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Time evolution of the spectrum of the cesium high pressure discharge light source

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ABSTRACT

The time development of the emission spectrum after the ignition of a high pressure cesium lamp has been studied by means of a high resolution digital spectrometer. Many different spectral phenomena of atomic, ionic or molecular origin have been followed in time. Xenon spectral lines were detected only within the first few seconds after the ignition. Cesium resonance lines appear almost immediately with xenon spectral lines. The former have an extraordinarily interesting time evolution, especially in their far quasistatic wings. Recombination continua to 6p and 5d levels appear almost immediately as Cs satellite and other molecular bands. Allowed and forbidden atomic spectral lines follow slightly different time evolutions. All these temporal spectral changes of the high pressure cesium lamp could be used for further improvement of this interesting white light source.

1. Introduction

Alkali metal light sources have been the subject of experimental studies over the past few decades [1–3]. So far, their spectra have been studied under various experimental conditions, i.e., with alternating currents or pulsed currents, with narrow or broad burners, with low or high pressure conditions etc. [4–8]. Previous studies conducted in our laboratory included the measurement of the visible spectrum for cesium discharge light sources [9]. We also compared the output of the infrared and visible spectra for cesium and sodium discharge light sources for different values of the supply voltage [10]. It was shown that the efficiency of the cesium lamp decreased significantly with an increased supply voltage, due to the rapid development of the infrared atomic and molecular spectral features. This was the motivation to study the time evolution of the spectrum. The measurements presented in this paper will demonstrate the time dependence characteristics of the cesium pulsed high pressure discharge spectra from the ignition to about 96 s. One of our main goals was to improve the efficiency of the Cs lamp, and, if possible decrease the losses in the near infrared spectral region [10]. An increased efficiency of about 85 lm/W had been already achieved by using special experimental conditions and supported by corresponding theoretical calculations [11,12]. However, an appreciable improvement was still required in order to compete with recently developed high brightness light emitting diode lamps (LED lamps). It is very important to develop a new light source with low power consumption as well as an excellent color rendering index or spectrum that resembles the sun's spectrum as closely as possible. It is also desirable for the light source not to contain toxic materials such as mercury.

2. Experimental details

The experimental setup is shown in Fig. 1. Measurements were performed with a test-model cesium discharge

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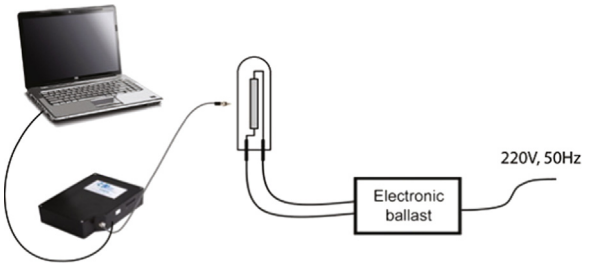

Fig. 1. Experimental setup. On the left is an Ocean Optics spectrometer. In the center is a discharge bulb and on the right is the electronic ballast. Inside the bulb is an alumina burner of 3 mm in inner diameter, filled with cesium and xenon.

bulb provided by OSRAM research laboratory in Berlin. Inside the bulb, there was an alumina burner with an outer diameter of 3 mm. The lamp was driven by a standard power supply with an integrated electronic ballast giving pulses at a repetition rate of 300 Hz. The nominal power of the lamp was 70 W. We used an Ocean Optics HR4000CG spectrometer (3648 pixels, pixel separation of 0.25 nm and spectral resolution of 0.75 nm) to measure the lamp spectrum.

Data were recorded and analyzed on the computer after recording the sequences of the spectra. We recorded the entire spectrum for each second in the first 96 s of the lamp burning with an exposure time of 0.1 s. The tip of the fiber was aimed toward the middle point of the burner. We did not spatially resolve the image of the burner, but rather took the total emission of the lamp, which was introduced into the spectrometer for the time and spectral resolved studies.

