12th Serbian Conference on Spectral Line Shapes in Astrophysics

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

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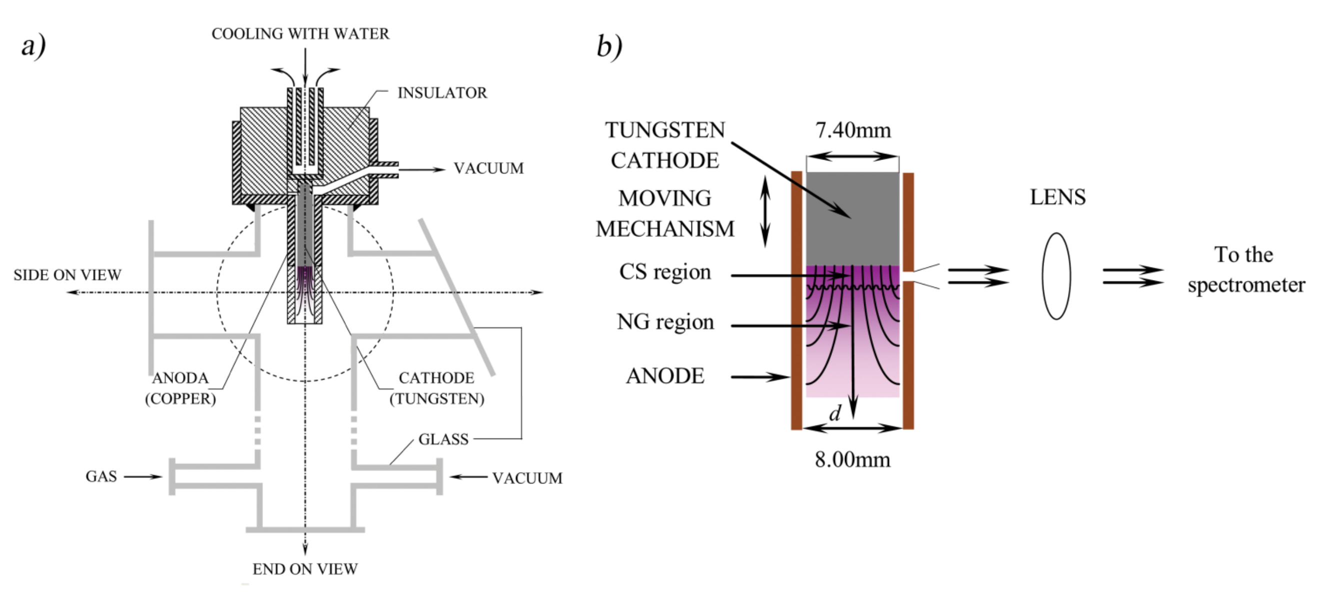
Experimental



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 cm^3/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 µm pixel width)

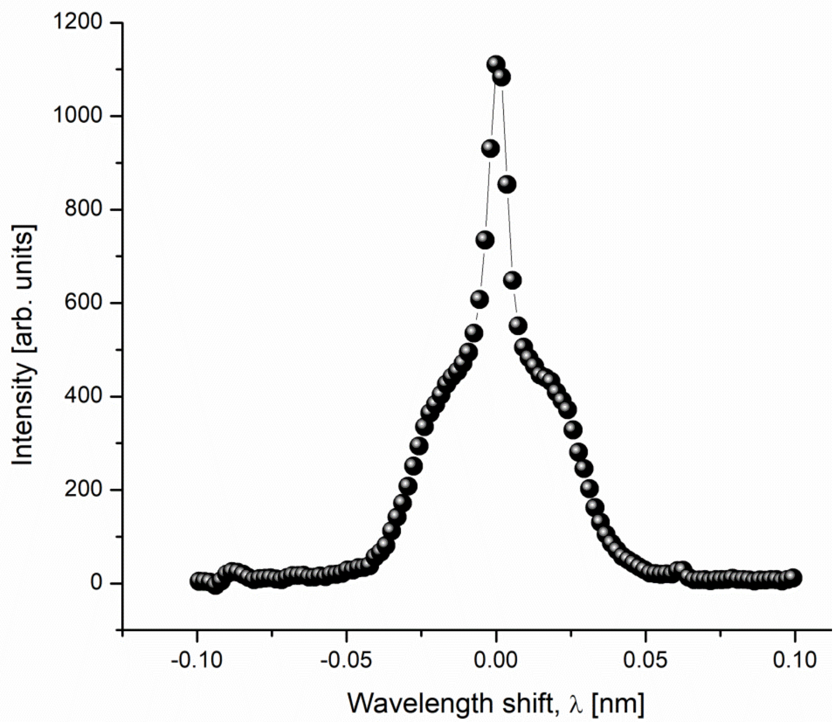
Gaussian instrumental profile; FWHM = 5.3 pm

