Laser-Driven Light Sources for Metrology Applications

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Which broadband light sources have the highest brightness (radiance) on the market today?

Laser-driven light sources (LDLS™), made by Energetiq Technology, Inc.

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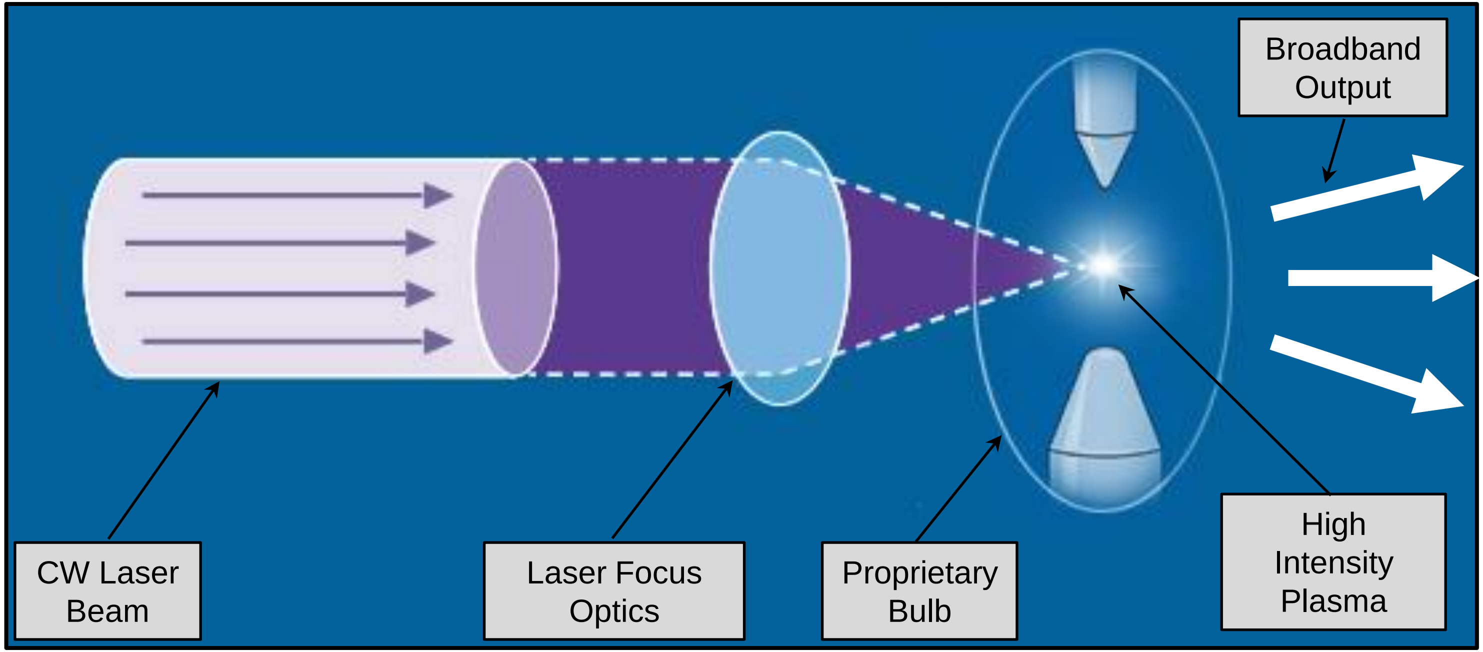
Laser-Driven Light Source (LDLS™): Principle of operation



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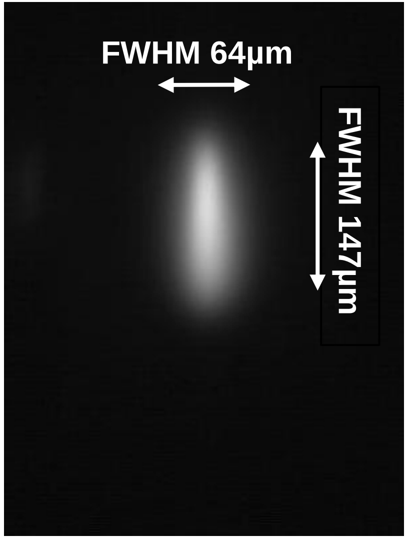
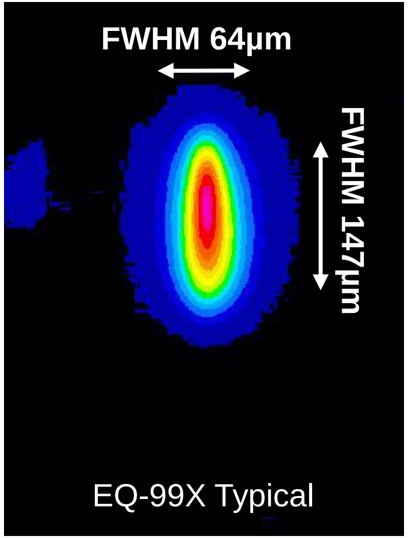
Small and Intense Emitting Size

- Small, intense light-emitting plasma size
  - ~100µm in size
- Allows imaging into a small spot
- Efficient coupling into small diameter fibers
- Efficient coupling into spectrometers
- Can be collimated better





