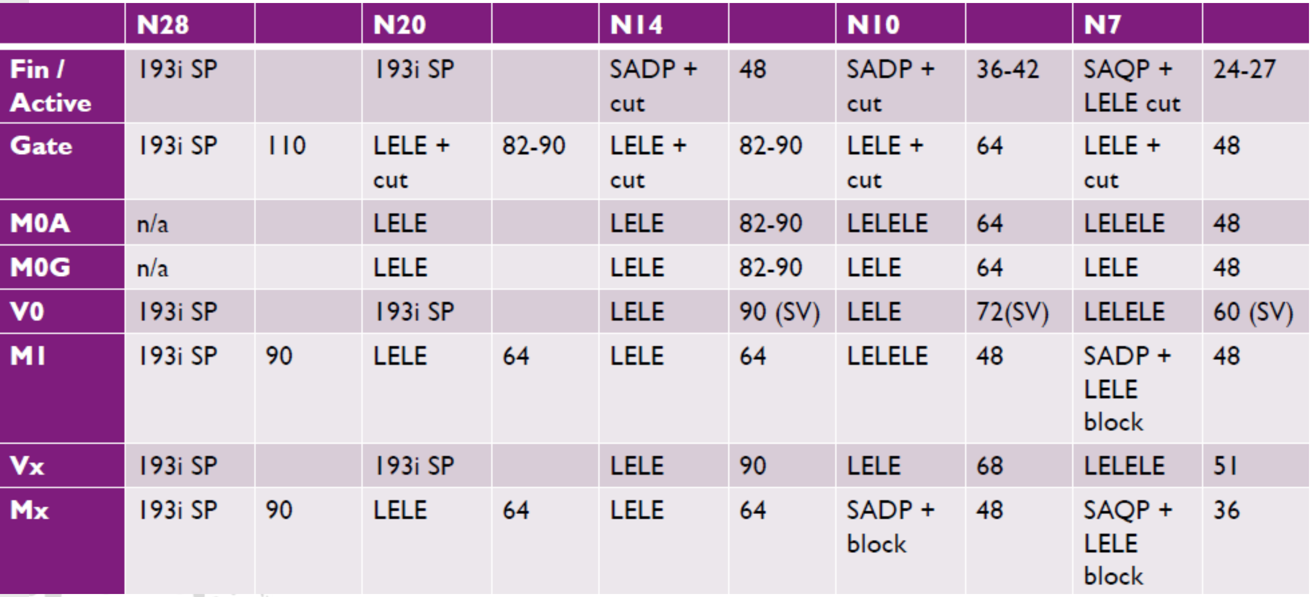
Laser-produced plasma source productivity

Erik R. Hosler

Expectations for EUV Manufacturing

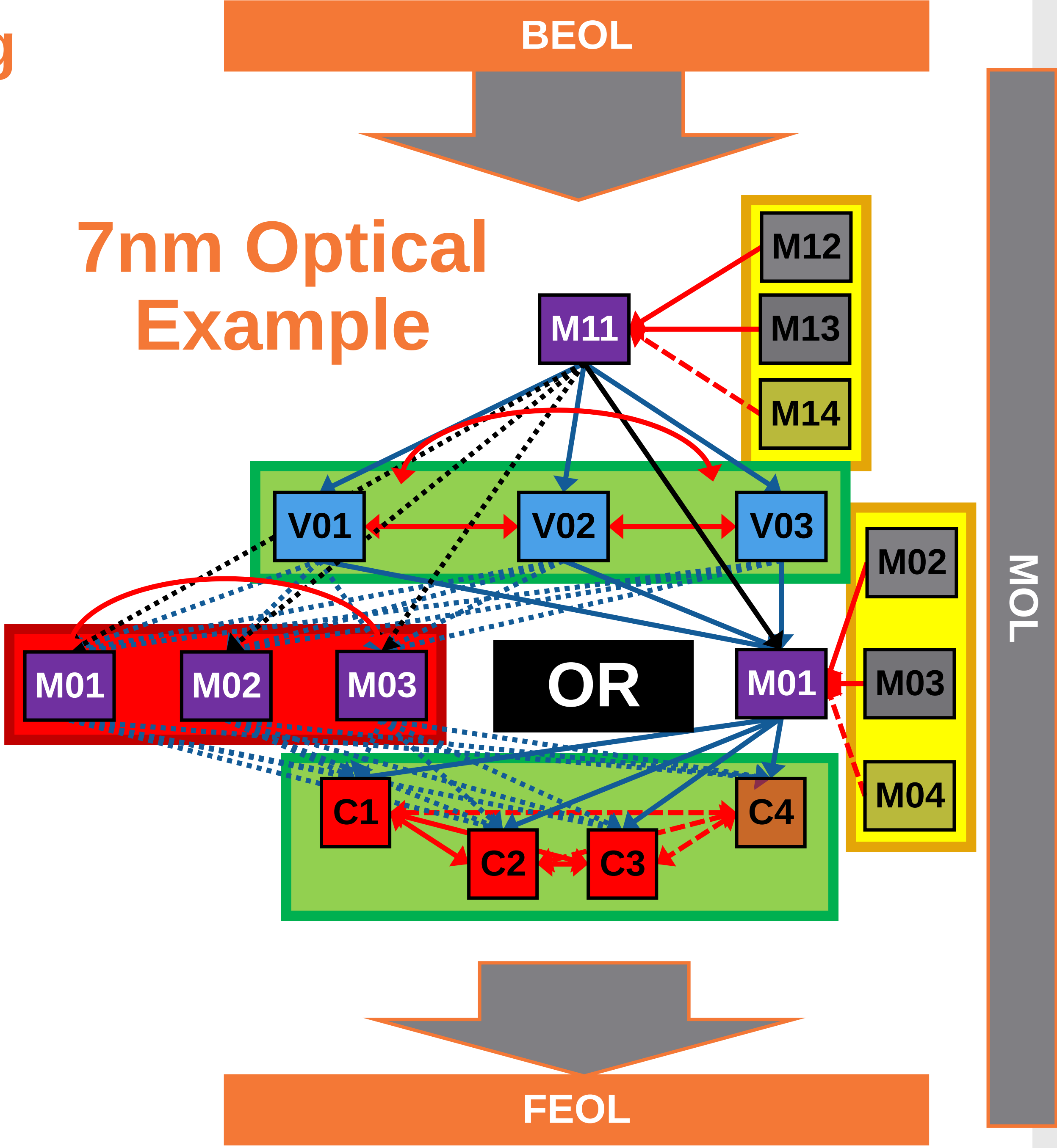
Cost Effectiveness

- EUV insertion…7nm? 5nm? Beyond?
  - LELE → LELELE → SADP/SAQP
- Productivity is key
- Need lithography performance at dose
  - Imaging, Overlay, Resolution, LER/LWR/T2T…
- Mask defectivity: Blank + ~~Adders~~



