EUV Light Source – The Path to HVM

Scalability in Practice

Harald Verbraak et al. (all people at XTREME)
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Today’s Talk

- LDP Technology – A Quick Refresher
- How to reach high powers of EUV?
- Where Are We Now?
- What’s Next?
- Conclusions
LDP* Technology Concept – A Quick Refresher

*Laser assisted Discharge Plasma

- Tin Supply Disc
- Tin Film
- Trigger Laser
- EUV in $2\pi$
- Plasma
- Liquid Tin Bath
- Cooling
- Capacitor Bank
LDP Technology – Tin Fulfills Multiple Roles

Tin as electrodes

Tin as wheel protection

Tin as conductor

Tin as dynamic coolant
LDP Technology – Producing, Collecting & Directing EUV

- Intermediate Focus (IF)
- Incident Angle $\alpha$
- Trigger Laser
- Foil Trap
- Collector Mirror
- Rotating Wheels
- Baffles
- Plasma
- Source Head
- Tin Supply
- Vacuum
- Cooling
- Power Supply
- Capacitor Banks
LDP Technology – Modular Architecture

Rotating Wheels

Source Head + Tin Cooling System

Trigger Laser + Capacitor Bank

Foil Trap + Collector Mirror
Enabling EUV Lithography

**EUV SCANNER**
- Imaging
- Yield
  - CD uniformity
  - Iso-Dense Bias
- Maximum Throughput
- Effective Throughput

**EUV Source**
- Clean Photon (& Spectral purity)
- Stability (Dose, Timing …)
- Power
- Duty Cycle
Why LDP - The Best Of Both Worlds

Laser-assisted Discharge Plasma

Traditional LPP
- Scalable

LDP
- Stable
- Scalable

Traditional DPP
- Stable
Clean EUV Power

- EUV power produced by the source (CE, input power)
- Collectable EUV power
- Foil Trap Transmission
- Collector Reflectivity
- Spectral Purity Filter (SPF) → LDP photons are clean, no need for SPF
 Timing = EUV Efficiency

- Breakdown delay time $\propto$
  - Expansion of the plasma

- Time to current maximum $\propto$
  - Inductance L (= mechanical design of Source Head)
  - Capacitance C (capacitor banks)

- Plasma compression time $\propto$
  - Force F (= magnetic pressure, i.e. current)
  - Inertia I (= mass of Tin atoms)
  - Distance D (= spatial distribution of Tin atoms at breakdown)
  - I & D are determined by the laser

**NOK**

- At timing of pinch
- All dissipated power $\rightarrow$ EUV power
Dose Stability Means CD Uniformity

- Dose stability is $3\sigma < 0.1\%$ [Spec. $3\sigma < 0.2\%$]

Conditions:
IMEC’s NXE:3100
0.25NA/ 0.81s
14.5mJ/cm²
27nm LS

Exposure time was
1hr. 11min. for 5-wafer lot full field, full wafer coverage

Exposure time 3hr. 10min. for 15-wafer lot full field, full wafer coverage

Dose Stability over multiple wafers (spec is > .0.2%)
Top: 2x 5 wafer lots
Bottom: 15 wafers lot
The dose stability and thus the dose delivered by the source remains constant during 3 hours without any calibrations in-between.

→ Dose control is perfect! This is a very good result!
LDP IF aperture spatially filters out DUV radiations

DUV is imaged outside the IF aperture and is thus mechanically blocked

Mostly, only EUV photons go through the IF aperture
LDP photons are clean
No need for SPF
No impact upon wafers
Proven @ ADT
Now being validated @ IMEC

LDP - NXE:3100

<table>
<thead>
<tr>
<th>LDP - NXE:3100</th>
<th>OOB/InBand (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>130 - 150 nm</td>
<td>0.0%</td>
</tr>
<tr>
<td>150 - 300 nm</td>
<td>2.5%</td>
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<tr>
<td>300 - 500 nm</td>
<td>1.5%</td>
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</tbody>
</table>

Measurements:
Output inband EUV power: 5 W

Filters:
- CaF2: 130 – 12000 nm
- Suprasil 300: 150 – 4000 nm
- WG295: 300 – 2800 nm
- GG495: 500 – 2800 nm
- Suprasil 300 + Si: 1500 – 4000 nm
- WG295 + Si: 1500 – 2800 nm
OOB IR – LDP Photons Are Clean

- NXE:3100 with LDP technology does not require a Spectral Purity Filter (SPF)

LDP photons are clean

- No SPF
- No loss of In-Band EUV power
- Lower kJoule/Wafer
- More wafers/year
Debris & Contamination Management

- XTREME’s unique Foil Trap module is designed:
  - To protect the collector mirror from Tin deposition and erosion (debris)
  - To prevent Tin transport towards the scanner and the pellicle-less mask
    - Tin contaminants on mask → Yield loss
No Tin Contaminant Beyond IF

- Mechanical baffles and Foil Trap prevent Tin contaminants to transport - through the IF aperture - towards the scanner and the pellicle-less mask.

