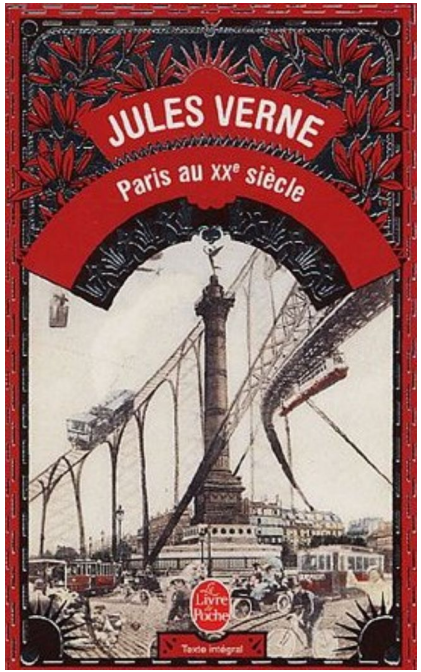


Metrology for scaling towards 2030

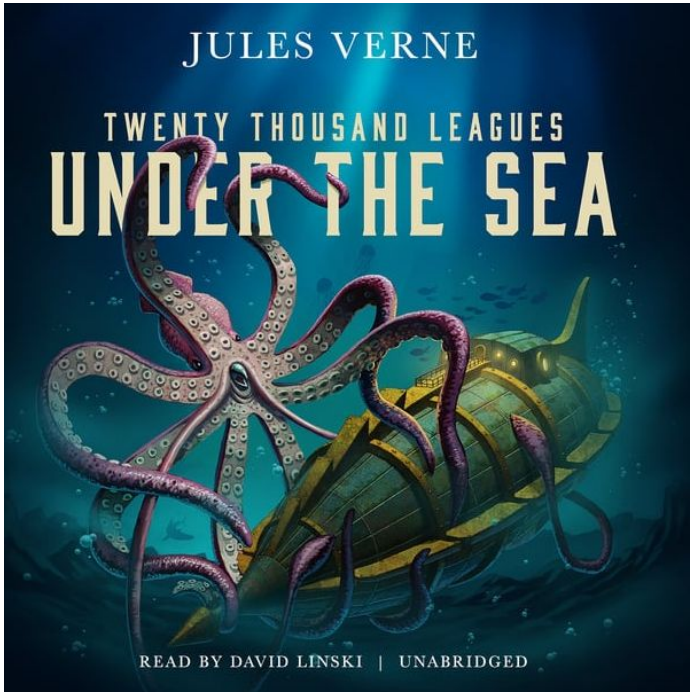
Philippe Leray, Mircea Dusa, Janusz Bogdanowicz, Victor Blanco, Danilo De Simone, Emily Gallagher, Hyo Seon Suh, Anne Laure Charley, Leander Verstraete, Annelies Delabie, Gian Lorusso, John Petersen, Mohamed Saib, Bappaditya Dey, Sandip Halder

Should you believe a French about the future?

"Anything one man can imagine, other men can make real" Jules Verne



1860



1879

French prediction is like its wine, it is getting better when it is ageing

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Potential roadmap extension

2018	2020	2022	2024				2032	2034	2036
N7	N5	N3	N2	A14	A10	A7	A5	A3	A2
							16-12	16-12	16-12
							4	<4	<4
							CFET	CFET	CFET
									Atomic



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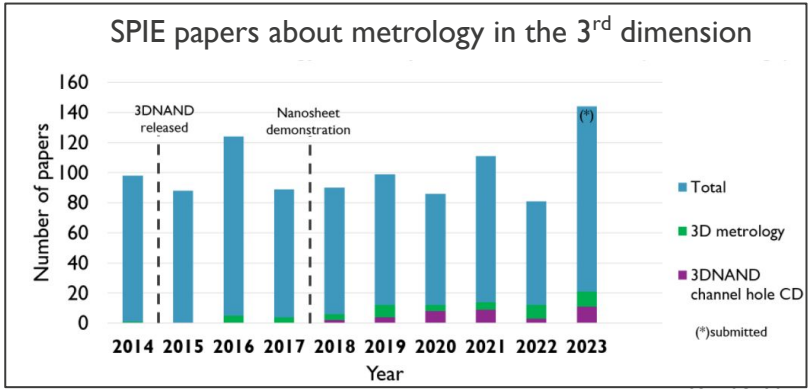
Metrology & inspection 20 years ago

