The electron number density measurements from pulsed needle-to-cylinder gas discharge source in helium

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The focus of this study is on the spectroscopic investigation of a newly constructed needle-to-cylinder atmospheric pressure gas discharge source operating in helium **(Figure 1)**, in particular the electron number density N_e measurement using the H_β and asymmetric He I 447.2 nm line **(Figs. 3 and 5)**. The discharge source can operate in DC continuous, pulsing and pulsed regime [3]. In the pulsed regime, $N_e=(0.77 \pm 0.12) \times 10^{15}$ cm^{-3} was measured by means of He I fitting procedure while $N_e=(0.16 \pm 0.03) \times 10^{15}$ cm^{-3} was obtained analyzing the H_β line profile **(Figure 5)**. However, N_e from the H_β can reach 0.55×10^{15} cm^{-3} but only at the beginning of plasma-water drop interaction when the partial pressure of water vapor is high in the plasma region P. For the reliable gas temperature T_g measurements, a Boltzmann plot technique was applied on $N_2(C^3\Pi_u–B^3\Pi_g)$ R_2 branch lines **(Figure 4)**. The T_g diagnostics procedure revealed the higher temperature in pulsed (1720 ± 110) K in comparison to DC regime (780 ± 35) K. In both regimes, the increase in current caused the increase in T_g. During the water drop treatment, intensive Fe I lines originating from cathode material were detected **(Figs. 6 and 7)**. The tentative explanation is that iron-oxide layers are formed on the cathode surface during the plasma–water interaction with subsequent decomposition in plasma. The spectra of cathode material may be used for plasma diagnostics purposes as well.

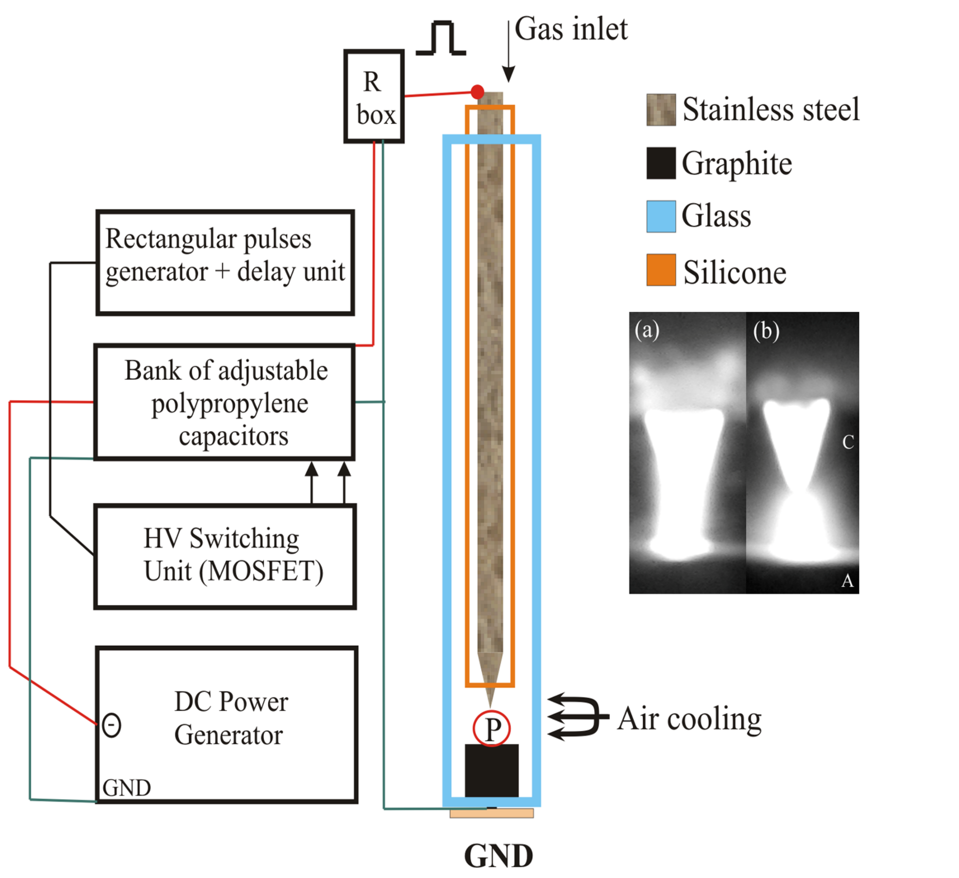

Figure 1. The schematic description of pulsed voltage generator and the cross section of atmospheric pressure gas discharge source. The photos of discharge burning in pulsed (a) and (b) DC regime are given in the inset.

