Optica Applicata, Vol. XXXVIII, No. 2, 2008

Using a halogen lamp to calibrate an optical system for UV-VIS radiation detection

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In the last few years plasmas have been used more and more in a great number of scientific and technological fields, and optical emission spectroscopy (OES) has been the most commonly used technique for their analysis. The usual optical system employed for plasma analysis is composed of a monochromator, a detector and an optical fiber, which must be calibrated to correct the different intensity response of each component in this system. For this calibration, the use of commercial halogen lamps is proposed as opposed to the commonly used ribbon lamp, involving lower economic cost.

Keywords: calibration, optical system, patron sources, halogen lamp, plasma spectroscopy.

1. Introduction

In the past few years plasma has been considered as one of the means that is best adapted to produce certain reactions that cannot take place using conventional chemical methods. In order to understand the possible advantages of a given plasma, it is necessary to know the energy available in it, mainly in the form of the kinetic energy of the electrons and heavy particles (such as atoms and ions), measurable by means of electron temperature T_e and gas temperature T_g, respectively. Other parameters of the discharge, such as the electron (n_e), atom (in several excited states, n_p), and ion (n^+) densities, also determine its capability for the excitation or ionization of the atom and molecules introduced into the plasma. Atom and ion densities describe the atomic state distribution function (ASDF) of the discharge, which informs how the atoms and ions are distributed in their different excited states. Moreover, this distribution describes the degree of thermodynamic equilibrium in the plasma, which is related directly to the processes (internal kinetics) that take place during the discharge and the possibility of using the plasma in different scientific and technological areas, for instance surface treatment, sterilisation of medical devices and chemical analysis of samples. Among all the techniques dedicated to the study of plasmas, that based on the analysis of the light emitted by plasma (optical emission spectroscopy, OES) is one of great interest due to its non-disturbing character which does not modify discharge kinetics. The system employed in OES is usually made up of a monochromator that selects the wavelength of the electromagnetic radiation emitted by the plasma to be registered, a detector that transforms the luminous signal into an electrical one and an optical fiber that picks up the radiation emitted by the plasma and drives it to the monochromator entrance slit.

The components of the optical system have a different intensity response to each wavelength. So, the use of this system to analyze the radiation emitted by any light source needs to be previously calibrated in intensity [1]. Calibration in intensity lies in the comparison between the radiation emitted by a patron source, whose emission is known, and this radiation registered by the optical system. In this manner, a global system response (monochromator, detector and optical fiber) is obtained.

Generally, tungsten ribbon lamps are used for this purpose [2–4]. The ribbon lamps are calibrated by the National Institute of Standards and Technology (NIST) using the equipment and procedures described in [5] for the range of temperatures between 800 °C and 2300 °C. The ribbon lamp has a high economic cost for a laboratory; thus, the possibility of using a commercial halogen lamp, as an alternative patron source to the ribbon lamp, is presented in this study where the calibration in intensity of an optical system (monochromator, detector and optical fiber) using both ribbon lamp and commercial halogen lamp has been carried out. In order to verify the proposed method, the populations (in absolute values, cm^{-3}) of the excited levels for an argon microwave plasma at atmospheric pressure have been calculated because the intensity of a spectral line is directly related to the highest population level of each corresponding transition.

2. Description of the optical system to be calibrated

The optical system was composed of a Jarrell–Ash (JA) monochromator with 0.5 m focal distance and a holographic diffraction grating of 1180 lines/mm. The photomultiplier used as a detector was a Hamamatsu R636-10 with a spectral output interval of 200–900 nm and a work tension of 1250 V. The radiation emitted by the light sources was collected by an optical fiber PCS 1000 with a silicon nucleus of 1000 and an 80 μm thick silicone case, and was conducted by the optical fiber to the entrance slit of the monochromator. In these experiments we used 50 μm width slits. Figure 1 shows a schematic diagram of the optical system described.

