

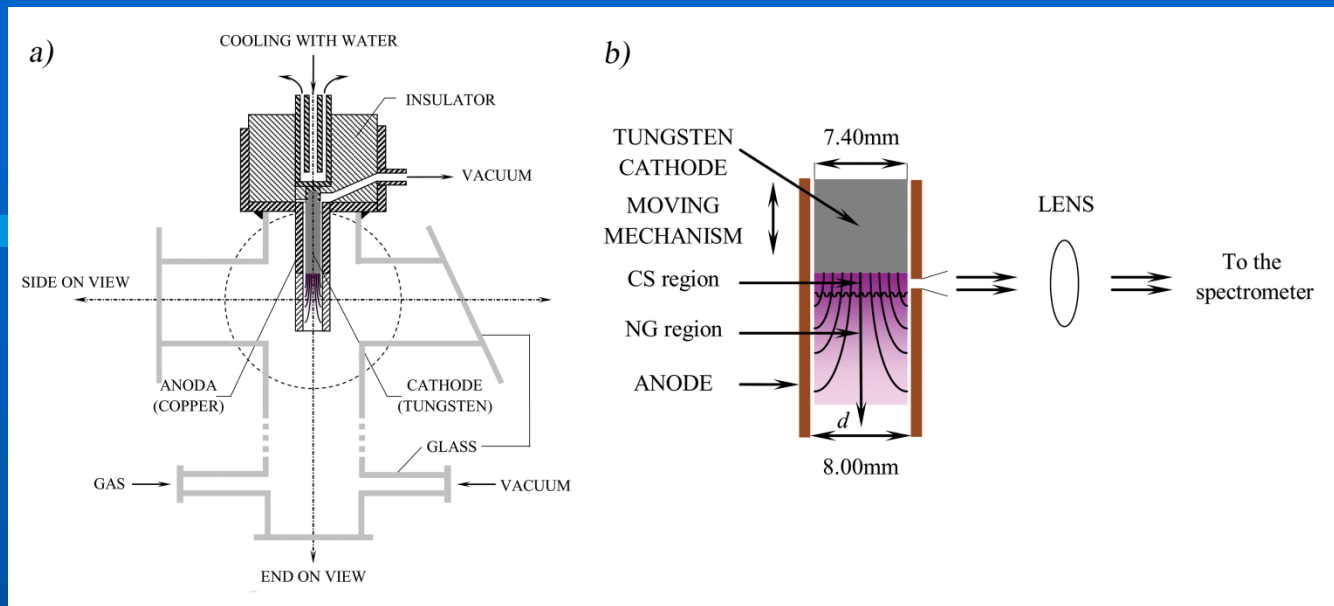
ON THE SPECTRAL SHAPES OF NE II LINES RECORDED
FROM THE CATHODE FALL REGION
OF AN ABNORMAL GLOW DISCHARGE

Dj. Spasojević¹, N. Ivanović², N.M. Šišović¹, N. Nedić¹, N. Konjević¹

¹ *Faculty of Physics, University of Belgrade
Studentski trg 12, POB 44, 11001 Belgrade, Serbia*

² *Faculty of Agriculture, University of Belgrade
Nemanjina 6, POB 14, 11080 Belgrade-Zemun, Serbia*

Experimental



Schematic diagram of the central part of the Grimm glow discharge and the experimental setup
CS – cathode sheet, NG – negative glow region.

- Hollow anode ($l=30$ mm, 8 mm dia.)
- Longitudinal slot (16 mm x 1.5 mm)
- Tungsten cathode ($l=18$ mm, 7.6 mm dia.)
- Gas flow 300 cm³/min
- Ebert type spectrometer $f=2$ m
- Reflection grating 651 g/mm blazed at 1050 nm
- Reciprocal dispersion 0.25 nm/mm
- CCD detector (1 x 3648 pixels, 8 μ m pixel width)

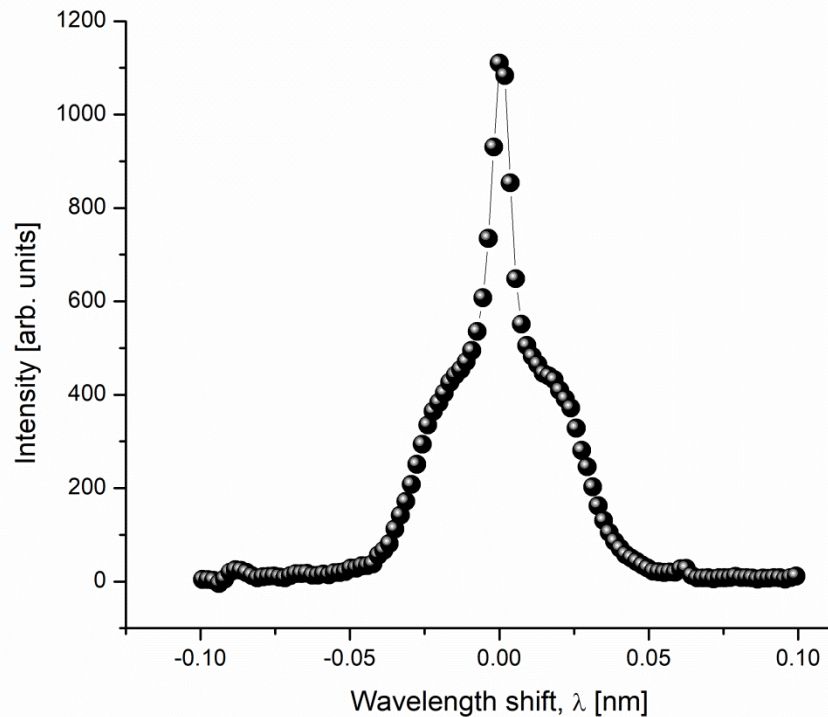
Gaussian instrumental profile; FWHM = 5.3 μ m

