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Enhancing Sustainability in Semiconductor Manufacturing: Energy-Efficient Optical Crosslinking for Lithography Processes

Innovation for a Sustainable World

SCREEN Semiconductor Solutions Co., Ltd.

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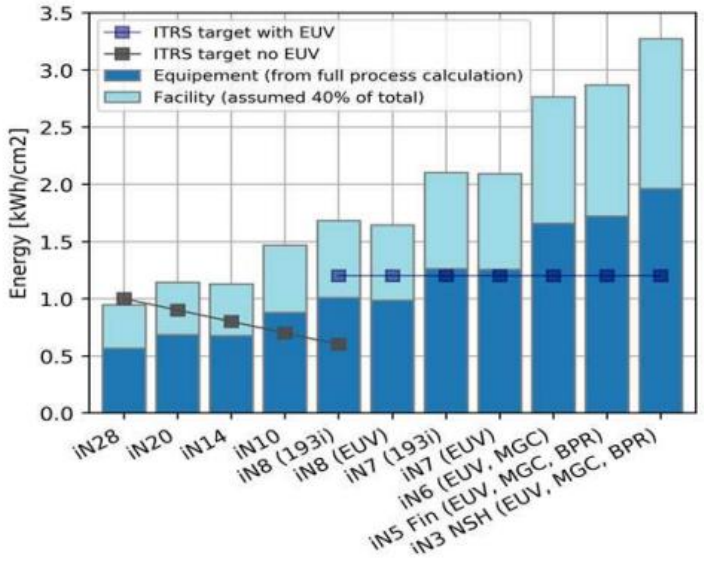
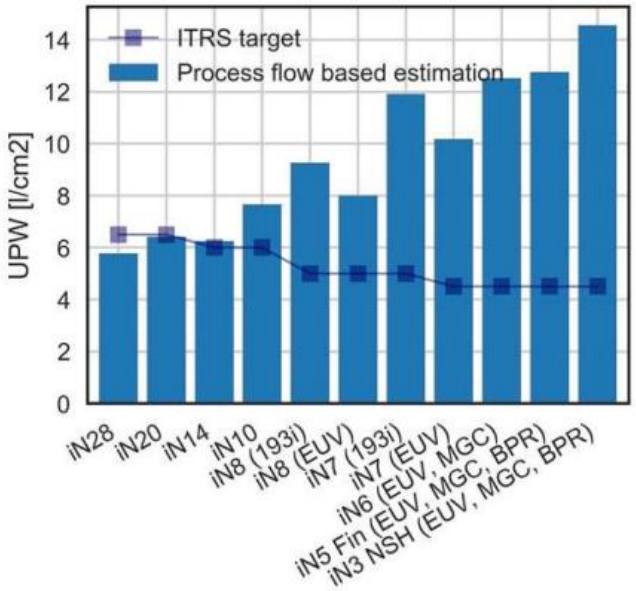
Process miniaturization has great environmental impact

Energy



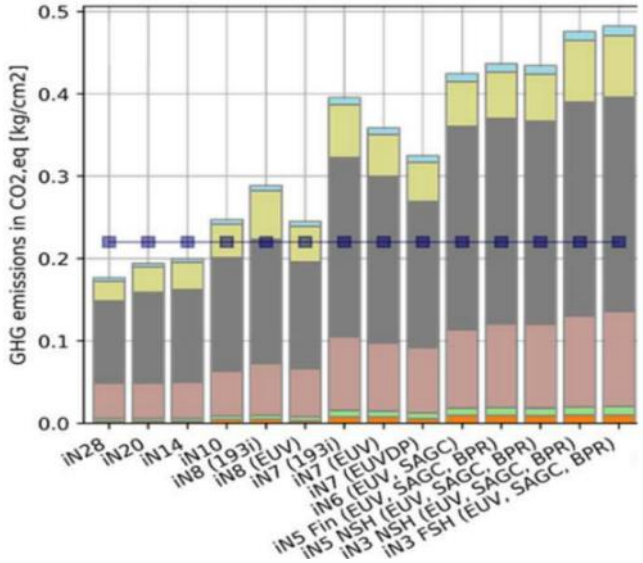
Total manufacturing electricity per cm^2 for full process flows (300mm wafer = 706cm^2). Facility energy is projected assuming 40% of the total energy.

UPW



Total Ultra Pure Water (UPW) usage in liters per cm^2 for full process flows from iN28 to iN3 for 300mm wafer equivalent.
ITRS guidelines shown as reference.

CO_2



GHG emissions in kg CO_{2eq} per cm^2 of wafer, per node, calculated using the GHG protocol for electronics industry of IPPC.

