

Virtual Fab for Advanced Semiconductor Engineering

Semicon Europa – Future of Computing

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Director Engineering - Semiverse™ Solutions – 11/13/2024



The future of computing



Bits

+ Neurons

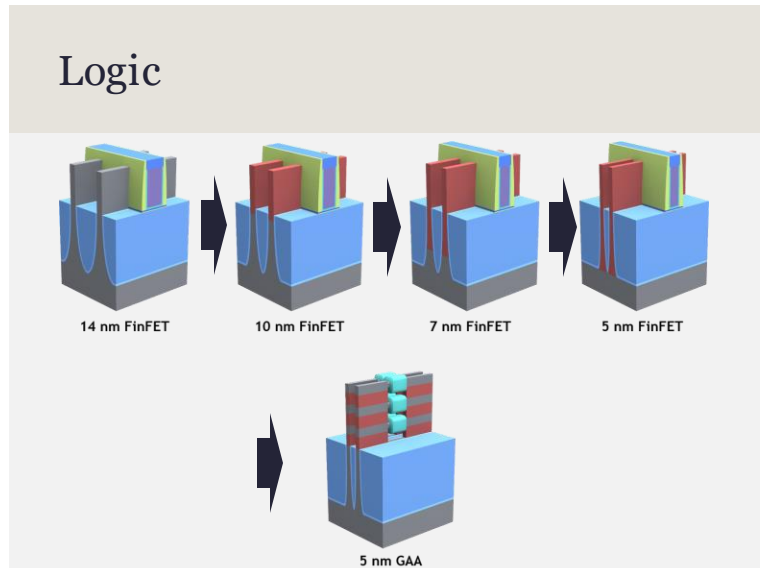
+ Qubits

Dario Gil, IBM Research

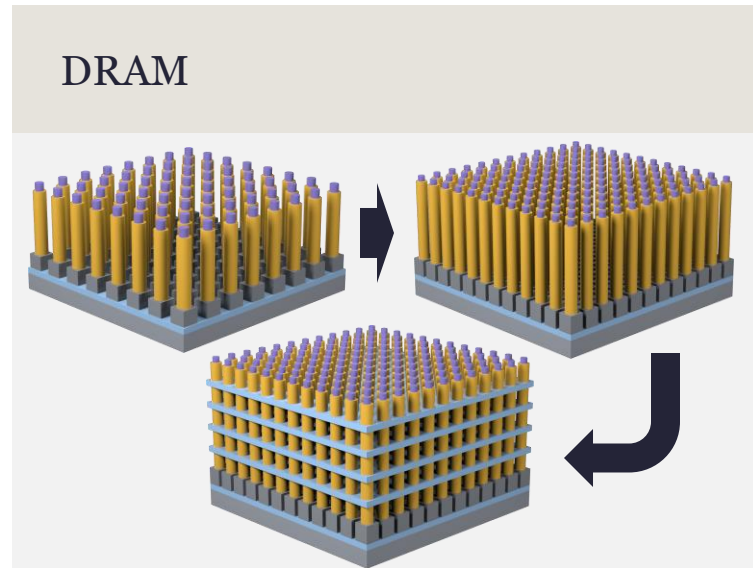
“The future depends on what we do in the present”

Mahatma Gandhi

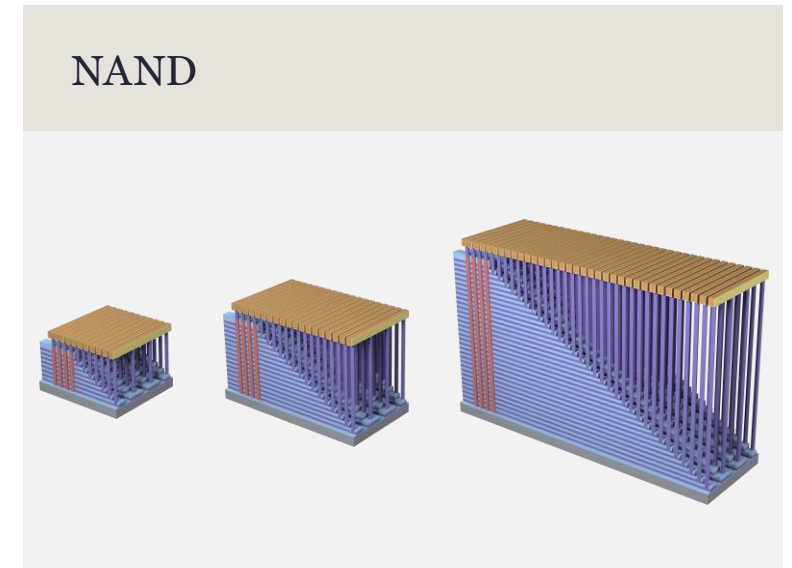
The present of computing is addressing already critical challenges to overcome the complexity of three leading technologies:



- Scalability challenges to address path to the angstrom era



- Scalability challenges to address high density and high aspect ratio patterning