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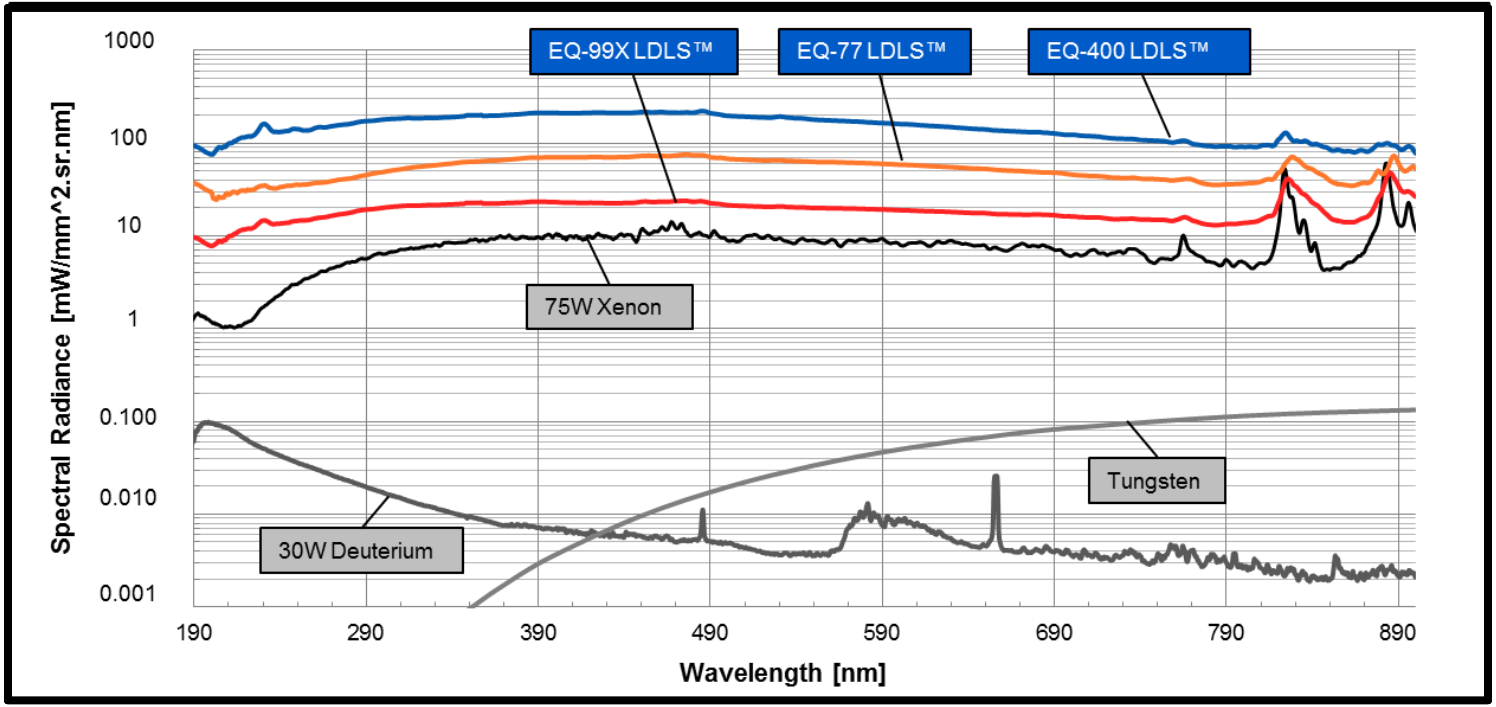
Highest Brightness and Broadest Wavelength Range



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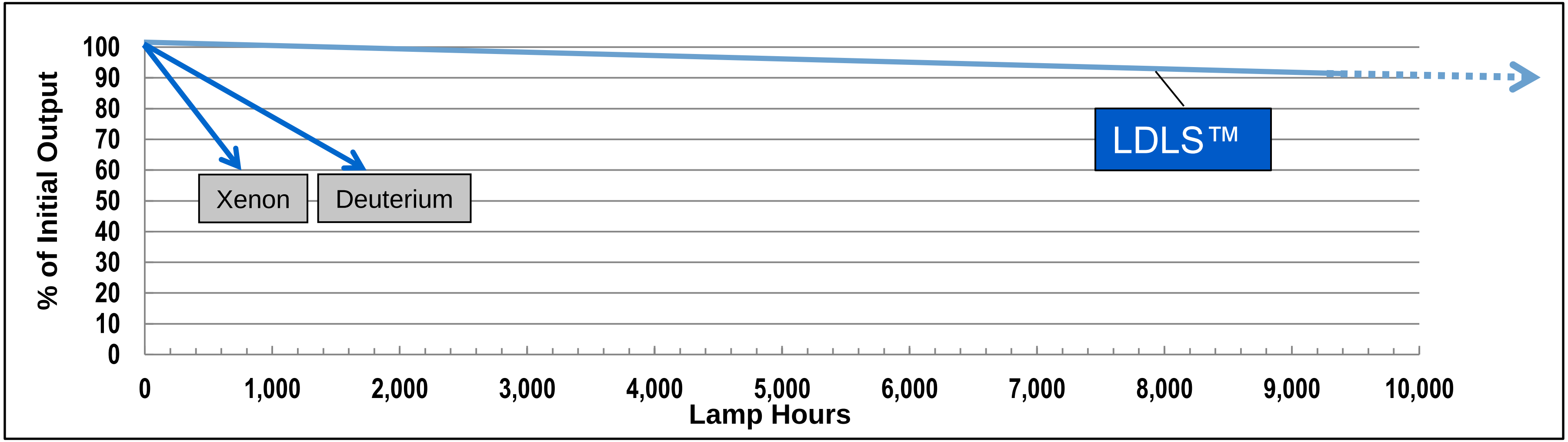
LDLS™: Long-Life for Low COO & 24/7/365 Operation



Light Source	Change in Broadband Output /1000 Hrs (Typical)	Typical Life (Hrs)
EQ-99X LDLS	**~ -1%**	**>10,000**
D2 Lamp	-25% (depending on model)	2000
Xe Lamp	-50% (depending on model)	1000

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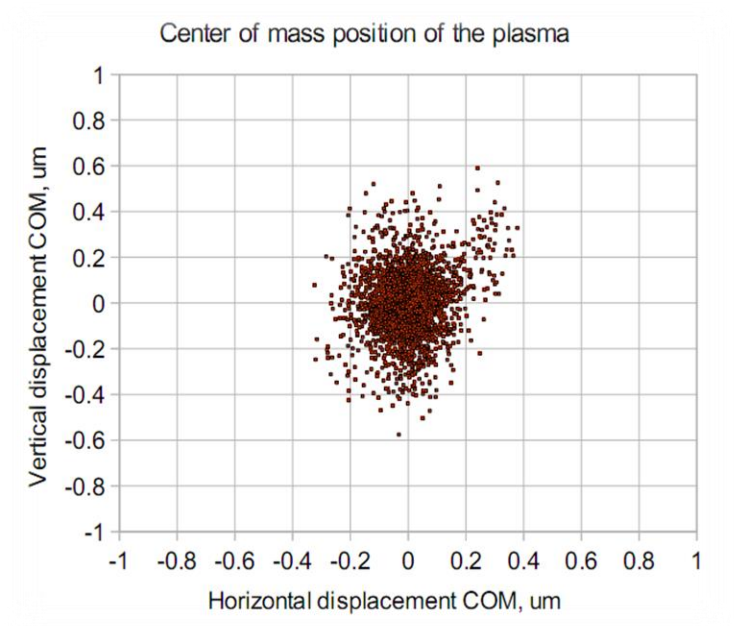
LDLS™ Excellent Spatial Stability

