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Influence of the Outer Bulb Coated with YVO_4:Eu^{3+} on the Hg HID lamp Light Quality

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Abstract

Spectral measurements have been performed in order to establish if the light quality of a Hg HID lamp is drastically influenced by the presence or absence of the external jacket with phosphor coating. Important changes in the profiles of spectra over time have been observed. The resonance line of 253.73 nm appears only when the external bulb jacket with phosphor coating is eliminated. The other Hg lines have their intensities much higher in the case of the lamp having an outer bulb coated with phosphor. Lower values obtained for the characteristic peak emission intensities of Hg for almost all wavelengths (except the 253.73 nm line) in the case of lamp without external jacket may be explained not only by the absence of phosphor coating but also by the lost of the energy through heat exchanged with the air environment. Polynomial fits for the time dependence of red 594 nm, 614 nm and 619 nm characteristic line intensities for YVO_4:Eu^{3+} "phosphor " coating are given.

1 Introduction

It is known that a low pressure mercury lamp may be used as germicidal lamps because the strongest emitted line is the UV resonance line of 253.73 nm, which has a good bactericidal effect. This kind of lamps with a clear glass with very low iron oxide content, which allow this line to pass through glass, are used in hospitals, warehouses or for water purification and disinfection [1].

When the pressure in a mercury vapor discharge increases, so does the self-absorption for ultraviolet of 253.65 nm resulting in UV 365 nm as well as in the visible green, yellow and violet lines becoming relatively stronger, the spectrum of the mercury discharge being altered significantly. Consequently the efficiency changes from about 10-12 lm/W to approximately 52 lm/W [1] and such a lamp can be used for illumination purposes. Although the color correlated temperature (CCT) is good for a high pressure mercury vapor lamp, the color rendering index (CRI) is not satisfactory because in the red part of the visible spectrum we do not have any emission lines, resulting a bad rendering of the red color. To improve CRI an outer bulb with an special "phosphor" coating for transforming the 253.73 nm UV lines into visible lines in the red part of the spectrum is needed [2], [3].

This sort of substances generically named "phosphor " exhibits the so called phosphorescence phenomenon which consists in a continuous emission of visible light under exposure sustained to energized particles such as electrons or ultraviolet photons. "Phosphor " materials usually made from a suitable host material, to which an activator is added. The host material are typically oxides, nitrides, oxinitrides, sulfides, selenides, halides or silicates of Zn, Cd, Mn, Al, Si, or various rare earth metals. When the phosphor is excited by 253.73 nm radiation, it produces visible photons. By changing the composition of the phosphor mixture, lamp manufacturers can produce lamps of slightly different colors (cool white, warm white, etc.). These phosphors are generally complex stoichiometric metal oxides that emit light in a narrow region of the visible spectrum. The precise color output of the phosphor depends not only upon the energy separation of the rare earth ions' valence levels (particularly the 5d and 4f levels) but on the nature of the host lattice as well. In this work we want to establish the differences between the spectra obtained in two cases: the lamp having an outer bulb with phosphor coating, and the lamp without the outer bulb. Although the discharge lamps do not behave as blackbody radiators, the color of the light they emit is characterized by a correlated color temperature (CCT), which is in fact the temperature of the corresponding blackbody having the same color.

2 Experimental results and discussion

A commercially available high intensity Hg discharge lamp with a nominal power of 125 W has been used in our experiments. This lamp has the arc tube enclosed in an evacuated outer bulb with "phosphor " coating, which isolates the hot arc tube thermally from the surroundings.

For ballast we used a tungsten filament that served as a series resistor for the high-pressure mercury discharge lamp. Additionally to the current-limiting element, an ignition device (a resistor of 10 kΩ) is needed to start the discharge.

In steady operation, the temperature in the arc is depending on tungsten filament resistance used as ballast. The energetic electrons collide with the heavy-atom particles present in the plasma, thus exciting them from the ground state to higher energy levels. The excitation energy is then released as an electromagnetic radiation with the spectral characteristics according to the composition of the fill gas. There are a number of operating parameters, which have been recognized as influencing the discharge lamp performance, such as temperature, nature and pressure of the fill gas, choice of the fill material, dimensions and quality of the lamp envelope [4]. The fill material is certainly the most important variable. Compared with the spectra of the conventional medium-pressure lamps, the short wavelengths (especially the resonance 253.73 nm peak) was found to be suppressed by increasing plasma pressure as well as by using a "phosphor" coated envelope [4].

As known, Hg is a two-electron system with a structure of 2 series. For this system since the spin-orbit interaction is relatively pronounced, only the total angular momentum J = L+S is an energy conservation parameter and splitting within a triplet (404.77 nm, 435.95 nm, 546.23 nm) is pronounced. Instead the selection rule is no longer valid because S is no longer a conservation parameter.