- Scalability challenges to address high aspect ratio patterning to reach 1000-layer 3D NAND structures

Semi industry suffering from its own complexity

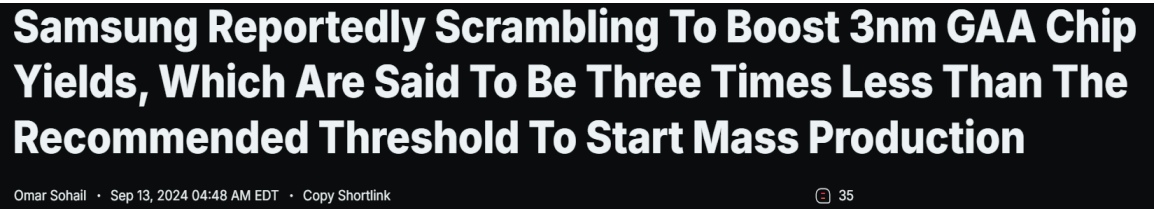
MANUFACTURING COST

- Lower profitability due to Yield issue



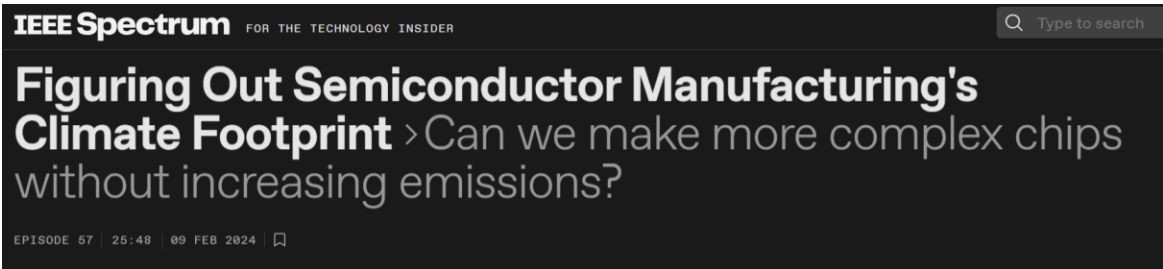
TIME TO SOLUTION

- Longer development time to meet specification



CARBON FOOTPRINT

- Highly demanding technologies for resource and waste



EDUCATION

- Capability gap increasing between academia infrastructures and leading edge fabs

White House launches semiconductor workforce center

The \$250 million investment from the Biden-Harris administration aims to address labor development challenges in the U.S. chip industry.

Published Oct. 7, 2024

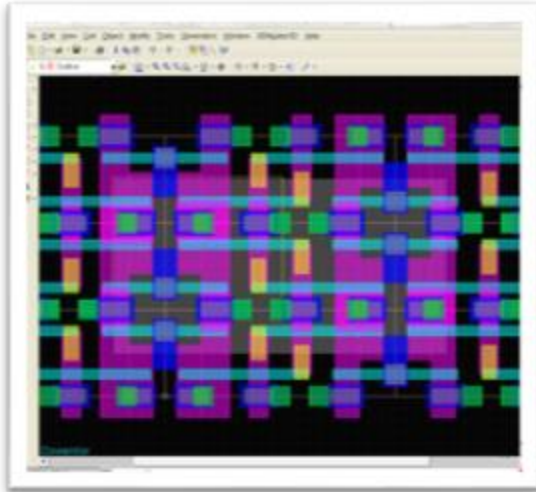
Semiverse™ Solutions Mission

Lead the evolution of the semiconductor digital ecosystem with software, platforms, and products to accelerate innovation and create opportunities for collaboration in an era of complexity



SEMulator3D[®] process modeling & virtual fabrication

Layout
(i.e. Blueprint
of your chip)

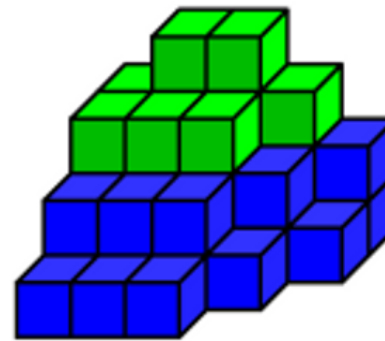


**Process
Sequence**

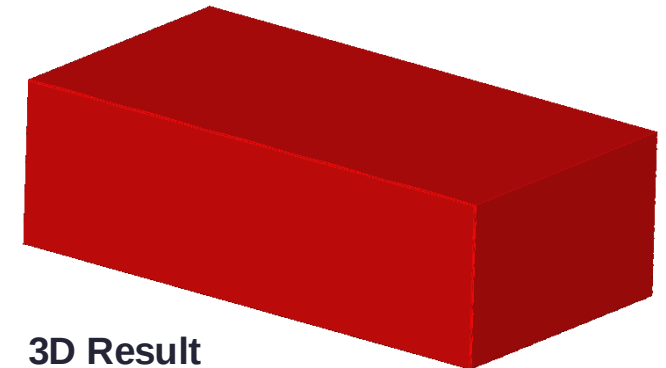
- Step-by-Step Process
- Behavioral Description

