OVERVIEW OF OPTICAL LITHOGRAPHY AT LETI: CAPABILITIES AND ACHIEVEMENTS

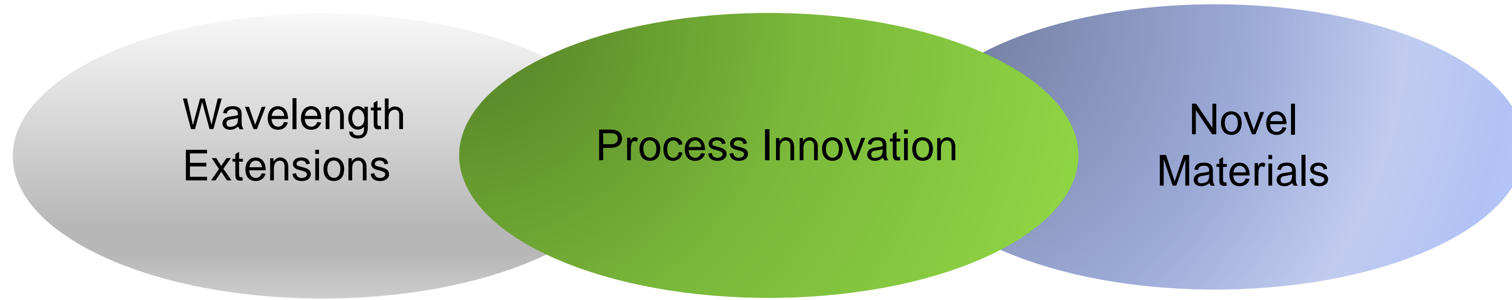
Leti litho workshop | ALLOUTI Nacima | 28 February 2019

OUTLINE

- **Overview of CEA-LETI lithography capabilities**
- **3D Lithography alternative & achievements**
- **CMOS Image sensor & achievements**
- **Conclusion**

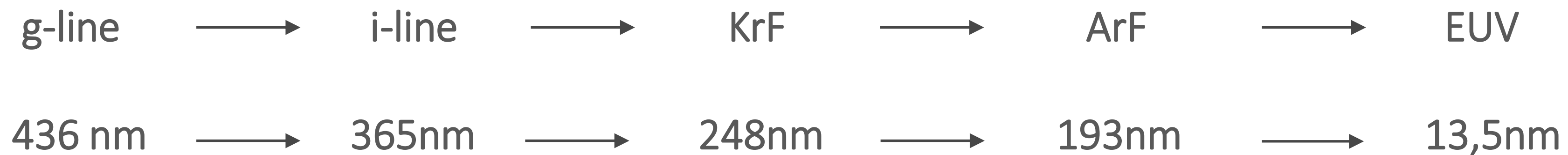
Overview of CEA-LETI lithography capabilities

PATTERNING ADVANCES

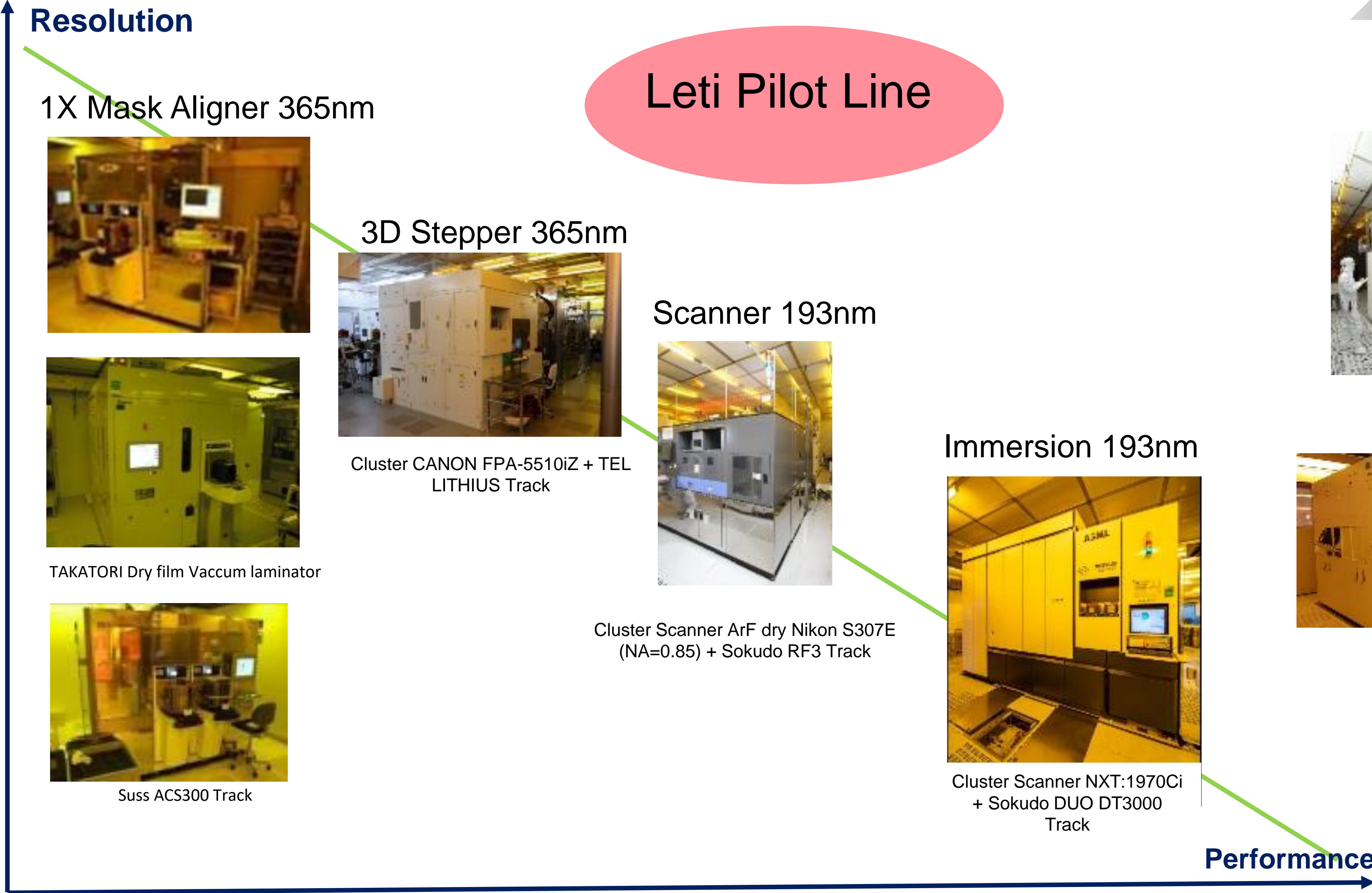


- **Progress in lithography has been the result of many advances**
  - Better lenses, resists, chemical-mechanical polishing, resists, chemical-mechanical polishing (CMP) etc.