Spectral profiles of Ne II 371.30826 nm line

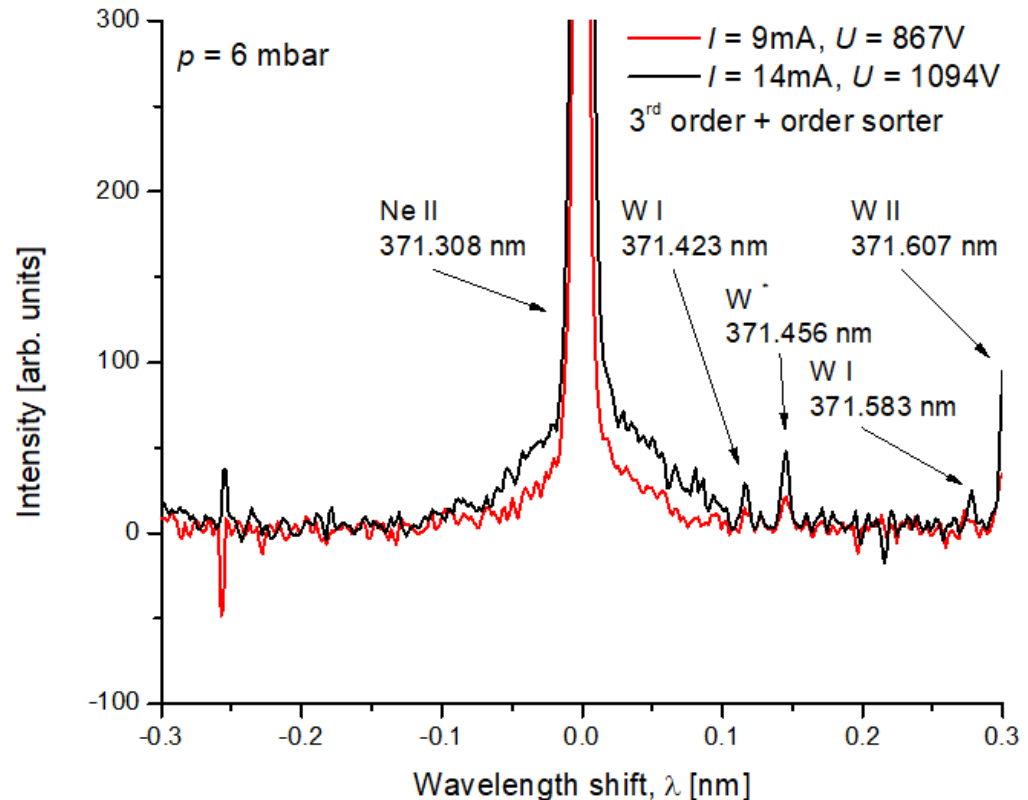
(Ne purity 99.999)

Wavelength (nm)	Lower level configuration, term, J	Upper level configuration, term, J
Ne II 371.30826	$2s^2 2p^4(^3P) 3s^2 P^{\circ} 3/2$	$2s^2 2p^4(^3P) 3p^2 D^{\circ} 5/2$
Ne I 520.38962	$2s^2 2p^5(^2P^{\circ}_{3/2}) 3p^2 [^3/2] 2$	$2s^2 2p^5(^2P^{\circ}_{3/2}) 5d^2 [^5/2]^{\circ} 3$

Side-on



End-on



Theoretical model

System of *stationary* kinetic equations, describing the cathode fall region of discharge :

$$\begin{aligned} \vec{v} \cdot \frac{\partial f_i}{\partial \vec{r}} + \frac{e\vec{E}}{m} \cdot \frac{\partial f_i}{\partial \vec{v}} &= I_i(\vec{r}, \vec{v}) & \vec{v} \cdot \frac{\partial f_e}{\partial \vec{r}} - \frac{e\vec{E}}{m_e} \cdot \frac{\partial f_e}{\partial \vec{v}} &= I_e(\vec{r}, \vec{v}) \\ \vec{v} \cdot \frac{\partial f_0}{\partial \vec{r}} + \frac{e\vec{E}}{m} \cdot \frac{\partial f_0}{\partial \vec{v}} &= I_0(\vec{r}, \vec{v}) & \frac{\partial}{\partial \vec{r}} \cdot \vec{E} &= \frac{e}{\epsilon_0} (f_i - f_e) \\ \int d^3\vec{v}_e \int d^3\vec{v}_{\text{Ne}} \int d^2\vec{b} \left[\sigma_{e,\text{Ne}^+}(|\vec{v}_e - \vec{v}_{\text{Ne}}|, b) |\vec{v}_e - \vec{v}_{\text{Ne}}| \times f_e(z, \vec{v}_e) f_0(z, \vec{v}_{\text{Ne}}) \right] &\approx \frac{n_{\text{Ne}}}{e} j_e(z) \sigma_{e,\text{Ne}^+}^{(\text{eff})} \\ f_0(\vec{r}, \vec{v}) &= n_0 (m_0/2\pi k_B T_0)^{3/2} \exp(-m_0 v^2/2k_B T_0) \end{aligned}$$