Spectral profiles of Ne II 371.30826 nm line

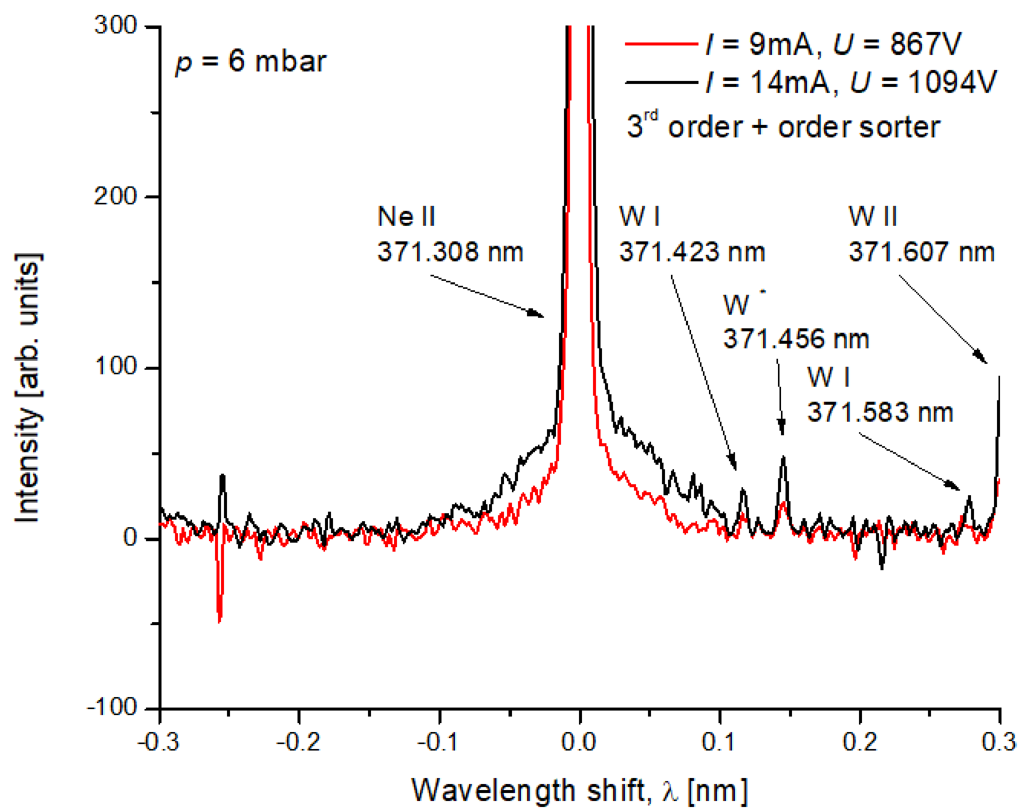
(Ne purity 99.999)

Wavelength (nm)	Lower level configuration, term, J	Upper level configuration, term, J
Ne II 371.30826	$2s^2 2p^4(^3P)3s\ ^2P\ ^3/_2$	$2s^2 2p^4(^3P)3p\ ^2D°\ ^5/_2$
Ne I 520.38962	$2s^2 2p^5(^2P°_{3/2})3p\ ^2[^3/_2]\ 2$	$2s^2 2p^5(^2P°_{3/2})5d\ ^2[^5/_2]°\ 3$

Side-on



End-on



Theoretical model

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

$$\vec{v}\cdot\frac{\partial f_i}{\partial \vec{r}}+\frac{e\vec{E}}{m}\cdot\frac{\partial f_i}{\partial \vec{v}}=I_i(\vec{r},\vec{v})$$

$$\vec{v}\cdot\frac{\partial f_e}{\partial \vec{r}}-\frac{e\vec{E}}{m_e}\cdot\frac{\partial f_e}{\partial \vec{v}}=I_e(\vec{r},\vec{v})$$

$$\vec{v}\cdot\frac{\partial f_0}{\partial \vec{r}}+\frac{e\vec{E}}{m}\cdot\frac{\partial f_0}{\partial \vec{v}}=I_0(\vec{r},\vec{v})$$

$$\frac{\partial}{\partial \vec{r}}\cdot\vec{E}=\frac{e}{\varepsilon_0}(f_i-f_e)$$

