Laser-Driven Light Source (LDLS™) With Multiple Fiber Outputs

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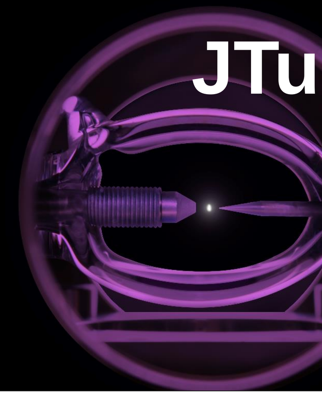

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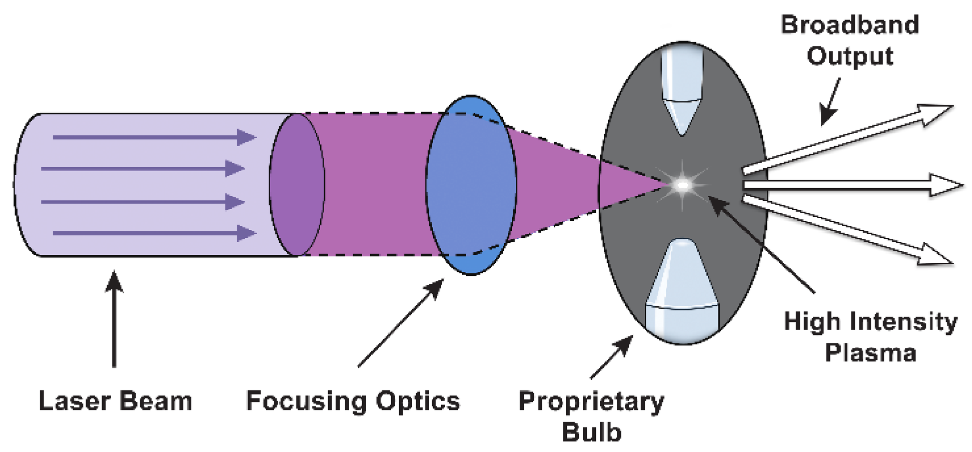
Abstract

A Laser-Driven Light Source (LDLS™) with multiple fiber outputs is developed for photonic or semiconductor processing applications. Simulation and measurement results of fiber-to-fiber uniformity from 380nm to 1000nm are presented. Experimental result shows the ratios of the six outer channels of the 7-channel fiber bundle compared to their average are within 95% to 110% in the 380nm to 1000nm wavelength range. Variation for normalized in-band flux for one channel over a 2-hours period is about 0.5%.

High Brightness, Broadband Light Source



LDLS Principle of Operation

In a typical plasma-based light source electricity is used to energize and sustain the plasma using electrodes. In the LDLS, electricity from the electrodes is only used to initially energize and ignite the xenon plasma. Once the source is ignited, the electrodes are turned off and the plasma is sustained using a CW laser.

