1st generation Laser-Produced Plasma 100W source system for HVM EUV lithography

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Outline

- **Introduction**
  - Concept of Gigaphoton LPP source

- **1st Generation system data**
  - Latest data
  - Critical issue and experimental data

- **2nd generation system development**
  - Design
  - Status of construction

- **Roadmap update and New facility**

- **Looking through 6.6nm**

- **Summary**
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- **Summary**
EUV sources

Original technologies

LPP: CO₂ laser and Sn source
1. High power pulsed CO₂ laser
2. Magnetic field plasma mitigation
3. Pre-Pulse plasma technology

<table>
<thead>
<tr>
<th>Type</th>
<th>LPP</th>
<th>DPP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maker</td>
<td>Gigaphoton</td>
<td>Company A</td>
</tr>
<tr>
<td></td>
<td>Company B</td>
<td></td>
</tr>
<tr>
<td>Size</td>
<td>Large</td>
<td>Very Large</td>
</tr>
<tr>
<td></td>
<td>Small</td>
<td></td>
</tr>
<tr>
<td>Power (at present)</td>
<td>104W/21W</td>
<td>90W/20W</td>
</tr>
<tr>
<td></td>
<td>34W/34W</td>
<td></td>
</tr>
<tr>
<td>Plasma</td>
<td>No electrode</td>
<td>No electrode</td>
</tr>
<tr>
<td></td>
<td>Disc electrode</td>
<td></td>
</tr>
<tr>
<td>Mitigation</td>
<td>Pre pulse + Magnet</td>
<td>Gas</td>
</tr>
<tr>
<td></td>
<td>Gas + mechanical shutter</td>
<td></td>
</tr>
<tr>
<td>Life limitation</td>
<td>( several 1000 hr )</td>
<td>Several 10 hr</td>
</tr>
<tr>
<td></td>
<td>Several 10 hr</td>
<td></td>
</tr>
<tr>
<td>Bottle neck</td>
<td>-</td>
<td>Mirror</td>
</tr>
<tr>
<td></td>
<td>Electrode/Mirror</td>
<td></td>
</tr>
<tr>
<td>Remark</td>
<td>• Theoretically no limit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Engineering items are lot</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Trade off of power and lifetime</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Trade off of power and beam quality</td>
<td></td>
</tr>
</tbody>
</table>

Original technologies
LPP: CO₂ laser and Sn source

① High power pulsed CO₂ laser
② Magnetic field plasma mitigation
③ Pre-Pulse plasma technology
# EUVA Project (LPP)

<table>
<thead>
<tr>
<th></th>
<th>1st Mid term 2004/9</th>
<th>2nd Mid term 2006/3</th>
<th>EUVA -1 final 2008/3</th>
<th>EUVA-2 final ~ 2011/3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EUV Power (IF)</strong></td>
<td>5.7W 1)</td>
<td>10W 1)</td>
<td>50W 2)</td>
<td>1st Generation (ETS)</td>
</tr>
<tr>
<td><strong>Stability Laser</strong></td>
<td>YAG:1.5kW</td>
<td>YAG:1.5kW</td>
<td>YAG:1.5kW</td>
<td>2nd Generation (proto/GL200E)</td>
</tr>
<tr>
<td><strong>Laser freq.</strong></td>
<td>10kHz</td>
<td>100kHz</td>
<td>100kHz</td>
<td>250W (clean@IF)</td>
</tr>
<tr>
<td><strong>CE (source)</strong></td>
<td>0.9%</td>
<td>0.9%</td>
<td>2.5%</td>
<td>3σ&lt;±0.3%</td>
</tr>
<tr>
<td><strong>Target</strong></td>
<td>Xe-Jet</td>
<td>SnO₂ choroid liquid jet</td>
<td>Sn-Droplet</td>
<td>CO₂: 23kW</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100kHz</td>
</tr>
</tbody>
</table>

**EUVA project-1**

**EUVA project-2**

**Commercial**

**Note**

Primary source to IF EUV transfer efficiency:

1) 43%
2) 28% with SPF
3) 36% without SPF

SPF: Spectral Purity Filter  IF: Intermediate Focus
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- **Looking through 6.6nm**

- **Summary**
1st generation system (ETS device)
## System operation Data (1)

