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LOOKING BEHIND THE NEGATIVE GLOW PLASMA: ESTIMATING CATHODE SHEATH PARAMETERS BY END-ON OPTICAL EMISSION SPECTROSCOPY IN A GRIMM-TYPE GLOW DISCHARGE SOURCE

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Abstract. A series of optical emission spectroscopy measurements of the Ne I 520.389 nm line in the Grimm-type glow discharge in pure neon has been performed in parallel from two positions: 1. from the end of the discharge, in line with the discharge axis (end-on view) and 2. side-on cathode view, at the position of the maximum external electric field F_{max} in the cathode sheath (CS), close to the cathode surface. The results collected at various conditions (pressure, voltage, current, cathode materials) show a stable linear correlation between the side-on recorded Stark component shift $\Delta\lambda_s$ at the position of maximum field F_{max} in the CS, and the end-on recorded wings broadening characteristic features shift $\Delta\lambda_e$. The obtained linear coefficient can be used to estimate the maximum CS electric field F_{max} and the CS thickness d_c within a reasonable margin of uncertainty in a standard analytical Grimm-type glow discharge source with an end-on view available only.

1. INTRODUCTION

Standard optical emission spectroscopy (OES), through the utilization of the Stark effect, successfully complements other experimental and theoretical efforts to measure the electric field distribution in the glow discharge cathode sheath (CS) and model the discharge kinetics. Starting from the early OES results in hydrogen and helium, the latest development included heavier gases like neon and argon (Majstorović et al. 2013, Šišović et al. 2014, Ivanović et al. 2017, Vasiljević et al. 2017). Conventionally used analytical Grimm-type abnormal glow discharge (GD) source with plane cathode and hollow cylindrical anode adjacent to the cathode does not allow for direct physical or optical access to the CS region for field measurements. OES discharge observations are enabled from the end of the discharge only, collecting integral light both from the bright negative glow and deep-lying low-intensity cathode sheath. In this paper we use the convenience of our modified Grimm design with enabled both end-on and side-on view OES measurements, to systematically compare the characteristic wings broadening feature shifts in end-on spectra of the Ne I 520.389 nm spectral line with the side-on recorded profile at the position of maximum electric field F_{max} with clearly defined Stark shifted component. A verified correlation between end-on and side-on recorded profiles would enable in turn end-on determination of F_{max} in the CS and the entire CS reconstruction (electric field distribution $F(d)$ and CS thickness d_c) for the Grimm-type analytical GD sources with end-on optical observation available only. A full systematical study of this correlation is made on six neon and four argon neutral lines in Nedić et al., 2022, JAAS, DOI: 10.1039/D2JA00109H.

2. EXPERIMENTAL

A modified Grimm GD source, proposed by Ferreira et al. 1980, is improved and described in detail elsewhere (Kuraica et al. 1992, Majstorović at al. 2013, Šišović et al. 2014, Ivanović et al. 2017). It has a hollow brass anode with an 8 mm inner diameter, equipped with two parallel 16 mm long and 1.5 mm wide longitudinal slots. An exchangeable cathode sample, 18 mm long and 7.4 mm in diameter is mounted onto a water-cooled cathode holder and partially inserted into the hollow anode. This enables, besides the usual end-on view, optical observations from the side of the cathode right away from the cathode surface, and distinguishing the light emission from the cathode sheath from that originating from the negative glow. The fine-moving mechanical discharge holder allows for a spatial resolution of approximately 1/16 mm. The discharge is sustained in high-purity neon (99.999%) in the pressure range of 3-8 mbar. The light is collected by an achromatic lens (focal length 75.8 mm) and focused onto the entrance slit (2 mm in height and 20 μm width) of an Ebert-type Carl Zeiss PGS-2 monochromator (2 m focal length with reflection grating of 651 grooves/mm, blazed at 1050 nm). The OES system with reciprocal dispersion of 0.37 nm/mm in the second diffraction order introduces a Gaussian instrumental profile with the measured full width at half maximum (FWHM) of 0.013 nm. The resolved light is detected by a thermoelectrically cooled computer-driven Hamamatsu CCD camera (T = -10°C, 2068×512 pixels, 12 μm pixel size, S10140/10141 series).

3. RESULTS

Figure 1 shows the typical set of OES measurements of the Ne I 520.389 nm spectral line in this investigation: end-on recording (red line), and a series of five side-on recordings in the CS at different positions, starting from the largest Stark shift $\Delta\lambda_s$, i.e. the strongest electric field F_{max} (blue line) nearby cathode surface, and decreasing with the distance from the cathode towards the negative glow. The end-on recording, besides the strong negative glow unshifted line at λ_0, features a prominent red structure at the distance $\Delta\lambda_e$, originating from the superposition of Stark components in the CS under the integral influence of the electric field. On the other hand, the side-on spectra show a strong Stark-shifted component and a weak unshifted line, originating from the discharge protruded through the anode observation slot into a zero-field region.

