Next Generation Source Power Requirements

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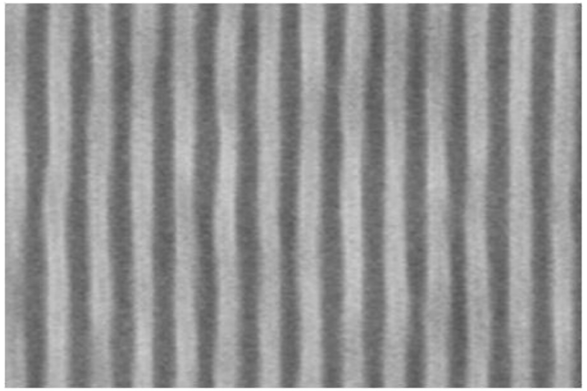
What will we need at the 3 nm node and beyond?

Can laser produced plasma sources continue the roadmap?

Needs to future EUV manufacturing…

Lithography Performance

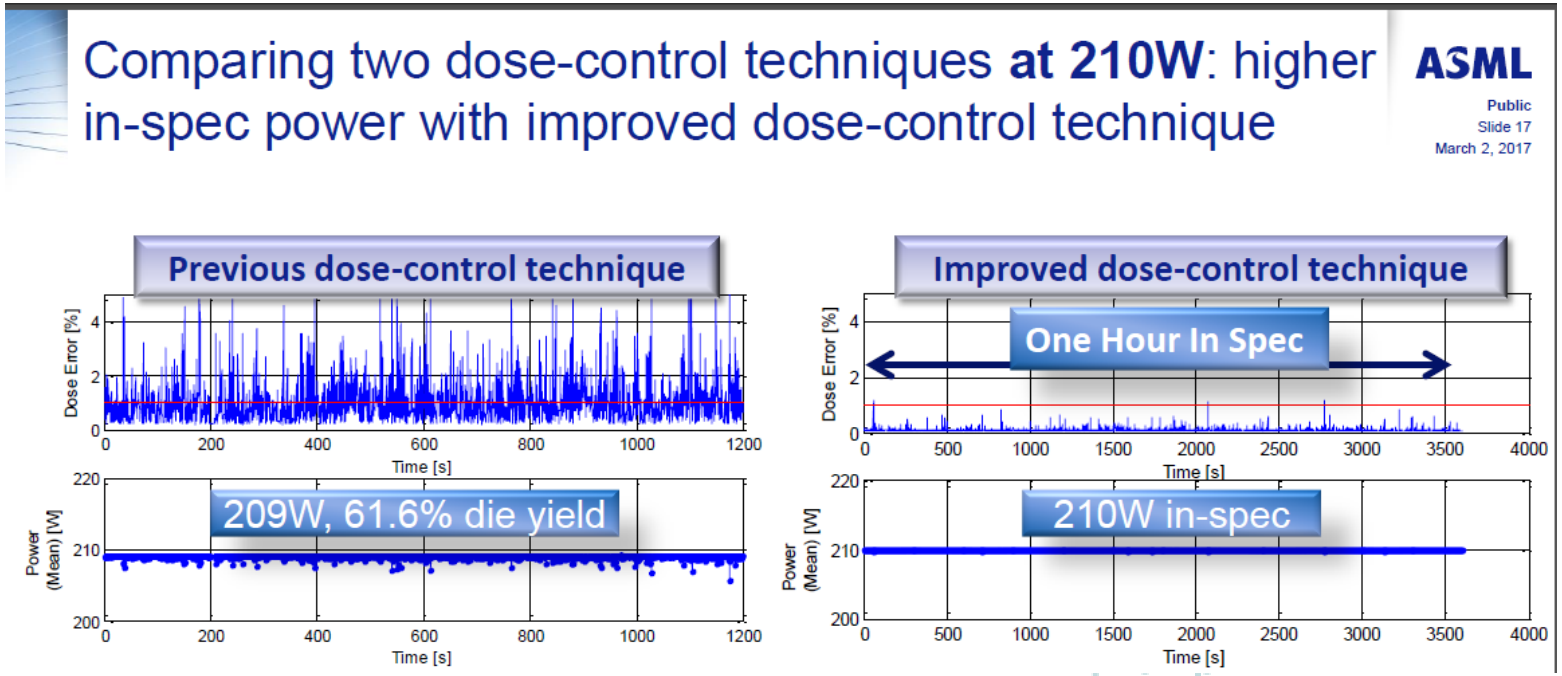
- Resolution
  - Sub-30 nm pitch
- LWR/LER
- LCDU
  - Stochastics
- Productivity



Technology Enablement

- Not a stop-gap for process complexity
- EUV needs to enable technology
- Change of mentality:
  - **NOT** what layers *need* EUV
  - **BUT** what layers ***can be enabled***
- Beyond EUV Insertion
  - Cost parity driven to match LELE
  - Longevity to vertical architecture transistors

Now…



SAMSUNG NEWSROOM

- **7LPP (7nm Low Power Plus):** 7LPP will be the first semiconductor process technology to use an EUV lithography solution. 250W of maximum EUV source power, which is the most important milestone for EUV insertion into high volume production, was developed by the collaborative efforts of Samsung and ASML. EUV lithography deployment will break the barriers of Moore's law scaling, paving the way for single nanometer semiconductor technology generations.

Proc. SPIE 10143, Extreme Ultraviolet (EUV) Lithography VIII, 101431I (5 May 2017); doi: 10.1117/12.2258628

designlines SoC

News & Analysis

Samsung Targets 4nm in 2020

Dylan McGrath
5/24/2017 05:01 PM EDT
5 comments

NO RATINGS
LOGIN TO RATE

Samsung has demonstrated the EUV power source production target of 250W in process development. According to Low, the "magic number" for productivity with EUV is 1,500 wafers per day. Samsung has already exceeded 1,000 wafers per day and has a high degree of confidence that 1,500 wafers per day is achievable, Low said.

