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Ray-trace analysis for improvement of spatial resolution in spectroscopy of microhollow cathode plasma
マイクロホローカソードプラズマの分光計測の高分解能化のための光線追跡シミュレーション

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For emission spectroscopy with high spatial resolution in a microhollow cathode plasma, we designed an optical observation system by means of a ray-tracing simulation. When we observe plasma emission spectra in microhollow cathode from the axial direction, emissions from atoms outside the microhollow cathode hinder the information from the inside. By using a spatial filter being composed of two aspheric lenses and a pinhole aperture, we numerically achieved a resolution of 0.7 mm of line-of-sight on the observation axis. Achieved resolution was expected to be sufficient to eliminate the emission from atoms outside the microhollow cathode.

1. Introduction

Recently, atmospheric pressure glow discharge plasma has been actively applied to environmental technologies and medical treatments. We have developed a high-density OH radical source by using a microhollow cathode discharge (MHCD) device operated in atmospheric pressure [1]. In order to make clear the relation between plasma parameters and reaction dynamics inside MHCD, we have performed spectroscopic measurements of the MHCD plasma emission and obtained spatially resolved spectra, whose line profile were distorted by the strong electric field inside the cathode. However, we found that the light emission from atoms outside the cathode hindered accurate measurements of spatially resolved spectrum inside the cathode [2]. To extract the emission from the hollow discharge plasma itself, we have to observe a spatially resolved spectrum along the observation axis, which is generally thought to be difficult in the passive spectroscopy.

In the present study, we designed an optical system to obtain the high spatial resolution in the line-of-sight direction by using a spatial filter and evaluated the quantitative resolution by performing a ray-tracing simulation.

2. Simulation

Schematic of the expected experiment is shown in Fig. 1(a). The microhollow cathode assembly is placed in a vacuum chamber. The cathode disk has an inner-hole diameter of 1.0 mm and a length of 2.0 mm. Visible emission emanating from the plasma is collected by an aspheric lens with a short focal length, and focused again with the same type lens onto a pinhole aperture. After passing through the pinhole, the light is fed into a high-resolution visible spectrometer. Because the focal point depends on the axial position of the light source, the intensity capable of passing through the aperture varies.

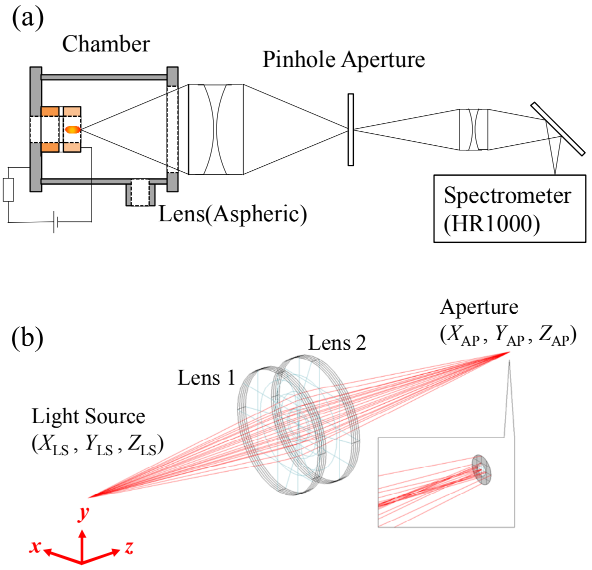

Fig.1. Schematic for spectroscopic observation of the MHCD (a), and three dimensional optical model used in the ray-tracing simulation (b).

In this study, we evaluated the intensity dependence on the position of light source by the ray-tracing. To this end, we used the optical design software CODE V®, and a part of results was checked by OpTaliX-LT®.

