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A Study on the Control of Luminous Color in Gas Discharge Tubes

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Abstract - In this paper, pulsed discharge is used to control the luminous color in gas discharge tubes. The luminous color of the positive column in gas discharge tubes filled with Hg-Ar-Ne (1: 9, 60 [Torr]) and having no phosphor material, varies from red to blue emitted by the Ne and Hg from the pulsed discharge. With changing of pulse-width and frequency, the electron temperature in the transient period affects changes to the residual ion and metastable atom densities. The first metastable atoms containing energy levels of about 16.6 [eV] have a very high probability that a collision will result in the ionization potential of Ar being 15.8 [eV]. The change of locus in the CIE chromaticity diagram with increasing pulse-width and frequency approves the variation of luminous color.

Keywords: Discharge, Luminous color, Plasma display, Mixed gas

1. Introduction

Since the first incandescent lamp was developed by T. Edison in 1879, the efficiency of light sources has continued to improve through many varieties of light emitting systems until now. The energy crisis combined with the requirements of a better visual environment have been great driving forces behind the development of lamps with higher efficiency and superior color performance [1]. The progress of new materials and process technology has also contributed to the development of new lamps [2].

Undoubtedly the oldest electro-optical phenomenon able to produce light is an electrical gas discharge. The progresses in the knowledge of the behavior of gas discharge and of the parameters that govern them have been essentially parallel to that of electronics and vacuums. The properties of gas discharge are numerous and have been, and still are applied in many difference devices like: rectifying and switching tubes, switching diodes and trigger tubes, counting tubes, stabilizers and voltage reference tubes, and display devices. None of these devices do make use of the light emitted by the discharge, but rather of the low voltage drop, its constancy, the short ionization time, the arc transfer capability, and the multiplication effects in a discharge. Except where very high powers, energies or voltages are involved, most of the above functions are nowadays better and more cheaply performed by solid state devices. The gas discharge still has decisive properties as a luminous device. Very efficient light sources rely on them such as fluorescent lamps, high pressure mercury lamps, high and low pressure sodium vapor lamps for street lighting, neon and other gas signs and flash tubes. As designed by the names of “Gas Discharge Displays” or “Plasma Display Panels (PDP)”, the latter expresses the physical fact that when emitting light, matter in its fourth state is made-up of free ions and electrons.

The response of the gas discharge depends on the gas composition, the vessel geometry, the type of electrode and the applied signals. To keep constant one of the electrical quantities or a composition of them, stabilizing the tube power, the arc position, or other features of importance becomes feasible. The basic problem in doing so is finding information that is representative of the actual condition of the tube, and to translate it into an electrical signal that can introduce the electronic power supply. As an example, recently the fluorescent discharge lamps that discharge the mixed Hg-Ar gas in the A.C. or D.C., use the ultraviolet radiation with the Hg resonant wavelength of 253.7 [nm] [1]. The type of phosphor and the spectroscopic properties of the ultraviolet radiation control the color of the plasma display [3].

In this paper, the pulsed mode operated gas discharge is introduced, which has the potential to modify the color and the color rendering index independently by means of controlling the spectroscopic properties of radiation in the discharge, just as in the case of the variable peak power and the variable repetition frequency of the pulse series [3 ~ 5].

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2. Experimental

In the experiment, the important parts are as follows; the discharge driving circuit, the gas discharge tube and the optical measuring instruments. The discharge driving circuit controls not only properly applied power but also pulse. During transistor Tr (2SC1325A) off time, the applied voltage E (2 [kV], 2 [A] NIPPON STABILIZER HVF-200R) charges to C capacitor (1.0 [μA]) in Fig. 1. When the C capacitor is charged, the cathode biases as a negative voltage in the gas discharge tube signifying the operating instant of Tr, initiating the discharge. As the pulse-width restricts by the base of Tr, the voltage decreases slowly with discharging the charge to C. The limitation of pulse-width regulation with the C capacitor obviously exists. As the repetition of pulse generates high frequency, which has a phenomenon of not providing enough charge to C capacitor in discharge time, the applied voltage E restricts the frequency. The applied voltage E restricts by the maximum voltage of 1500 [V] and the maximum collector current of 10 [A] between collector and base of the Transistor. Subsequently, to obtain the necessary high current, Tr is connected by 4 parallels. The R and Ri, which are summed up to be about 2.5 to 12[Ω] in the experiment, restrict the peak current.