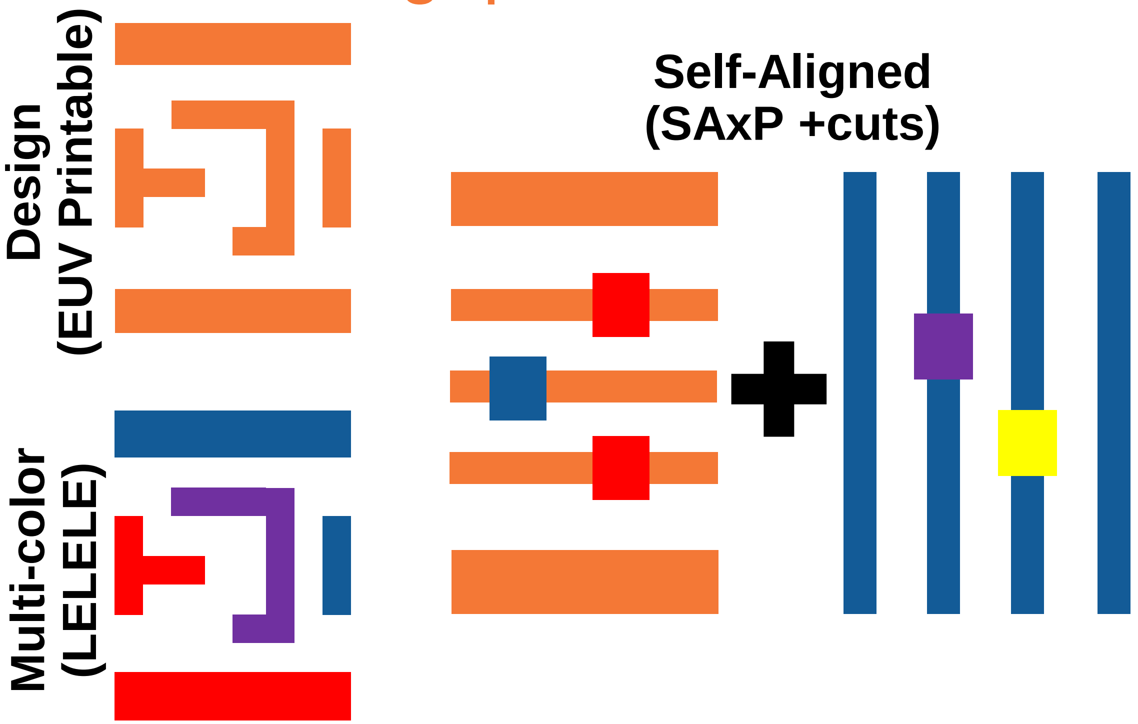
"We are confident that we are ready to bring [EUV] into production in 2018," Low said. "This is no longer a concept roadmap item."

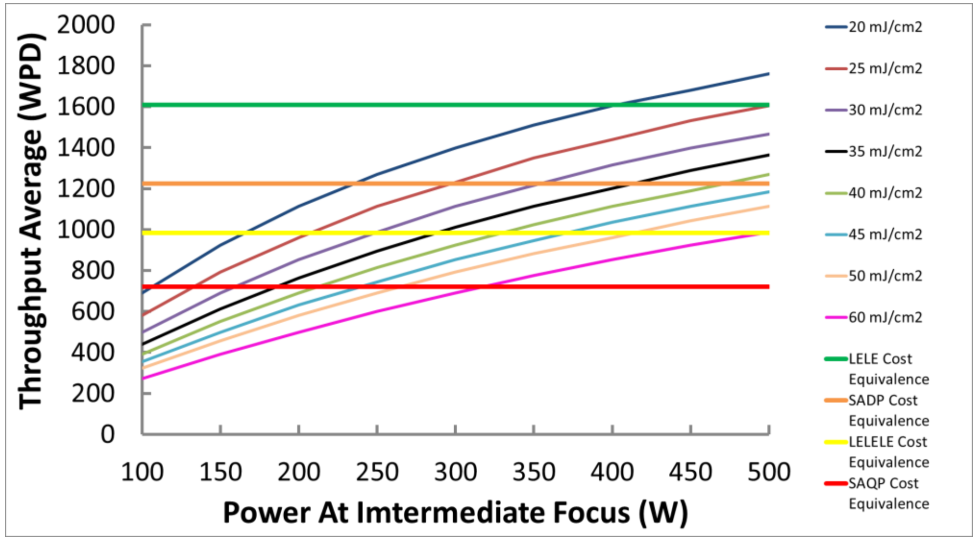
Dose Scaling with Technology and Wafer Throughput

- As target dimensions shrink
  - High-NA option → higher dose
  - NA 0.33 → EUV multi/self-aligned patterning

- Challenge of the middle-of-the-line (MOL)
  - ~2x mask increase per technology generation
    - OVL and Alignment
  - Self-aligned techniques (SAxP) + cuts
    - Design and Process Complexity

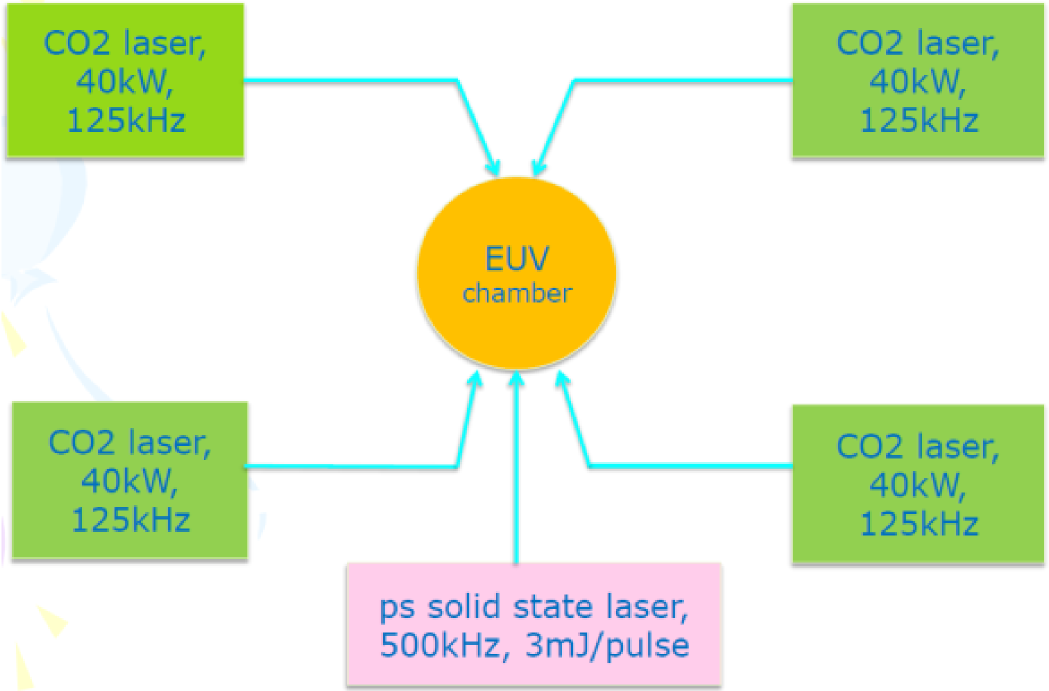
- EUV can reduce the number of cut, contact and via masks
  - Must be cost competitive





What EUV source will drive next generation fabs?