$$\int d^3\vec{v}_e\int d^3\vec{v}_{\mathrm{Ne}}\int d^2\vec{b}\left[\sigma_{e,\mathrm{Ne}^+}(|\vec{v}_e-\vec{v}_{\mathrm{Ne}}|,b)|\vec{v}_e-\vec{v}_{\mathrm{Ne}}|\times f_e(z,\vec{v}_e)\,f_0(z,\vec{v}_{\mathrm{Ne}})\right]\approx\frac{n_{\mathrm{Ne}}}{e}j_e(z)\sigma^{(eff)}_{e,\mathrm{Ne}^+}$$

$$f_0(\vec{r},\vec{v})=n_0(m_0/2\pi k_B T_0)^{3/2}\exp(-m_0v^2/2k_BT_0)$$

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

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

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

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

Ne^+ + Ne $\to$ Momentum Transfer

Ne^+ + Ne $\to$ (fast) Ne + (slow) Ne^+

Ne^+ + Ne $\to$ $(Ne^+)^*$ + Ne

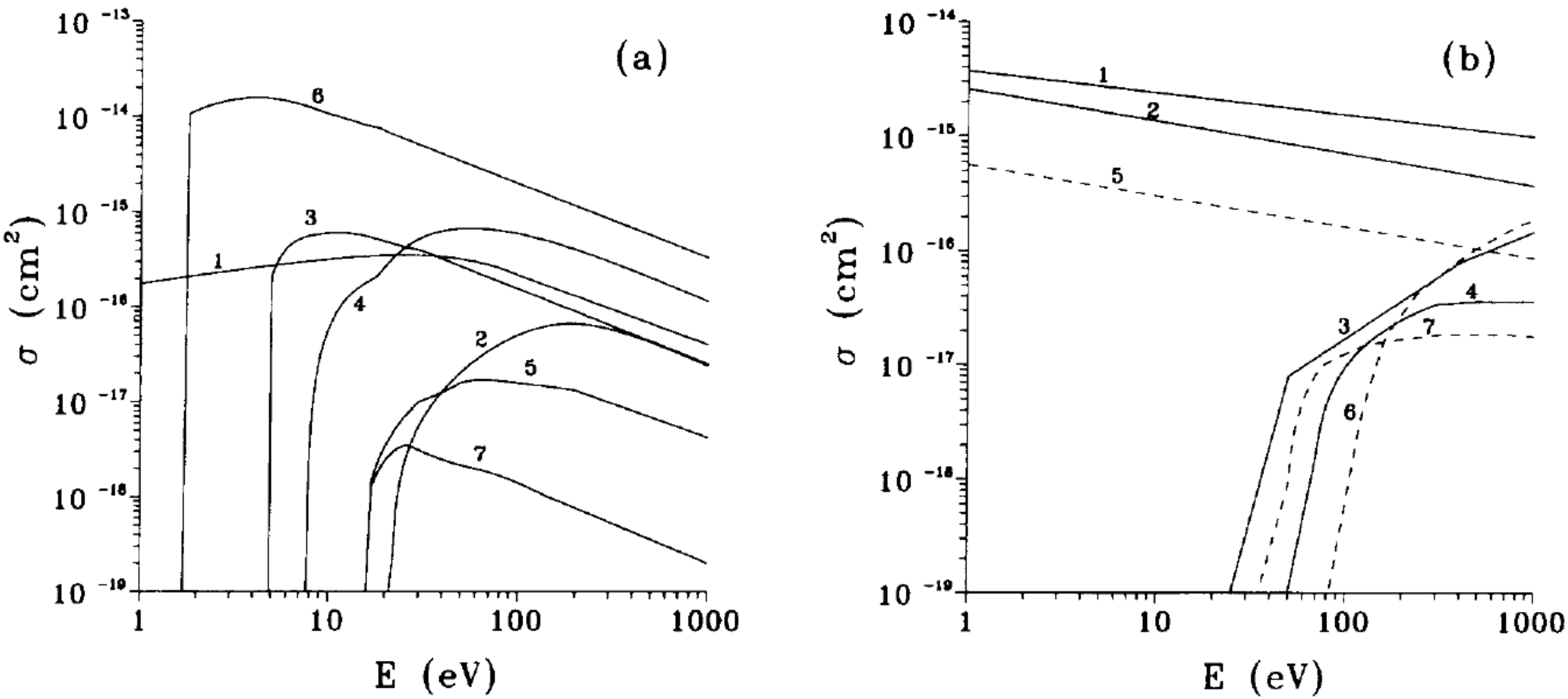
Model equations also solved iteratively starting from the NG boundary

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.