3. Patron sources and calibration procedure

3.1. Patron sources

Patron sources are used to determine the above-mentioned spectral response of an optical system, $R(\lambda)$. Among the different patron sources that can be used for this purpose, the most frequently employed lamps are those composed of a filament enclosed in

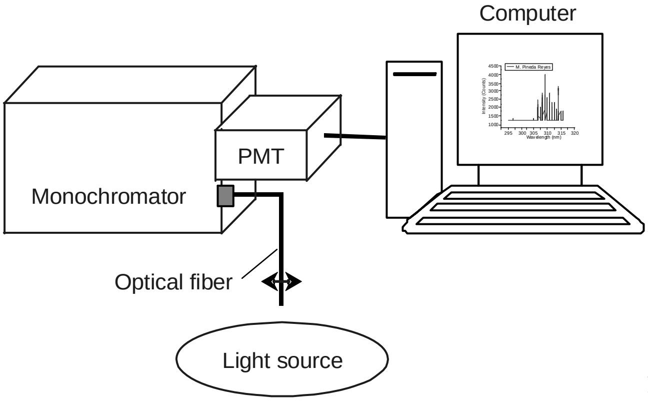

Fig. 1. Diagram of the optical system.

a quartz wrapper. This filament emits a spectrum of electromagnetic radiation depending on its temperature T which is a function of the electric current that circulates through it.

The theoretical electromagnetic radiation (spectral radiance) of the lamp at temperature T is given by:

$$I_{\mathrm{lamp}}^{\mathrm{th}}(\lambda, T) = \tau\varepsilon(\lambda, T)\rho(\lambda, T) \tag{1}$$

which is defined as the intensity emitted in a wavelength per area, per time and per solid angle. In this expression, τ is the absorption coefficient of the lamp wrapper, $\varepsilon(\lambda, T)$ is the emission given off by the lamp at a given temperature and $\rho(\lambda, T)$ is the blackbody spectral radiance that can be written as:

$$\rho(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{\exp\left(\dfrac{hc}{k\lambda T}\right) - 1} \tag{2}$$

$I_{\mathrm{lamp}}^{\mathrm{th}}$ and $\rho(\lambda, T)$ come given in units J·m^{-3}·s^{-1}·ster^{-1}.

The spectral response of the optical system $R(\lambda)$, is obtained from the comparison between the theoretical signal emitted by the lamp $I_{\mathrm{lamp}}^{\mathrm{th}}$ with the one experimentally registered and measured by the optical system $I_{\mathrm{lamp}}^{\mathrm{m}}$ which is the object of the calibration. The relation between $I_{\mathrm{lamp}}^{\mathrm{th}}$ and $I_{\mathrm{lamp}}^{\mathrm{m}}$ can be expressed as [4, 6]:

$$I_{\mathrm{lamp}}^{\mathrm{m}}(\lambda) = GR(\lambda)I_{\mathrm{lamp}}^{\mathrm{th}}(\lambda, T) \tag{3}$$

$R(\lambda)$ being the spectral response of the optical system and G – a constant which depends on the relative position of the source-optical fiber. For a known position, the ratio $I_{\mathrm{lamp}}^{\mathrm{m}}/I_{\mathrm{lamp}}^{\mathrm{th}}$ gives the spectral response in intensity of the optical system in the wavelength interval under consideration.

3.1.1. Ribbon lamp

A ribbon lamp, calibrated by the NIST [5], essentially consists of a tungsten filament wrapped in quartz. An electrical current passes through the thin filament, heating it and causing light emission (electromagnetic radiation). An emission temperature is associated with each electrical current passing through the filament.

The ribbon lamp used in this work was a tungsten lamp type 28/G/UV (Polaron Engineering Ltd.) whose schematic drawing is shown in Fig. 2.

