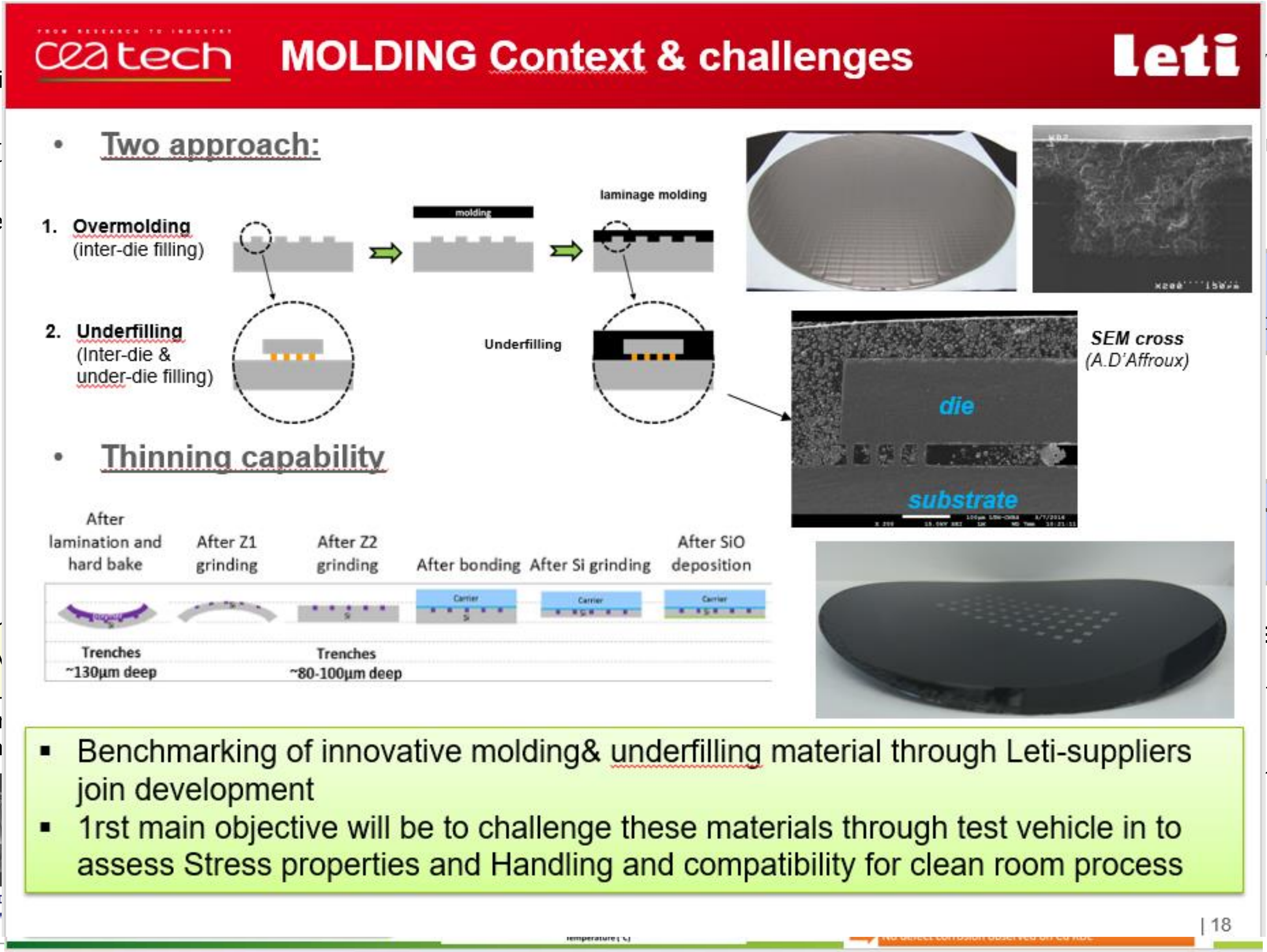
power »