<table>
<thead>
<tr>
<th></th>
<th>Last data (SPIE 2010)</th>
<th>Present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average power (@IF)</td>
<td>14 W</td>
<td>21 W</td>
</tr>
<tr>
<td>Brightness (@IF)</td>
<td>69 W</td>
<td>104 W</td>
</tr>
<tr>
<td>Duty cycle</td>
<td>20 %</td>
<td>20 %</td>
</tr>
<tr>
<td>Max. non stop op. time</td>
<td>&gt;1 hr</td>
<td>&lt;1 hr</td>
</tr>
<tr>
<td>Average CE</td>
<td>2.3 %</td>
<td>2.5 %</td>
</tr>
<tr>
<td>Dose stability (simulation)</td>
<td>(+/- 0.15%)</td>
<td>(+/- 0.15%)</td>
</tr>
<tr>
<td>Droplet diameter</td>
<td>60 μm</td>
<td>60 μm</td>
</tr>
<tr>
<td>CO₂ laser power</td>
<td>5.6 kW</td>
<td>7.9 kW</td>
</tr>
</tbody>
</table>
System operation Data (2)

- Burst stability data (70W open loop)
System operation data (3)

Fast ions are perfectly shielded across magnetic field!

- Laser power 5kW
- Duty 20% (ON 200msec:OFF 800msec)

Magnetically guided EUV plasma observation
Critical issue investigation

(Experiment with research device 10Hz experiment)

- Double pulse optimization
- Debris mitigation mechanism
- Higher Ce investigation
Liquid droplet experiment

Shadowgraphs of the liquid droplet target

Nd:YAG Laser
Wavelength: 1064 nm
Pulse length: 5 ns (FWHM)
Spot size: \(~\Phi100\ \mu m\)
Laser intensity: \(~1.6 \times 10^9\ \text{W/cm}^2\)

Target
Liquid droplet: \(\Phi60\ \mu m\)

Velocity 17 m/s

0 \(\mu s\) 10 \(\mu s\) 20 \(\mu s\) 30 \(\mu s\) 50 \(\mu s\)
Liquid droplet experiment with double-pulse

Perfect evaporation and high Ce(=2.2%) with double pulse irradiation at around 20 micron Tin droplet is demonstrated.

YAG irradiation

no CO2 irradiation

CO2 irradiation

SO-04  T. Hori “Investigation on high conversion efficiency and tin debris mitigation for LPP EUV light source.

SO-P15  A. Sunahara “Radiation Hydrodynamic Simulation of laser produced Tin plasma.”
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- Summary
## EUV Light Source Major Specifications

### 2nd generation GL-200E-proto is under development!

<table>
<thead>
<tr>
<th>Sub systems</th>
<th>1st generation</th>
<th>2nd generation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EUV model</strong></td>
<td>ETS</td>
<td>GL200E proto</td>
</tr>
<tr>
<td>Power W</td>
<td>100</td>
<td>&gt;100</td>
</tr>
<tr>
<td>Pulse energy mJ</td>
<td>1</td>
<td>&gt;1</td>
</tr>
<tr>
<td>Max rep rate kHz</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Max Duty Cycle %</td>
<td>75</td>
<td>&gt;75</td>
</tr>
<tr>
<td>Target Material and Shape</td>
<td>Sn droplet</td>
<td>Sn droplet</td>
</tr>
<tr>
<td>Droplet Diameter micro meter</td>
<td>60</td>
<td>10</td>
</tr>
<tr>
<td>Debris Mitigation</td>
<td>Magnet and cleaning</td>
<td>Magnet and cleaning</td>
</tr>
<tr>
<td>Collector Mirror Lifetime Bpl</td>
<td>11</td>
<td>&gt;200</td>
</tr>
<tr>
<td>Tool Interface</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

2nd generation GL-200E-proto is under development!
GL200E-proto System Overview

Clean room floor

Subfab

CO2 laser
Pre-pulse laser
Chiller

EUV chamber
Magnet
Utility
2nd gen. high power pulsed CO2 laser system

1st gen. laser system

2nd gen. laser system
- Compact: footprint -> <50%
- Efficient: Plug in eff. x2
- Higher power: 10kW -> 20kW
2nd Gen. CO₂ laser system is under construction
Main Amplifier performance

- Main amplifier characteristics: experimental results
  - ~10kW output achieved at 3kW input power
  - Good beam quality: $M^2 < 2.0$

SO-PO3  T. Ohta “Improving efficiency of pulsed CO2 laser system for LPP EUV light source.”
2nd Gen. Magnet system is under construction
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## Gigaphoton EUV Roadmap

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>500W</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>⭐</td>
<td></td>
<td>⭐️</td>
</tr>
<tr>
<td>350W</td>
<td></td>
<td></td>
<td></td>
<td>⭐</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>250W</td>
<td></td>
<td></td>
<td>⭐</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100W</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **GL400E**: 1st source delivery
- **GL200E+**
- **GL200E**
- **ETS**
Power roadmap (Clean EUV Power)