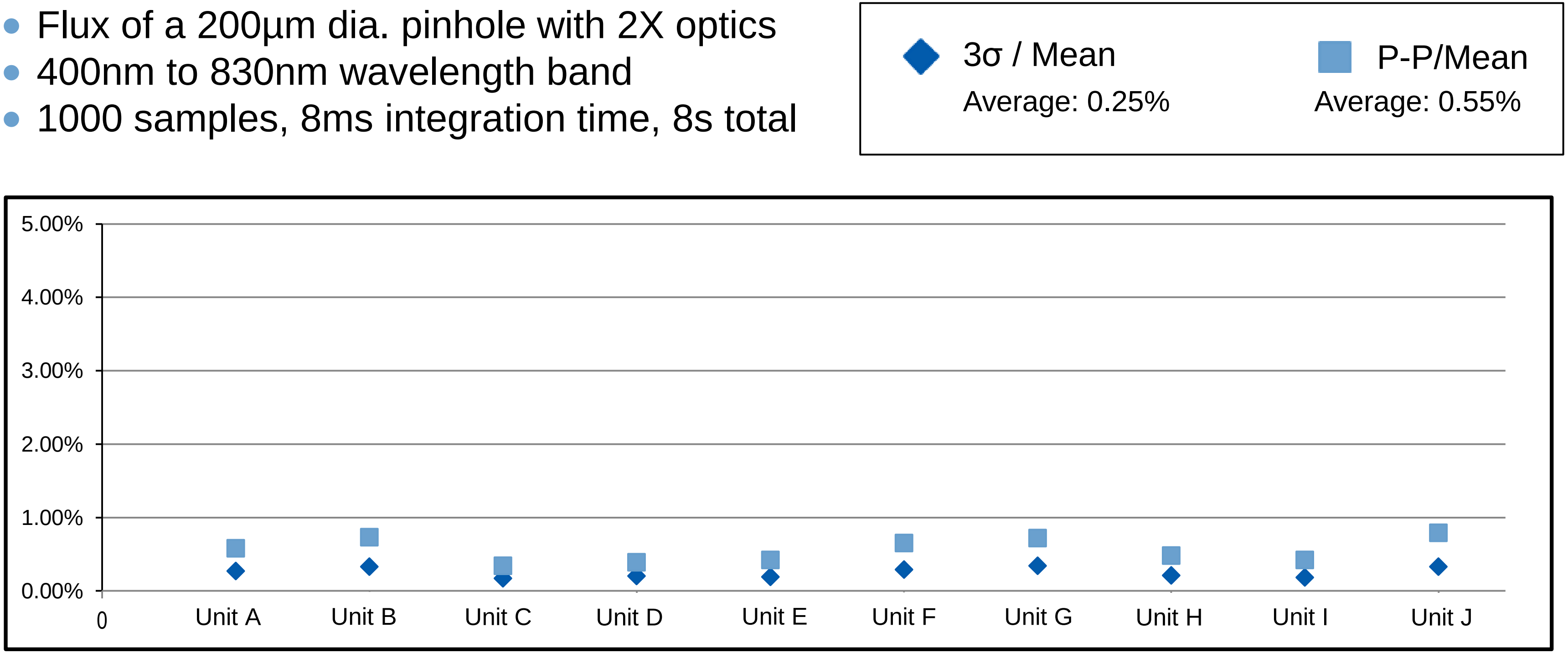
- Collected and stored 2500 images @ 200 frames per second
- Calculated center of mass for each image using *ImageJ* (image analysis software)
- Standard Deviation of plasma light intensity center of mass position:
  - Horizontal: 0.145µm
  - Vertical: 0.094µm



Typical Data EQ-99

Temporal Variation: Radiant Flux from 100µm Plasma, 0.3NA

- Flux of a 200µm dia. pinhole with 2X optics
- 400nm to 830nm wavelength band
- 1000 samples, 8ms integration time, 8s total



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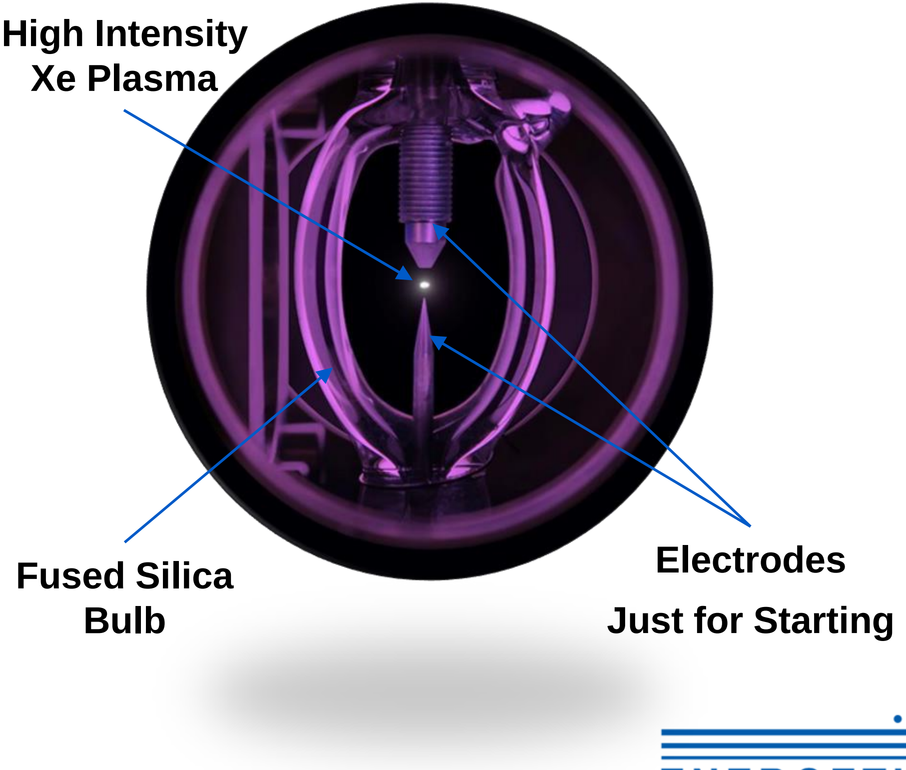
Desirable features of Laser-Driven Light Sources (LDLS™)