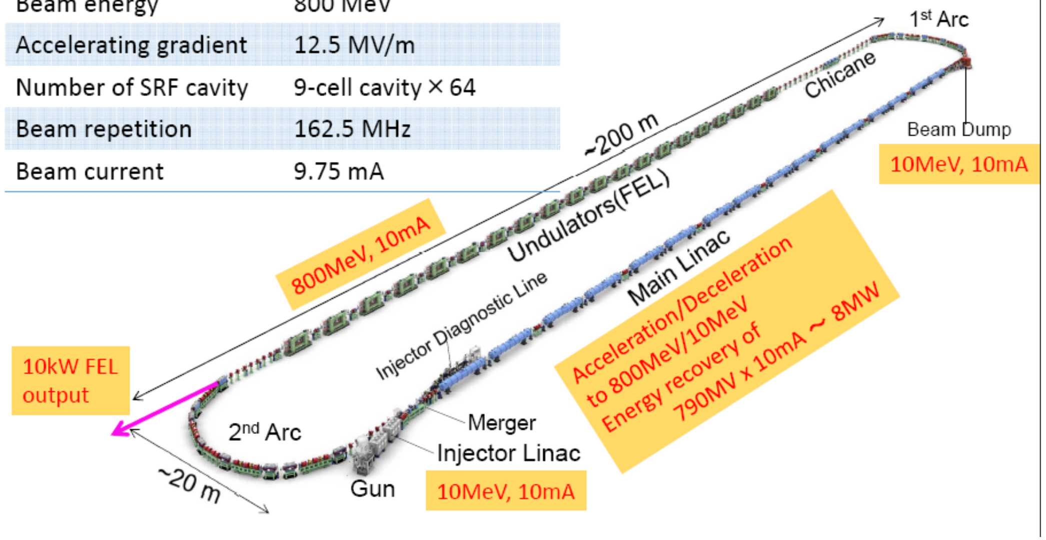
Advanced Laser Produced Plasma



Free-Electron Lasers

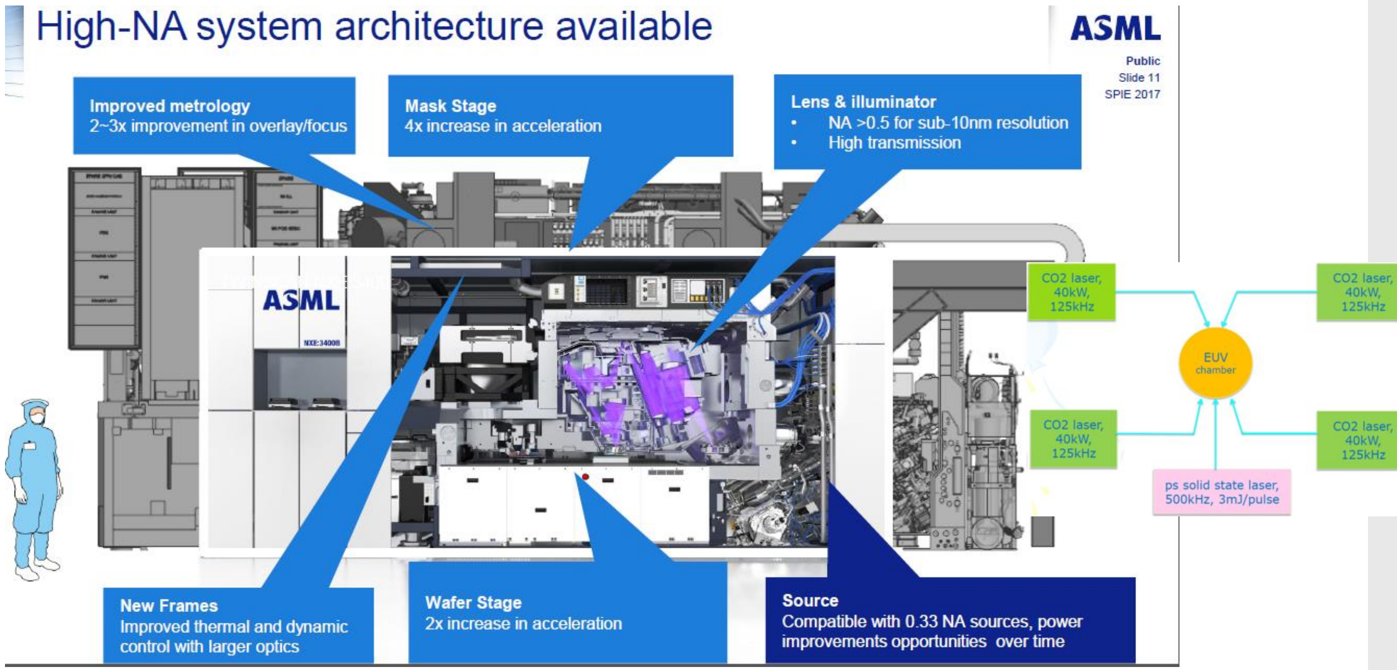
Parameter	Specification
Wavelength	13.5 nm
Output power	10 kW
Bunch chare	60 pC
Beam energy	800 MeV
Accelerating gradient	12.5 MV/m
Number of SRF cavity	9-cell cavity × 64
Beam repetition	162.5 MHz
Beam current	9.75 mA

