Applications of high efficiency FELs for EUV lithography

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Outline

- Semiconductor industry trends
- Introduction to EUV Lithography
- Future power needs
- Key FEL source requirements

Semiconductor industry is huge economic driver

$59 Billion

Semiconductor R&D (2017)

$412 Billion

Semiconductor device market (2017)

$2.0 Trillion

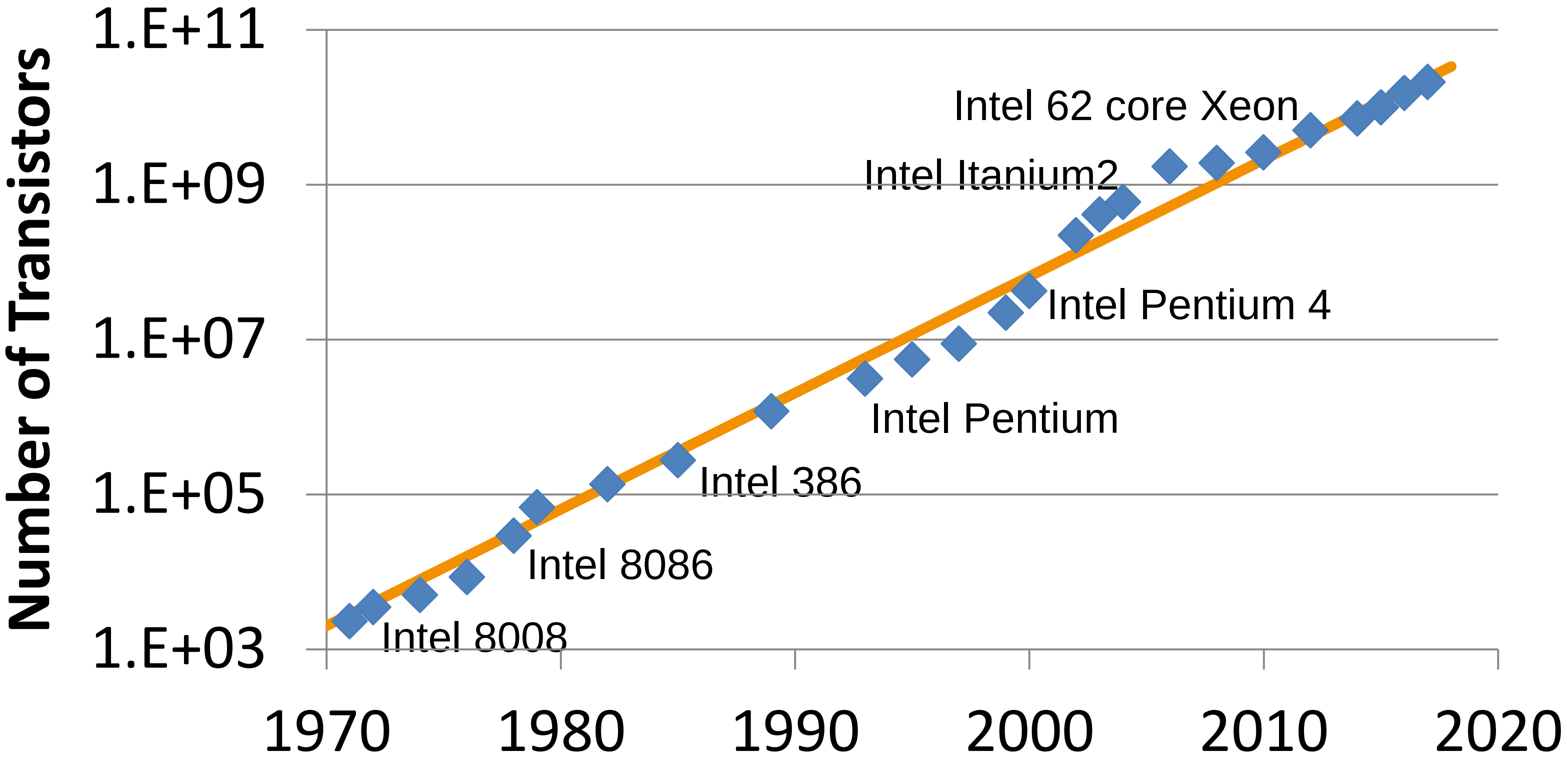
Global electronics market (2017)

SIA, www.persistencemarketresearch.com

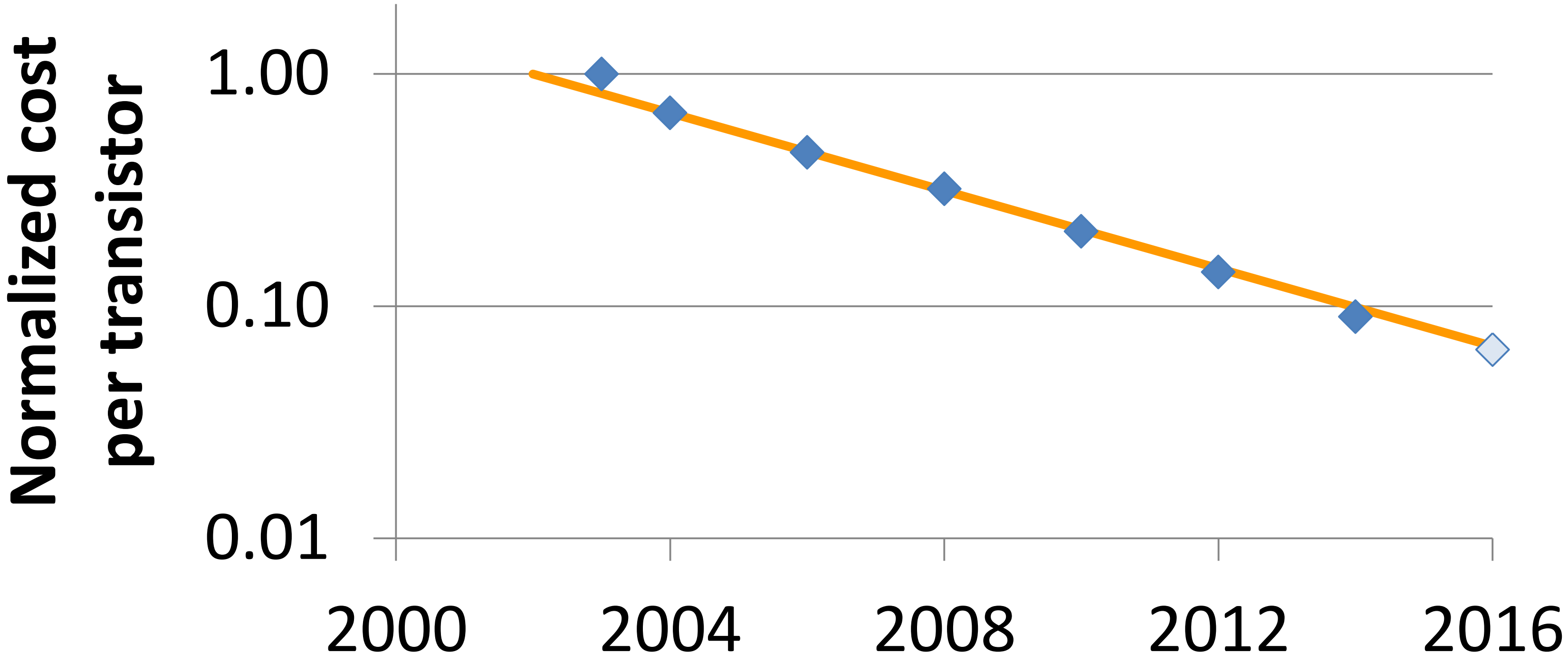
“By 2020, [expected] cost of between $15 and $20 billion for a leading-edge fab”