From different fields to a more complex interdependent ecosystem

- 20 years ago, the emphasis in metrology was on which tools could do what
  - Optical Microscopy, SEM and Electrical were the main tools

- Grand challenges (Bill Arnold SPIE 2013)
  - Support new, smaller device structures with metrology
  - Device metrology and process control loops which add back information that is lost during the patterning process
  - Measure structures much less than λ/NA in size with optics

- Grand challenges today
  - Smaller structures require sub nm performance
  - Device complexity is in the 3rd dimension
  - Process control loops are more complex
  - Structures much less than λ/NA in size with optics



Metrology challenges of imec research pillars

imec's ecosystem prepare to tackle the incoming Metrology challenges

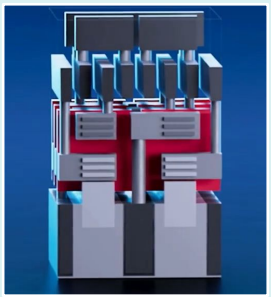
HNA EUV



Lithography

- *Stochastic defect*
- *Massive CD Data*
- *Intrafield overlay control*
- *Mask requirements*

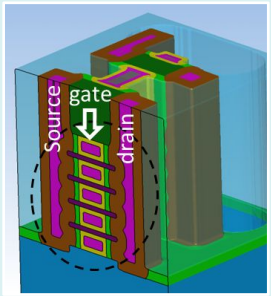
CFET



Compute

- *Overlay Mix&Match*
- *High Aspect ratio and buried structures*

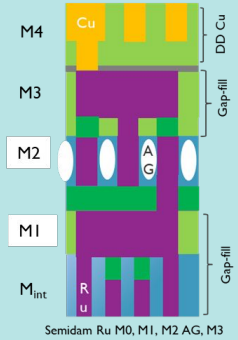
2D-FET



Compute

- *Mobility*
- *Defect*
- *Material Interface*

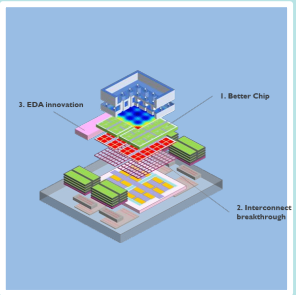
Semidamascene



Connect

- *Opaque (Ru, Mo) metal layers*
- *Impact of airgaps*

3Di -STCO



STCO

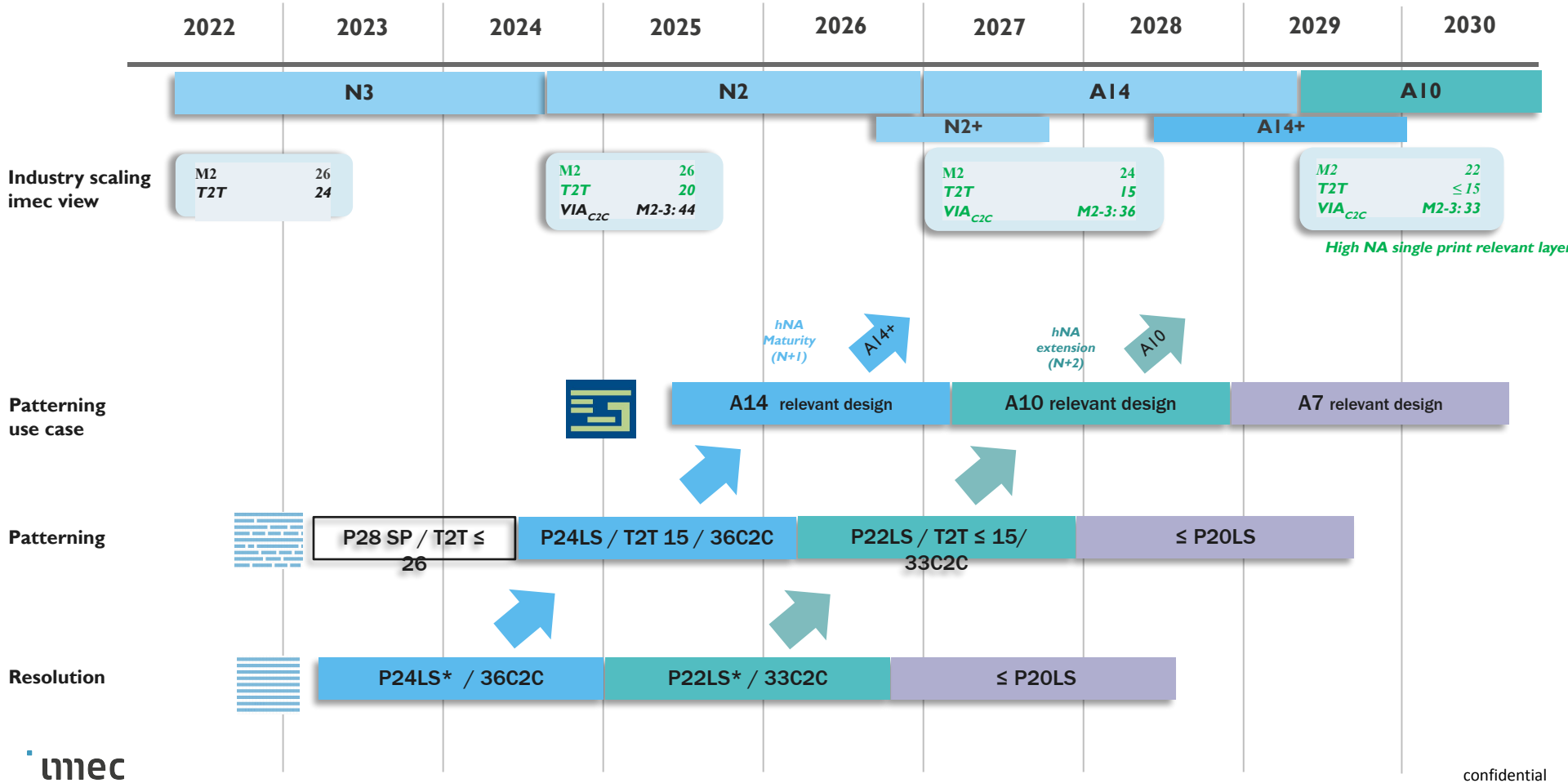
- *Alignment and overlay*
- *Edge metrology, backside, bevel inspection*
- *Very thick resist*
- *Bonding Void detection Bonding Strength & Stress Warpage.*

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Scaling X&Y

"They did not know it was impossible, so they did it"
Mark Twain

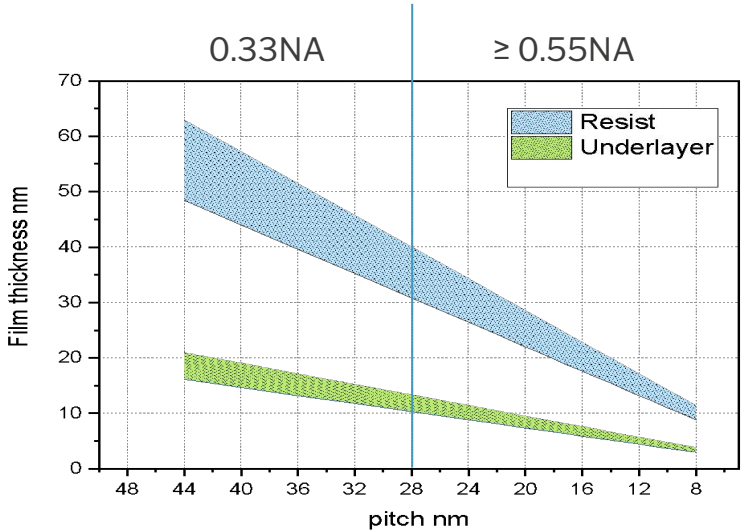
High NA single patterning logic roadmap



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EUV RESIST metrology paradigm shifts



