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Emission Characteristics of Discharge Tube with Mixed Gases

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Abstract - The positive column of a discharge tube filled with a mixture of mercury-xenon has a tendency to become contracted at room temperature. However, once the tube temperature is raised over 50 [℃], the positive column changes from a contracted state to a diffused state. The xenon emission is stronger in the contracted positive column than in the diffused column. Alternatively, the mercury emission is more intense in the diffused positive column, and the luminance of the phosphor coating on the inner surface of the tube is higher than that in the contracted positive column. Moreover, higher luminance can be obtained by increasing the xenon pressure.

Keywords: Positive Column, Plasma Discharge, Mercury-Xenon Discharge, Mixed Gases

1. Introduction

Plasma discharges have a variety of applications as light sources, the most common of which is their use as electric discharge lamps [1-4]. The energy consumption of these lamps equals a total of about 20% of the world's electric power production. The most common discharge lamp is the mercury-vapor fluorescent lamp [5-8], which uses the resonance radiation of ultraviolet (UV) light (254 and 185 [nm] wavelengths) from excited Hg atoms. The luminous efficiency of fluorescent lamps is determined by three factors. One is the radiation efficiency of the UV light from the electrical power input, another is the conversion efficiency from UV to visible light at the phosphor, and the third is the factor determined by the wavelength dependent effect of the visible light on the human eye. Subsequent to the technological improvements that have taken place over the past 75 years, the maximum efficiency with which commercial light sources convert energy into light is about 33%. For the argon–mercury fluorescent lamp, radiation efficiency is approximately 75%, conversion efficiency from UV to visible light is approximately 45% for 254 [nm], and luminous efficiency is approximately 300 [lm] per visible radiation watt. In addition, Kaňka [9] et al. performed a spectroscopic study of the positive column of glow discharge in Ne and Ar mixed gases. The total pressure of the mixture was up to 6 [Torr] and the discharge current was up to 30 [mA].

In this paper, we investigated emission characteristics of mixed gases to obtain high luminance lamp. The positive column of the discharge tube filled with xenon-mercury mixture changes suddenly from a diffused state to a contracted state when the discharge current is increased [10]. The maximum discharge current required to maintain the diffused positive column is about 10 [mA] depending on the xenon pressure at the room temperature. The mercury resonance spectra emitted by the contracted positive column are much feebler than those emitted by the diffused positive column. Therefore, the luminance of the phosphor excited by the resonance spectra is very low in the discharge tube with a contracted positive column. The maximum current needed to establish the diffused positive column increases as the peripheral temperature increases. The luminance increases as the diffused current increases. Therefore, high luminance can be obtained at high temperatures.

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2. Experimental

Fig. 1 indicates the mercury-xenon discharge tube with a distance between the electrodes of 80 [mm] and an inner diameter of 3.8 [mm]. Xenon is filled in the tube at the pressures of 200 [Torr] and 300 [Torr]. The blue phosphor (BaMg2Al16O27: Eu, NP-107) is coated on the inner surface of a half tube length. The discharge tube is set in a temperature-controlled chamber from 0 [℃] to 200 [℃]. The operating circuit for the tube is shown in Fig. 2.

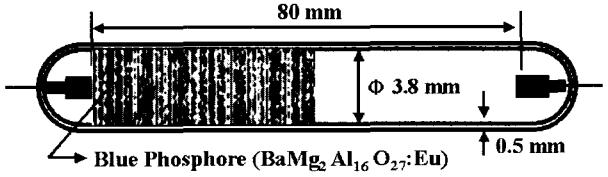


Fig. 1 The mercury-xenon discharge tube. Xenon pressures are 200 [Torr] and 300 [Torr].

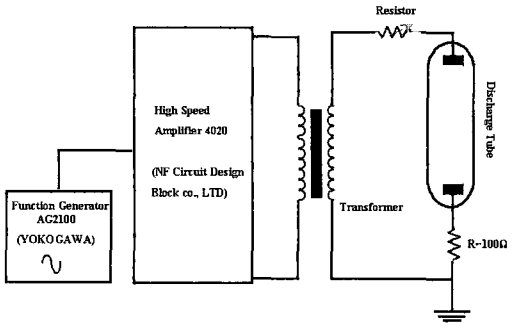
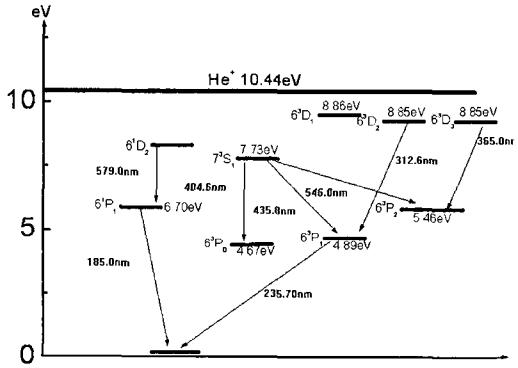
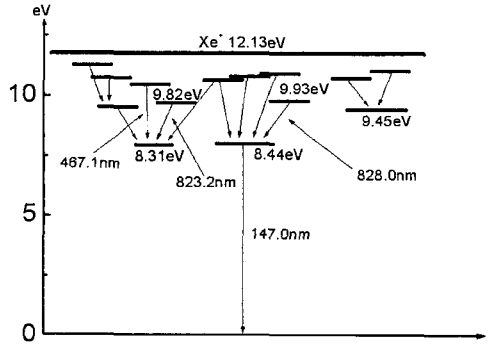


Fig. 2 The operating sine-wave circuit. Frequency is 30 [㎑].

