2004년도 대한전기학회 전기물성·응용부문회 추계학술대회 논문집 (2004.11.5-11.6)

Low-Pressure Mercury-Free Fluorescent Lamp for General Lighting

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Abstract – In this paper we report on development of our original mercury-less fluorescent lamps for general lighting. These new-type lamps have multi-pairs of electrodes to maintain multi-discharge paths and to keep positive column diffused state. The emission characteristics oft the lamps were investigated. These discharge lamps were operated by pulsed discharge. By using multi-pairs of electrodes for xenon pulsed discharge fluorescent lamps, higher intensity of luminance was obtained than the conventional type of lamps using single pair of electrodes. Recently this type of lamp achieved over 9000 cd/m^2 and 50 *l*m/W .

1. Introduction

Recently the interests in environmental issues have become stronger. In the filed of light sources, the efforts to reduce the amount of mercury used for fluorescent lamps and to develop mercury-less fluorescent lamps have become important. The authors have been trying to develop mercury-less fluorescent lamps using xenon pulsed discharge. The disadvantage of low-pressure xenon discharge lamps is the constriction of positive column which reduces efficacy. In order to avoid this constriction and to obtain a diffusive positive column, authors proposed a lamp which has multi-pairs of electrodes[1],[2]. Recently this type of lamps have achieved high efficacy of 50 *l*m/W and high luminance of 9000 cd/m^2. In this paper we report on this new type of mercury-less fluorescent lamps for general lighting.

2. Experimental Setup

2.1 Lamp Structure

The schematic diagram of the lamps used in this study is shown in Fig. 1. Two pairs of anode and cathode were placed in a lamp. The lamp tube is made of the Pyrex glass tube. The inner diameter of the lamp is 26 mm and the distance between anode and cathode is 50 mm. Xenon is introduced into the lamps at the pressure of 6.7 kPa, 10.7 kPa or 13.3 kPa. The insude wall of the glass tube is coated with mixture of three-bands white phosphor, which is mixture of NP-107, NP-220 and NP-360, the products of Nichia Co. Ltd.

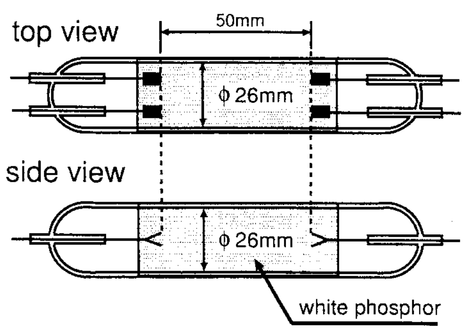


Fig.1 The lamp used in this study. Two types of the lamps were prepared: with phosphor and without phosphor.

2.2 Operational Conditions

The lamps are operated by pulsed discharge using the circuit shown in Fig. 2. In this circuit, the negative pulse voltage is applied to the lamp. Resistors R_1 and R_1' are used to make the current flowing two paths at same value and to limit the total current flowing the lamp. The resistance was adjusted at 50 kΩ for 6.7 kPa, 70 kΩ for 10.7 kPa and 100 kΩ for 13.3 kPa, respectively. The current of each path is measured as voltage drop by using the resistors R_2 and R_2'.

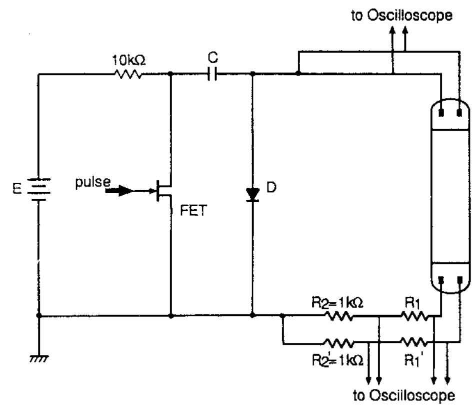
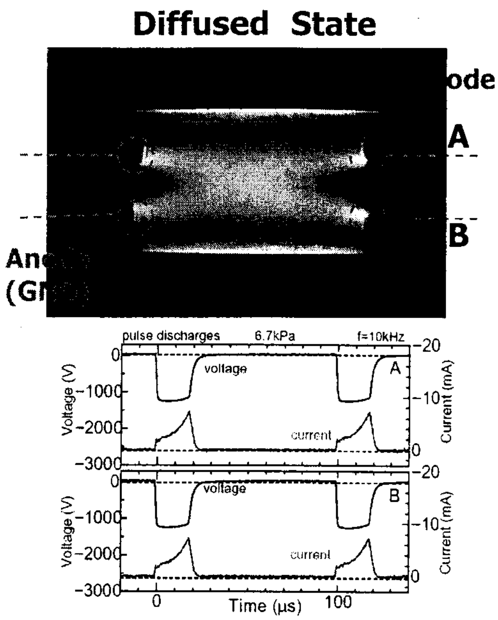