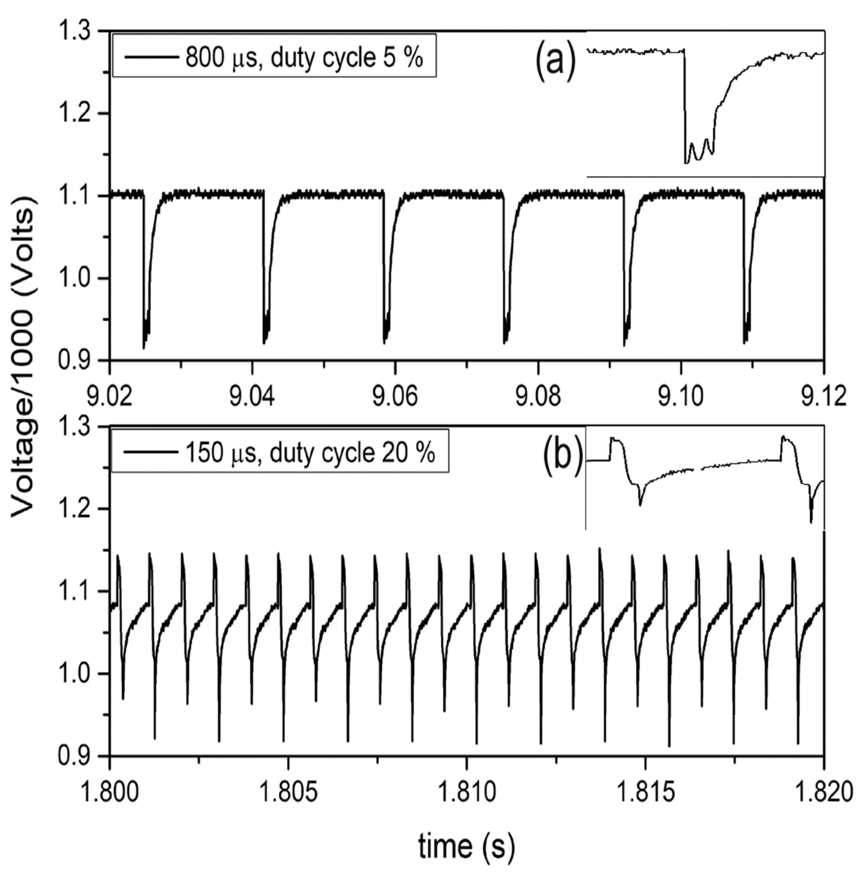

Figure 2. The normalized voltage signal (V/1000) for 800 µs (a) and 50 µs (b) pulsed width.

Table 1. The features of spectrometer, power supply and CCD.

Spectrometer	
Focal length (m)	2
Dispersion (nm/mm)	0.74
Power supply	
DC	0-2 kV, 0-100 mA
Pulse generator	2–999 µs pulse width, 0.1%–100% duty cycle
CCD	
Characteristics	2048 × 506 pixels; pixel width 12 µm; T= -10 °C

IMPORTANT REFERENCES

Ref. [1]: The He I lines fitting function in detail.

Ref. [2]: The gas temperature measurement procedure using N_2 and N_2^+ bands.

Ref. [3]: A comprehensive study of needle-to-cylinder atmospheric pressure gas discharge source.

