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Dynamics of plasma parameters changing in a pulsed mode of the non-self-sustained arc discharge

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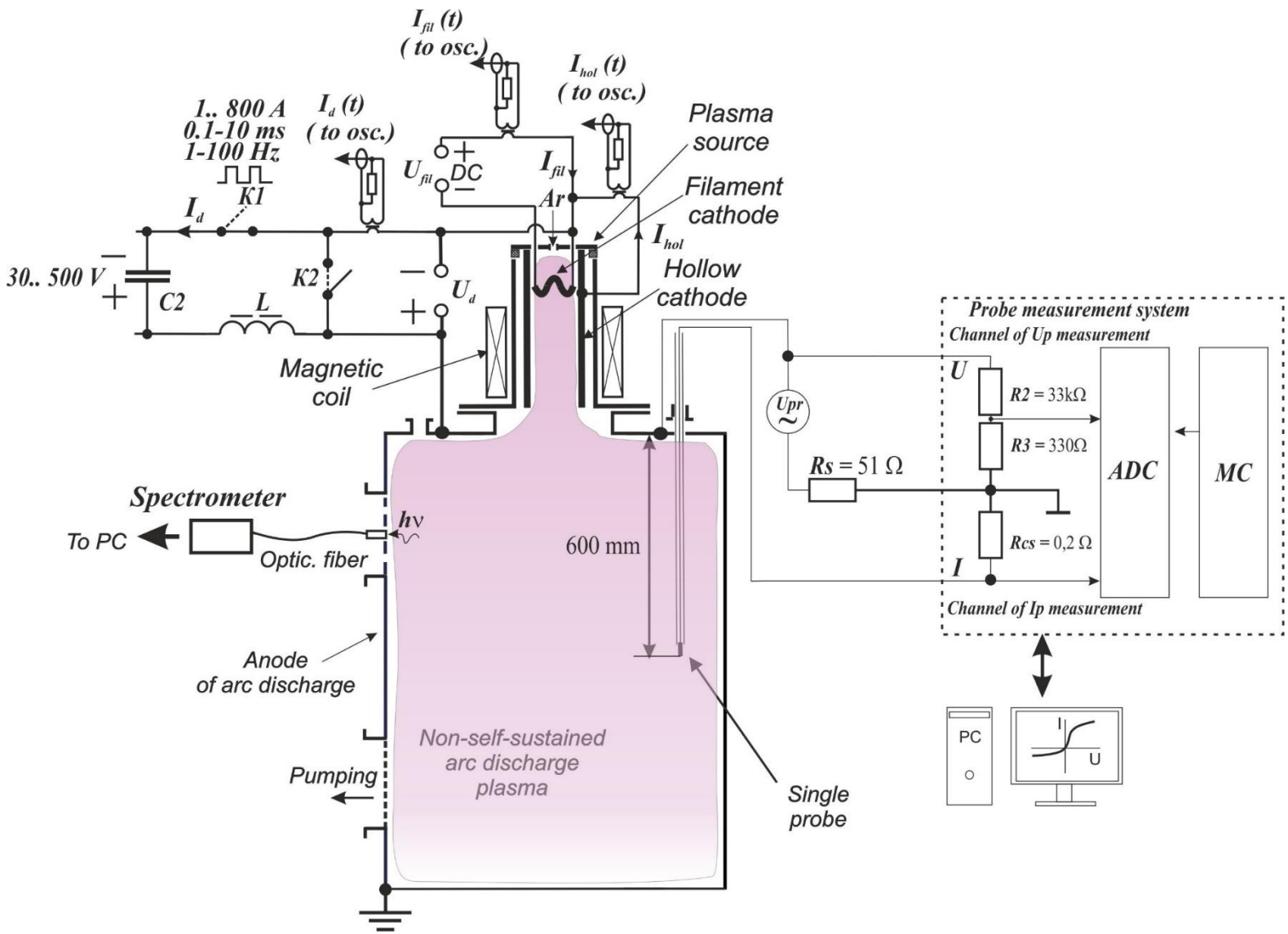
The Goal of the Investigation

To determine the influence of the conditions of burning of a non-self-sustained arc discharge in a plasma source with a thermionic and a hollow cathodes in a system with a hollow anode on the main characteristics and dynamics of plasma formation in the hollow anode.

