

Study on Charged Particle Distribution According to Dielectric Thickness Variation in a DBD Cell Using 2D Simulation

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ABSTRACT - Various studies are underway to improve the characteristics of Dielectric Barrier Discharge (DBD) cells. Given that the internal dielectric layer plays a pivotal role in DBD cells, continued analytical research on this component is essential. This paper investigates the distribution characteristics of charged particles in relation to variations in dielectric thickness using two-dimensional simulations. First, the luminance and luminous efficacy corresponding to different dielectric thicknesses are calculated; subsequently, the extent of charged particle diffusion is analyzed to identify the underlying causes. While increasing the dielectric thickness reduces both luminance and power consumption, it leads to a broader distribution of charged particles, which can enhance the luminous efficacy of the DBD cell.

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I. INTRODUCTION

Extensive research is being conducted to improve the characteristics of Dielectric Barrier Discharge (DBD) cells. A key feature of DBD is its ability to generate non-equilibrium plasma conditions through a much simpler method compared to other techniques, such as low-pressure discharge, high-speed pulsed high-voltage discharge, or electron beam injection. Thanks to this characteristic, DBD technology is applied in various critical fields—including industrial ozone generation [1], pollutant control [2], plasma-enhanced chemical vapor deposition and surface activation [3], excimer lamp operation, and, more recently, surface modification of diverse materials [4]—with Plasma Display Panels (PDPs) representing the most commercially successful application [5,6].

In this paper, we investigate the distribution characteristics of charged particles in a DBD cell as a function of dielectric thickness using two-dimensional simulation. We first calculate the luminance and luminous efficacy based on the dielectric thickness, then analyze the resulting distribution patterns of internal charged particles to identify the underlying mechanisms. Although increasing the dielectric thickness reduces both luminance and power consumption, the resulting broadening of the charged particle distribution can enhance the luminous efficacy of the DBD cell.

II. Simulation model and results

Figure 1 illustrates the cell structure used in the simulation, and Table 1 lists the specifications of the test panel. The simulation employed is a two-dimensional fluid model comprising the continuity equation, the drift-diffusion approximation for the momentum conservation equation, and Poisson's equation. In the simulation, Ne and Xe are set as static background gases; the particle species considered include electrons, Ne^+ , Xe^+ , Xe_2^+ , Ne_2^+ , NeXe^+ ions, as well as excited-state particles such as $\text{Xe}^*(^3\text{P}_1)$, $\text{Xe}^*(^3\text{P}_2)$, $\text{Xe}_2^*(\text{O}_u^+)$, $\text{Xe}_2^*(^1\Sigma_u^+)$, $\text{Xe}_2^*(^3\Sigma_u^+)$ and Xe^{**} , etc. The Local Field Approximation (LFA) was used to calculate electron collision rate coefficients. [7–10] To model the address electrode, a voltage equal to half of the firing voltage and sustain voltage is applied as the boundary condition for that electrode. However, since it is not feasible to simulate every cell in the panel, the simulation is performed on a single cell. Therefore, to determine whether the discharge reaches a steady state, the firing voltage is measured by applying successive pulses; the minimum voltage at which a steady state is achieved is defined as the firing voltage. For the sustain voltage measurement, the firing voltage is first applied between the two sustain electrodes; subsequently, the voltage of the following pulse is measured while verifying whether the subsequent waveform can maintain the discharge. The minimum voltage at which the subsequent discharge reaches a steady state is taken as the sustain voltage. The frequency of the applied pulse used in the simulation is 50 kHz. [11]