ic

Polymer TS

- EPPL in 200m
- In 2016 300mn

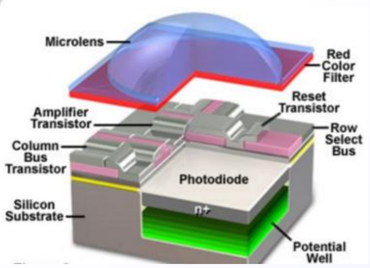




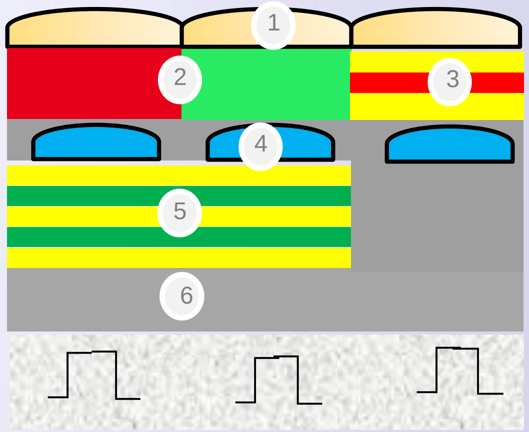
EDUCTION:

ties

LETI CMOS IMAGE SENSOR OFFER OVERVIEW

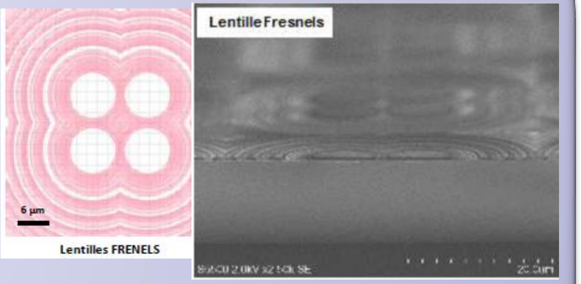


1. *Micro Lens*
2. *Colo Filters*
3. *IR BP Filters*
4. *Inner Micro Lens*
5. *IR CUT Filter*