Operating parameters:

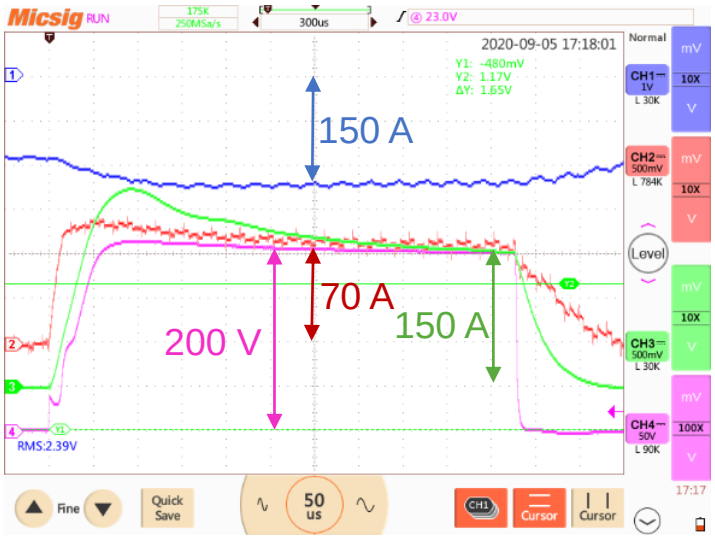
- Pressure;
- Discharge voltage;
- Magnetic coil current;
- Thermionic cathode current.

Experimental bench for the generation of a non-self-sustained arc discharge with hollow and thermionic cathodes



Waveforms of the arc discharge parameters

Conditions:
Gas – Ar;
Working pressure - 0,3 Pa;
Coil current - 0,6 A.

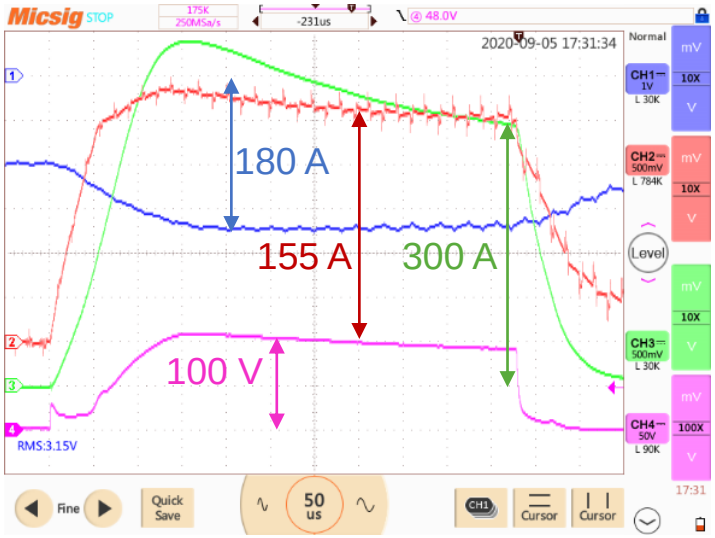


Pink – $U_d(t)$, discharge voltage (50V/cell);

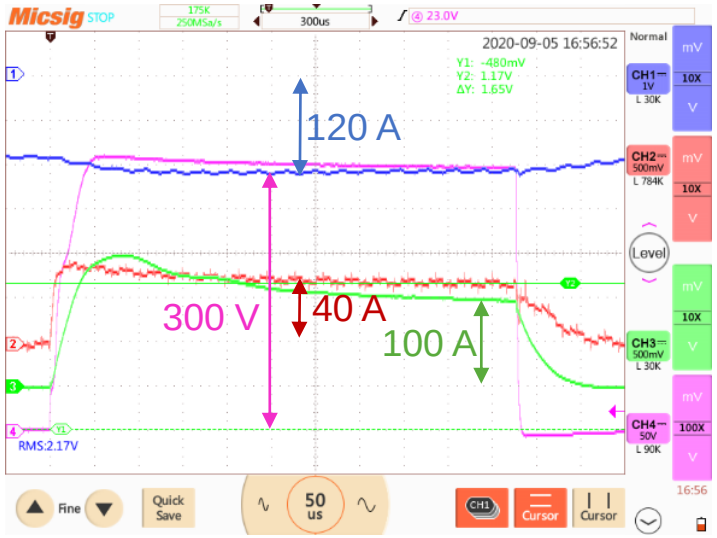
Green – $I_d(t)$, discharge current (50 Amperes/cell);