EE Times

Industry growth enabled by Moore's Law: transistors double every two years

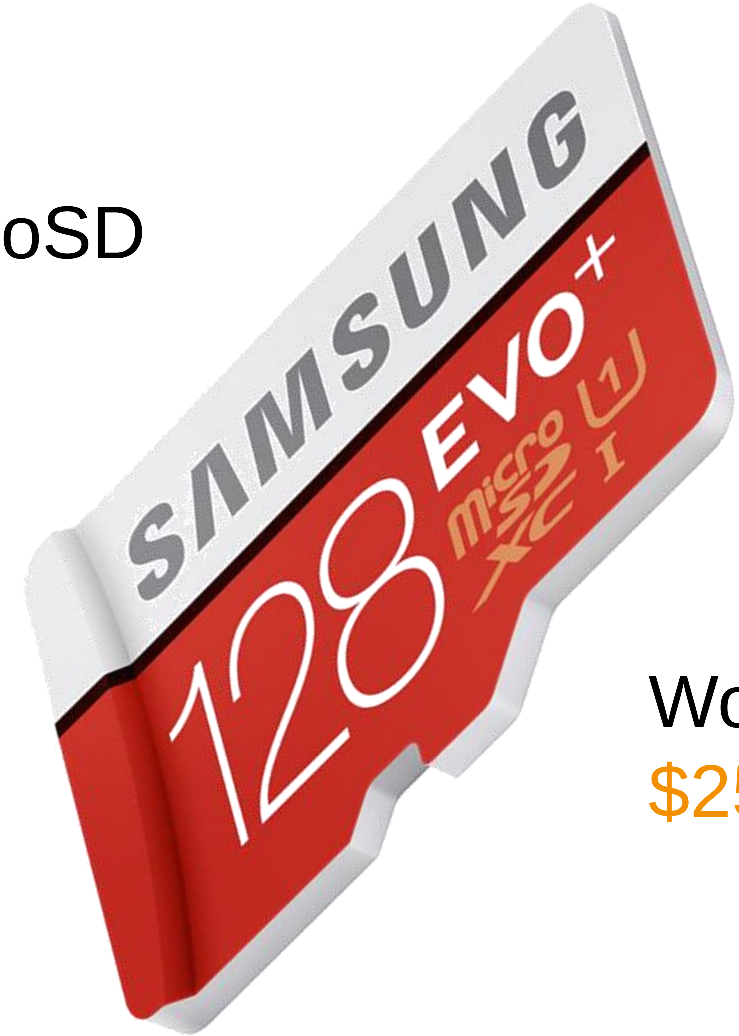


The other half of Moore's Law:
density increase at shrinking cost



Data from Intel (http://www.pcworld.com/article/2887275/intel-moores-law-will-continue-through-7nm-chips.html)