Number	Load	Action	Name	Material(s)	Depth(s)	Depth
1		Write Setup	Write Setup1	/JGIcon/2_Hel	/JGType/8	GeneralHelixTh...
2		Sequence	FEOL			
2.1		Sequence	Fin			
2.2		Sequence	FinCut			
2.3		Sequence	STI			
2.3.1		Conformal...	DEP STI HEP	/JGIcon/502_H...		STIHelixEngTh...
2.3.2		Polish	CMP HEP			
2.3.3		Basic Bth	AB STI Recov1	/JGIcon/1_Fig...		38
2.3.4		Basic Bth	WET HEP Clean	/JGIcon/1_Fig...		2
2.3.5		Basic Bth	WET PadRec1Bip	/JGIcon/1_Fig...		FePadRec1Thick...
2.3.6		Basic Bth	AB STI Recov2	/JGIcon/1_Fig...		STIHelixRecov...
2.4		Sequence	Wells			
2.5		Sequence	Gate			
2.6		Sequence	Source/Drain			
2.7		Sequence	BSG			
2.8		Sequence	PMO			
3		Sequence	MOI			
4		Sequence	BEOL			
5		Location OK...	ZLocationForm...			

Virtual Fabrication
Modeling Engine



SEMulator3D[®]

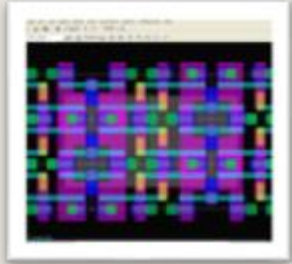


3D Result

- Predictive
- Accurate
- Fast

SEMulator3D® beyond process modeling - a fab digital twin

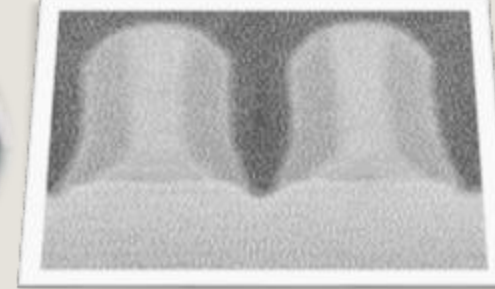
Actual fab activities



Process integration (Reticle + Process)



