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MEASUREMENT OF ELECTRIC FIELD DISTRIBUTION ALONG THE CATHODE SHEATH OF AN ABNORMAL GLOW DISCHARGE USING Ne I 556.277 nm LINE

N. V. NEDIĆ[1], N. V. IVANOVIĆ[2], Dj. SPASOJEVIĆ[1] and N. KONJEVIĆ[1]

[1]*University of Belgrade, Faculty of Physics, 11001 Belgrade, P.O. Box 44, Serbia*

[2]*University of Belgrade, Faculty of Agriculture, Nemanjina 6, 11080 Belgrade, Serbia*

Abstract. We present the results of an experimental study of the DC Stark shift of the Ne I 556.277 nm line in the cathode sheath region of an abnormal glow discharge in neon with traces of hydrogen. The electric field (of up to 13.4 kV cm^{-1}) is measured in the cathode sheath regionfrom the π-polarized profile of the hydrogen Balmer H_α line using the Stark polarization optical spectroscopy technique. The Ne I 556.277 nm line exhibits a quadratic Stark effect and the values of the coefficients, correlating its Stark shift and electric field strength, were determined. The results are in good agreement with the best-fit formula proposed by Jäger and Windholz indicating in this way that this spectral line can be used for the measurement of electric field strength in the cathode sheath region of an abnormal glow discharges with neon.

1. INTRODUCTION

Investigations of the DC Stark effect of neutral neon lines are numerous and a comprehensive review of relevant publications until 1976 were reported in Ryde (1976). Since then, several authors continued experimental (Jäger and Windholz 1984, Windholz and Neureiter 1988, Jäger et al. 1989) and theoretical (Ziegelbecker and Schnizer 1987) studies of Ne I lines in visible and near UV spectral regions at different electric field strengths, *E*. Recently, Ne I Stark effect studies have been directed towards lower *E* values in experiments carried out in the cathode sheath (CS) region of the Grimm-type glow discharge (GD), using optical emission spectroscopy (OES) with a CCD for spectral lines recording (Majstorović et al. 2013, Šišović et al. 2014). The Stark shift of the studied Ne I line has to be precisely measured in discharge with the distribution of *E* measured by other means (e.g. here from the Stark shifts of the hydrogen Balmer H_α spectral line). In this work, the axial distribution of *E* in the CS is determined in an abnormal glow discharge operated in neon with a small admixture of hydrogen using OES and the Lo-Surdo technique (Ryde 1976, Majstorović et al. 2013) applied to the Ne I 556.277 nm spectral line. The results are compared with those obtained using the

Ne I 520.390 nm spectral line, demonstrated in Ivanović et al. (2017) to be reliable for the measurement of electric field strength.

2. EXPERIMENTAL

In our study, a gas mixture of neon and 0.8% hydrogen is used as the working gas. A modified glow discharge source was laboratory-made after the Ferreira et al. design (Ferreira et al. 1980) described in detail elsewhere (Majstorović et al. 2013, Šišović et al. 2014, Kuraica et al. 1992). Hollow anode (30 mm long with 8 mm inner diameter) has a longitudinal slot (16 mm long and 1.5 mm wide) that serves for side-on observations along the discharge axis. The water-cooled cathode holder has a wolfram electrode (18 mm long and 7.40 mm in diameter) tightly screwed into its holder to ensure good cooling.

Spectroscopic observations of the so-called Grimm GD were performed side-on through an anode slit in translation steps of approximately 1/16 mm. For the H_α experiments, the radiation from the discharge was polarized by a polarizer before entering the spectrometer.

The radiation from the discharge is focused with an achromatic lens (focal length 75.8 mm with unity magnification) through the polarizer onto the 20 μm entrance slit (height restriction 2 mm) of the 2 m focal length Ebert-type spectrometer with 651 g mm^{-1} reflection grating blazed at 1050 nm. For the line shape measurements, the reciprocal dispersion of 0.37 nm mm^{-1} is used throughout this experiment. All spectral measurements were performed with an instrumental profile very close to a Gaussian with the measured full width at half maximum (FWHM) of 8.2 pm in the second diffraction order. Signals from the CCD detector (1 x 3648 pixels, 8 μm pixel width) are collected and processed by a PC.

3. RESULTS

The distribution of the electric field strength in CS region was determined from the π-polarized H_α line profiles by the method explained in (Ivanović et al. 2017).

In Figure 1, we show the profile of the spectral line Ne I 556.277 nm observed at five different axial positions along the discharge axis. The spectral line shapes, recorded in CS region at four distances *d* from the cathode surface, are shown in panels a)–d), and the line shape recorded in the negative glow, panel e).

On the blue and red wings of the examined spectral line, there are two spectral lines, Ne I 556.244 nm and Ne I 556.305 nm, which behave similarly to the Ne I 556.277 nm line in the presence of the electric field. Their relative intensity is low and they have not been analyzed.