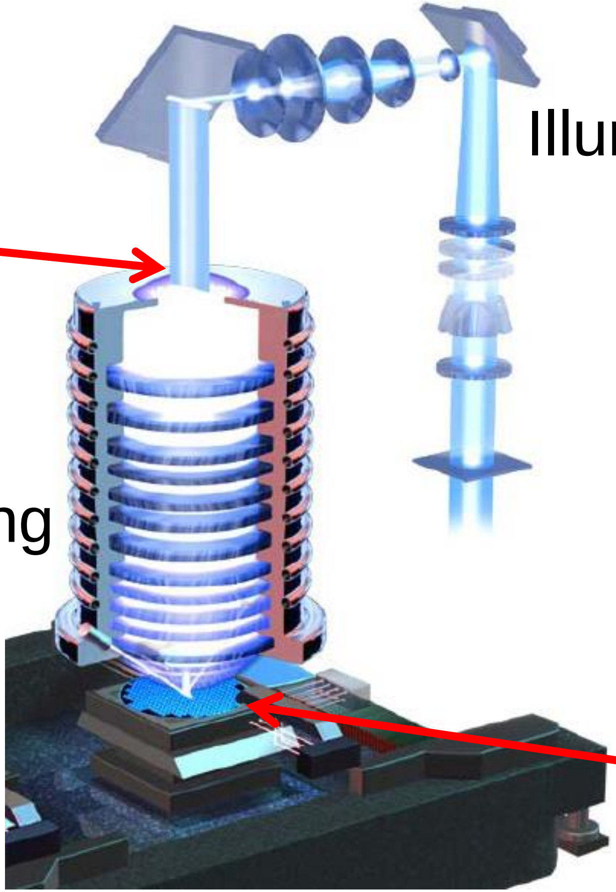
128 GB microSD
$59.99



Would have cost
$256 billion in 1970

Lithography drives shrink

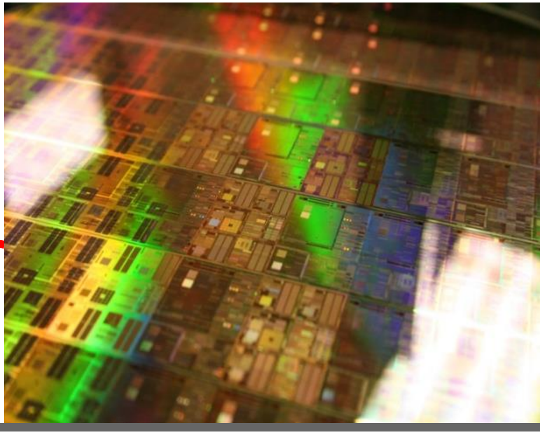
Mask



Illumination

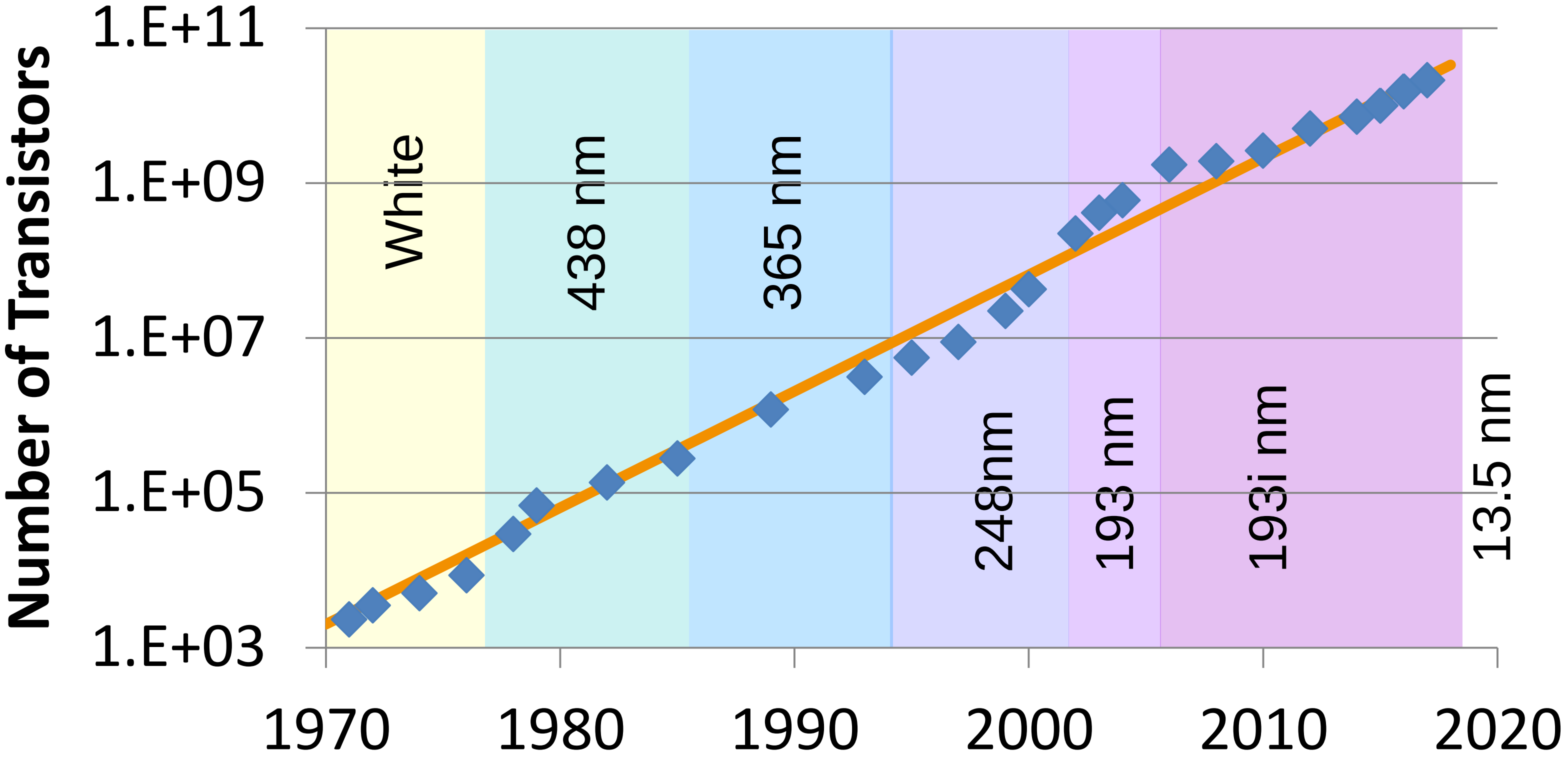
Demagnifying lens

Wafer

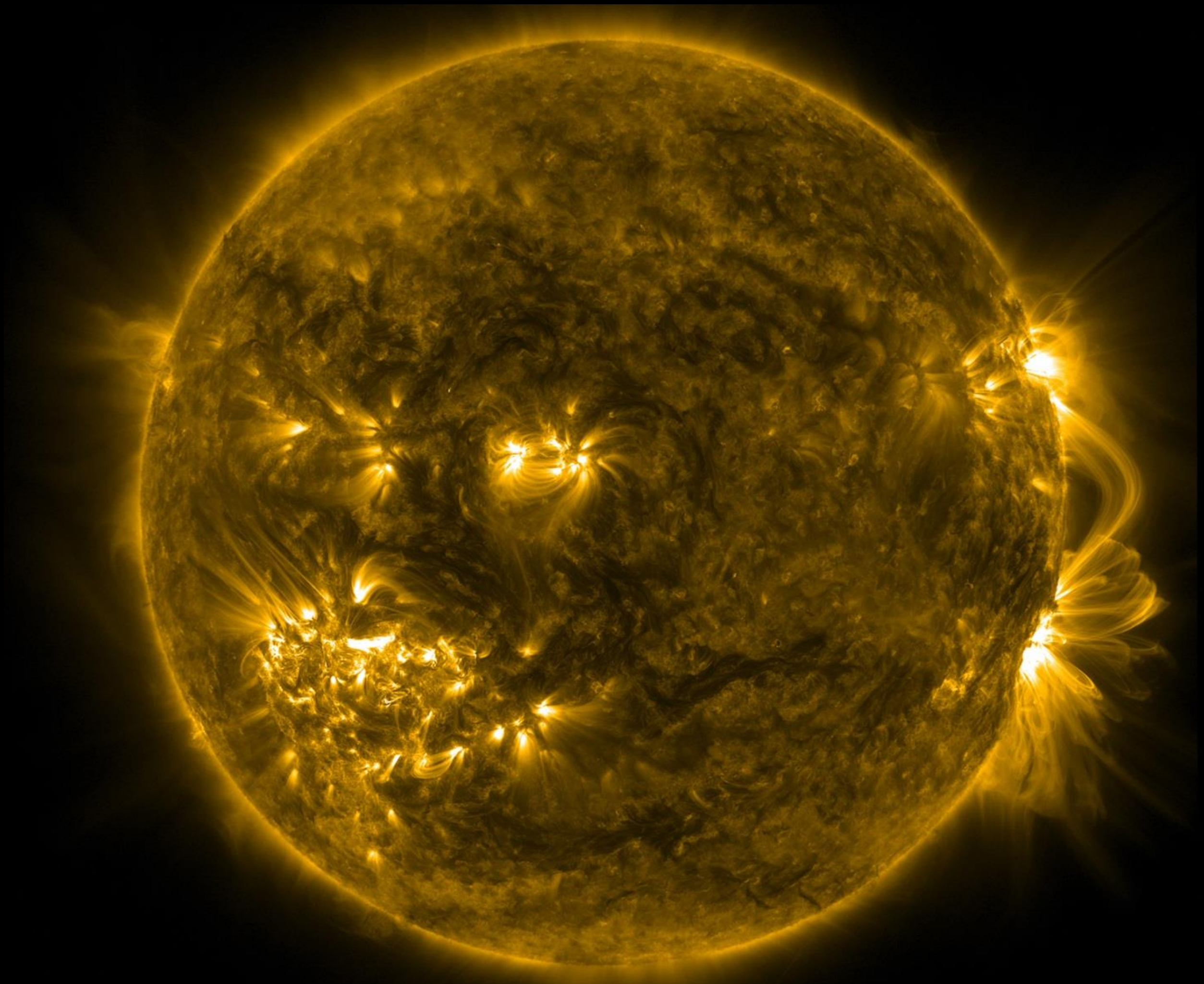


$Res \propto \lambda/NA$

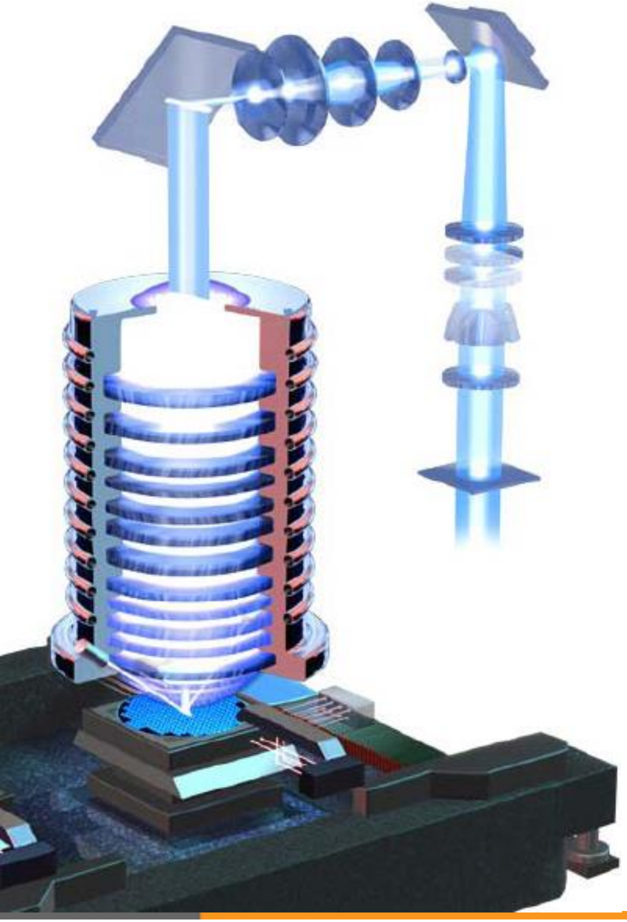
Moore's Law driven by wavelength shrink

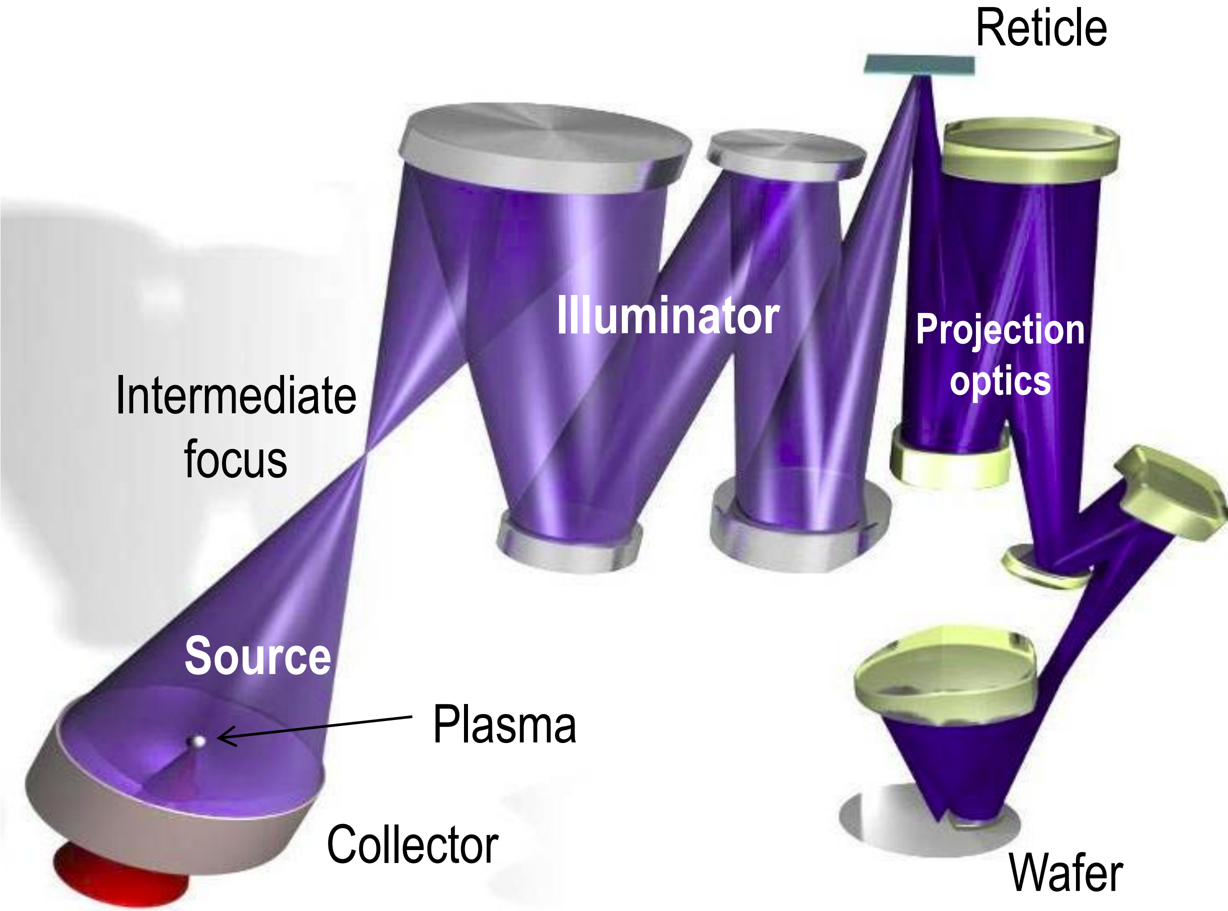


How does EUV lithography work?



EUVL: optical lithography at λ = 13.5 nm