Thinner resist and UL have to retain imaging performance

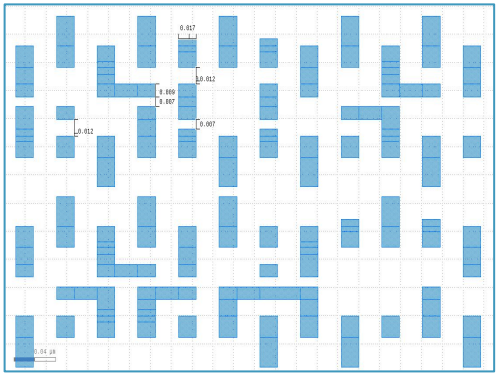
- e-beam CD Metrology
  - Noise level increases with thinner films
  - Imaging noise depends on resist type and underlayer
- Optical
  - No impact for CD and Overlay down to 10-15nm
  - Optical defect inspection is challenged
- New players: Shape / surface and Electrical
  - Rapid/large area AFM
  - BEOL metallization for line defectivity and VC for EPE

Ebeam CD Metrology OK down to 10 nm thickness, Inspection is challenged

≤ A10 logic nodes, anticipated metal layers topology

2D design is back !

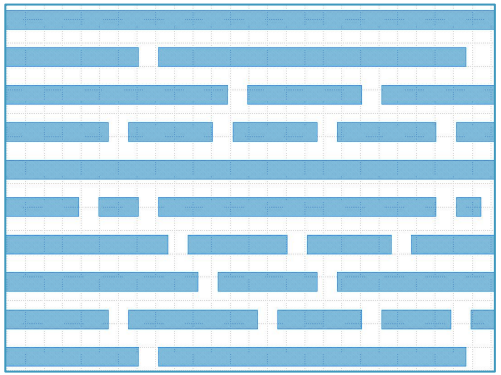
M0 2D style
(CFET)



2D M0 Pitch
≤ A10: 18-16nm

T2T or T2L
A10: 10-14nm

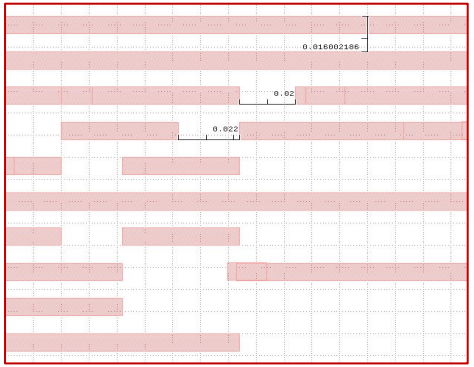
M0 regularly gridded 1D style
(NS, BS PDN)



1D M0 Pitch
≤ A10: 18-16nm

T2T
A10: 10-15nm

M2 random (non-gridded), 1D style
(NS, BS PDN)



M2 Pitch
≤ A10: 18-16nm

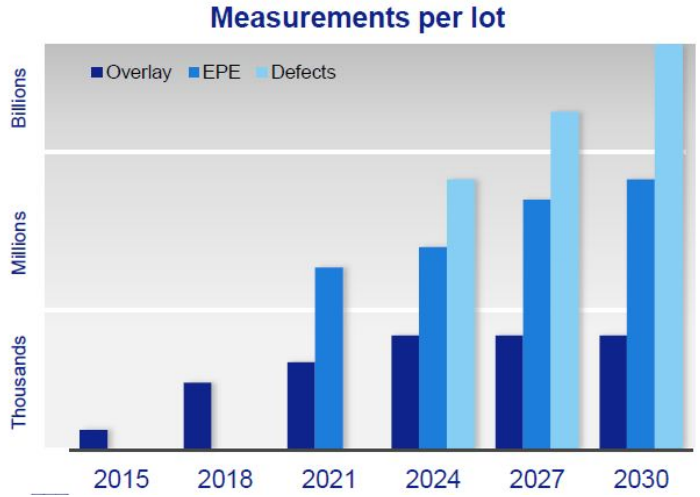
T2T
A10:15-20nm

T2T scaling and LCDU variability and control are the challenges

Metrology performance in the angstrom era

"Houston, we have a problem" Apollo13 - 1995

- EPE is shrinking below 3 nm after 2030
  - How to demonstrate 1 angstrom improvement ?
  - What means accuracy at +/- 1 angstrom ?
  - The increase of measurements to statistically reach these performance is inevitable;



Jim Koonmen, Investor Day ASML, Sept 2021

Do we have the discrimination power to ensure improvements required by the roadmap?