<table>
<thead>
<tr>
<th>EUV model</th>
<th>ETS</th>
<th>GL200E</th>
<th>GL200E+</th>
<th>GL400E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive laser power (kW)</td>
<td>10</td>
<td>23</td>
<td>33</td>
<td>40</td>
</tr>
<tr>
<td>Conversion efficiency (%)</td>
<td>3.0</td>
<td>5.0</td>
<td>5.0</td>
<td>6.0</td>
</tr>
<tr>
<td>C1 mirror collector angle (sr)</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
</tr>
<tr>
<td>Efficiency (%)</td>
<td>74</td>
<td>74</td>
<td>74</td>
<td>74</td>
</tr>
<tr>
<td>C1 mirror reflectivity (%)</td>
<td>(50)</td>
<td>57</td>
<td>57</td>
<td>57</td>
</tr>
<tr>
<td>Optical transmission (%)</td>
<td>95</td>
<td>95</td>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td>SPF (IR, DUV) (%)</td>
<td>N/A**</td>
<td>62</td>
<td>62</td>
<td>62</td>
</tr>
<tr>
<td>Total EUV power (after SF) (W)</td>
<td>100</td>
<td>250</td>
<td>350</td>
<td>500</td>
</tr>
</tbody>
</table>
LPP-EUV Development Facility (1)

- Shinomiya, Hiratsuka (60km south-west from Tokyo)
- In industry park of Hiratsuka beside the Sagami river
- Production capacity is up to 4 units/year (at present)
- Building is extendable to surrounded open space
LPP-EUV Development Facility (2)
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- **Summary**
Looking through 6.6nm

**Base line**
- For 1/2 shorter wavelength generation, 2x higher plasma temperature is needed. On the other hand LPP based on free standing plasma, plasma temperature may not showstopper of EUV generation.

**Engineering issue**
- Fundamental study of Gd, Tb plasma is important. Also conversion efficiency investigation on the plasma is important for system design.

- 2x higher exciting power intensity by LPP driver laser.

- Gd,Tb has similar property with Tin except melting point. (→ next table) Around 10 micron droplet generation of very high temperature (>1000 °C) materials is key technology.
# EUV emission materials

<table>
<thead>
<tr>
<th>Physical properties</th>
<th>Tin</th>
<th>Gadolinium</th>
<th>Terbium</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUV wavelength</td>
<td>13.6nm</td>
<td>6.5-6.7nm</td>
<td></td>
</tr>
<tr>
<td>Density (near r.t.)</td>
<td>g·cm⁻³</td>
<td>7.365</td>
<td>7.90</td>
</tr>
<tr>
<td>Liquid density at m.p.</td>
<td>g·cm⁻³</td>
<td>6.99</td>
<td>7.4</td>
</tr>
<tr>
<td>Melting point</td>
<td>°C</td>
<td>231.93 (449.47)</td>
<td>1312 (2394)</td>
</tr>
<tr>
<td>Boiling point</td>
<td>°C</td>
<td>2602 (4716)</td>
<td>3273 (5923)</td>
</tr>
<tr>
<td>Heat of fusion</td>
<td>kJ·mol⁻¹</td>
<td>7.03</td>
<td>10.05</td>
</tr>
<tr>
<td>Heat of vaporization</td>
<td>kJ·mol⁻¹</td>
<td>296.1</td>
<td>301.3</td>
</tr>
<tr>
<td>Specific heat capacity (25 °C)</td>
<td>J·mol⁻¹·K⁻¹</td>
<td>27.112</td>
<td>37.03</td>
</tr>
<tr>
<td>Ionization energies</td>
<td>kJ·mol⁻¹</td>
<td>1st: 708.6</td>
<td>1st: 593.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2nd: 1411.8</td>
<td>2nd: 1170</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3rd: 2943.0</td>
<td>3rd: 1990</td>
</tr>
<tr>
<td>EUV Conversion Efficiency</td>
<td>%</td>
<td>3.2 (max.8.0)</td>
<td>?</td>
</tr>
</tbody>
</table>
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Summary

ETS-2 (1st generation integrated setup LPP source)
- Latest operation data is reported
  - 104W at duty cycle of 20% (i.e. average power = 21W)
  - Stability under burst operation <+- 0.23% (dose simulation)
- Investigation of critical issue is in advance at research device.
  - Under 20 μm Tin droplet evaporated perfectly with double pulse method.

2nd generation LPP source
- Construction of 1st proto machine is on going.
  - CO2 laser operate with good beam quality around 10kW 30% duty.
  - Super conductive magnet is installed.

Product roadmap and new facility
- Target spec. and schedule of Gigaphoton LPP source product is updated.
- New EUV facility is introduced.

Looking forward 6.7nm
- Basically LPP-scheme is applicable even on 6.6nm.
- Fundamental study of Gd, Tb plasma, conversion efficiency investigation is important.
- 2x higher exciting power intensity by LPP driver laser.
- Around 10 micron droplet generation of very high temperature (>1000 °C) materials is key technology.
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