The discharge tube is operated at a constant frequency of 30 [㎑] with tube voltage under 3 [kV]. The temporal changes of the tube voltage, the discharge current and the spectral intensities of the mercury line 435.8 [nm] and the xenon line 823.2 [nm] were observed through a digital oscilloscope. The luminance of the phosphor was also measured by a luminance meter.



(a) Mercury atoms



(b) Xenon atoms

Fig. 3 Energy-level diagram.

Fig. 3 illustrates the schematic diagrams of the energy levels of mercury and xenon. The ionization voltage of mercury is 10.44 [eV] and that of the xenon atom is 12.13 [eV]. The wavelength of the resonance lines of mercury is longer than those of xenon.

Fig. 4 represents the mercury vapor pressure as a function of the temperature. The mercury vapor pressure is 1.84 [mTorr] at 25 [℃] and 88.8 [mTorr] at 80 [℃].

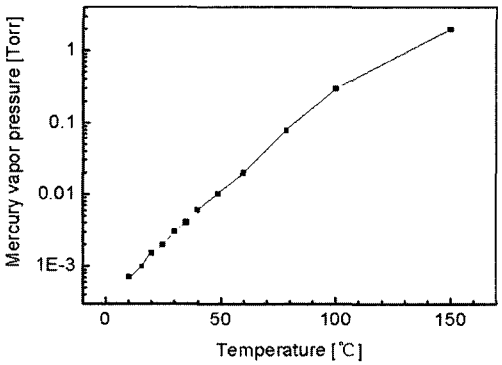


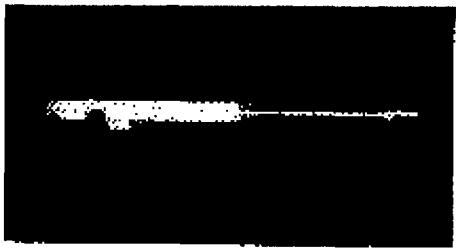
Fig. 4 Mercury vapor pressure as a function of the temperature.

3. Results and Discussion

Fig. 5 (a) and (b) show the photographs of a diffused positive column and a contracted positive column, respectively. The phosphor emits stronger light by the diffused positive column than by the contracted column.

The left sides of the discharge tubes are coated internally by phosphor. The state of the positive columns can be distinguished from the right side of the discharge tubes.

(a) Diffused positive column

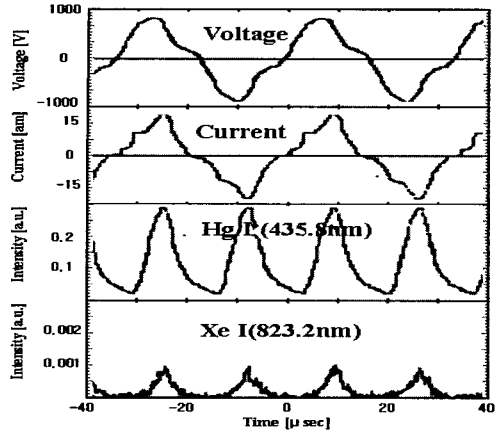


(b) Contracted positive column

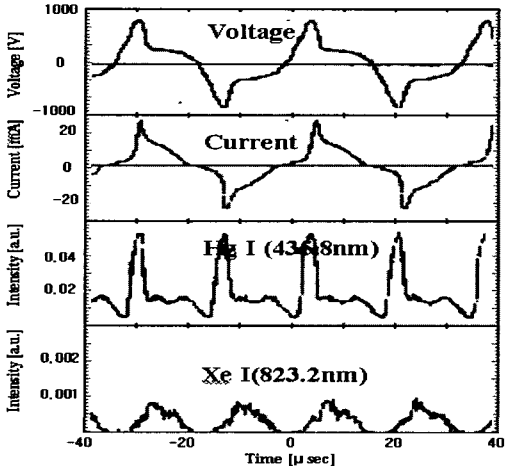
Fig. 5 Photographs of mercury-xenon discharge tubes.