Inline Control Metrology

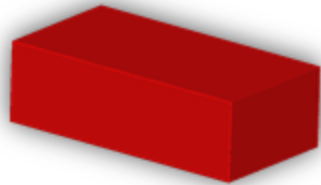


Inline or EOL Failure Analysis

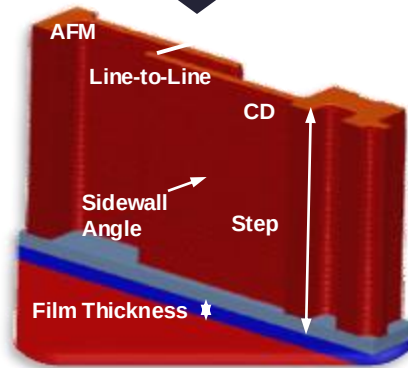


End Of Line Probing → Yield report

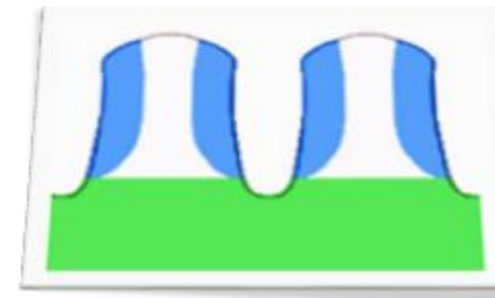
Virtual fab twinning capabilities



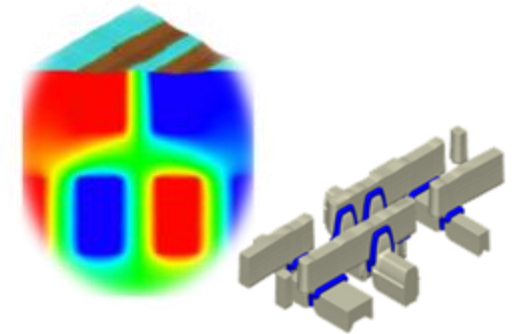
SEMulator3D® virtual processing



SEMulator3D® virtual metrology



SEMulator3D® virtual X-Section



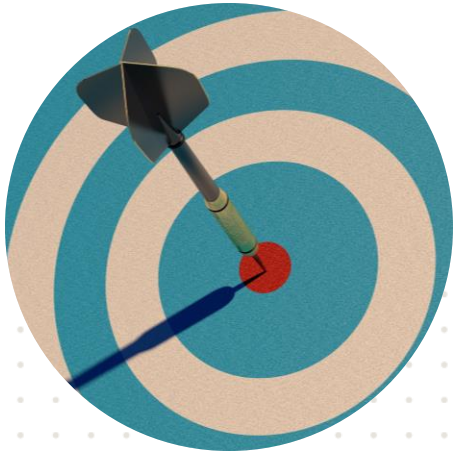
SEMulator3D® RC, 3D DRC

1:1 Pairing
1:1 Matching

1:1 Matching

Virtual Proxy
correlation to Actual
Yield

SEMulator3D[®] value proposition



Higher
Manufacturing Yield



Faster Time to
Solution

