

into the plasma generation region and the reaction chamber. The distance between the self-sustained discharge electrodes was 1 mm. The diameters of the conical holes in the peripheral electrode (2) were 8 and 20 mm. The diameter of the mushroom-shaped RGD cathode was 24 mm. The ballast resistors in the power circuits of RGD and SDRGD were 21.6 and 50 k Ω , respectively. The anode (peripheral electrode) is connected to the electrode and the cathode (ground) is connected to the peripheral flange (housing).

The current in the RGD power circuit was measured both by a milliammeter (I_{po}) and by oscillograms of the voltage across the 50 Ω measuring resistor (I_p). The voltage drop between the primary discharge electrodes of RGD was measured both by a kilovoltmeter with an input resistance of 10 M Ω (U_{po}) and by oscillograms from the output resistance of the 50 Ω voltage divider (1:10.000) – U_p .

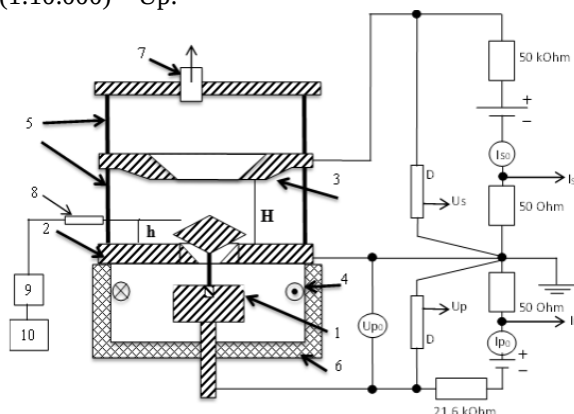


Fig. 2. Experimental setup for the activation of chemical transformations of gaseous substances by a secondary discharge plasma sustained by a rotating gliding discharge: 1 – high-voltage primary discharge electrode; 2 – grounding electrode; 3 – high-voltage secondary discharge electrode; 4 – gas inlet; 5 – quartz cylinder; 6 – dielectric; 7 – gas outlet; 8 – optical fiber; 9 – spectrometer; 10 – PC; 11 – liquid

The current in the SDRGD power circuit was measured both by a milliammeter (I_{so}) and by oscillograms of the voltage across the 50 Ω measuring resistor (I_s). The voltage drop between the primary discharge electrodes of RGD was measured both by a kilovoltmeter with an input resistance of 10 M Ω (U_{so}) and by oscillograms from the output resistance of the 50 Ω voltage divider (1:10.000) – U_s .

Fig. 3 shows a typical photograph of the secondary discharge – (b), sustained by a rotating gliding discharge – (a) at atmospheric pressure in an air stream.

The plasma parameters of the discharges were determined using UV and visible emission spectroscopy of the plasma (200...1.000 nm). The emission spectra were recorded using a Solar TII spectrometer. The values of electron temperature T^*e , vibrational temperature T_v , and rotational temperature T_r of the atomic and molecular levels were determined using calibrated curves for O atom, OH, and N₂ molecules. The calibration curves were constructed based on the results of numerical simulation of the emission spectra of the O, N₂ system (C-B) bands, and OH system (A-X) bands using the SPECAIR code [4, 5] in the temperature range of

500...20.000 K, taking into account the instrumental function of the Solar TII spectrometer (Gaussian with a width of 0.3 nm at half-height).

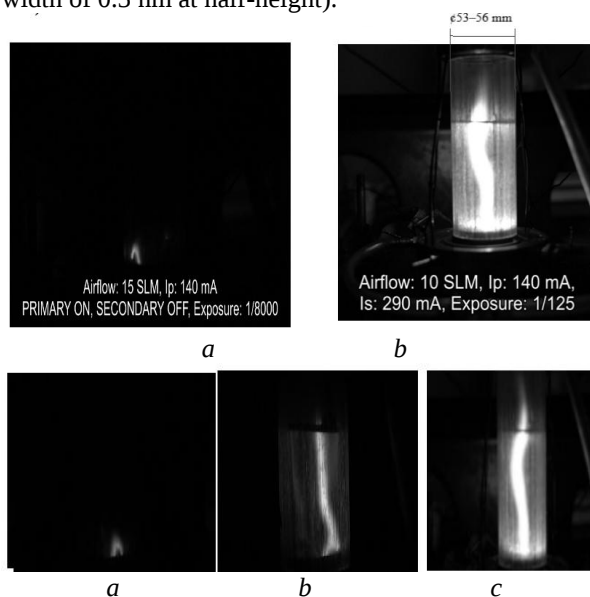


Fig. 3. Typical photographs of the rotating gliding discharge – (a) and the secondary discharge sustained by the rotating gliding discharge – (b) and (c), at atmospheric pressure in an air stream for the activation of chemical transformations of gaseous substances by a secondary discharge plasma sustained by a rotating gliding discharge