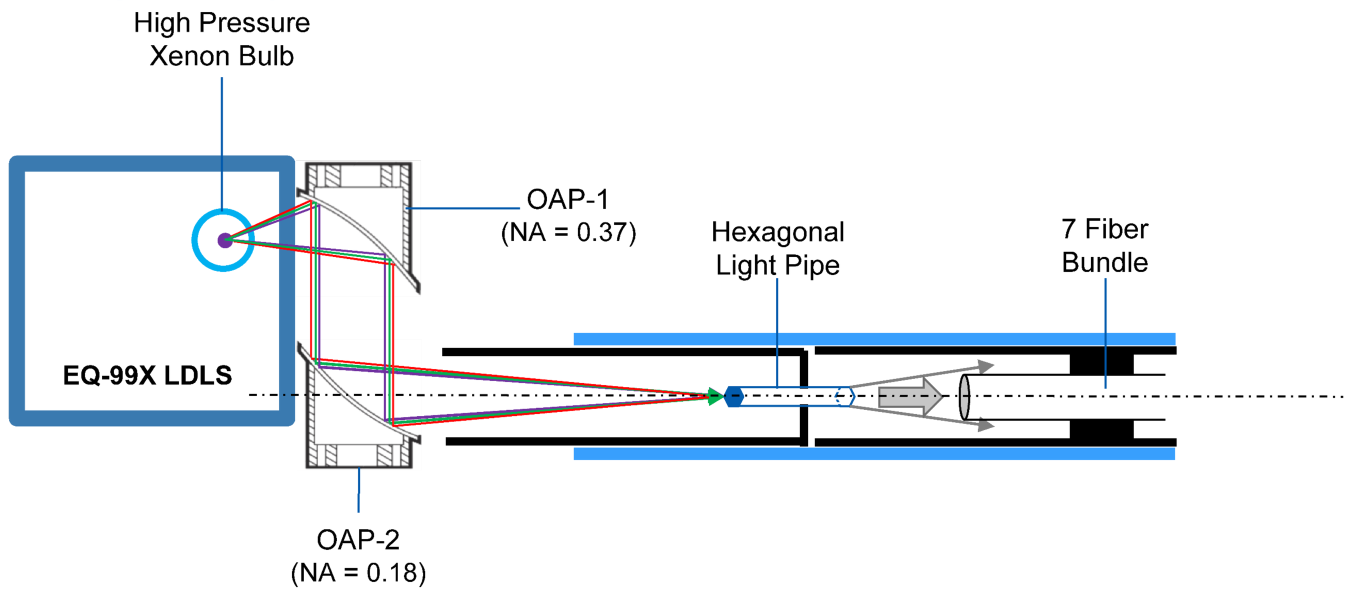
EQ-99X Laser-Driven Light Source

An EQ-99X with a broad spectral range of 170nm – 2400nm was used in this experiment. This source was selected because it is extremely bright and features a small, spatially coherent plasma that can be efficiently coupled into optical paths that require a small area of illumination.

Principle, Optical Layout & Results

The purpose of this experiment is to examine if a selected light source is suitable for applications that require multiple fiber optic outputs. This is done by examining the spatial irradiance of each fiber optic to determine output variation from a broadband, plasma-based light source.

Figure 1: Optical Layout



Description of Optical Layout

The xenon plasma output from the EQ-99X is collected and collimated by OAP-1 then focused by OAP-2 into a light pipe. The input end of the light pipe is positioned at the focal point of OAP-2 to homogenize the beam.

A fiber bundle with seven channels is attached to the output end of the light pipe to divide the light into seven channels. The outer six channels have uniform output. The seventh/center fiber is used a reference/monitor channel.

In design validations (simulation and experiment), numerical aperture (NA) of OAP-1: 0.37; NA of OAP-2: 0.18; aperture and length of the hexagon light pipe are 2mm and 25mm. The fiber bundle comprises seven channels, which are made of 400µm core diameter broadband multimode fibers with a 0.22NA.

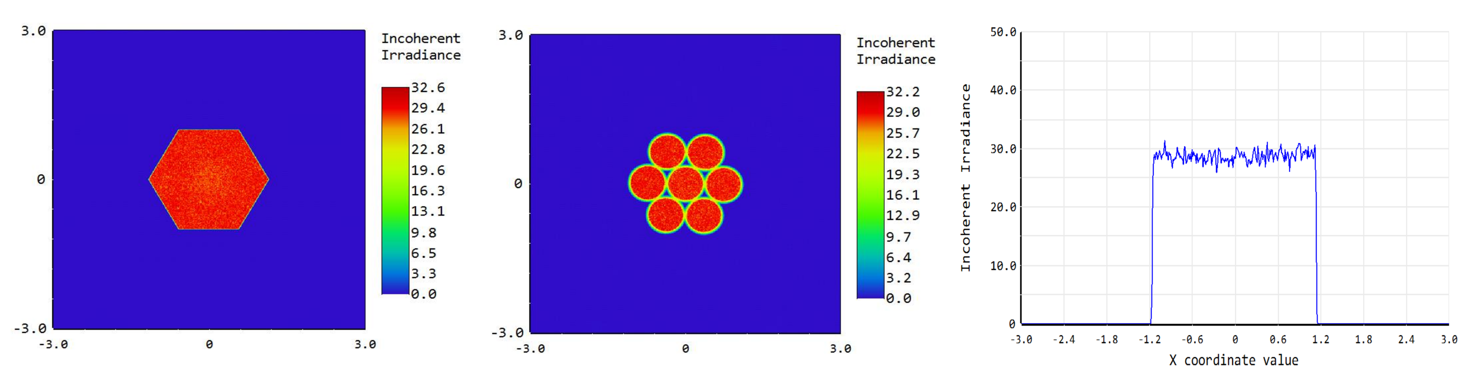
Spatial Irradiance

The spatial irradiance is defined as the flux of radiant energy per unit area (normal to the direction of flow of radiant energy through a medium). In this case it is described as the irradiance distribution for the light pile exit surface.

The spatial irradiance variation is defined as $(I_{max} - I_{min}) / I_{mean}$.

For the proposed design the irradiance variation is only 11% in an area of 2mm^2 on the output end of the 25mm long hexagon light pipe.

Figure 2: Observed Incoherent Irradiance



Zemax simulation results show incoherent irradiance view on the exit surface of the light pipe (A) and the entrance plane of the fiber bundle (B), and the irradiance distribution at the light pile exit surface (C).