Red – $I_{hol}(t)$, hollow cathode current (30 Amperes/cell);

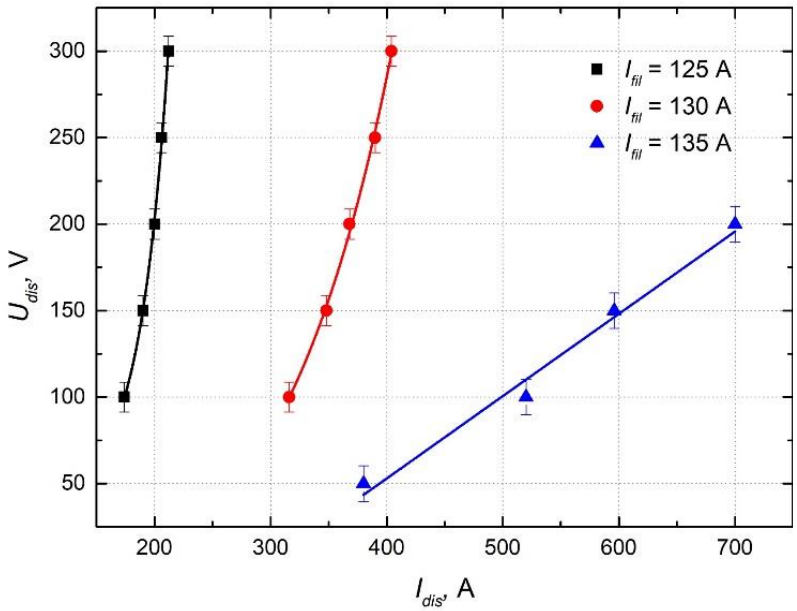
Blue – $I_{fil}(t)$, filament current (60 Amperes/cell).

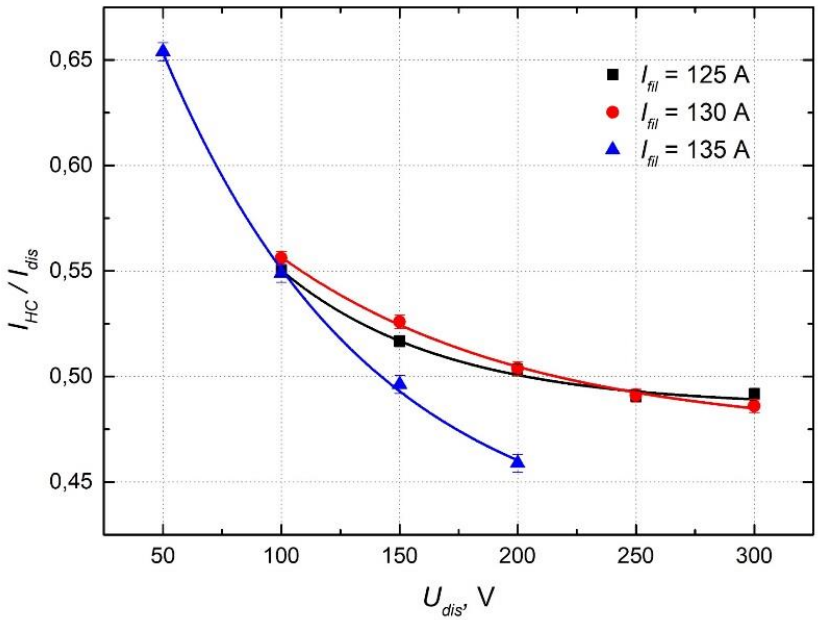


Three modes with similar pulse power. These modes was used in measurements of the plasma parameters.