Sustainable scaling of chip manufacturing is a major industry challenge

L.-Å. Ragnarsson et al., "Environmental Impact of CMOS Logic Technologies", 2022 6th IEEE Electron Devices Technology & Manufacturing Conference (EDTM), Oita, Japan, 2022, pp. 82-84)
M. Garcia Bardon et al., "DTCO including Sustainability: Power-performance-area-cost-environmental score (PPACE) analysis for logic technologies", Technical Digest - International Electron Devices Meeting (IEDM) 2020-Decem, 41.4.1-41.4.4

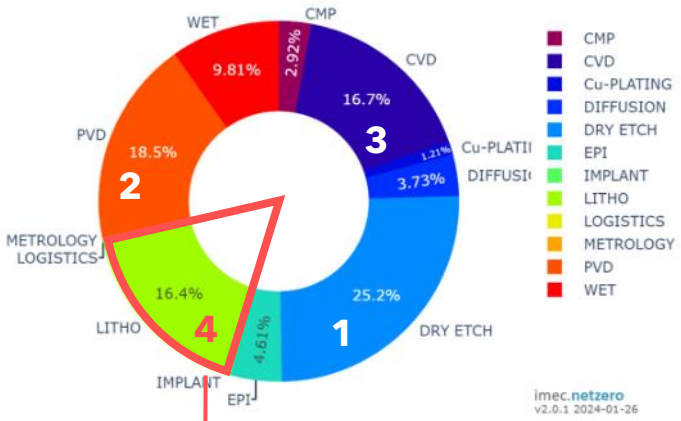
High impact problems in semiconductor manufacturing

