CO₂ Laser-Produced Sn-plasma Source for High-volume Manufacturing EUV Lithography

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Introduction
  - LPP source roadmap and concept

Update of CO\textsubscript{2} laser produced Sn plasma source
  - Laser output power
  - Sn droplet target
  - Sn plasma guiding by magnetic field

LPP/EUV future direction to HVM

Summary
## LPP Source Roadmap

<table>
<thead>
<tr>
<th></th>
<th>1st Mid term 2004/9</th>
<th>2nd Mid term 2006/3</th>
<th>EUVA Final 2008/3</th>
<th>HVM source-1 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EUV Power (IF)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Stability</strong></td>
<td>5.7W 1)</td>
<td>10W 1)</td>
<td>50W 2)</td>
<td>110W 2) /140W 3)</td>
</tr>
<tr>
<td><strong>Laser</strong></td>
<td>YAG:1.5kW 10kHz</td>
<td>CO₂:2.6kW 100kHz</td>
<td>CO₂: 7.5kW 100kHz</td>
<td>CO₂: 10kW 100kHz</td>
</tr>
<tr>
<td><strong>Laser freq.</strong></td>
<td>0.9%</td>
<td>0.9%</td>
<td>2.5%</td>
<td>4%</td>
</tr>
<tr>
<td><strong>CE (source)</strong></td>
<td>Xe-Jet</td>
<td>SnO₂ choroid</td>
<td>Sn-Droplet</td>
<td>Sn-Droplet</td>
</tr>
<tr>
<td><strong>Target</strong></td>
<td></td>
<td>liquid jet</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**EUVA project**

### Technology for <10W
- Nd:YAG Laser, Liquid Xe jet

### Technology for 115-200W
- CO₂ Laser, Sn droplet target
- Magnetic field mitigation

**Note**
Primary source to IF EUV transfer efficiency:
1) 43%
2) 28% with SPF
3) 36% without SPF
Light Source Concept

Requirement for EUV source for HVM

- High EUV power >115 W
- EUV Stability
- Collector mirror lifetime
- Low CoG / CoO

CO2 laser + Sn LPP light source + Magnetic field plasma guide

High power pulsed CO₂ Laser

Magnetic field plasma guiding

Sn collector

Sn target supply

LPP: Laser-Produced Plasma
LPP Concept : History

2001: Concept of CO₂ laser based LPP source. (Patent applied in 2001)
2001: Concept of MOPA CO₂ laser based LPP source. (Patent applied in 2001)
2002 /09: EUVA light source project starts (with Gigaphoton, USHIO and Komatsu)
2003: Concept of Magnetic field ion mitigation (Patent applied in 2004)
2004 /09: EUV 5.7 W IF was demonstrated (Nd:YAG and Xe jet)
2006 /03: EUV 10 W IF was demonstrated (CO₂ and SnO₂ choroid liquid jet)
2007 /02: EUV 40 W IF was demonstrated (CO₂ and Sn target)
2007 /10: EUV 60 W IF was demonstrated (CO₂ and Sn target)
Outline

- Introduction
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- Update of CO₂ laser produced Sn plasma source
  - Laser output power
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- LPP/EUV future direction to HVM

- Summary
# High power CO2 laser MOPA system

<table>
<thead>
<tr>
<th><strong>Laser Power</strong></th>
<th>13 kW</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pulse Width</strong></td>
<td>20 ns</td>
</tr>
<tr>
<td><strong>Repetition Rate</strong></td>
<td>100 kHz</td>
</tr>
<tr>
<td><strong>Beam quality</strong></td>
<td>M2 1.1</td>
</tr>
<tr>
<td><strong>Pulse energy stability</strong></td>
<td>2% (3s, 500 pulses)</td>
</tr>
</tbody>
</table>

## Laser System

- **Oscillator**
  - Wave length: 10.6um
  - Rep. rate: 100kHz
  - Pulse width: 20 ns (FWHM)

- **Pre-Amplifier**
  - RF-excited CO2 laser
  - Pulse width: 20 ns (FWHM)

- **Main-Amplifier**
  - RF-excited CO2 laser

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![Laser beam profile](image_url)
EUVV output evaluation at intermediate focus

System configuration

Oscillator → Pre-Amp → Main Amp

Collector mirror
1sr (=3sr x 1/3)

IF
(intermediate focus)

Rotating Sn plate target

Amp laser

EUV chamber
EUV IF power: 16 W (measured by 1sr collector)
60 W (4 sr collector, calculated)

Target: Rotating Sn plate
Laser irradiation power: 6 kW (100 kHz, 20 ns)
EUV energy stability: 3.8% (3σ, 500 pulses)
IF image size: 3.6 mm (H), 3.3 mm (V) at 1/e^2
Etendue: 1.9 mm^2sr (4 sr collector)
**Sn droplet target**

Sn droplets observed at 50mm from the nozzle

<table>
<thead>
<tr>
<th>Frequency (kHz)</th>
<th>Size (μm)</th>
<th>Spacing (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>92</td>
<td>φ47</td>
<td>176</td>
</tr>
<tr>
<td>112</td>
<td>φ44</td>
<td>146</td>
</tr>
<tr>
<td>142</td>
<td>φ41</td>
<td>115</td>
</tr>
<tr>
<td>320</td>
<td>φ28</td>
<td>65</td>
</tr>
<tr>
<td>500</td>
<td>φ19</td>
<td>44</td>
</tr>
</tbody>
</table>
Sn droplet target

Droplet generator and deviation system

Isolated 40-um Sn droplets

Deflection electrode

Charging Electrode

Droplet generator

Charging controller
DC or Pulse

Piezo. Driver
Syncro.