	N28		N20		N14		N10		N7	
Fin / Active	193i SP		193i SP		SADP + cut	48	SADP + cut	36-42	SAQP + LELE cut	24-27
Gate	193i SP	110	LELE + cut	82-90	LELE + cut	82-90	LELE + cut	64	LELE + cut	48
M0A	n/a		LELE		LELE	82-90	LELELE	64	LELELE	48
M0G	n/a		LELE		LELE	82-90	LELE	64	LELE	48
V0	193i SP		193i SP		LELE	90 (SV)	LELE	72(SV)	LELELE	60 (SV)
M1	193i SP	90	LELE	64	LELE	64	LELELE	48	SADP + LELE block	48
Vx	193i SP		193i SP		LELE	90	LELE	68	LELELE	51
Mx	193i SP	90	LELE	64	LELE	64	SADP + block	48	SAQP + LELE block	36

IMEC Patterning Comparison. Semiengineering.com.



7nm Optical Example

EUV Exposure Tool

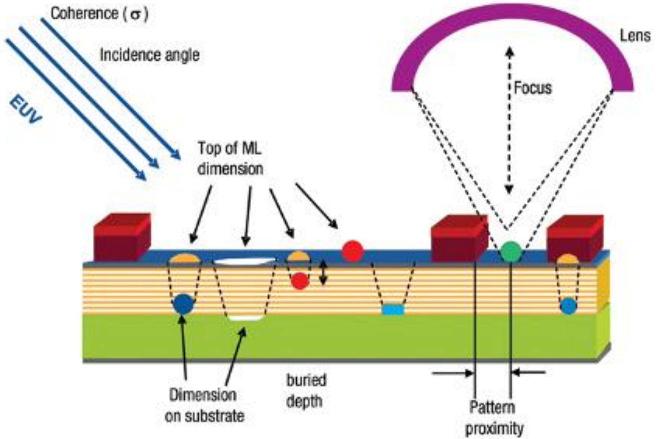
- 20+ years in development
- HVM insertion is coming…but when?
- Predictive Modeling Helps
  - ‘Bottoms-up’ predictive calculation of EUV source availability
    - Frequency of scheduled service events
  - Availability estimated for scanner, track and mask handling requirements
  - Throughput calculated via tool parameters and exposure conditions
  - Power → Pulses → Scan Speed
  - Avg. WPD with collector decay

Availability
DGEN Swap Time (hr)
DGEN lifetime (hr)
TCD lifetime (# of DGENs)
Added TCD Time (hr)
Reflectivity Decay (%/Gp)
Collector Swap Time (hr)
Time Period (hrs)
DGEN swaps (SOLVE, MIN)
TCDs (#)
Collector Lifetime (Gp)
Collector swap Calculator
Maintence Time (hr)
AVL Time (hr)
Total Time (hr)
Source AVL
Scanner AVL
Track AVL
Estimated USD
Mask Handling/Inspection Loss
Cluster Avalability

Throughput
Source Power (W)
Pellicle Transmission
Pellicalized Source Power
Duty Cycle (%)
Field_x (mm)
Field_y (mm)
Field Utilization
Scanner Utilization
Overall equipment effectiveness
Dose Margin (%)
Pulse Energy (mJ)
EUV Transmission Divisor
SLIE (mJ/cm)
Die Length plus overscan (cm)
Dies/Wafer
Die OH (s)
Wafer OH (s)
Lot OH (s)
Lot Size (wfs)
f_source

Cluster Availability

- Scheduled Services: Calculated
  - Droplet generator replacement
  - Collector replacement
  - Empty tin catch
- Unscheduled Service: SDT=UDT
  - Droplet generator failures
  - Drive laser failures
  - Hydrogen/abatement faults
- Scanner/Track: minor impact
  - Assume NXT performance
- Mask handling and inspection



Availability
DGEN Swap Time (hr)
DGEN lifetime (hr)
TCD lifetime (# of DGENs)
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Reflectivity Decay (%/Gp)
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Collector swap Calculator
Maintence Time (hr)
AVL Time (hr)
Total Time (hr)
Source AVL
Scanner AVL
Track AVL
Estimated USD
Mask Handling/Inspection Loss
Cluster Avalability

Throughput

- Source Power
  - pulse energy → scan speed
  - Optics performance
- Product layout
- Overall Equipment Effectiveness (OEE)
- Fab Operations
- Wafers out per day, averaged
  - collector degradation
  - service time
- Cost per wafer

Capacity Model

Day	Collector Reflectivity (%)	Productivity (WPD)	Pulse Fired (GP)
1	100.00	1622	1.4
2	99.73	1618	2.7
3	99.46	1613	4.1
4	99.19	1609	5.4
5	98.92	1604	6.7

Total Costs
Total EUV OpEx Cost (M€)
Total NXE:3400 Cost (M€)
Depreciation Timescale (yrs)
Annual Total EUV Cost (M€)
Cost Per wafer out (€)

Layer 1
Dose 1 (mJ/cm^2)
Layer 1
Pupil Efficiency (%)
Scan Speed (cm/s)
Layer 1 Pulses Fired (Gp)
Time Layer 1 (s)