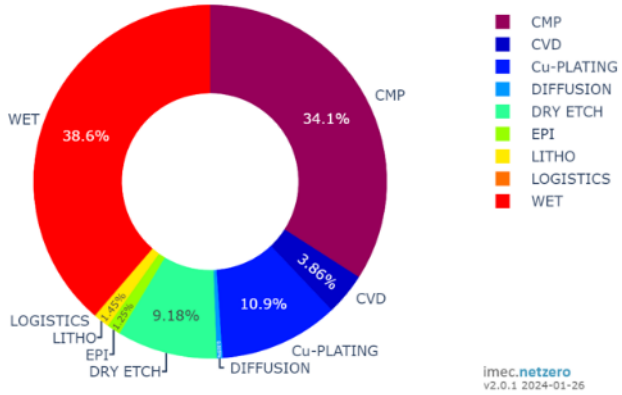
Scope 1 + 2 total emissions

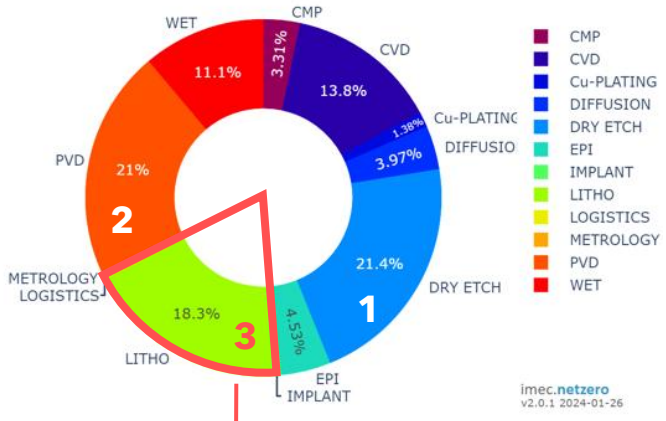
UPW usage

Full electric energy consumption

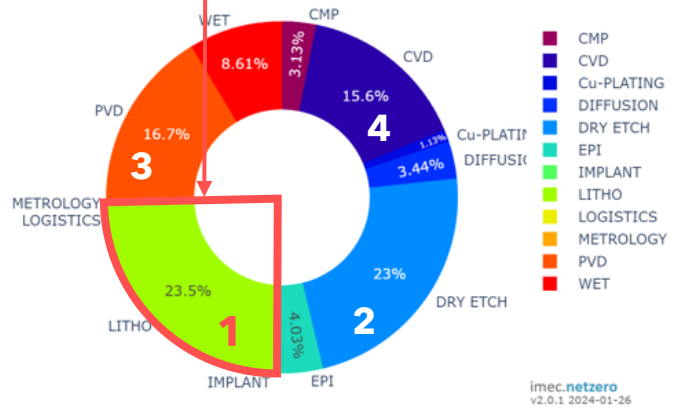
N5

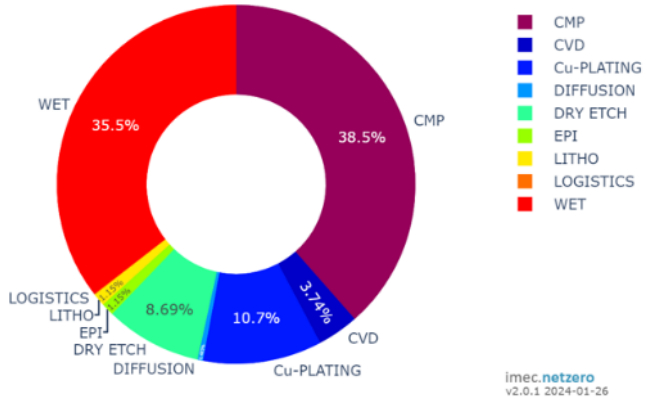


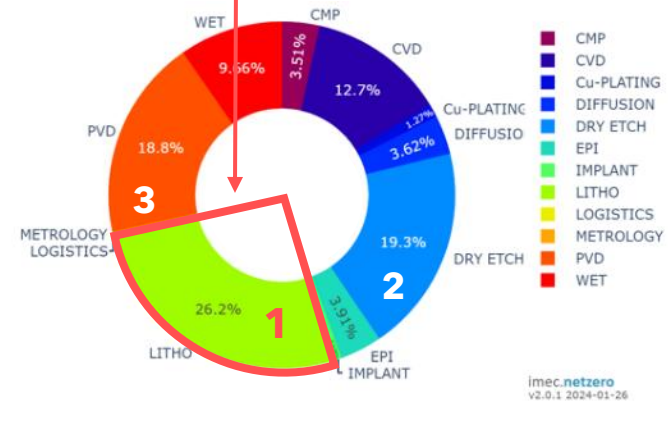




N3



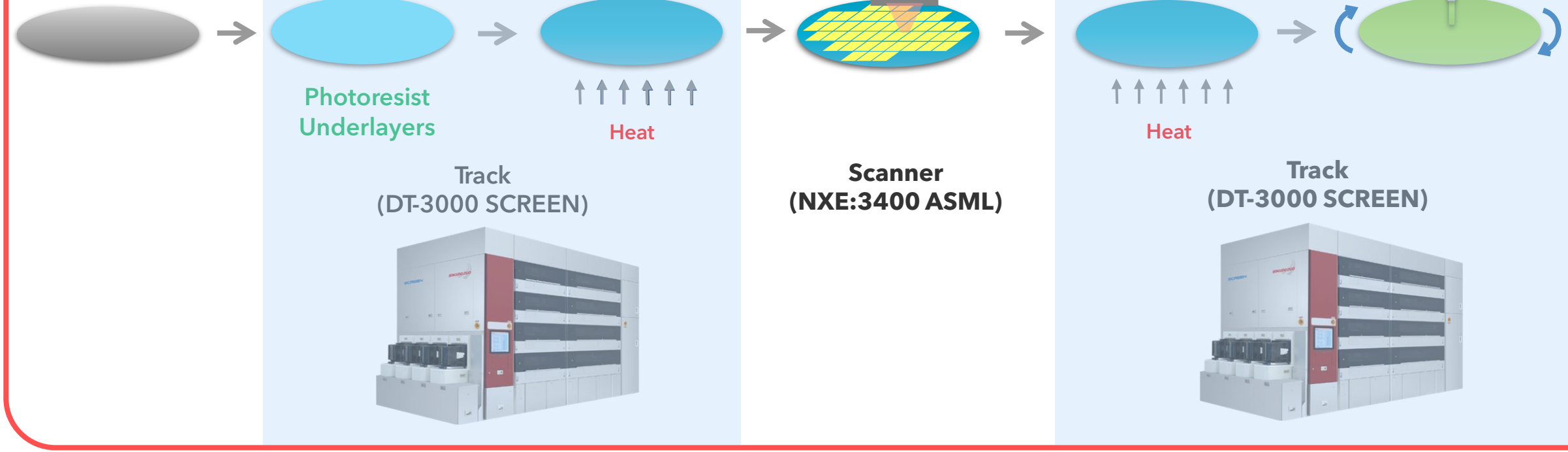




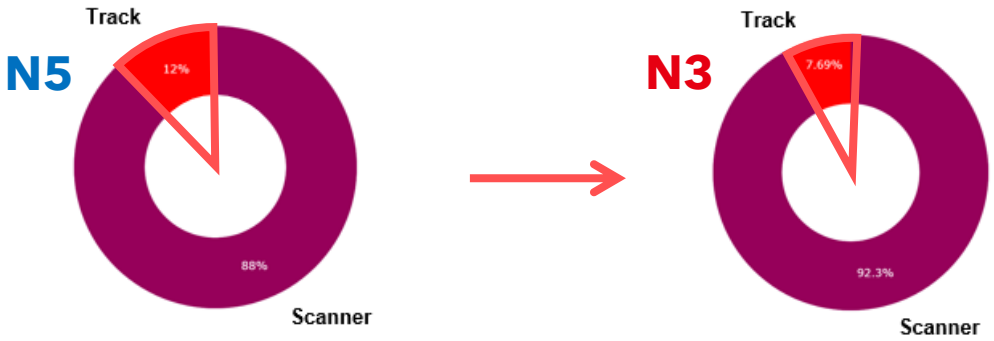
Electricity consumption rated as a top problem to address in the lithography area!

