The analysis of neutral particle in Mercury discharge lamp

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Abstract - In this paper, we introduced a LIF measurement method and summarized the theoretical side. When an altered wavelength of laser and electric power, lamp applied electric power, we measured the relative density of the metastable state in mercury after observing a laser induced fluorescence signal of 404.8nm and 546.2nm, and confirmed the horizontal distribution of plasma density in the discharge lamp.

The results confirmed the resonance phenomenon regarding the energy level of atoms along a wavelength change, and also confirmed that the largest fluorescent signal in 436nm, and that the density of atoms in 546.2nm ($6^3S_1 \rightarrow 6^3P_2$) were larger than 404.8nm ($6^3S_1 \rightarrow 6^3P_1$). According to the increase of lamp applied electric power, plasma density increased, too. When increased with laser electric power, the LIF signal reached a saturation state in more than 2.6mJ. When partial plasma density distribution along a horizontal axis was measured using the laser induced fluorescence method, the density decreased by recombination away from the center.

1. Introduction

The electron plays an important role in the generation and maintenance of plasma mentioned above, in addition, the most important elements to participate the process are ions and neutral particles. Recent studies on these particle have become the focus of attention because the characteristics of plasma can be configured by these particles. Therefore, a LIF method has the merit that it is able to selectively identify most situations, including a ground state, which is principally possible. In practice, it has limitations in optical devices to configure a practical device, such as the performance of a laser. In recent years, the usability of the LIF method has been proved in various fields owing to the development of a particular laser, which has a high standard of safety and precision, and the merits of this laser have been highlighted in the measurement of neutral particles or ions for the plasma used in the process of display, or semiconductor industries [1][2].

This paper introduces a LIF method, and examines the theoretical aspects of this method. In addition, a device for this LIF method was configured to measure the relative density of mercury under a metastable state by varying the wavelength of the laser, applied power to the lamp. The spatial distribution of the plasma was also investigated by varying the distance from the central axis of the lamp. .

2. Experiments

A LIF (Laser Induced Fluorescence) method excites incident energy beams, which has a wavelength equal to the transition energy (E=hv) of an atom or molecule, and then observes the radiation of fluorescence when the atom or molecule returns to a lower state of energy. This LIF method can generate resonance for a lower energy level of a molecule, and can apply a certain measurement at a lower density state (below $10^{-8}cm^{-3}$) because it can generally obtain a large and sensitive signal. In addition, this method can apply a measurement selectively for a different kind of object without certain interferences. Moreover, the small beam spot of the laser generated through this method presents a highly specified time and spatial resolution. Fig. 1 illustrates a conceptual diagram of the energy level of mercury at a metastable state at the wavelengths of 546.2nm ($6^3S_1 \rightarrow 6^3P_2$) and 404.8nm ($6^3S_1 \rightarrow 6^3P_1$), which are excited using the laser of 436.0nm ($6^3P_0 \rightarrow 6^3S_1$), by applying the LIF mehtod [3].

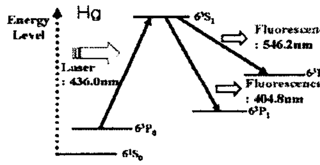
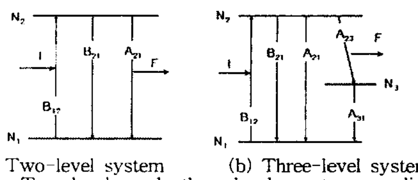


Fig. 1 Energy level diagram of mercury using a laser induced fluorescence method

Fig. 2 presents the basic principle of a LIF method using an equation where the relative relationship between the fluorescence signal and the plasma density, which is caused by the application of a LIF method, by understanding the transition between the energy levels in an atom or molecule. Eq. (1) presents the change in the state density of a level system as shown in Fig. 2 (a) and (b).

$$\frac{dn_2}{dt} = -\frac{dn_1}{dt} = \frac{I(\nu_0)}{c} g(\nu_0)(B_{12}n_1 - B_{21}n_2) - A_{21}n_2 \qquad (1)$$

where c is the speed of light, n1 and n2 are the state density for each energy level, and B_{12}, B_{21}, A_{21}, A_{23}, and A_{31} are Einstein constants for the conditions of absorption, induction, and natural emission. In addition, $g(\nu_0)$ means a line profile, and is assumed as a normalized condition, and ν_0 presents the frequency of incident laser. The solution of Eq. (1) at a metastable state can be expressed as Eq. (2).