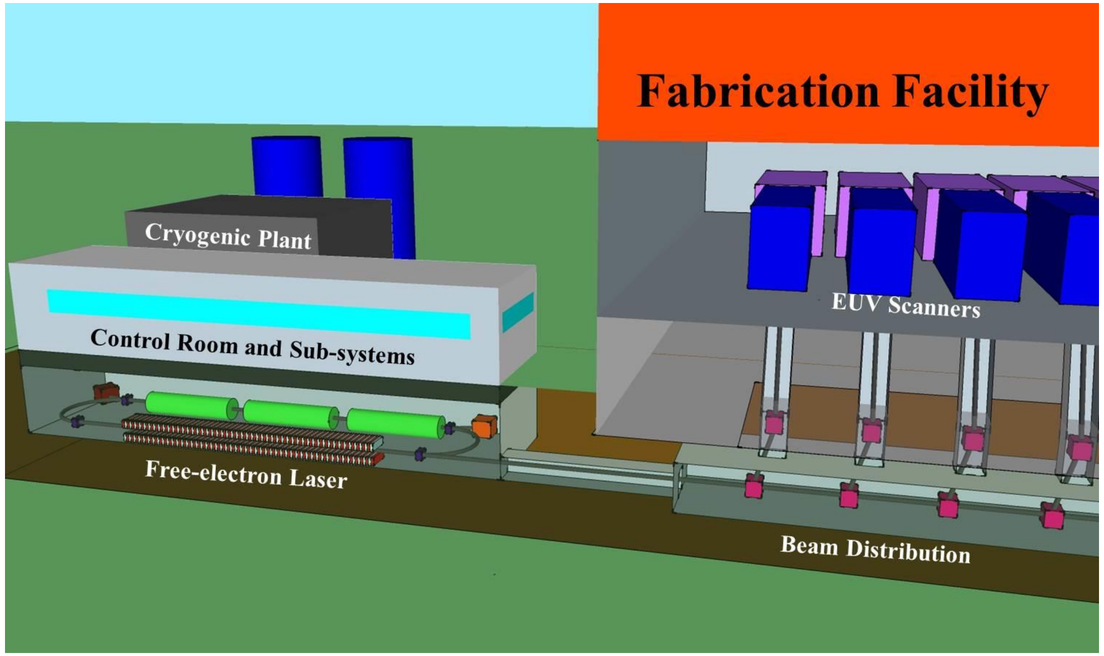
EUV-FEL Design



Next Generation Fabs…

- Necessary infrastructure changes
  - Larger fabs
- Increased CapEx investment in facility and equipment
- High-NA tools, greater productivity at 0.33 NA or increased number of EUV tools?





Pirati, A., et al. Proc. SPIE 10143, Extreme Ultraviolet (EUV) Lithography VIII, 101430G (27 March 2017); doi: 10.1117/12.2261079

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)

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

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

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

Dose Scaling and Productivity – “double” patterning

Approximate throughput calculation for either EUV LELE or high-NA

- Assume improvements in source uptime and servicability
- Improvement in optics column
- Pellicle is required, 90% transmission at all interfaces
- Source power approaching 1 kW would be preferred

Patterning Cost per layer - Dose v. Power

Source Power (W)	Dose (mJ/cm^2) 40	45	50	55	60	65	70	75
200	0.99	1.05	1.12	1.19	1.25	1.31	1.38	1.45
300	0.88	0.93	0.98	1.04	1.09	1.14	1.20	1.25
400	0.83	0.87	0.92	0.97	1.01	1.06	1.10	1.15
500	0.80	0.84	0.88	0.92	0.96	1.01	1.05	1.09
600	0.78	0.81	0.85	0.90	0.93	0.97	1.01	1.05
700	0.76	0.80	0.84	0.87	0.91	0.95	0.99	1.02
800	0.75	0.78	0.82	0.86	0.89	0.93	0.97	1.00

Cost Parity

0.6	0.8	1	1.2	1.4

Advanced LPP EUV Source Architectures

Gigaphoton

- Increased conversion efficiency and increased drive laser power
- Beyond 400-500 W requires strides in architecture development

High Power EUV Source for High NA EUV exposure tool

EUV ave.Power[W] @100kHz		Conversion Efficiency [%]						
CO2 laser Energy [mJ]	CO2 laser ave. Power [kW]	2%	3%	4%	5%	6%	7%	8%
15	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	5	19.1	28.7	38.2	47.8	57.3	66.9	76.4
100	10	46.4	69.6	92.8	[illegible]	139.2	162.4	185.6
150	15	73.7	110.6	147.4	[illegible]	221.1	258.0	294.8
200	20	101.0	[illegible]	202.0	[illegible]	303.0	353.5	404.0
250	25	128.3	192.5	256.6	320.8	384.9	449.1	513.2
300	30	155.6	233.4	[illegible]	389.0	466.8	544.6	622.4
350	35	182.9	274.4	365.8	457.3	548.7	640.2	731.6
400	40	210.2	315.3	420.4	525.5	630.6	735.7	840.8
450	45	237.5	356.3	475.0	[illegible]	712.5	831.3	950.0
500	50	264.8	397.2	529.6	662.0	794.4	926.8	1059.2
550	55	292.1	438.2	584.2	730.3	876.3	1022.4	1168.4
600	60	319.4	479.1	638.8	798.5	958.2	1117.9	1277.6
650	65	346.7	520.1	693.4	866.8	1040.1	1213.5	1386.8
700	70	374.0	561.0	748.0	935.0	1122.0	1309.0	1496.0
750	75	401.3	602.0	802.6	1003.3	1203.9	1404.6	1605.2
800	80	428.6	642.9	857.2	1071.5	1285.8	1500.1	1714.4
850	85	455.9	683.9	911.8	1139.8	1367.7	1595.7	1823.6
900	90	483.2	724.8	966.4	1208.0	1449.6	1691.2	1932.8
950	95	510.5	765.8	1021.0	1276.3	1531.5	1786.8	2042.0
1000	100	537.8	806.7	1075.6	1344.5	1613.4	1882.3	2151.2

Lithography	R(nm)*	NA	λ/n (nm)	Power (W)
KrF dry	102	0.85	248	40
ArF dry	73	0.93	193	45
F_2 dry	69	0.80	157	-
ArF immersion	50	1.35	134	90
EUV	14	0.33	13.5	>250
EUV (High NA)	7	0.6	13.5	>500

	HVM1	HVM2	HVM3
EUV Power	250W	300W	500W
Pulse Rate	100kHz	100kHz	100kHz
CE	4.5%	5%	5%
CO_2 Laser Power	25kW	25kW	40kW

SPIE Advance Lithography 2017

GIGAPHOTON March 1, 2017

OSC	PA1	MA1	MA2	MA3	Plasma Point

For 250W EUV	100W	5kW	10kW	20kW	30kW	25kW
For 500W EUV	100W	10kW	20kW	30kW	50kW	40kW

