Ultrahigh Brightness and Broadband Laser-Driven Light Source

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ABSTRACT

Today's cutting edge research and manufacturing applications in semiconductor, materials and life sciences require light sources capable of delivering highly bright and stable radiation over long lifetimes. Laser-Driven Light Sources (LDLS™) were developed to use high power diode lasers to energize high intensity xenon (Xe) plasma. The light sources produce 170nm to 1700nm radiation with ultrahigh brightness and long source life.

1. INTRODUCTION

Growing development of new instruments and equipment in the biomedical, analytical and semiconductor industries creates pressing needs for light sources with higher brightness, a UV/visible/NIR broadband, and long lives. Lasers, HB-LEDs, deuterium (D2) lamps, and short arc lamps cannot meet all of these requirements with a single source. However, an LDLS meets these requirements since its design properties include: (1) ultrahigh power density in the plasma at the focal point of a laser beam which produces a Xe plasma with much higher temperatures than that of a regular short arc Xe lamp and resulting in higher brightness; (2) higher temperature Xe plasma that produces a higher UV-to-visible radiation ratio, emitting a flatter broadband spectrum; (3) electrodeless operation which allows the source to last longer than 9000 hours. An LDLS is more stable than a conventional source due to the elimination of interactions between a high-temperature plasma and tungsten electrodes.

2. OPERATION PRINCIPLES

An ideal light source for spectroscopy applications would provide a flat spectral output between the deep-UV and the IR, a very small, ultrahigh-brightness emitter, and a constant light output over years of operation. In an LDLS, high-intensity plasma consisting of Xe or other inert gas mixtures is sustained by absorbing optical energy from a focused laser beam from a diode or fiber laser (see Figure 1 [1]). This plasma is called an optical-discharge plasma (ODP), as opposed to the electric-discharge plasma used in short-arc Xe lamps with electrodes. The ODP plasma in an LDLS is formed at the focusing spot of the laser beam in the center of a fused-silica bulb filled with high pressure gases. The power density of the laser beam at the focusing spot is more than enough to sustain a small intense plasma with temperatures in the 10,000K - 20,000K range, significantly higher than the 5000K-7000K typically achieved in a short-arc Xe lamp. The higher Xe plasma temperatures enable UV emission to be greatly increased relative to visible radiations.

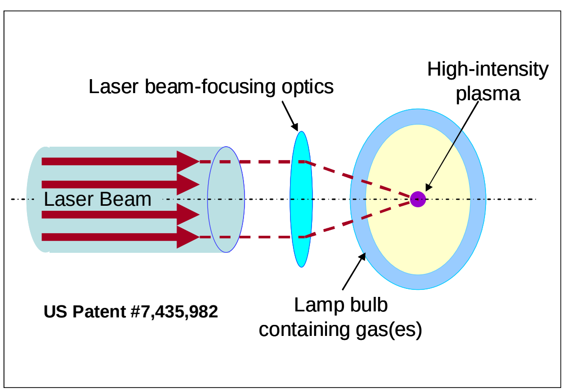

Figure 1. High-intensity plasma of Xe, or a mixture of inert gases, absorbs laser energy at the laser focal point and emits ultrahigh-brightness broadband radiation

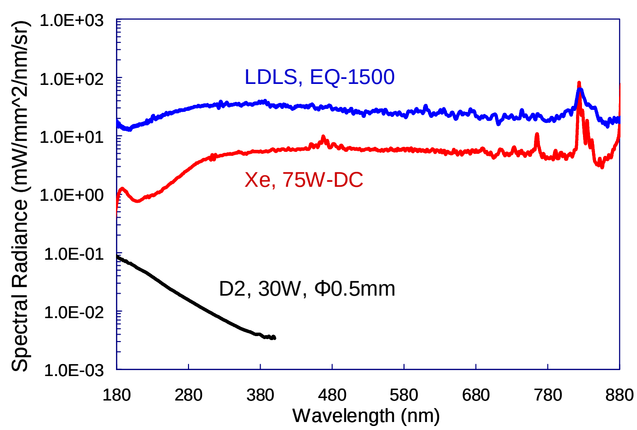

Figure 2. Compared with that of a Xe arc lamp and a D2 lamp, the spectral radiance of an LDLS (model EQ-1500) is one and two orders of magnitude higher and varies less vs. wavelength.

The size of an LDLS plasma is defined mainly by the focal spot of the laser, with the full-width-half-maximum (FWHM) typically around 100µm in diameter at 20W laser power. Spatial and temporal stability of the plasma is constrained primarily by the stability of the optical system and the laser drive power, both of which can be maintained with high precision. Because there are no electrodes in contact with the plasma to cause energy loss, almost all the laser power absorbed by the plasma is reradiated across the broadband spectrum. The scalability of this technology has been demonstrated over laser input powers from 20W to 5kW.

4. ADVANTAGES OF LDLS SOURCES

Analytical instruments require sources with high brightness in order to achieve high throughput and high signal-to-noise ratio (SNR). With a high-brightness, small-size light source, the emitting area of the source can be efficiently imaged, with matching étendue, onto a small diameter optical fiber or a narrow monochromator entrance slit. A higher brightness light source enables greater sensitivity and higher resolution for these instruments.

Spectral radiance data for an LDLS (model EQ-1500, 60W), a high-brightness 30W D2 lamp, and a high-brightness 75W Xe arc lamp are compared in Figure 2. Spectral radiance of the LDLS source is much higher across the entire UV/visible/NIR band than that of the D2 lamp and the Xe lamp. At 200nm, the spectral radiance for the D2 lamp, the Xe lamp, and the LDLS are about 0.1, 1.0 and 10 [mW/mm^2-nm-sr], respectively.

A single light source that delivers the wavelength range from deep-UV to NIR reduces the design complexity and increases the operating range of an analytical instrument. Light at different wavelengths being emitted from the same emitting volume allows simpler and more efficient coupling of the light to an optical system.

5. LIFETIME AND STABILITY

Frequent lamp changes and system recalibrations will lower productivity by consuming valuable technical and financial resources. In regular arc lamps, the evaporation of electrode materials will lower the output and change lamp discharge properties so that the lamp life is usually shorter than 1000 hours. In an LDLS, the energy is delivered to the Xe plasma optically, so there is much less thermal, electrical, or mechanical stress on the lamp bulb. In the LDLS, the electrodes are used only for ignition during plasma starting and they are spaced away from the plasma during operation. During the first 6,000 hours of an LDLS source life test, the total output dropped about 1% per 1000 hours.

For a high-brightness, small-emitting-volume light source, spatial stability is critical in permitting efficient coupling to small étendue applications. Any movement of the plasma, as seen in the flicker of regular Xe arc lamps, translates to signal noise. In an LDLS source, precise control of the laser focusing optics and tight regulation of the laser power ensures a high spatial stability of its plasma location with displacements of less than ±1 µm during a 12.5-second sampling period.

6. PRACTICAL APPLICATIONS OF LDLS SOURCES

The LDLS sources have been used as a tool in several scientific research projects and have been installed as a radiation source in many industrial instrumentations and production processes. Some application examples include: semiconductor metrology; photo-emission electron microscopy (PEEM); UV/visible/NIR spectroscopy; advanced endoscopy; optical birefringence measurements; UV microscopy; spectroscopic ellipsometry; and circular dichroism (CD) spectroscopy.

7. REFERENCE

[1] US Patent #7,435,982