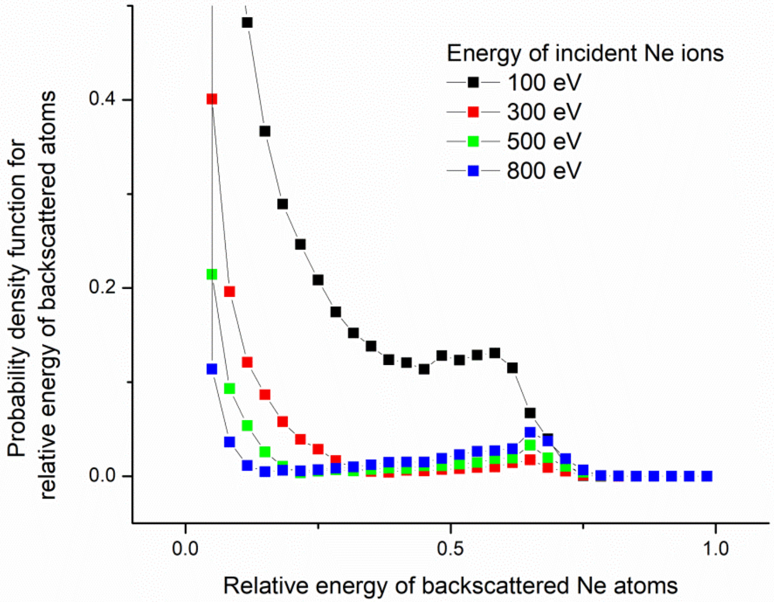
Cross sections

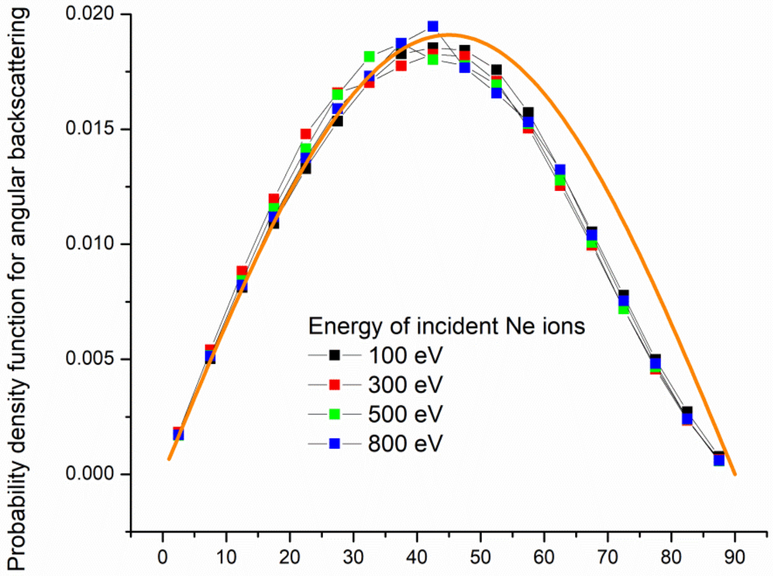
A. Bogaerts, R. Gijbels, Spectrochimica Acta Part B **52**, 553 (1997)