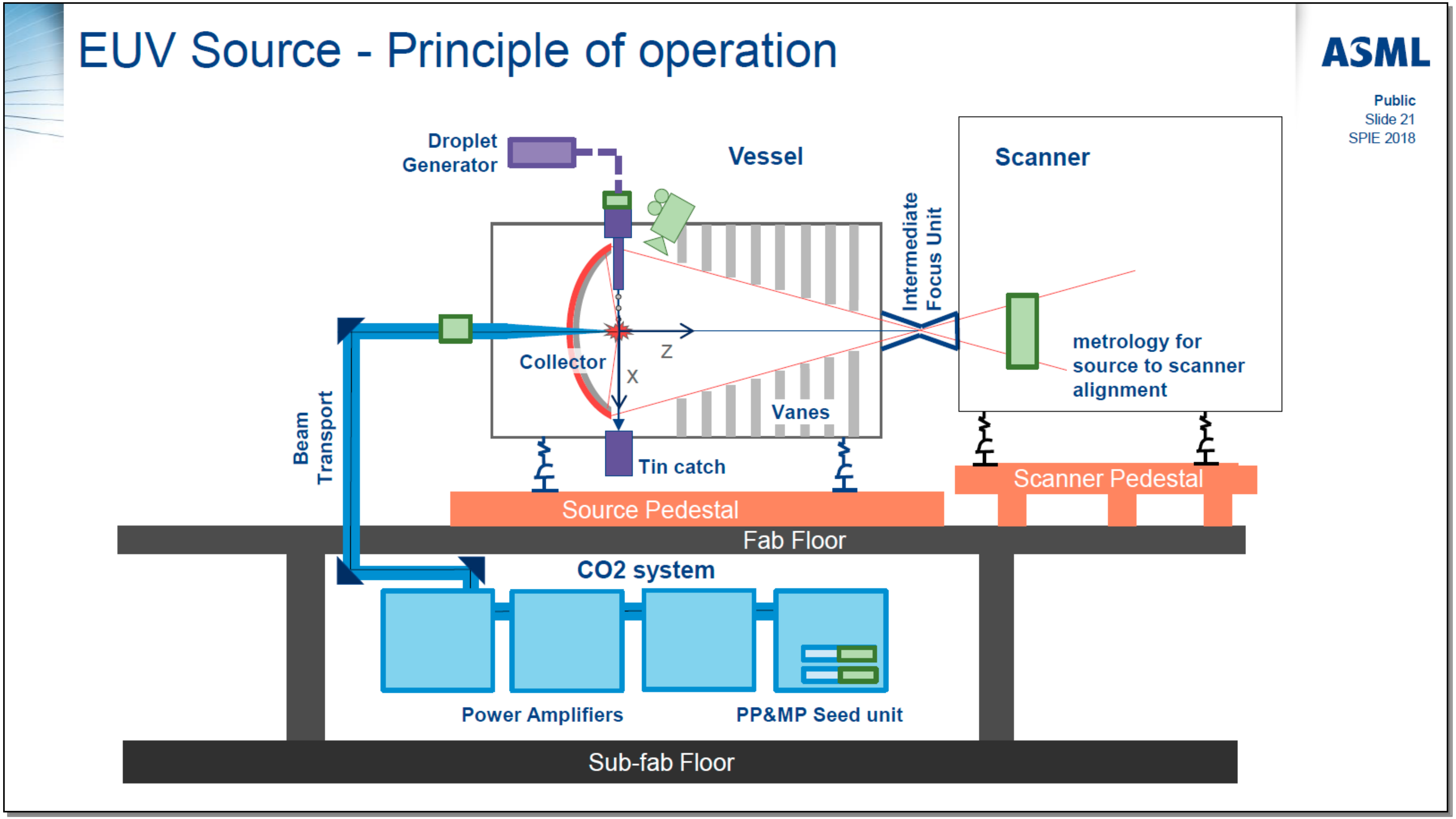




Near term source power requirements

Wafer Throughput	wafer/h	145
Total wafer time	sec	24.8
Stage motion overhead	sec	18
Wafer exposure time	sec	6.8
Wafer diameter	mm	300
Wafer fill factor	%	89%
Resist Sensitivity	mJ/cm^2	15
Required Power at Wafer	W	1.38
POB reflectivity (0.66^6)	%	8.27%
Mask reflectivity	%	62%
Illuminator reflectivity (0.66^4)	%	18.97%
Overfill efficiency	%	75%
Pellicle efficiency	%	76%
Total Optical Efficiency	%	0.55%
Required collected source power	W	250