The “dirty” area physically isolated

- No Tin transport
- No scanner contamination
- No Tin printing defects
- No yield loss

Confirmed by ASML: over 1 year of utilization w/ ADT
Long Collector Mirror Lifetime Is Proven

- The FT protects the collector mirror
- Ruthenium (Ru) coating can also be used as sacrificial material with constant optical performance of the collector

LDP collector lifetime ~ 1 year

Reflectivity is independent of removed material (Measured at XT)

* Confirmed by ASML: over 1 year of utilization w/ ADT
High Duty Cycle Means Throughput

- High Source Duty Cycle = Source is ready when the scanner needs light
  - High Source Duty Cycle ⇔ Source Duty Cycle (Supply) > Process Duty Cycle (Demand)

Source Duty Cycle (%) = \( \frac{T_{\text{burst on}}}{T_{\text{burst on}} + T_{\text{burst off}}} \)

Process Duty Cycle (%) = \( \frac{T_{\text{scan}}}{T_{\text{scan}} + T_{\text{step}}} \)
High Duty Cycle Means Productivity

- High Source Duty Cycle is required to enable maximal throughput
  - Low source Duty Cycle = Scanner waits for the Source = Low throughput
Where Are We Now?
The Initial Breakthrough

20 W
100 % Duty Cycle

Far Field image 35cm behind IF
Removing The Bottleneck – Design For Manufacturing

Previous Foil Trap design

- Bended blades
- Irregular spacing
- Low optical transmission < 60%
- Higher heat load

New Foil Trap design

- Straight blades
- Regular spacing
- High optical transmission > 76%
- Reproduced on 5 newly manufactured FTs
The Initial Breakthrough

- New Foil Trap design → output power now scales linearly
Dose Stability Is Also Within Specifications

- NXE:3100 Specification: $3 \sigma \leq \pm 0.2 \%$

Automated feedback implemented since ADT

Continuous Tin delivery ensures timing stability

LDP dose control independent of the power level
The Breakthrough Is Sustainable

- Cumulative 9 hours @ 20W over 3 days proven

20 W output power
20 kW input power
100 % DC
Variable DC
(to simulate scanner actual operations)
Since Then, Progress Is Steady

33 W  
50% Duty Cycle

30 W  
100% Duty Cycle

37 W  
50% Duty Cycle

Far Field images 35cm behind IF
What’s Next?
Higher Power Is Around The Corner

<table>
<thead>
<tr>
<th>2010</th>
<th>2011</th>
<th>2012</th>
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</thead>
<tbody>
<tr>
<td>7 W</td>
<td>50% Duty Cycle</td>
<td>33 W</td>
</tr>
<tr>
<td>15 W</td>
<td>50% Duty Cycle</td>
<td>37 W</td>
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<tr>
<td>7 W</td>
<td>100% Duty Cycle</td>
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<tr>
<td>7 W</td>
<td>100% Duty Cycle</td>
<td>7 W</td>
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<tr>
<td>50 W</td>
<td>100% Duty Cycle</td>
<td>80 W</td>
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48 kW Source Head Will Soon Deliver 50 W

- Next generation Source Heads are now tested as stand alone module

48 W output power
48 kW input power
100% DC
40 minutes
Equiv. 50W Proven At Module Level

- 76 kW Source Head will be used to generate 100 W EUV output power
  - 1700 W/2psr / 76kW \(\Rightarrow\) ~ 2.3% CE

50 W equiv. 100 W equiv.

- 20% Duty Cycle
- 100% Duty Cycle

- June 2011
- February 2011
- Sept. 2011
- October 2009
Towards HVM

- The path towards HVM high power is clear

250 W Source

- 48 kW Source Head
  - Increase electrical input power by increasing repetition rate
  - Increase the rotation speed of Source Head wheel
  - Increase Tin cooling capacity

- 300 kW Source Head

- 50 W Foil Trap
  - Increase distance to plasma
  - Increase cooling efficiency

- 250 W Foil Trap
Conclusions

- 30 W / 100% DC has been achieved at system level
- 37 W / 50 % DC has been achieved at system level
- 50 W / 100% DC has been achieved at the module level (SH)
- Higher power is around the corner
- LDP is scalable to higher power. The path to 250 W is identified
THANK YOU VERY MUCH FOR YOUR ATTENTION
XTREME technologies GmbH
www.xtremetec.de
Why LDP – The Rationale
High Duty Cycle Means Useful Power

- Useful Power = Burst Power \times Duty Cycle
To achieve 100 W EUV power, higher input power Source Heads is required. The 100 W enabling 76 kW Source Head is being tested.

Higher Power Is Around The Corner

- 20% Duty Cycle
- 100% Duty Cycle

- June 2011
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