A Critical Comparison of Xenon Lamps

Introduction

When selecting a lamp as an excitation source for spectroscopic studies, the overall power produced by the lamp should not be the only parameter that is used for comparison of its effectiveness as an excitation source. Certainly, it is expected that a 450W lamp emits more light than e.g. a 300W lamp but this number alone does not guarantee that more light is available for exciting a sample. There are other factors such as the optics and geometry that play a role, but we will focus our attention only to the light source for now. Indeed, we will show that the 300W Cermax lamp mounted on ISS spectrofluorometers provides more usable intensity than the traditional 450W Xenon lamp mounted on other spectrofluorometers.

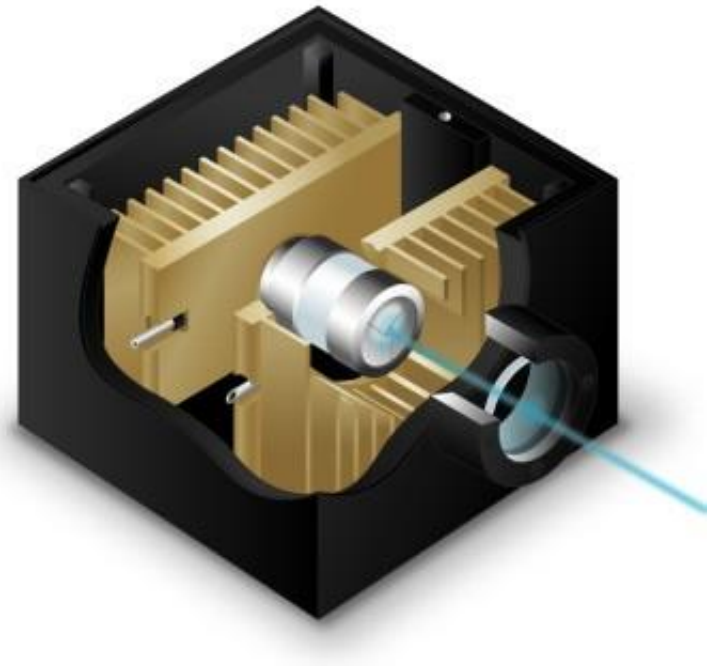

Figure 1. Schematic drawing of the Cermax arc lamp and lamp housing in ISS spectrofluorometers.

Spatial Light Distribution and Collection Optics

A traditional **450W lamp** is about 10 cm (4 inches) long; the bulb is filled with inert gas at about 75 atm. The lamp is usually mounted vertically, with the cathode below the anode. The light emitted by this lamp is concentrated in a donut-like shape around the plane perpendicular to the electrodes. The light distribution is asymmetrical: more light is emitted around the cathode than the anode. Roughly, the light extends in the lower plane of about 70° and in the upper plane about 50°. A lens (condenser) is placed in front of the lamp for the collection of light. Usually, a mirror is placed in the back to increase the amount of the light collected and directed forward: the use of the rear reflector

increases the total collected light by about 60%. Based on the calculations (see below) the total collected light from this lamp is around 30-32%.

The **300W Cermax lamp** is a compact and rugged light source whose bulb, built in ceramics, encloses the electrodes and an internal pre aligned parabolic reflector built around the anode. The lamp can be utilized in any position. The built-in reflector is vacuum deposited onto the precision ceramic surface. The total light produced by the lamp is emitted in one direction only, that is, the axis defined by the electrodes. The light beam is distributed in a cone of 10° around the axis. A lens (condenser) placed in front of the lamp collects the total light emitted by the lamp (Figure 1). The geometry of this lamp allows it to collect around 90% of light.

Figure 2. Photos of a conventional Xenon arc lamp (left) and a Cermax lamp (right).

Calculation of the Amount of Collected Light

In order to calculate the amount of light collected when using a traditional 450W xenon arc lamp, we assume that the outer area of the donut-shape distribution can be estimated assuming it has a spherical curvature with radius R. Light is emitted at the point O; at distance R, the light crosses a sphere of area 4πR. the area of a lens placed in front of the light source at

$$S_L = R^2 \int_0^{2\alpha} d\phi \int_{-\alpha}^{\alpha} \cos\theta d\theta = 4\alpha R^2 \sin\alpha \qquad [1]$$

Assuming that the light is emitted isotropically in space, the amount R_L of light, which is collected by the lens, whose surface is S_L, is given by:

$$R_L = \frac{4\alpha R^2 \sin\alpha}{4\pi R^2} = \frac{\alpha}{\pi}\sin\alpha \qquad [2]$$

When a mirror is placed opposed to the lens, with respect to the light source, the quantity R_L is multiplied (ideally) by a factor 2 (in fact, the factor is less due to reflection from the lens); that is:

$$R_{2L} = \frac{2\alpha}{\pi} \sin\alpha \qquad [3]$$

Let us introduce the following definitions, useful to work with optical elements

Lens diameter ˜ 2d
Focal length ˜ R
f-number ˜ F/#

As a result,

$$\sin\alpha = \frac{d}{R} = \frac{1}{2F/\#} \qquad [4]$$

The following table reports estimates of R_{2L} for different values of f-number, lens diameter and focal length:

F/#	2d [mm]	R [mm]	sin α	α	R_{2L}
1	38	38	0.5	30°	1/6
1.5	38	57	0.33	19.5°	2/27

For instance, when a lens with F/# = 1 is utilized, $R_{2L} = \frac{1}{6} = 0.17$, that is only 17% of the light is collected if emitted isotropically in space. In practice, a xenon arc lamp emits in a donut-like region around the optical axis and $R_{2L} = \frac{1}{5} = 0.2$, that is 20% of the light is collected.