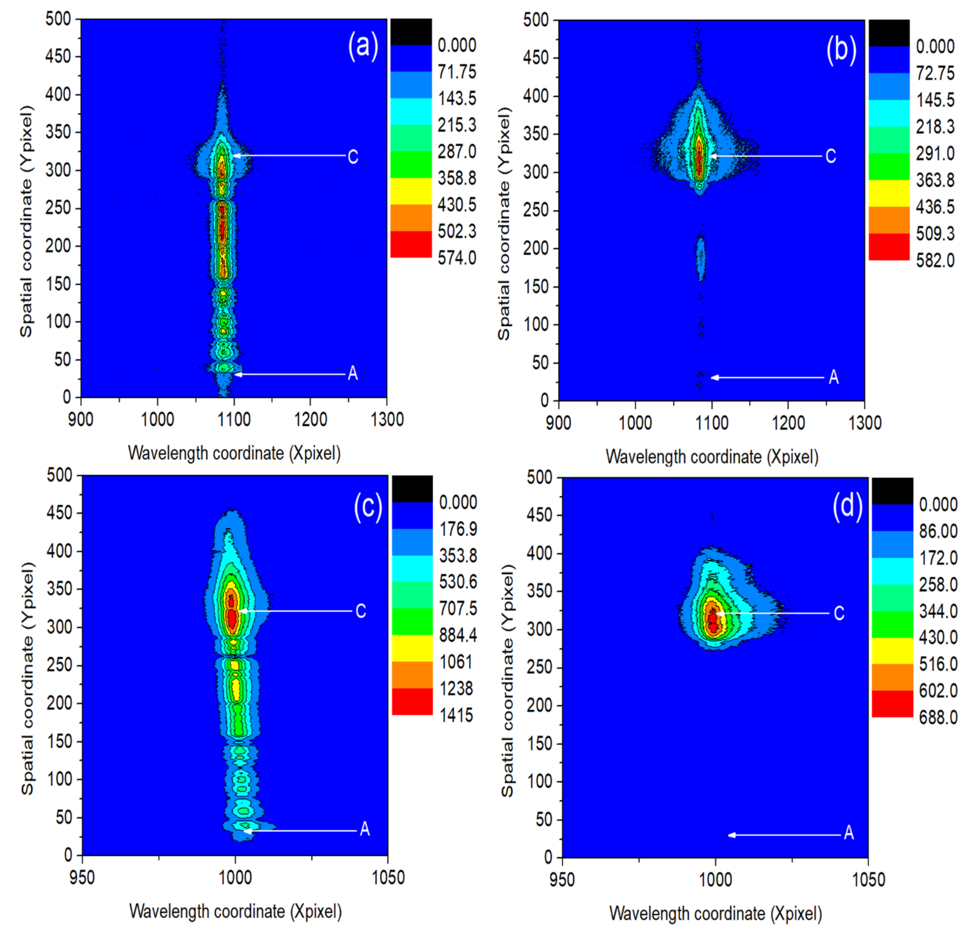

Figure 3. The H_β line in pulsed (a) and DC regime (b) and He I 447.2 nm line in pulsed (c) and DC regime (d) recorded by means of CCD camera imaging mode. Experimental conditions: pulse width of 800 µs, duty cycle of 5 %, gap of 2 mm, I= 20 mA, U_{PULS}= 435 V (U_{DC}= 1500 V).