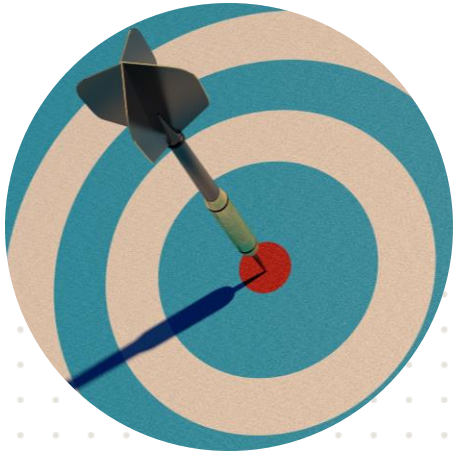


Carbon Footprint
Reduction



Education Access

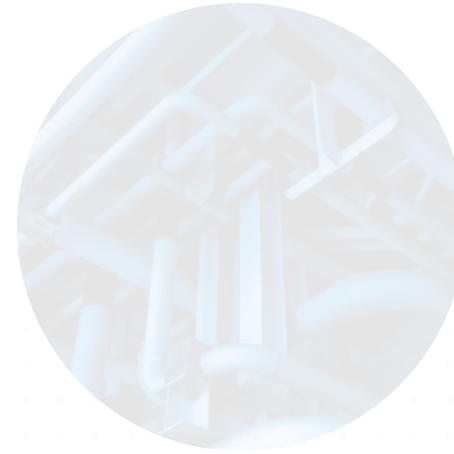
SEMulator3D[®] value proposition



Higher
Manufacturing Yield



Faster Time to
Solution



Carbon Footprint
Reduction

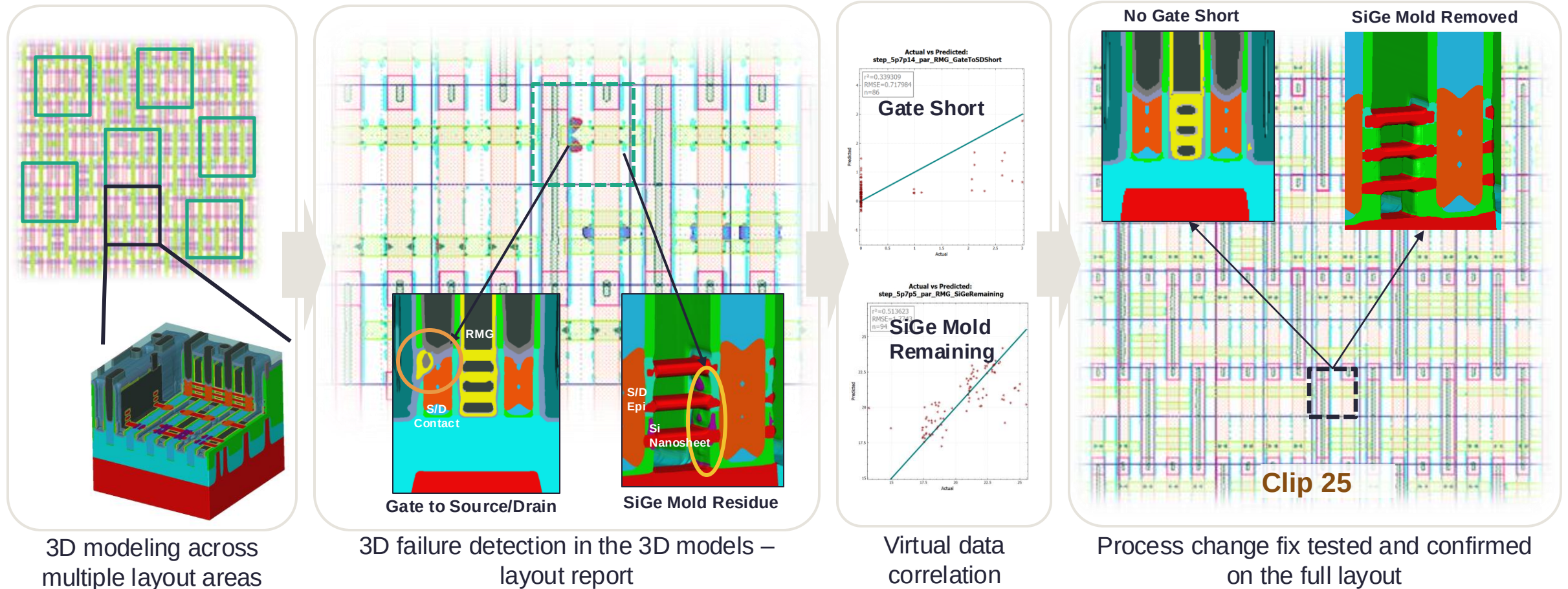


Education Access

Manufacturing: yield loss prevention

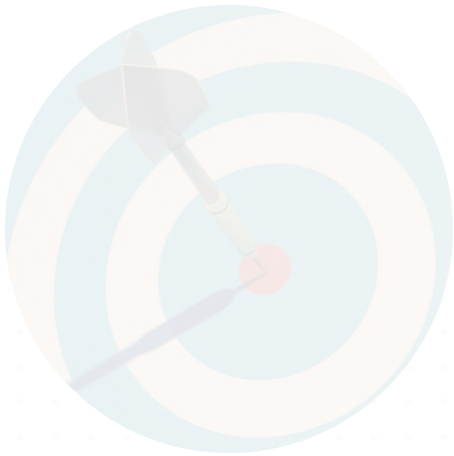
Problem Statement: Classical 2D DRC on new product designs do not cover 3D process-design related issues

Solution: Virtual 3D Design Rule Check Solution across a large layout domain



Industry avoiding 10s of yield-limiting failures in HVM thanks to systematic virtual 3D-DRC