(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



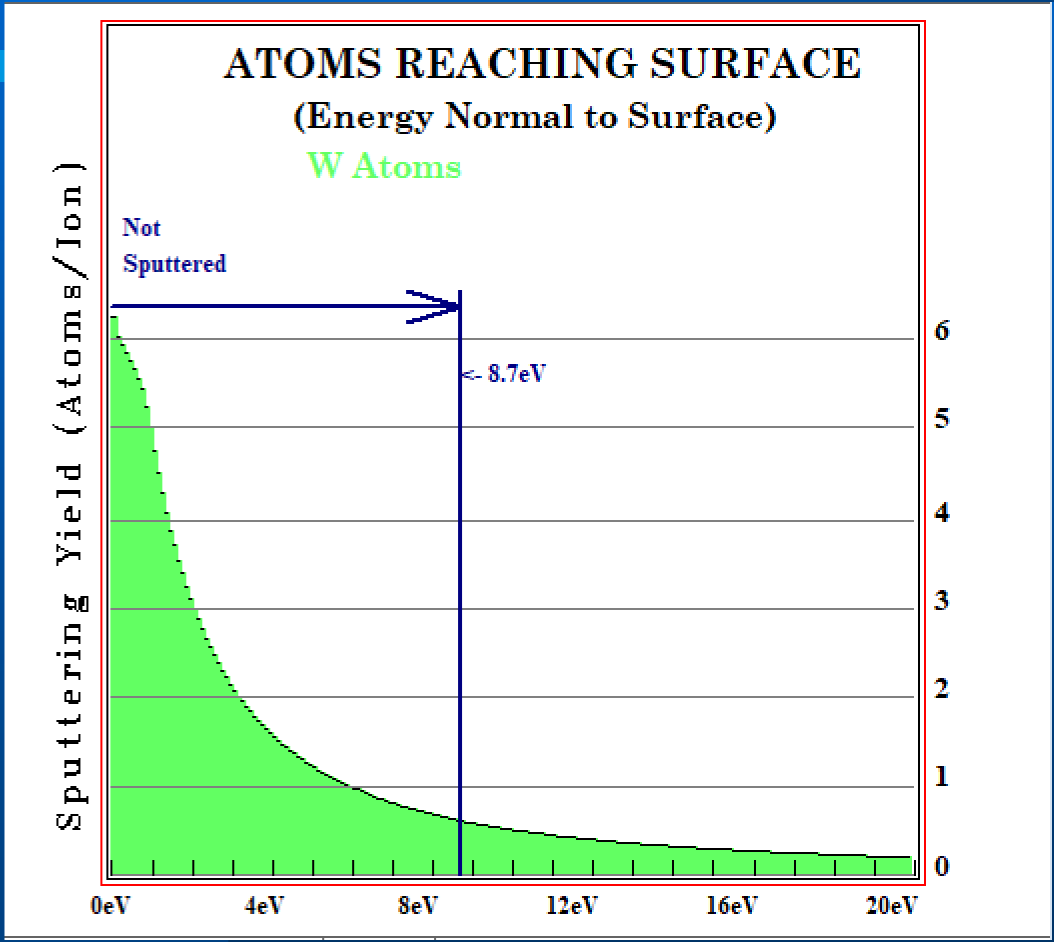


$$dP(\theta) = \sin(\theta)\,d\theta$$

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)

