Update on One Hundred Watt HVM LPP-EUV Light Source

2015 International Workshop on EUV Lithography

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Gigaphoton Inc.
• Introduction
• Prototype LPP Source System Development Update
  » Gigaphoton’s LPP Light Source Concept
  » Gigaphoton’s EUV Source Configuration
  » Proto Device #1
    Debris Mitigation Technology Update
  » Proto Device #2
    High Power Operation Data Update
• New Pilot System Development Update
• Summary
DUV Installations are Rapidly Growing

Gigaphoton for the first time achieved **52%** share of new DUV light source unit sales in **2014** – expected to reach more than **68%** by end of fiscal 2015.
EUV Power Achievements and Target

Consistent results have been demonstrated for the last 9 quarters

EUV power status

250W Pilot Target

140W (2014.12)

118W (2014.10)

92W (2014.6)

8W (2013.2)

43W (2014.2)

15W (2013.8)
OUTLINE

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• New Pilot System Development Update

• Summary
Gigaphoton’s LPP Light Source Concept

- High ionization rate and CE EUV tin (Sn) plasma generated by CO$_2$ and pre-pulse solid laser dual wavelength shooting
- Hybrid CO$_2$ laser system with short pulse high repetition rate oscillator and commercial cw-amplifiers
- Accurate shooting control with droplet and laser beam control
- Tin (Sn) debris mitigation with a super conductive magnetic field
- High efficient out of band light reduction with grating structured C1 mirror
Based on basic physical consideration and experiments, Gigaphoton has chosen to adopt the pre-pulse technology since 2009.

In 2012 Gigaphoton discovered that shortening the pre-pulses duration dramatically enhance the conversion efficiency.
Pre-Pulse Technology (2)

Experiment shows picosecond pre-pulse dramatically enhances ionization rate and CE.

**Data in 10Hz Experimental Device**

- **CE performance**
  - Conversion efficiency vs. CO2 energy on droplet
  - Improvement indicated for picosecond (psec) vs. nanosecond (nsec) pulses

- **Ionization performance**
  - Ionization rate vs. CO2 energy on droplet
  - Improvement indicated for picosecond (psec) vs. nanosecond (nsec) pulses

**Sn Droplet Smash**

- Dome like target
- Flat disk like target

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Pre-Pulse Technology (3)

Fragment distribution measurement

- The mist shape of a picosecond pre-pulse is different from the nanosecond
- Nano-cluster distribution could be a key factor for high CE

<table>
<thead>
<tr>
<th></th>
<th>10 ps</th>
<th>10 ns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse energy</td>
<td>2.0 mJ</td>
<td>2.7 mJ</td>
</tr>
<tr>
<td>delay</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60 deg view</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90 deg view</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Modeling of pre-pulse plasma

- All laser energy irradiated before plasma expansion
- Pre-pulse plasma Expansion ~60nm (~10psx6 km/s)
- Liquid Tin move to opposite of pre-pulse plasma expansion
- Liquid deformation speed ~1000m/s (Sonic speed)
- Thicker disk like fragment
- Fragment expansion
Gigaphoton, in cooperation with CW-CO\textsubscript{2} laser companies, has been jointly developing a unique high power pulsed CO\textsubscript{2} laser system since 2004.

**Main Pulse CO\textsubscript{2} Laser System**

- **OSC**: Gigaphoton Oscillator Laser
- **EO isolator**
- **PA**: Fast axial flow CO\textsubscript{2} laser amplifier
- **MA#1**: Transverse-flow CO\textsubscript{2} laser amplifier
- **MA#2**
- **MA#3**
- **Amplifier Lasers**

**Pre-pulse Laser Performance**

- **Wavelength**: 1064.3 nm
- **Max Pulse Energy**: 1 mJ
- **Pulse Duration**: 12 ps
- **Rep Rate**: single~120 kHz
- **Average Power**: 100 W
## High Power CO$_2$ Laser Technology (2)

<table>
<thead>
<tr>
<th>Target at Plasma</th>
<th>System</th>
<th>Oscillator</th>
<th>Pre-Amplifier</th>
<th>Main Amplifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>5kW</td>
<td>Endurance Testing Platform</td>
<td>GPI</td>
<td>R</td>
<td>T</td>
</tr>
<tr>
<td>8kW</td>
<td>Power Up Testing</td>
<td>GPI</td>
<td>R</td>
<td>T</td>
</tr>
<tr>
<td>14kW</td>
<td>Power Up Testing</td>
<td>GPI</td>
<td>M</td>
<td>T</td>
</tr>
<tr>
<td>&gt;20kW</td>
<td>Customer Beta Unit</td>
<td>GPI</td>
<td>M</td>
<td>M</td>
</tr>
</tbody>
</table>

- **Proto #1**
- **Proto #2**
- **Under Construction Pilot #1**

Validated performances at system
Gigaphoton EUV Sources

2 – proto system are in operation
1 – pilot system is under construction

Pilot #1 (under construction)