Standard litho evaluation flow

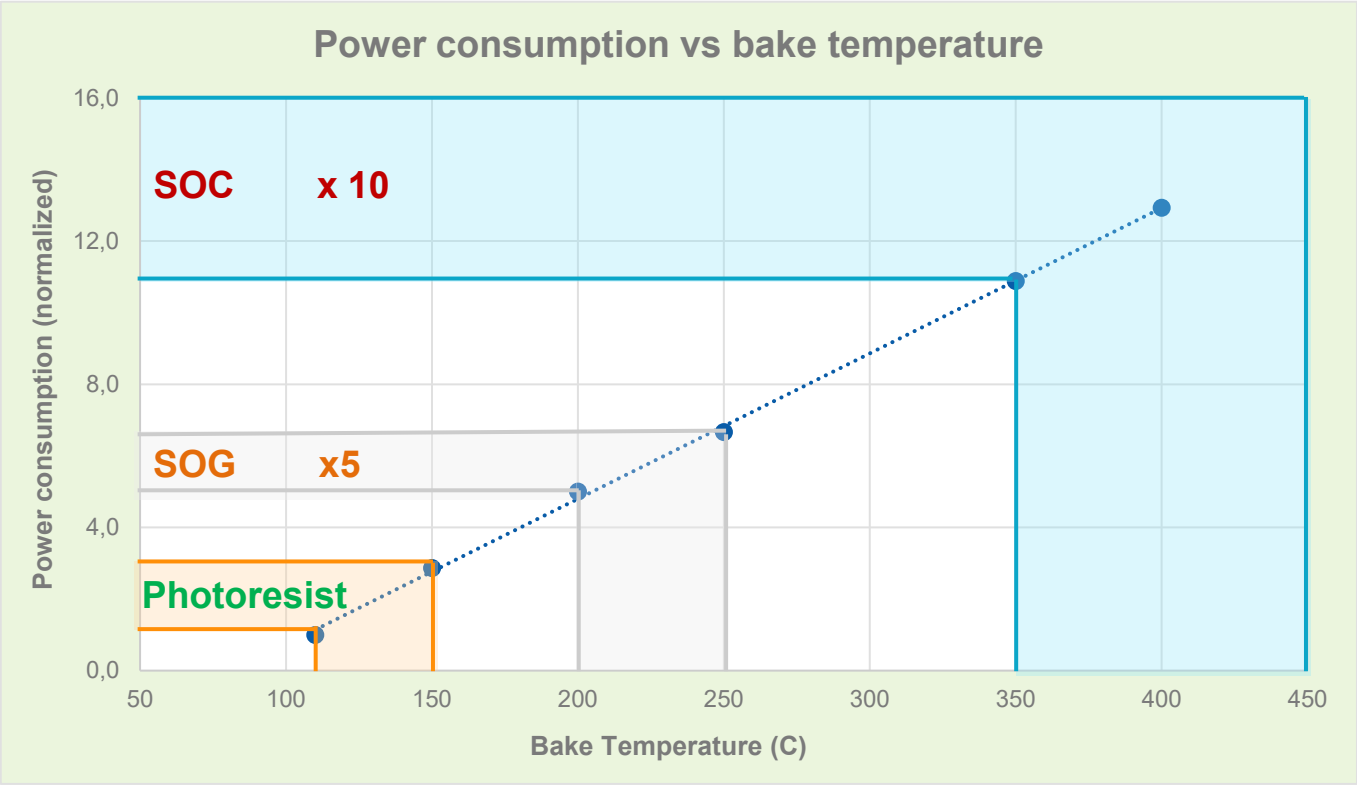
Process flow



Full electric energy consumption on Litho Area

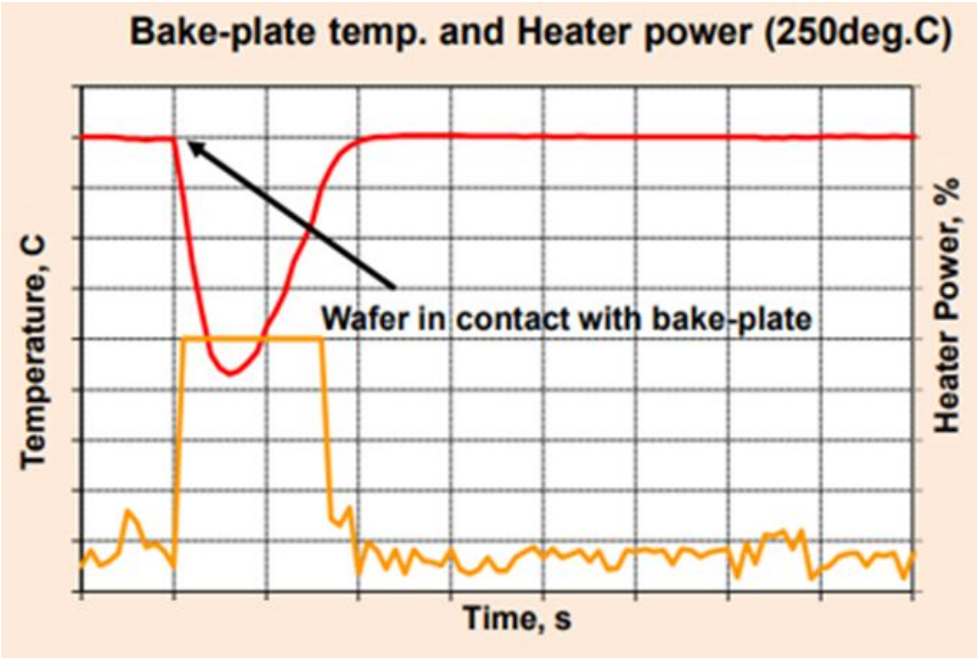


Energy-saving during bake process



Due to the high temperatures required, the baking of underlayer materials is one of the top track energy consumers

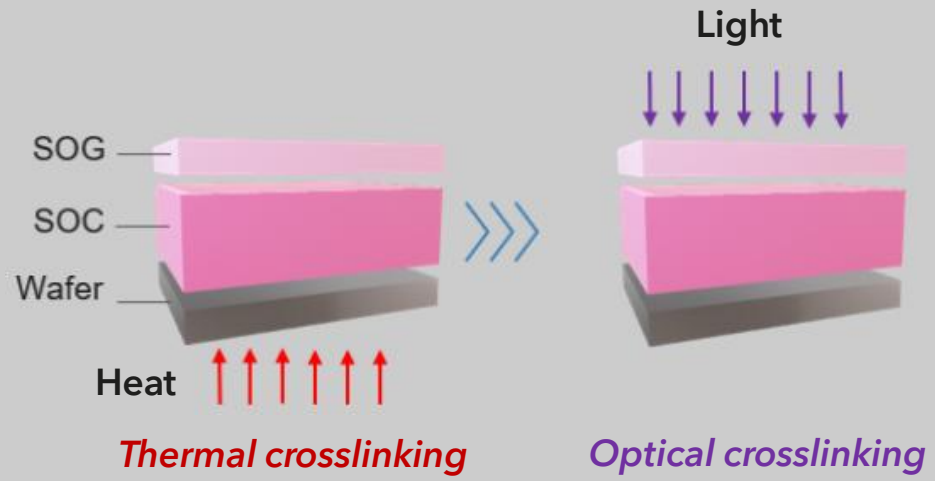
Thermal crosslinking processes require constant electricity supply:

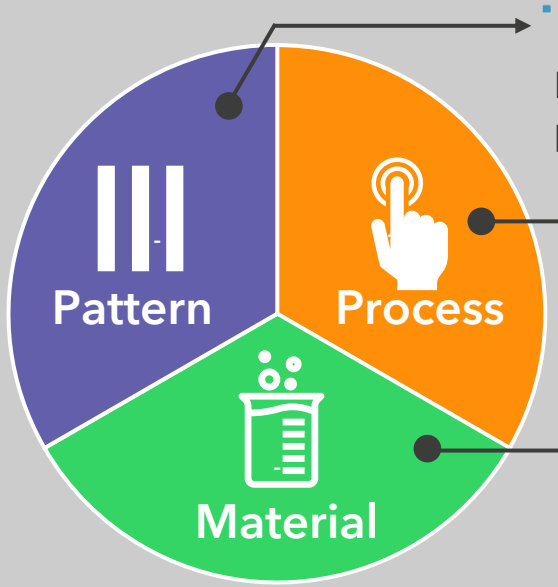


- Track needs to keep bake temperature 24h/day
- Every time a wafer is exchanged, extra heater power is needed to keep the hotplate temperature

A joint effort towards more sustainable track processes

Alternative underlayer crosslinking processes & materials





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Impact of new processes on patterning

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Alternative crosslinking process

brewer science
Light-curable SOC/SOG materials

Traditional:

Thermal crosslinking process

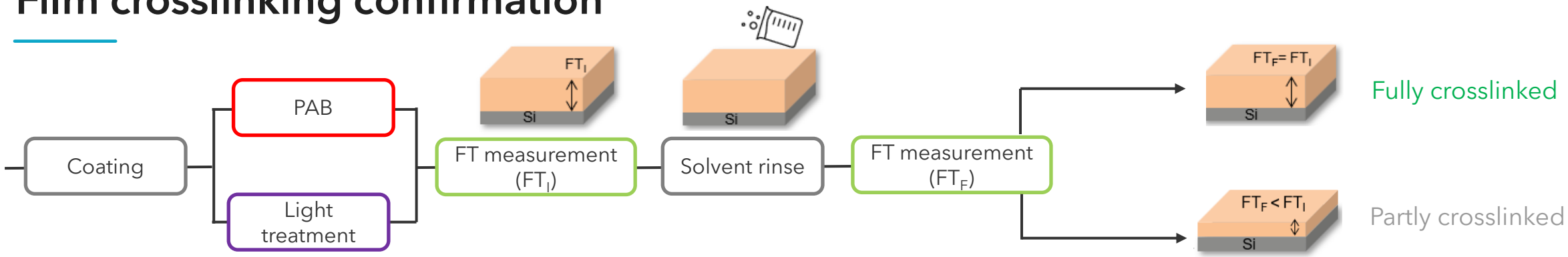
Coating → PAB →

New concept:

Optical crosslinking process

Coating → Light treatment <500mJ/cm^2

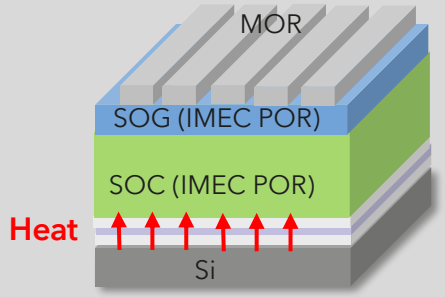
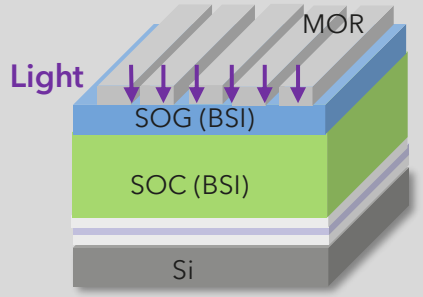
Film crosslinking confirmation



Thickness loss after strip: > 5% / < 5% / 0%		Bake Temperature		
		Spin-On Carbon (SOC)		
		Thermal curable (IMEC POR)		Light curable (BSI)
		180°C → 350°C	No bake	No bake
Exposure dose (mJ/cm^2)	0			
	50			
	100			
	200			
	800			
	1000			

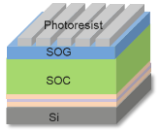
SOC & SOG light curable materials can be fully crosslinked without heat, using very low dose

Patterning Performance assessment

	Thermal crosslinking	Optical crosslinking
Material Stack		
SOC	Bake 1: 180°C 60s Bake 2: 350°C 60s	200mJ/cm^2
SOG	220°C 60s	200mJ/cm^2
Pattern	14L28P	

How does the performance of a stack composed with underlayers optically crosslinked compare to a standard stack?