Required source power = 250W

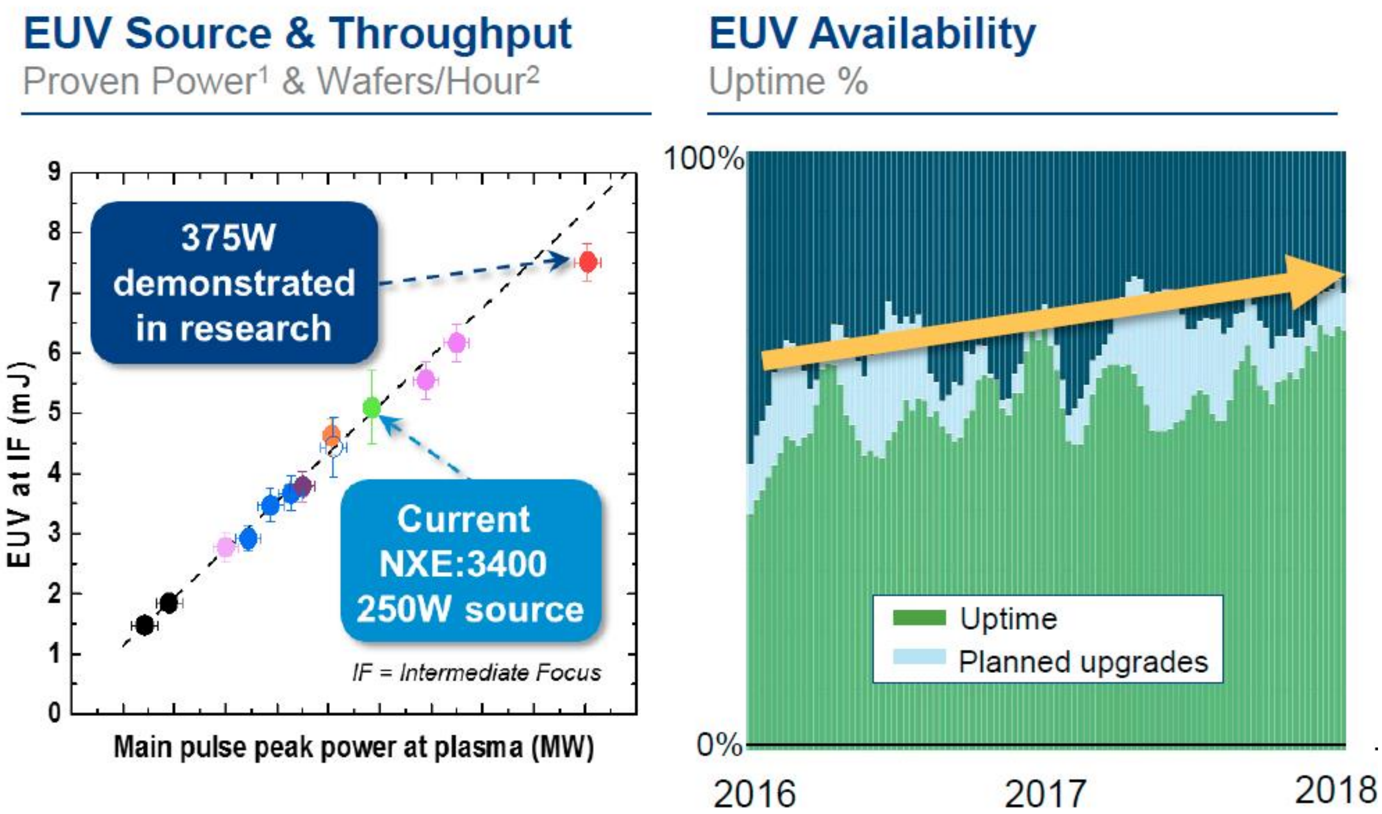


EUV Source - Principle of operation

ASML

Public
Slide 21
SPIE 2018

LPP source status



EUV Source & Throughput

Proven Power[1] & Wafers/Hour[2]

EUV Availability

Uptime %

ASML, SPIE Advanced Lithography Conference 2018

Future source power needs?

