Three-Dimensional Simulations of Patterned Electrodes in Mercury-Free Flat Fluorescent Lamps

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***Abstract*—The effect of patterned electrodes in Hg-free flat fluorescent lamps is investigated by using 3-D fluid simulations. The visualization of $Xe^*(^3p_1)$ density profiles is important to observe the efficiency dependence on the 3-D electrode shapes. The luminous efficiency of the patterned-electrode models increases about 20% as compared with that of the reference model because of the reduction of power consumption.**

***Index Terms*—Flat fluorescent lamp, fluid model, patterned electrode.**

THE LIQUID-CRYSTAL displays need a back-light source, because they are not a self-emissive device unlike plasma display panels (PDPs). The flat fluorescent lamps (FFLs) without mercury are one of the candidates for the next-generation back-light source for the green-display devices [1]. The understanding of plasma dynamics in FFL cells is coupled to improving the efficiency. The visualization through numerical simulations is very useful for the study of plasma-discharge behaviors, which are difficult to obtain from experiments and suggestion of the new FFL cell structure with high efficiency [2]. In particular, the 3-D fluid simulations provide the effect of 3-D geometrical factors, such as the shape of electrodes and barrier ribs. Because patterned electrodes can obtain the low firing and driving voltage, as well as the wide and long discharge path, it is important to design adequate patterned electrodes to achieve the high luminous efficiency [3]. We present the $Xe^*(^3p_1)$ density profile and visible-light distribution with respect to the various patterned electrodes.

Our 3-D fluid model solves the continuity equations, momentum transfer equations in the drift-diffusion approximation, and Poisson's equation for electric potential in order to describe the plasma dynamics and behaviors of species [4]. The total visible light is the product of visible photon flux and energy. Therefore, the visible light is dominantly related to the amount of excited species which can generate the UV photons converted at the phosphors. We check the $Xe^*(^3p_1)$ density which is dominant in low Xe content. The luminous efficiency is defined as the ratio of total visible light and external energy loss on conductors.

The reference model in Hg-free FFLs is similar to the conventional model of PDPs except for the cell size and the number of electrodes. The sustain electrodes are formed underneath the lower dielectric layer. The cell length is 12.0 mm, and height is 3.7 mm. The gap distance d between the sustain electrodes and the length l of each sustain electrode are 2 mm and 3 mm, respectively. The injected gas is Ne 90% and Xe 10% at 100-torr gas pressure. The square pulses of 500 V and 100 kHz are applied to the sustain electrodes.

Fig. 1(a)–(d) shows the side- and top-views of $Xe^*(^3p_1)$ density in the reference model and three proposed models. The $Xe^*(^3p_1)$ density profile is changed by the pattern of the sustain electrodes [Fig. 1(b)–(d), top-view]. Because the gas discharge is mainly generated in a small region between the sustain electrodes, discharge uniformity of the T- and Pi-shape models is not good. In the ladder-shape model, the $Xe^*(^3p_1)$ is distributed in the cell space that is comparable to the reference model. Fig. 1(e)–(h) shows the emitted visible-light distribution through the top window. The proper patterned-electrode model has the uniform emitted-light distribution and the small electrode area [Fig. 1(h)]. The luminous efficiency of the ladder-, T-, and Pi-shape models increases by about 15%, 20%, and 30% as compared to that of the reference model, respectively [Fig. 1]. This enhancement of efficiency is attributed to the reduction of the unnecessary electrode area. New proposed model, interlocked-shape model, which is designed for high uniformity of the $Xe^*(^3p_1)$ density, is the asymmetric electrode type [Fig. 2]. An interlocked-shape model, which has the bigger center electrode than the side electrode by about 1.5 times, shows the good discharge uniformity. If the interlocked-shape model has the proper thickness ratio of the center and side electrodes, we can utilize the whole cell space for the discharge and obtain high luminous efficiency and low power consumption.

In conclusion, we investigated the effect of patterned-electrode models and suggested a new electrode shape model for high luminous efficiency in Hg-free FFLs by using 3-D fluid simulations. We can improve the utilization of cell space for discharge and reduce the power consumption by various patterned-electrode models. The role of patterned-electrode parts (front, middle, and end) should be considered to design the optimum patterned-electrode models.