The Stark shifts of the Ne I 556.277 nm line were measured relative to the unshifted peak of the W I 370.792 nm line whose profile from the third diffraction order appears in the recorded spectra near the profiles of the studied Ne lines from the second diffraction order, see Figure 1. In the fitting procedure of the experimental Ne I 556.277 nm spectral line profiles,we employed the model function:

$$I_{mod}(\Delta\lambda;\Gamma) = \Im * \left[G(\Delta\lambda; H_{Ne}, c_{Ne}, w_{Ne}) + G(\Delta\lambda; H_W, c_W, w_W) \right] + b \quad (1)$$

where $\Delta\lambda$ is the wavelength shift from the line center, Γ stands for the list $\{H_{Ne}, c_{Ne}, w_{Ne}, H_W, c_W, w_W\}$ of the model function fitting parameters, and b is the baseline level. The model function (1) is a sum of two Gaussians:

$$G(\Delta\lambda; H, c, w) = H \exp\left[-\left(2\sqrt{\ln 2}\, \frac{\Delta\lambda}{w} \right)^2 \right], \quad (2)$$

each specified by height *H*, center *c*, and FWHM *w*. In (1),* denotes the convolution with the instrumental profile $\Im$:

$$\Im = \frac{2}{w_{\text{inst}}} \sqrt{\frac{\ln 2}{\pi}} \exp\left[-\left(2\sqrt{\ln 2}\, \frac{\Delta\lambda}{w_{\text{inst}}} \right)^2 \right] \quad (3)$$

which is in our case the unit-area Gaussianof w_{inst}= 8.2 pm FWHM.

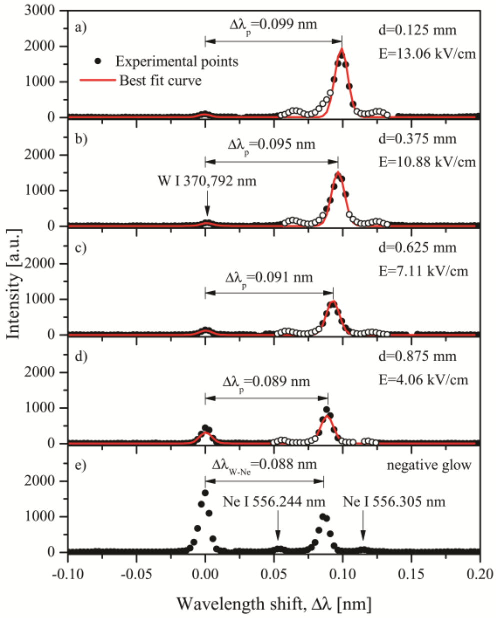

Figure 1: Experimental profiles of the Ne I 556.277 nm spectral line (dots) and their best-fit (red) curves obtained by the model function (1). Hollow experimental points were discarded in the fitting process.

The Stark shifts determined with the foregoing numerical procedure are presented in Figure 2. Our results, depicted by hollow points and red solid line, show reasonable agreement with Jäger and Windholz's prediction for the Ne I 556.277 nm line. The red solid line was obtained by the equation (4) given in Jäger and Windholz (1984), which in the case of small electric fields reduces to Ivanović et al. (2017).

$$\Delta\lambda = -\lambda_0^2 C E^2 \ , \quad (4)$$

where is $\lambda_0 = 556.277$ nm and $C = -0.0021$ kV^{-2}cm.

The Ne I 556.277 nm spectral line of neon was also observed in the cathode sheath region of an abnormal glow discharge with pure neon. Figure 3. shows the distributions of the CS electric field strength in the pure neon discharge obtained from observed profiles of the Ne I 556.277 nm and Ne I 520.390 nm spectral lines.

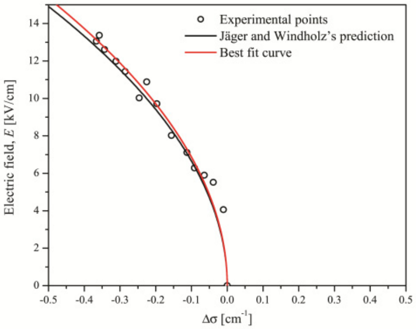

Figure 2: Dependence of the electric field strength E on the Stark shift of the wavenumber Δσ for the Ne I 556.277 nm spectral line.

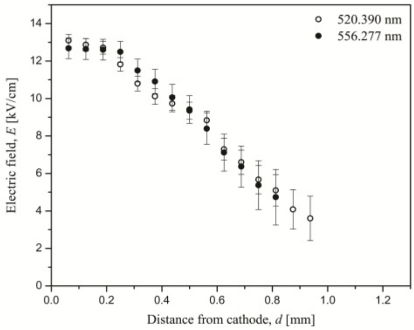

Figure 3. Comparison of the distribution of electric field strength E obtained from observations of Ne I 520.390 nm and Ne I 556.277 nm spectral lines.

4. CONCLUSION

In this work, we showed that the Ne I 556.277 nm spectral line, so far not investigated in our laboratory, is a good candidate for spectroscopic determination of the electric field strength in the cathode sheath region of an abnormal glow discharges with neon. This research expanded the list of the studied Ne I spectral lines, which can be used for reliable electric field strength measurements.

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