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



LITHOGRAPHY EQUIPMENT CAPABILITIES



LITHOGRAPHY RESOLUTION MATERIAL CHARACTERISATION PLATFORM

More than 100 m² dedicated to characterization

Thermal analysis
ATG, DMA & DSC

Resist outgassing
ATD GCMS

Atomic surface analysis
ICPMS, FTIR, XPS, AFM
Fluorescence X, XRD ..

Morphological analysis
MEB, FIB, TEM

Area between chip and substrate with high pillar density

die
substrate

Log Modulus (Pa)
Glassy state
High crosslinked
Low crosslinked
Rubbery plateau
Liquid state
Amorphous
Semi-crystal
Crosslinked
Temperature (°C)

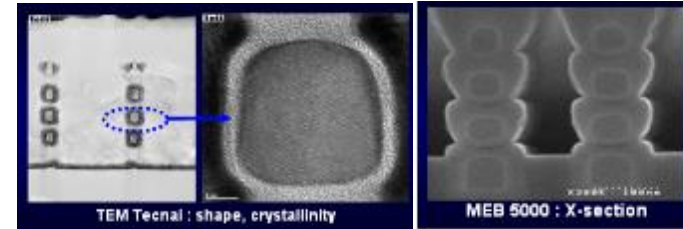
$$\text{Modulus} = \frac{Stress}{Strain}$$

XPS = X-ray Photo-electron Spectroscopy*

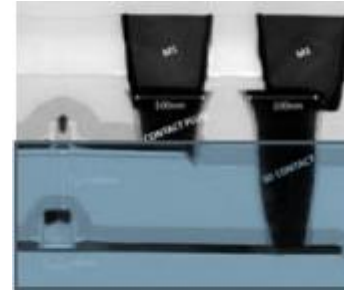
AFM analysis cases
2D surface roughness analysis
3D surface roughness analysis

OPTICAL LITHOGRAPHY KEY ACTIVITIES

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



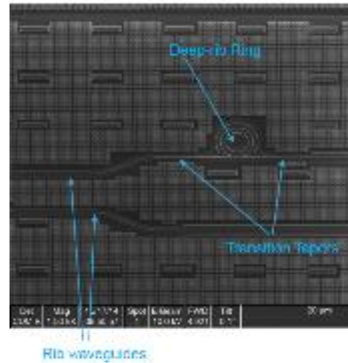
- **3D Integration**
  - Si interposer
  - High density TSV, TSV Mid/Last etc..



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

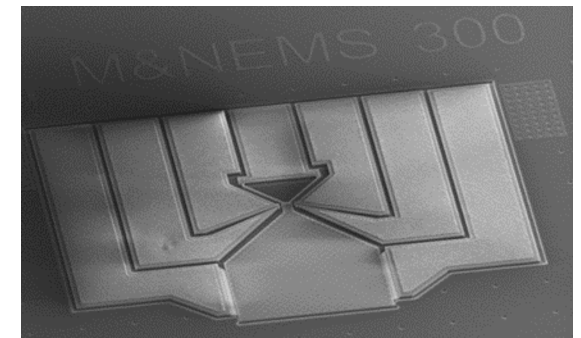
- **Memories**
  - Embedded non volatile memories
  - Focus on resistive memories (PCM, CBRAM, OXRAM and MRAM) for speed, consumption, reliability