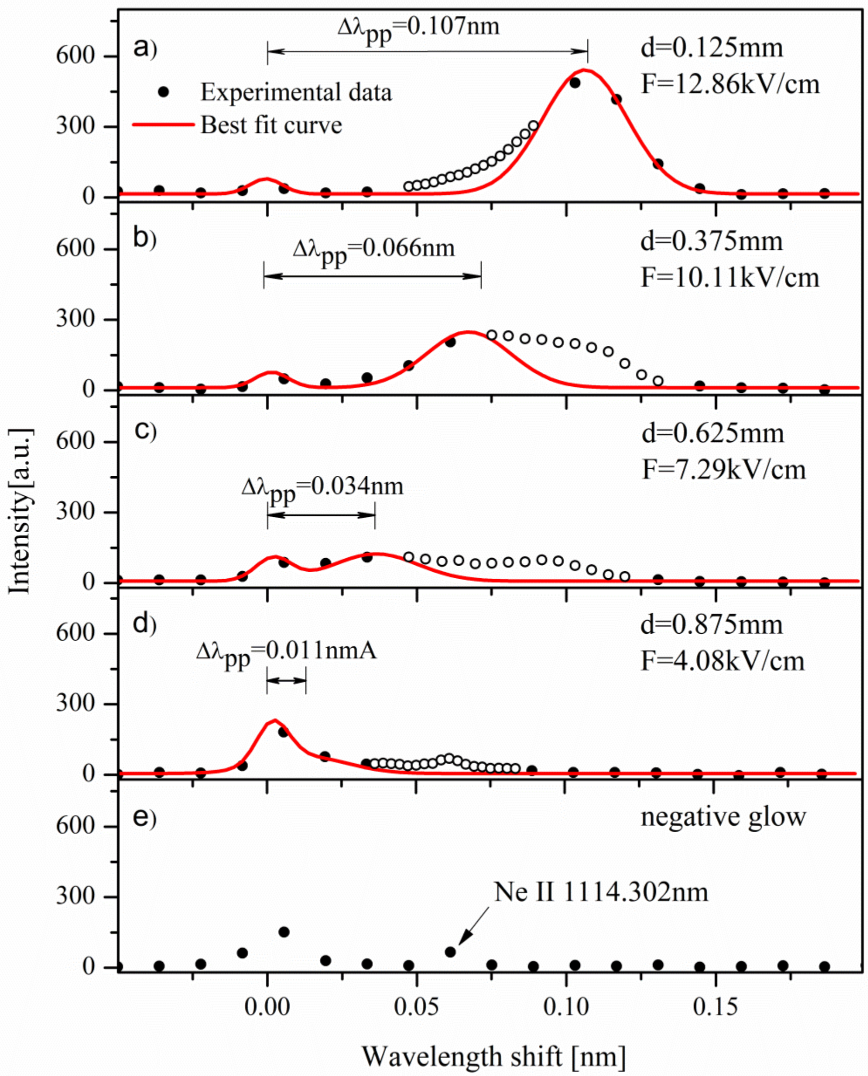
Sputtering



Average sputtering yield ≈ 0.6 for 500 eV Ne ions

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

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



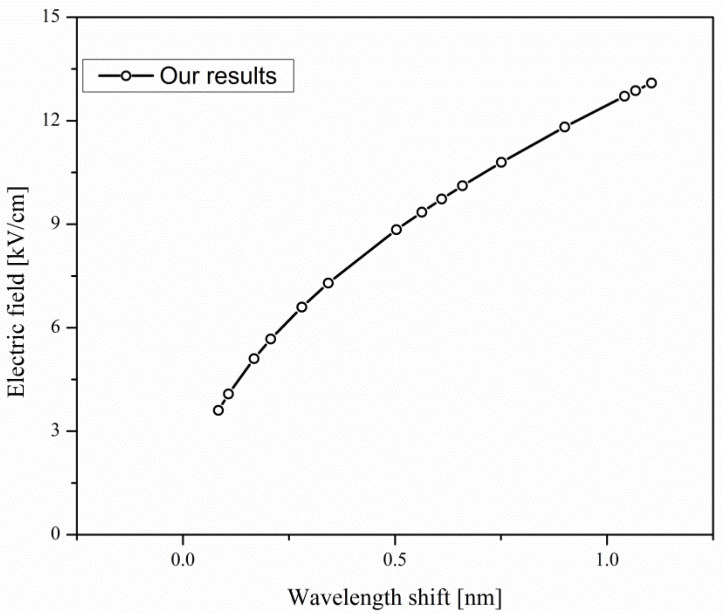
$$I_{\mathrm{Ne}}(\Delta\lambda; H, c, b) = A\mathfrak{I}(\Delta\lambda) + \mathfrak{I} * G(\Delta\lambda; H_{\mathrm{Ne}}, c_{\mathrm{Ne}}, w_{\mathrm{Ne}}) + b_{\mathrm{Ne}}$$

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

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

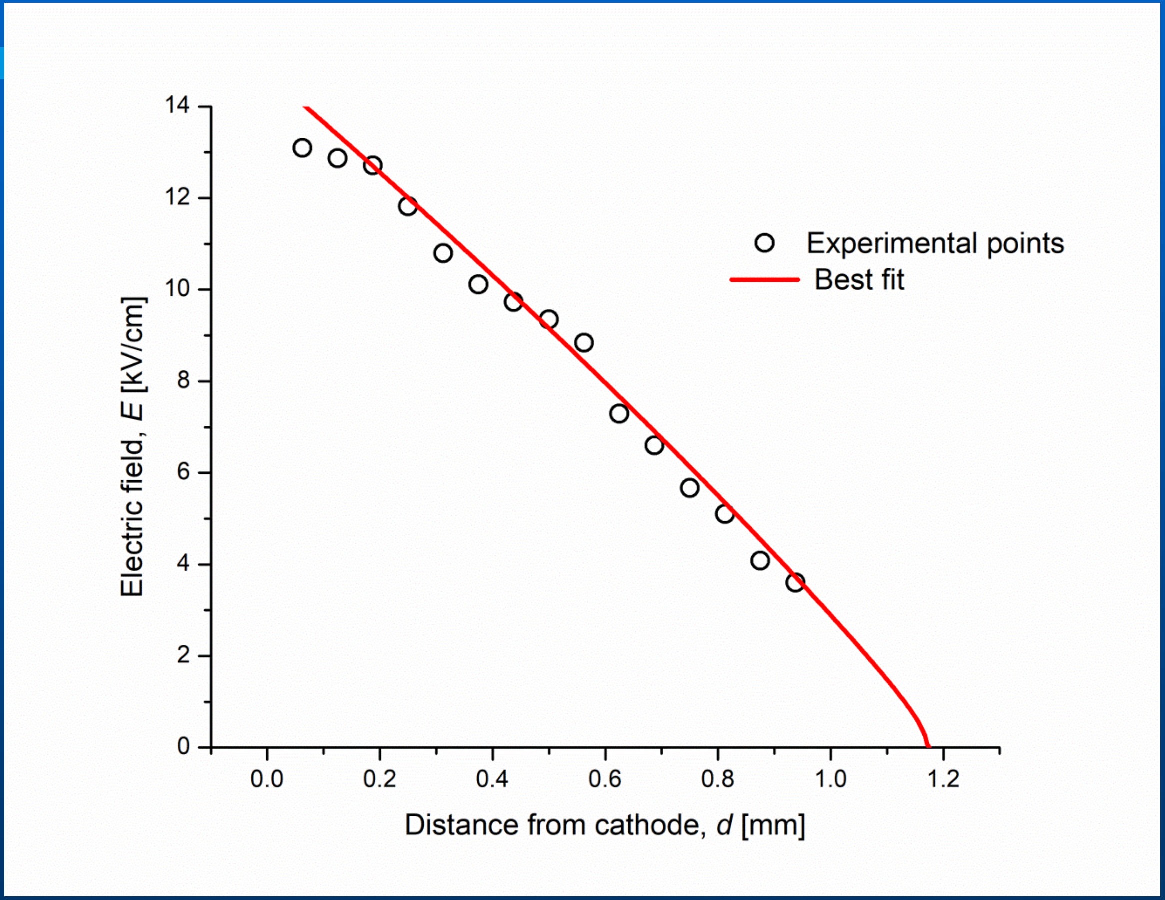
$$\Delta\lambda \approx -\lambda_0^2 C E^2$$