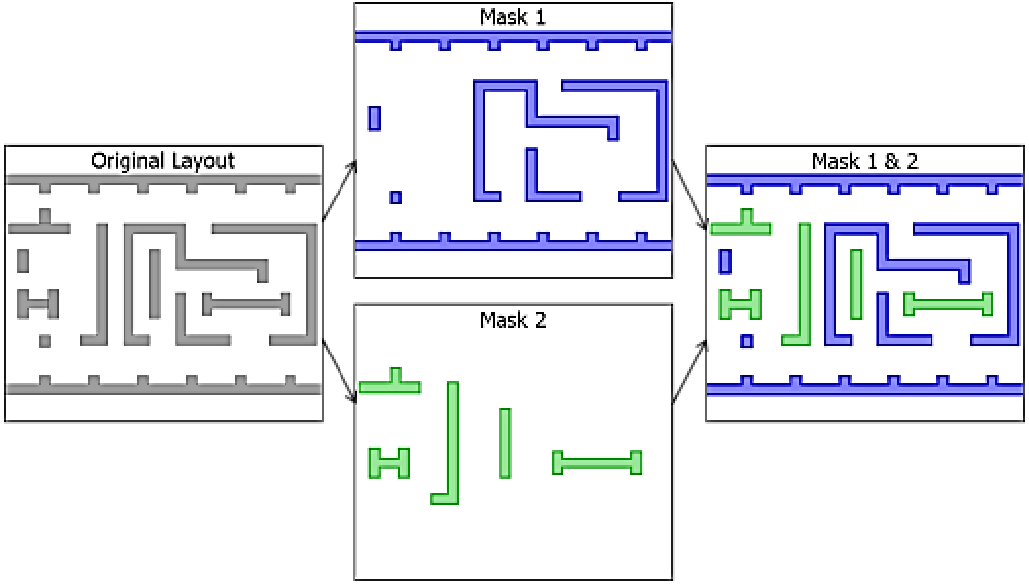
Key variable assumptions in 250W number

- Throughput = 145 Wafers/hr
- Wafer size = 300 mm
- Dose = 15 mJ/cm^2

Source power requirements expected to grow significantly in the future

Double patterning

- Throughput
  = 220 wafers/hr
- Stage overhead
  = 12 seconds

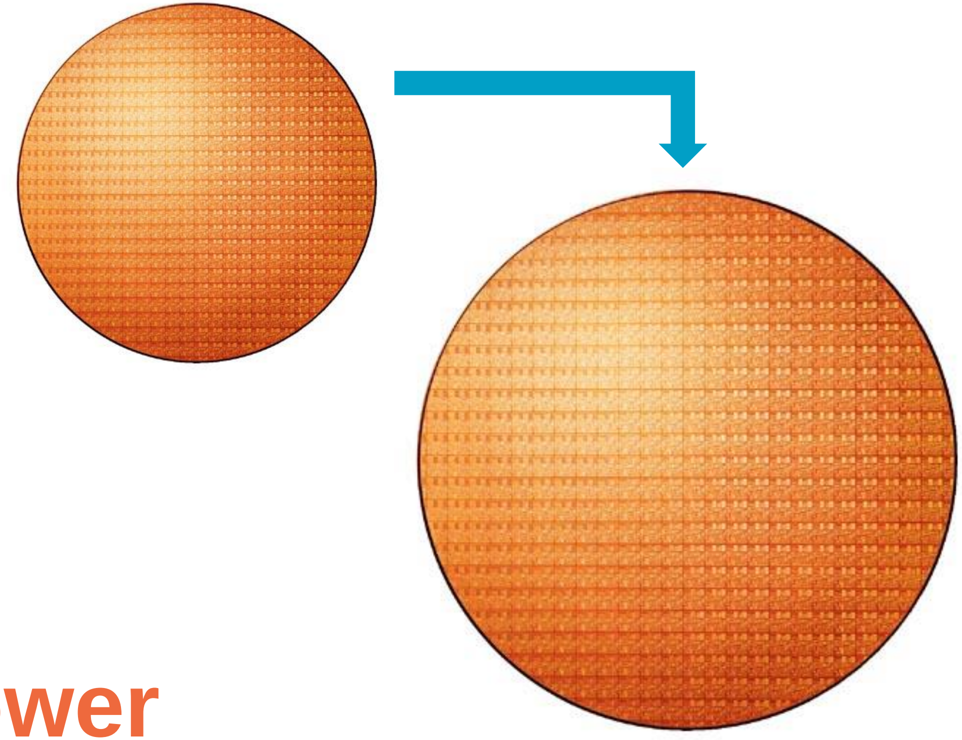


1.6x more power

Source power requirements expected to grow significantly in the future

450-mm wafers

- Throughput
  = 105 wafers/hr
- Stage overhead*
  = 12 seconds



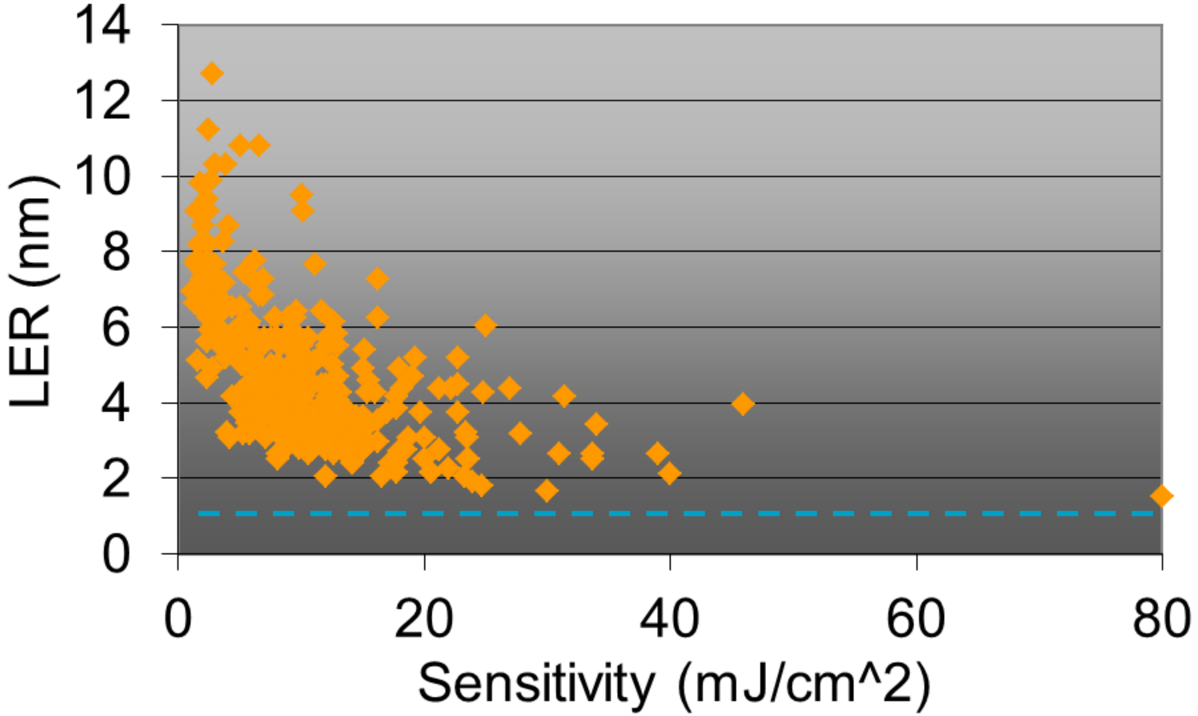
1.5x more power

* Normalized to 300-mm wafer

Source power requirements expected to grow significantly in the future

Dose

- 15 mJ/cm^2 likely not enough in the future



Source power requirements expected to grow significantly in the future

Dose

- 15 mJ/cm^2 likely not enough in the future

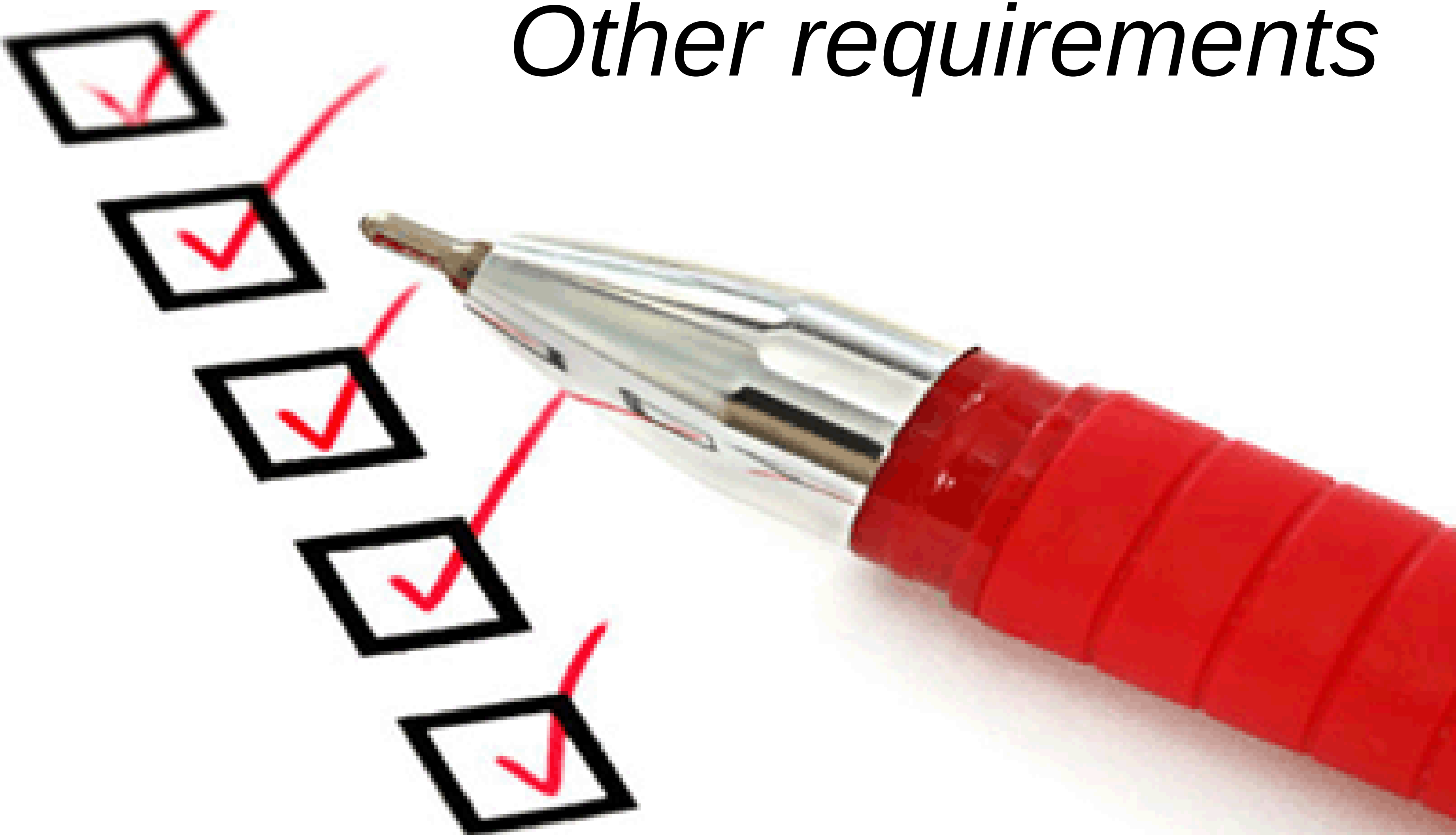
	Resist CA-C	Resist CA-A	Resist NCA-A
Resolution (nm)	15	16	15
LWR (nm)	3.8	3.1	1.5
Dose (mJ/cm^2)	22	30	80
Shot noise scaled dose (mJ/cm^2)	162	147	92

2-4x more power

$$LWR \propto 1/\sqrt{dose}$$

Depending on resist performance, future power needs could range from 500W to 2000W