Fig.2 The pulsed circuit for a lamp with multi electrodes

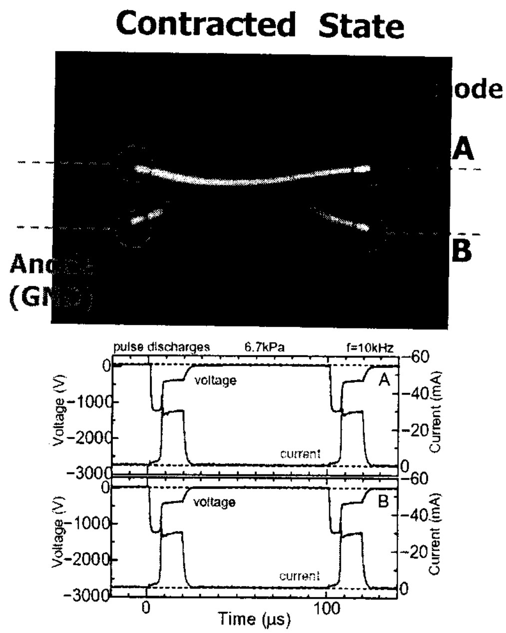
3. Results and Discussion

Fig. 3 shows appearances of diffused and contracted positive columns of the lamps with two pairs of anode and cathode filled with xenon at 6.7 kPa with traces of lamp voltage and current. It is clear that two pairs of electrodes expand the positive column. In order to maintain diffused positive column with preventing from contraction both currents flow through each pair of electrode, that is each path, must be kept same value and the each current must be kept under the threshold value of contraction as well. Even if one of these conditions is broken, the positive column suddenly changes into contracted mode and the luminance of the phosphor shows critical drop though direct visible luminance of positive column greatly increases.

Figs.4,5,6 and 7 respectively show peak voltage, peak current versus pulse width for each case, using single pair electrodes (SPE) and two pares electrodes (TPE) when xenon is filled at the pressure of 10.7 kPa. The positive column is maintain diffusive and the condition is at the boundary where the positive column is just before changing from diffusive to contracted mode. As shown in these figures, pulse width and frequency are varied. The peak voltage values are almost same between SPE and TPE. The peak current of SPE is higher than the peak current per one discharge path of TPE, however total peak current of TPE is higher than that of SPE.



(a) Diffused State



(b) Contracted State

. **Fig.3** Diffused positive column (Top : a) and Contracted positive column (Bottom : b) with traces of lamp voltage and current. The lamps are not coated with phosphor. Xenon pressure is 6.7 kPa

Figs. 8 and 9 show luminance of the lamp coated with phosphor versus pulse width for the cases of SPE and TPE respectively. The pulse frequency is shown as a parameter. These results shows that as the pulse width decreases, the luminance increases in both SPE and TPE cases at any pulse frequency from 15 kHz up to 40 kHz. On the other hand, as the pulse frequency increases, the luminance decreases. These resulrs also show that TPE type gives higher luminance than SPE type gives, that is, TPE type works well.

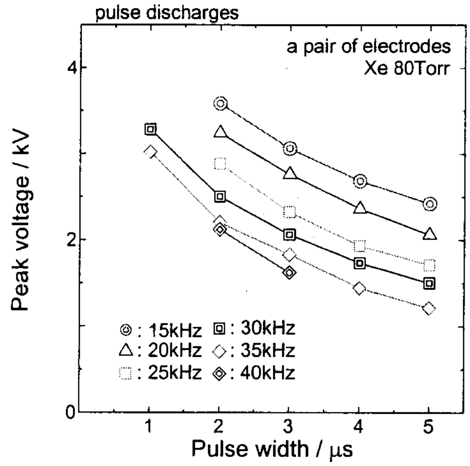


Fig.4 The peak voltage of the single pair electrodes lamps at the mode change boundary when pulse width and frequency are varied and operated with single pair of electrode.

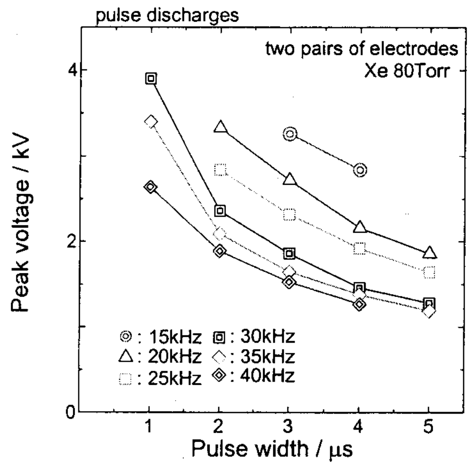


Fig.5 The peak voltage of two pairs of electrodes lamp at the mode change boundary when pulse width and frequency are varied and operated with two pairs of electrodes.