V-I discharge characteristics and dependence of the discharge voltage on the hollow cathode current to discharge current ratio at different filament currents

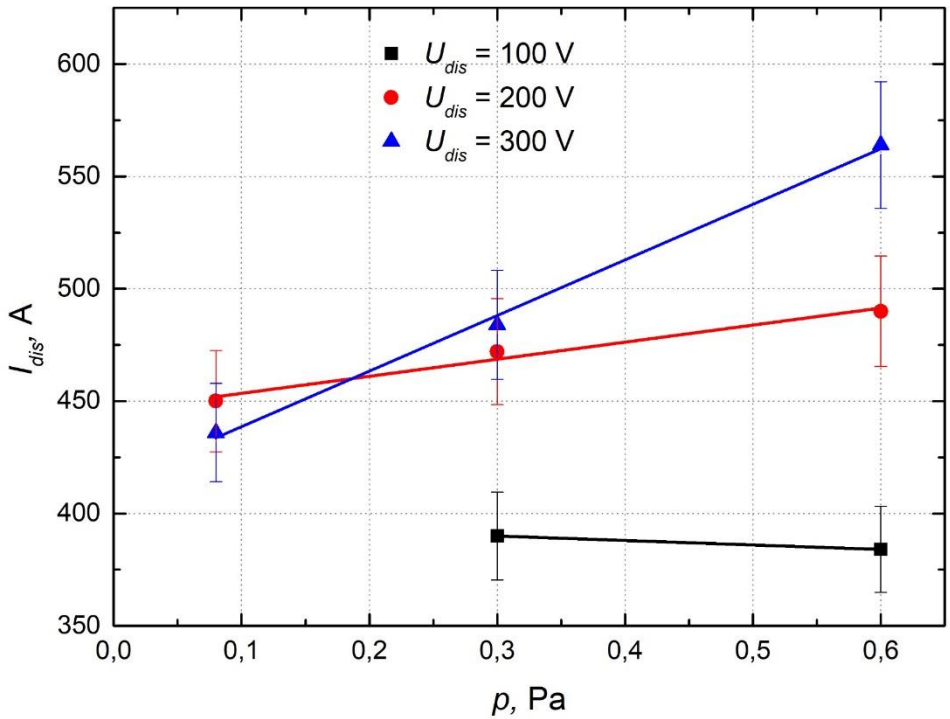




Gas – Ar;
Working pressure = 0,3 Pa;
Coil current = 0,6 A.

An increase of the discharge voltage leads to an increase in the thermionic-field emission current. The hollow cathode current remains practically unchanged.

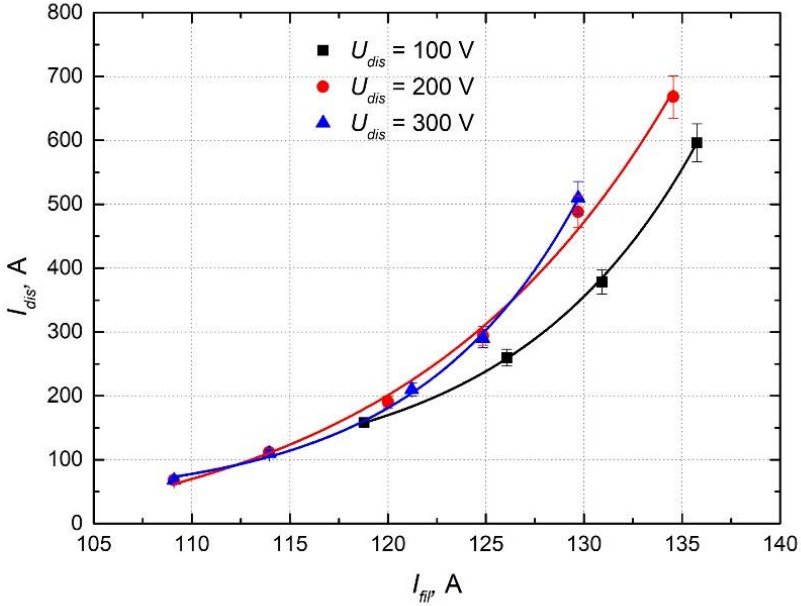
Influence of working gas pressure on discharge current at different discharge voltages