Other requirements



Size: about the size of a shipping container

- Allowable source footprint: ~ 10m x 3m

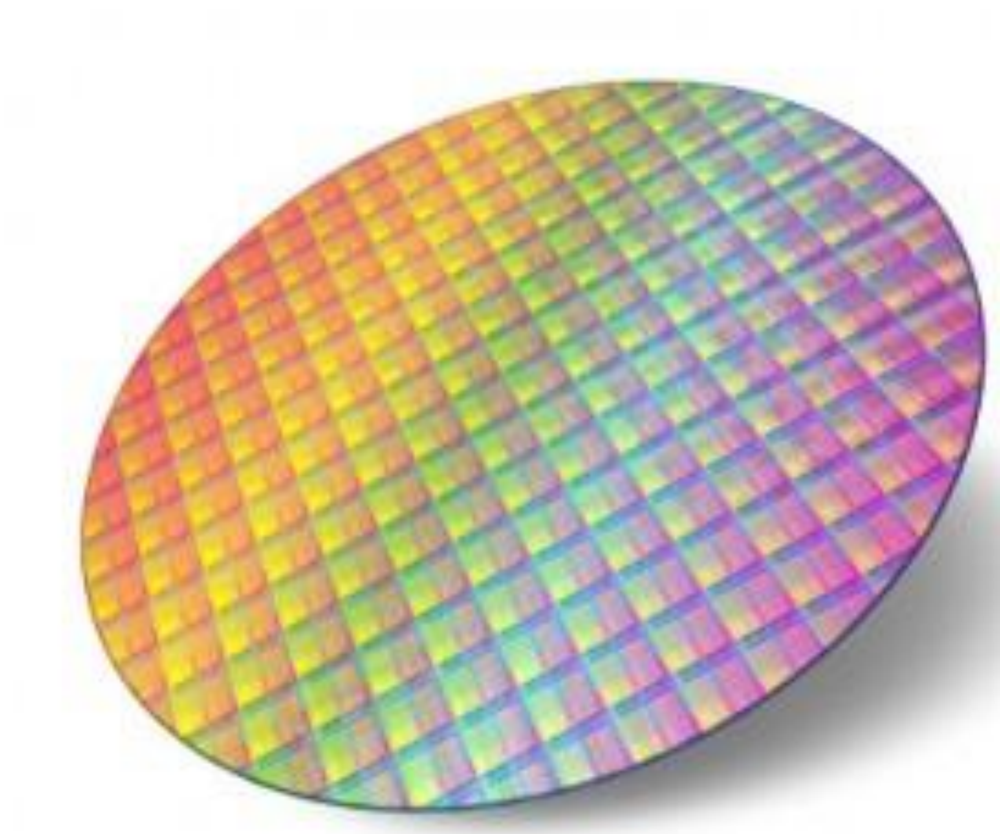
Reliability: Require > 95% uptime

Even better uptime required
if driving multiple tools

Source power stability

Need <1% with 1 ms integration window

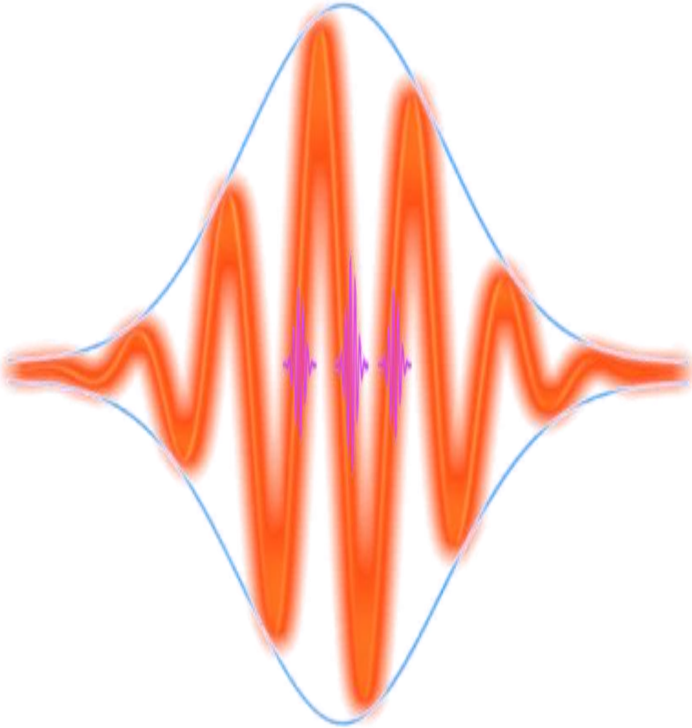
- Implies rep rate >1kHz x FPN^2
- 30% pulse noise => rep rate > 900kHz



FPN = fractional pulse noise

Pulse length

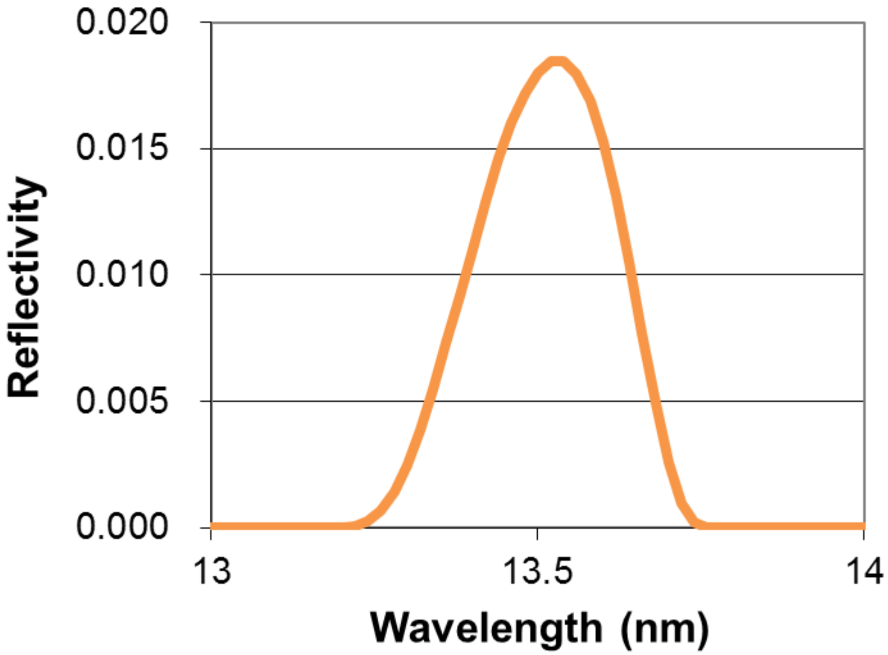
- Multilayer BW limits require pulse > 2.5 fs
- Longer is better to avoid optics damage issues



Bandwidth

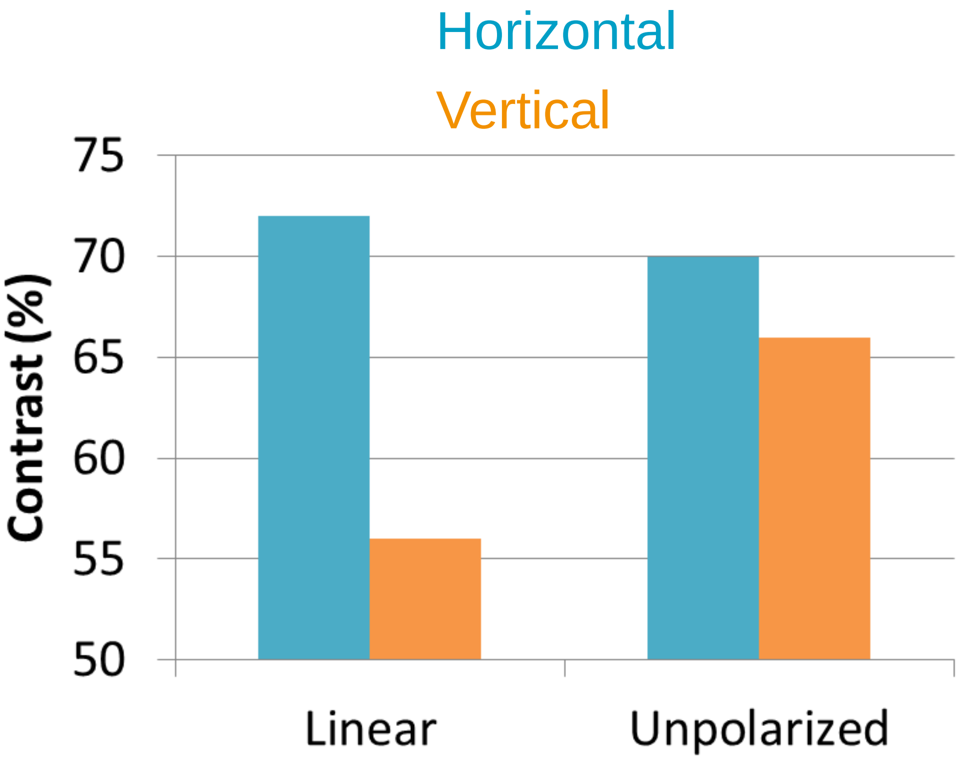
- Multilayer mirrors require bandwidth
  < +/-0.14nm (1%)
- Narrower bandwidth = greater effective optical throughput
  - +/-0.02nm BW would provide 28% effective power boost