Throughput
Source Power (W)
Pellicle Transmission
Pellicalized Source Power
Duty Cycle (%)
Field_x (mm)
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Field Utilization
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Overall equipment effectiveness
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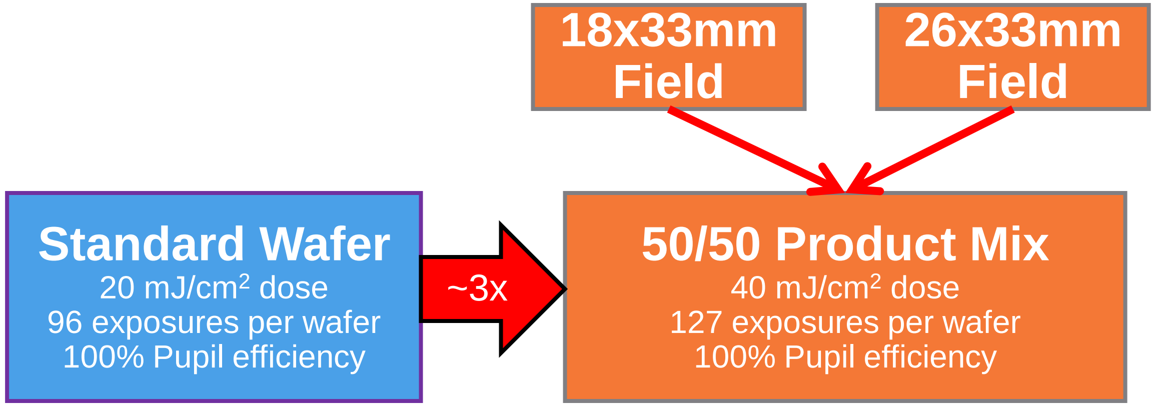
Dies/Wafer
Die OH (s)
Wafer OH (s)
Lot OH (s)
Lot Size (wfs)
f_source

ASML Standard Wafer to Product Layouts

- Standard Wafer to Product Wafers
- Base Calculation Conditions
- Calculate with respect to LELELE cost parity (immersion throughput)