Basic Experiment in 2013 *1st Amplifier installation in 2015* *Amplifier system installation in 2016*

SPIE Advance Lithography 2017

GIGAPHOTON March 1, 2017

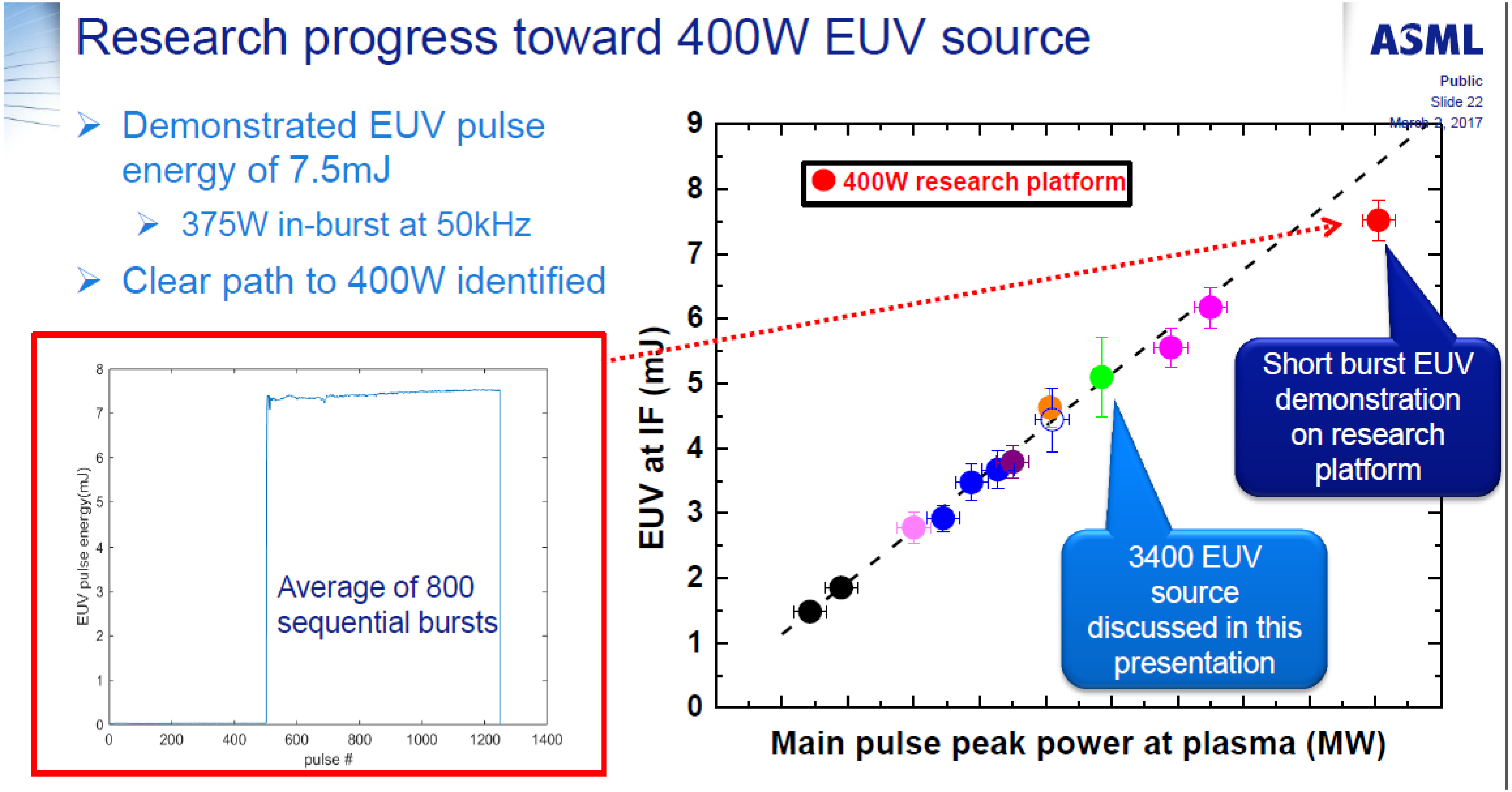
Next Generation Pre-pulse Laser

- ✓ Pre-pulse laser technology is one of the most important component of HVM EUV Source.
- ✓ Recently we achieved 250W operation with 4% CE on Prot#2. Also Pilot#1 system is on operation around 100W with 5% CE.
- ✓ Hilase laser is one of the candidate on pre-pulse laser.

47

Mizoguchi, H., et al. Proc. SPIE 10097, High-Power Laser Materials Processing: Applications, Diagnostics, and Systems VI, 1009702 (22 February 2017); doi: 10.1117/12.2261075

