High Power Source Feasibility

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Critical Issues Facing EUV Lithography
Industry Risk Perspective

- Source output power and lifetime, including condenser optics lifetime (1,3)
- Availability of defect-free masks (2,5)
- Reticle protection during storage, handling and use (6)
- Projection and illuminator optics lifetime (7)
- Resist resolution, sensitivity and line width reduction (LWR) (10)
- Optics quality for the 32 nm node (8)

* 2002 ranking in brackets

Source: 2nd International EUVL Symposium Steering Committee, October 2003

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Industry Source Requirements

Central wavelength	13.5 nm
EUV Power (2% bandwidth)	80-120 W
Repetition frequency	>6000 Hz
Integrated energy stability (3σ, 50 pulses)	+/- 0.3%
Etendue of source output*	1-3.3 mm^2str
Max. solid angle input to illuminator*	0.03-0.2 str
Source cleanliness	>30,000 hours
Spectral purity* duv/uv, 130-400nm infra-red, >800nm	TBD – 7% TBD

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* Not agreed among ASML,Nikon and Canon

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Choices for EUV Source Technology

The choice of EUV source technology can be broken into two major decisions:

1) Method of plasma excitation

Discharge Produced Plasma (DPP)

Laser Produced Plasma (LPP)

2) Source element

Xe, Sn, In, Li…

Problems to be Solved for Any EUV Source Technology

- EUV power scaling: 100+W (in-band) at the intermediate focus
- Collector lifetime: 100 G shots
  (A shorter collector lifetime can be tolerated if its cost is low and replacement time is short)
- System Affordability:
  DPP: collector lifetime, electrode lifetime, debris shield lifetime
  LPP: system price, collector lifetime, laser component lifetime

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EUV Power Scaling: Source Element Choice

- Though xenon will remain a convenient source element during development, it will not likely be the High Volume Manufacturing (HVM) source element due to low conversion efficiency.
- The remaining candidates (with potentially higher CE) are condensable materials at room temperature.
  - Thus, improved CE comes with the new challenge of collector protection/cleaning of low vapor pressure source elements.

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EUV Power Scaling: Source Multiplexing

- Since the DPP source etendue is equal to the allowed upper limit, combining multiple DPP sources requires temporal multiplexing with moving mirrors or sources.
- The LPP source etendue is much smaller than the allowed upper limit, thus multiple LPP sources can be combined optically.
  - EUV power scaling for LPP can be achieved by adding identical systems (for example: a 100W source can be made up of 2 X 50W sources).
  - Only the technology problems of a smaller power source must be solved for LPP (50W instead of full 100W).

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EUV Power Scaling: Thermal Engineering

- Electrode cooling is the greatest thermal challenge for DPP
  - The technical path to provide the required thermal extraction to achieve 100+W at intermediate focus is very challenging.
- Jet nozzle cooling was greatest thermal challenge for LPP
  - With the development of liquid jet and droplet source delivery at large distances, nozzle cooling no longer an issue.
  - Thermal engineering challenge of LPP has “moved upstream” to the laser head – a more tractable challenge.

Primary Collector Lifetime: Debris

- DPP systems can produce the following types of debris:
  - Fast source element ions
  - Fast source element neutrals
  - Source element particles
  - Fast electrode material ions
  - Fast electrode material neutrals
  - Electrode material particles
  - Insulator material
- LPP systems can produce the following types of debris (assuming long distance source element delivery):
  - Fast source element ions
  - Fast source element neutrals
  - Source element particles

Primary Collector Lifetime: Debris

- The primary difference between debris from DPP and LPP is the existence of DPP electrode and insulator material.
- DPP erosion tests show that tungsten is the best electrode material.
- Tungsten has a higher atomic mass than any proposed source element.
- Thus, regardless of source element choice the DPP must contend with high atomic mass debris.

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System Affordability

Major components of EUV source system cost:

<u>DPP</u>

Grazing incidence collector (multi shell)

Source vacuum vessel system

Electrodes with cooling

Source element delivery

SSPPM

<u>LPP</u>

Multi-layer mirror collector (single element)

Source vacuum vessel system

Beam delivery

Source element delivery

Laser source

<u>Consumables</u>

DPP:

Collector

Electrodes

Debris trap

LPP:

Collector

Pump diodes / Laser chamber

Laser optics

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EUV Power

	Today	Future	Required	Required
Steady State Mode	(Xe)	(Xe)	(Xe)	(Sn)
Thermal Extraction Power (W)	25000	50000	100000	35000
Conversion Eff.	0.45%	0.60%	0.70%	2.00%
EUV Power (W), 2% bw,2π sr	113	300	700	700
Collection Efficiency	20%	30%	30%	30%
Collected EUV (W)	23	90	210	210
Collector Trans.	70%	70%	70%	70%
Debris Mitigation	80%	80%	80%	80%
SPF	100%	100%	100%	100%
Gas Trans.	90%	90%	90%	90%
EUV at Interm. Focus (W)	11.3	45.4	105.8	105.8

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EUV Power

	Extrapolation	ultra high	Required	Required
Steady State Mode	(Xe)	(Xe)	(Sn)	(Sn)
Thermal Extraction Power (W)	25000	150000	30000	30000
Conversion Eff.	0.45%	0.50%	2.00%	2.00%
EUV Power (W), 2% bw,2π sr	113	750	600	600
Collection Efficiency	20%	20%	25%	45%
Collected EUV (W)	23	150	150	270
Collector Trans.	70%	70%	70%	60%
Debris Mitigation	80%	80%	80%	80%
SPF	100%	100%	100%	100%
Gas Trans.	90%	90%	90%	90%
EUV at Interm. Focus (W)	11.3	75.6	75.6	116.6