18x33mm Field

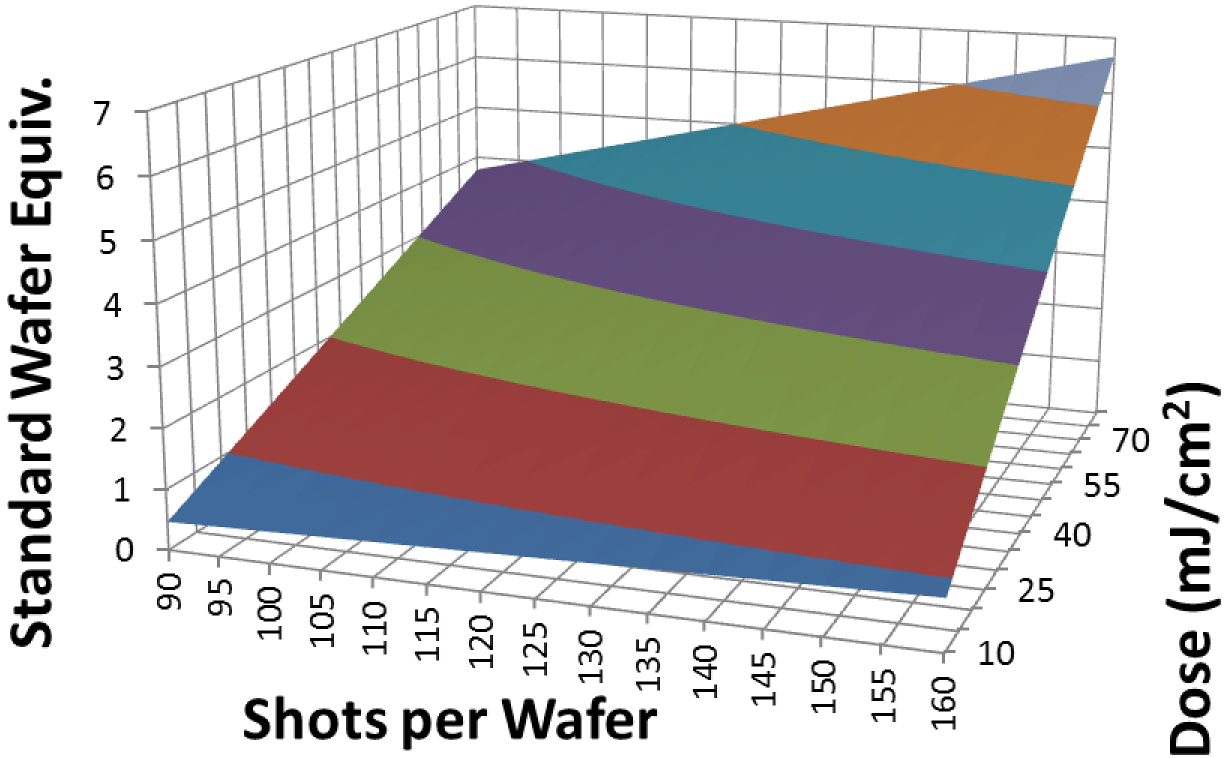
26x33mm Field

Standard Wafer
20 mJ/cm² dose
96 exposures per wafer
100% Pupil efficiency

~3x

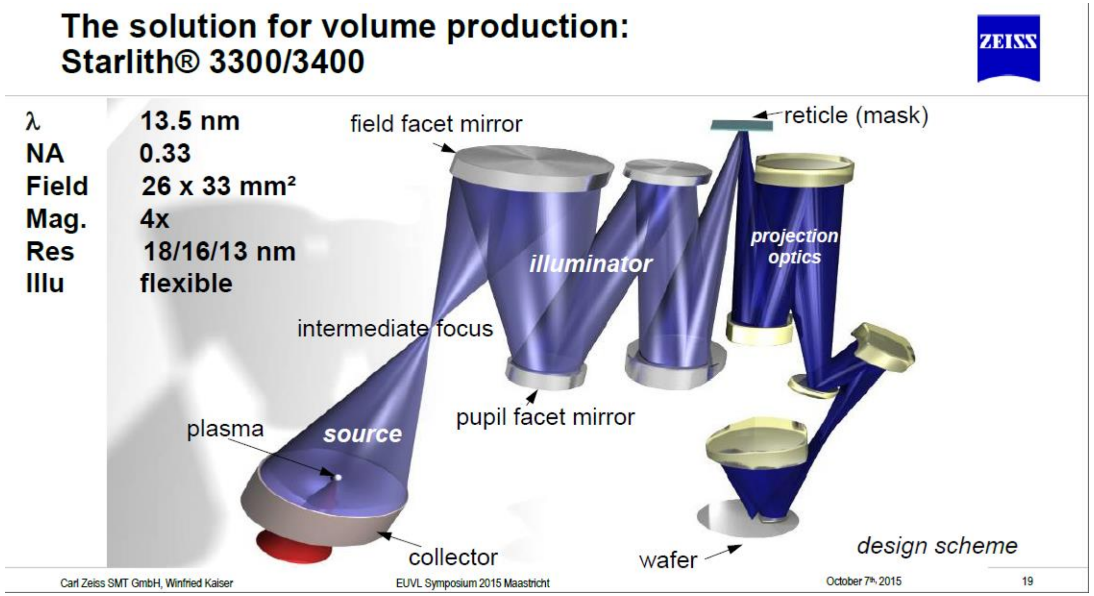
50/50 Product Mix
40 mJ/cm² dose
127 exposures per wafer
100% Pupil efficiency

NXE:3400 Model Variables			
Initial Soure Power (W)		SDT	UDT
250		10%	10%
Cluster Availability	Utilization	OEE	Field Utilization
73%	90%	66%	51%
Collector Degradation (%/Gp)		Dose (mJ/cm^2)	Shots/Wafer
0.2		40	127



Optics Transmission

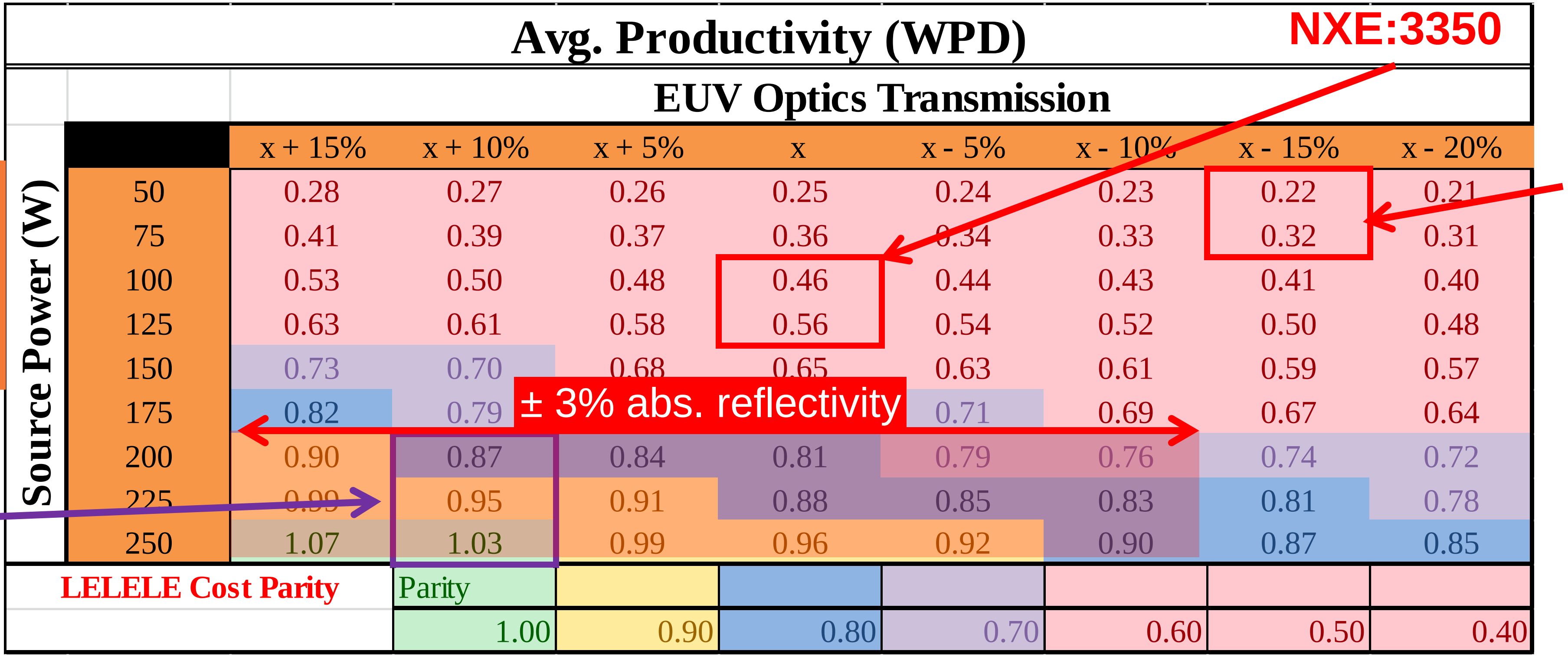
- Incorporates ‘ALL’ components
- Substantial improvements each generation
- Single optic variation ±few abs %...



The solution for volume production:
Starlith® 3300/3400

λ	13.5 nm
NA	0.33
Field	26 x 33 mm²
Mag.	4x
Res	18/16/13 nm
Illu	flexible

Carl Zeiss SMT GmbH, Winfried Kaiser
EUVL Symposium 2015 Maastricht
October 7th 2015
19



Avg. Productivity (WPD)

EUV Optics Transmission

Source Power (W)	x + 15%	x + 10%	x + 5%	x	x - 5%	x - 10%	x - 15%	x - 20%
50	0.28	0.27	0.26	0.25	0.24	0.23	0.22	0.21
75	0.41	0.39	0.37	0.36	0.34	0.33	0.32	0.31
100	0.53	0.50	0.48	0.46	0.44	0.43	0.41	0.40
125	0.63	0.61	0.58	0.56	0.54	0.52	0.50	0.48
150	0.73	0.70	0.68	0.65	0.63	0.61	0.59	0.57
175	0.82	0.79			0.71	0.69	0.67	0.64
200	0.90	0.87	0.84	0.81	0.79	0.76	0.74	0.72
225	0.99	0.95	0.91	0.88	0.85	0.83	0.81	0.78
250	1.07	1.03	0.99	0.96	0.92	0.90	0.87	0.85
LELELE Cost Parity		Parity						
		1.00	0.90	0.80	0.70	0.60	0.50	0.40