- **Optronic**
  - Silicon Photonic
  - CMOS image sensor



B.Szellag: Photonic guide

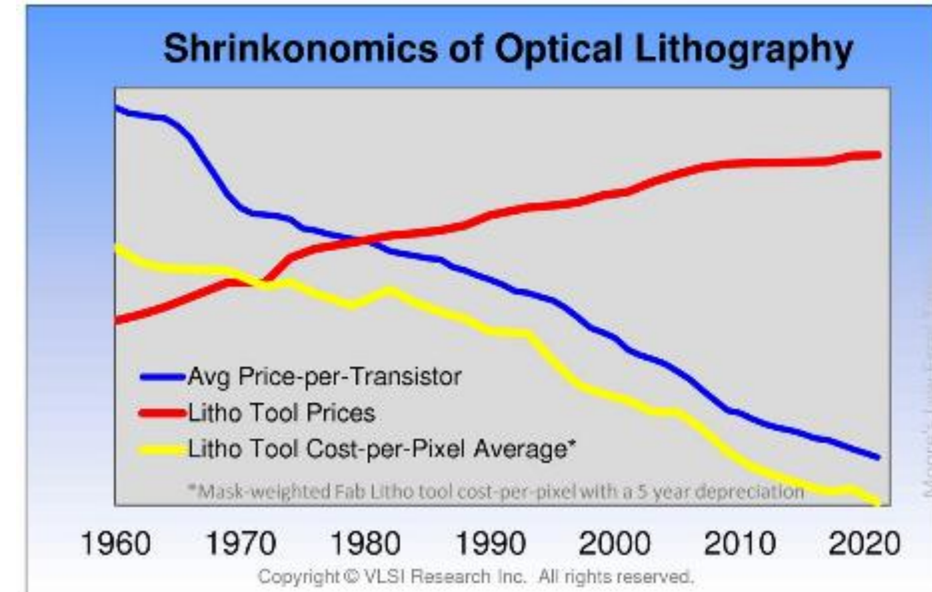
A.Berthelot: M&NEMS 300mm accelerometer



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

OPTICAL LITHOGRAPHY FUTURE

- Introducing new lithographic technologies will be hard and expensive



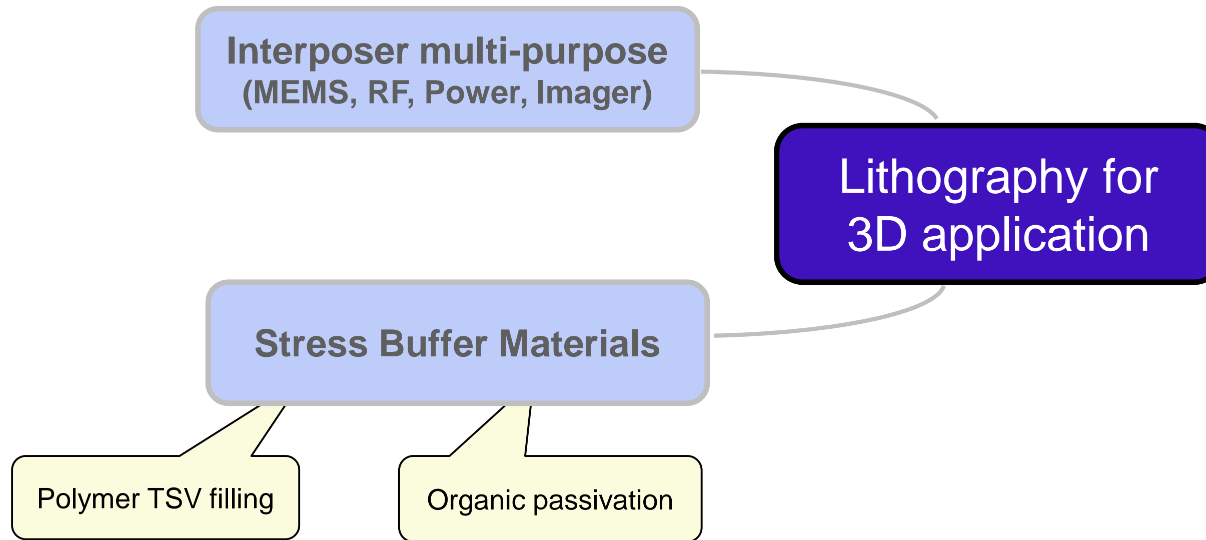
- The End of optical lithography is finally approaching… But not immediately!

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

leti
cea tech

3D lithography alternatives activities & achievements

3D LITHOGRAPHY ALTERNATIVES ACTIVITIES



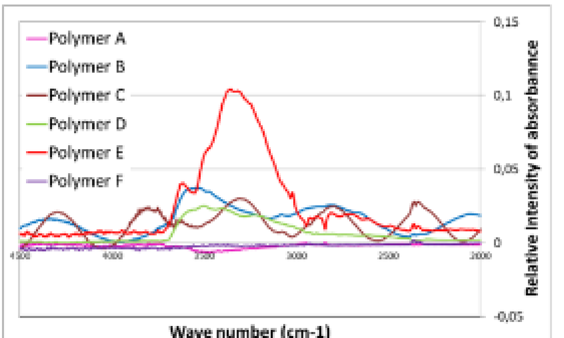
PASSIVATION RESIST BENCHMARKING

- *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				
Properties	AL-X2010 (AGC)	WPR1021 (JSR)	PN0324D (TOK)	SiNR3170 (SE)	SiX81 (SE)	HD8930 (HD)
Tone	Negative	Negative	Positive	Negative	Negative	Positive
Polymer type	Epoxy fluore	Phenol	Phenol	Siloxane	Siloxane	PBO
Developer	PGMEA	TMAH	TMAH	IPA	TMAH	TMAH
Cure	190°C	200°C	180°C	180°C	180°C	200°C
Dielectric constant	2.65	3,5	3,5	2,6	3,1	3,1
CTE (ppm/°C)	60	54	49	180	217	60
Tg	230°C	210°C	190°C	<50°C	242°C	230°C
1% weight loss in air	354°C					250°C (5%)
Elongation	20%	7%				100%
Tensile strength	90MPa	94MPa				170MPa
Young's Modulus	2,2GPa	2,5GPa	2,2GPa	0,09GPa	0,44Gpa	2.2GPa
Residual Stress	32					25
Moisture uptake	0.2%	<10%	20%	<1%	6%	<9%
ESH Compliant	Yes	Yes	Yes	Yes	Yes	No
Performance		Cu compatible	TMAH developable	TMAH developable	Low stress	TMAH developable
Drawbacks	Expensive, Production stop in 2018	Low chemical resistance moisture senstitive	Bad adhesion moisture senstitive	Stress behavior after aging ?	Low chemical resistance	NMP presence

	2016							2017		
Properties	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	Positive	Positive	Negative	Negative	Positive	Positive	Positive	Negative	Negative	Negative
Polymer type	PBO	PI	PI	PI	Phenol	PBO	cyclic olefin polymer	PI	PI	Siloxane
Developer	TMAH	Cyclopentanone + PGMEA	Cyclopentanone + PGMEA	Cyclopentanone + PGMEA	TMAH	TMAH	PGMEA	Cyclopentanone + PGMEA	Cyclopentanone + PGMEA	IPA
Cure	200°C	375°C	200°C	350°C	200°C	320°C	190°C	200°C	200°C	250°C
Dielectric constant	3,1	3,4	3.25	2,98	3,5	2,94	2.9	3.3	3.3	3,2
CTE (ppm/°C)	60	35	38	50	65	55	51	65	65	236
Tg	230	330	235°C	310	>250°C	270°C	200°C	200°C	200°C	<50°C
1% weight loss in air	250°C (5%)	430	255°C	470 (5%)	200%	400°C	290°C			
Elongation	100%	45%	40%	4800%		25%	8%	50%	50%	
Tensile strength	170Mpa	200	139MPa	120		114MPa	100MPa	130MPa	130MPa	
Young's Modulus	2.2	3.3	3GPa	2.8	1,8GPa	2GPa	2.9GPa	3.5GPa	3.5GPa	0,16Gpa
Residual Stress	25	34		36			23	19	19	
Moisture uptake	<9%	9,50%	<5%	<5%	15%	<3%	<2%	tbd	tbd	0.2%
ESH Compliant	NMP <0.3%,	No	Yes but drains compatibility?	Yes	Yes	No	Yes	No	Yes but drains compatibility?	Yes
Performance	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	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

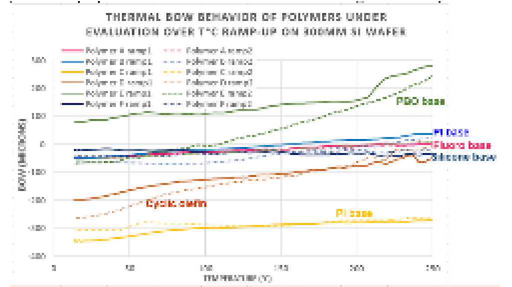
Moisture environment test resistance



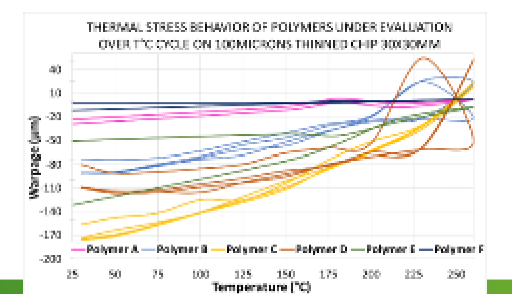
Normalized FTIR spectra focus on 3000 to 3800 cm⁻¹ band to estimate water uptake of polymers after an exposition to uHAST