3.1.2. Commercial halogen lamp

Invented by GE Lighting in 1958, the halogen lamp provides a highly efficient compact source of light that has revolutionized the world of lighting. This is also an incandescent lamp, consisting of a tungsten filament sealed in a small wrapper filled with a halogen

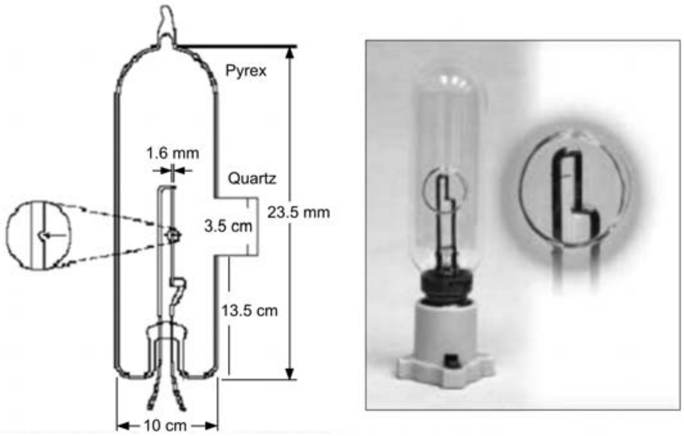

Fig. 2. Schematic drawing of the ribbon lamp [7].

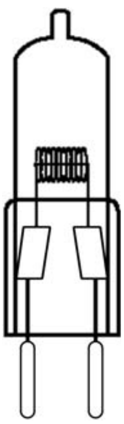

Fig. 3. Schematic drawing of the GY6.35 halogen lamp.

gas such as iodine or bromine. This gas creates a reaction to avoid the evaporation of the tungsten towards the walls of the wrapper. Because the lamp must be very hot to create this reaction, the halogen lamp wrapper can be made of hard glass or fused quartz, instead of ordinary soft glass which would soften and flow too much at these temperatures. For this reason, these lamps are designed to run about 7.2×10^6 s, twice as long as a typical ordinary incandescent lamp [8]. So, unlike the standard incandescent lamp, halogen lamps use a halogen gas that allows them to shine more brightly without sacrificing duration, at a smaller physical size and a lower economic cost.

Currently there are many types of halogen lamps which are classified according to their bulb, filament and base. GY6.35 halogen lamps from different companies are the ones that have been used in this study. A schematic drawing of this kind of lamp is shown in Fig. 3.

3.2. Calibration procedure of the optical system using two patron sources: ribbon lamp and halogen lamp

The spectral response of the optical system $R(\lambda)$ is obtained from Eq. (3) when the lamp theoretical emission $I_{\text{lamp}}^{\text{th}}$ and the experimental emission $I_{\text{lamp}}^{\text{m}}$ registered by the optical system are known.

Figures 4 and 5 show the theoretical electromagnetic radiations emitted by the ribbon lamp and the halogen lamp, respectively. In the case of the ribbon lamp, $I_{\text{lamp}}^{\text{th}}$ is given by the manufacturer and for the halogen lamp it can be approximated to the electromagnetic radiation emitted by a blackbody.

Figures 6 and 7 depict the electromagnetic radiation emitted by the ribbon lamp and four different commercial GY6.35 lamps and measured by the optical system. In Figure 7, one observes that the emission registered by the optical system is the same for all lamps, except in the ultraviolet region; in this region one of the lamps does not emit radiation and it has the so-called UV-STOP technology. In order to differentiate the lamps, we have designated the lamp that does not emit in the UV-region as type A and the rest of the lamps as type B.

A study is carried out on the relative position source-optical fiber (G factor). In Figure 8 the intensity measured by the optical system for the different halogen lamps appears represented as a function of the distance between the light source (halogen lamp) and optical fiber. One observes that the intensity of lamp A decreases as the distance between the optical system and the lamp increases according to the inverse square law. The same behaviour is presented by the type B lamp for distances over 4.5 cm. However, for type B lamps, the intensity decreases on approximating it to the optical system at distances under 4.5 cm, which is due to the cone vision effect [9]. This effect is negligible for lamp A because its wrapper is like a convergent

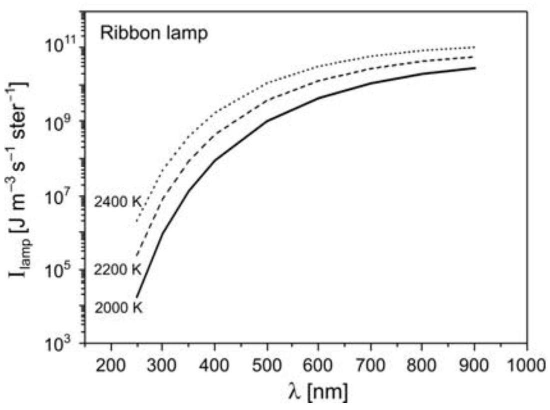

Fig. 4. Theoretical electromagnetic radiations emitted by the ribbon lamp.