- Higher brightness, smaller emitter size
- Broad spectrum range: 190 – 2100nm
- Incoherent and un-polarized radiation
- Better temporal and spatial stability
- Highly reliable for 24/7/365 operation
- Long operating life: > 9000 hour



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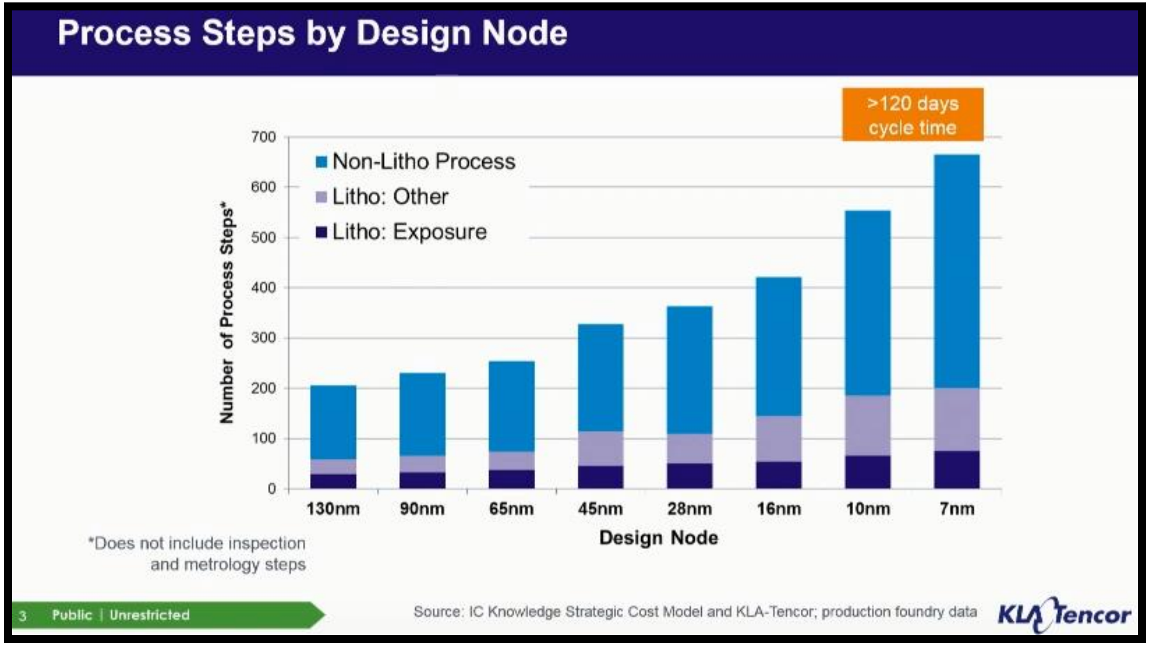
Shrinking nodes - Number of metrology steps are increasing

- Advanced technology nodes will continue to shrink
- The number of chip process steps increase as nodes getting smaller
- More metrology steps are necessary
- More metrology tools and faster tools are needed
- The workhorse for high-volume manufacturing remains optical tools



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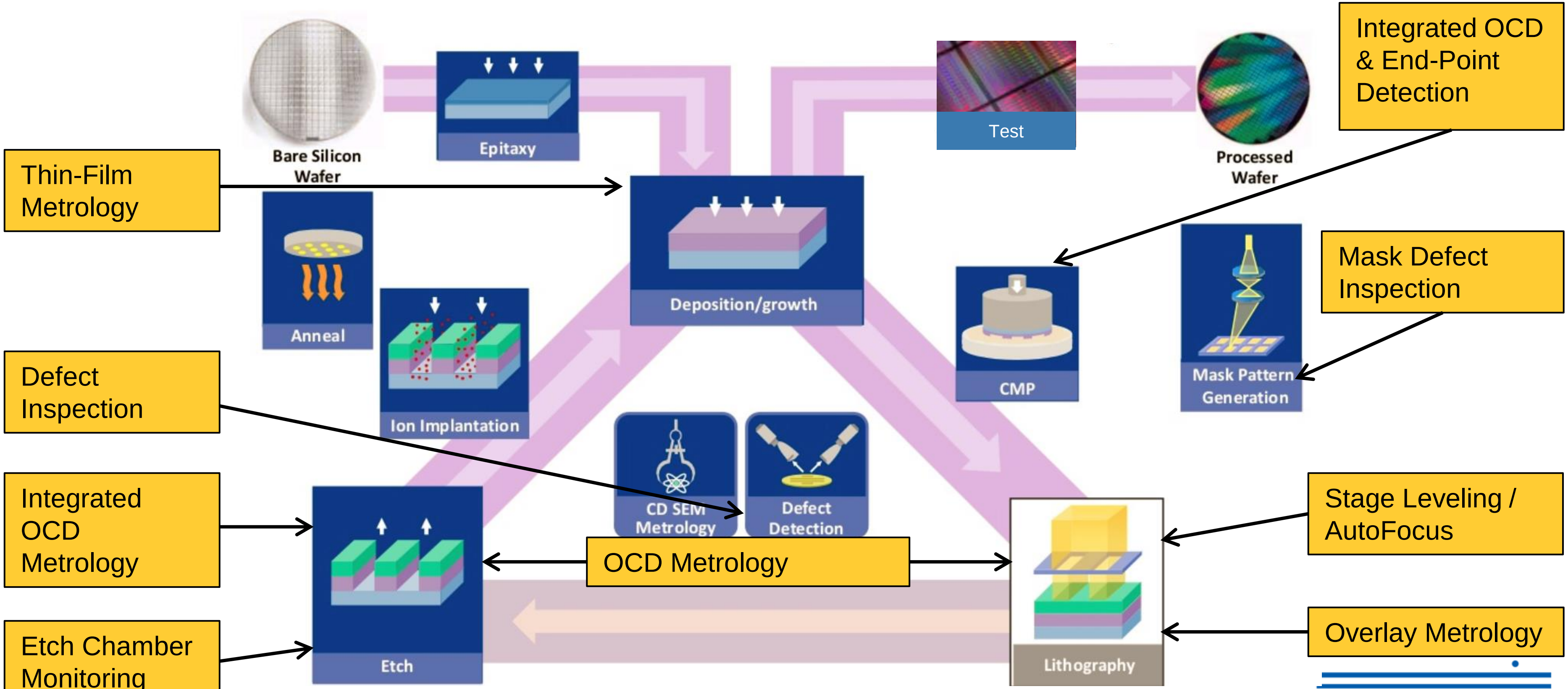
Optical Metrology Operations in Wafer Processing