(a) Two-level system (b) Three-level system

Fig. 2 Two-level and three-level system applied to the LIF method

$$n_2 = \frac{g_2 n}{(g_1 + g_2)} \cdot \frac{S}{(S+1)} \quad (2)$$

where g1 and g2 are the statistical weight for the level 1 and 2, respectively. S is a saturation parameter, and can be defined as Eq. (3).

$$S == I(\nu_0)\frac{g_1 + g_2}{g_1} \cdot \frac{c^2}{8\pi h \nu_0^3} g(\nu_0) \quad (3)$$

where

$$n = n_1 + n_2$$

and

$$g_1 B_{12} = g_2 B_{12} = g_2 A_{21} c^3 / 8\pi h \nu^3.$$

In addition, a fluorescence signal per hour when the transition is performed from the state density of n2 described in the equation mentioned above to the state density of n1 as follows.

$$F = \frac{\Delta\Omega}{4\pi} V n_2 A_{21} = Kn$$
$$K = \frac{\Delta\Omega}{4\pi} \frac{g_2}{g_1 + g_2} \frac{S}{1+S} \quad (4)$$

where $\Delta\Omega$ is a solid angle, which detects a fluorescent signal, V is the volume of fluorescent radiation that is actually defined by the solid angle and diameter of the laser beam. It is evident that the fluorescent signal is proportional to the density of n. The change in the state density of dn1/dt, dn2/dt, and dn3/dt for the three-level system as presented in Fig. 2 (b) can also be calculated the same as that shown in Eq. (1). Because the Einstein coefficient can only be changed when the fluorescent signal is changed from n2 to n3, the factor of F can be expressed as $\Delta\Omega/4\pi V n_2 A_{23}$. This experiment used a three-level system, which can detect a different wavelength from the wavelength of incident laser beam [3].

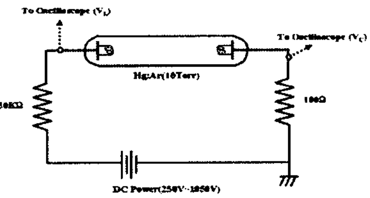


Fig. 3 Configuration of the discharge lamp used in this experiment

The external and internal diameters of the discharge tube used in this experiment were 25mm and 23mm, respectively. The inside of the discharge tube was filled with 1 Torr and 99.999% purity of argon gas as a buffer gas, and amalgam was inserted as a major medium to radiate UV. The voltage applied in the experiment was DC 250V~1,050V, and an external resistor of 50KΩ was also connected to limit the current as presented in Fig. 3, where a resistor of 100Ω was used to measure the current.

The LIF experiment consists of a laser preparation process, plasma generation process, and measurement process. The laser used in this experiment consisted of a Nd:YAG laser (LQ 829) and OPO (Optical Parametric Oscillator, OPO 483), in which the Nd:YAG laser plays a role as a pump, and has a very narrowed linear width, which is required for the LIF experiment.

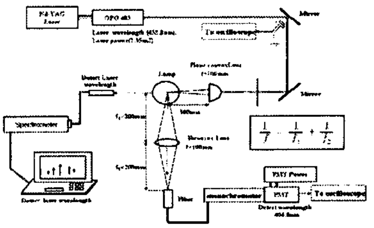


Fig. 4 Configuration of the experiment using a LIF method

The light radiated from the Nd:YAG laser generates a type of pulse laser, which has an on-time of 10nsec and high peak power of 10Hz, through a Q-switching. therefore a biconvex lens was used to measure a fluorescence signal owing to use a LIF method where a distance applied to the measurement was controlled using the equation of the lens, such as $\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$. In the case of the fluorescence signal, a monochrometer was used to detect the wavelength of 546.2nm ($6^3S_1 \rightarrow 6^3P_2$) and 404.8nm ($6^3S_1 \rightarrow 6^3P_1$), and the detected signal was amplified using a PMT. Then, the signal was measured using an oscilloscope. The wavelength of the laser was measured using a spectrometer (S150HR), and the power of the laser was measured using a power meter [4][5].

3. Results and considerations

In order to verify the resonance of the energy level based on the wavelength of 436nm, the laser induced fluorescence signal was investigated by varying the applied wavelength of laser from 435.8nm to 436.2nm with an interval of 0.1nm. The power of laser was maintained as a constant value of 2.33mJ, and the power was maintained by about 1.96W with the applied voltage of 255V, and current of 7.697mA when the applied voltage of the lamp was fixed at 650V.

As a result, the largest fluorescence signal appeared at 436nm as illustrated in Fig. 5, and the larger fluorescence signal was detected at 546.2nm rather than that of the wavelength of 404.8nm.