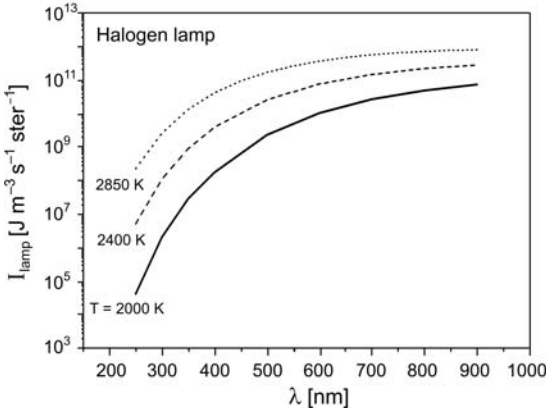

Fig. 5. Theoretical electromagnetic radiations emitted by the halogen lamp.

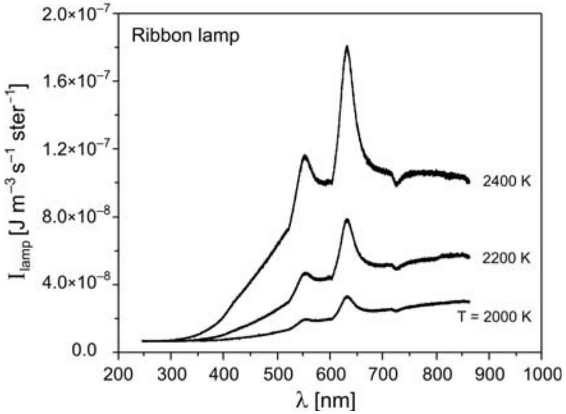

Fig. 6. Electromagnetic radiation emitted by the ribbon lamp measured by the optical system.

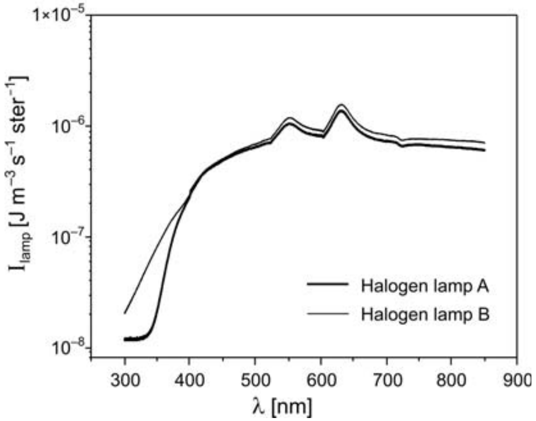

Fig. 7. Electromagnetic radiation emitted by the halogen lamp measured by the optical system.

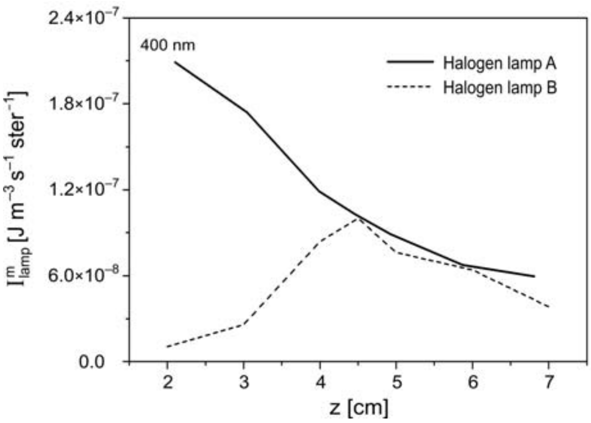

Fig. 8. Dependence of the electromagnetic radiation emitted at 400 nm by both lamp types on the distance optical system-lamp.