Proto #1
From Oct 2012

Proto #2
From Nov 2013

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# Proto Systems in Operation

## Target System Specification

<table>
<thead>
<tr>
<th>Operational Specification</th>
<th>Proto #1</th>
<th>Proto #2</th>
<th>Pilot #1 (under construction)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Target Performance</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EUV Power</td>
<td>25 W</td>
<td>&gt; 100 W</td>
<td>250 W</td>
</tr>
<tr>
<td>CE</td>
<td>3%</td>
<td>4%</td>
<td>4%</td>
</tr>
<tr>
<td>Pulse rate</td>
<td>100 kHz</td>
<td>100 kHz</td>
<td>100 kHz</td>
</tr>
<tr>
<td>Output angle</td>
<td>Horizontal</td>
<td>62° upper (matched to NXE)</td>
<td>62° upper (matched to NXE)</td>
</tr>
<tr>
<td>Availability</td>
<td>1 week operation</td>
<td>1 week operation</td>
<td>&gt; 75%</td>
</tr>
<tr>
<td><strong>Technology</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Droplet generator</td>
<td>20 – 25 μm</td>
<td>20 μm</td>
<td>&lt; 20 μm</td>
</tr>
<tr>
<td>CO2 laser</td>
<td>&gt; 8 kW</td>
<td>&gt; 12 kW</td>
<td>25 kW</td>
</tr>
<tr>
<td>Pre-pulse laser</td>
<td>picosecond</td>
<td>picosecond</td>
<td>picosecond</td>
</tr>
<tr>
<td>Debris mitigation</td>
<td>validation of magnetic mitigation in system</td>
<td>10 days</td>
<td>&gt; 30 days</td>
</tr>
</tbody>
</table>
Gigaphoton’s High Power EUV Light Source

Prototype high power EUV light source is in operation

Proto 1 Exposure & Mitigation test
Proto 2 High power Experiment
Proto#1: 77 hrs. EUV Emission

- Average power 10W with dose control, **77 hrs.** EUV emission was achieved by Proto#1 (total operation time is **261 hrs.**)
- Total pulse number is 4.4 Bpls.
- Dose stability 3 sigma typically < 0.3%
Tin Back-diffusion Issue from the Ion Catcher

- Issue: tin depositions on mirror caused by back-diffusion from the ion catcher
- Reduction of the back-diffusion from the ion catcher is key
Tin Back-diffusion Issue from the Ion Catcher

Progress of resolving back-diffusion issue

Improvement of back-diffusion from the ion catcher is very clear

Oct. 2014

Nov. 2014

Present (Testing)

unwanted tin (Sn) debris
Proto #2 System for High Power Testing

- **EUV Light Beam**
- **Droplet Generator**
- **Intermediate Focus**
- **EUV Plasma Point**
- **Driver Laser Beam**
Proto #2 System Layout

Mitsubishi pre-amplifier was installed in Proto #2 and performance was confirmed.
Proto #2 EUV Power Data

Champion Data: 140W EUV in burst power with 70kHz, 50% duty cycle
Proto #2 EUV Power Data

2014 Sep

Average power: 40W
50kHz, 50% duty cycle

(data shown at EUV Symposium 2014)

2014 Dec

Average power: 50W
80kHz, 50% duty cycle

2 hrs. :60-50W

120-100W in-burst, 80kHz, 50% duty cycle (Clean power in burst) during 120min
Output power 60-50W (120-100W @ 50% duty ) average during 120 min.
Proto#2: Dose control performance

20% dose margin

Open loop, 35kHz, 50% duty cycle

- In-band power vs. CO2 RF duty cycle (%)
  - Dose margin 20%

Open loop, RF 90%

- Average power: 46W
- In band power: 92W

Dose control

- Average power: 37W
- In band power: 74W

Dose error: < +/-0.1%
Proto#2: High Duty Cycle with Dose Control

Dose control capability up to 95% duty cycle with 20% dose margin was confirmed in proto#2 system at 75W in burst, 70W in average level operation.

Average power with dose control

- 35kHz, 20% dose margin
- 37W average power, 75W in band power
- 70W average power, 75W in band power

95% duty cycle

- Average power: 70W
- In band power: 75W

50% duty cycle

- Average power: 37W
- In band power: 75W
Availability Status

Availability is continuously increasing in 13wk level moving average.
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Pilot #1 EUV Light Source for HVM