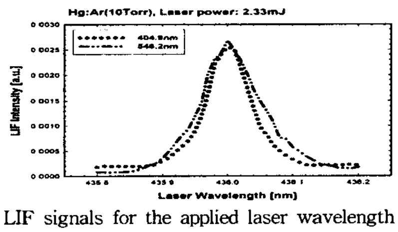


Fig. 5 LIF signals for the applied laser wavelength

Similar to the energy level of mercury, the relative density of atoms or molecules, which corresponded to the wavelength of 404.8nm ($6^3S_1 \rightarrow 6^3P_1$) and 546.2nm ($6^3S_1 \rightarrow 6^3P_2$), was measured by varying the applied voltage to the lamp based on the wavelength of 436nm because the largest fluorescence signal was measured at 436nm. The applied voltage to the lamp was varied from the minimum voltage of 250V to the maximum voltage of 1,050V with an interval of 100V in order to maintain the plasma, and the power of the laser was maintained at a constant value of 2.33mJ. The density of the plasma was measured under these conditions. The values of V_L and V_C were measured using an oscilloscope as shown in Fig. 3, and the current and power were also measured. As a result, the laser induced fluorescence signal linearly increased according to the increase in the applied voltage to the lamp as illustrated in Fig. 6. Thus, the number of excited atoms or molecules relatively increased according to the increase in the applied power to the lamp. The density of plasma also increased.

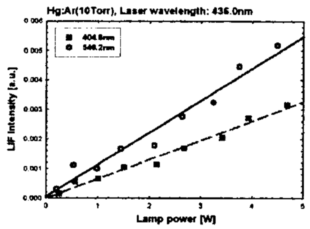


Fig. 6 LIF signals for the applied lamp power

Fig. 7 presents the results of the saturation test on the plasma according to the applied power of the laser. The laser induced fluorescence signal was measured at the wavelength of 404.8nm (6^3S_1-6^3P_1) and 546.2nm (6^3S_1-6^3P_2) by increasing the power of the laser at 436nm as presented in Fig. 6.

The power of the laser was measured using a power meter, and the power consumption was about 2.1W when the applied voltage to the lamp was 650V. When the saturated parameter was expressed as S<<1 as presented in Eq. (3), the laser induced fluorescence signal was proportional to the value of $I(\nu_0)$, and the value linearly increased in this area according to the applied power of laser. However, in the case of the condition of S>>1, the signal approaches a saturation state, and fails to increase due to the increase in the laser output. Fig. 7 presents a saturation state, in which the power of laser exceeded more than 2.6mJ.

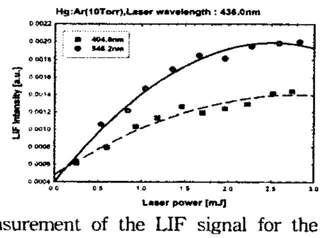


Fig. 7 Measurement of the LIF signal for the applied laser power

In order to examine the partial distribution of the density of plasma for the horizontal axis using a LIF method, the laser induced fluorescence signal was measured by moving the applied laser to the lamp from the center to the left and right at an interval of 1mm using the wavelength of 436nm of the applied laser. The power of the laser and applied power to the lamp were constantly maintained at 2.33mJ and 650V, respectively. In addition, the measurement was performed by removing the fluorescence signal due to the scattering of the glass of the discharge lamp according to each position. As a result, it is evident that the laser induced fluorescence signal decreased according to the increase in the distance from the center position. This was also verified in the decrease of the density of plasma due to the reunion of atoms or molecules on the surface area.

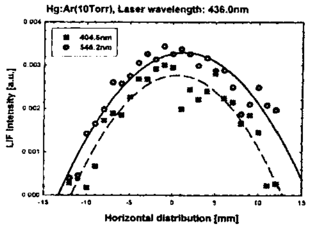


Fig. 8 Distribution of the plasma density at the horizontal axis of the discharge lamp

4. Conclusions

In order to investigate the resonance for the energy level of an atom or molecule based on the wavelength of 436nm, the results present the largest fluorescence signal at 436nm for the applied wavelength from 435.8nm to 436.2nm with an interval of 0.1nm. In addition, the density of atoms or molecules presents a larger value at the observed wavelength of 404.8nm (6^3S_1-6^3P_1) than that of 546.2nm (6^3S_1-6^3P_2). and the density of plasma increased when the relative density of atoms or molecules, which corresponded to 404.8nm (6^3S_1-6^3P_1) and 546.2nm (6^3S_1-6^3P_2), based on the wavelength of 436nm increased according to the increase in the applied power to the lamp.

The laser induced fluorescence signal presents a constant value due to the saturation of the applied power exceeded by 2.6mJ for the wavelength of 404.8nm (6^3S_1-6^3P_1) and 546.2nm (6^3S_1-6^3P_2) while the power of the wavelength for the 436nm laser increased. and the partial distribution of the density of plasma for the horizontal axis using a LIF method decreased in the density of ions and neutral objects due to the reunion according to the increase in the distance from the center point.

Acknowledgement

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