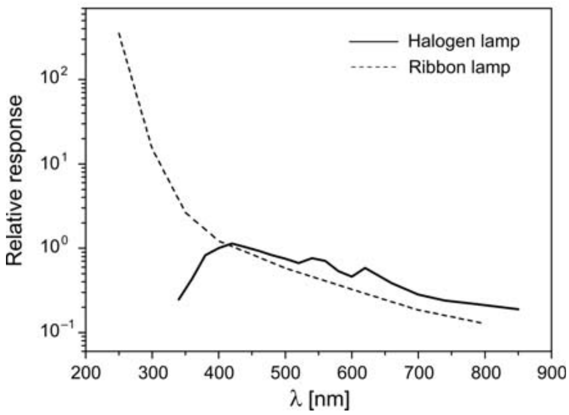

Fig. 9. Comparison between the two relative responses (halogen lamp and ribbon lamp).

lens [9]. For this reason, in order to use any halogen lamp type, it is advisable to register electromagnetic radiation for distances over 4.5 cm. In the case of the ribbon lamp, its behaviour with respect to its distance from the optical fiber was the same as that of lamp A.

Figure 9 shows the responses obtained for both sources (ribbon and halogen lamps) by using expression (3), observing that the values for halogen lamps present a difference of 10% with respect to those for the ribbon lamp. In order to validate the use of the halogen lamp as the patron source, the calibration obtained for the optical system described in this section has been applied to obtain the absolute values of the excited level populations (atomic state distribution function, ASDF) of an argon microwave plasma generated at atmospheric pressure in the next section.

4. Excited level populations (ASDF) of argon microwave plasma at atmospheric pressure

The discharge was created in a quartz tube with one end open to the atmosphere, obtaining a plasma column. The dimensions of inner and outer diameter of the discharge tube were 1 and 4 mm, respectively. The plasma gas was argon with a purity of about 99.999% at a flux of 8.33 m^3/s controlled by a HI-TEC flow controller (model IB31). The microwave power for the creation and maintenance of the plasma was supplied by a SAIREM generator GMP 12 kT/t in continuous mode at a frequency of 2.45 GHz and at 250 W level. This power was coupled to the plasma by using a surfaguide exciting device [10]. Stub systems were also used in order to optimize the impedance coupling discharge-surfaguide and ensure that the reflected power was less than 5% of the incidental power.

The absolute populations of the different atomic level n_p for the argon system are related by the intensity of the spectral lines emitted ($I = I_{\mathrm{plasma}}^{\mathrm{emit}} = I_{\mathrm{plasma}}^{\mathrm{th}}$); for that, knowing $I_{\mathrm{plasma}}^{\mathrm{emit}}$ the n_p populations are known well. The intensity of a spectral line corresponds to atomic transitions starting at each specific level as in the following expression:

$$I = \frac{hc}{4\pi} \frac{A_{pq} \Lambda_{pq}}{\lambda} n_p \tag{4}$$

T a b l e. ArI spectral lines and their features.

λ [nm]	E [cm^{-1}]	g_p	A_{pq} [$\times 10^8$ s^{-1}]
842.46	105617	5	0.233
706.72	107290	5	0.0395
696.54	107496	3	0.067
826.45	107496	3	0.168
750.39	108723	1	0.472
425.12	116660	3	0.0013
430.01	116999	5	0.00394
427.22	117151	3	0.0084
426.63	117184	5	0.0033
425.93	118871	1	0.0415
641.63	119683	5	0.0121
591.20	121012	3	0.0105
560.67	121933	3	0.0229
603.21	122036	9	0.0246
555.87	122087	3	0.0148
518.77	123373	5	0.0138
549.58	123653	9	0.0176
522.12	124610	9	0.0092

where A_{pq} is the coefficient for spontaneous emission from level p to level q, λ – the wavelength of the corresponding transition, and Λ_{pq} – the escape factor of these transitions. The atomic lines utilized in this study and their spectroscopy features are shown in the Table. Measurements of radiation absorption have revealed that, in the observation direction (transversally to the plasma tube cross-section), the plasma is optically thin for all spectral intervals considered and, consequently, $\Lambda_{pq} \approx 1$ for all transitions studied.