Piezo.

Back light

CCD

1mm

4mm

Lo

L

δ
Emission from laser produced plasma

Electron density profile

$n_c = \frac{\varepsilon_0 m \omega^2}{e^2}$

$n_c = \frac{1.11 \times 10^{21} (e/cm^3)}{\lambda^2 (\mu m)}$

<table>
<thead>
<tr>
<th>Critical density $n_c$ (e/cm$^3$)</th>
<th>Frequency $\omega_p/2\pi$</th>
<th>Wavelength $\lambda_c$</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>$2.5 \times 10^{12}$</td>
<td>14 GHz</td>
<td></td>
<td>Ku-band microwave</td>
</tr>
<tr>
<td>$1.0 \times 10^{19}$</td>
<td></td>
<td>10.6 mm</td>
<td>CO2 laser</td>
</tr>
<tr>
<td>$1.0 \times 10^{21}$</td>
<td></td>
<td>1.06 mm</td>
<td>Nd:YAG laser</td>
</tr>
<tr>
<td>$1.8 \times 10^{22}$</td>
<td></td>
<td>248 nm</td>
<td>KrF excimer laser</td>
</tr>
</tbody>
</table>
Double pulse laser irradiation onto Sn droplet

The maximum conversion efficiency of 2.5% is obtained at a YAG-CO2 delay time of about 5μs.
Magnetic field plasma beaming

1) Investigation of Tin ion flux in “Real” 3D-space
2) Optimization of Tin debris evacuation.
Magnetic field plasma guiding

Superconducting magnet was installed for:
1) Investigation of Tin ion flux in “Real” large space.
2) Optimization of Tin debris evacuation.

Visible image of Sn plasma flow in magnetic field
Laser : CO2 laser, Target : Sn plate

Without magnetic field
Magnetic flux density : 2T
Results on symmetry axis with & w/o B-field

Tin ions are effectively confined and guided by the magnetic field.
Magnetic field plasma guiding

Nanopowder

Dendolite

Etching

Sn plate

CO2 laser

22.5°

0°

7.5°

22.5°

52.5°

67.5°

Erosion

Strong deposition

Low deposition

No deposition

No deposition

No deposition
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Gigaphoton LPP Light Source

- Sn Droplet
- High power pulsed CO2 laser
- Magnetic-field Plasma Guiding

Sn supply
Magnet
Plasma
IF
CO2 laser
Collector mirror
Sn collector
# EUV LPP light source roadmap

<table>
<thead>
<tr>
<th></th>
<th>ETS (Internal use only)</th>
<th>SD (1st Gen.) (proto/integration possible)</th>
<th>HVM (2nd Gen.) (product)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Timing</strong></td>
<td>2009/1Q</td>
<td>2009/4Q</td>
<td>2011/1Q</td>
</tr>
<tr>
<td><strong>Power</strong> (Source to IF: 34% (R=0.6, 4sr(0.64), T=0.9))</td>
<td>100W</td>
<td>140W</td>
<td>280W</td>
</tr>
<tr>
<td><strong>Drive laser</strong></td>
<td>10kW</td>
<td>10kW</td>
<td>20kW</td>
</tr>
<tr>
<td><strong>CE</strong></td>
<td>3.5%</td>
<td>4.0%</td>
<td>4.0%</td>
</tr>
<tr>
<td><strong>Target</strong></td>
<td>Tin droplet</td>
<td>Tin droplet</td>
<td>←</td>
</tr>
<tr>
<td><strong>Mitigation</strong></td>
<td>Single magnet &amp; ionization</td>
<td>magnet &amp; ionization</td>
<td>←</td>
</tr>
<tr>
<td><strong>C1 Mirror Spec.</strong></td>
<td>4sr 60 Bi-layer, R&gt;60%</td>
<td>TBD Heat Protected</td>
<td>TBD</td>
</tr>
<tr>
<td></td>
<td>Life 200Bplhs</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td><strong>Tool interface (I/F)</strong></td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Duty</strong></td>
<td>&gt;75%</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
</table>
Power roadmap

- **Today to SD**
  - Non-commercial system

- **Commercial system**
  - 140W (SD: 1st generation)
  - 280W (HVM: 2nd generation)

- **Power at IF (W)**
  - 40W (Today)
  - 100W (ETS)
  - 140W (SD: 1st generation)
  - 280W (HVM: 2nd generation)

- **140W will be available in 2010 & 280W in 2011**
Summary

LPP source at EUVA (non-integrated setup)

- Further advance of component technology is reported
  - 13 kW drive laser output power; 100 W in-band EUV at I/F equivalent.
    scalable to 20 kW.
  - Sn droplet active control and 1.5% efficiency is achieved.
- EUV output evaluation at intermediate focus.
  - 60 W at I/F achieved with 6kW CO₂ driver laser power.
  - Preliminary target: solid Sn disk and 2.5% efficiency is achieved.
  - Magnetic field plasma guiding of CO₂ laser produced Sn plasma.
    - Sn deposition reduced by magnetic field.
    - Sn plasma is guided by magnetic field.
    → Basic technology for Sn evacuation is established.

Next step (integrated setup)

- Integrated system demonstration with advanced component technology and mirror lifetime evaluation.