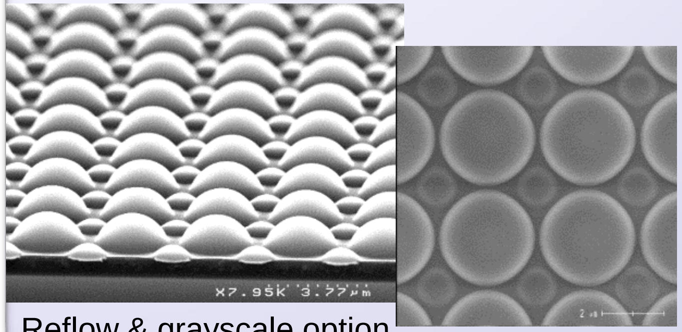
4. Inorganic Micro Lens

✓ Inorganic diffractive binary micro lens



1. Micro Lens

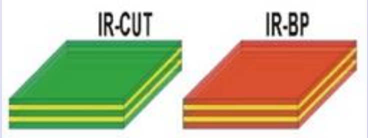
✓ Organic micro lens



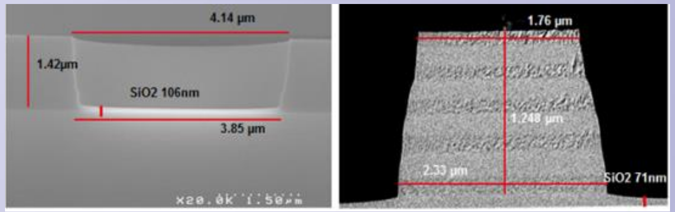
Reflow & grayscale option

3. IR BP Filters

✓ Litho Cluster CANON IRBP



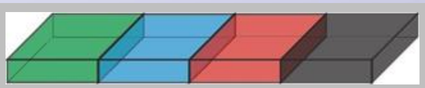
5. IR CUT Filters



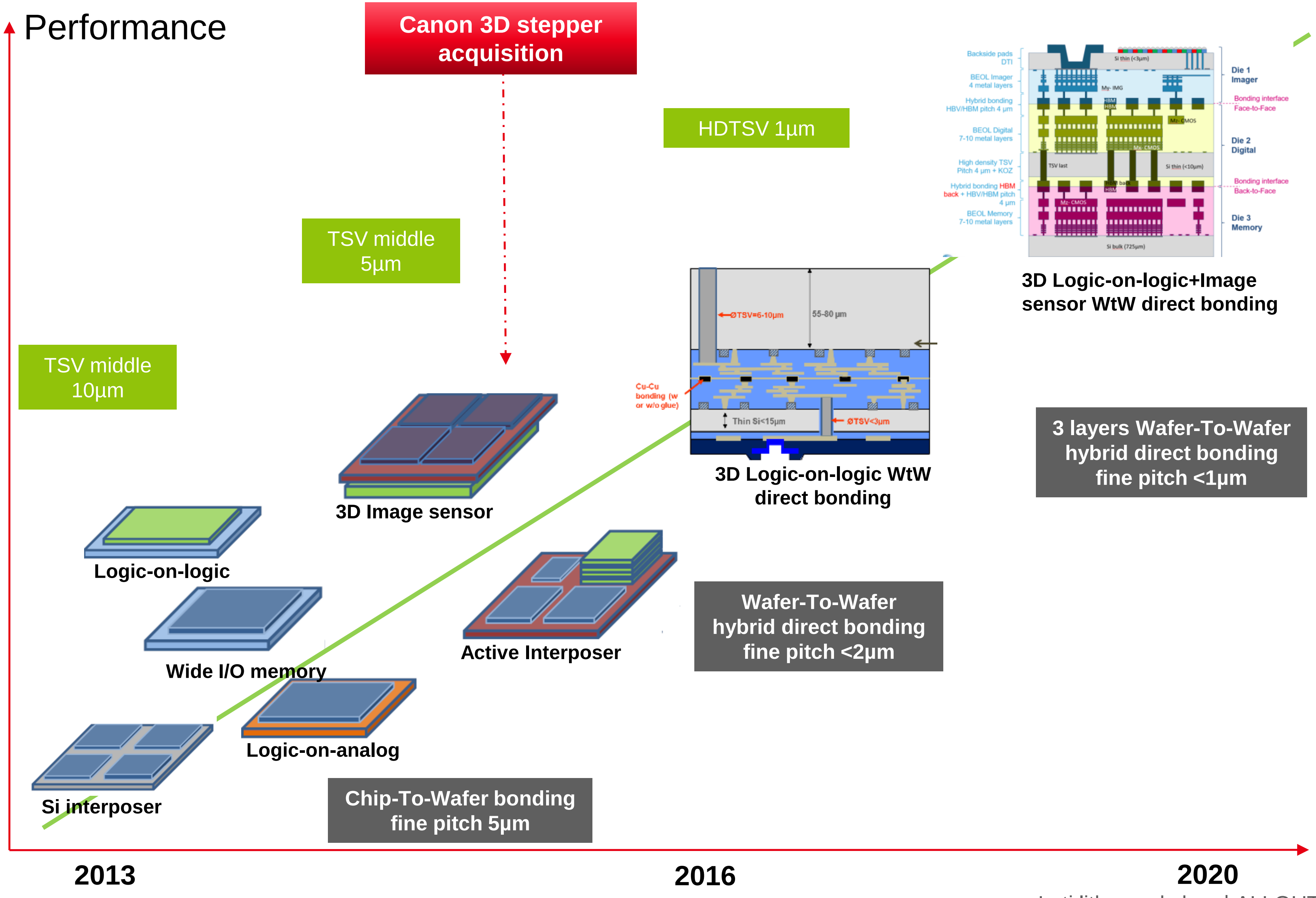
Post Etch MEB IRCUT filters cross-view with 7 consecutive filters