2. RESULTS AND DISCUSSION

2.1. ELECTROPHYSICAL PARAMETERS OF THE DISCHARGE

The volt-ampere characteristics of the discharge system (see Fig. 1), measured with analog instruments, for the primary and secondary discharges when the system was filled with distilled water with a volume of 100 ml are shown in Fig. 4.

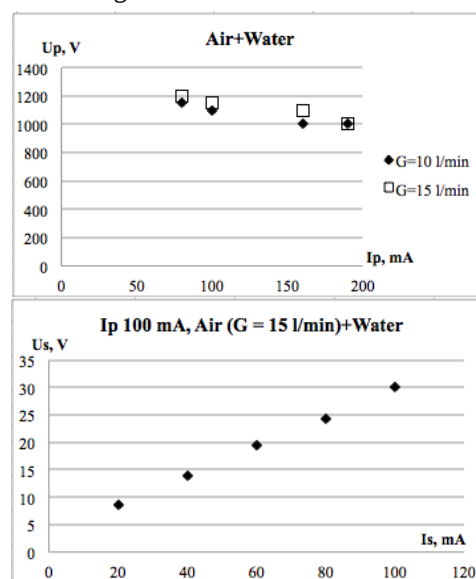


Fig. 4. Volt-ampere characteristics of the primary discharge – RGD at air flow rates of 10 and 15 l/min. Volt-ampere characteristic of the secondary discharge – SDRGD at a current of I_p 100 mA and an air flow rate of 15 l/min

As can be seen from the volt-ampere characteristics (V-A curves), the primary discharge has a decreasing nature and, within the measurement error, is weakly dependent on the gas flow rate. The V-A curve of the secondary discharge in the investigated range of currents has a linear character.

Typical oscillograms of currents and voltages in the RGD and SDRGD circuits, recorded on the setup for the activation of chemical transformations of gaseous substances by a secondary discharge plasma sustained by a rotating gliding discharge (see Fig. 2), are shown in Figs. 5 and 6, respectively.

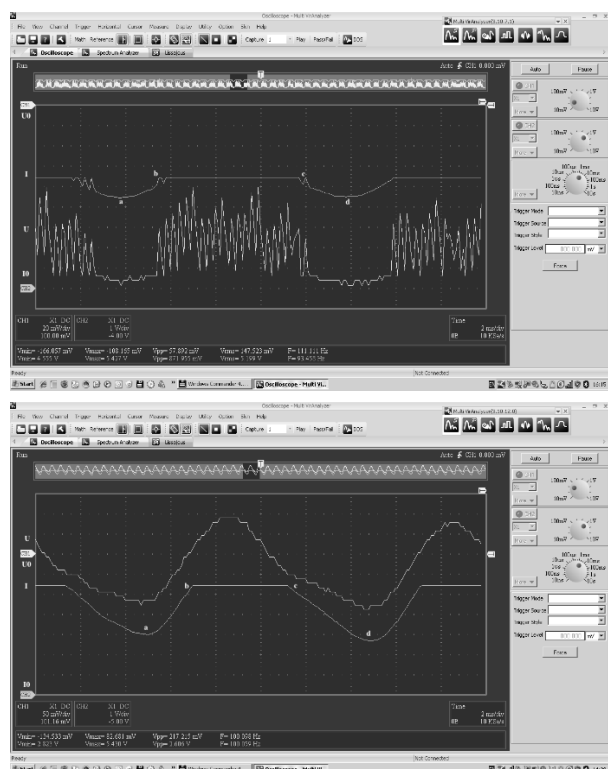


Fig. 5. Typical oscillograms of current and voltage in the RGD circuit recorded on the setup (see Fig. 1). At an air flow rate of 10 l/min, $I_{po} = 100$ mA