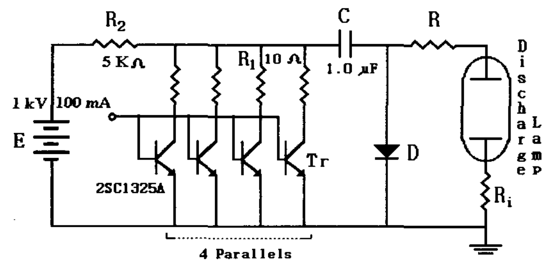


Fig. 1 The discharge driving circuit.

The structure of the gas discharge tube is as follows in Fig. 2. The electrode is coated inside the gas discharge tube. The inner diameter, the electrode length and electrode interval are 12.9, 10.0 and 128.0 [mm], respectively. In the gas discharge, Hg-Ar-Ne (1: 9, 60 [Torr]) is filled with mixed gas.

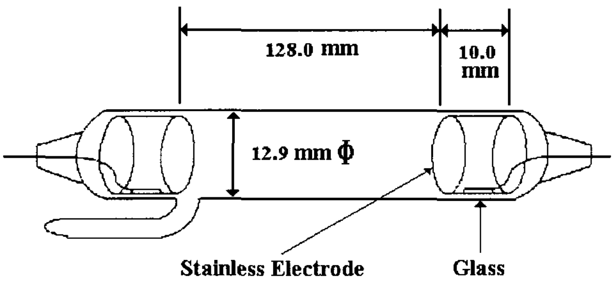


Fig. 2 Structure of the gas discharge tube.

Fig. 3 shows the optical measuring instruments. The radiation of the gas discharge through the slit is derived to the monochrometer (Nikon P250). The photomultiplier (Hamamatsu C659) converts optical to electrical signal and then the converted signal is amplified. To measure the distributions of the radiation, Boxcar Averager (EG&G PAR 162) averages the amplified signals and then amplifies the signal output to the pen recorder. To obtain the radiation with time domain variable, the amplified signals are compared with applied signals on the digital oscilloscope (Tektronix 2430A) and are stored to the personal computer. To consider the color change, luminance colormeter (BM-7, TOPCON) is used to plot the CIE chromaticity chart.

To measure the optical radiation of the gas discharge in the visible region, the discharge driving circuit control observes the color change of the plasma, signifying that there is a change in the pulse-width, frequency and variation of the spectroscopic property in the radiation.

In the experiment, the change in color of the gas discharge tubes from red to blue color is introduced at 25 and 50[μs] pulse-widths at 100, 500 and 1000[Hz]. The intensity of each distribution is compared with the biased signals at the checked wavelengths, which are in the restricted visible region.

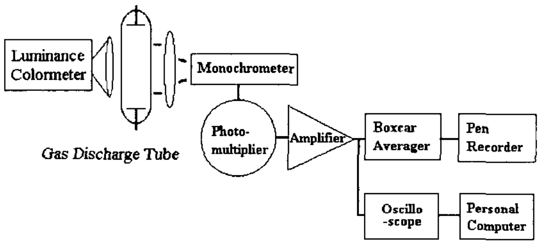


Fig. 3 The schematic diagram of the optical measuring instruments.

3. Results and Discussion

The radiation in the gas discharge contains lights with variable wavelengths. In the experiment, with variable pulse-width and frequency, the colors of the lights changed. Hg and Ne gas make many related distributions, indicating that their gases contain many excitations at distinct wavelengths, especially the wavelengths of 365.0, 435.8, 585.2 and 640.0 [nm] in the visible region. Hg radiated intensities of 365.0 and 435.8 [nm] are increased with pulse-width and frequency but Ne radiated intensities of 585.2 and 640 [nm] are abruptly decreased with pulse-width and frequency, particularly as illustrated in Fig. 4.