Assessment of Patterning Performance

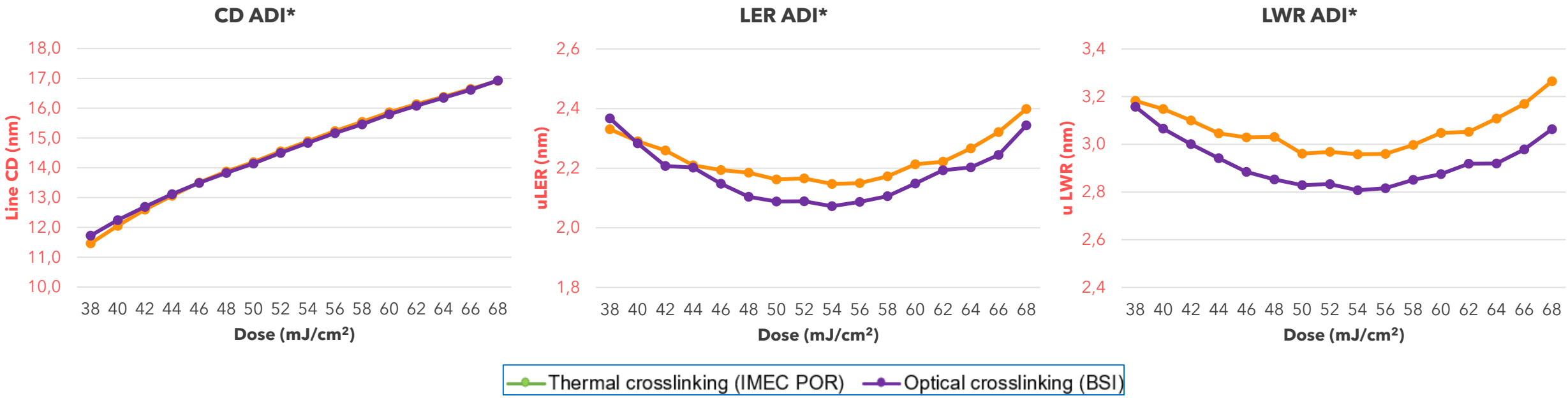


14L28P

FRACTILIA

*20 images collected per dose

Crosslinking mechanism	SOC curing	SOG curing	Dose-to-size (mJ/cm²)	uLER (nm)	uLWR (nm)	DOF (nm)	EL (%)
Thermal crosslinking (IMEC POR)	Bake 1: 180°C 60s Bake 2: 350°C 60s	220°C 60s	50	2.16	2.96	90	24.27
Optical crosslinking	200mJ/cm²	200mJ/cm²	50	2.09	2.83	98	26.69



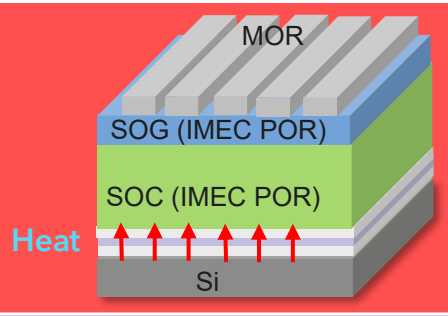
Optical crosslinked materials show very competitive lithography performance

Cross-section SEM images

14L28P

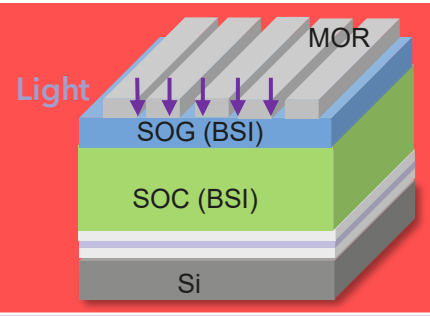
Thermal crosslinking

SOC: 180°C 60s + 350°C 60s
SOG: 220°C 60s

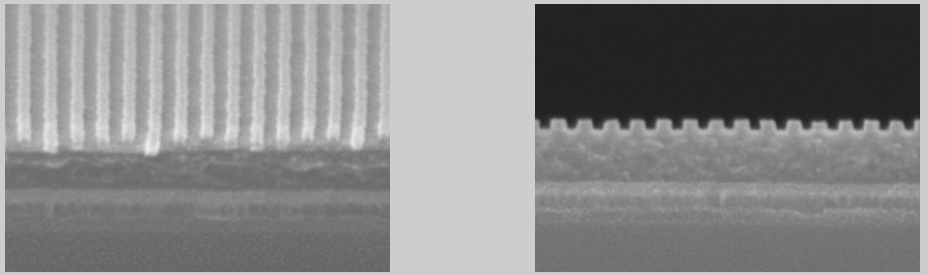


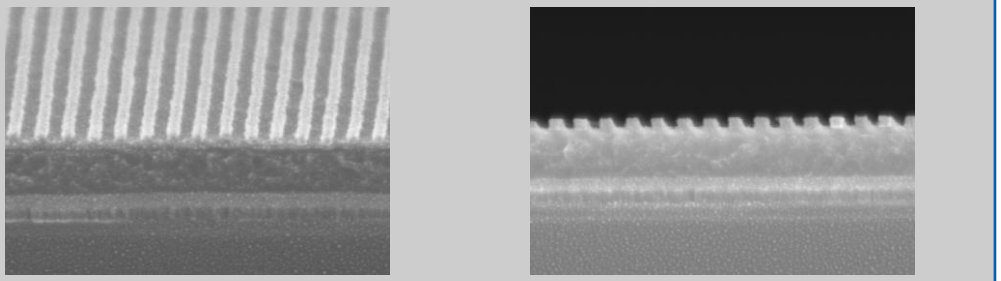
Optical crosslinking

SOC: 200mJ/cm²
SOG: 200mJ/cm²



ADI





Cross-section images for both approaches are showing comparable profiles

Is optical crosslinking a truly energy efficient approach?