Scaling Z & Material

"Nothing in this world is worth having or worth doing unless it means effort, pain, difficulty"

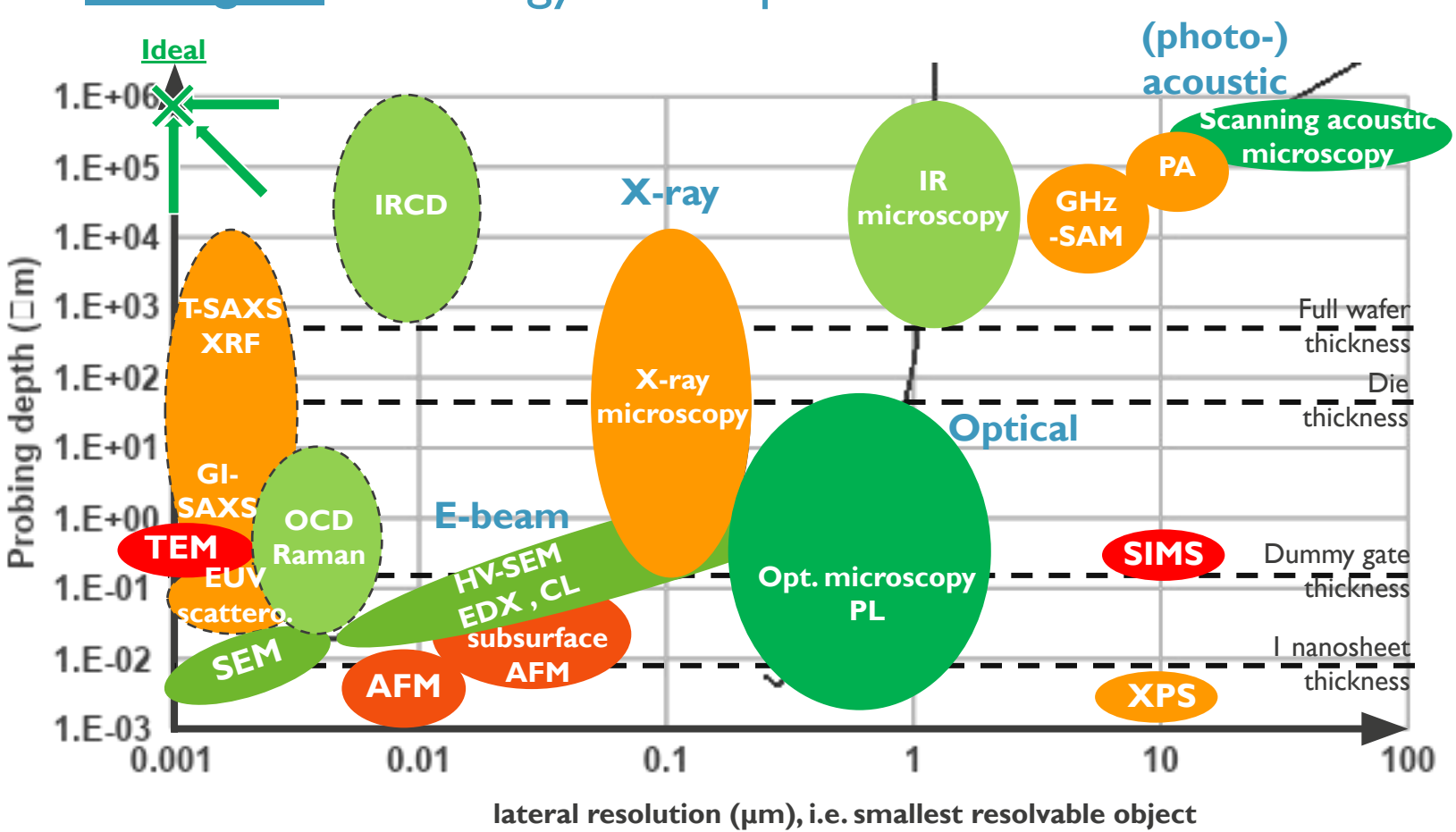
Theodore Roosevelt

New devices force the needs for a new "See through" Metrology

Application	Metrology type	CD	Overlay	Defectivity
Logic	NS	• Lateral SiGe recess • Final NS width • MDI recess (mCFET) • Vertical edge placement	X	• SiGe residues • WFM residues • Wall void
	FS			
	CFET			
3D integration	D2W HB	X	Through Si	• Bonding voids • TSV voids • Grinding-induced defects
	W2W HB			
	BSPDN		X	
	3D sequential			
Memory	3DNAND	• HAR hole/slit • Lateral recess	Through opaque HM	X
	3DDRAM			• SiGe residues • Crystalline defects
Beyond 3D devices		X	Through metal	X