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

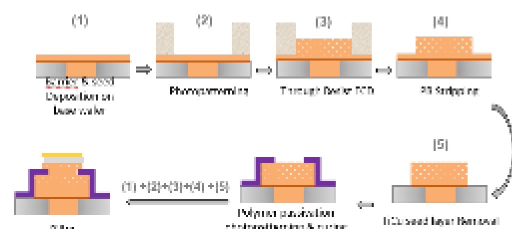
Stress measurement on 300mm wafers



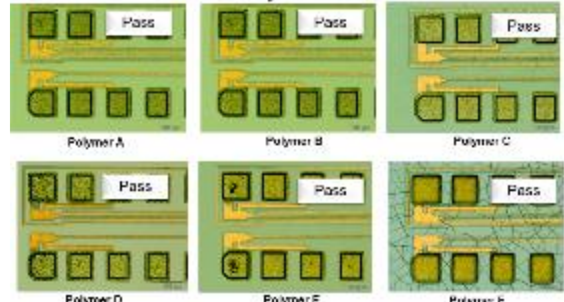
Stress measurement on thinned chip



Electrical test vehicle

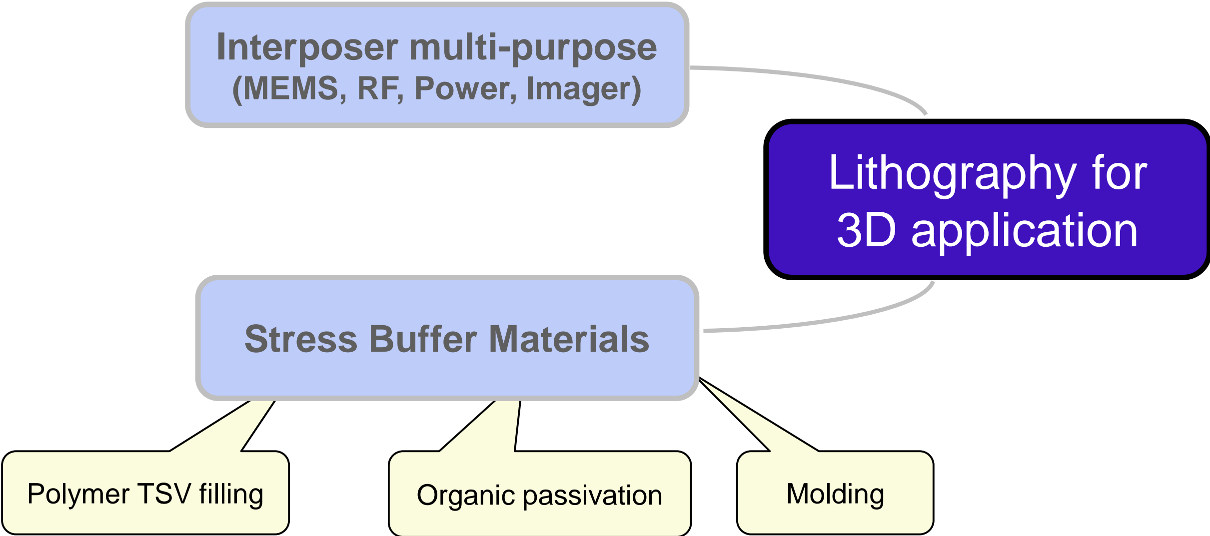


uHAST reliability test results



No defect co... observed on Cu RDL

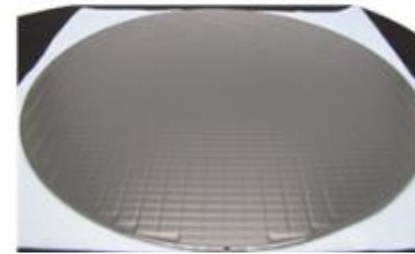
3D LITHOGRAPHY ALTERNATIVES ACTIVITIES

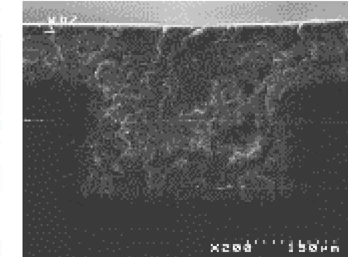


MOLDING material interest & challenges

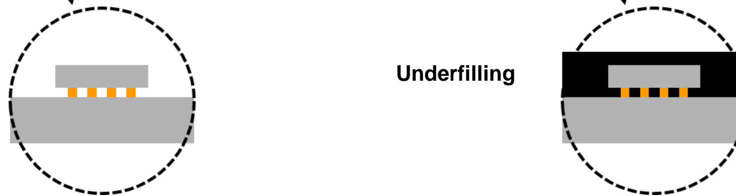
- **Two approach:**

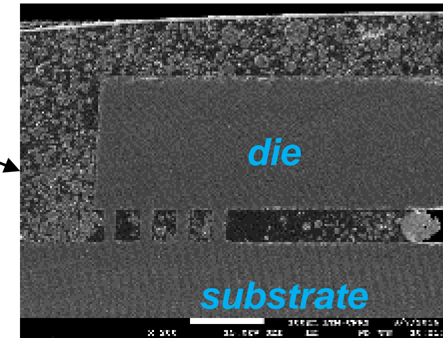
1. **Overmolding**
   (inter-die filling)





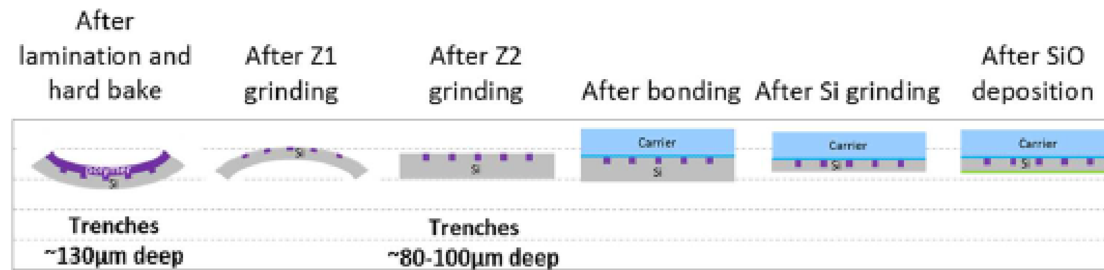
2. **Underfilling**
   (Inter-die &
   under-die filling)