Layout of 250W EUV Light Source

First HVM EUV Source

- 250W EUV source

<table>
<thead>
<tr>
<th>Operational specification (Target)</th>
<th>HVM Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Performance</strong></td>
<td></td>
</tr>
<tr>
<td>EUV Power</td>
<td>&gt; 250W</td>
</tr>
<tr>
<td>CE</td>
<td>&gt; 4.0 %</td>
</tr>
<tr>
<td>Pulse rate</td>
<td>100kHz</td>
</tr>
<tr>
<td>Availability</td>
<td>&gt; 75%</td>
</tr>
<tr>
<td><strong>Technology</strong></td>
<td></td>
</tr>
<tr>
<td>Droplet generator</td>
<td></td>
</tr>
<tr>
<td>Droplet size</td>
<td>&lt; 20mm</td>
</tr>
<tr>
<td>CO2 laser</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>&gt; 20kW</td>
</tr>
<tr>
<td>Pre-pulse laser</td>
<td></td>
</tr>
<tr>
<td>Pulse duration</td>
<td>psec</td>
</tr>
<tr>
<td>Debris mitigation</td>
<td></td>
</tr>
<tr>
<td>Magnet, Etching</td>
<td>&gt; 15 days  ( &gt;1500Mpls)</td>
</tr>
</tbody>
</table>

EUV Exposure Tool

EUV Exposure Tool

First HVM EUV Source

- 250W EUV source
EUV Pilot #1 Light Source or HVM

CO$_2$ laser construction in progress – target spec. is >27KW
Utility Specification (EXPECTED)

- GPI specification of Pilot#1.
- It is remarkable low consumption compare with other source.

<table>
<thead>
<tr>
<th>Pilot#1 Specification</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUV Power</td>
<td>250</td>
<td>W</td>
</tr>
<tr>
<td>Electrical power input (at full load)</td>
<td>880</td>
<td>kVA</td>
</tr>
<tr>
<td>Thermal load to water</td>
<td>780</td>
<td>kW</td>
</tr>
<tr>
<td>Cooling water flow rate (at 17 °C)</td>
<td>1608</td>
<td>L/min</td>
</tr>
<tr>
<td>Hydrogen gas consumption</td>
<td>30</td>
<td>NL/min</td>
</tr>
</tbody>
</table>
EUV Pilot #1 construction status update

- Driver laser: All amplifiers are delivered, assemble will complete end of July 2015
- EUV Chamber: Under designing. Device will complete end of September 2015
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## Power-Up Milestones

We are achieving **solid** and **steady** progress towards realizing our HVM EUV source

<table>
<thead>
<tr>
<th></th>
<th>EUV clean power</th>
<th>Target</th>
<th>CO₂ power at plasma</th>
<th>CE</th>
<th>Plasma to IF clean</th>
<th>CO₂ laser</th>
<th>Collector mirror</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25W</td>
<td>2013, Q4</td>
<td>5kW</td>
<td>2.5%</td>
<td>21.7%</td>
<td>2 main amp. system: Proto#1</td>
<td>Normal Type</td>
</tr>
<tr>
<td></td>
<td>43W</td>
<td>2014, Q1</td>
<td>8kW</td>
<td>3%</td>
<td>21.7%</td>
<td>3 main amp. system: Proto#2</td>
<td>Normal Type</td>
</tr>
<tr>
<td></td>
<td>92W</td>
<td>2014, Q2</td>
<td>14kW</td>
<td>4.2%</td>
<td>21.7%</td>
<td>Mitsubishi pre-amp.: Proto#2</td>
<td>Normal Type</td>
</tr>
<tr>
<td></td>
<td>140W</td>
<td>2014, Q4</td>
<td>&gt;14kW</td>
<td>&gt;4.2%</td>
<td>26.7%</td>
<td>Mitsubishi pre-amp: Proto#2</td>
<td>Grating Type</td>
</tr>
<tr>
<td></td>
<td>250W</td>
<td>2015, Q3</td>
<td>&gt;20kW</td>
<td>&gt;4.5%</td>
<td>26.7%</td>
<td>Mitsubishi main amp. system</td>
<td>Grating Type</td>
</tr>
</tbody>
</table>

**Proto #2** (current work)  
**Pilot #1** (under construction)
Summary

• Progress of Proto #1 unit
  » Further improvement of “Magnetic debris mitigation”
  » Simulation expect further improvement of back-diffusion
  » New 77 hrs., 10W operation data without maintenance was reported

• Progress of Proto #2 unit
  » Driver CO2 laser system achieved 20 kW with pre-amplifier by Mitsubishi Electric
  » Maximum power champion data: 140 W (CE 3.7%) in burst at 70 kHz, 50% duty
  » 120-100 W power in burst, 50% duty, (60-50 W average) for 120 min.
  » Reported new data: Dose control capability is proved experimentally (control margin 20%), until 95% duty cycle with 75W in burst level (70W in average power)
  » Next step is higher average power (>100W) operations during more than 24 hrs.

• Pilot #1 is under construction
  » Design of system is almost fixed - most parts are already ordered
  » Construction will finish in Q3, 2015. First data will be expected in Q4, 2015
Acknowledgements

Thanks for co-operation:

Mitsubishi electric CO₂ laser amp. develop. team: Dr. Yoichi Tanino *, Dr. Junichi Nishimae, Dr. Shuichi Fujikawa and others.

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