Figure 3: Relative Spectral Flux

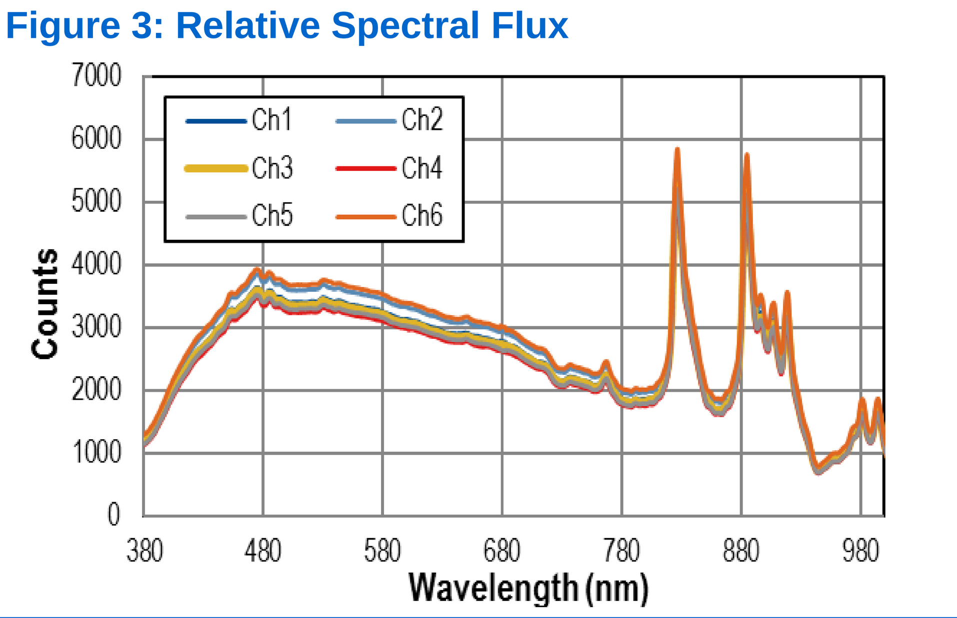


Figure 4: Ratio of Output/Average

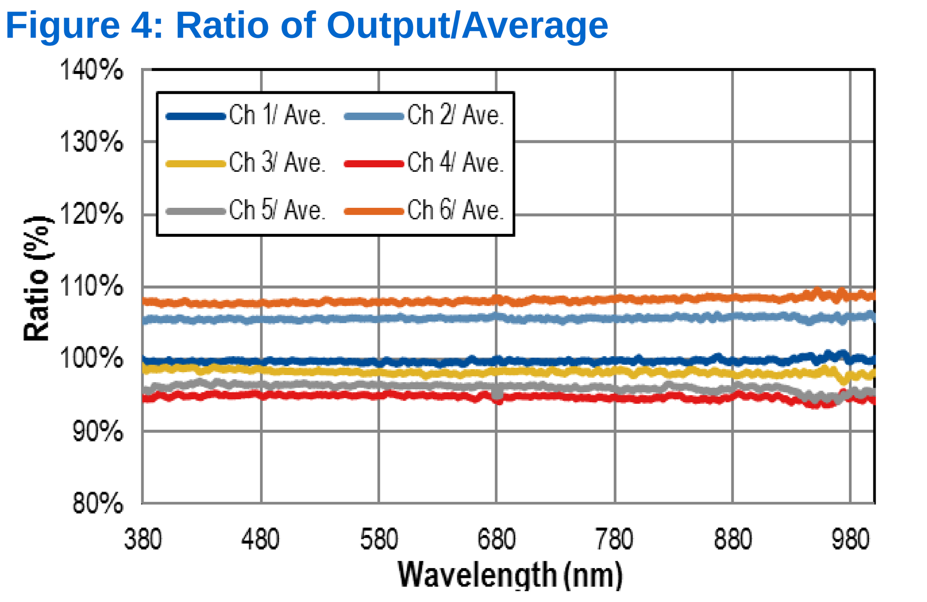


Figure 5: Temporal Stability

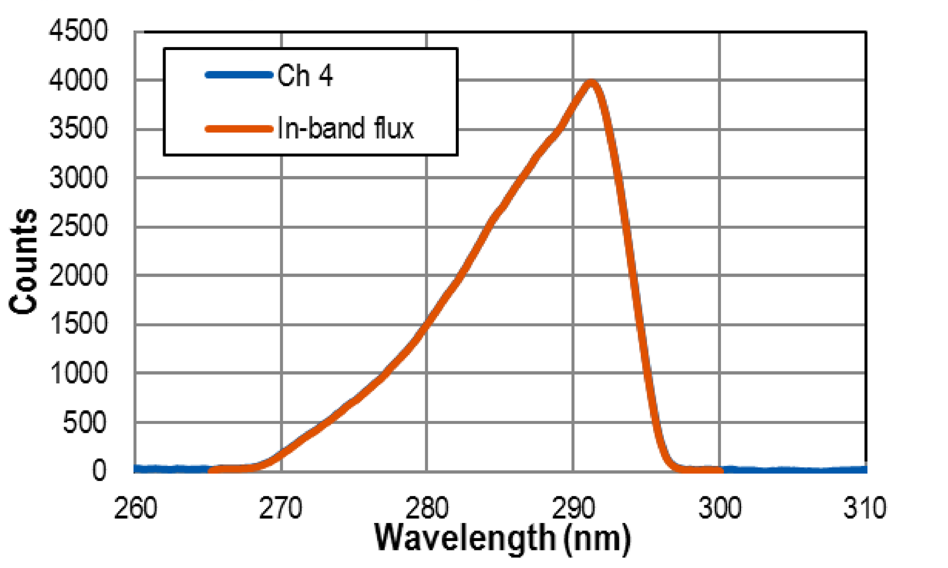
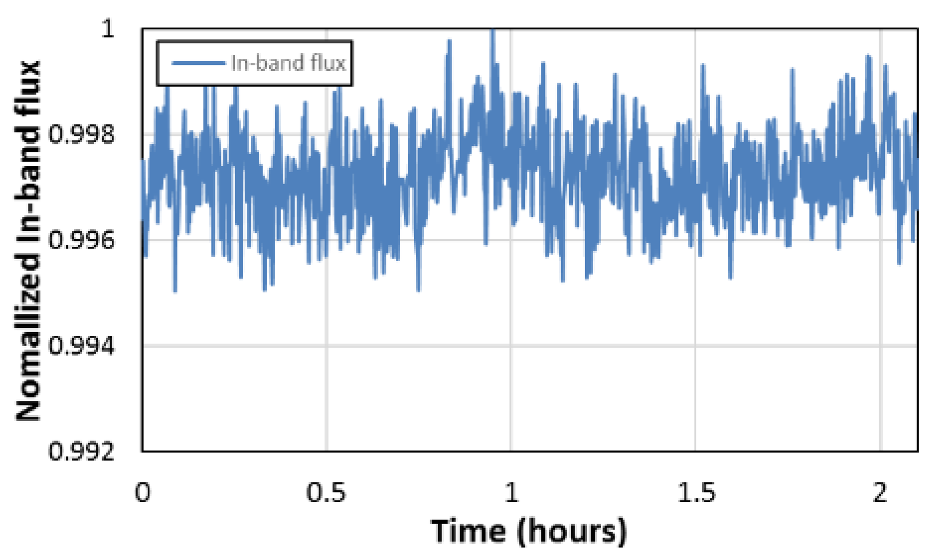


Figure 6: Temporal Variation



Results

- The spectral flux from the center fiber is about 30% higher than the average of the six outer channels. This fiber was used as a reference channel.
- The six outer fibers have ~7% spectral flux variations, shown in Figure 4.
- The ratios of the six outer channels vs their average are within 95% to 110% in the 380nm to 1000nm wavelength range
- The variation for normalized in-band flux for one channel over a 2-hours period is about 0.5%, as shown in Fig.6.
- The variation is calculated by the 2-hour in-band flux for channel 4 described in Figure 5.

Applications for Multi-Channel Light Sources

This experiment was conducted to test the suitability of a broadband light source with multi-channel output using a fiber bundle for a semiconductor metrology application. There are numerous other applications and industries that would also benefit from a highly efficient multi-fiber broadband light source.

Key Applications:

- Semiconductor metrology
- Thin film deposition analysis
- Microscopy
- In vivo optical stimulation
- Spectroscopy
- Endoscopy

Conclusion

A broadband light source with multiple fiber outputs was developed and experimentally evaluated. Output uniformity for the six outer fibers is observed to be within 15% over the 380nm to 1000nm wavelength range. The temporal flux variation in a 2-hour operation is ~0.5%. **It is determined that the EQ-99X Laser-Driven Light Source can be effectively coupled with a fiber-bundle for applications that require multiple fiber optic outputs.**

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[1] Donald K. Smith, "Laser-driven light source," US patent, Pub. No.: US7786455B2 (2010).
[2] X. Ye et. al., "LDLS™ Powered Tunable Light Source for Advance Sensor Characterization," in Optical Sensors and Sensing Congress (ES, FTS, HISE, Sensors), OSA Technical Digest (Optical Society of America, 2019), paper ETu3A.2.
[3] Donald K. Smith, "High brightness laser-driven light source," US patent, Pub. No.: US9048000B2 (2015).