The intensity of radiation, which is described as pulse-widths of 25 and 50[μs], are respectively obtained at 100, 500 and 1000[Hz] in Fig. 5. The Hg radiation on 365.0[nm]

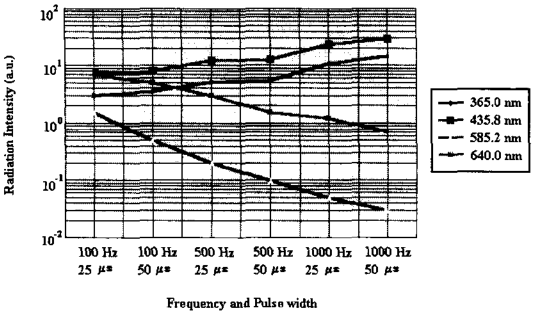
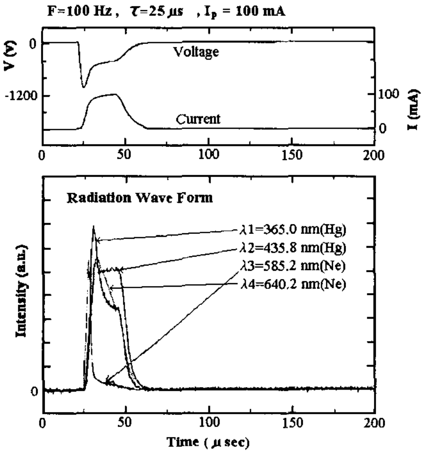


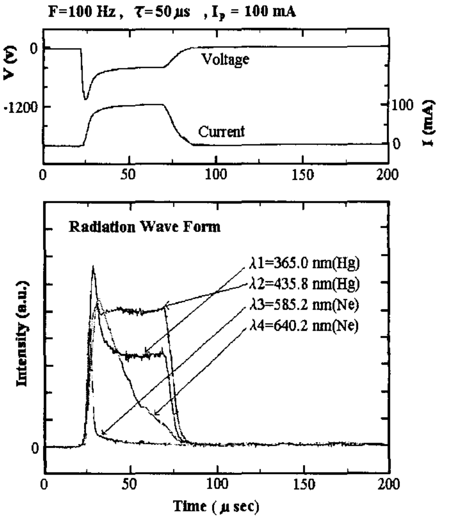
Fig. 4 The distribution of radiated intensity with wavelengths.

rapidly increases to the peak energy during the first stage, exponentially decreasing to the stable state and then disappearing in the time domain. At 435.8[nm], the Hg radiation is similar to currents below 50[μs] and has the highest intensities in the visible region, which is related with Fig. 4. Hg radiation at 365.0[nm] and 435.8[nm] is augmented with an increase in the pulse-width and frequency. Ne radiation of 585.2[nm] in a low frequency (100[Hz]) have intensities during the initial stage but in high frequency have very small intensities. At 640.0[nm], Ne radiation, which also has small intensities in high frequency, increases and slowly dwindles until the current ends.

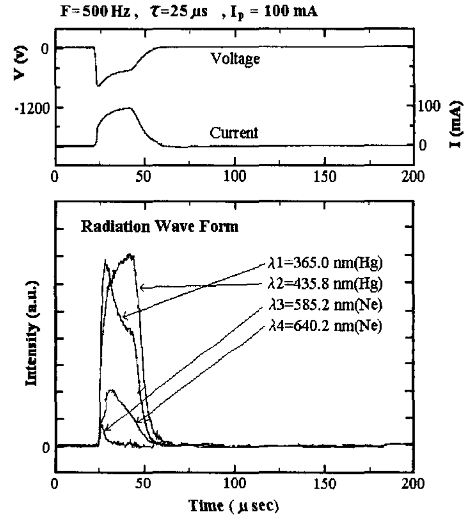
When the pulse is changed from 25[μs] to 50[μs]and the frequency is varied from 100 to 1000[Hz], the luminous color changes from red, which is restricted (0.4734, 0.3023) by CIE chromaticity coordinates, to blue (0.2362, 0.2253) as shown in Fig. 6 and Fig. 7. The luminous colors of Hg and Ne are located at points Hg (0.217, 0.198) and Ne (0.705, 0.295), respectively. Increasing the pulse-width and frequency, the color of the gas discharge varies from color red of Ne to blue of Hg. Whenever Ne with high excitation levels is excited, Hg with low excitation levels is excited and emits radiation, because of the spread of the distribution of electron energy.