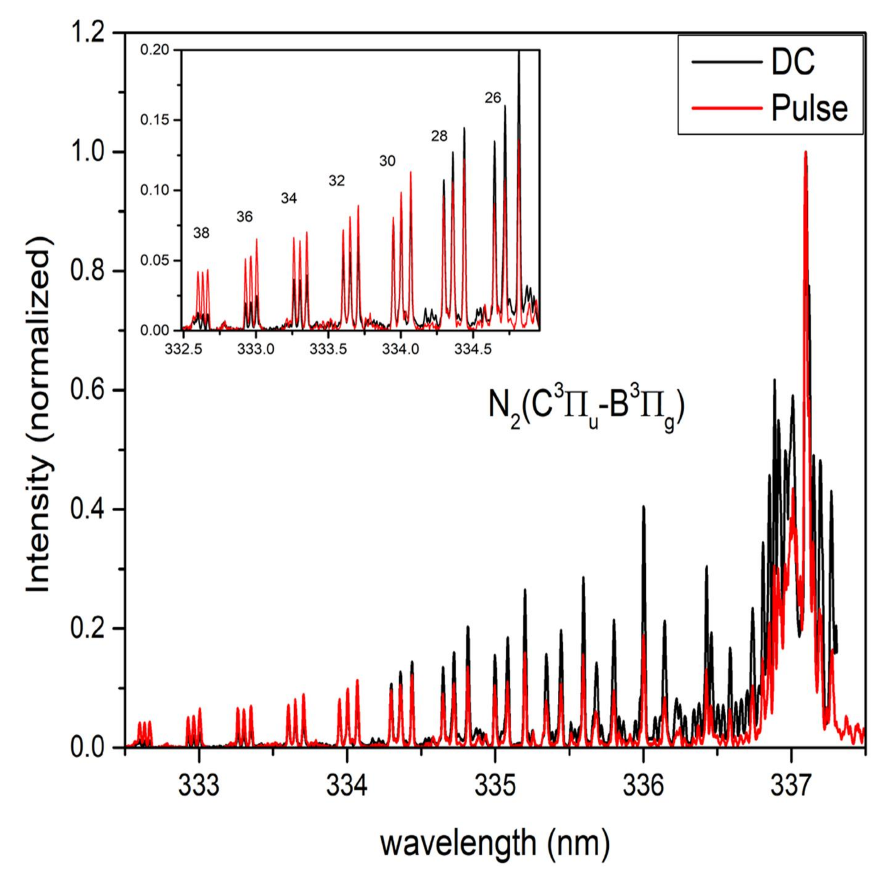

Figure 4. The comparison between $N_2(C^3\Pi_u-B^3\Pi_g)$ band recorded in the second order of diffraction grating during pulsed and DC regime. The enlarged part of spectrum showing R_2 branch lines with J'=26-38 is given in the inset. Experimental conditions: pulse width of 800 µs, duty cycle of 5 %, gap of 2.5 mm, I= 20 mA, U_{PULS}= 460 V (U_{DC}= 1500 V).