± 3% abs. reflectivity

NXE:3350

NXE:3300

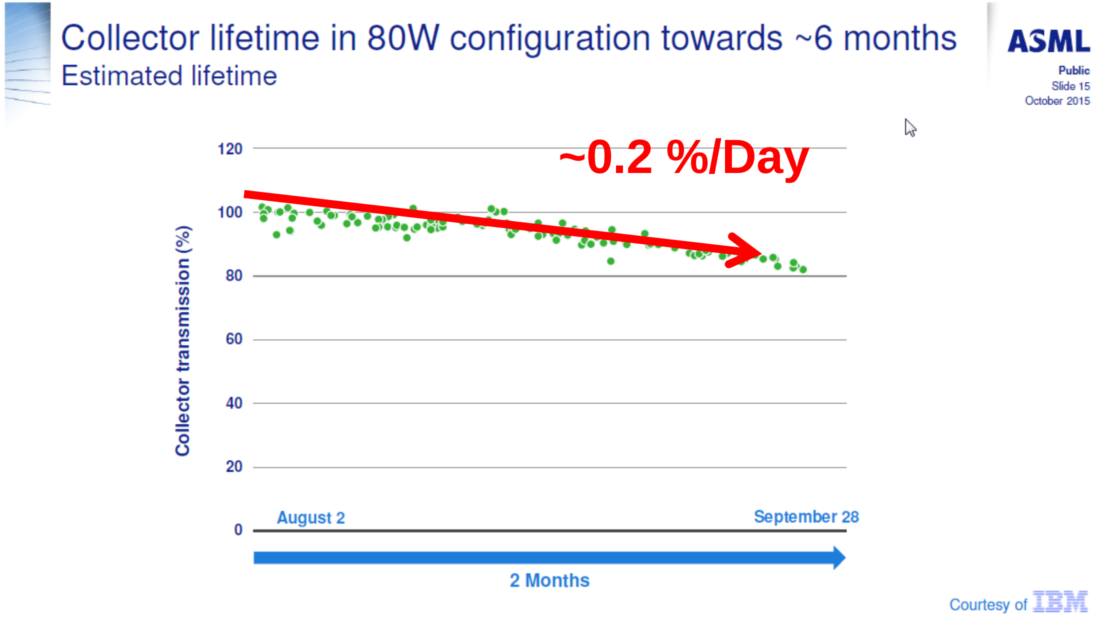
NXE:3400

Cost parity of 1 indicates patterning cost equivalence to LELELE

Kaiser, W. EUVL Symposium 2015. Maastrict, Netherlands.