Generally in a pulsed discharge, luminance increases as pulse frequency increases, however, here the results show opposite. This is interesting result and could be explained form the view point of diffusion. Multi-pairs of electrodes enlarge positive column and gives higher luminance. This means that a positive column should diffuse as much as possible. On of the factors which can enlarge positive column is diffusion. It would be acceptable that if the time for species in plasma especially metastable atoms making diffusion is longer, positive column would be more diffused. This can explain why shorter pulse width and low frequency bring higher luminance. In other words, non-discharge period must be enough longer to make species well-diffused.

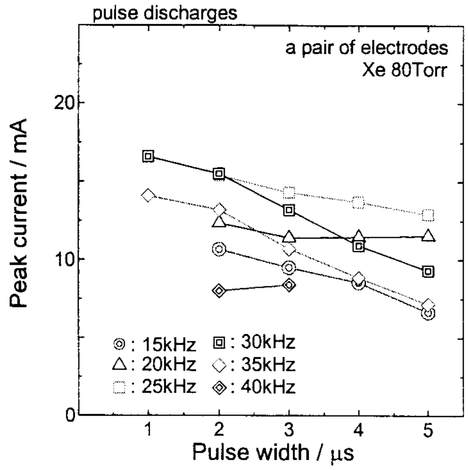


Fig.6 The peak current of the single pair electrodes lamp at the mode change boundary when pulse width and frequency are varied.

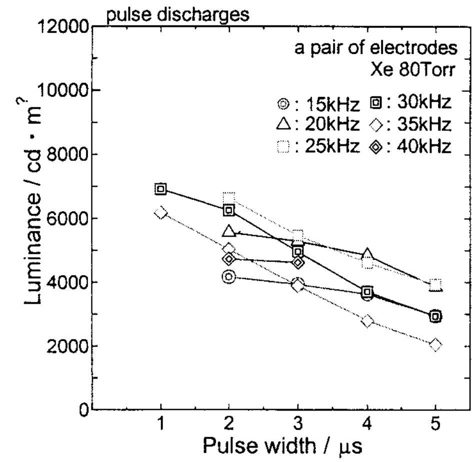


Fig.8 The luminance of single pair electrodes case at the mode change boundary when pulse width and frequency are varied.

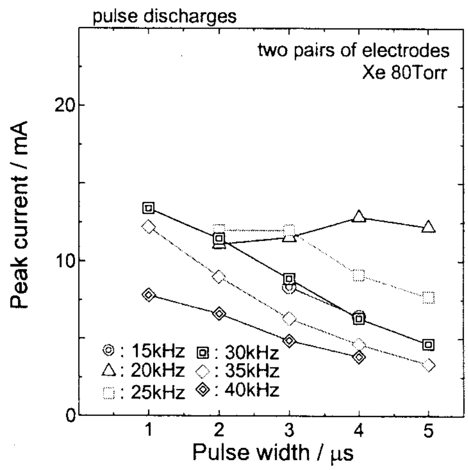


Fig.7 The peak current per one discharge path of the two pairs of electrodes lamp at the mode change boundary when pulse width and frequency are varied.

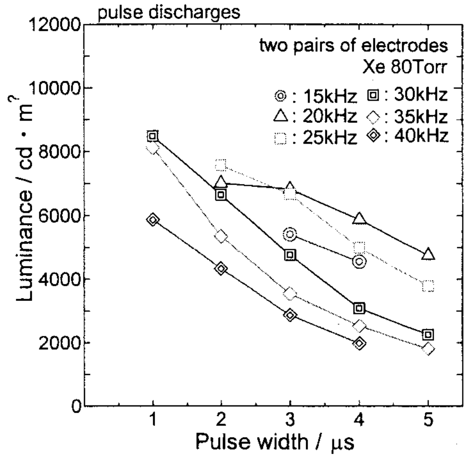


Fig.9 The luminance of two pairs electrodes case at the mode change boundary when pulse width and frequency are varied.

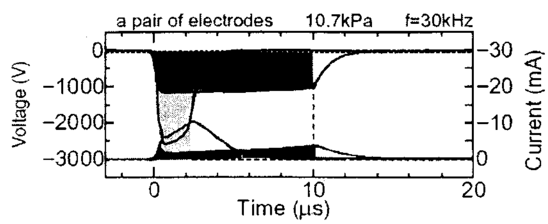


Fig.10 The peak current per one discharge path at the mode change boundary when pulse width and frequency are varied.