Source of art work: Dr. Bill Flounders, UC Berkeley Microlab

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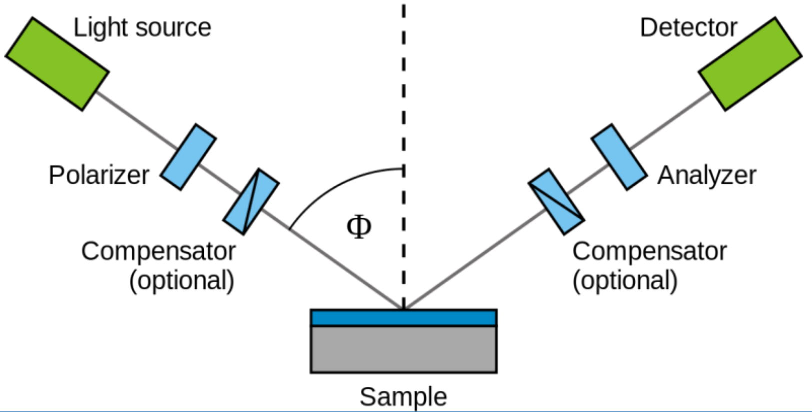
Thin-film metrology – Spectroscopic ellipsometry

- Spectroscopic ellipsometry is a model based technique to measure
  - Film thickness
  - Optical parameters (n & k)
  - Surface Roughness
  - Composition
  - Crystallinity
  - Anisotropy
- Critical Light Source Requirements
  - **Broadband** - visible down to DUV 190nm
  - **Low Noise** - better measurement resolution of very thin films
  - **High Brightness** - higher throughput

Spectroscopic Ellipsometry



* https://en.wikipedia.org/wiki/Ellipsometry

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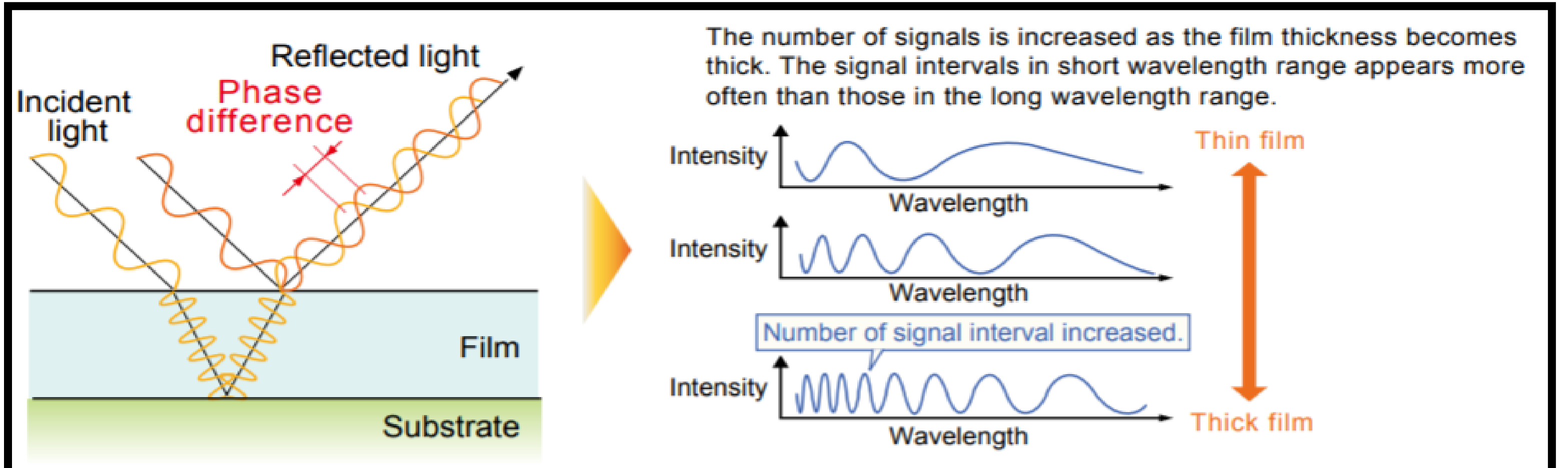
Thin-film metrology – Spectral interferometry



* https://www.hamamatsu.com/resources/pdf/sys/SSMS0043E_OGauges.pdf

- Spectral interferometers for quantifying film thickness, surface roughness, step heights, critical dimensions with excellent precision and accuracy
- Critical Light Source Requirements
  - **Broadband, Low Noise, and High Brightness**

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Measuring CD and overlay using scatterometry