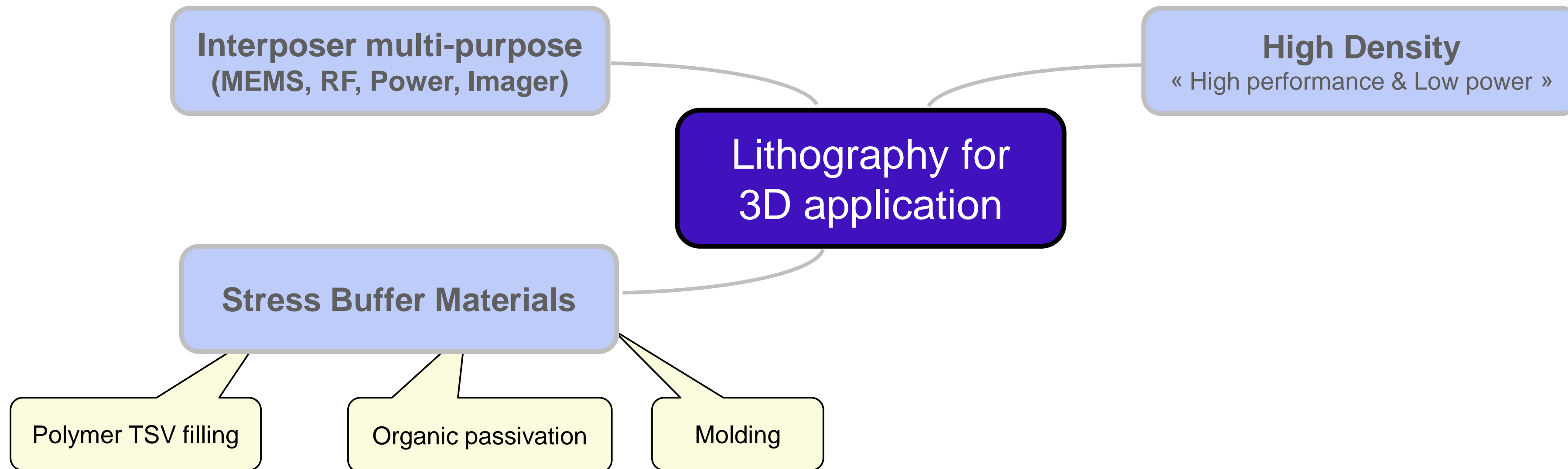
SEM cross
(A.D'Affroux)

- **Thinning capability**

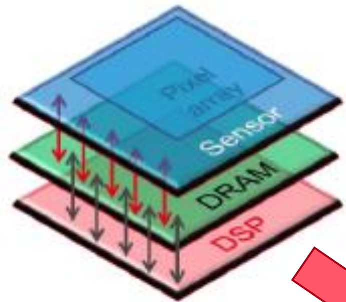


- Benchmarking of innovative molding& underfilling material through Leti-suppliers join development
- 1rst main objective will be to challenge these materials through test vehicle in to assess Stress properties and Handling and compatibility for clean room process

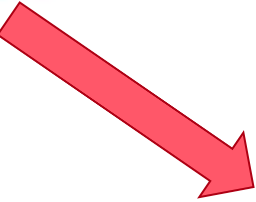
3D LITHOGRAPHY ALTERNATIVES ACTIVITIES



Lithography for High density device



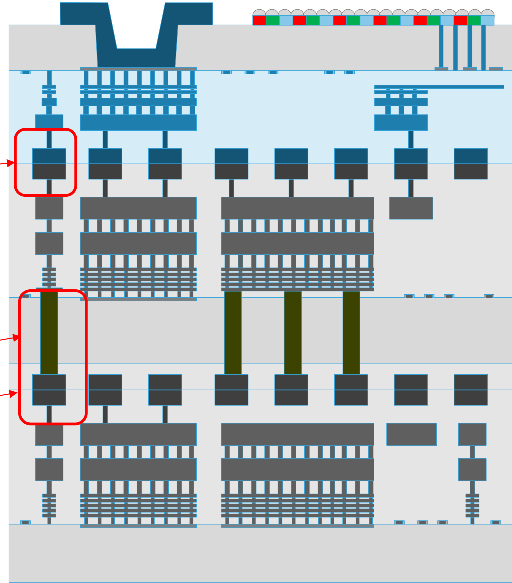
3 couches -Sony
(ISSCC'17)