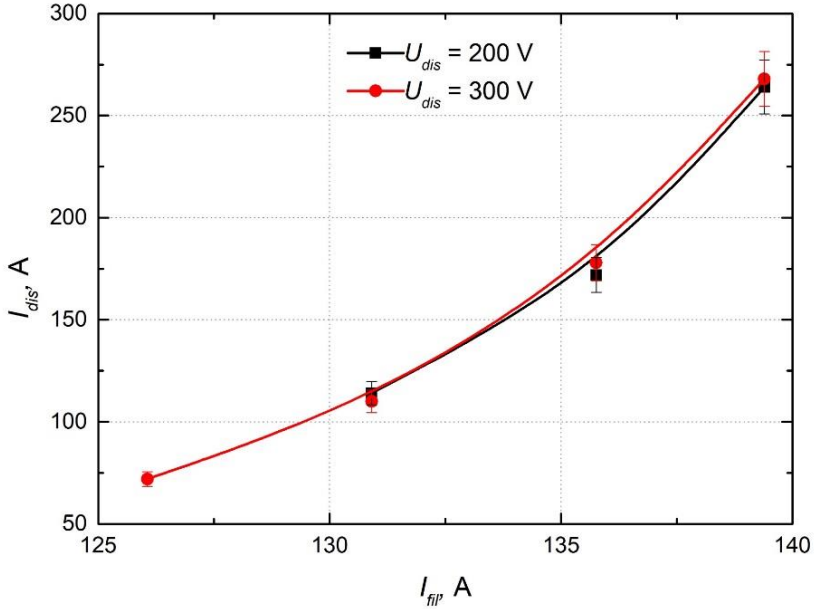
Gas – Ar;
Coil current = 0,6 A;
Filament current = 130 A.

An increase of the discharge current with increasing working gas pressure is associated with incomplete thermalization of the emitted fast electrons at high discharge voltages.

Influence of filament current on discharge current at different discharge voltages and gases



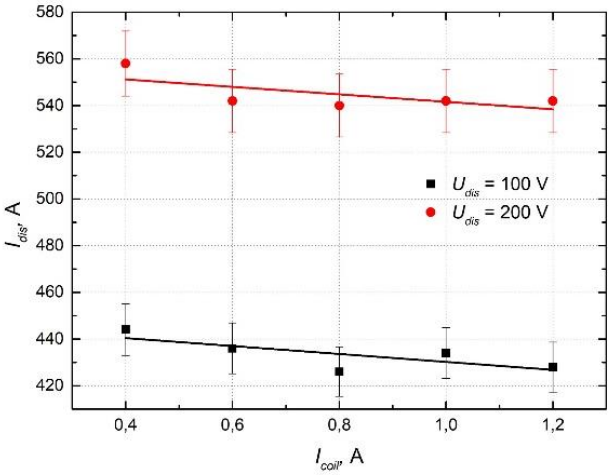
Gas – argon;
working pressure = 0,3 Pa



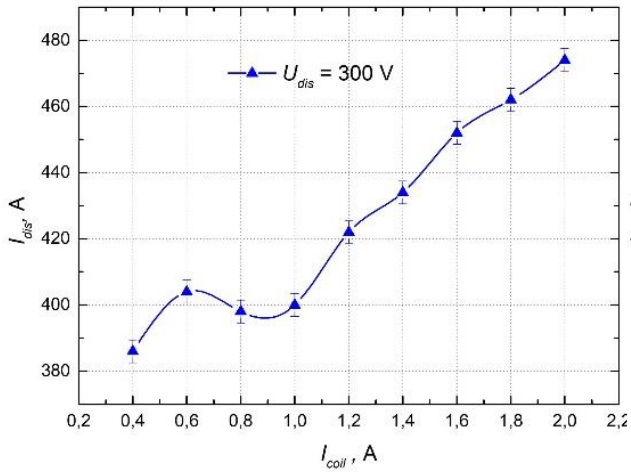
Gas – nitrogen;
working pressure = 0,3 Pa

