acta phys. slov. 42 (1992), No. 2, 91–97

LASER ACTION ON CORONA PULSES[1)]

LAAN, M.,[2)] PARIS, P.,[2)] PERELYGIN, V.,[2)] Tartu

The influence of UV laser radiation on the formation and development of corona pulses were investigated. In the case of a positive point a nonbranched streamer was obtained which had good reproducibility in time and space. In the case of a negative point the formation of discharge pulses below the onset potential is explained by thermoionic emission, at higher voltages electron explosive emission is supposed to be active in pulse formation.

I. INTRODUCTION

Corona pulses have several interesting applications in plasma chemistry. However, many details of their nature have not been elucidated so far. The aim of our study was to investigate the corona pulse formation and development under the influence of UV laser radiation.

II. EXPERIMENTAL SET-UP

Corona pulses were investigated in a point-to-plane discharge gap (Fig. 1). The distance between the electrodes was 40 mm. The point electrode was a hemispherically capped platinum wire 1.2 mm in diameter. A plane electrode 150 mm in diameter was made from stainless steel grid. The discharge chamber was evacuated to residual pressure of 5×10^{-6} Torr and then filled with pure nitrogen up to the atmospheric pressure. Radiation from the UV pulse excimer laser ($n\omega = 4$eV, pulse energy ≤ 30 mJ, pulse duration $\approx$60 ns, repetition rate 5 p.p.s., the laser pulse shape is presented in Fig. 3) was directed along the discharge gap axis and focused by help of the lense (F=180 mm) at the distance of $\approx$ 5 mm from the point. Maximum mean intnesity (Fig. 3) of laser radiation was $I_0 \approx 5 \times 10^7$ W/cm^2. Radiation intensity was changed by calibrated grids. The plane electrode was grounded over the resistor $R = 50\Omega$. Light emitted by the discharge was detected using a movable slit 1 mm height, a monochromator M and a fast photomultiplier PM.

---

1) Contribution presented at the 8th Symposium on Elementary Processes and Chemical Reactions in Low Temperature Plasma, STARÁ LESNÁ, May 28–June 1, 1990

2) Tartu University, TARTU, Estonia

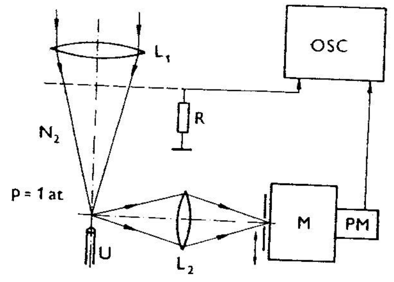

Fig. 1. Experimental set-up. osc - Oscilloseope, M - monochromator, PM - photomultiplier.

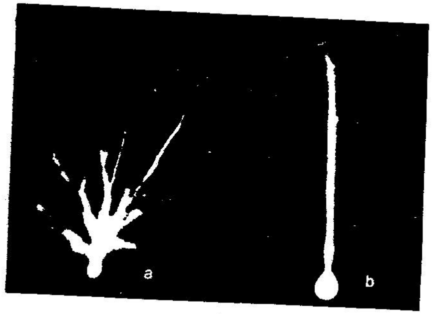

Fig. 2. Streamers fixed by image intensifier. a - spontaneous streamer, b - laser assisted streamer.

III. POSITIVE POINT

Experimental results

If there was no laser radiation, streamers were detected when the voltage exceeded U_0 = 11.4kV (Fig. 2a) and at U = 11.8kV a steady-state corona was established. All discharge characterstics were very similar to those found in [1]. As it was recorded at low voltage ($U = 0.3$kV) $\sim 10^7$ electrons were created along the gap axis by laser radiation. If $I = I_0$, then starting from U = 9kV a nonbranched streamer (Fig. 2b) developed along the laser beam path and at U = 10.5kV a streamer channel bridged the gap. Laser assisted streamer parameters were very stable in time and space. Delay time t_d depended both on voltage and intensity of laser radiation (Fig. 3) and had a jitter < 2 ns for t_d < 60 ns. The half-width (HW) of a single streamer trace on the photo was ≈0.1 mm and the HW of 600 overlapped streamer traces was 0.3 mm. Near the onset potential U_0 nonaxial branches started near the point and with the decrease of radiation intensity the axial branch became fainter and its length diminished. If $I = I_0/16$, the structure of the streamer resembled that of a spontaneous streamer. Current pulse amplitude i_{max} (Fig. 4) increased from 4 mA (U = 9kV) to 20 mA (U = 12kV). The current pulse duration exceeded 4 μs and HW of a current pulse at the same voltage did not depend on the intensity of laser radiation I. The duration of the light pulse (λ = 337 nm) emitted from the channel part 1 mm in legth was < 15 ns. The propagation velocity of the channel was determined. It depended strongly on the presence of laser radiation. At higher I, the velocity had the value of up to 8x10^{7}cm/s. After the termination of the laser pulse the velocity diminished quickly to the value of 3x10^6 cm/s for all voltages used in the experiment.

