EUVL throughput considerations

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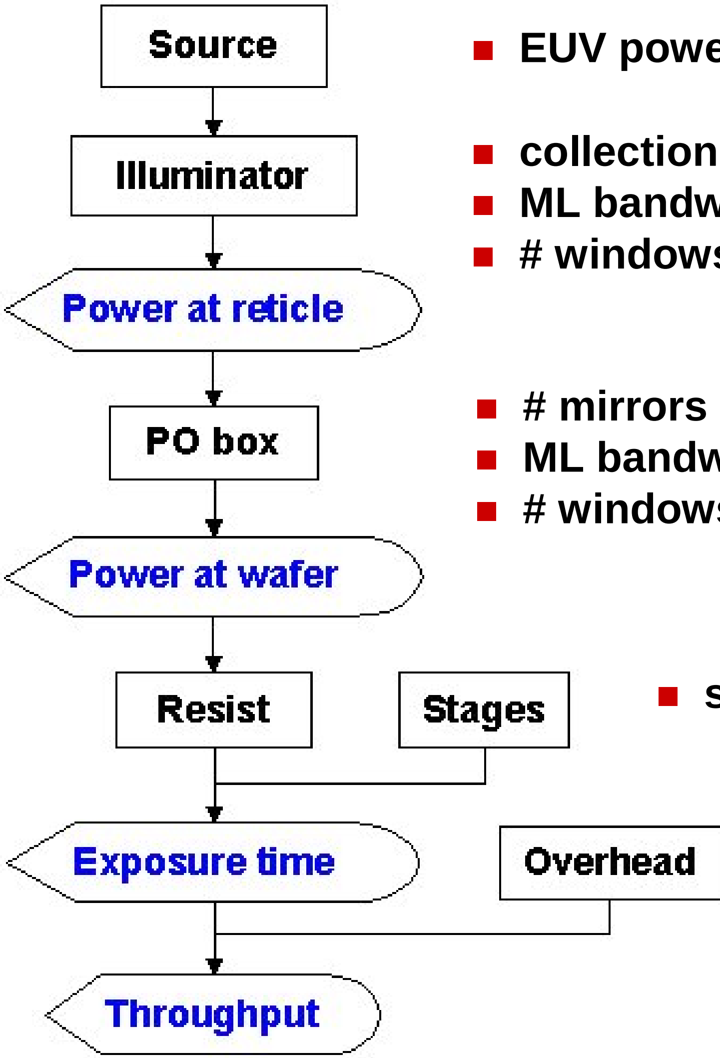
Content

- Throughput model, key parameters
- System interdependencies
- 40 wph (300 mm) throughput case study
- Sensitivity analysis
- Summary and conclusions

Throughput model



- EUV power / 2π / % BW

- collection efficiency, # near normal mirror, # grazing mirrors
- ML bandwidth, peak reflection, mis-match
- # windows

- # mirrors
- ML bandwidth, peak reflection, mis-match
- # windows

- sensitivity
- scan speed

- step, settle, acceleration, jerk
- alignment, leveling
- handling

Throughput contributors

Throughput determined by:

- Exposure time (T_E)
  - source
  - optics
  - resist
  - scan speed
- Stage overhead (T_S)
  - step, settle, acceleration, jerk
- Other overhead (T_O)
  - alignment, leveling, ...
  - handling

Exposure time is only part of the whole story!

$$T_E : T_S : T_O = 1 : 1 : 1$$

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Throughput case 40 wph

Assume: $T_E : T_S : T_O = 1 : 1 : 1$

For 40 wph: $T_E + T_S + T_O = 3600 / 40 \text{ s} = 90 \text{ s}$

⇨ Exposure time / wafer (T_E) = 30 s

- Wafer size: 300 mm
- Field size (A_F): 25 x 25 mm²
- Fields per wafer (N_F): 89
- Resist sensitivity (S): 5 mJ/cm²

⇨ Power at wafer: $P_W = S \times N_F \times A_F / T_E = \underline{93 \text{ mW}}$