The spectral power distribution of the mercury discharge depends, to a very great extent, on the pressure at which it is operating [5]. At low pressures (as in fluorescent lamps) the output is predominantly in the ultraviolet, but as pressure increases (like in

HID lamps) so does the self-absorption for ultraviolet of 253.73 nm resulting in the visible Hg lines becoming relatively stronger [6]. Above about one atmosphere pressure, a very small amount of continuum radiation begins to enter the spectrum and this progressively increases in strength as pressure continues to rise. On the other hand, the 253.73 UV radiation that passes through the lamp discharge tube causes the phosphor coating on the walls of the lamp to glow.

The time evolution of emission spectra of the Hg discharge lamp has been recorded with an Ocean Optics Spectrometer S2000 UV-VIS by using a detector CCD with an Interface ADC500 in the range 186.2 nm to 877.47 nm. The spectrometer was pre-calibrated by OceanOptics Inc..

Spectra were recorded for two different situation: without the outer bulb (case (a)), and with the outer bulb present (case (b)), showing the effects of "phosphor " on the light output. In Figure 1 are shown the two spectra recorded at t=100 s. In the case (a) all the Hg atom lines are observed, including UV 253.73 nm. As shown also in other papers ([7], [8]) for the case when the "phosphor " coating is present, case (b), the Hg resonance line of 253.73 nm is found completely absent from the spectrum because it is absorbed by "phosphor ".

Table1. Mercury emission lines.

Wavelength (nm)	Characteristic transition
253.73	$6^3P_1 \longrightarrow 6^1S_0$
312.66	$6^3D_2 \longrightarrow 6^3P_1$
334.24	$8^3S_1 \longrightarrow 6^3P_2$
365.12	$6^3D_3 \longrightarrow 6^3P_2$
404.77	$7^3S_1 \longrightarrow 6^3P_0$
435.95	$7^3S_1 \longrightarrow 6^3P_1$
546.23	$7^3S_1 \longrightarrow 6^3P_2$
577.12	$6^3D_2 \longrightarrow 6^1P_1$
579.13	$6^1D_2 \longrightarrow 6^1P_1$

The mercury emission lines shown in Figure 1, case (a), describes the transitions presented in Table 1.

From the Figure 2 where the intensities of lines 253.73 nm and 546.23 nm are plotted versus time for the case of lamp when the external bulb with "phosphor " coating is eliminated, we observe that the UV 253.73 nm resonance line is affected by self-absorbtion after about 14.56 s from the ignition moment while the 546.23 nm line intensity is increasing becoming the highest in the spectrum. In Figure 3 the time dependences of 435.95 nm line intensity for the two situations, with and without external bulb coated with "phosphor ", are given. The shape of intensity versus time curves for all the other Hg lines is similar with that of the 435.95 nm line. In the case without external bulb the steady state is already achieved around 200 s, as a thermal equilibrium between the burner walls and the ambient environment is established more rapidly. In the other case (with the external bulb and phosphor coating) the steady state is not attained until about 700 s. This happens because the outer bulb isolates the burner from environment and the burner wall temperature will be much higher, implying also a hotter discharge resulting in intensities becoming more than four times higher than in the former case.

The effective contribution of the "phosphor " coating on the spectrum is given by the characteristic lines: 594.27 nm, 614.82 nm, 619.18 nm, and 700 nm. This fact may prove