3. Results

In Fig. 2, we show the visible and the near infrared spectrum of the Cs high pressure pulsed discharge from 400 nm to 1100 nm. Spectra were taken at 20 s separation from the ignition toward fully developed stable plasma formation at 96 s. In what follows, we shall present the results and the discussion of different spectral phenomena that appear or disappear during the time evolution of the Cs lamp burning.

In Fig. 3, we present the time evolution for several prominent locations in the spectrum of the high pressure cesium discharge lamp, from the moment of ignition to 90 s. In the first place, we have the well-known D1 Cs 852 nm resonance spectral line (red trace) and the 455 nm spectral line (blue trace), the stronger line of the second doublet of the principal series [13]. The cesium molecular satellite band at 472 nm (magenta trace) appears at about 20 s and has a moderate increase of up to 90 s. The forbidden Cs line at 685 nm (green trace) was observed from 20 s onward. Cs_2 B–X molecular band peaking at 760 nm (pink trace) appears also at 20 s and increases appreciably toward 90 s. A Xe spectral line at 881 nm (black trace) could be traced only in the first 7 s, after which it completely disappeared. However, at the same spectral position, the intensity rose again due to the increase of the Cs resonance line quasistatic wings. After

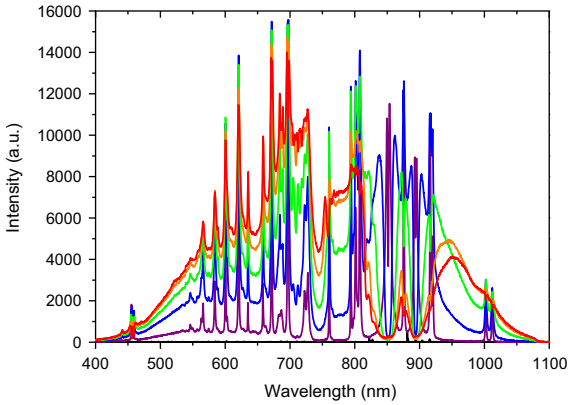

Fig. 2. Visible and near infrared spectrum of the Cs high pressure pulsed discharge. Spectra were taken at 0, 20, 40, 60, 80, and 96 s after the ignition of the lamp discharge. Traces of black, purple, blue, green, orange, and red color are in order of increasing time starting from the lowest to the highest intensities. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

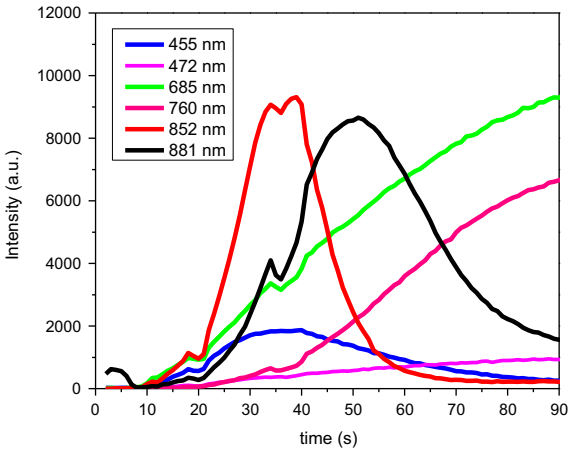

Fig. 3. The time dependence for several prominent locations in the spectrum of the high pressure cesium discharge lamp, from the moment of ignition to 90 s. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

50 s, it decreased again due to self-absorption within the resonance line wings. At about 18 s and 34 s, the lamp light exhibited instability, which could be observed in all presented traces.

In Fig. 4, we expanded the spectral region around the D_2 and D_1 Cs resonance lines where the most prominent Xe spectral lines exist immediately after the ignition. The satellite bands of Cs are observed first in emission at 24 s after ignition and then in absorption when the density of cesium atoms has already appreciably increased (96 s after ignition). The high pressure Cs discharge spectrum exhibits an interesting inversion process, which is important for the depression of the near infrared spectrum at later times after the ignition.

In Table 1, we reproduce the wavelength, energies and configurations of the three xenon spectral lines from NIST data [14,15] that appear at the very early stage of the cesium discharge. From Fig. 4, it may be readily seen that