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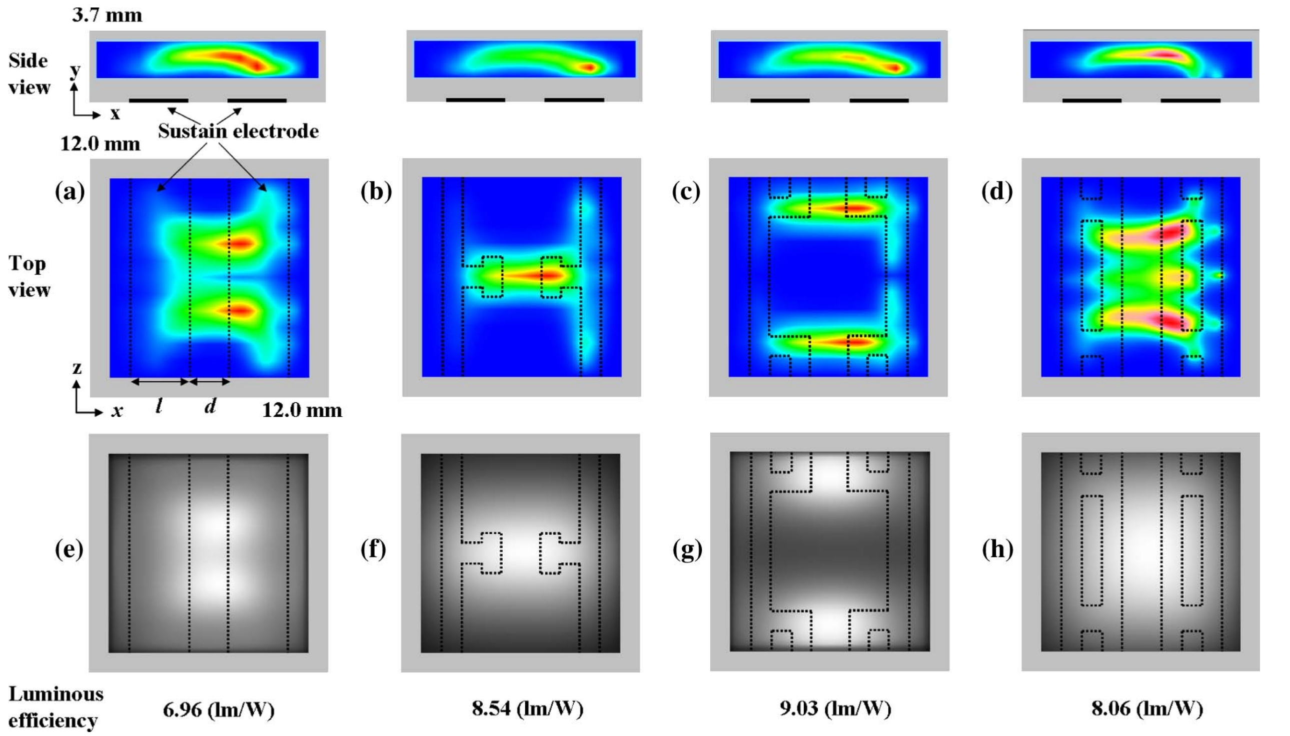

Fig. 1. Side- and top-views of $Xe^*(^3p_1)$ density in (a) reference model, (b) T-, (c) Pi-, and (d) ladder-shape models, and the total light distribution in (e) reference model, (f) T-, (g) Pi-, and (h) ladder-shape models.

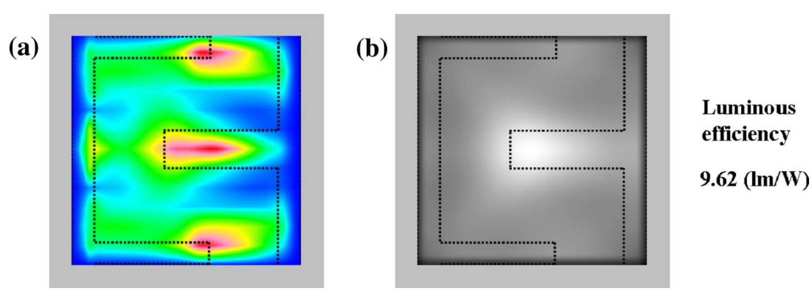

Fig. 2. (a) $Xe^*(^3p_1)$ density profile and (b) total light distribution in the interlocked-shape model.

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