Solution exists Solution under study No solution

3D through-Si metrology landscape

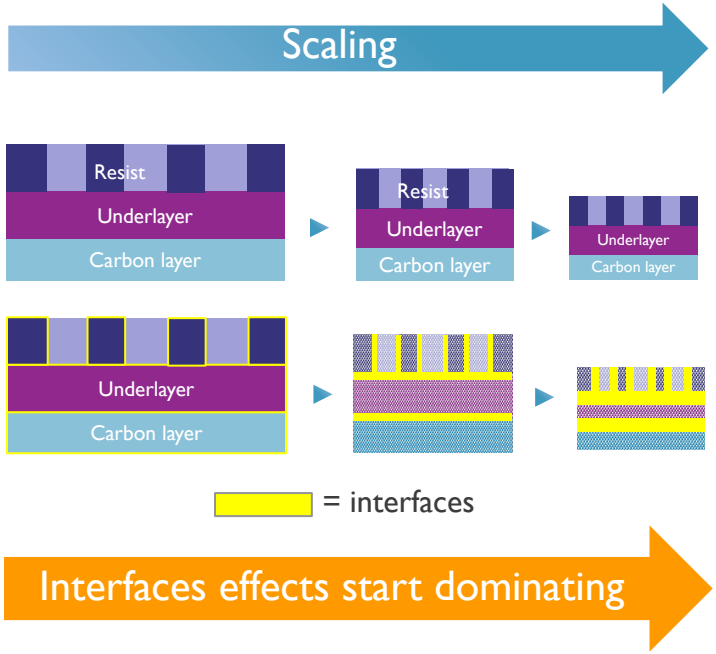


Landscape is vast and opportunities are numerous

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Interfaces and cross-layer interactions could dominate

Individual atoms start to matter...



Engineering and control of the interfaces importance will increase

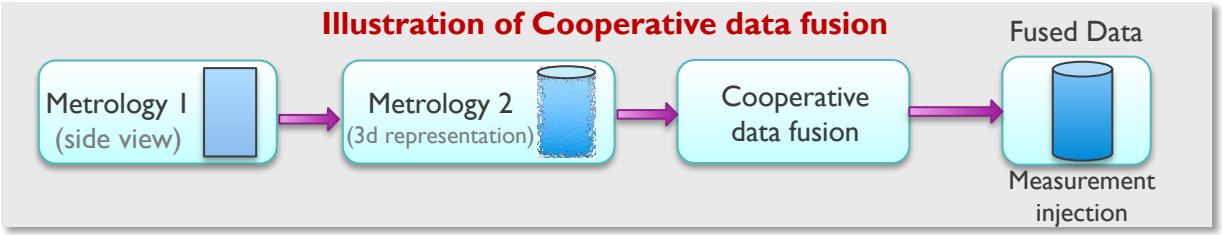
(litho, Si/SiGe multilayer, 2D material)