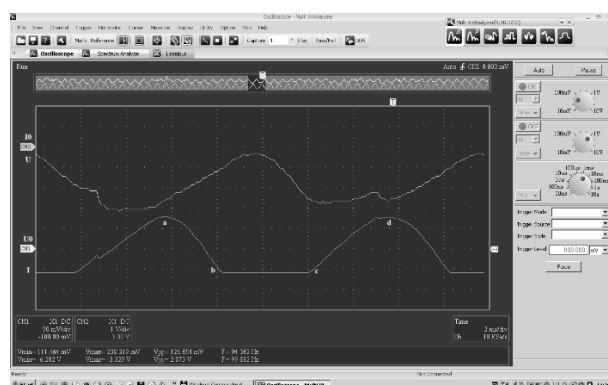


Fig. 6. Typical oscillograms of current and voltage in the SDRGD circuit recorded on the setup (see Fig. 2). At an air flow rate of 15 l/min, $I_{po} = 100$ mA, $I_{so} = 100$ mA, and a quartz cylinder height of 53 mm

The volt-ampere characteristics determined from the time intervals ab in the oscillograms in Figs. 5, 6 are shown in Figs. 7, 8.

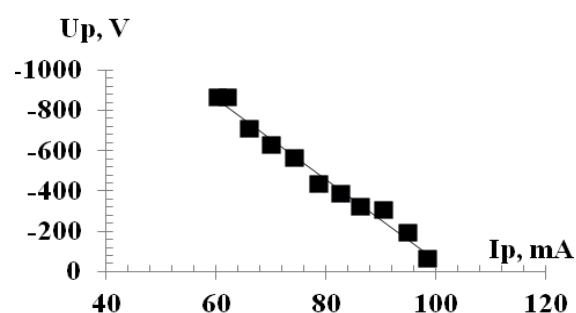


Fig. 7. Volt-ampere characteristics of RGD determined from the time interval ab in the oscillogram in Fig. 5.

At an air flow rate of 15 l/min, $I_{po} = 100$ mA, $I_{so} = 100$ mA, and a quartz cylinder height of 53 mm

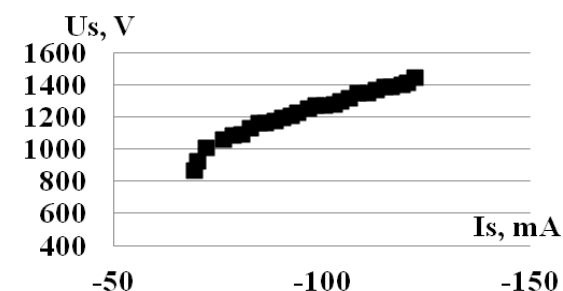


Fig. 8. Volt-ampere characteristics of SDRGD determined from the time interval ab in the oscillogram in Fig. 6. At an air flow rate of 15 l/min, $I_{po} = 100$ mA, $I_{so} = 100$ mA, and a quartz cylinder height of 53 mm

Typical results of spectral optical measurements of the dependence of radiation intensity – I for both RGD and SDRGD on the wavelength – L in the range of L 300...600 nm are shown in Figs. 9 - 13. For all measured emission spectra, there is characteristic radiation from OH (A-X), N_2 (C-B) molecular bands, and atomic lines of both the plasma-forming gas (O) and the components of the electrode material (major components of stainless steel – Cr, Fe).

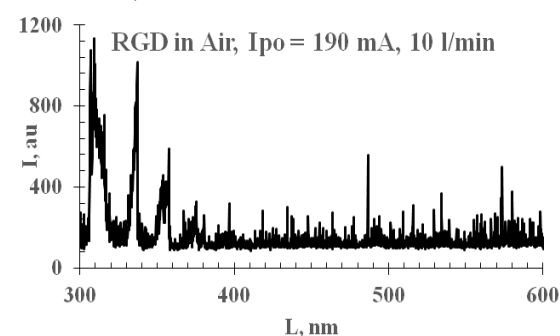


Fig. 9. Dependence of radiation intensity – I on wavelength – L for RGD in the plasma system (see Fig. 1) in the absence of liquid. At a current of $I_{po} = 190$ mA and an air flow rate of 10 l/min. $Tr(OH) = 2.900$ K, $Tr(N_2) = 4.000$ K, $Tv(N_2) = 4.000$ K, $Te(O) = 7.500$ K, $Te(Cr) = 7.500$ K

Comparison of the component composition of plasma radiation (see Figs. 9, 10) in the system with a secondary discharge submerged in liquid sustained by a rotating gliding discharge shows that when the system is filled with distilled H_2O , in addition to the above-mentioned components, the radiation of the A-X band of NH radical (336 nm) also becomes noticeable.