Source requirement for 40 wph

Neglect: Multilayer mismatch, contingencies, polarization **! !**

Projection optics: 6 ML coated mirrors

- Peak reflectivity (R): 69 % (Mo/Si); 72 % (MoRu/Be)
- Window transmission (T_W): 50 %

⇨ Power at reticle: $P_R = P_W / (R^{6+1} \times T_W)$

Mo/Si: $P_R = 2.50$ W

MoRu/Be: $P_R = 1.85$ W

Source requirement for 40 wph (2)

Illuminator: 2 Grazing Inc. + 2 ML mirrors

- Peak reflectivity ML (R): 69 % (Mo/Si); 72 % (MoRu/Be)
- Refl. GI mirrors (R_G): 86 %
- Window transmission (T_W): 50 %

⇨ Collected source power: $P_S = P_R \,/\, (R^{2} \times R_G^{2} \times T_W)$

⇨ Collected by first condenser mirror in effective Band Width :

- Mo/Si: P_S = 14.2 W in 0.26 nm BW @ 13.4 nm (55 W/nm)
- MoRu/Be: P_S = 9.7 W in 0.16 nm BW @ 11.3 nm (61 W/nm)

LPP source for 40 wph

Example: MoRu/Be + Xe LPP source

- Conversion efficiency (*CE*): 1.2 % / % BW / 2π (0.18 % / eV / sr)
- Effective bandwidth (BW_{eff}) : 1.4 % (0.16 nm)
- Geometrical Collection efficiency (Ω_{col}): 40% of 2π sr
- Xe gas transmission (T_{Xe}): 80%

⇨ Laser power: $P_L = P_S / (CE \times BW_{eff} \times \Omega_{col} \times T_{Xe})$ = 1.8 kW (at target)

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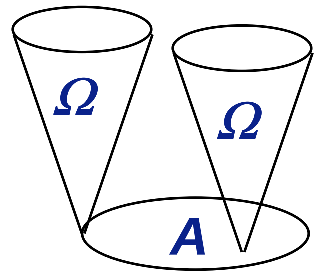
Boundary condition source (etendue)

- Etendue $E = A \times \Omega$

  for small NA:
  $\Omega \approx \pi \; NA_x \, NA_y$



- Cannot decrease during propagation through optical system without throwing away light.
- For practical purposes this is valid for two orthogonal directions independently ($d_x \times NA_x$; $d_y \times NA_y$)
- Limiting factor determined by small slit width : $d_{slit} \sim 2$ mm

  E.g., for $NA_{wafer} = 0.2$ and $\Omega_{source} = \pi$ sr : $d_{source,\,y} < 0.4$ mm

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Boundary condition source (dose repeatability) -1-

Requirement for dose repeatability: better than 0.5 %

Minimum number of pulses-in-slit depends on:

- pulse-to-pulse fluctuation
- dose control
- slit illumination profile

Target for 2% pulse-to-pulse fluctuation: 30 pulses-in-slit

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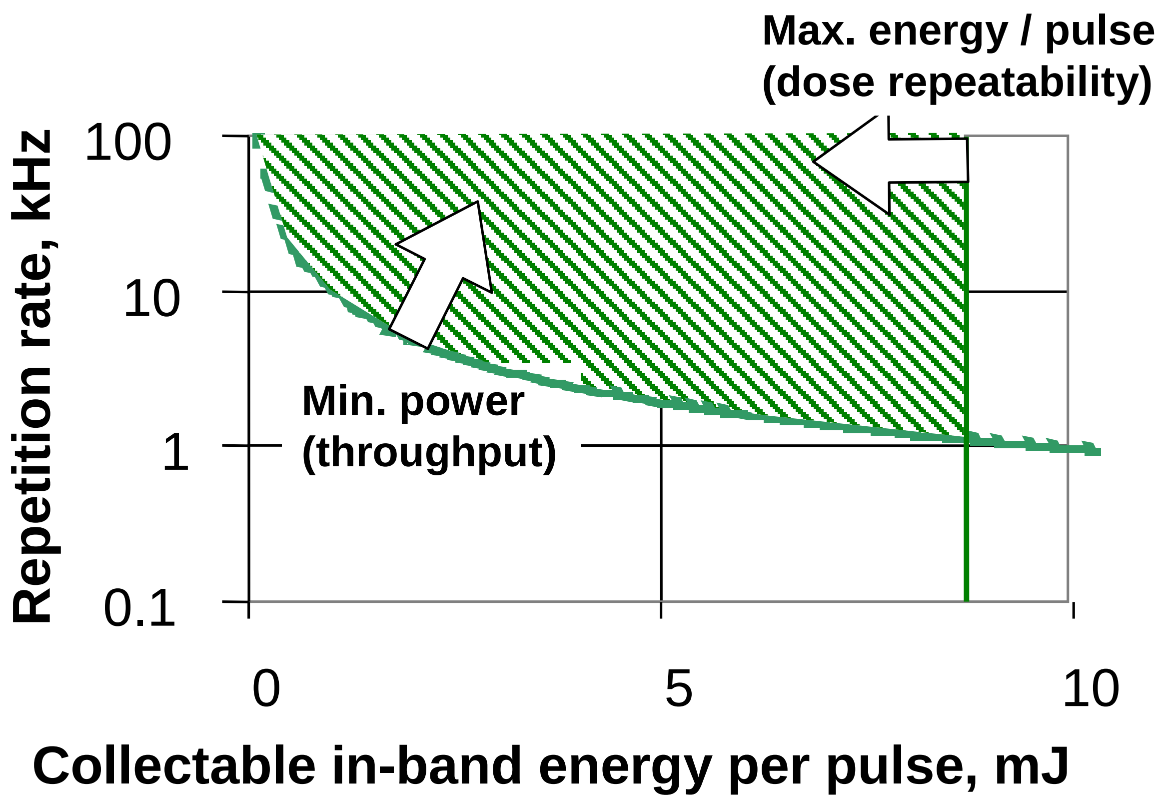
Boundary condition source (dose repeatability) - 2 -

Requirements:
- 40 300 mm wph
- > 30 pulses in slit

Assumptions:
- 5 mJ/cm² resist
- Mo/Be coating
- Optical system as described



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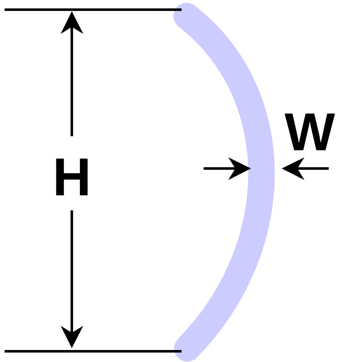
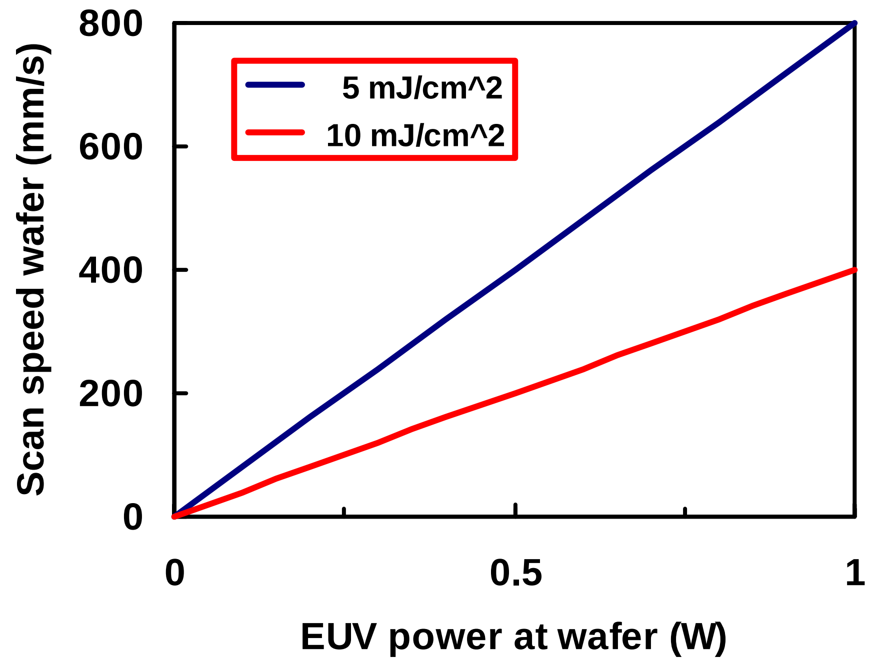
Stage requirement for 40 wph