Fig. 6 (a) illustrates the oscillograms of the tube voltage, the discharge current and the spectral intensities of mercury and xenon in the tube filled with xenon at 300[Torr] in the diffused column at 10.3 [mA] (rms) and in the contracted tube at 13.5 [mA] (rms). The bottom intensity on the waveform of the mercury spectrum 435.8 [nm] increases in the contracted positive column and conversely, decreases in the diffused one. Therefore, they can be dis-

tinguished from each other by the waveform of the mercury spectrum 435.8 [nm].



(a) At the discharge current of 10.3 [mA] (rms).



(b) At the discharge current of 13.5 [mA] (rms).

Fig. 6 Waveforms for the tube voltage, the discharge current and the intensities of mercury spectrum 435.8 [nm] and xenon spectrum 823.2 [nm] of the peripheral temperature of 90 [℃].

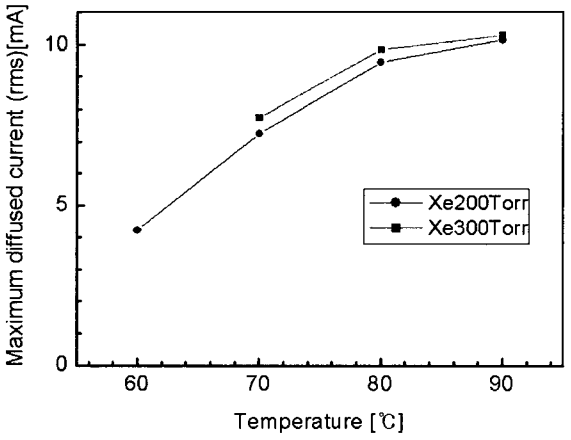
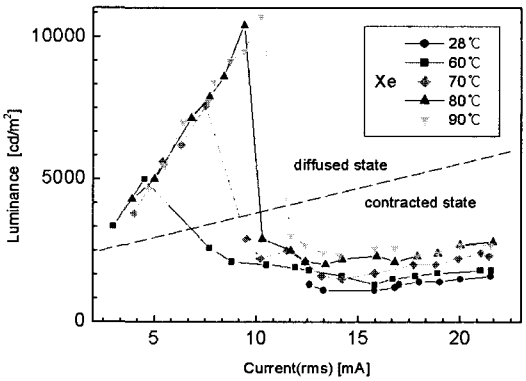


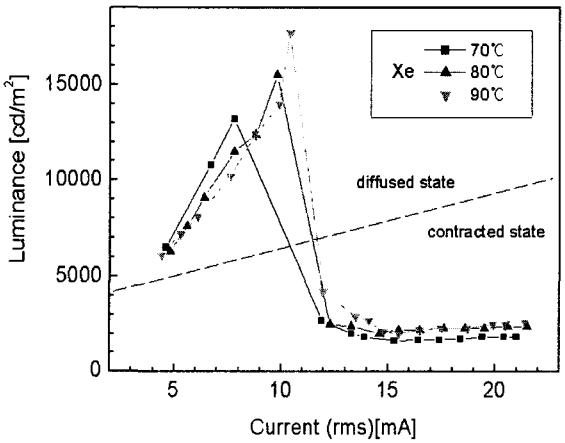
Fig. 7 Maximum diffused current as a function of peripheral temperature at the xenon pressures of 200 [Torr] and 300 [Torr], respectively.

It is shown in Fig. 7 that the maximum diffused current increases as the peripheral temperature and the xenon pressure rise.

Fig. 8 (a) and (b) show the luminance as a function of the maximum diffused current at the xenon pressures of 300 [Torr] and 200 [Torr], respectively.



(a) The tube filled with xenon at 200 [Torr] and mercury.



(b) The tube filled with xenon at 300 [Torr] and mercury.

Fig. 8 Luminance as a function of the discharge current at the various peripheral temperatures.

The maximum luminance of 17,700 [cd/m²] was obtained by the tube filled with xenon at 300 [Torr], mercury at the peripheral temperature of 90 [℃] and at the discharge current of 10.3 [mA].

The charged particles in the positive column flow inward to the central axis by centripetal force, which exerts on the current by the pinch effect and causes the positive column to become contracted. In contrast, the charged particles flow outward in the radial direction by the diffusion phenomenon. The radius of the positive column is determined so that the inflows and the outflows of the changed particles come to equilibrium. Since the diffusion effect is enhanced by increasing the temperature, the diffused positive column is enlarged at high temperatures.

4. Conclusion

The positive column of the tube filled with xenon can be diffused by raising the peripheral temperature. The luminance of the tube filled with xenon at 300 [Torr] and 90 [℃] is three times as high at room temperature. High luminance lamp is expected by applying the technique reported in this paper.

Acknowledgement

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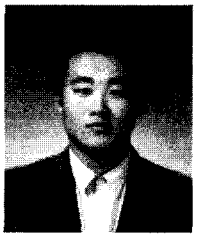

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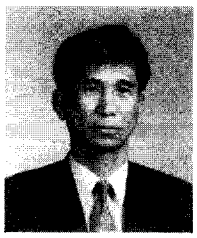

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