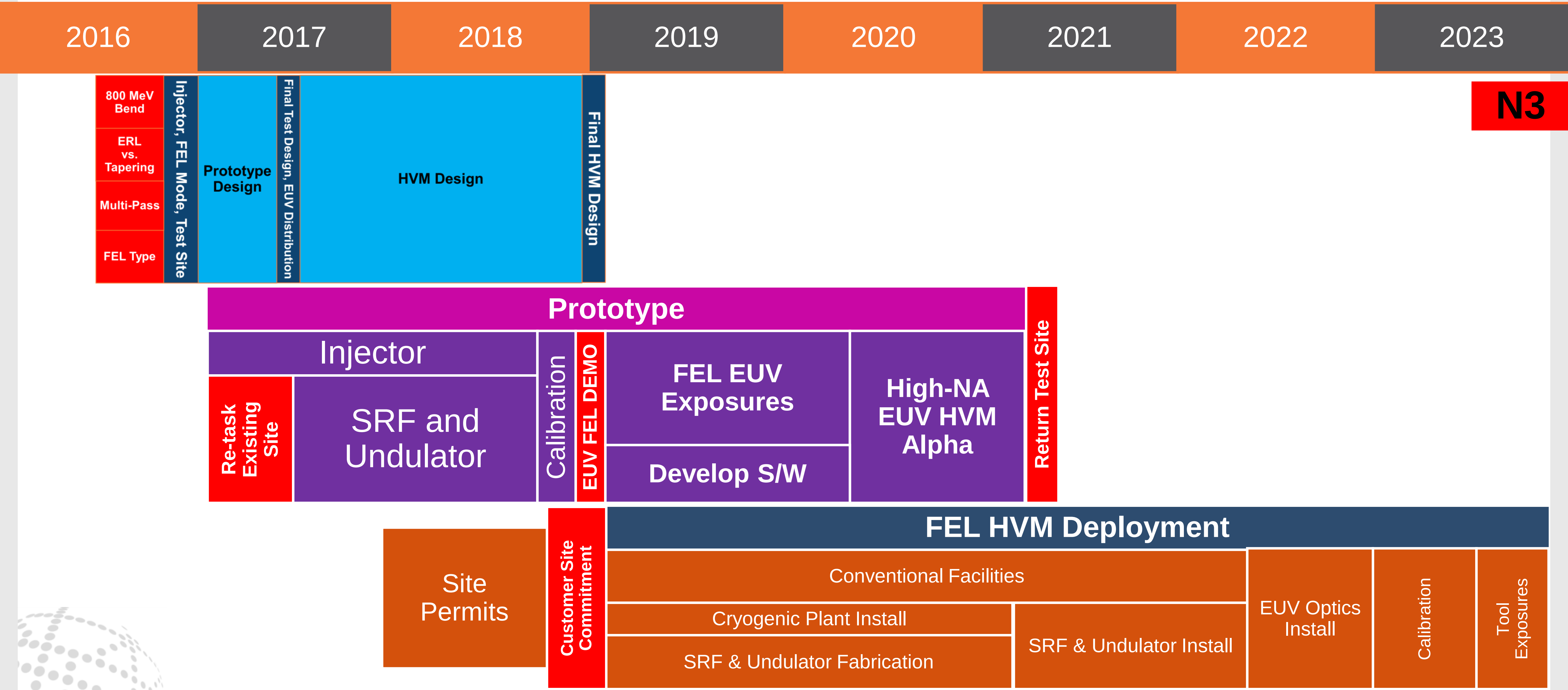
ASML-Cymer: Establishing a history of execution…



Proc. SPIE 10143, Extreme Ultraviolet (EUV) Lithography VIII, 101431I (5 May 2017); doi: 10.1117/12.2258628

Free-Electron Lasers

Free-Electron Lasers HVM N3



Development of a Lithography-based FEL Scorecard

- Evolving evaluation of various FEL options

- FEL emission architecture will drive different bounds
  - SASE: self-amplified spontaneous emission
  - SS-FEL: self-seeding
  - RAFEL: regenerative amplifier FEL

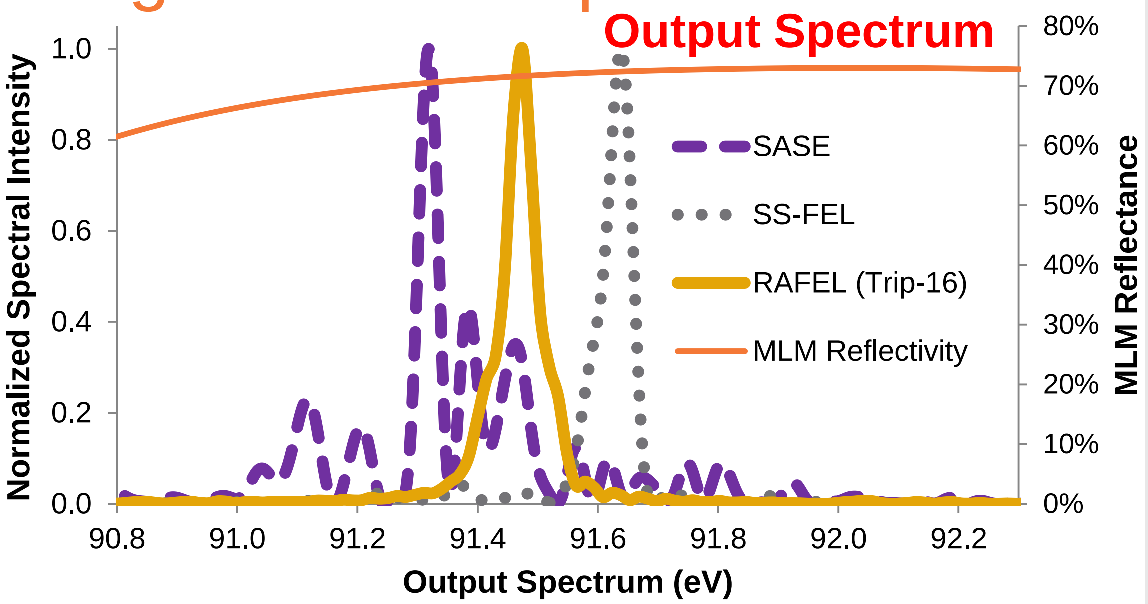
- FEL requirements will drive accelerator specifications

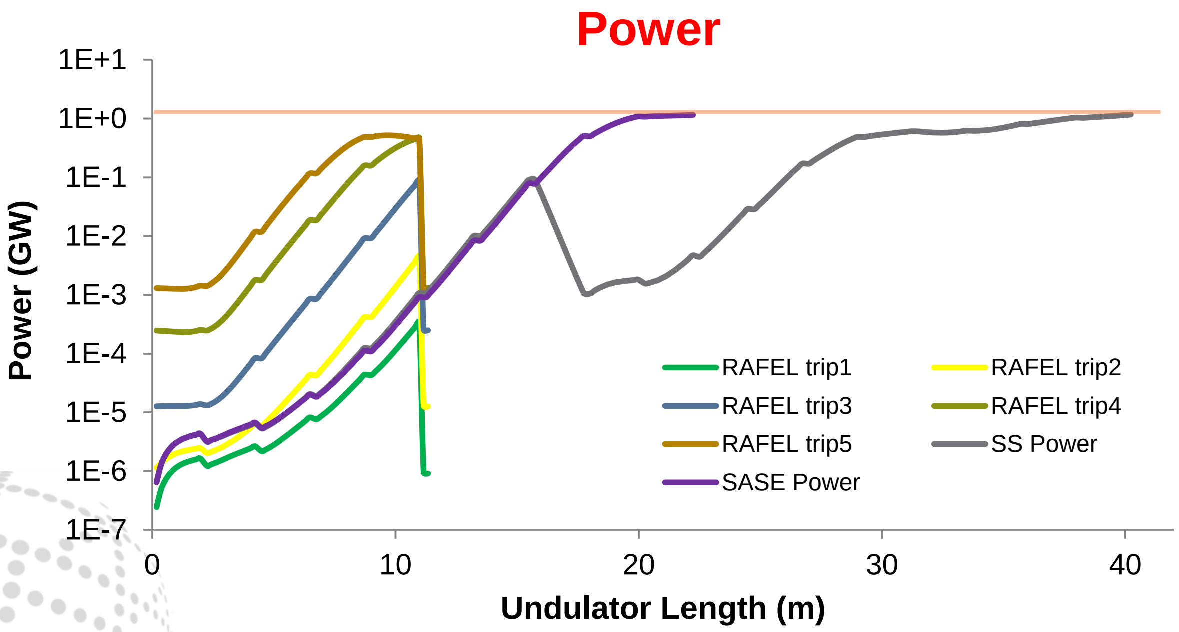
- Lithographers ↔ Accelerator/FEL Physicists
  - Scorecard needs to be evaluated for each accelerator and FEL emission architecture