Resist sensitivity: S

Slit area: $A = H \times W$

Power at wafer: P_W

Slit illumination time: $t_S = S / (P_W / A)$

Velocity wafer stage: $v_{WS} = W / t_S$ or $v_{WS} = P_W / (S \times H)$

For H = 25 mm: v_{WS} = 74 mm/s

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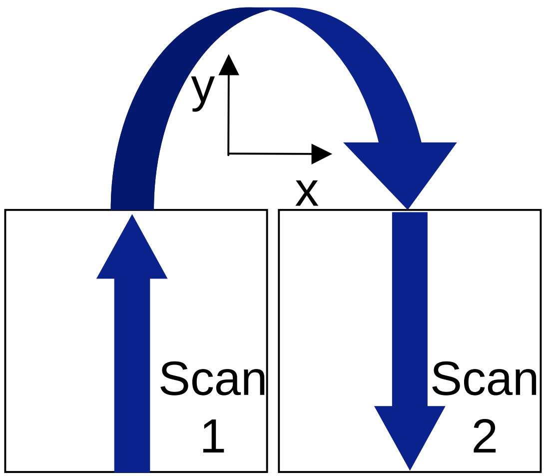
Stage requirement for 40 wph (2)

Simplified case study:

If Stage overhead: T_S = 30 s

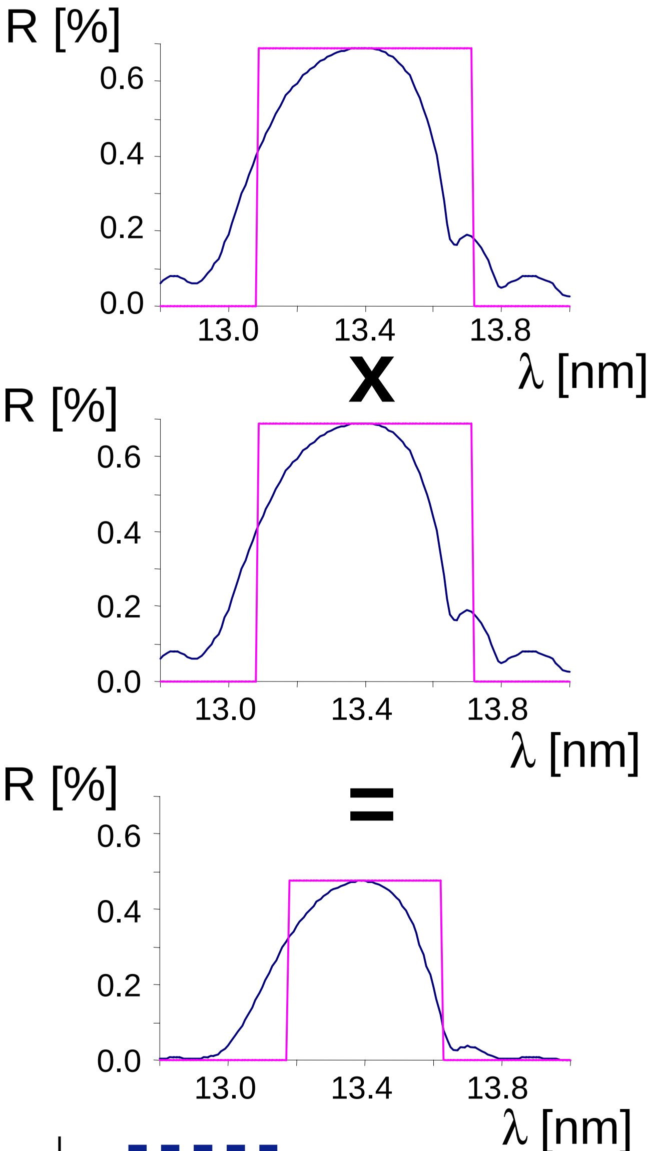
and Step time : settle time = 2 : 1

then Step time per field: t_{step} = 20 sec / N_F = 225 ms