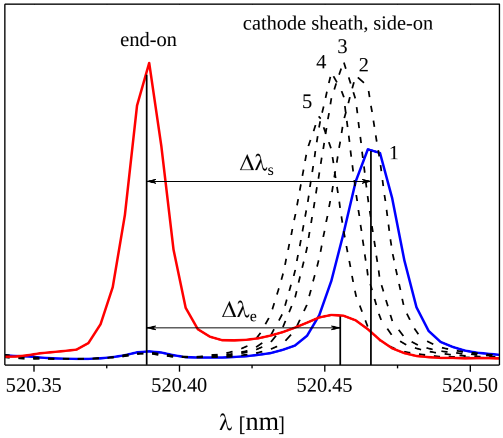

Figure 1. Ne I 520.389 nm spectral line recorded end-on (red line) and side-on in the CS at five different distances from the cathode (in 1/16 mm steps), starting from the maximum shift at F_{max} (blue line). Measured shifts, end-on $\Delta\lambda_e$, and side-on $\Delta\lambda_s$, are indicated.

The correlation between the side-on shifts $\Delta\lambda_s$ (at F_{max}) and end-on shifts $\Delta\lambda_e$ for the Ne I 520.389 nm spectral line is further investigated for various discharge conditions (voltage, current, pressure), with either tungsten or copper cathode. The results presented in Fig. 2 show that the $\Delta\lambda_s$ vs. $\Delta\lambda_e$ dependence appears linear, with the slope k = 1.100±0.020 for both employed cathodes.

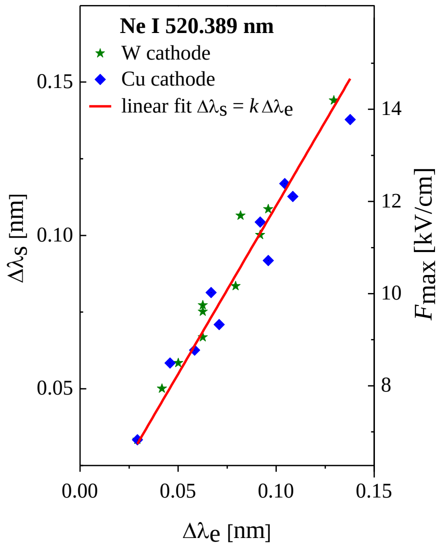

Figure 2. The side-on Stark shifts $\Delta\lambda_s$ (and corresponding F_{max}, Eq. 1) against the end-on Stark shifts $\Delta\lambda_e$ for the spectral line Ne I 520.389 nm. Each point represents different discharge conditions (pressure, current, voltage), with either tungsten or copper cathodes.

For small electric fields up to 14 kV/cm, Ivanović et al. 2017 have shown that Stark shifts of the side-on recorded Ne I 520.389 nm spectral line in the CS can be expressed as

$$\Delta\lambda_s = -\,\lambda_0^2\, C\, F^2 \tag{1}$$

where $C = -\,0.0238\ \mathrm{cm/kV^2}$ is a line-specific coefficient. The corresponding field strengths, ranging between 8 and 15 kV/cm, are also shown on the right-hand axis in Fig. 2. Therefore, a direct correlation between the end-on Ne I 520.389 nm spectra shifts $\Delta\lambda_e$ and maximum CS electric field F_{max} can be established:

$$F_{max} \approx \sqrt{-\frac{k}{C}\cdot\frac{\Delta\lambda_e}{\lambda_0^2}} \tag{2}$$

Having obtained the F_{max} in the CS, the CS thickness d_c as another important discharge parameter can be estimated using a suitable electric field distribution model (typically linear regression) and the value of applied voltage *U*.

4. CONCLUSION

We demonstrated the possibility of using the standard end-on view optical emission spectroscopy of the Grimm-type glow discharge source to learn more about the parameters of the low-intensity cathode sheath, “hidden” behind the bright negative glow plasma. For the Ne I 520.389 nm spectral line a stable linear correlation is found between the shifts $\Delta\lambda_e$ in end-on recorded characteristic line broadening features, and side-on measured Stark shifts $\Delta\lambda_s$, recorded at the position of the maximum electric field F_{max} in the cathode sheath.

Acknowledgment

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