<u>On going</u>:

2 *Color Filters process in progress*



3D HIGH DENSITY LETI ROADMAP



Conclusions

LETI OPTICAL LITHOGRAPHY CAPABILITIES AND FUTURE

- Leti offer a large equipment capability, starting from 1X mask aligner to Arf scanner immersion

- Leti team expertise & strength to propose advanced patterning solutions
  - Data preparation
  - Material characterization
  - Innovation material evaluation
  - Close link with etch team

- Leti position focus
  - IS NOT on the main stream of advanced lithography
  - BUT on the development of industrial alternative patterning and disruptive solutions

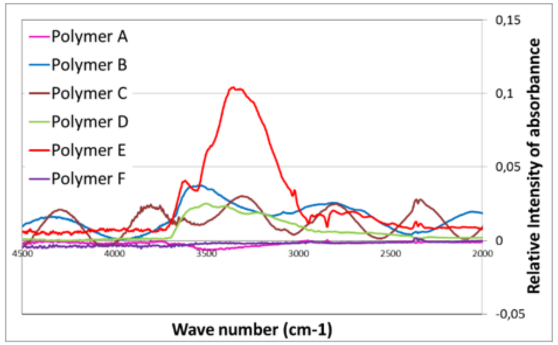
Thanks for your attention

PASSIVATION RESIST BENCHMARKING

- *More than 15 resist evaluated* following a specific characterization protocol
- *Five materials emerged*, including our reference (a fluoropolymer), covering a wide range of chemistry

	Ref	2015					2016							2017		
Properties	AL-X2010 (AGC)	WPR1021 (JSR)	PN0324D (TOK)	SiNR3170 (SE)	SiX81 (SE)	HD8930 (HD)	HD8940 (HD)	HD4104 (HD)	LTC-9305 (FFEM)	FB5610 (FFEM)	WPR-S395P (JSR)	HD8820 (HD)	ZC100-T (Zeon)	BL-301 (Asahi Kasei)	BL-401 (AsahiKasei)	WL-5510 (DowCorning)
Tone	Negative	Negative	Positive	Negative	Negative	Positive	Positive	Positive	Negative	Negative	Positive	Positive	Positive	Negative	Negative	Negative
Polymer type	Epoxy fluore	Phenol	Phenol	Siloxane	Siloxane	PBO	PBO	PI	PI	PI	Phenol	PBO	cyclic olefin polymer	PI	PI	Siloxane
Developer	PGMEA	TMAH	TMAH	IPA	TMAH	TMAH	TMAH	Cyclopentanone + PGMEA	Cyclopentanone + PGMEA	Cyclopentanone + PGMEA	TMAH	TMAH	PGMEA	Cyclopentanone + PGMEA	Cyclopentanone + PGMEA	IPA
Cure	190°C	200°C	180°C	180°C	180°C	200°C	200°C	375°C	200°C	350°C	200°C	320°C	190°C	200°C	200°C	250°C
Dielectric constant	2.65	3,5	3,5	2,6	3,1	3,1	3,1	3,4	3.25	2,98	3,5	2,94	2.9	3.3	3.3	3,2
CTE (ppm/°C)	60	54	49	180	217	60	60	35	38	50	65	55	51	65	65	236
Tg	230°C	210°C	190°C	<50°C	242°C	230°C	230	330	235°C	310	>250°C	270°C	200°C	200°C	200°C	<50°C
1% weight loss in air	354°C					250°C (5%)	250°C (5%)	430	255°C	470 (5%)	200%	400°C	290°C			
Elongation	20%	7%				100%	100%	45%	40%	4800%		25%	8%	50%	50%	
Tensile strength	90MPa	94MPa				170MPa	170Mpa	200	139MPa	120		114MPa	100MPa	130MPa	130MPa	
Young's Modulus	2,2GPa	2,5GPa	2,2GPa	0,09GPa	0,44Gpa	2.2GPa	2.2	3.3	3GPa	2.8	1,8GPa	2GPa	2.9GPa	3.5GPa	3.5GPa	0,16Gpa
Residual Stress	32					25	25	34		36			23	19	19	
Moisture uptake	0.2%	<10%	20%	<1%	6%	<9%	<9%	9,50%	<5%	<5%	15%	<3%	<2%	tbd	tbd	0.2%
ESH Compliant	Yes	Yes	Yes	Yes	Yes	No	NMP <0.3%,	No	Yes but drains compatibility?	Yes	Yes	No	Yes	No	Yes but drains compatibility?	Yes
Performance		Cu compatible	TMAH developable	TMAH developable	Low stress	TMAH developable	TMAH developable	Used in mass production in Osat's	NMP Free	TMAH developable	TMAH developable	Used in mass production in Osat's	Cu compatible	Used in mass production in Osat's	NMP Free	Low stress, chemical resistance
Drawbacks	Expensive, Production stop in 2018	Low chemical resistance moisture senstitive	Bad adhesion moisture senstitive	Stress behavior after aging ?	Low chemical resistance	NMP presence	Stress behavior at chip level	NMP presence	Solvent developable	low chemical resistance	Low chemical resistance moisture senstitive	NMP presence	Stress behavior at chip level	NMP presence	Solvent developable	Solvent developable