To obtain the absolute value of the population of each excited level, the intensity of the spectral line emitted by the plasma ($I_{\text{plasma}}^{\text{emit}}$) should be registered by the optical system ($I_{\text{plasma}}^{\text{m}}$). The register of the radiation from the patron source and the plasma has to be similar, that is to say, using the same relative position source-optical fiber (G factor). In this way, for the intensity from the plasma one can write:

$$I_{\text{plasma}}^{\text{m}}(\lambda, T) = GR(\lambda) I_{\text{plasma}}^{\text{emit}}(\lambda, T) \tag{5}$$

and for the intensity from the patron source:

$$I_{\text{lamp}}^{\text{m}}(\lambda, T) = GR(\lambda) I_{\text{lamp}}^{\text{th}}(\lambda, T) \tag{6}$$

Combining Eqs. (5) and (6) the intensity of each spectral line emitted by the plasma can be calculated as:

$$I_{\text{plasma}}^{\text{emit}}(\lambda, T) = I_{\text{plasma}}^{\text{m}}(\lambda, T) \frac{I_{\text{lamp}}^{\text{th}}(\lambda, T)}{I_{\text{lamp}}^{\text{m}}(\lambda, T)} = I_{\text{plasma}}^{\text{m}}(\lambda, T) GR(\lambda) \tag{7}$$

and the n_p population is obtained from Eq. (4).

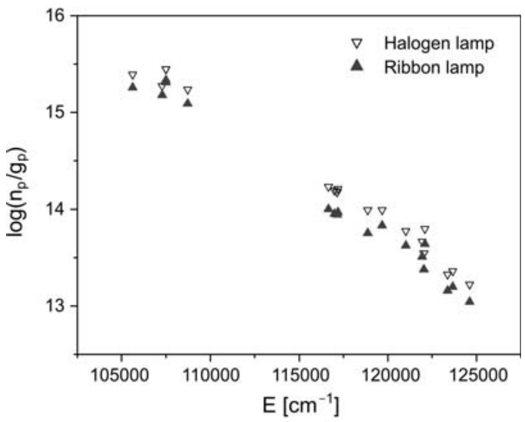

Fig. 10. Populations of the argon plasma excited levels obtained from the calibration of the optical system by two patron sources (ribbon lamp and halogen lamp). The dispersion of the populations is equal to 10%.

In Figure 10 the populations of the excited levels of the Table appear depicted as a function of the excitation energy corresponding to these levels, g_p being their statistical weights. The values of these populations have been calculated using ribbon lamp and halogen lamps of type A and type B as patron sources. These values are at an interval of 20% in all cases, which indicates that a halogen lamp instead of a ribbon lamp can be used as a patron source to calibrate an optical system used to detect the radiation emitted by a light source. This leads to great financial savings for a laboratory due to the economical cost of halogen lamps along with the fact that the electric intensity source for its operation is 90% lower than for a ribbon lamp.

5. Conclusions

In this work, a GY6.35 halogen lamp has been used as the patron source for calibrating an optical system replacing the ribbon lamp for this purpose. The use of the halogen lamp has advantages such as its low cost (90% less than a ribbon lamp) and its availability in any electronics store.

Although it is possible to use any halogen lamp type, it is advisable to measure the radiation emitted from these lamps at distances over 4.5 cm to avoid the cone vision effect and over 400 nm if the lamp employs the UV-STOP technology.

Finally, the proposed procedure has been validated measuring the populations of the excited levels (ASDF) of argon surface-wave discharge from the optical system calibration at atmospheric pressure by using both ribbon lamp and halogen lamp as patron sources.

Acknowledgements – The authors are grateful to Professor Santiago Mar for his comments. The authors also wish to acknowledge the subsidies for this study granted by both the Spanish Dirección General de Investigación (Secretaría de Estado de Política Científica y Tecnológica) under contracts No. FTN2002-02595 and No. ENE2005-00314 and the European community (FEDER funds).

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Received September 21, 2007
in revised form October 26, 2007