Laser-produced plasma source for EUV lithography

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Introduction
- EUVA project
- Concept of Gigaphoton LPP source

ETS (1st generation integrated system) Experiment
- Configuration
- Latest data
- Status summary of ETS experiment

HVM EUV light source product specification and roadmap

Summary
Outline

- Introduction
  - EUVA project
  - Concept of Gigaphoton LPP source

- ETS (1st generation integrated system) Experiment
  - Configuration
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- Summary
### EUVA Project

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>5.7W 1) --- YAG:1.5kW 10kHz 0.9% Xe-Jet</td>
<td>10W 1) σ&lt;±10% CO₂:2.6kW 100kHz 0.9% SnO₂ choroid liquid jet</td>
<td>50W 2) σ &lt;±5% CO₂: 7.5kW 100kHz 2.5% Sn-Droplet</td>
<td>110W 2) /140W 3) 3σ&lt;±0.3% CO₂: 10kW 100kHz 4% Sn-Droplet</td>
<td></td>
</tr>
</tbody>
</table>

**EUVA project-1**

#### 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

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Concept of Gigaphoton LPP Source

Requirement for EUV source for HVM

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

Original technologies
1. CO$_2$ laser and Sn LPP source
2. Magnetic field plasma guiding
3. High power pulsed CO$_2$ laser

High power pulsed CO$_2$ laser

EUV Collector

Sn supply

Plasma guiding Magnet

Plasma

IF
① CO2 Laser and Sn LPP source

- CO2 laser + Sn
  Create EUV light with essentially high efficiency.
  Theoretically 8% is feasible.
  *(Gigaphoton original 2002)*

- Double pulse LPP
  Enhance conversion efficiency.
  Also ionization efficiency enhanced, therefore clean plasma quality will be realized.
  *(Gigaphoton original 2004)*
② Magnetic field plasma guiding

- **Mirror protection**
  
  First energy ion is perfectly shielded by strong magnetic field.
  
  *(Gigaphoton original 2004)*

- **Clean Operation**
  
  Sn debris is guided to plasma collector.
  
  Not only C1 mirror but also EUV chamber maintain clean operation.
  
  *(Gigaphoton original 2004)*

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**Sn target**

**CO2 laser**

**Dendolite formation**

**Erosion**

**Low Deposition**

**No deposition**

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**Komatsu**

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③ High power pulsed CO2 laser

High power pulsed CO2 laser

Combination of short pulsed high rep. rate Osc. and Industrial CW CO2 laser.

*(Gigaphoton original 2003)*

![Diagram showing the components of a high power pulsed CO2 laser system: OSC, Pre-AMP, Main-AMP.](image)

- **Power**: 10kW
- **Pulse**: 100kHz, 20ns
- **Beam**: $M^2<2$ at 10% duty

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ETS Experiment

- 1st generation integrated LPP system

- Demonstration of 100W (av. 75W) operation
  - Prove system concept with real data with integrated system
    - Pre-pulse target heating
    - Mass limited target
    - Magnetic mitigation
    - Mirror cleaning

- Clarify the engineering issues of component and find solution
  - CO2 laser
  - EUV chamber (mirror, droplet gen., etc.)

- Feedback engineering data to GL100E
ETS System Configuration

System layout

**Laser System**
- Oscillator
  - Wave length: 10.6μm
  - Rep. rate: 100kHz
  - Pulse width: 20 ns (FWHM)
- Pre-Amplifier
  - RF-excited CO2 laser
- Main Amplifier
  - RF-excited CO2 laser

**EUV chamber**
- Laser beam profile

- Laser Power: 13 kW
- Pulse Width: 20 ns
- Repetition Rate: 100 kHz
- Pulse energy stability: 2% (3s, 500 pulses)
ETS EUV Chamber Configuration

- Super Conducting Magnet
- Droplet Generator
- Collector Mirror
- Ion Collector
- YAG Laser Beam
- IF Position
- CO₂ Laser Beam
New Droplet Generator

Good stability is realized

Video Droplet for ETS-2
Diameter: 60um
Stability: ±13um
Velocity: 60m/s
Frequency: 400kHz
Stability data

- Stability satisfy the target spec.
Latest ETS operation data (10%/20% duty)

- Video of EUV plasma (20%duty)

- Output data (10% duty)
  - Short term
  - Burst mode stability
  - Middle term
  - Long term
EUV Plasma observation (Video)

- Laser power 5kW
- Duty 20%
  - Burst ON 200msec
  - Burst OFF 800msec
- With Droplet position control
- w/o Droplet timing control
- w/o Energy control
System operation Data (1) - Short term data-

- Short term output data
  1. Average power (@I/F) 2.5W
  2. Brightness (@I/F) 25W
  3. Duty cycle 10% (ON/OFF=20ms/180ms)
  4. Experiment time 7 hr
  5. Average CE 1.5%

- System operation Data (1) - Short term data-
  - Droplet diameter 60 μm
  - CO2 laser power 5kW

![Graph showing EUV energy vs. number of pulses]
**System operation Data (2)**

- Short term output data (envelope)