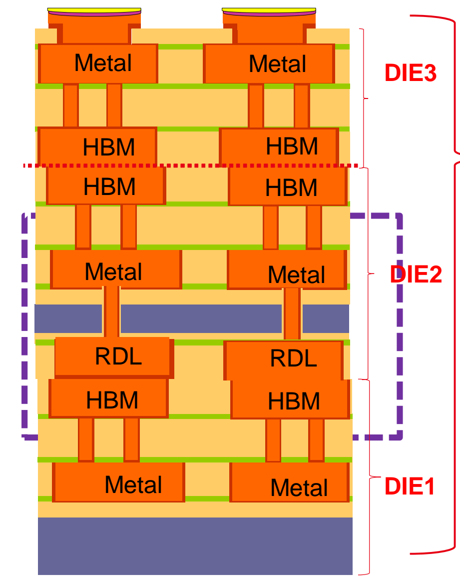
WtW bonding
interface pitch <4µm

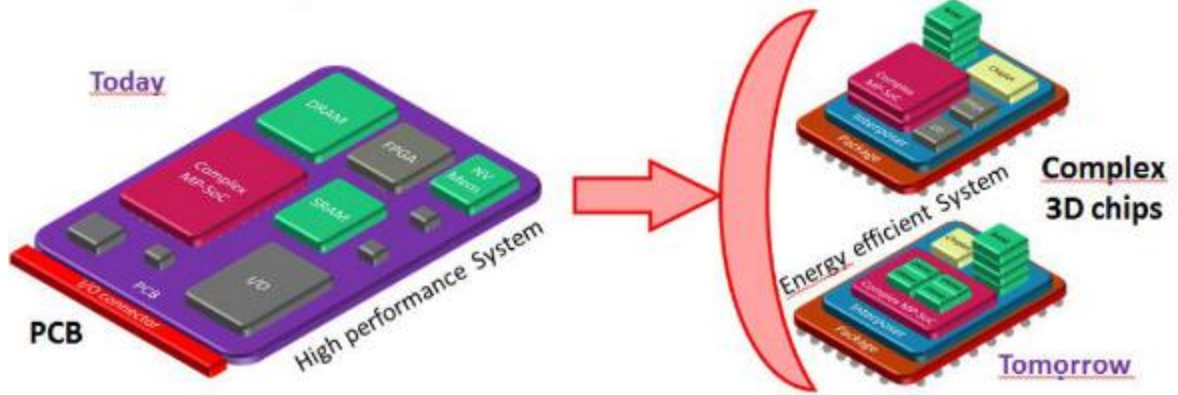
High Density TSV
pitch< 4µm

WtW bonding
interface pitch <4µm



TSV HD
&
Face to Back Bonding



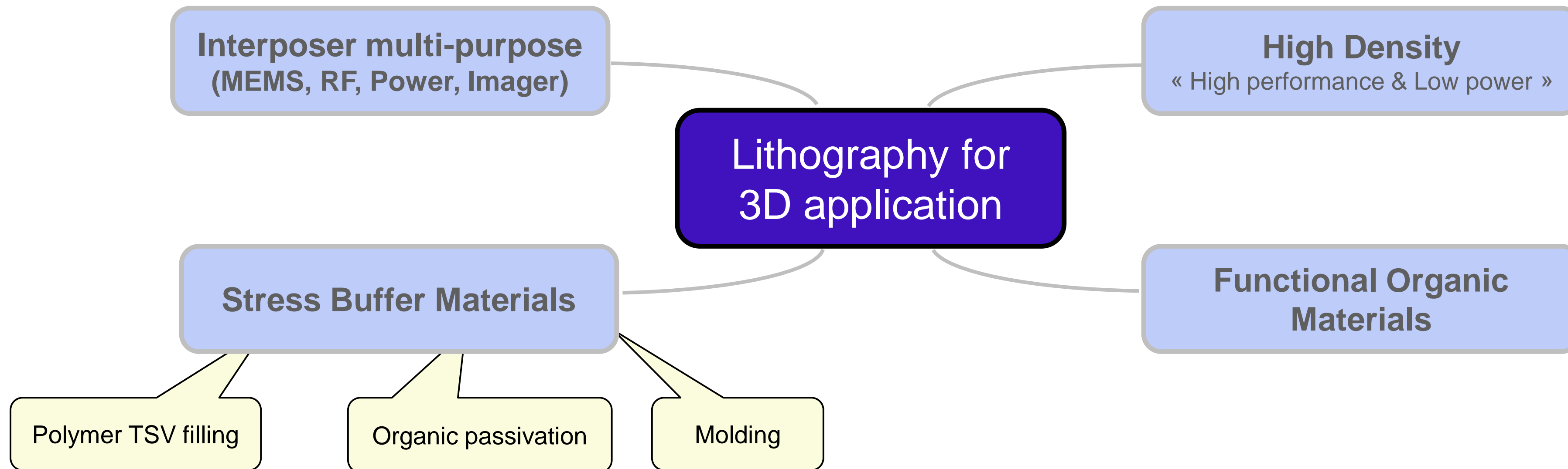


Chalenge IR Alignent with Iline Stepper CANON for TSV HD STEP
Overlay < 500nm

P.Coudrain : *Active interposer technology for chiplet-based advanced 3D system architectures, proceeding ECTC 2019*

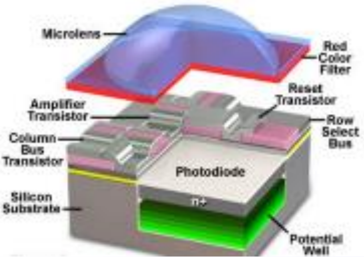
3-layer technological demonstrator for photonics, Image Sensor, Memory-On-Logic, 'CoolCube'…

3D LITHOGRAPHY ALTERNATIVES ACTIVITIES

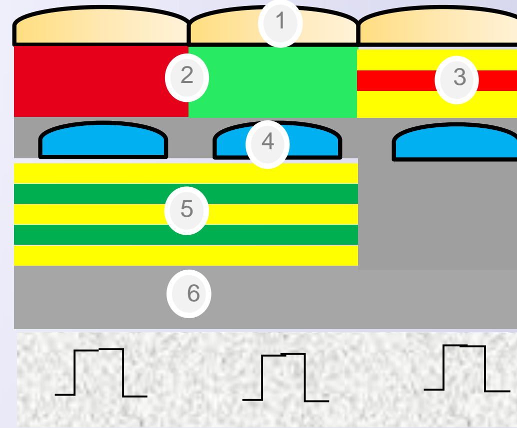


CMOS Image sensor & achievements

LETI CMOS IMAGE SENSOR OFFER OVERVIEW

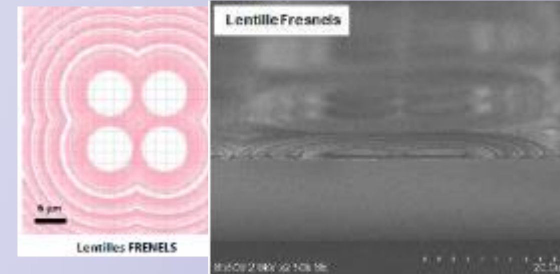


1. *Micro Lens*
2. *Colo Filters*
3. *IR BP Filters*
4. *Inner Micro Lens*
5. *IR CUT Filter*