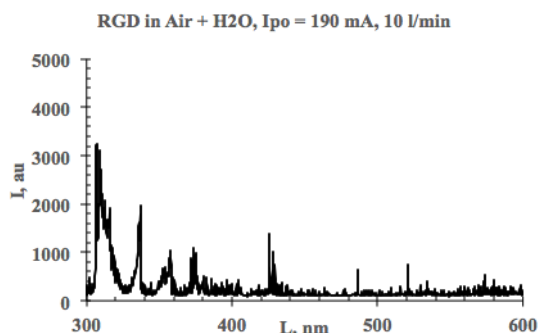


Fig. 10. Dependence of radiation intensity – I on wavelength – L for RGD in the plasma system (see Fig. 1) filled with distilled water. At a current of $I_{po} = 190$ mA and an air flow rate of 10 l/min. $Tr(OH) = 3.300$ K, $Tr(N_2) = 4.500$ K, $Tv(N_2) = 5.000$ K, $T^*e(O) = 5.200$ K

The temperatures of population of rotational and vibrational levels of molecules and electronic levels of atoms determined from $I(L)$ in Figs. 9, 10 are shown in Table. Comparison of the obtained values of population temperatures of different excited levels indicates the non-equilibrium nature of the plasma of the rotating gliding discharge in the air flow, both submerged and not submerged in water ($Tr < Tv < Te$). It is also noticeable that submerging RGD in water leads to an increase in plasma non-equilibrium due to a decrease in Tr and an increase in T^*e without a significant effect on Tv .

It should be noted that the level of non-equilibrium of the plasma in the RGD system in the setup for the activation of chemical transformations of gaseous substances by a secondary discharge plasma sustained by a rotating gliding discharge in the air flow (see Fig. 2) was practically similar. Although the systems differed significantly in the geometry of the cathode.

h, mm	RGD	$Tr(OH)$, K	$Tv(OH)$, K	$Tr(N_2)$, K	$Tv(N_2)$, K	$T^*e(O)$, K	$T^*e(Cr)$, K
5	Air	3800	-	4000	4000	-	5800
5	Air+H ₂ O	2900	-	4000	4000	7500	7500

SDRGD in Air, $I_{po} = 100$ mA, $I_{so} = 40$ mA, 10 l/min

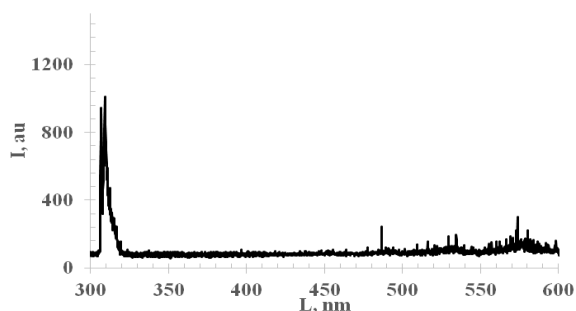


Fig. 11. Dependence of radiation intensity – I on wavelength – L for SDRGD in the plasma system (see Fig. 2, $h = 30$ mm, $H = 65$ mm). At a current of $I_{po} = 100$ mA, $I_{so} = 40$ mA, and an air flow rate of 10 l/min. $Tr(OH) = 2.800$ K

Interesting features were observed in the emission spectra of the secondary discharge plasma when changing the ratio of the current in the SDRGD power supply circuit to the current in the RGD circuit, i.e., I_{so}/I_{po} . Specifically, when $I_{so} < I_{po}$, only the emission of the (A-X) OH band was observed in the SDRGD plasma spectrum, with the absence of emissions from the 2+

system of N_2 (C-B) bands (see Fig. 11). In contrast, when the ratio (I_{so} / I_{po}) was ≥ 1 , emissions from the 2+ system of N_2 (C-B) bands appeared in the spectra of the secondary discharge plasma (see Fig. 12). Considering the significant difference in the excitation energy between the C state of nitrogen molecules and the A state of hydroxyl (OH) molecules, this effect may be attributed to a substantial change in the electron energy distribution function (EEDF) in the secondary discharge plasma as the current in this discharge (I_{so}) increases, while keeping the primary discharge current (I_{po}) constant.