$$I_k(\vec{r}, \vec{v}_k) = \sum_l I_{k,l}(\vec{r}, \vec{v}_k)$$

$$I_{k,l}(\vec{r}, \vec{v}_k) = A_{p,l \rightarrow k}(\vec{r}, \vec{v}_k) - E_{k,l}(\vec{r}, \vec{v}_k)$$

$$A_{p,l \rightarrow k}(\vec{r}, \vec{v}_k) = \int \underbrace{d^3\vec{v}'_p \int d^3\vec{v}'_l}_{(\vec{v}'_p, \vec{v}'_l) \rightarrow \vec{v}_k} \int d^2\vec{b} \sigma_{p,l}(|\vec{v}'_p - \vec{v}'_l|, b) |\vec{v}'_p - \vec{v}'_l| f_p(\vec{r}, \vec{v}'_p) f_l(\vec{r}, \vec{v}'_l)$$

$$E_{k,l}(\vec{r}, \vec{v}_k) = \int d^3\vec{v}_l \int d^2\vec{b} \left[\sigma_{k,l}(|\vec{v}_k - \vec{v}_l|, b) |\vec{v}_k - \vec{v}_l| f_k(\vec{r}, \vec{v}_k) f_l(\vec{r}, \vec{v}_l) \right]$$

Ne⁺ + Ne → Momentum Transfer

Ne⁺ + Ne → (fast) Ne + (slow) Ne⁺

Ne⁺ + Ne → (Ne⁺)* + Ne

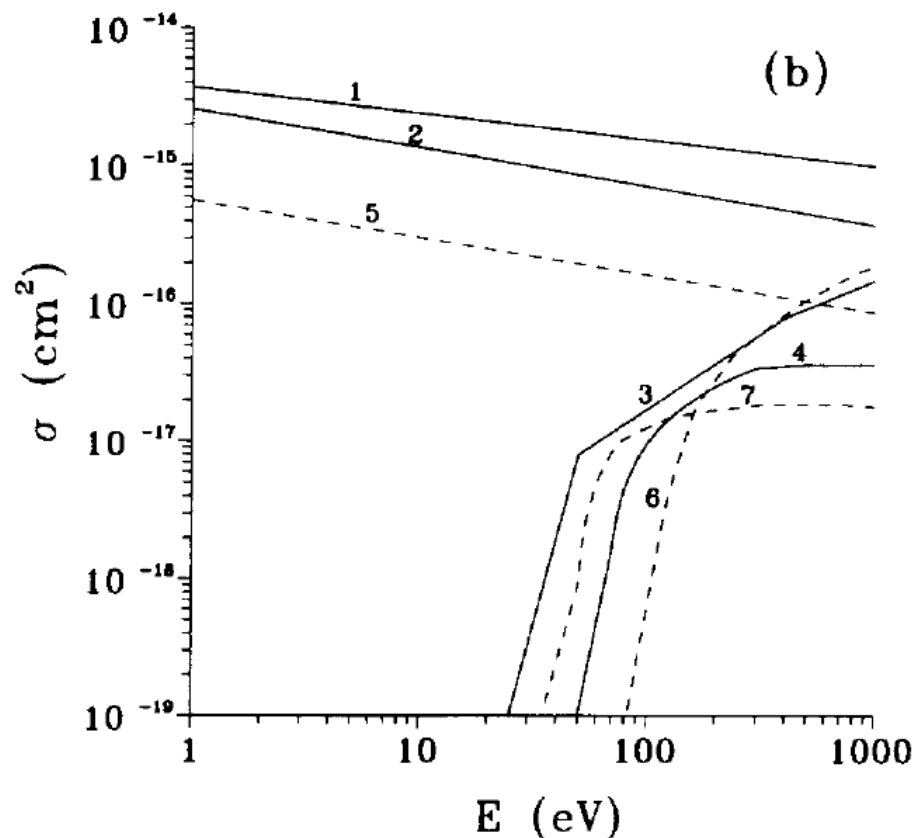
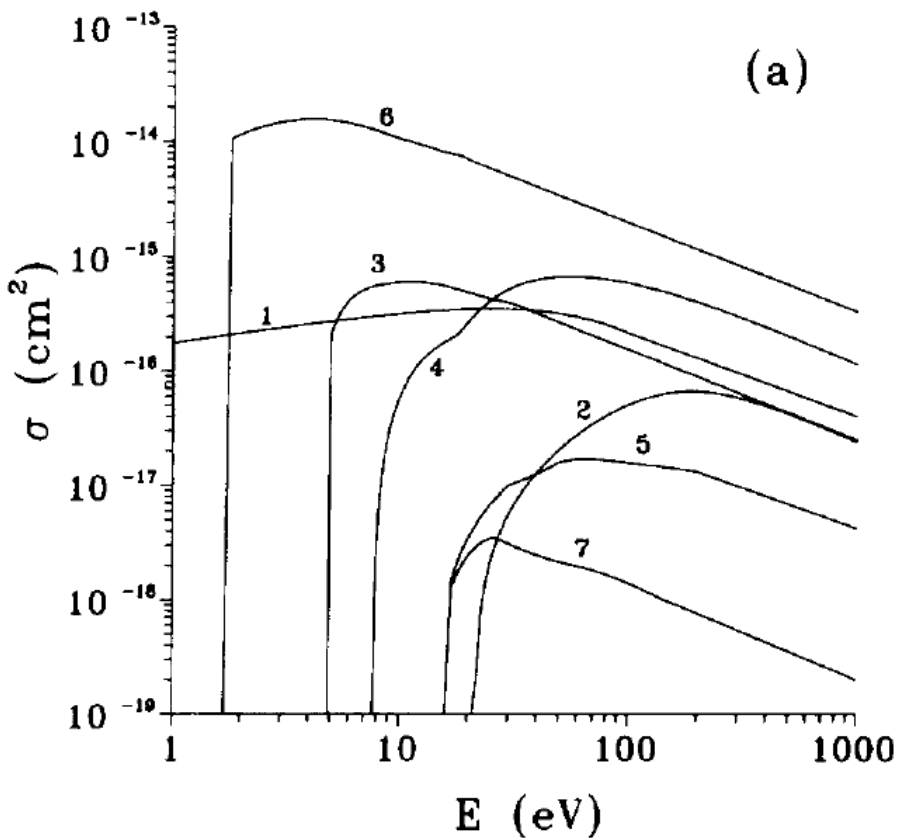
Model equations also solved iteratively starting from the NG boundary