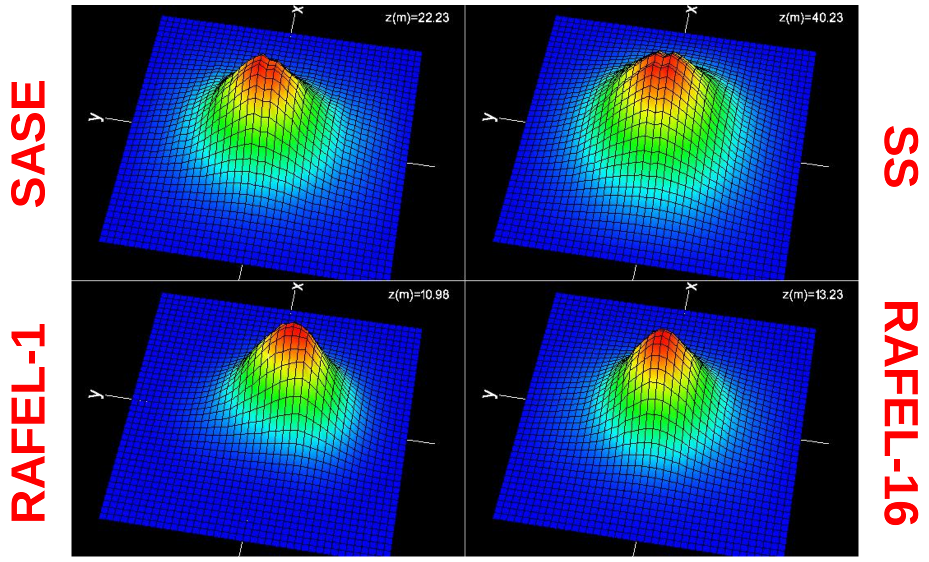
Metric	Bounds
e^- Beam Energy	± x dE/E
FEL; e^- Beam Pointing Stability	± x μm
Magnetic Field	± %K
Electron Beam Emittance	± %Δε mm mrad
EUV/e^- Beam Matching	± e^- BL/x
Output Pointing Stability	± x μm
Peak Intensity Maximum	x W/cm^2
Output Pulse Energy	± x μJ

FEL Emission Architecture – Base Configuration Comparison

- SASE has the most rapid build-up
- SS-FEL and RAFEL yield a narrower output spectrum
  - All outputs are well within the standard EUV Mo/Si multi-layer mirror bandwidth
- Photon flux spatial distribution is tightest for RAFEL







Evaluation of planned Lithography-based FEL Scorecard

- Baseline FEL emission architecture were defined and are currently being explored in detail
  - **SASE**
    - Evaluated for several parameters, **more robust to fluctuations, higher variation in photon energy**
  - **SS-FEL**
    - Improve monochromator design, evaluate similar parameters as with SASE
    - **More sensitive to fluctuations**
    - **More critical parameters**
  - **RAFEL**
    - Narrow output spectrum
    - Acceptable performance within expected stability
    - **Recirculating overlap of electron-EUV beam critical**

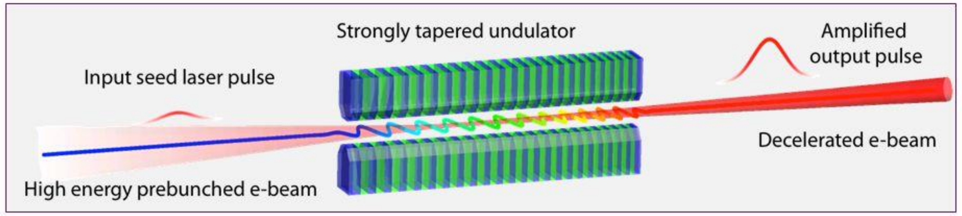
Metric	Bounds
e^- Beam Energy	± **0.4%** dE/E
Magnetic Strength Parameter (K)	**± 2 x 10^{-4}%**
e^- Bunch Emittance ($\varepsilon_{x,y}$)	**ε < 0.3** mm mrad
EUV/e^- Beam Matching (SS-FEL)	± **e^- BL/3**
EUV/e^- Beam Matching (RAFEL)	± << **e^- BL/3**
Output Pointing Stability	± 5 μm
Peak Intensity Maximum	<500 mJ/cm^2
Output Pulse Energy	± 11 μJ

- **Lithographers ↔ Accelerator Physicists**

Disruptive technologies…

TESSA

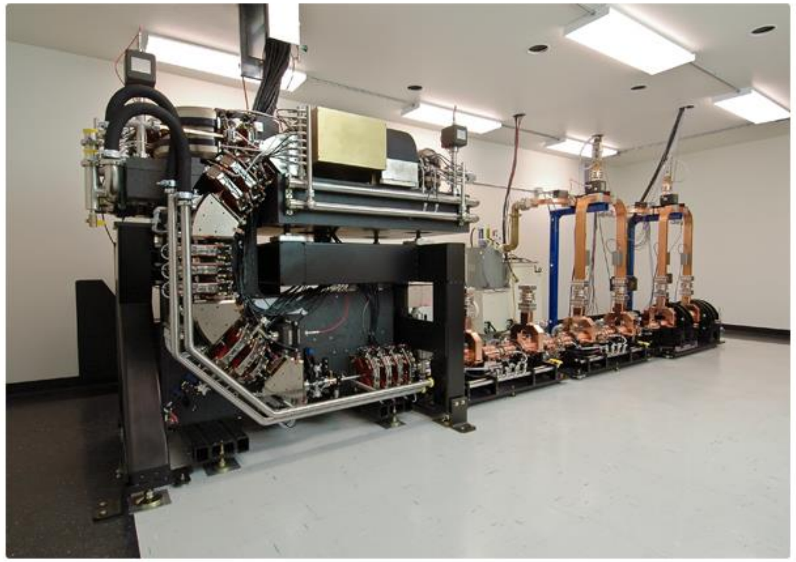
- Inverse IFEL = ~~FEL~~ TESSA (**T**apering **E**nhanced **S**timulated **S**uperradiant **A**mplification)
- E-beam rapid deceleration → laser amplification
- Requires seed pulse of high intensity (larger than FEL P_{SAT})
- E-beam can be prebunched, or it can be bunched in the first few undulator periods