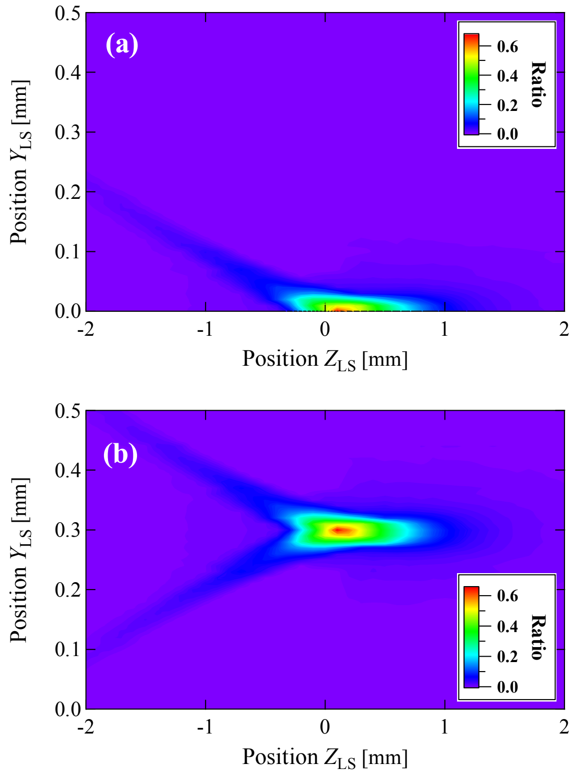

Fig.2. Two-dimensional maps of intensity of light from the light-source placed at (Y_{LS}, Z_{LS}) passing through the spatial filter with pinhole aperture placed at Y_{AP}=0.0 [mm] (a), and Y_{AP}=-0.3 [mm] (b). The axial position of the aperture Z_{AP} was adjusted to the focal point.

The optical model in consideration is shown in Fig. 1 (b). The wavelength was set to 486.2 nm, which is the wavelength of Balmer-β line of atomic hydrogen. Lenses 1 and 2 were aspheric lenses, having 75-mm diameter and 150-mm focal length (AL75150-A, THORLABS). The entrance pupil diameter (EPD) was set to 37.5 mm. The diameter of the pinhole aperture was optimized to 40 μm by considering the spot size at focal point.

We calculated the ratio of light passing through the aperture, depending on the position of light source (Y_{LS}: 0.00 ~ 0.50 mm, 0.01-mm step. Z_{LS}: -2.0 ~ 2.0 mm, 0.1-mm step). For the position of light source, we considered only a single plane surface (X_{LS}: 0.0 mm) because the light from other surface would be cut by the entrance slit of the spectrometer. The position of aperture (Y_{AP}, Z_{AP}) was fixed in Z-direction at the optimized focal point, but varied in Y-deirection for changing observation region.

3. Results and Discussion

Table I. FWHMs of the intensity of light varied by the light source position.

Aperture position Y_{AP}[mm]	FWHM on Y_{LS} [mm]	FWHM on Z_{LS} [mm]
0.0	0.04593	0.6724
-0.3	0.04602	0.6829

Two-dimensional intensity distribution maps of light passing through the spatial filter from various position of light source are shown in Fig. 2. The radiations from front and behind the observation regions were eliminated by the spatial filter. The FWHMs of the vertical and line-of-sight direction of spatial profile obtained by gaussian fitting are shown in Table I. Considering the results of Fig. 2 and Table I, we can observe vertical distribution of the spatially-resolved spectrum without loss of resolution only by changing the vertical position of the pinhole aperture. These results show a potential that we can achieve spatial resolution of 1 mm line-of-sight direction on the observation axis.

It is worth to mention that the shape of the tail of the distribution is asymmetric along the line-of-sight direction. In front of the observation region, the tail shows indistinct distribution, whereas the tail shows distinct lines behind the observation region.

4. Conclusion

We performed a ray-tracing simulation to develop the optical system having a high spatial resolution of line-of-sight direction. As a result, we obtained spatial resolution about 0.7 mm in line-of-sight direction with 0.05 mm in vertical direction by using spatial filter being composed of aspheric lenses and pinhole aperture. Obtained resolution is expected to be sufficient to be used for spatially-resolved spectroscopy of microhollow cathode plasma. Note that the vertical spatial resolution obtained here is the resolution of the spatial filter. In the emission spectroscopy, the spatial resolution is determined by the spot size of the light on the detection camera after the spectrometer, which may be better than the resolution obtained here.

References

[1] S. Namba, T. Yamasaki, Y. Hane, D. Fukuhara, K. Kozue, and K. Takiyama: J. Appl. Phys., **110**, 073307 (2011).

[2] L. Mastuoka, D. Maki, K. Yanagiya, S. Namba: The Papers of Technical Meeting on Plasma Science and Technology, IEE Japan, PST-14-21, pp. 13-17 (2014) [in Japanese].