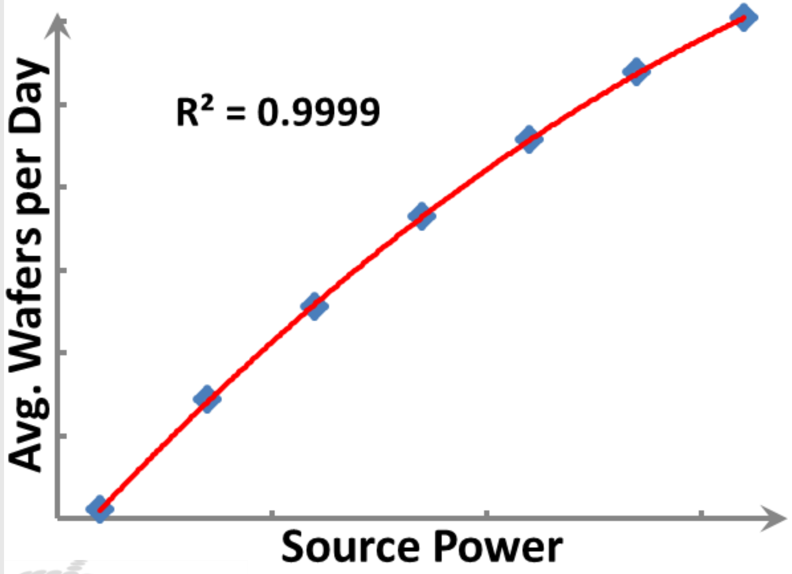
Collector Degradation Rate

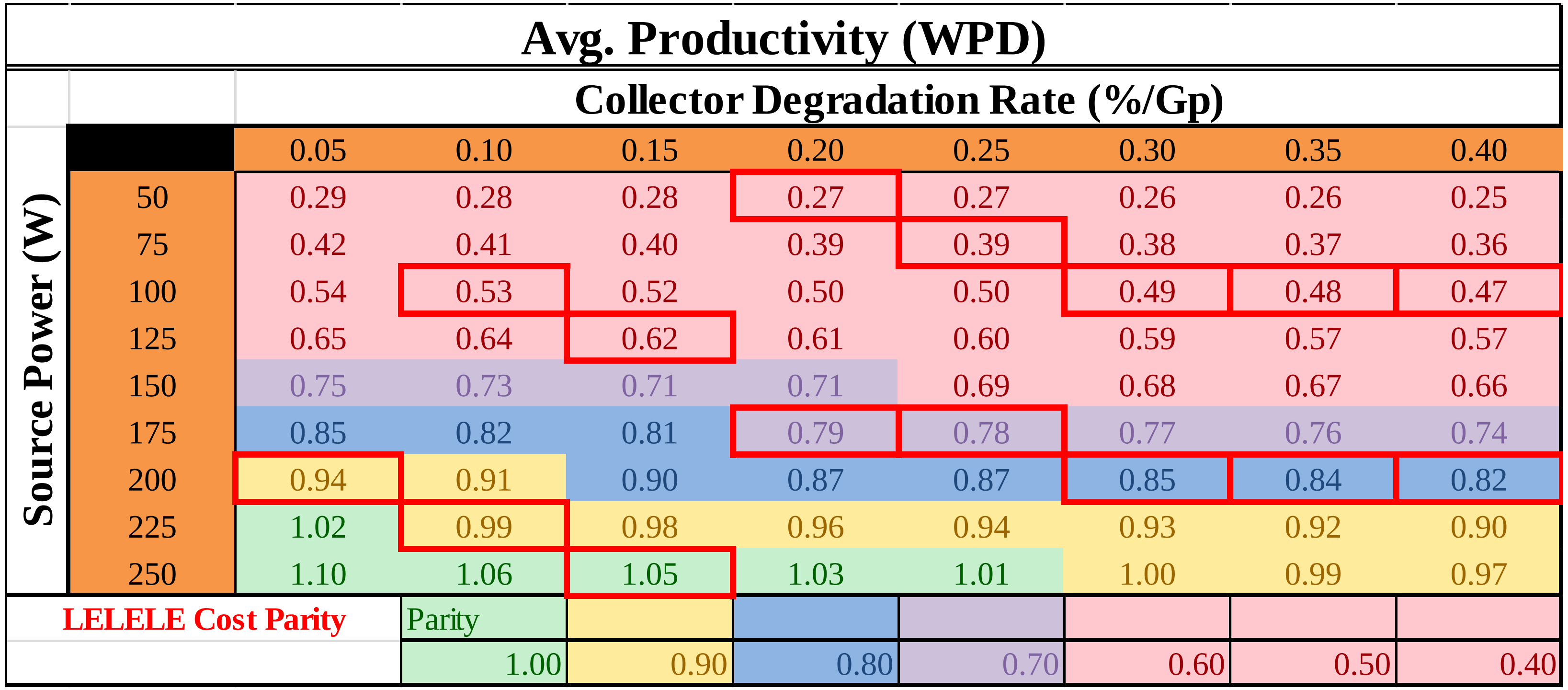
- WPD vs. Source power and Collector Contamination
- Source power vs. throughput
  - Non-linear w.r.t. average WPD
- Pulse energy
- Critical transition at 0.2 %/Gp
- Spans 2x swaps – criterion dependent



Collector lifetime in 80W configuration towards ~6 months

Estimated lifetime





Avg. Productivity (WPD)									
		Collector Degradation Rate (%/Gp)							
		0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40
Source Power (W)	50	0.29	0.28	0.28	0.27	0.27	0.26	0.26	0.25
	75	0.42	0.41	0.40	0.39	0.39	0.38	0.37	0.36
	100	0.54	0.53	0.52	0.50	0.50	0.49	0.48	0.47
	125	0.65	0.64	0.62	0.61	0.60	0.59	0.57	0.57
	150	0.75	0.73	0.71	0.71	0.69	0.68	0.67	0.66
	175	0.85	0.82	0.81	0.79	0.78	0.77	0.76	0.74
	200	0.94	0.91	0.90	0.87	0.87	0.85	0.84	0.82
	225	1.02	0.99	0.98	0.96	0.94	0.93	0.92	0.90
	250	1.10	1.06	1.05	1.03	1.01	1.00	0.99	0.97
LELELE Cost Parity			Parity						
			1.00	0.90	0.80	0.70	0.60	0.50	0.40

Pirati, A. EUVL Symposium 2015. Maastrict, Netherlands.

Cautious Performance Prediction

- Cautiously optimistic parameters…
- 6 collector swaps per year
- Expected NXE:3400 optics performance
- ~3x Standard Wafers
- Achieves cost parity with LELELE

NXE:3400 Model Variables

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250		10%	10%
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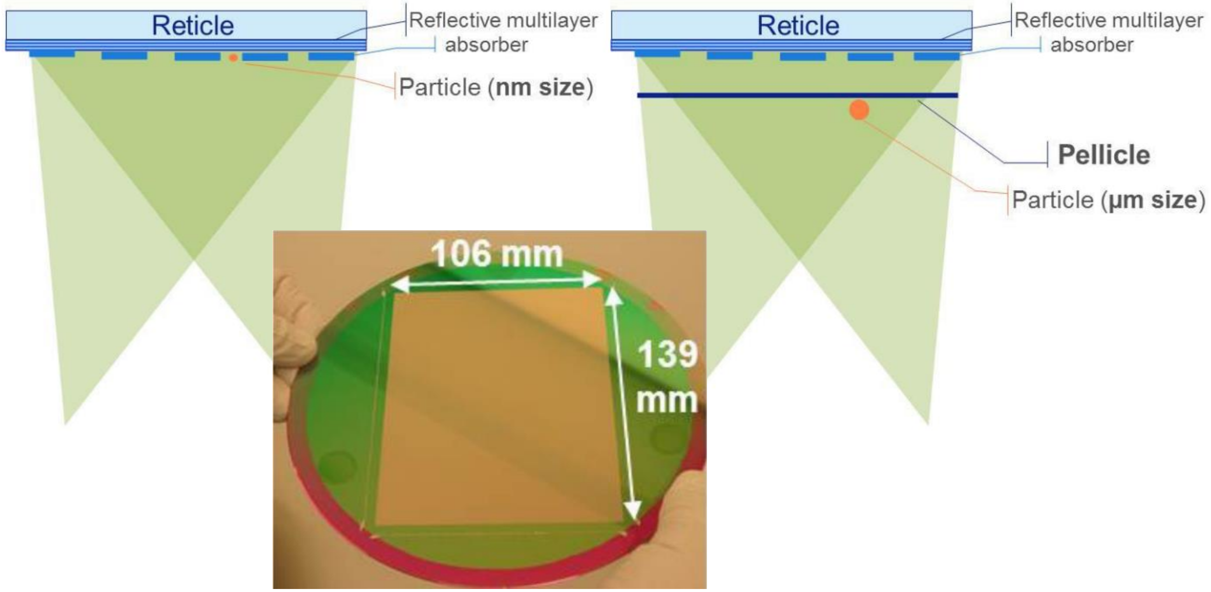
73%	90%	66%	51%
Collector Degradation (%/Gp)		Dose (mJ/cm^2)	Shots/Wafer
0.2		40	127