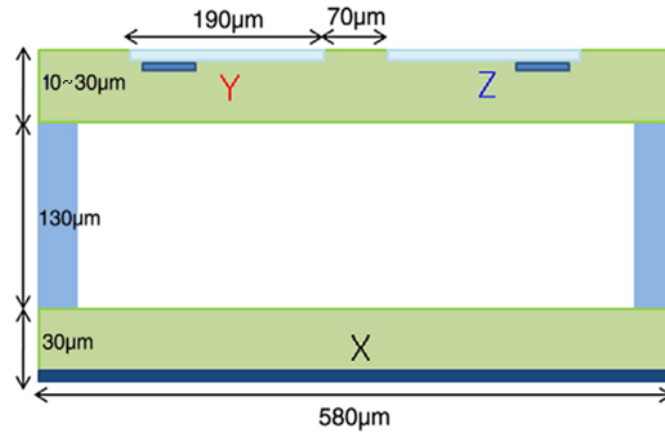
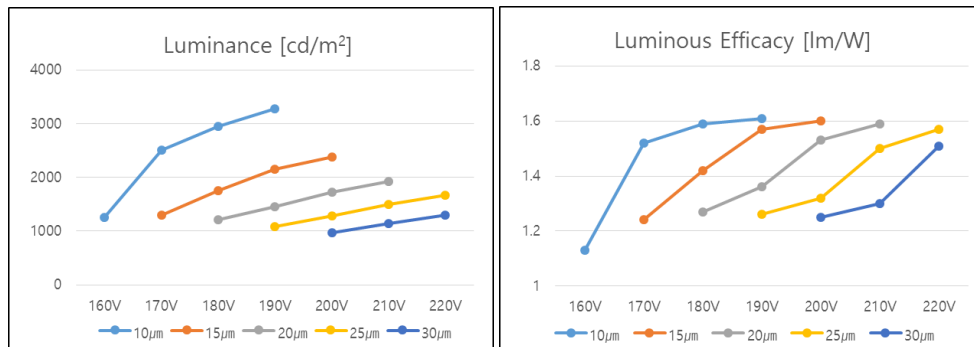


Figure 1: Cell structure used in the simulation

Figure 2 shows the changes in luminance (a) and luminous efficiency (b) according to dielectric thickness. Simulation results indicated that the sustain voltage increased by approximately 10 V for every 5 μm increase in dielectric thickness. As the dielectric layer becomes thicker, the effective electric field applied to the surface wall charges weakens, necessitating a higher sustain voltage. A DBD cell with a dielectric thickness of 30 μm exhibited a 21.8% decrease in luminance compared to a cell with a thickness of 10 μm . However, luminous efficiency increased by 9%, resulting in a 27.6% reduction in power consumption. In other words, while increasing the dielectric thickness reduces luminance due to decreased light generation from the gas discharge, it also lowers the plasma density within the DBD cell, thereby reducing discharge current and power consumption and ultimately improving luminous efficiency.

Table 1: Cell specification of the test panel.

Front panel		Rear panel	
ITO electrode width	190 μm	Address (Ag) electrode width	100 μm
Electrode gap	70 μm	Dielectric thickness	30 μm
Bus (Ag) electrode width	80 μm	Barrier rib height	130 μm
Dielectric thickness	10, 15, 20, 25, 30 μm	Barrier rib width	25 μm
		Phosphor (green) thickness	30 μm
Working gas		Ne(92%)+Xe 8%	
Gas pressure		400 Torr (53.3 kPa)	
Cell size		580×190 μm^2	



(a) Luminance

(b) Luminous Efficacy

Figure 2: Variation of luminance (a) and luminous efficacy (b) as a function of dielectric thickness

To analyze the causes of the aforementioned results, Figure 3 illustrates the changes in light emission at wavelengths of 147 nm, 150 nm, and 173 nm as the dielectric thickness varies. Figures 3(a) and (b) show cases with dielectric thicknesses of 30 μm and 10 μm , respectively; simulations were conducted for each thickness under sustain voltage conditions of 160 V and 200 V. The values were calculated by integrating the amount of light emitted from the start of a cycle until the discharge ended, and the sum of these values is proportional to the resulting luminance. When the dielectric thickness was 30 μm , the amount of light generated by ultraviolet radiation at wavelengths of 147 nm, 150 nm, and 173 nm decreased to 30%, 37%, and 32% of the levels observed with a 10 μm thickness, respectively. This indicates a reduction in the amount of plasma and vacuum ultraviolet (VUV) radiation generated, resulting in simultaneous decreases in discharge current, power consumption, and luminance.