Beyond the hardware

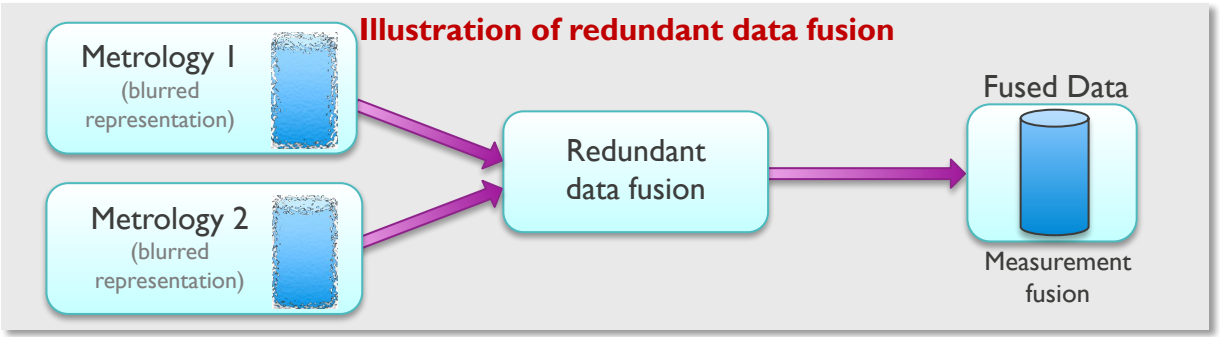
"May the force be with you"

Star wars 1977

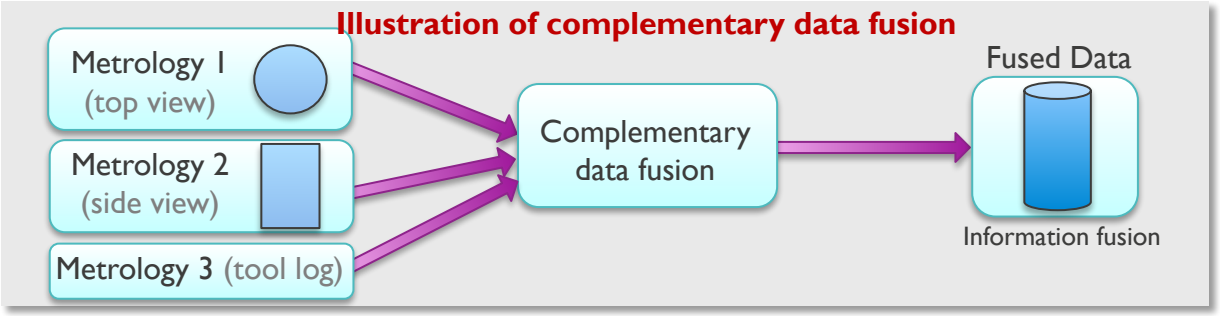
Hybrid metrology : Reduce tool limitations by combining HW



Successfully implemented



Multiple CDSEM tools and combining results?



Example "OCD and AFM for the characterization of Area Selective Deposition"

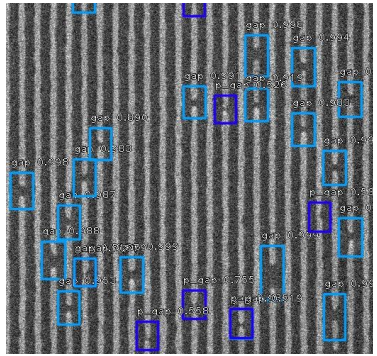
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Deep learning algorithms to improve classification/detection

Machine Learning based classification w/wo denoising

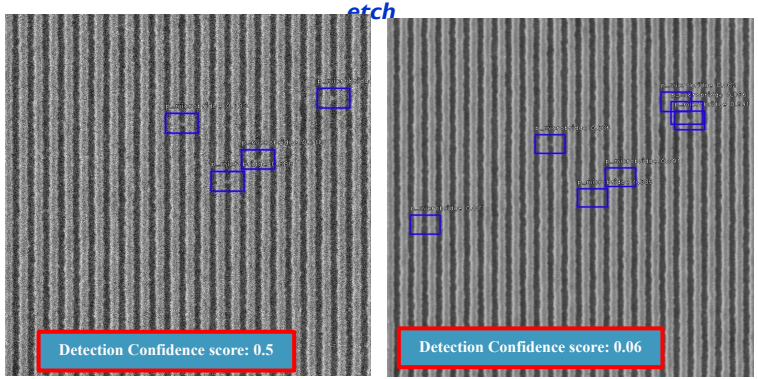
Machine Learning based classification w/wo denoising

- Accurately detecting nano bridges and breaks
- Classification of defect severity
- Improve classification errors by using un-supervised systems.