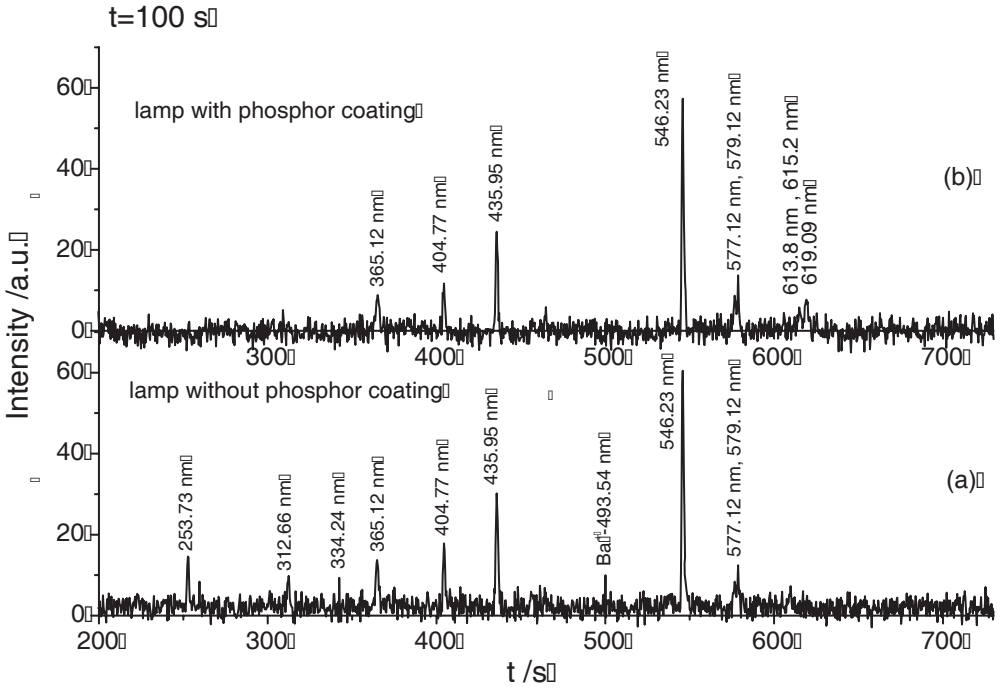

Figure 1: (a)-the spectrum in the case of lamp without phosphor coating. (b)-the spectrum recorded for the lamp with phosphor coating.

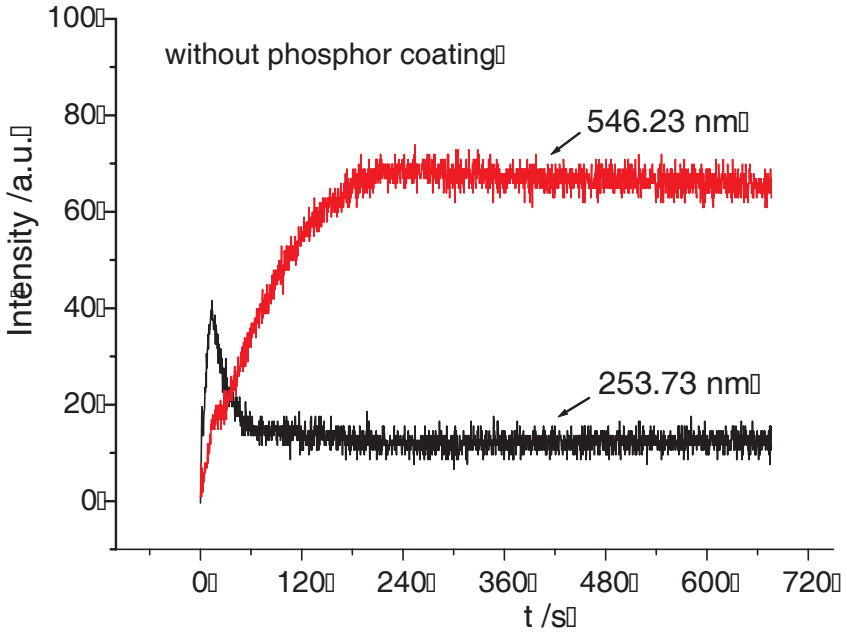

Figure 2: Experimental plots for time dependence of 253.73 nm and 546.23 nm lines intensities in the case of lamp without external bulb coated with "phosphor ".

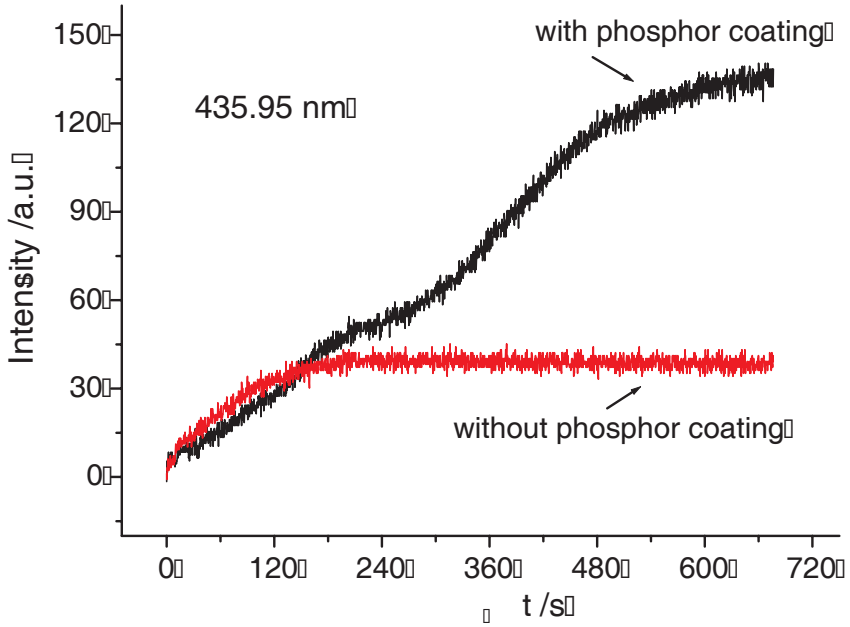

Figure 3: 435.95 nm line intensity versus time in two cases: with an external bulb coated with "phosphor " and without it.