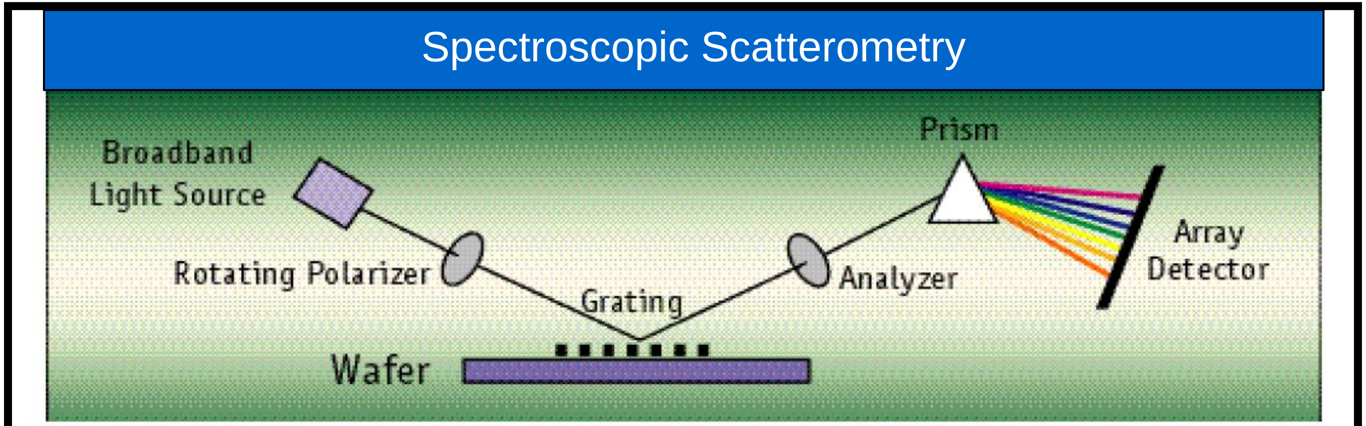

Figure 1. Schematic of SCD measurement.

- Critical Light Source Requirements
  - **Broadband** - visible down to DUV 190nm
  - **Low Noise** - repeatable measurements & better resolution of complex device structures
  - **High Brightness** - higher throughput

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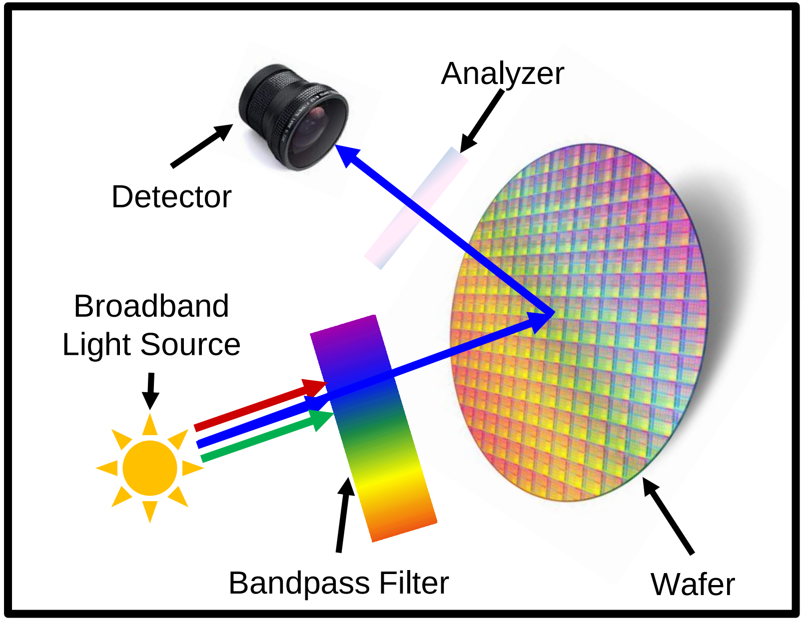
Wafer Defect Inspection

- Images of devices are compared with images of defect-free devices.
- Systems comprise:
  - Light Source Requirements
    - **High Brightness** - higher throughput
    - **Broadband** – Capture more information
    - **DUV** – for detection of smallest defects
  - Microscope
  - Fast & sensitive camera/detector
  - Supercomputer



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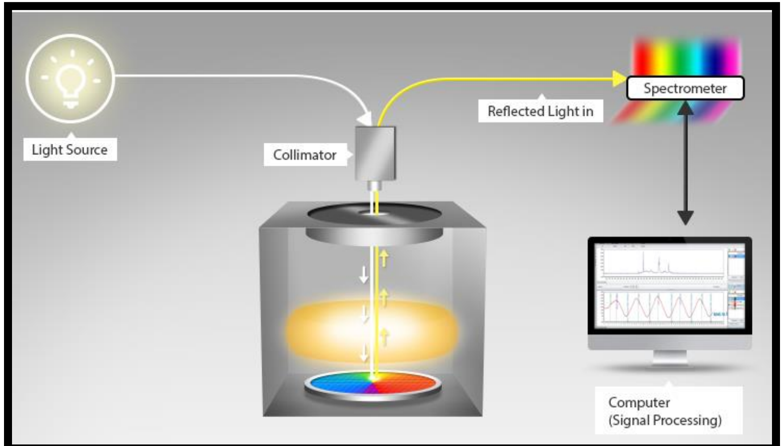
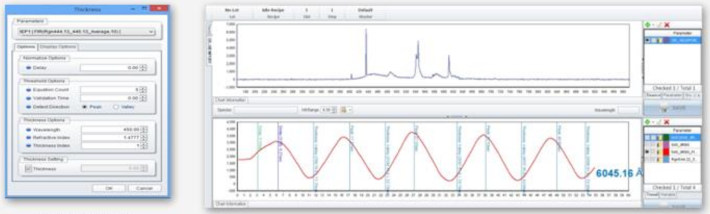
Process Monitor & Integrated Optical Metrology

Etch, CVD and CMP process monitoring

- Etch
  - Spectral Reflectometry for endpoint detection (EPD)
  - Optical Absorption Spectroscopy for chamber condition monitoring
- CVD
  - Spectral Reflectometry for thin-film measurement
  - Optical Absorption Spectroscopy for chamber condition monitoring
- CMP
  - Optical Scatterometry and Spectral Reflectometry for endpoint detection