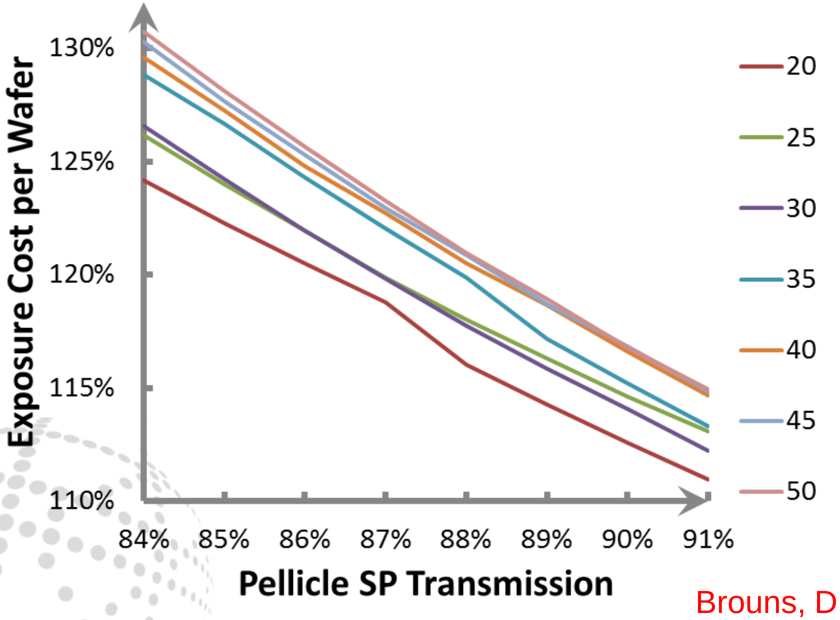
Avg. Productivity (WPD)

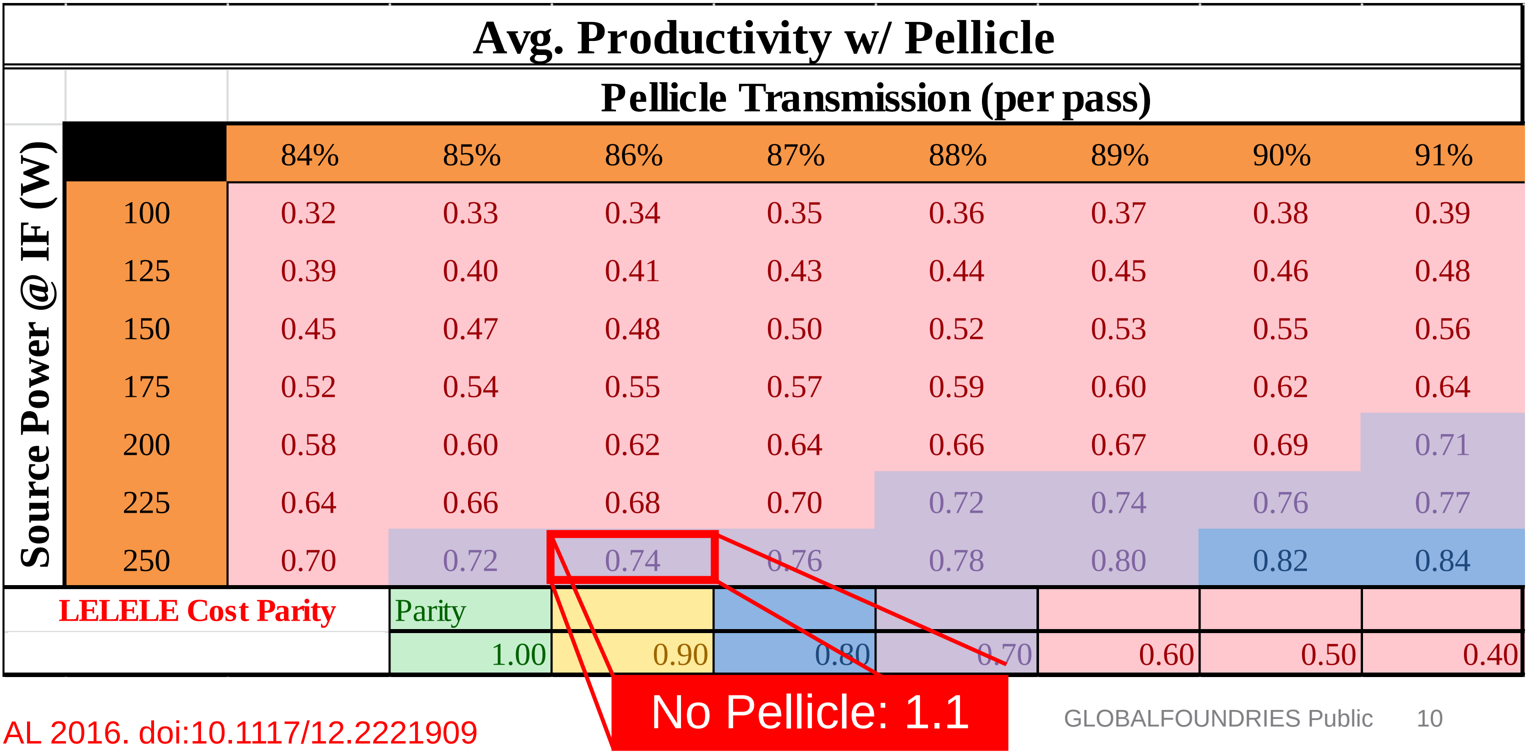
	Dose (mJ/cm^2)							
Source Power (W)	20	25	30	35	40	45	50	60
100	1.0	0.8	0.7	0.6	0.6	0.5	0.5	0.4
125	1.1	1.0	0.8	0.7	0.7	0.6	0.6	0.5
150	1.3	1.1	1.0	0.9	0.8	0.7	0.7	0.6
175	1.4	1.2	1.1	1.0	0.9	0.8	0.7	0.6
200	1.5	1.3	1.2	1.1	1.0	0.9	0.8	0.7
225	1.6	1.4	1.3	1.1	1.0	1.0	0.9	0.8
250	1.7	1.5	1.3	1.2	1.1	1.0	1.0	0.8
LELELE Cost Parity		Parity						
		1.00	0.90	0.80	0.70	0.60	0.50	0.40