Here let us focus on the specific energy E_i defined as follows. The energy input into the lamp between the ignition (a exsample of this period is shown in Fig. 10.) and the current peak in one cycle, we call this energy as initial energy E_i versus pulse width under the condition in which the energy E_i, is at the upper limit to maintain diffused positive column is shown in Fig.11. As shown in this figure, the energy E_i is almost constant against pulse width.

We observed the results that as the pulse width becomes shorter, both lamp voltage and current increase with same E_i . As the voltage, that is electric field, increases, direct ionisation becomes dominant and metastables are not populated due to decrease in stepwise ionisation populating metastables, and also electron temperature becomes too high to occur volume recombination due to high field. The numerical simulation done by authors tells positive column constriction is caused by increasing in volume recombination rate[3]. Short pulse causing higher electron temperature prevents volume recombination and this is the one of the ways to avoid positive column constriction and to achieve higher luminance.

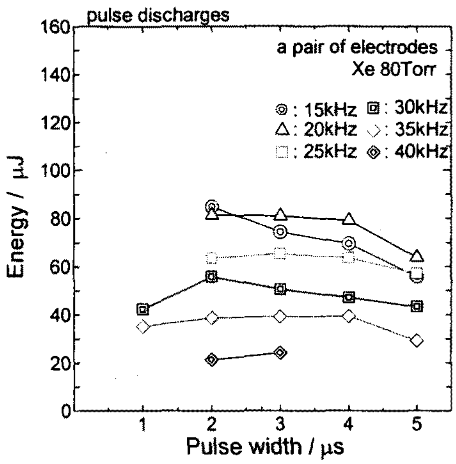


Fig.11 The peak current per one discharge path at the mode change boundary when pulse width and frequency are varied.

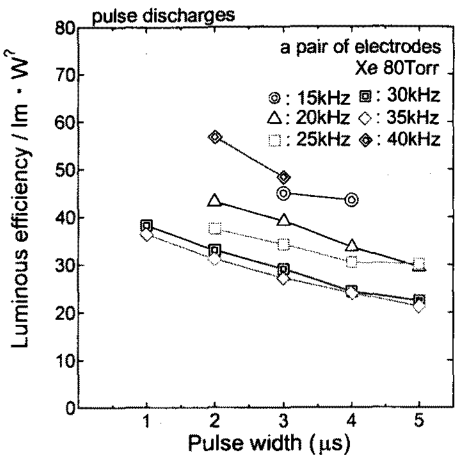


Fig.12 The luminous efficacy versus pulse width of the single pair electrodes lamp at the mode change boundary when pulse width and frequency are varied.

Figs. 12 and 13 shows luminance efficacy versus pulse width. These figures shows as the pulse width decreases, the efficacy increases. By using two pairs of electrodes, the efficacy drops comparing with the lamp with single pairs of electrodes. However, as shown in Figs.8 and 9, luminance increases. So, luminous flux increases by using two pairs of electrodes.

By using two pairs of electrodes, at the best condition we made, we have achieved high efficacy of 50 *l*m/W and high luminance of 9000 cd/m^2 simultaneously.

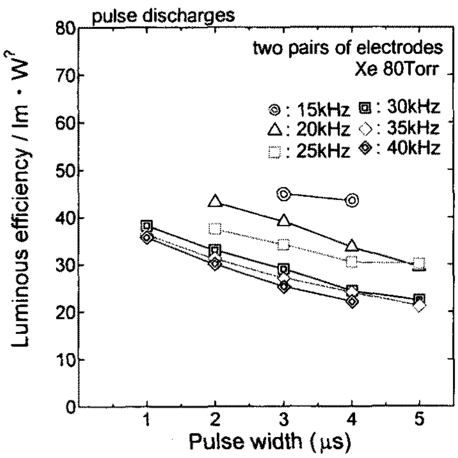


Fig.13 The luminous efficacy versus pulse width of the two pairs electrodes lamp at the mode change boundary when pulse width and frequency are varied.

4. Conclusion

By using multi pairs electrode style, Xe discharge fluorescent lamp has achieved high efficacy of 50 *l*m/W and high luminance of 9000 cd/m^2. Though there are still some issues such as high operational voltage and electrical noise due to pulsed operation, this type of lamp has a potential to replace and to drive away conventional argon-mercury fluorescent lamps for general lighting in future.

Acknowledgements

Part of this work was done as master and bachelor project by Messrs Kazuya Nomoto and Kenjiro Toryuu. The authors would like to thank to them.

Reference

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