* http://www.prisol.co.kr/eng/sub2/p2-3.html



Fringe Count or Target Thickness set_up

Insitu-Reflectometry SIN Film Thickness

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LDLS for a broadband Mueller matrix ellipsometry (MME)

S. Liu et al. / Thin Solid Films 584 (2015) 176–185

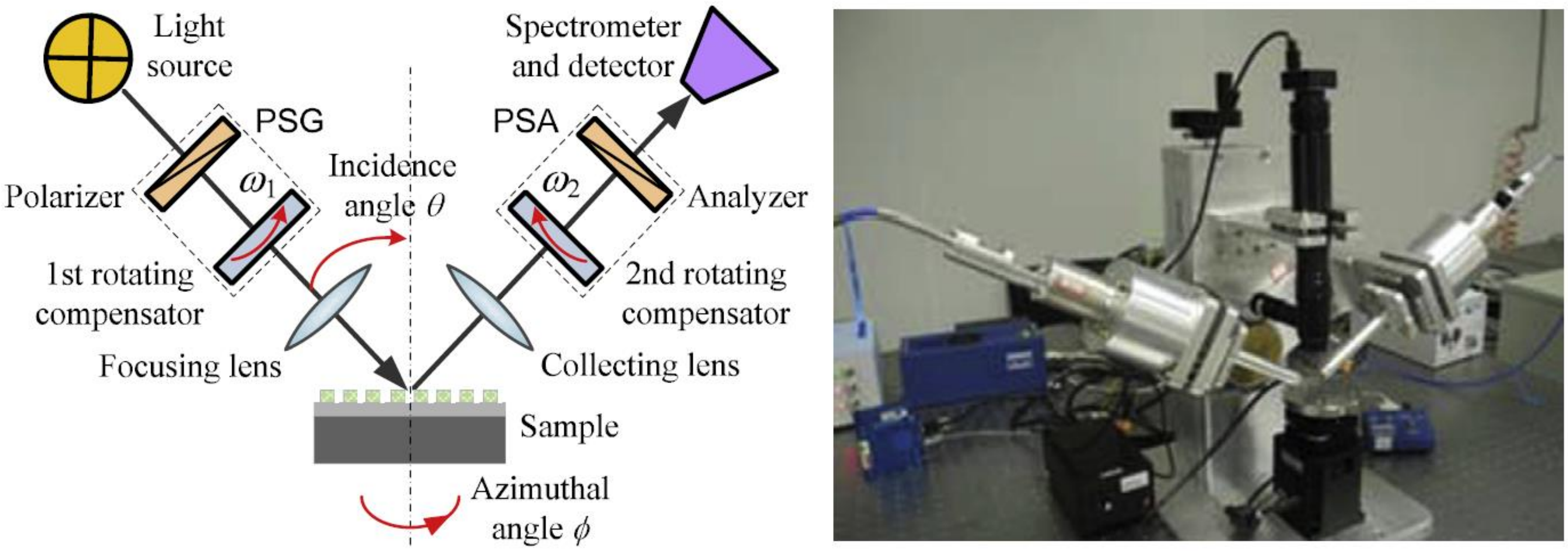

Fig. 1. Principle and prototype of the dual rotating-compensator Mueller matrix ellipsometer.

* S. Liu, X. Chen, C. Zhang, "Development of a broadband Muelle matrix ellipsometer as a powerful tool for nanostructure metrology," *Thin Solid Films, **584**, 176-185 (2015)*

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LDLS used in Mueller matric imaging ellipsometry (MMIE)

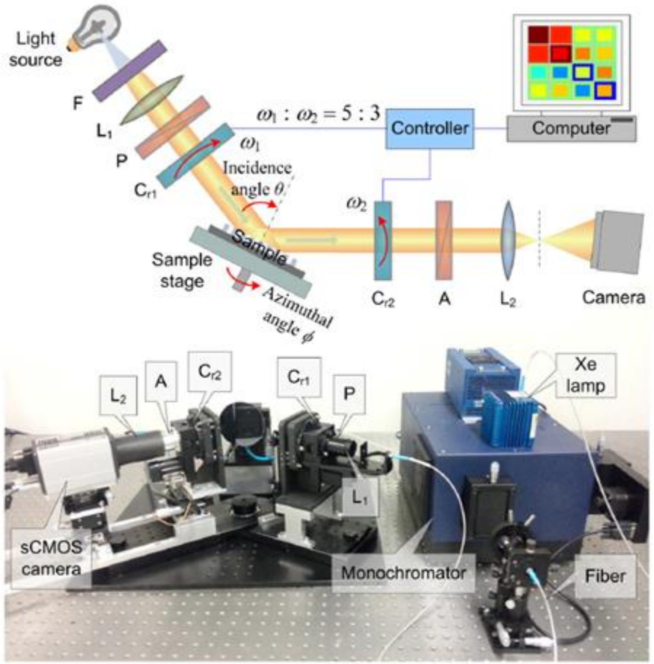

Fig. 1. Scheme (top) and prototype (bottom) of the dual rotating-compensator Mueller matrix imaging ellipsometer. L_1 and L_2, collimating lens and imaging lens; F, filter or monochromator; P and A, polarizer and analyzer; C_{r1} and C_{r2}, the 1st and 2nd rotating compensator.

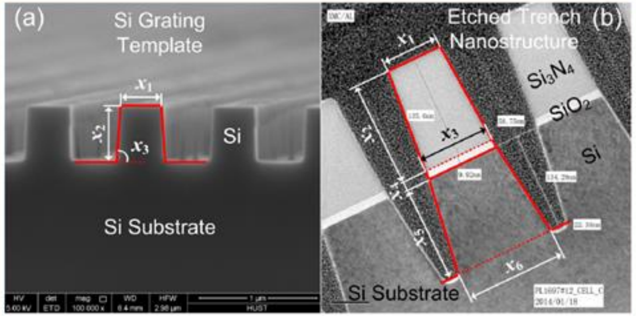

Fig. 2. SEM/TEM micrographs and geometric models of the Si grating template and etched trench nanostructure.