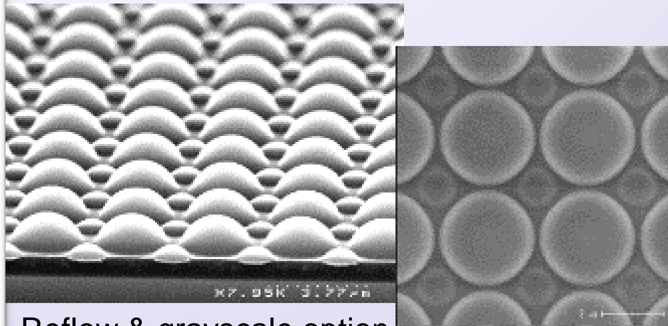
4. Inorganic Micro Lens

- ✓ Inorganic diffractive binary micro lens



1. Micro Lens

- ✓ Organic micro lens

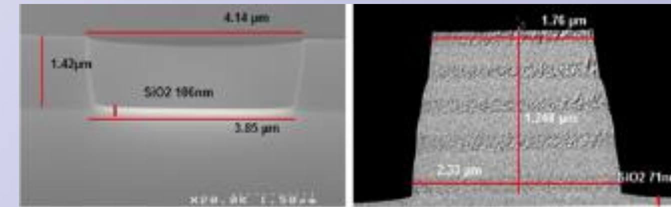


Reflow & grayscale option

3. IR BP Filters

- ✓ Litho Cluster CANON IRBP

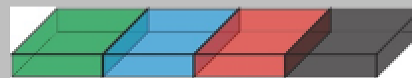
5. IR CUT Filters



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

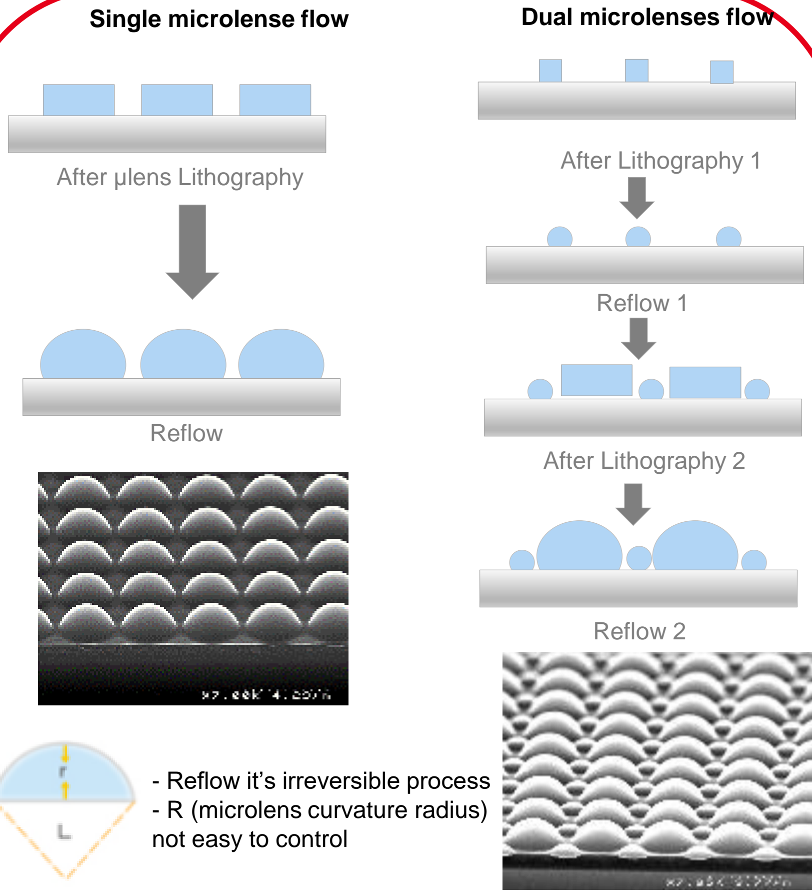
__On going__:

2 Color Filters process in progress



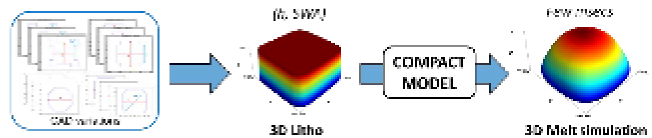
MICRO LENS PATTERNING – INTEREST OF GRAYSCALE

(1) Micro Lens with reflow

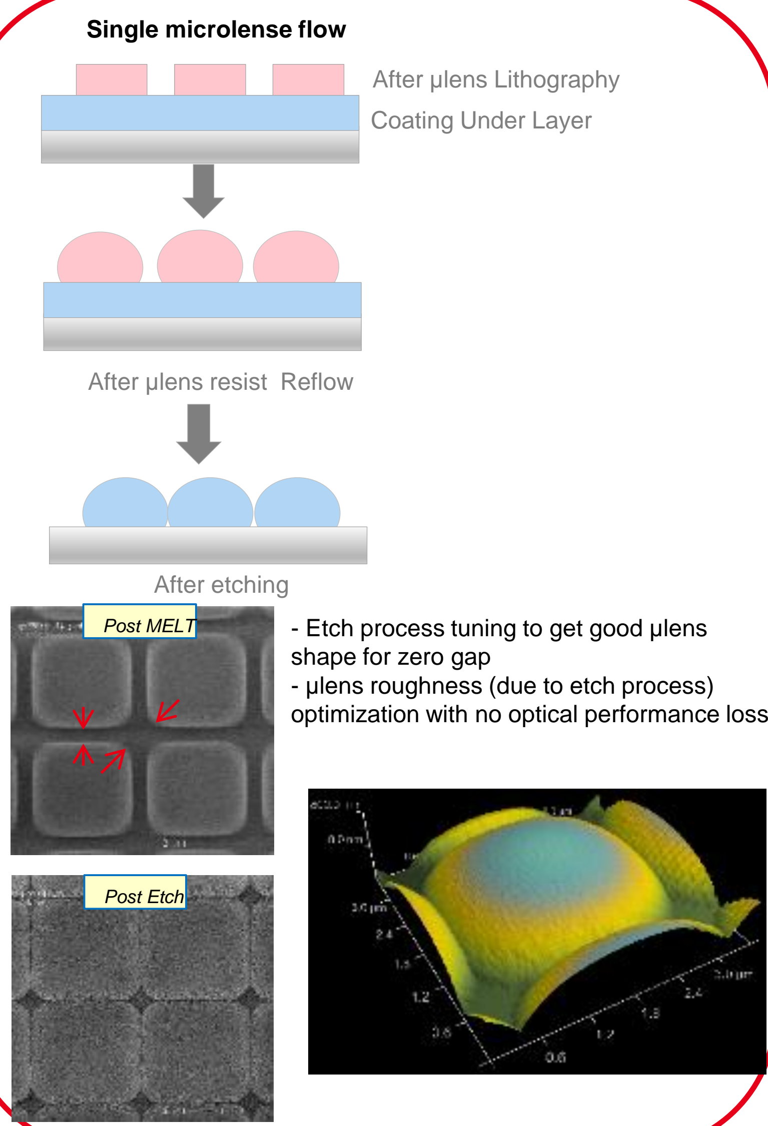


- Reflow it's irreversible process
- R (microlens curvature radius) not easy to control

- Reflow compact model with some limitations (Cf. SPIE 2019 Paper No.10962-16)