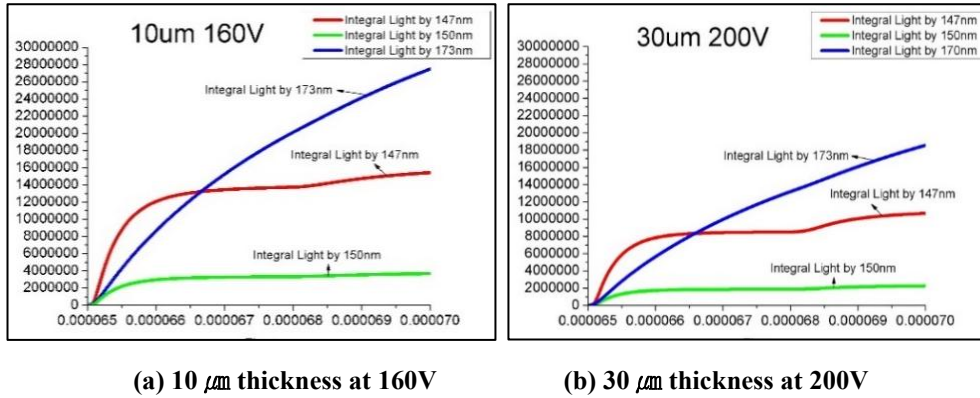


Fig. 3. Variation of the light by 147 nm, 150 nm, 173 nm as a function of dielectric thickness

Figure 4 illustrates the variation in $\text{Xe}^*(^3\text{P}_1)$ and $\text{Xe}^*(^3\text{P}_2)$ densities according to dielectric thickness. Point A was designated as the onset of the discharge and point D as the time of peak discharge, while points B and C were defined as the 15% and 50% marks of the time interval between A and D, respectively. The density distributions of $\text{Xe}^*(^3\text{P}_1)$ and $\text{Xe}^*(^3\text{P}_2)$ were simulated for each of these time points and dielectric thickness conditions. An examination of the Xe^* density distributions at each time point reveals that the distribution is broader when the dielectric thickness is 30 μm compared to 10 μm . As the discharge progresses, Xe^* diffuses throughout the entire DBD cell. Consequently, with a dielectric thickness of 30 μm , the luminance decreases due to a reduction in the amount of plasma, but luminous efficiency increases as the plasma diffuses across the entire cell area.

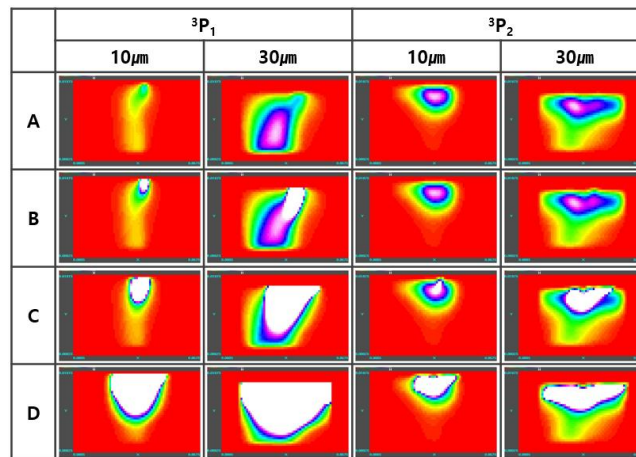


Fig. 4. Variation of the density of $\text{Xe}^*(^3\text{P}_1)$ and $\text{Xe}^*(^3\text{P}_2)$ as a function of dielectric thickness

III. DISCUSSION AND CONCLUSION

In this study, we investigated the luminance, luminous efficiency, and the underlying mechanisms by varying the dielectric layer thickness of a DBD cell from 10 μm to 30 μm . As the dielectric thickness increased, the plasma density generated within the DBD cell decreased, resulting in a reduction of both luminance and power consumption. However, it was observed that increasing the dielectric thickness led to the diffusion of Xe^+ across the entire DBD cell area, thereby enhancing luminous efficiency.

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