Pellicle Impact on Productivity

- Best EUV transmission: 86% single pass
  - 56 nm material (pSi + capping)
- Source power vs. throughput
  - Non-linear w.r.t. average WPD
- 2x pellicles (3-passes)
- 90% Transmission Target?
  - 27% transmission loss
  - Max ~180 W operation
  - >15% increase in exposure cost







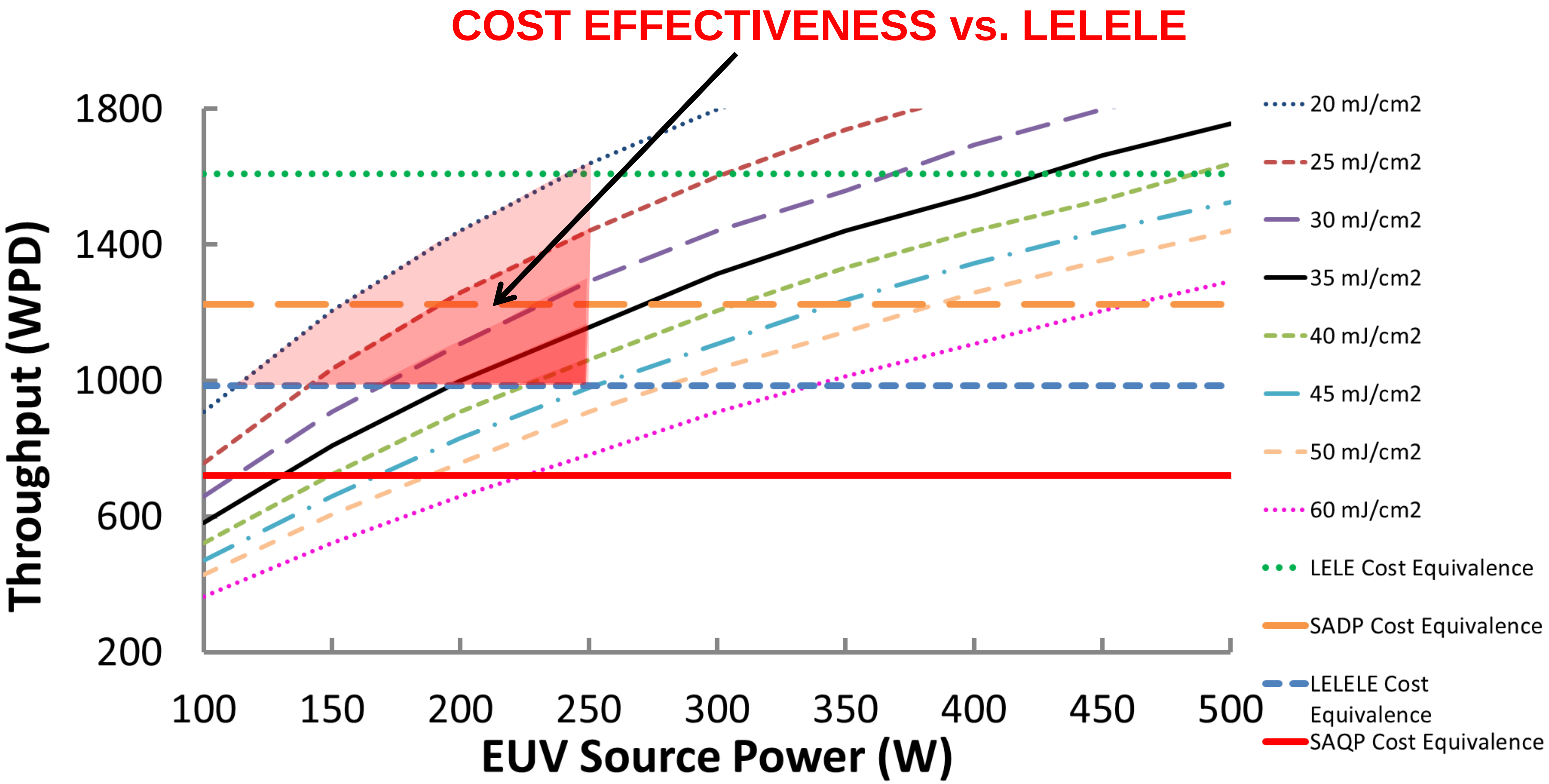
Avg. Productivity w/ Pellicle

	Pellicle Transmission (per pass)							
Source Power @ IF (W)	84%	85%	86%	87%	88%	89%	90%	91%
100	0.32	0.33	0.34	0.35	0.36	0.37	0.38	0.39
125	0.39	0.40	0.41	0.43	0.44	0.45	0.46	0.48
150	0.45	0.47	0.48	0.50	0.52	0.53	0.55	0.56
175	0.52	0.54	0.55	0.57	0.59	0.60	0.62	0.64
200	0.58	0.60	0.62	0.64	0.66	0.67	0.69	0.71
225	0.64	0.66	0.68	0.70	0.72	0.74	0.76	0.77
250	0.70	0.72	0.74	0.76	0.78	0.80	0.82	0.84
LELELE Cost Parity		Parity						
		1.00	0.90	0.80	0.70	0.60	0.50	0.40

No Pellicle: 1.1

Brouns, D. SPIE:AL 2016. doi:10.1117/12.2221909

Patterning Cost



Summary

- Predictive model evaluation of potential high-volume manufacturing EUV scanner productivity
  - Developing confidence in NXE:3400 future manufacturing performance
- Predictive collector decay for reliable wafer productivity
- Reticle pellicle and projection optics box-wafer stage membrane
  - Complete removal of resist outgassing criterion– enablement for novel, low dose materials
  - Must have interdependent engineering of the two membranes
- Without pellicle, EUV remains cost completive with 193i triple patterning for a variety of resist doses
  - Adding pellicle requires a further scaling of resist dose **AND/OR** increased EUV source power

Thank you!

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