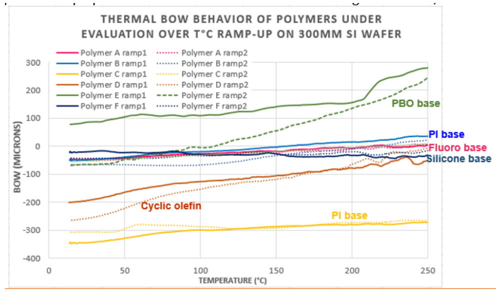
Moisture environment test resistance



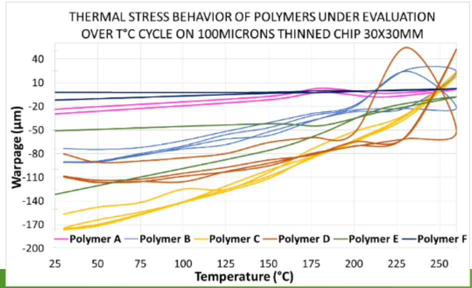
Normalized FTIR spectra focus on 3000 to 3800 cm^{-1} band to estimate water uptake of polymers after an exposition to uHAST

- Polymers A, F have absorbed no water
- Whereas the other polymers are more moisture-sensitive and seem less resistant against humidity environment

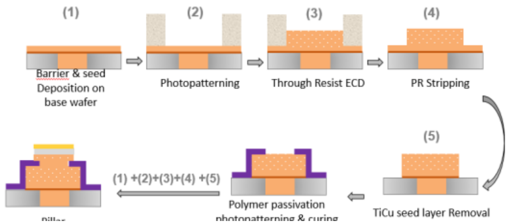
Stress measurement on 300mm wafers



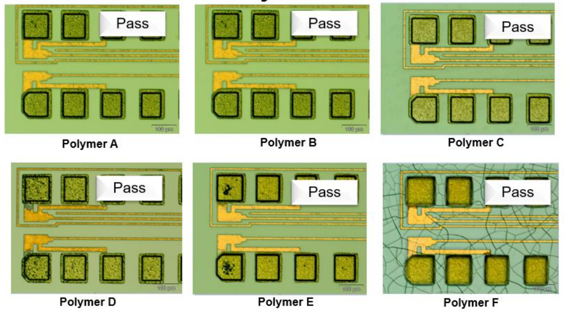
Stress measurement on thinned chip



Electrical test vehicle



uHAST reliability test results

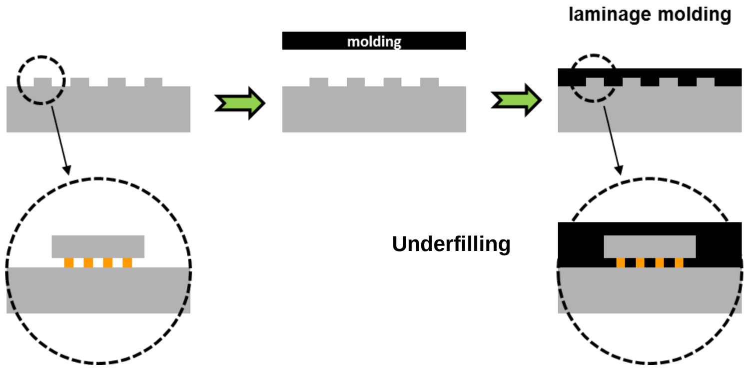


