Laser Driven Light Source (LDLS) use for critical high brightness applications

Debbie Gustafson
Lasers & Electro Optics Seminar
March 27, 2012
Agenda

• Existing Lamp Technologies
• Laser Driven Light Source Technology
• Performance Data LDLS
• Applications
  – PEEM
  – Monochromator
  – UV Microscope
  – Circular Dichroism Spectroscopy
Today's Lamp Technologies

- Xe & Hg Arc
- Mercury Discharge
- Excimer
- Deuterium
- Metal Halide
- Halogen

- All have limitations in:
  - Brightness
  - Lifetime/Stability
  - Spectral Range
Limitations with Arc-Lamps

- Arc-Lamps use electrodes to conduct electrical current through the gas heat the gas to high temperature
  - The electrodes limit the temperature of the gas
    - Limited temperature leads to limited DUV
  - The electrodes erode and shorten lamp lifetime
  - Arc flicker reduces effective brightness and adds noise

| Broadband | √ |
| Brightness | √ |
| Stability | X |
| Lifetime | X |

• DUV output falls below 300nm

(Source: Hamamatsu)
Limitations with Deuterium Lamps

- Limited wavelength range ~190nm – 400nm
- Low brightness, relatively large plasma
- Short life: 500-1000hrs to 50% output

| Broadband | X  |
| Brightness | X  |
| Stability   | ✓  |
| Lifetime    | X  |

Source: Hamamatsu
Limitations with Tungsten-Halogen Lamps

- Short lifetime, large filament area, low power <400 nm
- Usually combined with Deuterium lamp to cover broad spectrum
  - Gap in spectrum around 400 nm
  - Low brightness from 2 separate emitters
  - Changing spectrum from 2 different lifetimes

<table>
<thead>
<tr>
<th>Feature</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadband</td>
<td>✓</td>
</tr>
<tr>
<td>Brightness</td>
<td>✗</td>
</tr>
<tr>
<td>Stability</td>
<td>✓</td>
</tr>
<tr>
<td>Lifetime</td>
<td>✗</td>
</tr>
</tbody>
</table>

Source: Ocean Optics
Laser-Driven Light Source: Principle of Operation

- Beam from CW Laser
- Laser Beam Focusing Optics
- Lamp Enclosure Containing Gas(es)
- High Intensity Plasma
- Broad Spectral Output

US Patent # 7,435,982
Light from Arc-Lamp and LDLS

• **Xe Arc-Lamp**
  - Large plasma limits brightness
  - Arc position Instability
  - Note: anode glowing red

• **LDLS**
  - Small plasma ...high brightness
  - Highly stable position
  - Note: anode NOT glowing

- High brightness: ~100 um diameter Xenon plasma,
- Efficient coupling into small fibers or spectrometer slits
- Point source enables collimation over long distances
Benefits of LDLS Technology

• Very high brightness across complete spectrum
  – 170nm through visible and out to 2100 nm

• Eliminates need for multiple lamps (replaces D2/Tungsten/Xenon Arc)
  – Simplified optical system

• Excellent Spatial stability
  – Repeatable measurements

• Superior short and long term power stability
  – Repeatable measurements

• Electrodeless operation for long life
  – Reduced consumable costs
  – Minimal recalibration of instrument

| Broadband | ✓ |
| Brightness | ✓ |
| Stability | ✓ |
| Lifetime | ✓ |
The LDLS Product Range

- EQ-99FC LDLS™ System
  - Compact LDLS with fiber-coupled output

- EQ-99 LDLS™ System
  - Compact LDLS for free-space optics

- EQ-1500 LDLS™ System
  - High brightness LDLS for free-space optics
EQ-99 Spectral Distribution

Wavelength, nm

Spectral Radiance (mW/mm²/nm/sr)

• EQ-99

• 30Watt Deuterium Lamp

Typical Data
EQ-99FC Typical Performance:
with 230µm diameter, 0.22NA, 1m long, Ocean Optics XSR fiber

<table>
<thead>
<tr>
<th>Wavelength, nm</th>
<th>Spectral Power, µW/nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>170</td>
<td>1</td>
</tr>
<tr>
<td>270</td>
<td>10</td>
</tr>
<tr>
<td>370</td>
<td>100</td>
</tr>
<tr>
<td>470</td>
<td>1000</td>
</tr>
<tr>
<td>570</td>
<td>1</td>
</tr>
<tr>
<td>670</td>
<td>10</td>
</tr>
<tr>
<td>770</td>
<td>100</td>
</tr>
<tr>
<td>870</td>
<td>1000</td>
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</tbody>
</table>