Multilayer to the 11th power



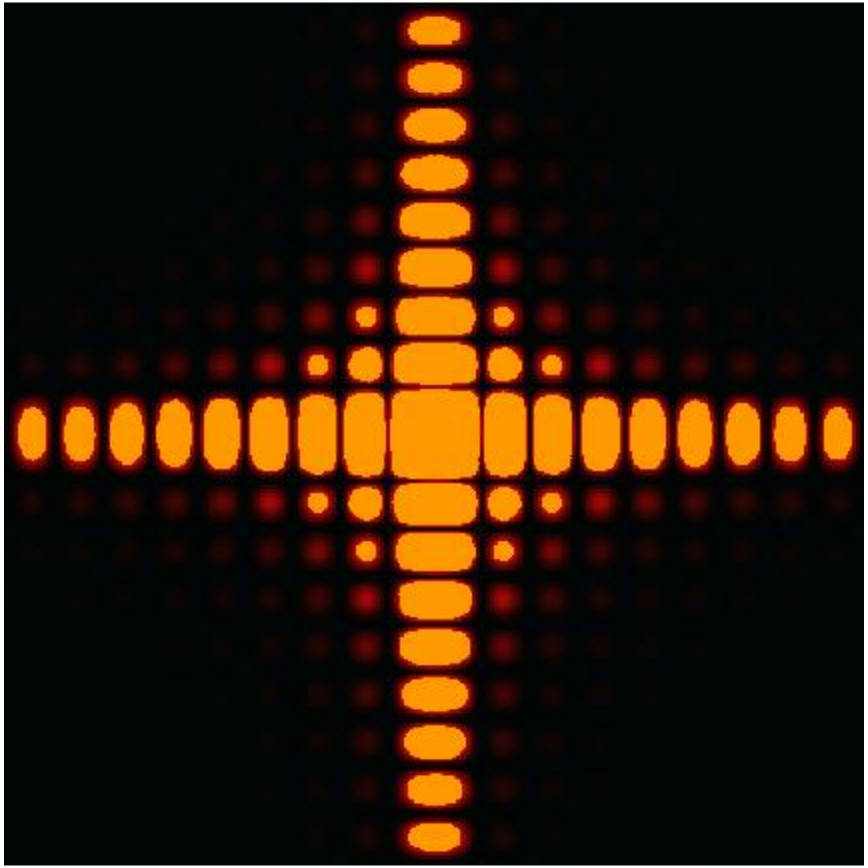
Polarization

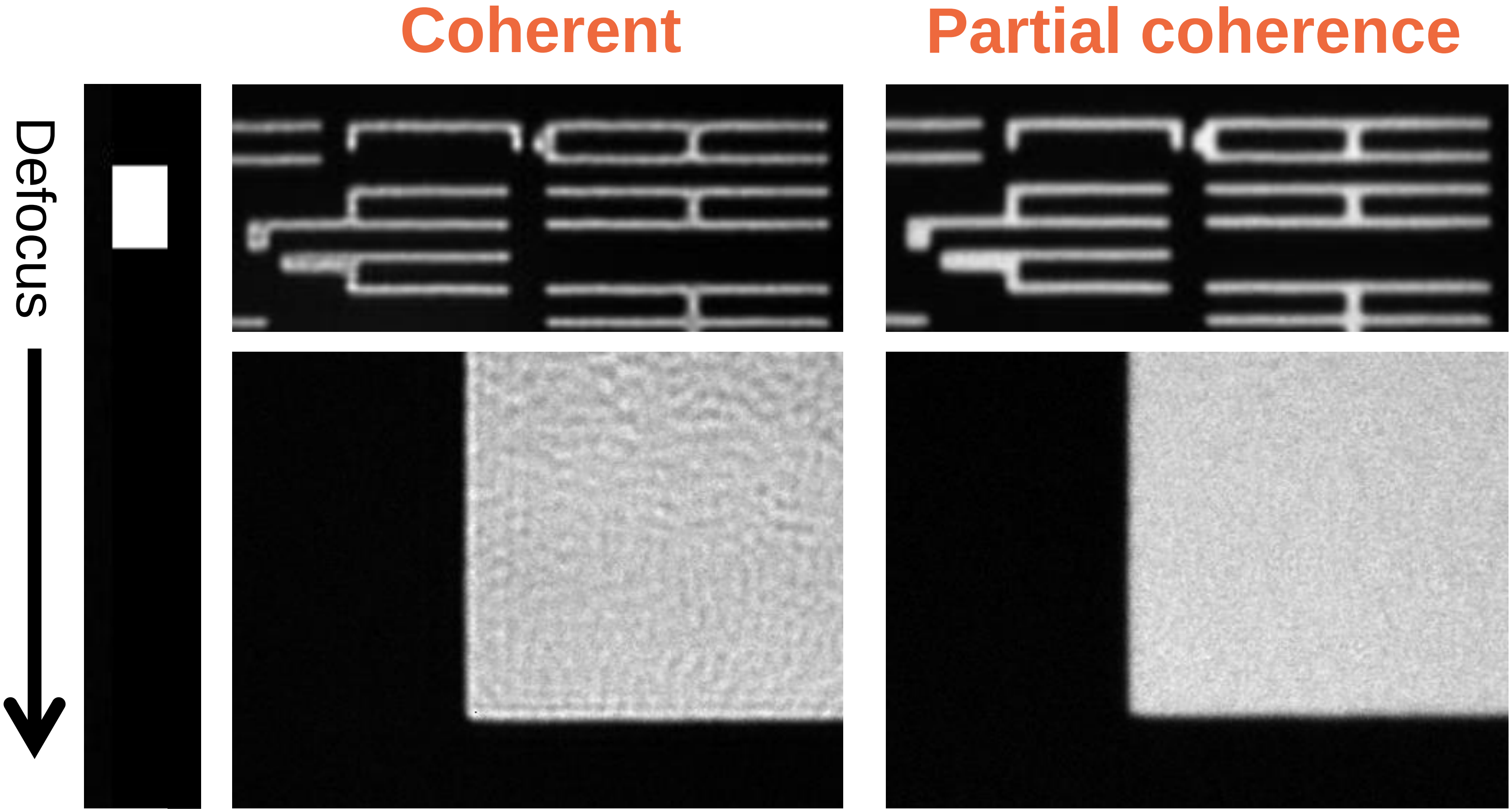
- Linear polarized light causes significant imaging anisotropy
- If it can be manipulated, polarization can be viewed as asset



Coherence

- No longitudinal coherence needed
- No lateral coherence needed (coherence must be destroyed)





Data courtesy of K. Goldberg, A. Wojdyla, LBNL

Summary

- EUV is on its way
- We need creative solutions to carry the technology well into the future

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