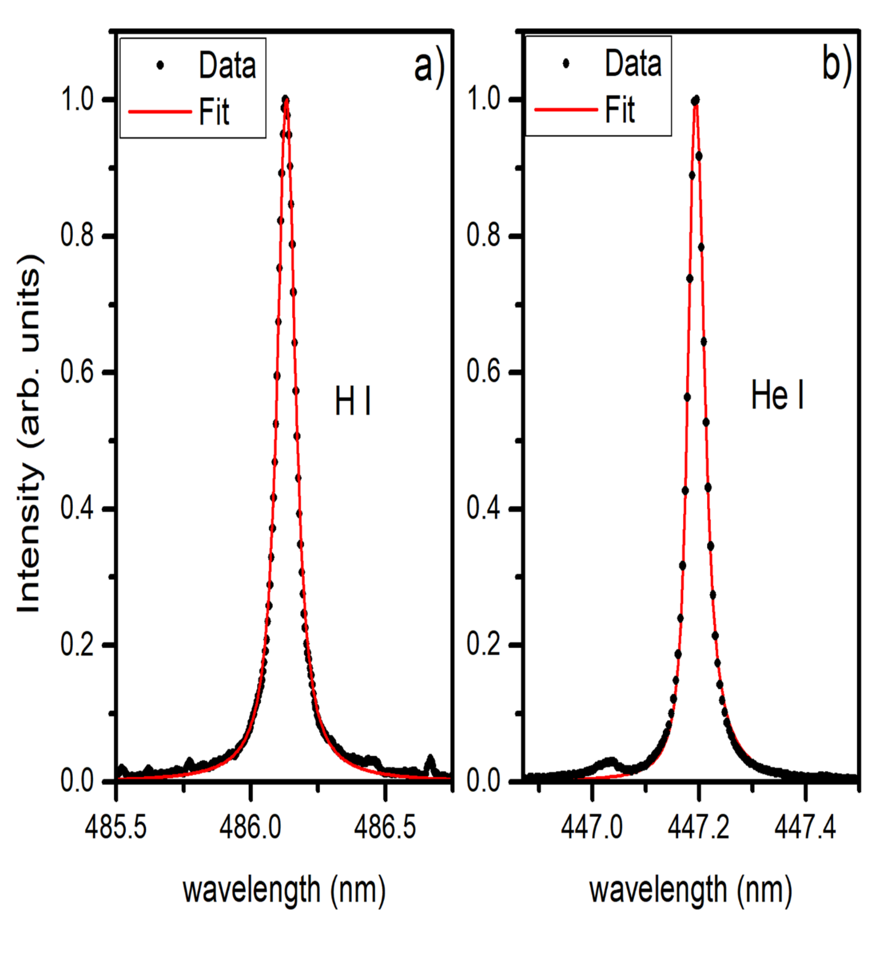

Figure 5. The best fit of (a) the H_β and (b) He I 447.2 nm line profiles recorded in the second order of diffraction grating. Experimental conditions: pulse width of 800 µs, duty cycle of 5 %, gap of 2 mm, I= 20 mA, U_{PULS}= 434 V (U_{DC}= 1500 V).

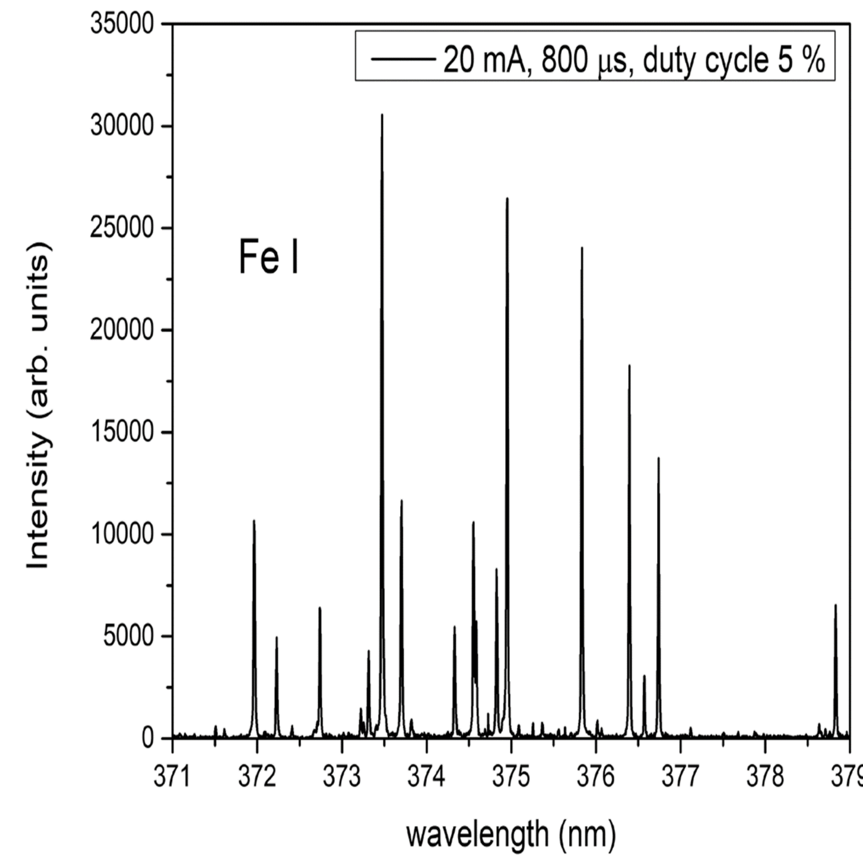

Figure 6. The spectrum of Fe I lines in the range of 371-379 nm (I= 20 mA and pulse width 800 µs). The diffraction grating operated in the second diffraction order.