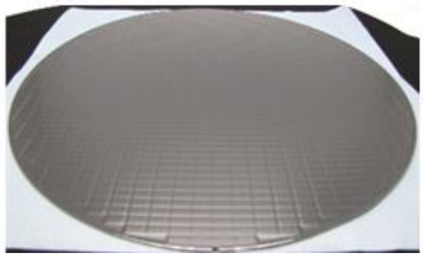
No defect corrosion observed on Cu RDL

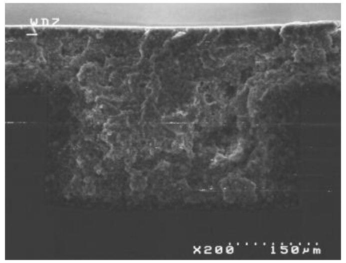
MOLDING Context & challenges

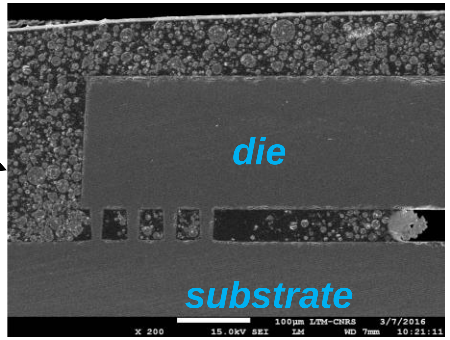
- **Two approach:**

1. **Overmolding**
   (inter-die filling)
2. **Underfilling**
   (Inter-die &
   under-die filling)



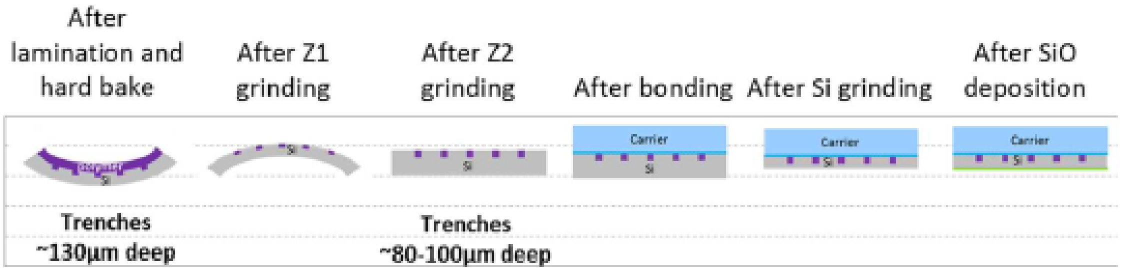






SEM cross
(A.D'Affroux)

- **Thinning capability**



- Benchmarking of innovative molding& underfilling material through Leti-suppliers join development
- 1rst main objective will be to challenge these materials through test vehicle in to assess Stress properties and Handling and compatibility for clean room process