Sure breaks

Possible break post etch

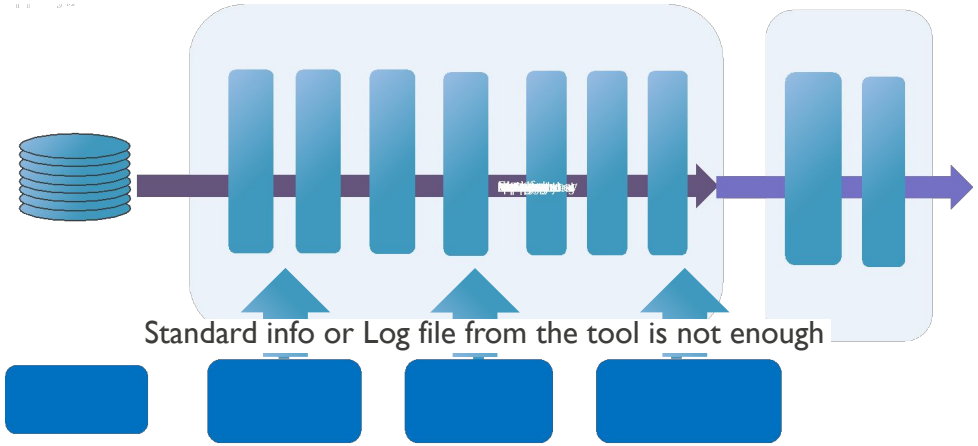


Noisy Image (Less defects detected) → *Denoised Image (Extremely small defects detected)*

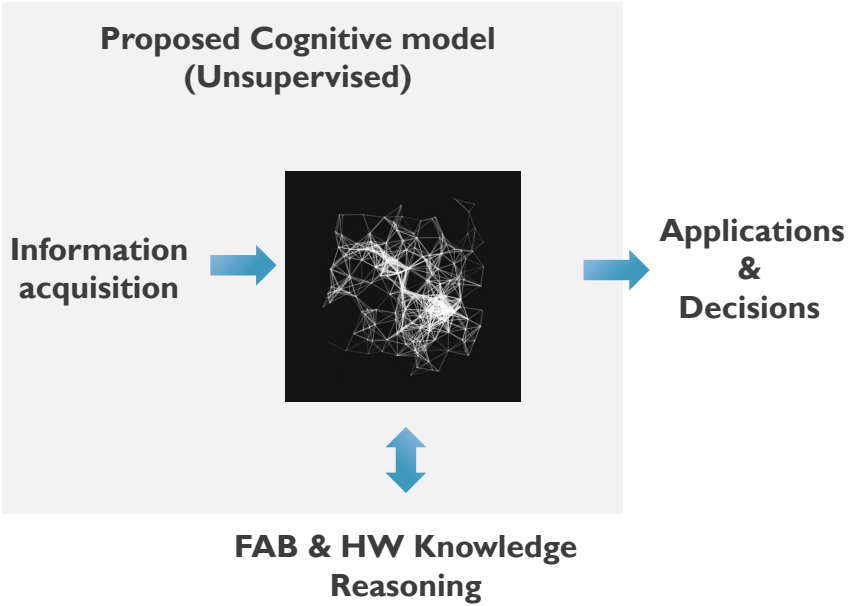
"I have a dream ....": Toward Virtual Metrology using tool sensors information to predict product characteristics

True collaboration between suppliers and Fabs under protective IP

Process knowledge is in the FAB



Hardware knowledge is with suppliers



But *"it creates a gap between human knowledge and human understanding"*

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Metrology for scaling towards 2030

"To infinity and beyond" Buzz Lightyear

- Penetrate deeper in complex 3D structures: Improved Sensors (Ebeam, Xray, IR, etc...) and more intrusive (bringing Lab Metrology in Fab means automation)
- Distance to raw data will increase with enhanced and efficient use of data (i.e. Hybrid metrology, Machine learning, Virtual Metrology)
  - But, will we still understand the physics ? What sampling is required to reach the desired performance ?
- Tools have to be faster to allow large data collection (multi beam inspection). Storage will need to be ready
- Time to recipe and analysis will be reduced through automation and ML
  - But, where is the limit on how fast we can acquire and analyze data ?

“J’ai pu me tromper mais je n’ai jamais trompé personne.”

“I might have been wrong but I never lied”

Marquis de La Fayette


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