- Laser power 5kW
- CE=1.5%
- Duty 10%
  - Burst ON 20msec
  - Burst OFF 180msec

- w/ Droplet position control
- w/o Droplet timing control
- w/o Energy control

200 sec

1 msec average/point
System operation Data (3)

Burst stability data

![Graph showing burst stability data with x-axis as Number of pulses [x2] and y-axis as EUV energy [a.u.]](image-url)
System operation Data (4) - Long term -

**Long term operation**

- Laser power 5kW
- CE=1.5%
- Duty 10%
  - Burst ON 20msec
  - Burst OFF 180msec

- w/ Droplet position control
- w/o Droplet timing control
- w/o Energy control

**Graphs:**
- **START**
- **30min**
- **60min**
Sn Debris issue

Now correcting debris mitigation data of ETS!

Peak velocity angular distribution

Velocity distribution

ions
fragments
laser
neutral atoms
tin target
Smaller droplet development (for next step)

Mass limited target is essential for small debris!

Size: \(\phi\) 47\,\mu m \quad \phi\) 44\,\mu m \quad \phi\) 41\,\mu m \quad \phi\) 28\,\mu m \quad \phi\) 19\,\mu m \quad < \phi\) 10\,\mu m

Freq.: 92\,kHz \quad 112\,kHz \quad 142\,kHz \quad 320\,kHz \quad 500\,kHz

Spacing: 176\,\mu m \quad 146\,\mu m \quad 115\,\mu m \quad 65\,\mu m \quad 44\,\mu m
Sn mitigation strategy

Integrate new technologies

Mass limited target and Cleaning technology into ETS is our major concern!
## Status summary of ETS Experiment

(13, October 2009)

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Type</th>
<th>Performance at Plasma</th>
<th>Integrated Performance</th>
<th>Performance Projections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gigaphoton Komatsu EUVA</td>
<td>Sn LPP</td>
<td><strong>Demonstrated operating time</strong></td>
<td><strong>Average EUV power in 2π at plasma (measured)</strong></td>
<td><strong>Level of integration</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 hours @ 10% duty cycle</td>
<td>7.5W @ 10% duty cycle</td>
<td>With droplets No integrated Source</td>
</tr>
</tbody>
</table>
Average power improvement chart (scheduled)

Climbing up the average power cliff very rapidly
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- Summary
## EUV Light Source Major Specifications

<table>
<thead>
<tr>
<th>EUV model</th>
<th>ETS</th>
<th>GL100E proto</th>
<th>GL200E</th>
<th>GL400E</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power</strong></td>
<td>W</td>
<td>100</td>
<td>&gt;100</td>
<td>&gt;200</td>
</tr>
<tr>
<td><strong>Pulse energy</strong></td>
<td>mJ</td>
<td>1</td>
<td>&gt;1</td>
<td>&gt;2</td>
</tr>
<tr>
<td><strong>Max rep rate</strong></td>
<td>kHz</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td><strong>Max Duty Cycle</strong></td>
<td>%</td>
<td>75</td>
<td>&gt;75</td>
<td>&gt;75</td>
</tr>
<tr>
<td><strong>Sub systems</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Target Material and Shape</strong></td>
<td></td>
<td>Sn droplet</td>
<td>Sn droplet</td>
<td>Sn droplet</td>
</tr>
<tr>
<td><strong>Droplet Diameter</strong></td>
<td>micro meter</td>
<td>60</td>
<td>10</td>
<td>10</td>
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<tr>
<td><strong>Debris Mitigation</strong></td>
<td></td>
<td>Magnet and cleaning</td>
<td>Magnet and cleaning</td>
<td>Magnet and cleaning</td>
</tr>
<tr>
<td><strong>Collector Mirror Lifetime</strong></td>
<td>Bpl</td>
<td>11</td>
<td>&gt;200</td>
<td>&gt;1250</td>
</tr>
<tr>
<td><strong>Tool Interface</strong></td>
<td></td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
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</table>

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## EUV Light Source Roadmap

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<tr>
<td>&gt;400W</td>
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<td>GL400E</td>
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<tr>
<td>&gt;200W</td>
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<td>GL200E</td>
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<tr>
<td>&gt;100W</td>
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<td></td>
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<td>⭐️ GL100E proto</td>
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<tr>
<td>100W</td>
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<td>ETS</td>
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</table>

- **ETS**: European Technology Strategy
- **GL100E proto**: Prototype GL100E
- **GL200E**: GL200E
- **GL400E**: GL400E
Layout of GL-100E

preliminary

Scanner
Source
Cleanroom floor
Subfab
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ETS-2 (1st generation integrated setup LPP source)
- Design concept is reported.
- Droplet generator works very stable.
- First operation data is reported.
  - Short term
  - Stability at Burst operation
  - Long term
- Debris mitigation data is now under correction.
- Average power status and schedule is summarized.

Product roadmap
- Target specification and schedule of Gigaphoton LPP source product is updated.
- Now GL-100E is under development.