Coil current = 0,6 A

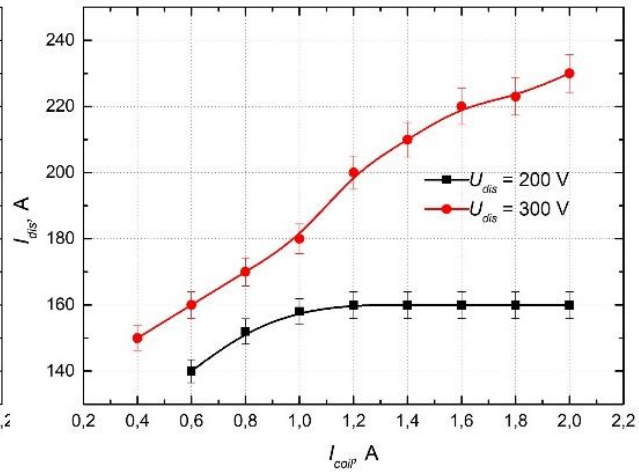
Influence of coil current on discharge current at different discharge voltages and gas type



Gas – argon;
working pressure = 0,3 Pa;
filament current = 130 A



Gas – argon;
working pressure = 0,3 Pa;
filament current = 125 A

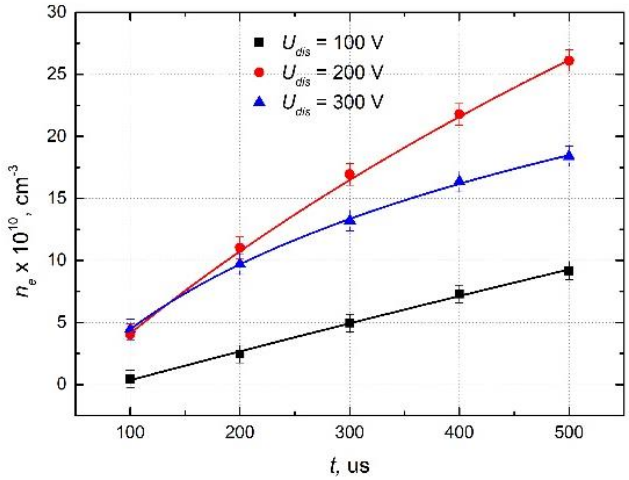


Gas – nitrogen;
working pressure = 0,3 Pa;
filament current = 130 A

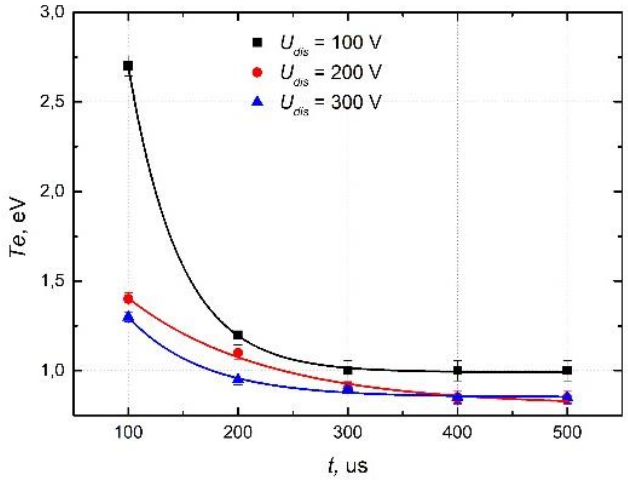
An increase of the discharge current with an increase in the coil current at discharge voltage of 300 V is associated with incomplete thermalization of fast emitted electrons and an increase in their path length in a larger magnetic field.