Formation of Ne II 371.30826 nm line profiles:

- central part: ionization (and excitation) of Ne atoms by electron impact;
- wings: mostly by excitation of (fast) Ne ions in collisions with matrix atoms.

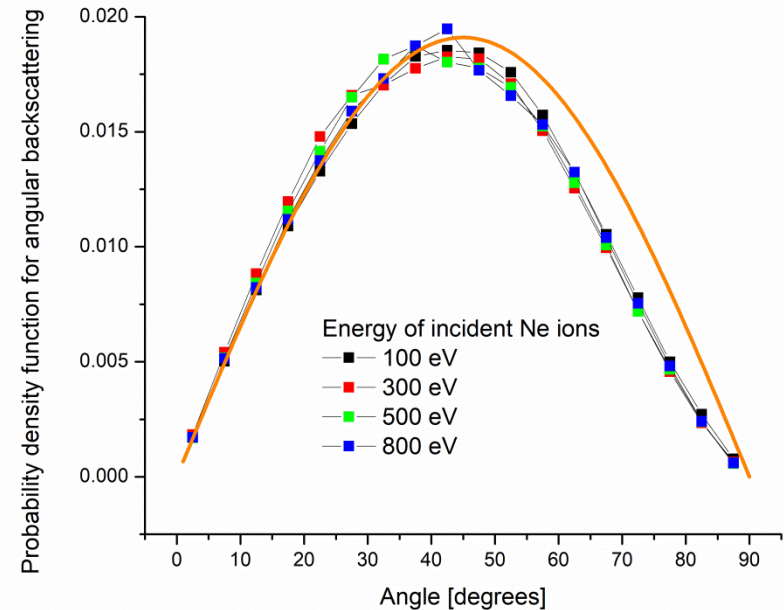
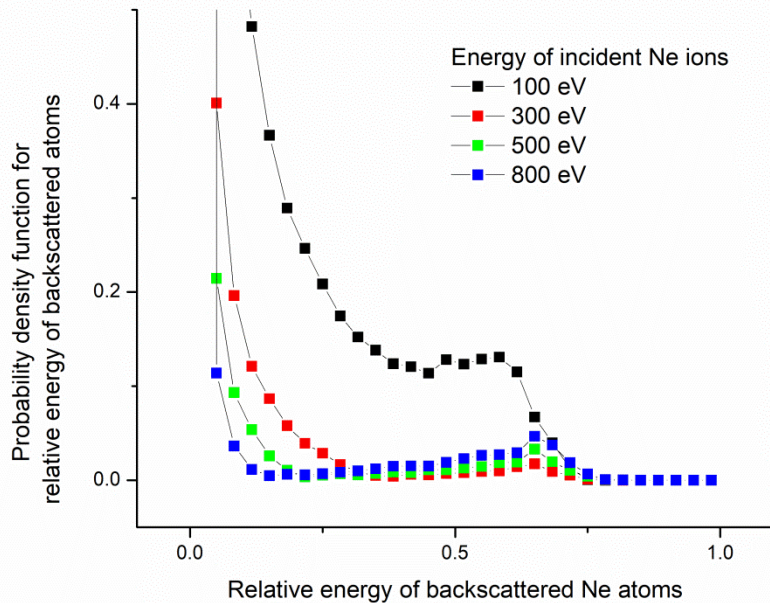
Cross sections

A. Bogaerts, R. Gijbels, *Spectrochimica Acta Part B* 52, 553 (1997)



(a) Cross sections of the collision processes of electrons, incorporated in the model, for the neon discharge. 1: electron elastic collisions [24,25], 2: electron impact ionization of neon ground state atoms [24], 3: electron impact ionization of neon metastable atoms [26], 4: electron impact ionization of sputtered copper atoms [29], 5: total electron impact excitation of neon ground state atoms [25], 6: total electron impact excitation of neon metastable atoms [26,27], 7: electron impact excitation of neon ground state atoms to the metastable levels [28]. (b) Cross sections of the collision processes of neon ions and fast atoms, incorporated in the model, for the neon discharge. Solid lines: neon ion collisions. 1: ion symmetric charge transfer [30], 2: ion elastic collisions [30], 3: ion impact ionization [31], 4: ion impact excitation to the metastable levels [32]. Dashed lines: neon fast atom collisions, 5: atom elastic collisions [33,34], 6: atom impact ionization [35], 7: atom impact excitation to the metastable levels [36].