$\lambda_0 = 520.389\ 62\ \mathrm{nm}$, $C = -0.0238\ \mathrm{cm/kV^2}$



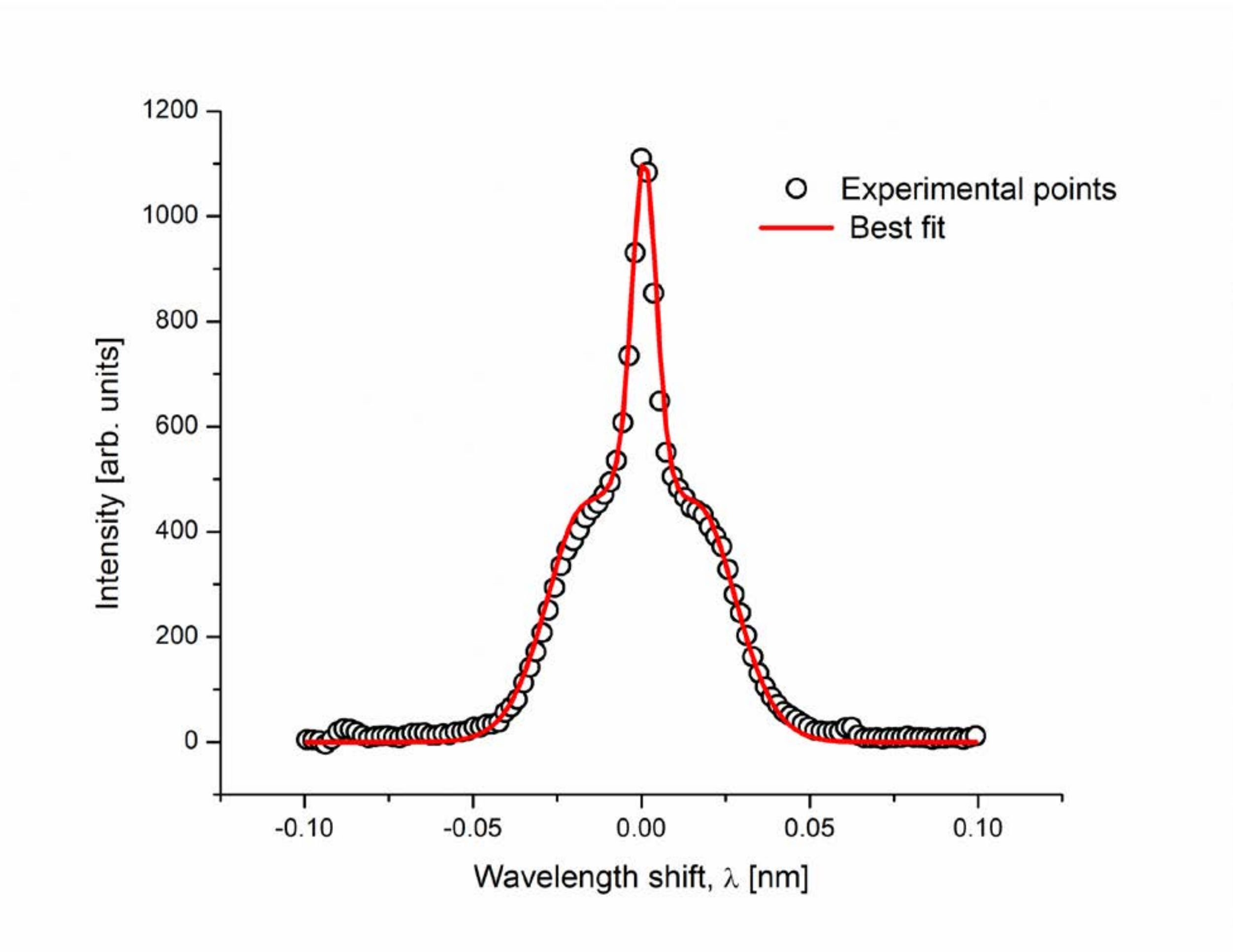
Ivanović N V, Šišović N M, Spasojević Dj and Konjević N, *J. Phys. D: Appl. Phys.* **50** 125201 (2017)

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* = 6mbar, discharge voltage *V* = 900V, discharge current *I* = 10mA.