Dynamics of plasma parameters changing during a pulse of the non-self-sustained arc discharge

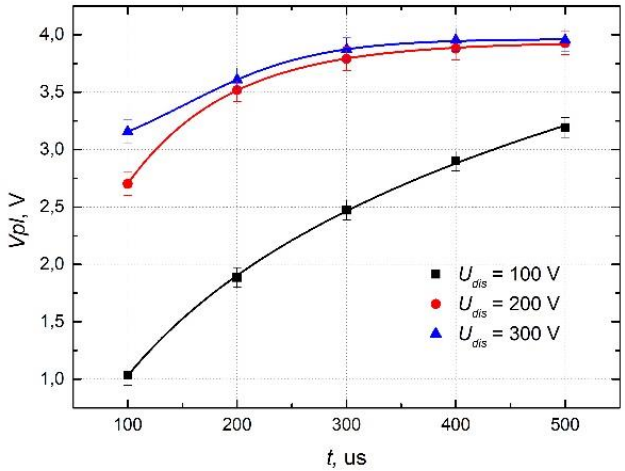
Plasma concentration



Electron temperature



Plasma potential

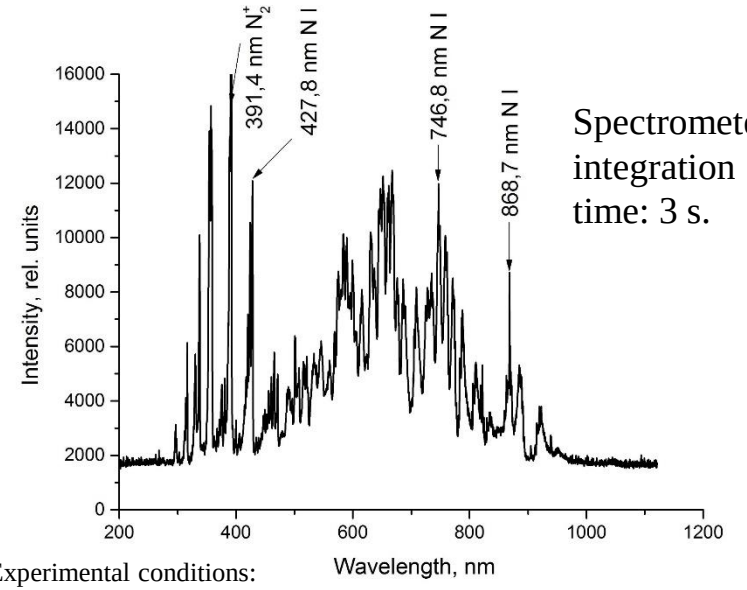


Gas – argon;
working pressure = 0,6 Pa;
filament current = 130 A;
coil current = 0,6 A

A single cylindrical electric probe was located in the center of the chamber. Probe measurements were performed every 100 μs of the discharge pulse. The measurements were carried out at three discharge voltages at similar discharge pulse power.

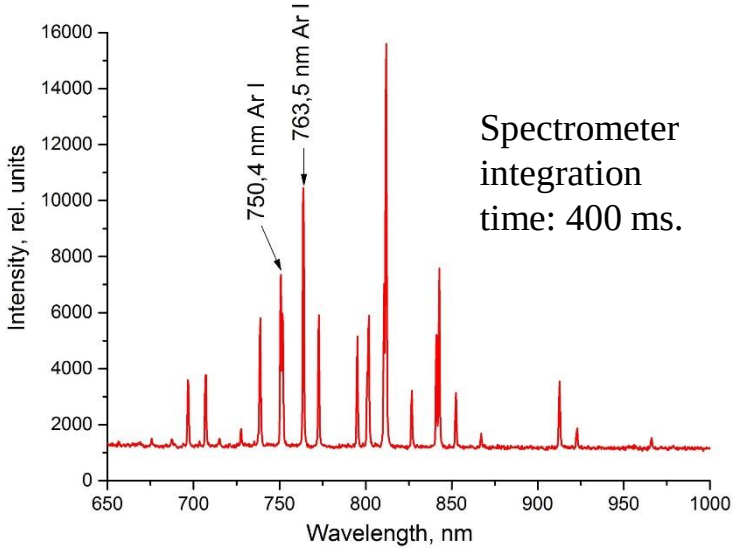
The increase in the plasma concentration for 200V as compared to 300V in this region is apparently associated with a decrease in the cross section of argon ionization with an increase in the electron energy. With an increase in the pulse duration, the electron temperature tends to values typical for the similar stationary discharges (~1 eV).