Backscattering of Ne atoms from tungsten cathode

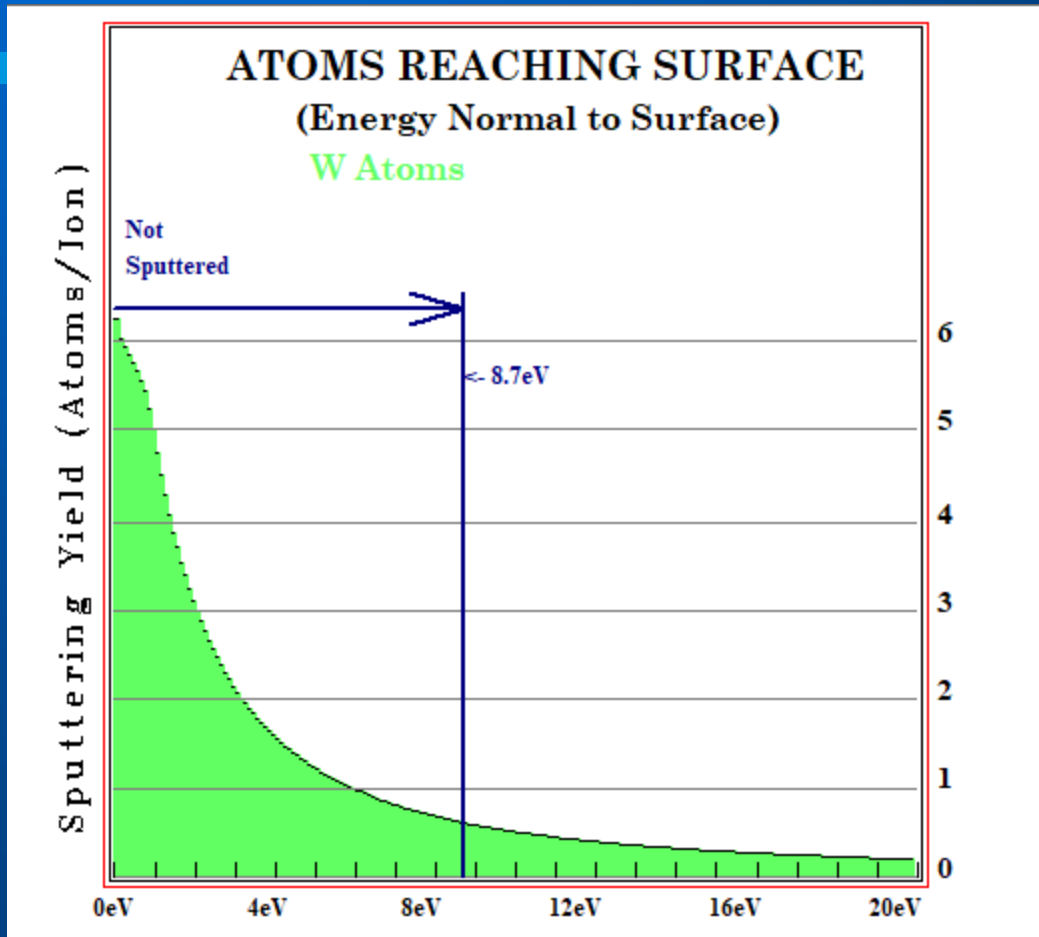


$$dP(\theta) = \sin(\theta) d\theta$$

Ne atoms originate from incident Ne ions that are neutralized and subsequently backscattered from the tungsten cathode.

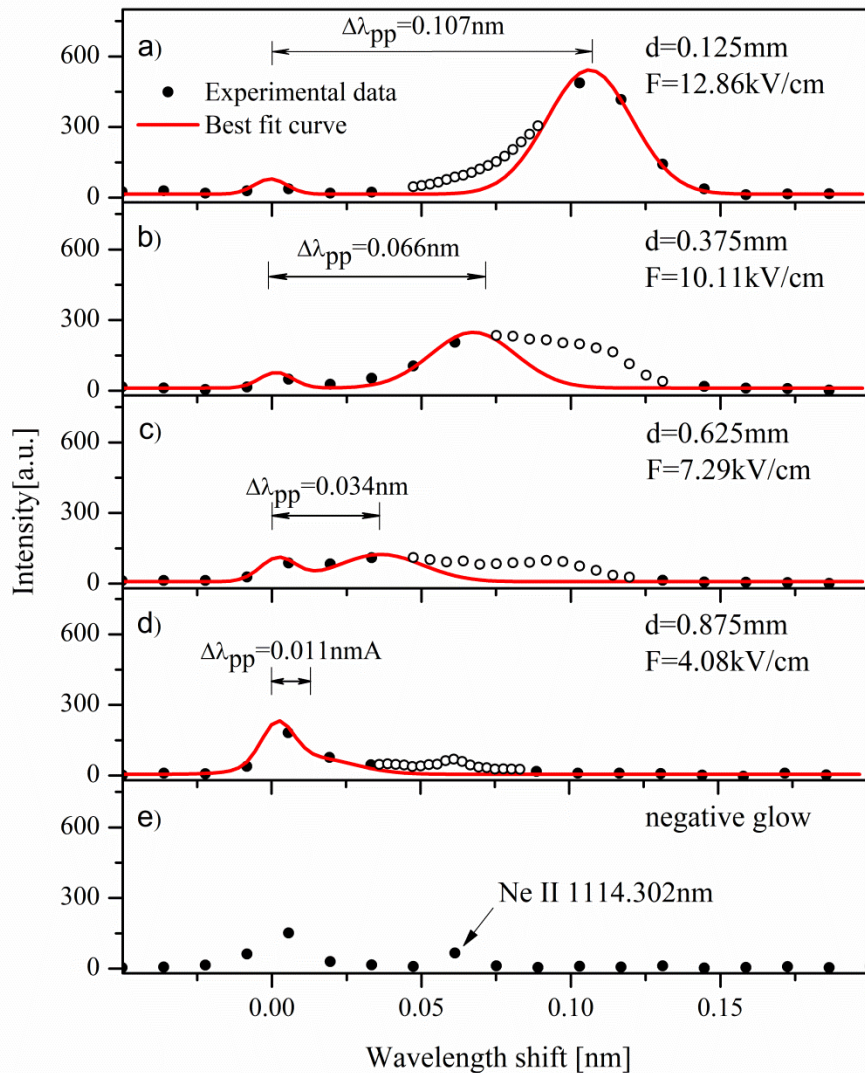
SRIM-2008, Ziegler J F, Ziegler M D and Biersack J P (www.SRIM.org)