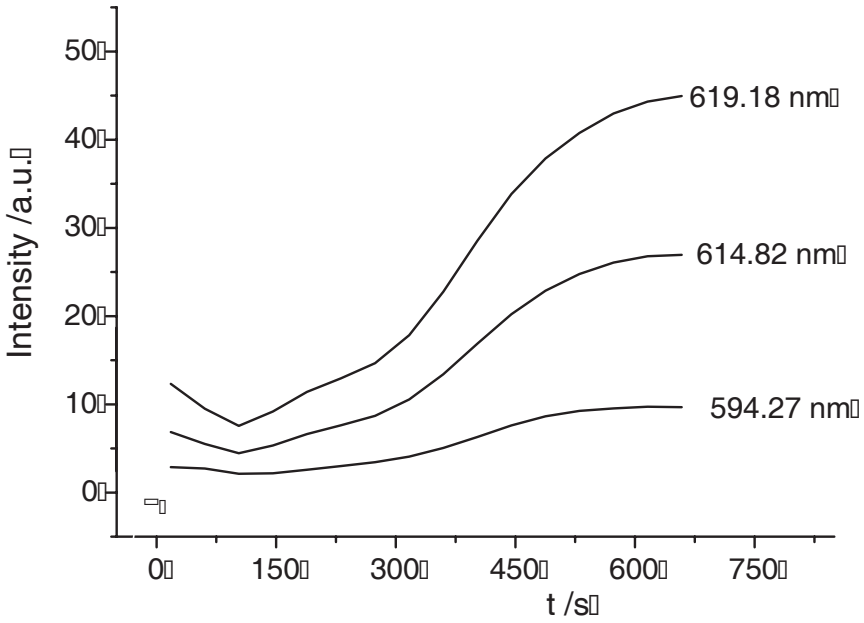

Figure 4: Polinomial fits for time dependences of characteristic YVO_4:Eu^{3+} "phosphor " line intensities.

that we have an europium doping giving a red emission in host lattice YVO_4, with three main groups of lines at 594 nm ($^5D_0 \longrightarrow ^7F_1$), 614 nm and 619 nm ($^5D_0 \longrightarrow ^7F_2$) , and 700 nm ($^5D_0 \longrightarrow ^7F_4$) ([10] - [13]]. Discovered since 1964 [3], the YVO_4:Eu^{3+} phosphor is used as red phosphor in color television cathode ray tube displays and high pressure mercury lamps. Recent studies show that nanosized YVO_4:Eu^{3+} has significant promise in plasma display panels (PDP) considered as a candidate for red phosphor for flat panel displays (FPDs) because of its good color purity.

In Figure 4 are given the polynomial fits for the time dependences of intensities for the most intense lines characteristic to the YVO_4:Eu^{3+} "phosphor " coating obtained through optical emission spectroscopy. The first decrease of the red lines coincide with the intensity fall of UV 253.73 nm line (for the lamp without the outer bulb as seen in figure 2), but after that the 253.73 line intensity remains almost constant while the intensity of red lines are growing (for the lamp with the outer bulb). This increase in the case of a lamp with an outer bulb, may be due, on one hand to the accumulation of UV photons effect over "phosphor " and on the other hand, to the supplemental isolation provided by the outer bulb would permit the burner to attain higher wall temperature and thus determining an increase in the 253.73 nm line intensity.

3 Conclusions

This paper investigates the evolution in time of recorded Hg emission lines intensities of a high pressure Hg lamp before and after the elimination of its external bulb with phosphor coating. We recorded lower intensities for emission Hg lines in the case of lamp without external bulb compared with those corresponding the normal lamp. The time evolution for the lamp intensities exhibits a first region of strong growth after which the intensity remains almost constant when the lamp reaches the steady state. Surprisingly the steady state seems not to be attained until 700 s in the case of lamp with outer bulb coated with phosphor. This is explained by the fact that the outer bulb isolates the burner from environment and the burner wall temperature will be much higher, implying also a hotter discharge. The contribution of the YVO_4:Eu^{3+} "phosphor " coating on the optical emission spectrum is given by the 594 nm, 614 nm, 619 nm, and 700 nm characteristic red lines, their time dependences being fitted by polynomial functions.

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