The following Table summarizes the differences between the two types of lamps.

300W Cermax Lamp	450W USHIO Lamp	Comments
The **CERMAX** Lamp is a compact and rugged light source with internal reflector, which is prealigned. The reflector design results in a large collection angle around the arc, which maximizes the efficiency of output. Dimensions: 32mm-diameter, 43mm-long	The **USHIO lamp** is much less compact and does not have an internal reflector. Dimensions: bulb approx. 100 mm-long	The external reflector in Ushio lamp requires adjustment and alignment. If the user is not aware that an alignment is necessary, then the result may be less than optimal performance.
Radiation output: Reliable and efficient source of broadband ultraviolet, visible and infra-red radiation. The single crystal sapphire windows used in all CERMAX lamps have excellent transmission from the UV to deep infra-red.	For a good light throughput in the ultra-violet, a lamp with a quartz bulb, filled with argon and mercury, is needed.	The ozone-free version of the 450 W lamp has a throughput in the ultraviolet which is inadequate for most experiments with proteins which require excitation at 280-290 nm.
Reflector: The built-in reflector, which enhances the lamp's throughput, is vacuum deposited with aluminum onto the precision ceramic surface.	The external reflector is made of aluminum-coated glass and is subject to corrosion and degradation.	The coating of the reflector surface in a CERMAX lamp not only enhances the throughput but also gives the lamp a longer useful lifespan.
Mounting: The lamp is mounted in a prealigned assembly by means of the bolt circle in the anode plate.	The lamp ends are covered with cylindrical metal bases with threaded pin and sleeve nut for electrical connections to the power source. Installation with correct polarity is critical. If lamp is operated with reversed polarity it will be instantly damaged.	The CERMAX lamp installation can be performed with little prior training. The installation of USHIO lamp needs training or supervision and eye protection.
Optical Characteristics: CERMAX lamps have highly collimated beams with essentially Gaussian beam profiles.	The externally located reflector mirror defines the beam profile. The beam is normally not collimated but focused at a certain distance from the lamp. The intensity distribution is not Gaussian, but is distributed within 50 degrees of the arc center.	A collimated beam has predictable properties, whereas an uncollimated beam may be partially lost upon impinging on reflector surfaces and polarizers. In polarization experiments intensities are low and the user cannot 'afford' to lose any intensity.
Temperature: The operating temperatures reach only about 200 degrees C on the lamp surface.	The operating temperatures reach higher than 700 degrees C on bulb and surrounding surface.	Precautions are needed in material handling and operating heat sensitive equipment near the lamp.

300W Cermax Lamp	450W USHIO Lamp	Comments
Output vs. Time: After approx. 1000 hours of operation, the peak intensity is reduced only about 20%.	The total flux drops to less than 70% of its peak value after 2000 hours of operation.	The lifespan characteristics of the two lamps are not very different.
Arc Stability: The radiant output is free from flicker during the average lifespan of lamp.	The gap between the electrodes of a new lamp is 3 mm. As the lamp ages this gap increases and as a result the arc becomes unstable.	The output stability is critical for the best S/N ratio. Arc jitter causes phase fluctuations and unpredictable consequences in the phase angle comparisons.
Start-up characteristics: The lamp reaches steady- state luminosity within 3 seconds of being turned on.	The 450 W mercury lamp takes several seconds to start because of the time taken in the development of arc and the internal pressure. To achieve a smooth start-up process, the starter, ballast and cooling conditions of housing should be compatible with each other.	Quick stabilization of lamp output is desirable in all experiments, particularly in the Kinetics experiments with certain time constraints.
Factors Affecting Output: Among the factors that affect output is the degradation of the electrode material. The electrodes of the CERMEX lamp do not corrode to any significant degree during the average life of lamp, although the aluminum coating on the reflector may degrade.	As lamp operation hours accumulate, electrode material spatters on to the inner bulb surface and these spattering obstruct radiation, resulting in reduced radiation output and changes in spectral characteristics.	All lamps show changes in output and spectral characteristics owing to changes in internal surfaces and/or electrodes. Electrode degradation causes both the loss of intensity and spectral distortion. The changes in the reflector surface mainly reduce the radiation output.
Lamp Disposal: A burnt lamp can be disposed with ordinary precautions only.	Precautions are needed to prevent accidental explosion.	This may be an issue in labs where disposal equipment may not be available.

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