Sputtering



Average sputtering yield ≈ 0.6
for 500 eV Ne ions

Experimental determination of the electric field distribution (from shifts due to quadratic Stark effect of Ne I 520.39 nm line)



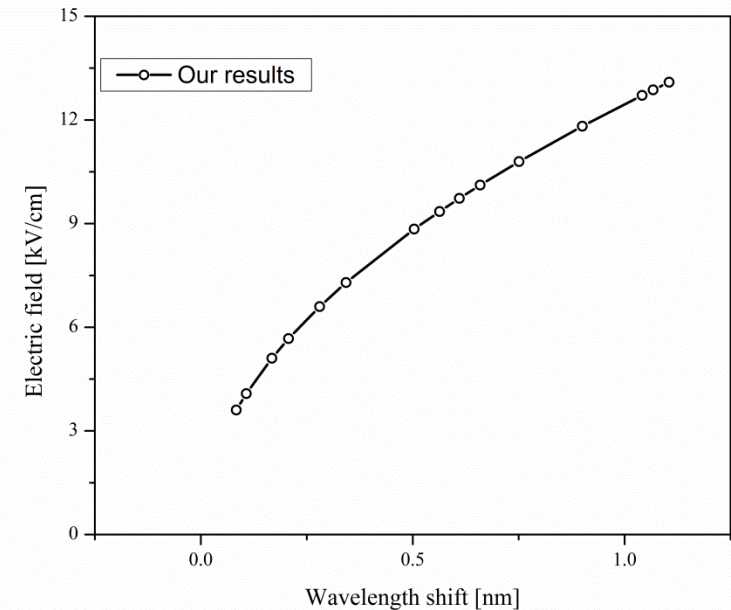
$$I_{\text{Ne}}(\Delta\lambda; H, c, b) = A\mathfrak{Z}(\Delta\lambda) + \mathfrak{Z} * G(\Delta\lambda; H_{\text{Ne}}, c_{\text{Ne}}, w_{\text{Ne}}) + b_{\text{Ne}}$$

$$G(\Delta\lambda; H_{\text{Ne}}, c_{\text{Ne}}, w_{\text{Ne}}) = H_{\text{Ne}} \exp \left[- \left(2\sqrt{2\ln 2} \frac{\Delta\lambda - c_{\text{Ne}}}{w_{\text{Ne}}} \right)^2 \right]$$

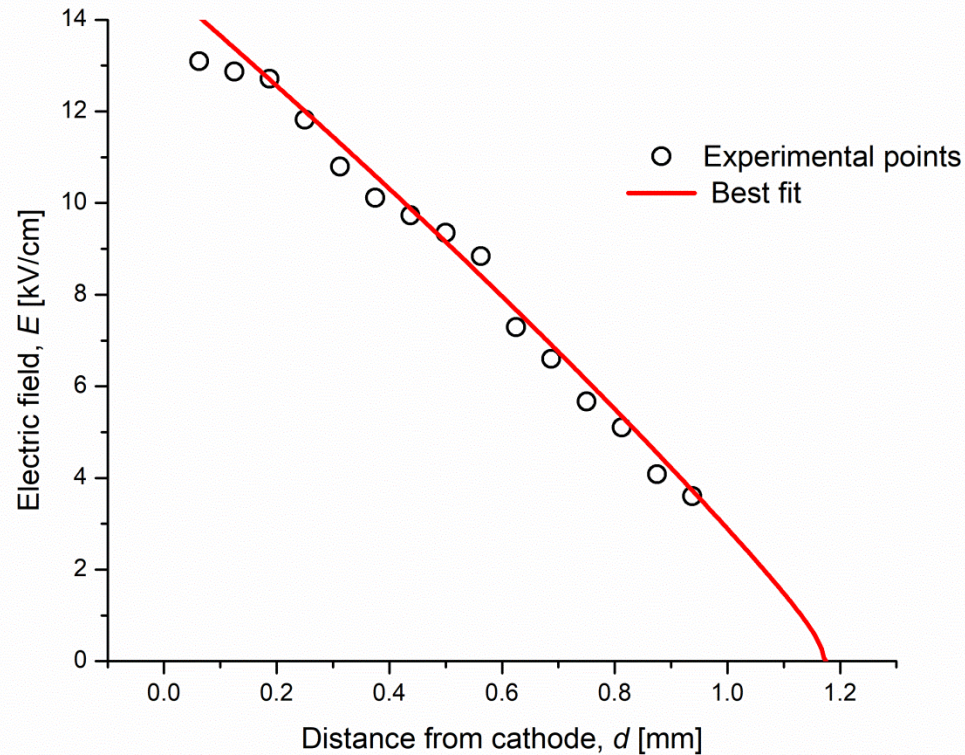
$$\mathfrak{Z} = \frac{2}{w_{\text{inst}}} \sqrt{\frac{2}{\pi}} \exp \left[- \left(2\sqrt{2\ln 2} \frac{\Delta\lambda}{w_{\text{inst}}} \right)^2 \right]$$