- High efficiency conversion of electron beam energy to coherent radiation opens door to very high average power light sources.
- Wavelength set by e-beam energy and resonant condition -> wide tunability
  - High average power IR and visible lasers.
  - X-rays.
  - EUV-L applications.

THE LYNCEAN COMPACT LIGHT SOURCE (CLS)

A breakthrough in local, on-demand X-ray synchrotron light



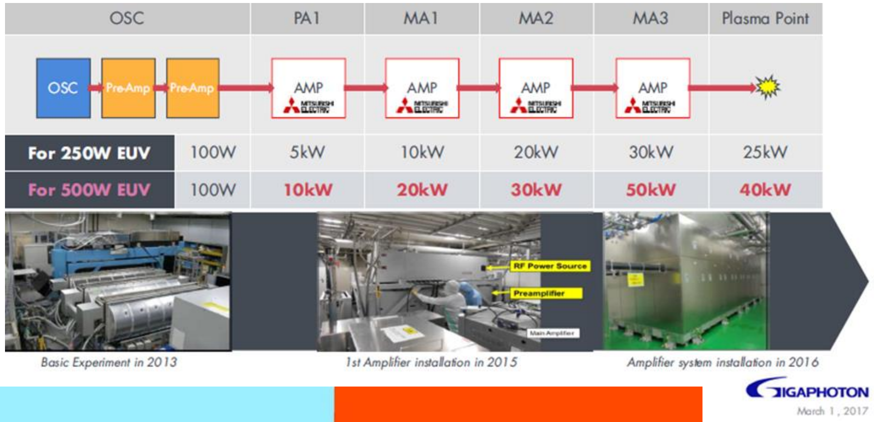
The Lyncean CLS assembled at the headquarters of Lyncean Technologies, Inc. in Fremont, CA

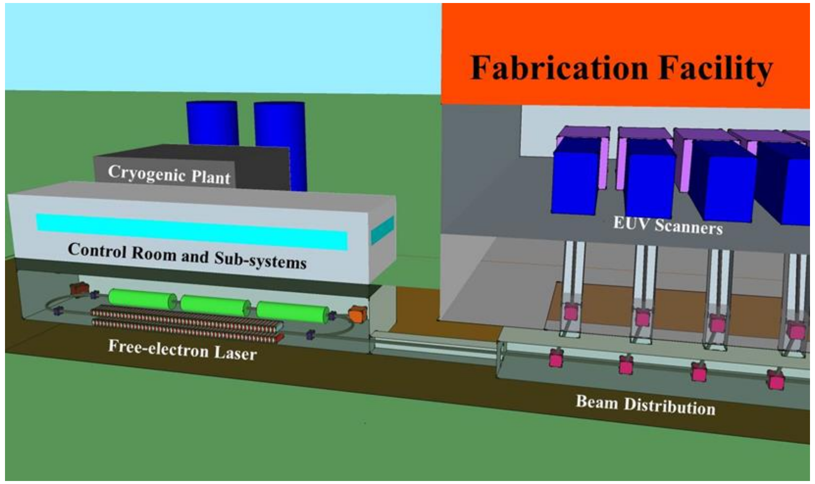
Considerations at 3nm and beyond…

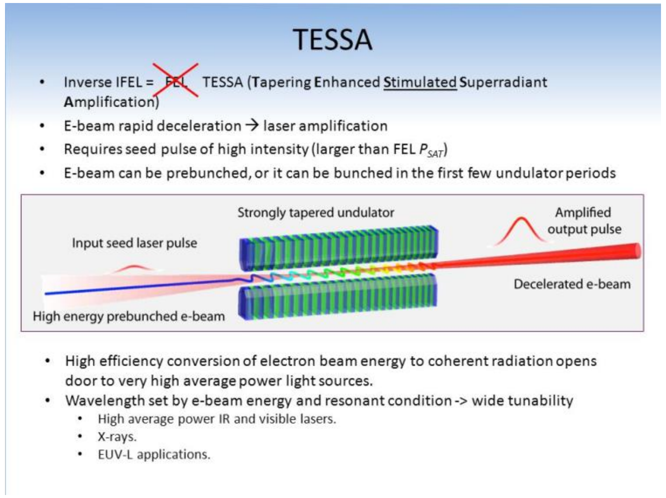
Conclusions

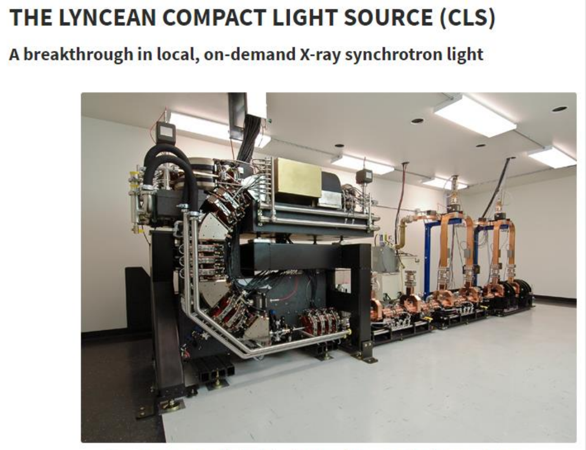
- Source power must scale beyond 250W
  - Pellicles must follow w.r.t. survivability
- Potential for continued LPP scaling
- Disruptive sources still possible to intercept next major architecture change

- What should be the target source power (w/pellicle) for each progressive technology?
  - 7 nm → 250 W
  - 5 nm → 350 W
  - 3 nm → 500 W
  - ‘2 nm’ → 1 kW
- ***Beyond?***









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Thank you

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