imec SSTS PROGRAM

Sustainable Semiconductor Technologies and Systems

Power measurements carried out under imec SSTS umbrella:

SCREEN DT-3000

Standard approach

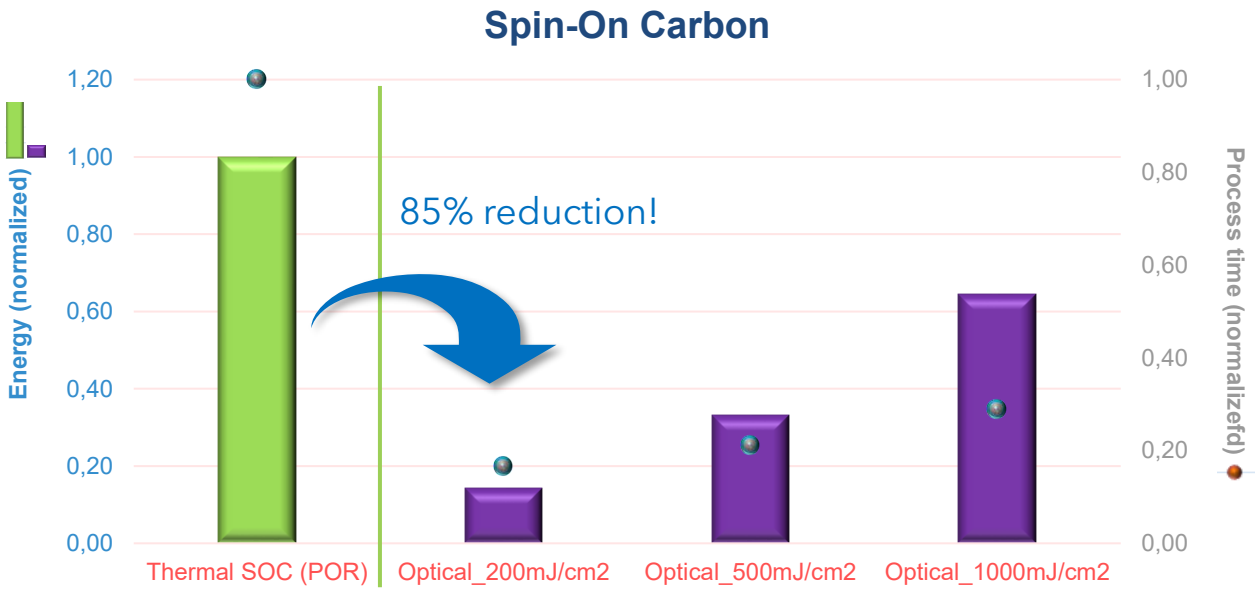
Optical approach

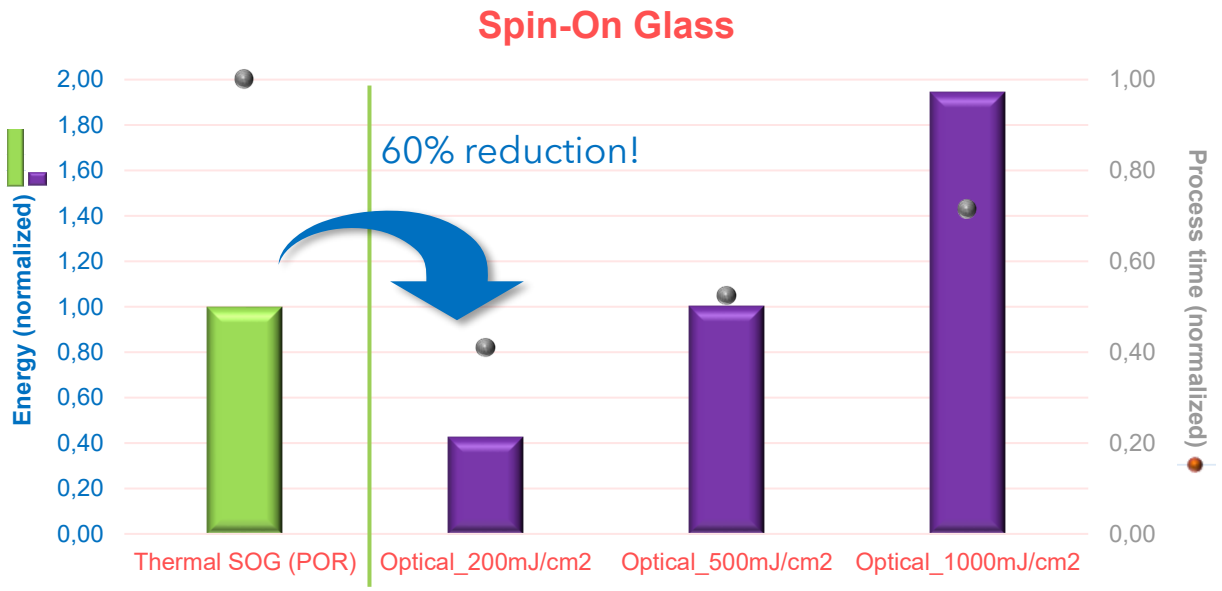
Thermal crosslinking

Exposure unit

- High dose
- High throughput

Process benchmark





Optical crosslinking leads to significant savings of energy and process time, without compromising litho performance

Take-away

Collaboration across the semiconductor supply chain is THE KEY to create a more sustainable industry!