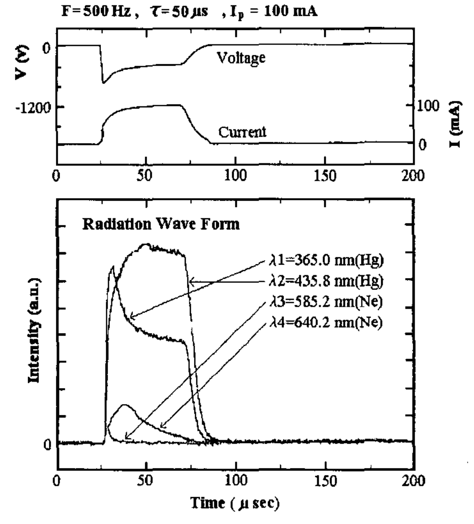
(a) In 100[Hz] and 25[μs]



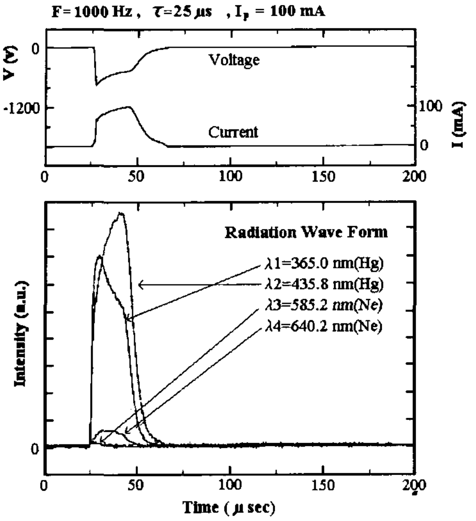
(b) In 100[Hz] and 50[μs]



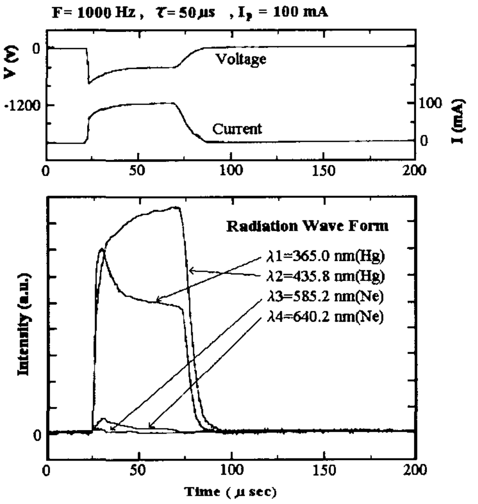
(c) In 500[Hz] and 25[μs



(d) In 500[Hz] and 50[μs]



(e) In 1000[Hz] and 25[μs]



(f) In 1000[Hz] and 50[μs]

Fig. 5 Radiation wave forms at 25 and 50[μs] at 100, 500 and 1000[Hz].