- y: turn around
  speed: 74 => 0 => -74 mm/sec
  a = v/t = 74/(0.225/2) = 658 mm/s^2
- x: step 26 mm
  a = 2 * 13 / (0.225/2)^2 = 2054 mm/s^2
  v = 2054 * (0.225/2) = 231 mm/s

Effective bandwidth



Successive reflections:

- Reduce overall transmission
- Narrows the bandwidth
  Mirror bandwidth BW:

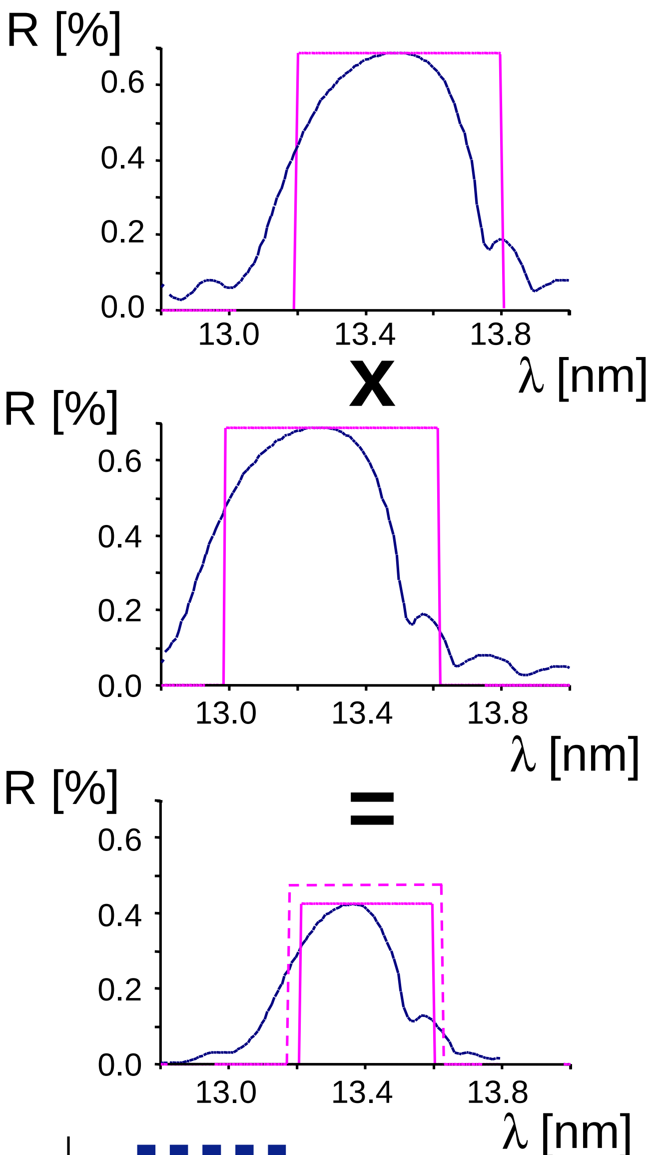
$$BW \times R_{max} = \int R(\lambda)\, d\lambda$$

Effective bandwidth *BW_{eff}* derived from top-hat equivalent of overall system transmission:

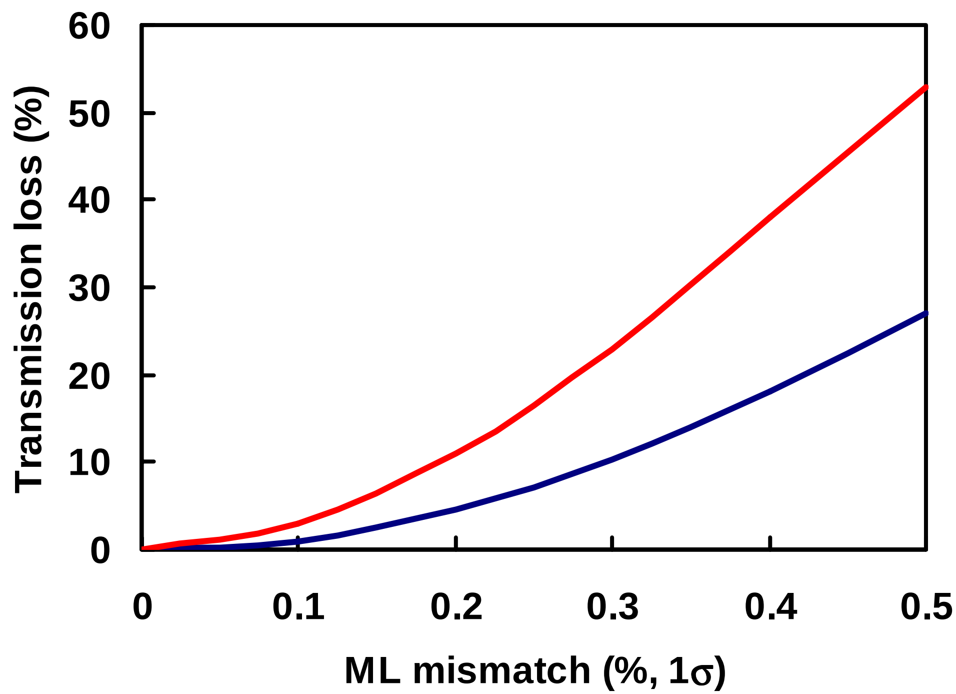
BW_{eff} for 9 reflections:

- Mo/Si: 0.26 nm
- MoRu/Be: 0.16 nm

Multilayer mismatch (MLM)



Multilayer mismatch occurs when center wavelength of coatings are not identical.



MoRu/Be much more sensitive to ML mismatch than Mo/Si

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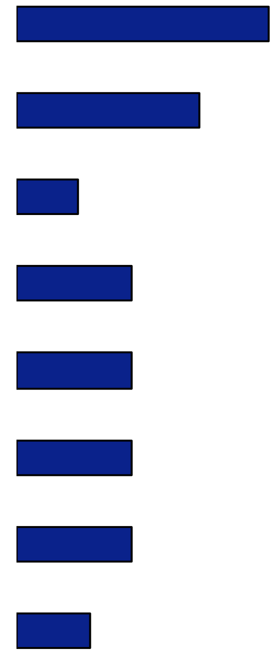
Sensitivity

Parameter						Δ Throughput
T_W	50	⇒	65	%	[1]	+15.8 %
R	72	⇒	75	%	[2]	+11.4 %
BW_{eff}	0.16	⇒	0.18	nm	[2]	+ 3.8 %
P_L	1.8	⇒	2.25	kW		+ 7.1 %
CE	1.2	⇒	1.5	%/%BW/2π		+ 7.1 %
Ω_{col}	40	⇒	50	%		+ 7.1 %
S	5	⇒	4	mJ/cm²		+ 7.1 %
MLM	0.3	⇒	0.2	%		+ 4.5 %



[1]: Werij, “Debris mitigation for EUVL”, this workshop
[2]: Singh, “Enhanced Reflectivity of Multilayer Extreme Ultraviolet Mirrors”, this workshop

Summary & conclusions

- Throughput is only partly determined by exposure time; stage performance and overhead are at least equally important.
- Exposure time is influenced by source, optical transmission and resist sensitivity.
- Source and optics are strongly coupled, both by fundamental physics (etendue) as well as many practical considerations.
- A “realistic” case study resulting in 40 300 mm wph has been presented for a Xe LPP and MoBe coatings.
- Various system improvements have been indicated that could lead to a significantly larger throughput.