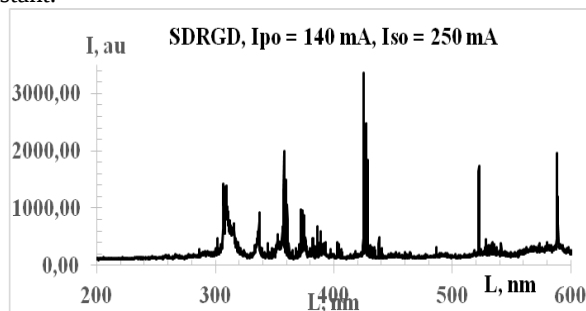


Fig. 12. Dependence of plasma emission intensity (I) on wavelength (L) for SDRGD in the plasma system (see Fig. 2). At a current of $I_{po} = 140$ mA, $I_{so} = 250$ mA, and an airflow rate of 10 l/min, with $h = 25$ mm and $H = 65$ mm

Based on the fact that both the intersection of the plasma column of the secondary discharge and its color and brightness are practically constant along the column (see Fig. 3), it can be assumed that the electric field – E in the plasma column of the secondary discharge is constant. Taking into account this assumption and the measured difference in voltage drop on the secondary discharge when changing the distance between the secondary discharge electrode and the primary discharge anode at constant discharge currents $I_{so} = I_{po} = 100$ mA and an air flow rate of 10 l/min, the value of E was estimated to be 300 V/cm. At atmospheric pressure and a kinetic temperature of the plasma $T \sim 2.800$ K as determined by Tr , the reduced electric field $E/N \approx 10$ Td.

As known [6], characteristic of gliding discharges in gas flows perpendicular to the discharge current channel is the sawtooth-like modulation of the voltage on the discharge, which is caused by the oscillatory nature of the change in the length of the discharge current channel, observed in high-speed video recording of the discharge. Taking into account the amplitude of the sawtooth signal (see Fig. 5) $\Delta U = 370$ V and the video image (see Fig. 3,a) $\Delta l \approx 0.3$ cm, the electric field in the plasma is $E \geq 1.200$ V/cm. At atmospheric pressure and a kinetic temperature of the plasma $T \sim 4.000$ K as determined by Tr , the reduced electric field $E/N \approx 57$ Td. Additionally, it is necessary to consider that the gas flow velocity and static pressure in RGD are lower than in SDRGD.

Thus, it can be argued that even with proportional currents $I_{so} = I_{po}$, the reduced electric fields of these discharges are significantly different. The significant differences in the electron energy distribution function (EEDF) due to this can be seen in Fig. 13, which shows simulated EEDFs in a mixture of $N_2/O_2 = 0.8/0.2$ plas-

ma at a temperature of 3.000 K for various values of E/N from 10 to 100 Td.

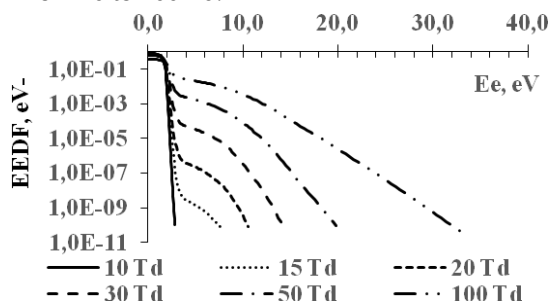


Fig. 13. Electron energy distribution function (EEDF)

CONCLUSIONS

It is shown that high-pressure plasma systems with a secondary discharge, which is supported by a rotating gliding discharge, can generate a non-equilibrium plasma of a significantly larger volume with a change in its parameters over a wider range of parameters than in systems with a self-sustained discharge with the possibility of scaling the plasma-chemical process.

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ВЛАСТИВОСТІ ПЛАЗМИ ВТОРИННОГО РОЗРЯДУ, ЩО ПІДТРИМУЄТЬСЯ ОБЕРТОВИМ КОВЗНИМ РОЗРЯДОМ

В.Я. Черняк, В.В. Юхименко, К.В. Юхименко, Д.Д. Третяков, О.М. Цимбалюк, С.С. Недовесов, З.О. Прокоф'єва

Наведено результати експериментального дослідження параметрів плазми вторинного розряду атмосферного тиску, що підтримується малопотужним (~ 100 Вт) обертовим ковзним розрядом у потоці повітря за умов значного перевищення довжини плазми каналу вторинного розряду від довжини каналу самостійного розряду в межах 1...100. Визначення параметрів плазми проводили методами емісійної спектроскопії плазми з використанням програми SpecAir. Оцінку напруженості електричного поля в плазмі вторинного розряду зроблено на основі залежності падіння напруги на розряді від довжини струмового каналу розряду.