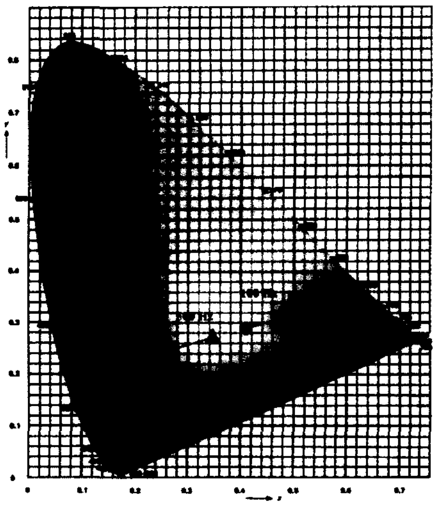
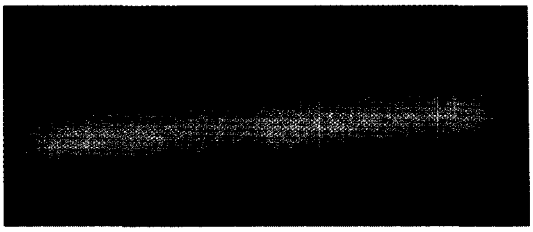
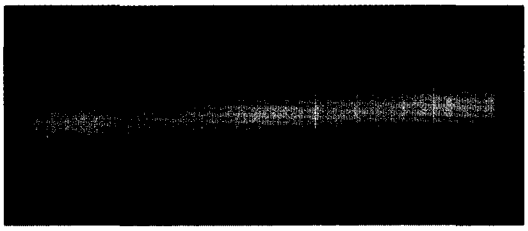


Fig. 6 CIE chromaticity diagram for luminous color in the Hg-Ne gas discharge.



(a) Red



(b) Blue

Fig. 7 Photograph of (a) red (0.4734, 0.3023) and (b) blue (0.2362, 0.2253).

4. Conclusions

The control method for luminous color of the positive column in gas discharge has been proposed by using the shifting of pulse-width and frequency. In the gas discharge filled with Hg-Ar-Ne (1:9, 60 [Torr]) gases, luminous color of the positive column varies from red to blue. With increasing pulse-width and frequency in the gas discharge, there exists a phenomenon that the electron temperature in the positive column and the radiation from atoms of higher upper state energy levels both increase. From the increasing pulse-width and frequency, Hg demonstrated high intensity and small distributions but Ne had the contrary result. The variation of luminous color is from red to blue in the CIE chromaticity diagram with increasing pulse-width and frequency.

(1) The electron temperature in the transient plasma resulted from the sudden increase of current rising much higher than that of the steady state. In the transient plasma, not only the atoms having low excitation levels (Hg: 10.43 [eV]) but also the atoms having high excitation levels (Ne: 21.56 [eV]) emit radiation. The penning mixture contains 10% of Ar. The first metastable atoms having an energy level of about 16.6 [eV] and the ionization potential of Ar being 15.8 [eV] indicate a very high probability for a collision result in the ionization of the Ar atom. With changing pulse-width and frequency, the electron temperature in the transient period is effected by the changes of the residual ion and metastable atom densities.

(2) The intensity of Hg with high intensity and small distribution, more greatly effects the color becoming blue in the high pulse-width and frequency. However, Ne with low intensity and large distribution, more greatly effects

the color becoming red.

(3) In the mixed gases of Hg-Ar-Ne (1:9, 60 [Torr]) discharge, the colors change from red (0.4734, 0.3023) to blue (0.2362, 0.2253) in the CIE chromaticity diagram with increasing pulse-width and frequency.

In gas discharge tubes having no phosphor material, the changing method of pulse-width and frequency has been shown to be suitable for the luminous color control and it can be applied to various related devices.

Acknowledgements

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References

[1 Yosio Wataru et al., "Linear Tube Dependence of 253.7nm Optic Efficiency in Ar-Hg Discharge", J. of the Illuminating Eng. Institute of Japan, Vol.11, No.11, pp.762 ~ 677, 1995.

[2 Tadao Kanou, "Technical Trends and its Prospect of Lighting Source System", Technical Report of the Illuminating Eng. Institute of Japan, pp.147 ~ 155, 3.

[3 M. Aono, et al., "Color Control of Fluorescent Lamps", Symp. Proc. of The 7th Inte. Symp. Scie. & Tech. of Light Sour., Japan, p.81 ~ 82, 1995.

[4 T. Hanada, "Lighting Industries in Japan", ibid, pp.17 ~ 25, 1995.

[5 K. Gunther, "Electronic Optimization of HID Lamps", ibid, pp.93 ~ 100, 1995.

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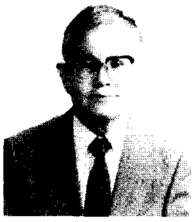

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