SEMulator3D[®] value proposition



Higher
Manufacturing Yield



Faster Time to
Solution



Carbon Footprint
Reduction



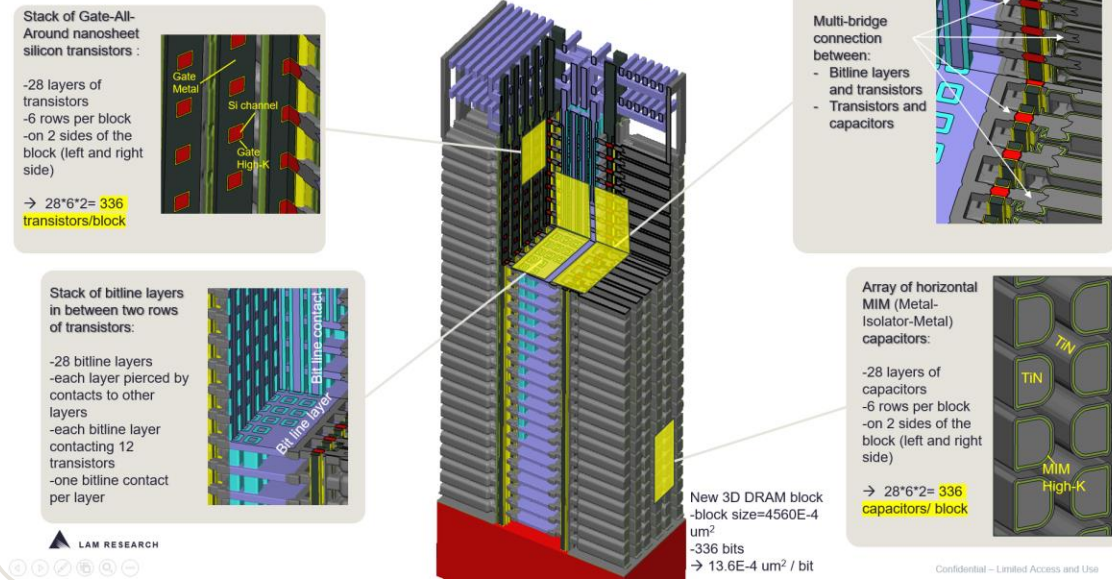
Education Access

Development: faster time to solution

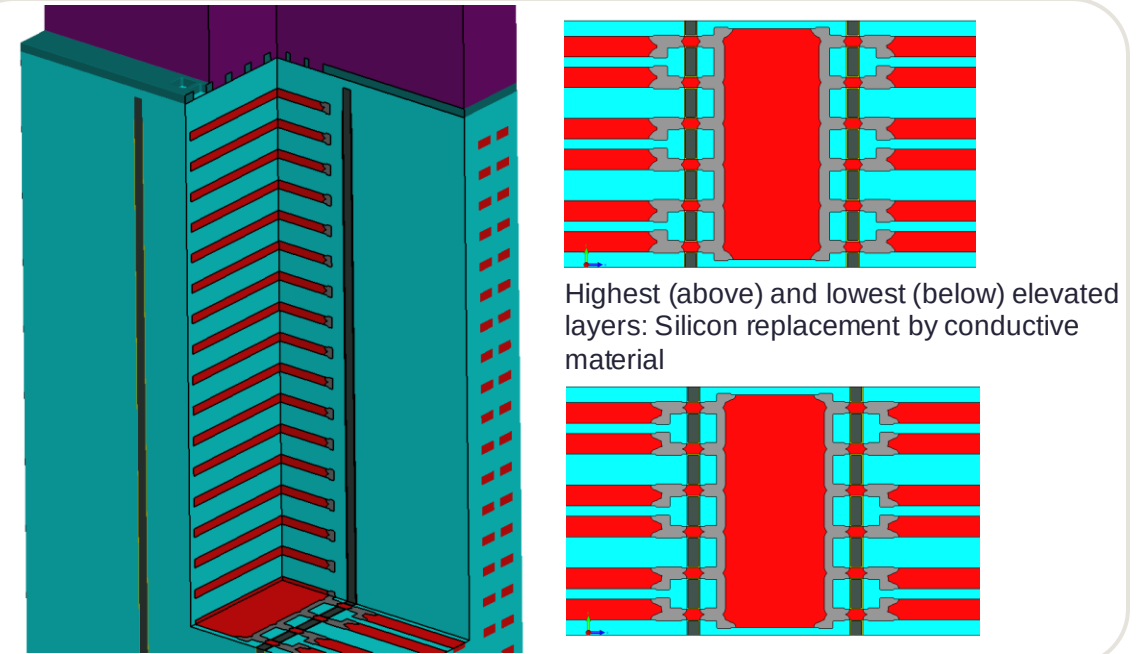
Problem Statement: Development time for new architectures requires years of experimental work to analyze and solve all the process integration risks

Solution: Virtual 3D prototyping of process integration that analyzes all critical process steps and specifications

The 3D DRAM Nanosheet key components



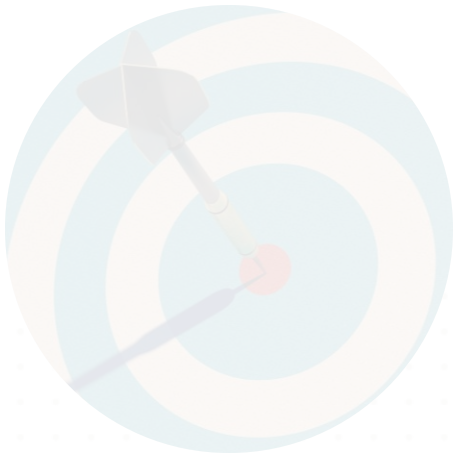
Technology virtual prototype



Patterning requirement and specification

Industry saving ~30% of learning cycle time by making strategic decisions on process and integration development based upon learning from virtual studies