$$\Delta\lambda \approx -\lambda_0^2 C E^2$$

$$\lambda_0 = 520.38962 \text{ nm}, C = -0.0238 \text{ cm/kV}^2$$



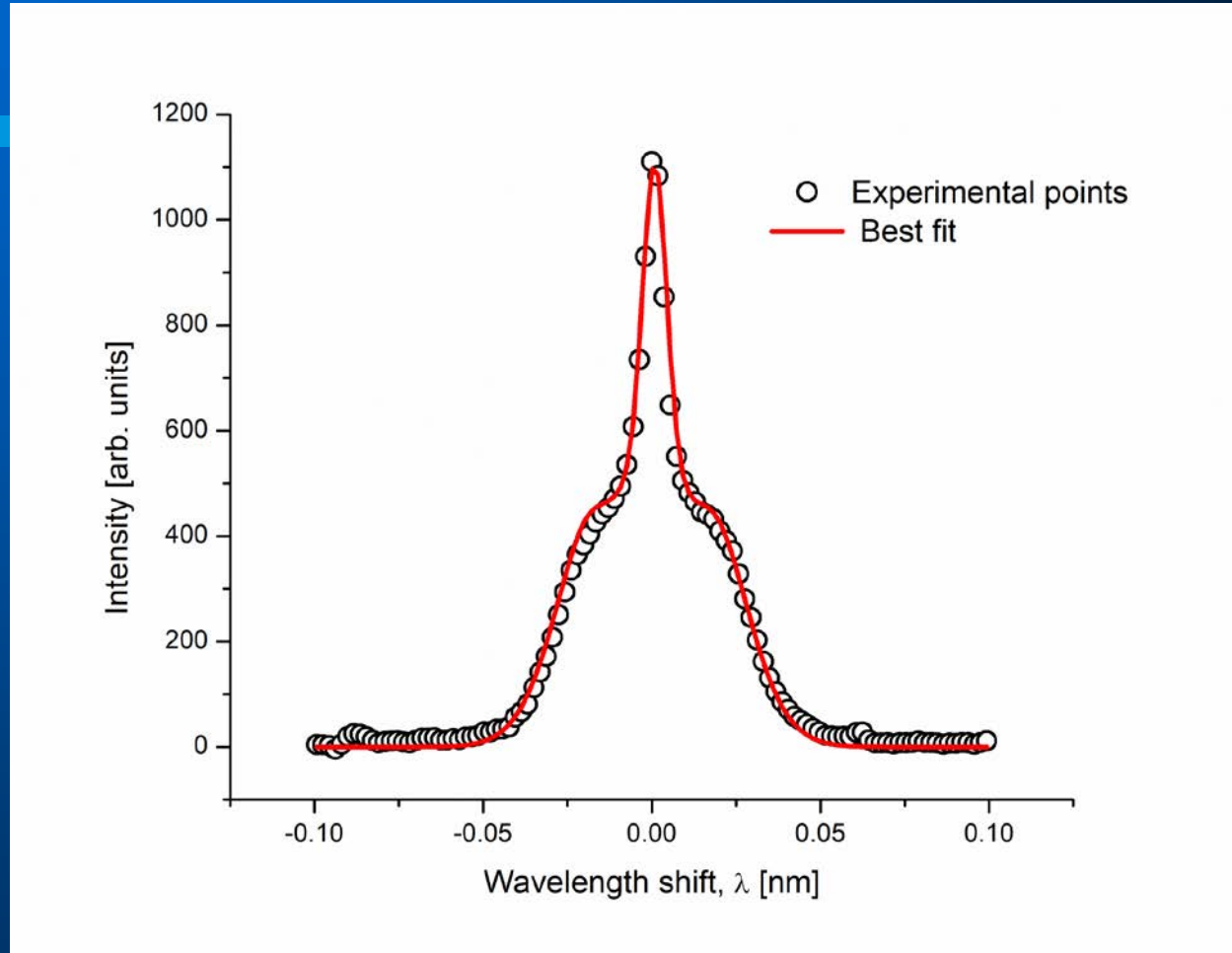
Results :



Electric field strength, E , vs distance from cathode, d ,
determined with the aid of Ne I 520.38962 nm line.

Discharge conditions: pressure $p = 6$ mbar, discharge voltage $V = 900$ V, discharge current $I = 10$ mA.