Emission spectra of (Ar, N2) plasma of pulsed non-self-sustained arc discharge



Spectrometer integration time: 3 s.

Experimental conditions:
U_{d_max} = 100 V, I_{d_max} = 240 A, I_{fil} = 113 A, $p(N_2)$ = 0,6 Pa, I_{coil} = 0,6 A, pulse repetition rate – 200 Hz, duty factor – 14 %.



Spectrometer integration time: 400 ms.

Experimental conditions:
U_{d_max} = 300 V, I_{d_max} = 180 A, I_{fil} = 112 A, p(Ar) = 0,6 Pa, I_{coil} = 0,6 A, pulse repetition rate – 200 Hz, duty factor – 14 %.

	Intensity, N^+_2 - 391,4 nm	Intensity, N I - 427,8 nm	Intensity, N I - 746,8 nm	Intensity, N I - 868,7 nm
U_{d_max} = 100 V, I_{d_max} = 90 A, I_{fil} = 109 A, $p(N_2)$ = 0,6 Pa, I_{coil} = 0,6 A, f = 200 Hz, γ = 28%	11422	5726	7770	4721
U_{d_max} = 100 V, I_{d_max} = 90 A, I_{fil} = 109 A, $p(N_2)$ = 0,6 Pa, I_{coil} = 1,5 A, f = 200 Hz, γ = 28%	3465	5567	15432	7636
U_{d_max} = 100 V, I_{d_max} = 180 A, I_{fil} = 113 A, $p(N_2)$ = 0,6 Pa, I_{coil} = 0,6 A, f = 200 Hz, γ = 14%	14033	6793	9530	5611
U_{d_max} = 100 V, I_{d_max} = 180 A, I_{fil} = 113 A, $p(N_2)$ = 0,6 Pa, I_{coil} = 1,5 A, f = 200 Hz, γ = 14%	3190	5741	13795	6769

$$N_2 + e \rightarrow N_2^+$$
391,4 nm

$$N_2^+ + e \xrightarrow{10^{-7}\ см^3/с} N^{**} + N$$
(746,8 nm, 868,7 nm)

An increase in the magnetic coil current from 0.6 A to 2 A at a discharge voltage = 100 V leads to an increase in the intensity of the plasma glow in the investigated region (near the output aperture of the hollow cathode) at line lengths of 746.8 nm and 868.7 nm (N I lines) by 60 and 100%, respectively, which indicates an increase in the number of recombination reactions of molecular nitrogen ions with the formation of atomic nitrogen in the studied plasma region.

Conclusions

- An increase in the pulse duration is accompanied by a proportional increase in the plasma concentration in the center of the chamber. In this case, the plasma concentration in the center of the chamber at a discharge voltage of 200 V is significantly higher than in other cases (~ 20% for 300 V and ~ 80% for 100 V). Apparently, this is due to the rapid thermalization of emitted electrons at 100 V (mean free path <15 cm at 0.6 Pa) and a smaller ionization cross section at 300 V (~ 20%).
- With an increase of the discharge pulse duration (≥ 200 μs) the temperature of plasma electrons decreases down to standard values for a similar types of discharge burning in a steady-state mode (~1 eV).
- With an increase in the pulse duration, the plasma potential increases to typical stationary values (3-4V). The growth rate of the plasma potential increases with the discharge burning voltage.
- An increase in the magnetic field due to an increase in the magnetic coil current from 0.2 to 2 A leads to an increase in the non-self-sustained arc discharge current by 20% at an increased (300 V) discharge voltage. An increase in the magnetic coil current from 0.6 A to 1.5 A at a discharge burning voltage of 100V leads to an increase in the intensity of the plasma glow in the investigated region (near the output aperture of the hollow cathode) at line lengths of 746.8 nm and 868.7 nm (N I lines) by 60 and 100%, respectively, which indicates an increase in the number of recombination reactions of molecular nitrogen ions with the formation of atomic nitrogen in the observable plasma region.

Thank you for attention!