SEMulator3D[®] value proposition



Higher
Manufacturing Yield



Faster Time to
Solution



Carbon Footprint
Reduction



Education Access

Carbon footprint reduction

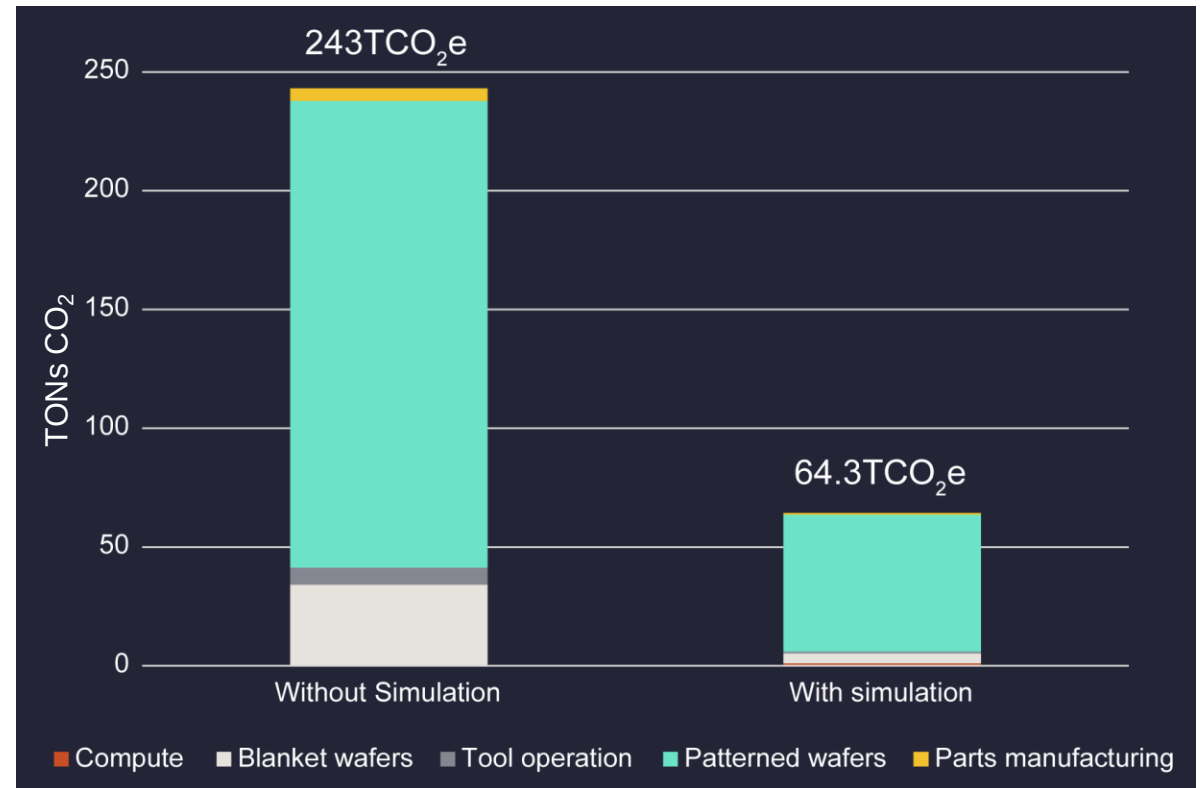
Σ of CO₂ Equivalent for a Simulation

- Methodology developed by Lannelongue et al.
 - Energy required to run the algorithm
 - Pollutants emitted when producing such energy
 - CO₂ equivalent = power consumption × carbon produced based on local grid
- PLUS physical experimentation & silicon required to calibrate

VS

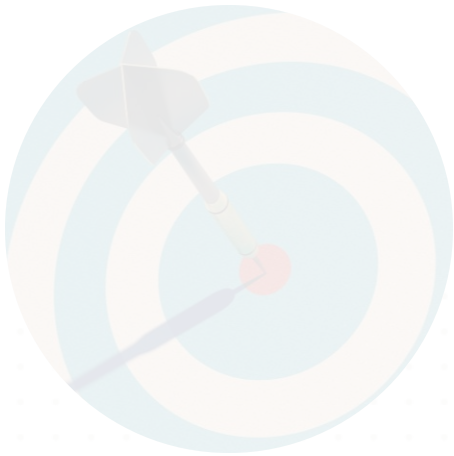
Σ of CO₂ Equivalent for Experiment

- imec.netzero v2.0 — IC chip footprint calculator developed by imec
- IPCC tier 2c methodology for process gases
- S23 energy consumption reports
- Proprietary Lam Research lab eco sensors



Carbon footprint of both physical experiments and simulations are dominated by silicon processing

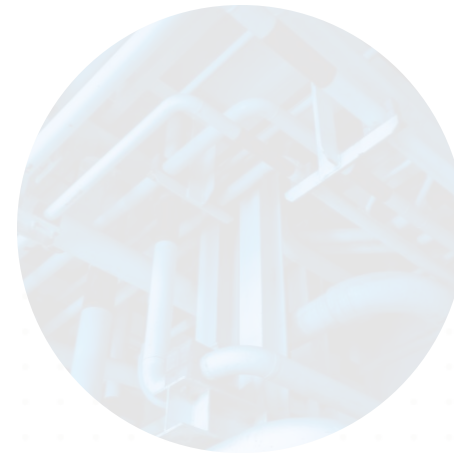
SEMulator3D[®] value proposition



Higher
Manufacturing Yield



Faster Time to
Solution



Carbon Footprint
Reduction



Education Access

Education access

SEMulator3D and the Future of Engineering Education



David Fried | Jun 22, 2023 | Technology



- Up to 60,000 engineers in India to be trained on Lam's unique virtual fabrication platform
- Programs are designed to tackle semiconductor's next inflection points, virtually

Today we are excited to announce that Lam Research has been included in a strategic partnership between the United States and India governments with the initiative on Critical and Emerging Technology. (ICET)

Our proposal to the Indian government to transform the education of the next generation of semiconductor engineers has been included in [a joint statement by the U.S. and Indian governments](#) at the White House earlier today and in [a detailed fact sheet](#).

As part of the proposal, up to 60,000 engineering students can be trained in India using SEMulator3D®, our groundbreaking virtual fabrication platform as part of our Semiverse™ Solutions portfolio of products. This represents an innovative approach to workforce development.

\$1 Trillion Dollar Semiconductor Industry Needs One Million More Workers...and Lam

Nikki Salenger and Elizabeth Greene | May 14, 2024 | Corporate, Life at Lam



As semiconductor complexity increases with scaling, specialized expertise in areas like plasma physics and artificial intelligence (AI) becomes crucial. Lam faces challenges in workforce readiness, with graduates often unaware of the semiconductor market and industries vying for similar talent.

- That's why we're innovating ways to attract, develop, and retain skilled professionals.

Why it matters: By 2030, the semiconductor industry aims for a \$1 trillion annual revenue, necessitating an additional [one million global semiconductor workers](#).

Democratizing Education

Lam collaborates with global universities and organizations to cultivate a diverse, skilled STEM workforce for various technical disciplines.

- Universities struggle to train semiconductor engineers due to limited access to cutting-edge equipment and the hazards of working with volatile chemistry.

Lam's answer is Semiverse™ Solutions, a virtual lab simulation that democratizes engineering skills training, enhances safety, promotes sustainability, and expands access to lab environments to global talent. Virtual environments are already in use with Lam's customers and U.S. academic partners.