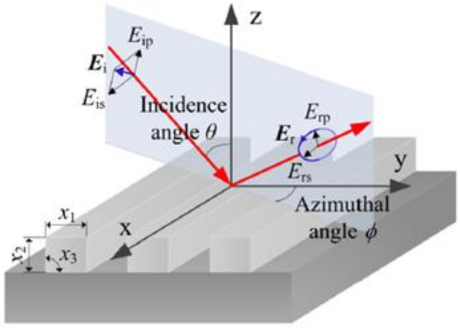

Fig. 3. Representation of polarized light incidence for a one-dimensional grating structure.

* S. Liu, W. Du, X. Chen, H. Jiang, C. Zhang, “Muelle matrix imaging ellipsometry for nanostructure metrology,” *Optics Express, 17316-17329 (June 2015)*

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Industrial publication using laser sustained plasma sources - The ratio of photon flux at three deep-UV wavelengths

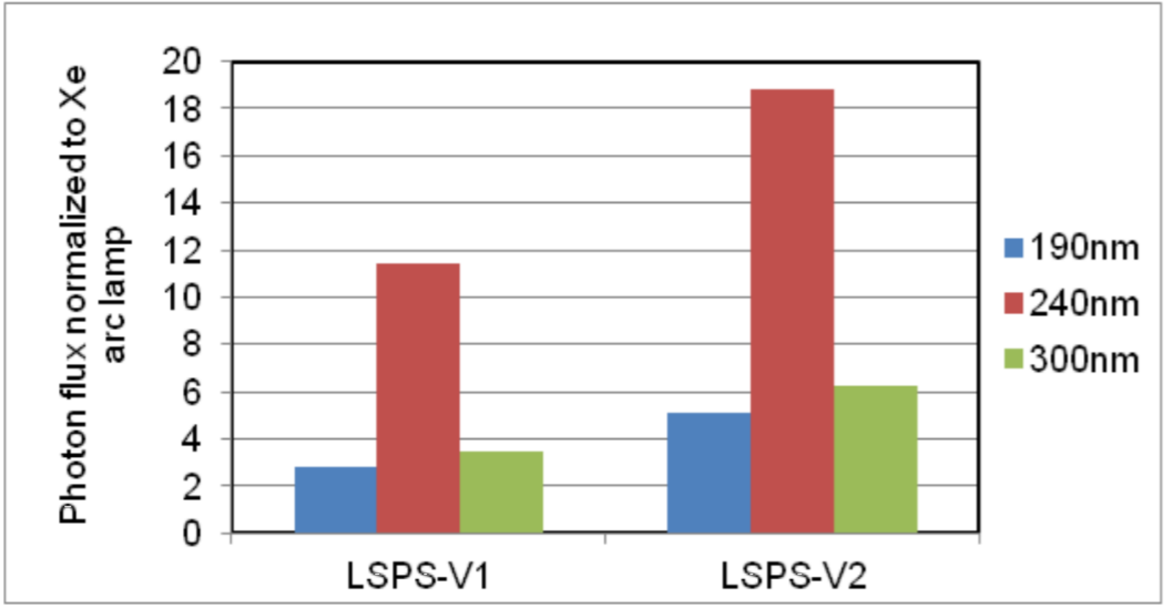

Figure 7. LSPS lamps show several times greater photon flux than Xe arc lamp in the 190 – 300nm λ range. LSPS – V1 and LSPS – V2 represent an older and newer generation of LSPS lamps respectively

* S. Mahendrakar, K. Venkataraman, et al., GLOBALFOUNDRIES, KLA-Tencor Corp. “Optical metrology solutions for 10nm films process control challenges,”, *Proc. Of SPIE Vol. 9778, 97780Z-1-14*

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Industrial publication using laser sustained plasma sources
- Higher deep-UV photon flux increase signal to noise ratio (SNR)

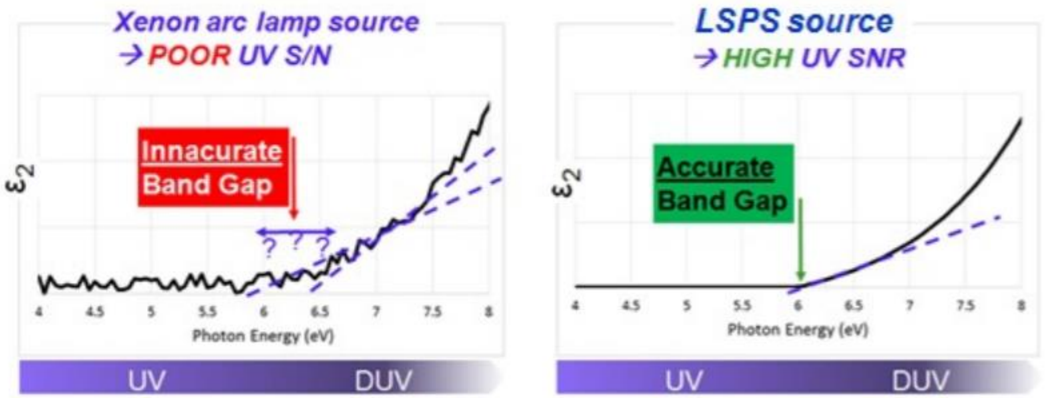

Figure 18. Bandgap of a material is estimated by the tangent to the ε2 (obtained from dispersion) vs photon energy curve at the inflection point. The noisier the data, the more tangent solutions would be possible, thereby increasing inaccuracy

* S. Mahendrakar, K. Venkataraman, et al., GLOBALFOUNDRIES, KLA-Tencor Corp. "Optical metrology solutions for 10nm films process control challenges,", *Proc. Of SPIE Vol. 9778, 97780Z-1-14*

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Takeaways

- Patterning features are getting smaller and smaller
  - Number of patterning steps are increasing
  - More metrology tools with higher throughput are needed
  - The brightest broadband light sources should be used for those tools
- LDLS meet the needs of optical metrology tools
  - Higher brightness for higher throughput, more measurements/second
  - Broadband and DUV light increases resolution for thinner films and smaller structures
  - Higher stability and low noise for repeatable measurements
  - Longer life with low maintenance for 24/7/365 operation

Thank you.

For additional information, please visit www.energetiq.com.

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