- Typical Data
Comparing LDLS with Traditional Lamps

Spectral Radiance of 30W D2, 75W Xe, EQ99 and EQ1500 - Log

• Spectral radiance calibrated at 254nm
**LDLS™: Stable & Long-Life**

<table>
<thead>
<tr>
<th>Light Source</th>
<th>Change in Broadband Output /1000 Hrs (Typical)</th>
<th>Life-Test Hours to Date</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>EQ-1000</td>
<td>~ -2%</td>
<td>&gt;16,000</td>
<td>Test on-going</td>
</tr>
<tr>
<td>EQ-1500</td>
<td>~ -1%</td>
<td>&gt;10,000</td>
<td>Test on-going</td>
</tr>
<tr>
<td>EQ-99</td>
<td>~ -1%</td>
<td>&gt;6,000</td>
<td>Test on-going</td>
</tr>
<tr>
<td>30W D2 Lamp</td>
<td>-50% (depending on model)</td>
<td></td>
<td>Source: Heraeus Data Sheet</td>
</tr>
<tr>
<td>75W Xe Lamp</td>
<td>-25% to -50% (depending on model)</td>
<td></td>
<td>Source: Hamamatsu Data Sheet</td>
</tr>
</tbody>
</table>
Spatial Stability of Arc Lamp vs LDLS

- 450W Xenon Lamp
- EQ-1500
Applications

- UV-Vis Spectrometry
- PEEM
- Atomic Absorption Spectroscopy
- Materials Characterization
- Environmental Analysis
- Hyperspectral Imaging
- Gas Phase Measurements
- Advanced Microscopes
- Endoscopes/Borescopes
- Etc…

EQ-99 LDLS System

EQ-1500 LDLS System
<table>
<thead>
<tr>
<th></th>
<th>PS37LH34</th>
<th>PS38LH39</th>
</tr>
</thead>
<tbody>
<tr>
<td>FWHM horizontal, µm</td>
<td>64</td>
<td>61</td>
</tr>
<tr>
<td>FWHM vertical, µm</td>
<td>147</td>
<td>140</td>
</tr>
<tr>
<td>Images</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
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</table>
Spatial Stability Results

- Collected and stored 2500 images @ 200 frames per second
- Calculated center of mass for each image using ImageJ (image analysis software)
- Standard deviation of the plasma light intensity center of mass position
  - Horizontal: 0.145 µm
  - Vertical: 0.094 µm
Laser Driven Light Source Applications
EQ-1500 Laser Driven Light Source for PEEM

Gary Hembree and Robert Nemanich
Arizona State University
Department of Physics

Huiling Zhu and Peter Dwyer
Energetiq Technology, Inc.
Sample of periodically polarized lithium niobate, a ferroelectric in which the direction of electric polarization is poled lithographically into alternating domains aligned into and out of the surface. The ends of the negative domains are visible as areas of lower electron emission intensity. Field of view is approximately 100 micrometers in each image. Illumination wavelengths are determined by band pass filters.

Note: Images taken with Hg-arc at 214 nm and 193 nm show zero contrast (white images).
EQ-1500 integrated into Monochromator
Test Method

- Compare EQ-1500 To 150W Xenon Lamp
Test result

Silt width 10um

Silt width 0.25mm
UV Microscope with Integrated EQ-99
DUV Microscope Configuration

- Camera
- Emission Filter
- Ultrafluar Objective
- UV-Kond Condenser
- Bandpass Filters
- 1mm Fiber from EQ-99

www.energetiq.com
Compare to 600µW UV LED, 280 nm

( and you only get 60 microwatts from UV LED at 260 nm…)

LED, unfiltered, 5 sec exp.       LED, filtered, 5 sec exp.       EQ-99, filtered, 10 msec exp.

LED illumination, unfiltered, 5 sec exposure.
LED illumination, 280 nm/20 nm filter; 5 sec exposure.
EQ-99 illumination, 280 nm/10 nm filter; 10 ms exposure.

Both systems fiber coupled through identical optics.
Exposure rate 250 times faster.
Imaging Performance

\[ a = 280\text{nm} \]
\[ b = 260\text{nm} \]
\[ c = 214\text{nm} \]
\[ d = \text{fluorescence} \]
\[ e = \text{white light}, \]
\[ f = e, \text{inversion} \]

A, B, C, D, E, F
= 10X digital zoom

- Arrows show nuclear structures
Deep-UV imaging of Chinese Hamster Ovary (CHO) cells show wavelength dependent UV absorption
EQ-1500 LDLS for CD Spectroscopy

July 14, 2011
Energetiq Technology – CD Spectroscopy

Optical System/Design

[Image of optical system and design components]
Photon Flux Measurement

Module B light intensity

- Xe-lamp (150 W)
- Energetiq (EQ-1500)
- Synchrotron (B23)

slit: 0.5 mm
blazing wl: 250 nm
Summary

- Very high brightness across complete spectrum
  - 170nm through visible and out to 2100 nm
  - Easy coupling to small fibers and spectrometer slits
  - Ease of collimation

- Eliminates need for multiple lamps (replaces D2/Tungsten/Xenon Arc)
  - Simplified optical system

- Excellent Spatial stability
  - Repeatable measurements

- Superior short and long term power stability
  - Repeatable measurements

- Electrodeless operation for long life
  - Reduced consumable costs
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Thank You!