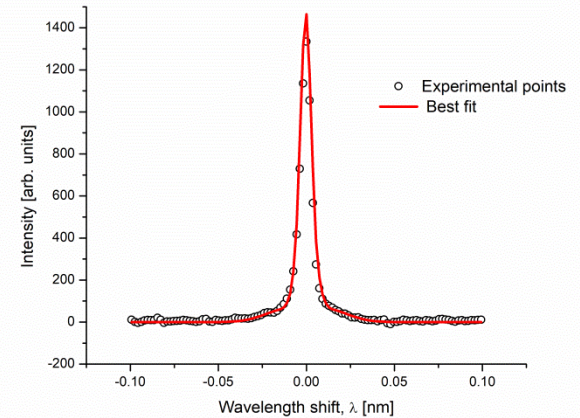
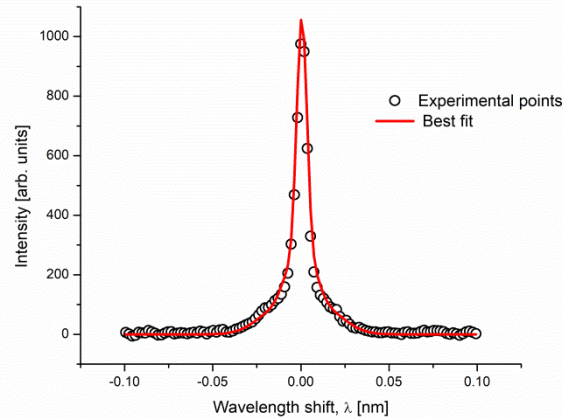
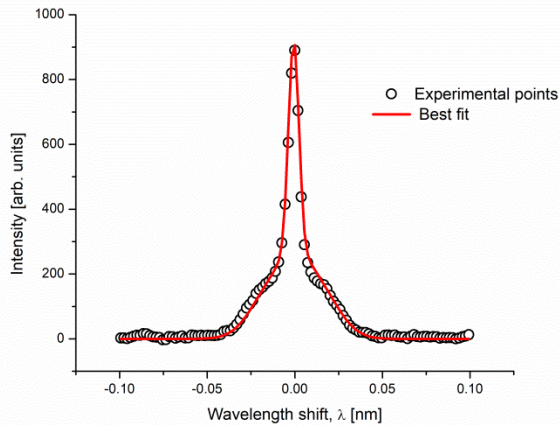
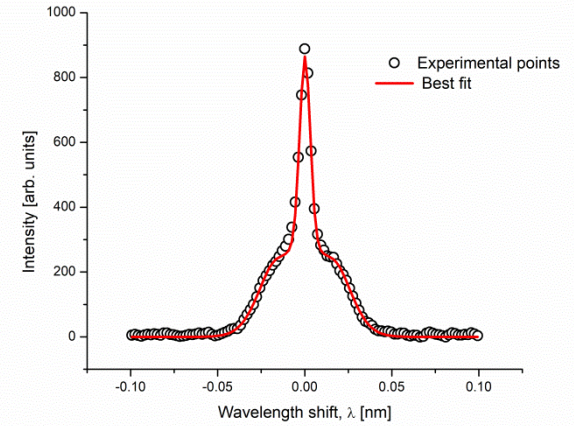
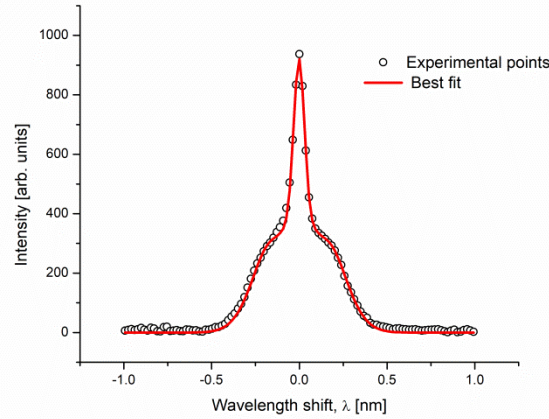
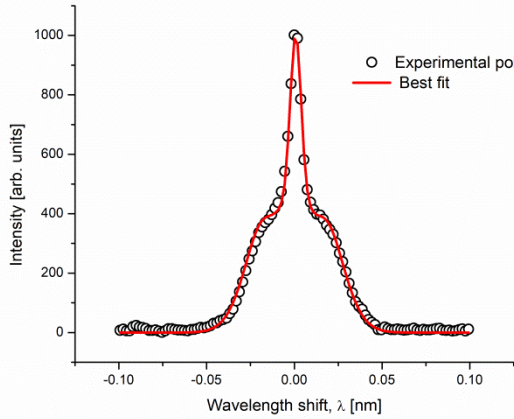
Results (1) :



Intensity vs wavelength shift for the spectral profile of the Ne II 371.30826 nm line recorded side-on at the 0.125mm distance from the cathode.

Discharge conditions: pressure $p = 6$ mbar, discharge voltage $V = 900$ V, discharge current $I = 10$ mA.

Results (2) :



Same as in previous graph, but for distances:
0.250mm, 0.375mm, 0.500mm,
0.625mm, 0.750mm, 0.850mm.

Best fit values of model parameters:

Model parameter	Value
Cathode sheath thickness	(1.2 ± 0.1) mm
Temperature	(570 ± 50) K
Electron – Ne ionization cross-section	$(1.6 \pm 0.3) \times 10^{-20}$ m ²
Ne ⁺ number density at NG boundary	$(1.1 \pm 0.2) \times 10^{17}$ m ⁻³

Predicted voltage = (930 ± 40) V vs experimental 900 V

Ion current at cathode = (3.2 ± 0.4) mA out of 10 mA

What next ?

- Variation of discharge conditions
- Different cathode material
- Prediction of end-on profile

This work was supported by the
Serbian Ministry of Education, Science and Technological Development
under Projects # 17114 and # 171027.

Thank you for your attention