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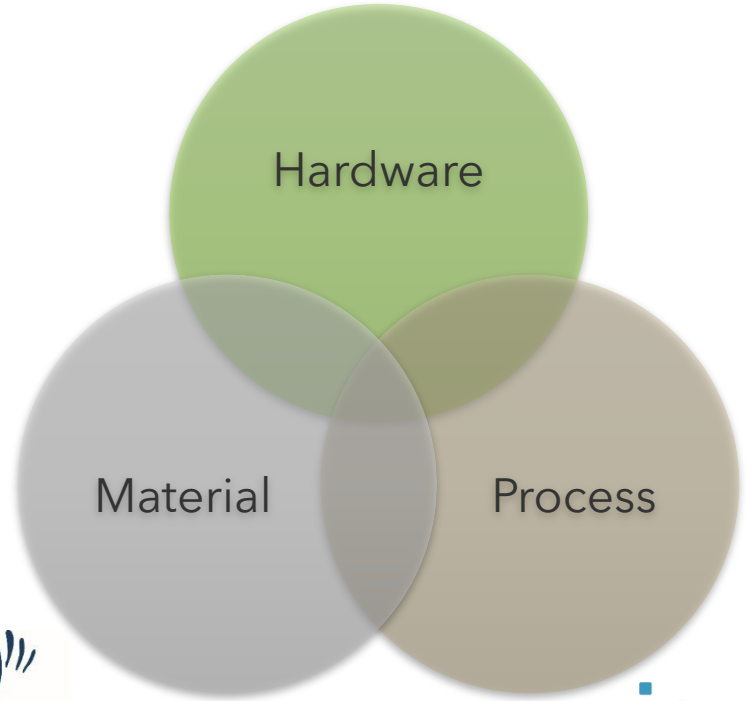

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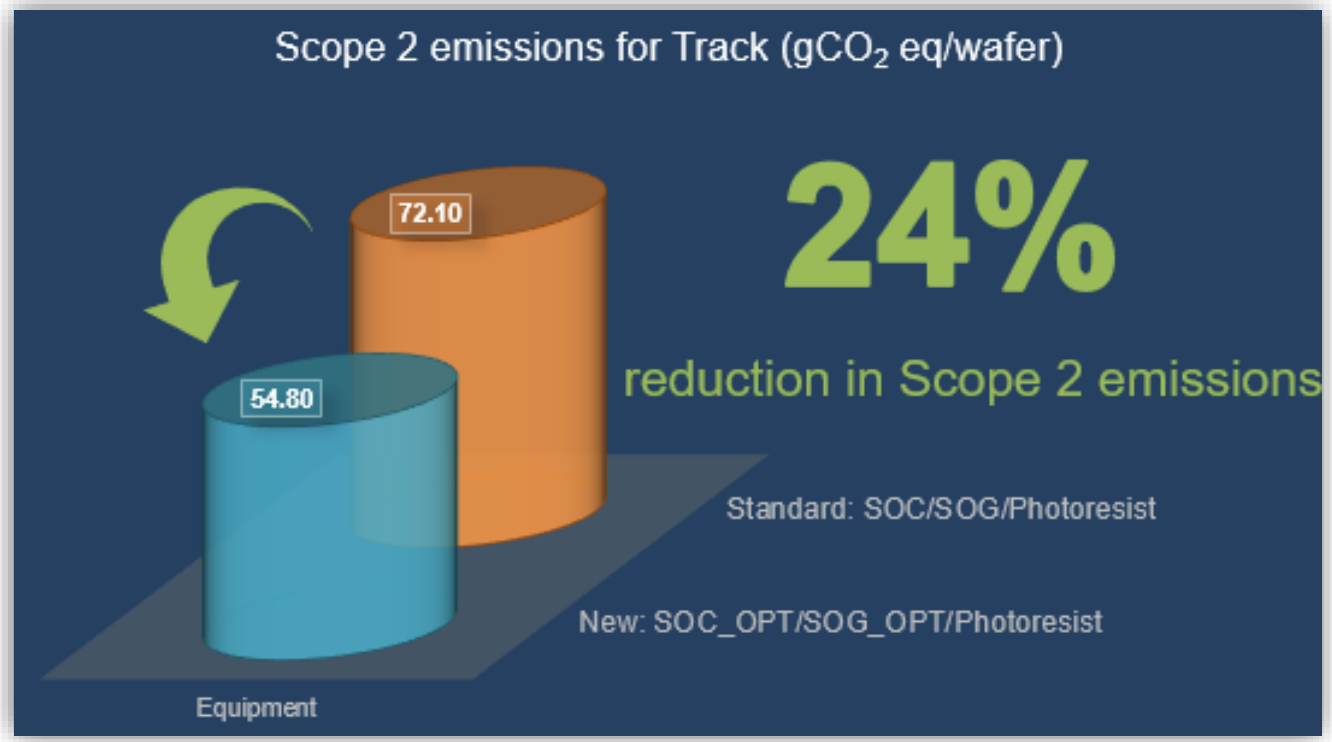

SCREEN is continuously seeking and evaluating solutions to reduce greenhouse gas emissions and material utilization for a more sustainable semiconductor industry

Acknowledgements:

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Bram Vangestel

Alexander Dockx

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