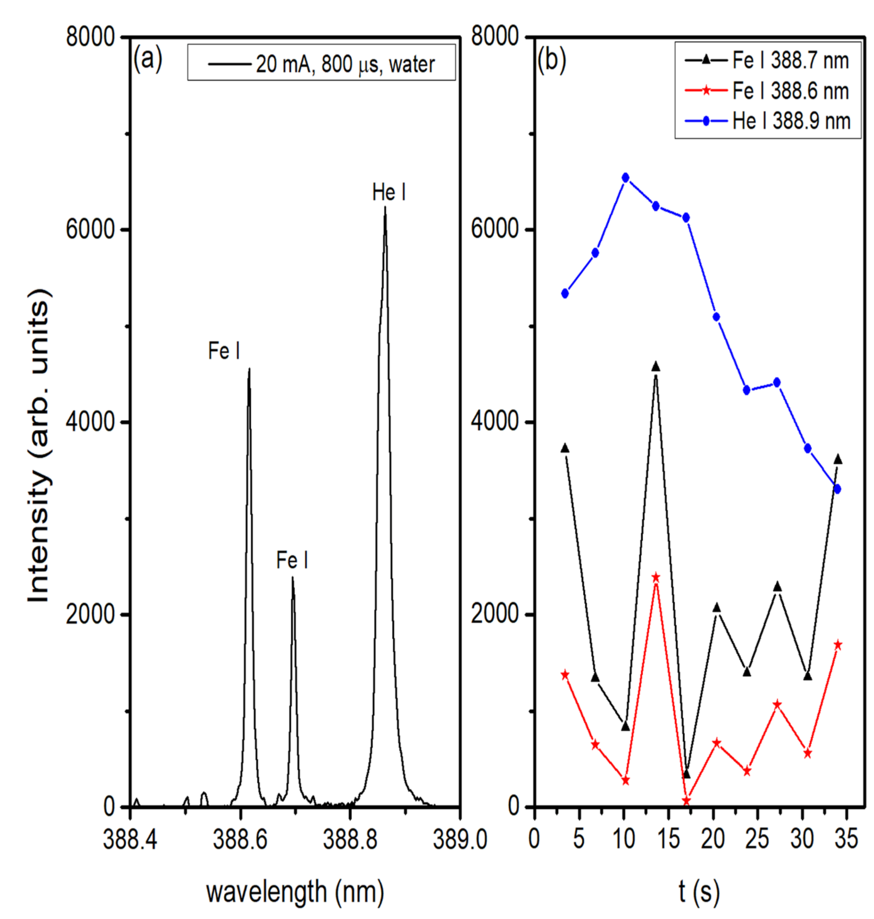

Figure 7. The Fe I and He I lines in the range of 388.4-389 nm: (a) the intensity alteration during time period of 0-35 s (CCD acquisition time 3400 ms). Experimental conditions: water drop treatment, pulse width of 800 µs, duty cycle of 5 %, overall gap of 3 mm, I= 20 mA, U_{START}= 800-1000 V, U_{STABLE}= 550 V.

Table 2. The **F/A** and N_e values (in 10^{15} cm^{-3}) measured from He I 447.2 nm line. The results for 5 mA and 10 mA are related to DC while for 20 mA N_e values correspond to pulsed regime.

	F/A	$Ne^{F/A}$	Ne^{FIT}
5 mA	0.1 ± 0.01	1.45 ± 0.2	1.25 ± 0.18
10 mA	0.11 ± 0.01	1.62 ± 0.2	1.05 ± 0.16
20 mA	0.051 ± 0.005	0.7 ± 0.1	0.77 ± 0.12

Table 3. The **s (nm)** and N_e values (in 10^{15} cm^{-3}) measured from He I 447.2 nm line. The results for 5 mA and 10 mA are related to DC while for 20 mA N_e values correspond to pulsed regime.

	s (nm)	Ne^{S}	Ne^{FIT}
5 mA	0.19 ± 0.005	1.63 ± 0.2	1.25 ± 0.18
10 mA	0.183 ± 0.005	1.4 ± 0.2	1.05 ± 0.16
20 mA	0.165 ± 0.005	0.57 ± 0.2	0.77 ± 0.12

References

[1] Jovović, J., Šišović, N. M. : 2015, *J. Phys. D: Appl. Phys.*, **48**, 365202.

[2] Majstorović, G. Lj, Jovović, J., Šišović, N. M. : 2017, *Contrib. Plasma Phys*, **57**, 282.

[3] Jovović, J: 2020, *Phys. Plasmas*, **27**, 053505.

SPIG 2020