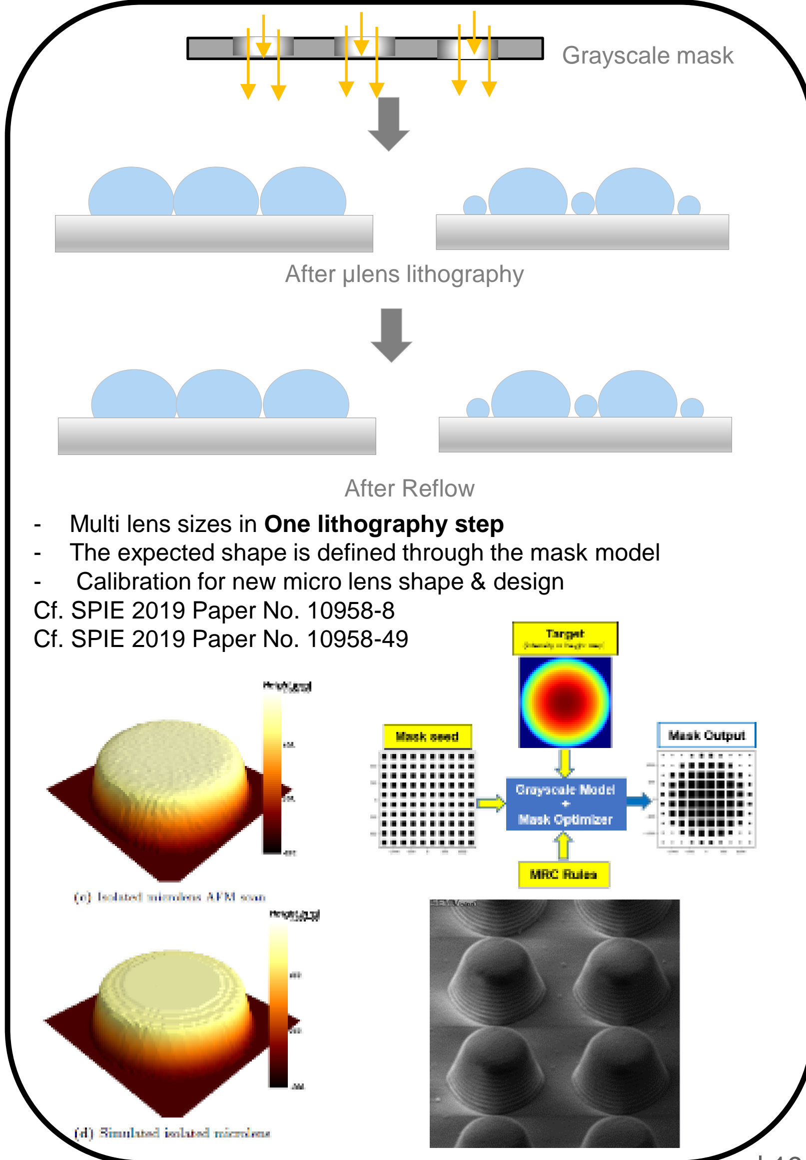


(2) Micro Lens with Etching



- Etch process tuning to get good µlens shape for zero gap
- µlens roughness (due to etch process) optimization with no optical performance loss

(3) Micro Lens with Grayscale

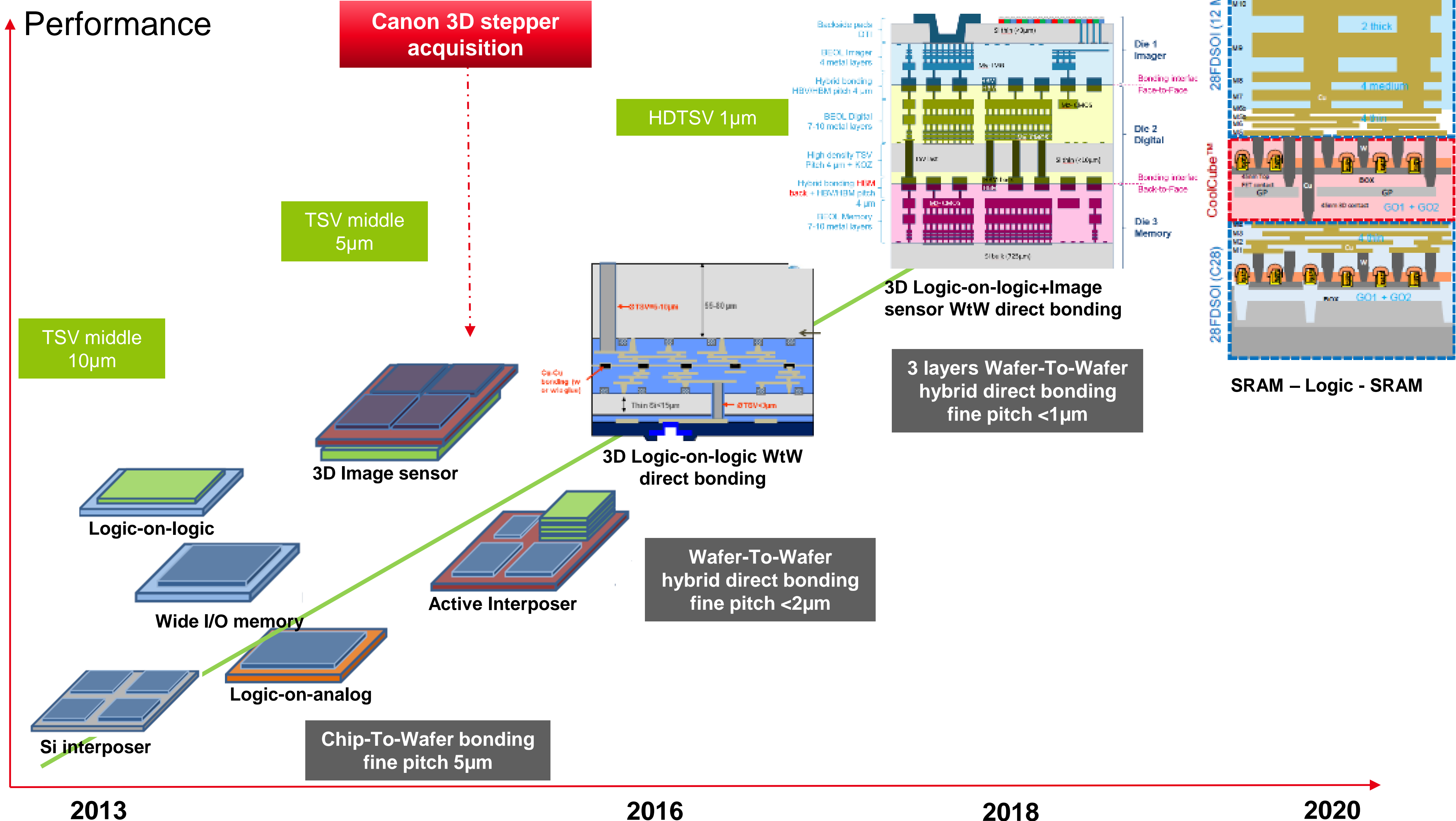


- Multi lens sizes in **One lithography step**
- The expected shape is defined through the mask model
- Calibration for new micro lens shape & design

Cf. SPIE 2019 Paper No. 10958-8
Cf. SPIE 2019 Paper No. 10958-49

Conclusions

LITHOGRAPHY DEVELOPMENT FOR HIGH DYNAMIC DEVICE ROADMAP



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