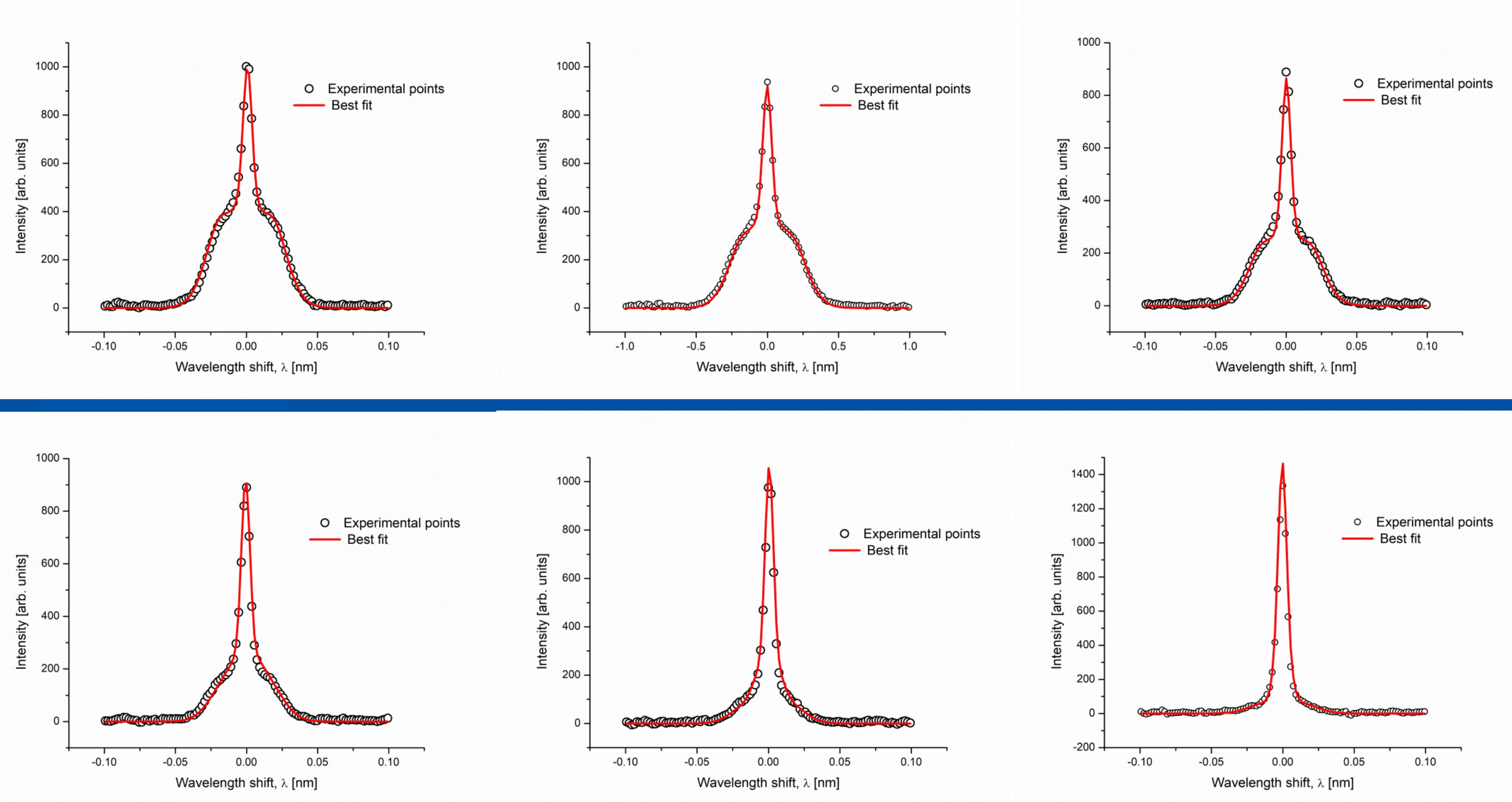
Results (1) :



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 = 6mbar, discharge voltage V = 900V, discharge current I = 10mA.

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

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Thank you for your attention