- Notably, Lam India and the Centre for Nano Science and Engineering [developed a custom course](#) on semiconductor fabrication technology using SEMulator3D®.

By the numbers: In 2020 Lam invested \$1.3 million in education programs at both nonprofits and schools.

- For instance, Lam offers 18-month internships through Portland Community College and Clackamas Community College for Oregon microelectronics students.
- In Ohio, Silfex, a Lam subsidiary, collaborates with Clark State Community College on a 40-hour advanced manufacturing training program, with many of the program's graduates joining Lam's workforce.

Virtual semiconductor fabrication allows students to practice and work on (virtually) process development of leading-edge technologies

An aerial, high-angle view of a dense urban landscape, likely New York City, showing a vast array of skyscrapers and buildings. The perspective is looking down from a high altitude. In the center of the image, there is a bright, hazy light source, possibly the sun or a large fire, which creates a strong lens flare and illuminates the surrounding city. The text is centered over this bright area.

The Future belongs to those who prepare for it today

Malcolm X

Some technical challenges ahead of us

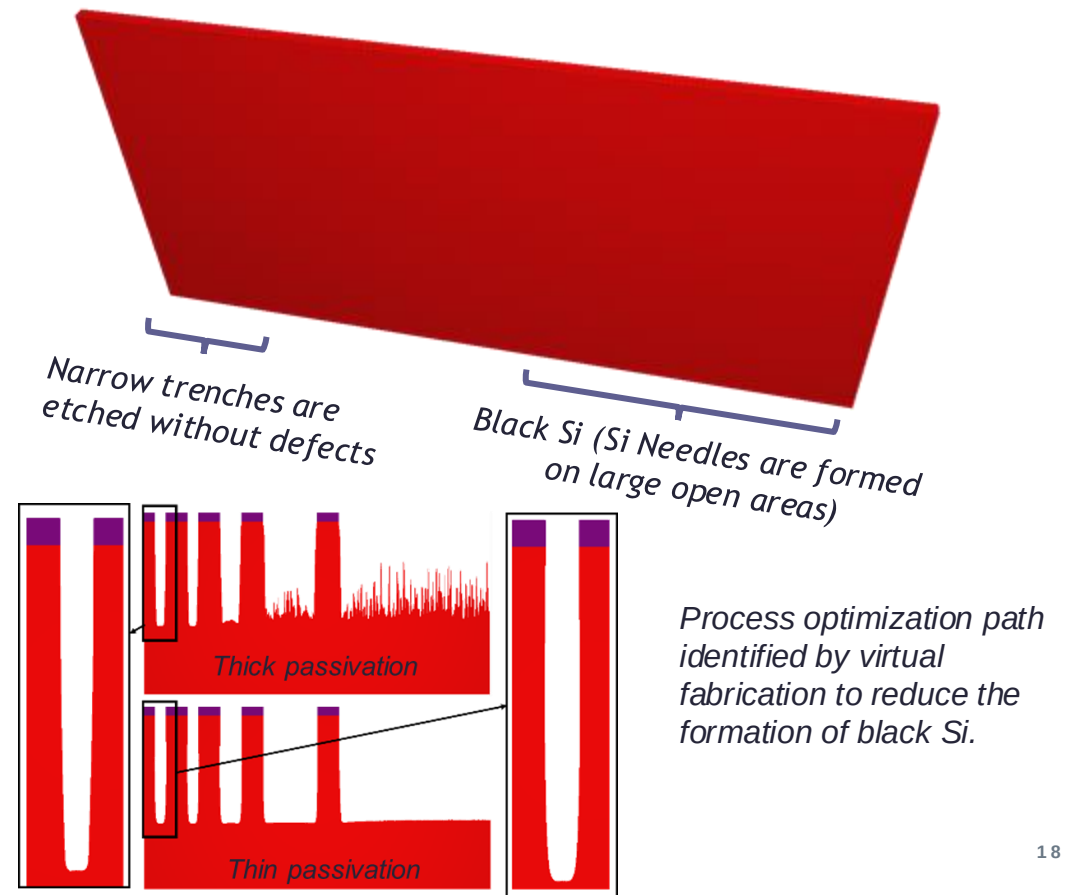
(and already prepared)

High aspect ratio etch: stress deformation structures bending

High aspect ratio etch: Si grass (Black Si) formation on large open areas

Deformation of the layer stack tracked after each process of a patterning step - downstream impact of potential failures are proactively analyzed

Lam Research continues to provide new capabilities in virtual semiconductor fabrication to address future critical technical challenges



Conclusions

Future semiconductor development will be even more complex than today's already complex process

The industry will require computing (virtualization) to enable the future of computing and tackle a wide range of challenges:

- At the manufacturing cost level
- At the development time-to-solution level
- At the environmental impact level
- At the educational access level

Lam Research's Semiverse™ Solutions has developed and continues to develop innovative solutions (including the SEMulator3D® virtual semiconductor fabrication platform) to address these different challenges