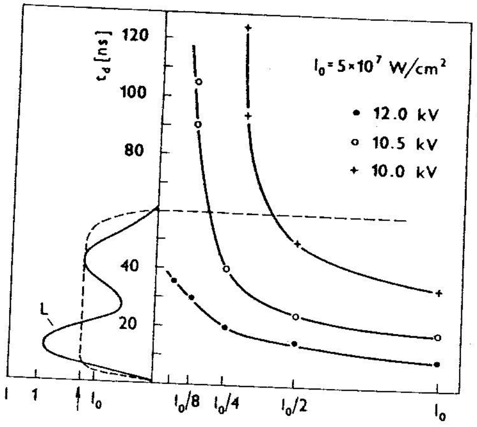

Fig. 3. Delay time t_d dependence on laser intensity for different voltages; L - laser pulse.

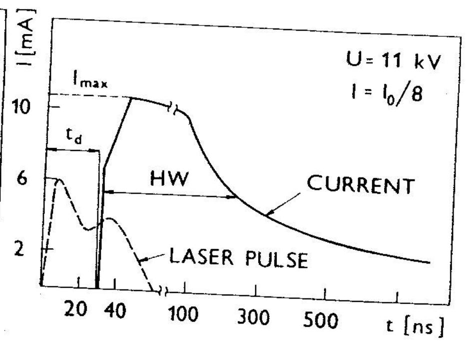

Fig. 4. A typical current pulse.

Discussion

According to experimental results the following qualitative explanation of the laser-assisted streamer formation and development may be proposed. Near the laser beam focus primary electrons are generated. They move towards the point electrode in the DC field which is superimposed by a week laser field. The electrons absorb energy from the laser field by induced free-free transition. This process influences mainly the tail of the electron distribution function, which causes the increase of the ionization rate [2]. It makes the streamer formation possible at voltages below the onset potential. After that the streamer develops along the weakly preionized (and/or excited) path created by the laser beam. The streamer velocity increase in the laser field can be explained by the radiation influence on the distribution function as well. Such a laser-assisted streamer is a convient object for further theoretical investigation.

IV. NEGATIVE POINT

Experimental results

It is known [3] that under pure conditions in nitrogen there are two different steady state modes of a point-to-plane discharge. Transition from one state to another occurs with the appearance of the current and light pulses similar to those in the case of a Trichel pulse in air. Our conditions were not pure enough and for that reason the discharge near the onset potential existed in a pulsed form. The onset potential of spontaneous Trichel pulses was 9.2 kV. The current pulse achieved its maximum value of 5 mA after 5 ns, it was followed by a slow decay and after 1.5 μs a quasistationary value of 0.2 mA was established ("tail" of the pulse). After the filling of the discharge chamber with pure gas the tail lasted longer than after some days of work (Fig. 5). When the discharge chamber was refilled, the previous pulse duration was achieved. If the laser radiation was directed into the discharge gap, current pulses were recorded already at $U = 2$kV. Charge $q = \int idt$ created per pulse as a function of voltage is presented in Fig. 6 ($I_0 = 3\times10^7$W/cm^3). If $U < 7$ kV, q strongly depended on the laser pulse intensity, the duration and the shape of the current pulse corresponded to the shape of the laser pulse.

Typical schematic current pulses for $U > 7$ kV are presented in Fig. 7. The amplitude value i_{max} of the sharp peak at the beginning of the current pulse as well as its shape were correlated with the laser pulse intensity and its "fine" structure. For $t > 60$ ns the current pulse time dependence did not differ from the shape of the spontaneous pulse. If $I \sim 10^7$W/cm^2, the current pulse had a delay time of $t_d \approx 5$ ns from the beginning of the laser pulse. If $I \sim 10^6$W/cm^2 and $U = 8.3$kV, $t_d = 90$ns. The laser radiation energy concentration was high enough to cause thermoionic emission from the point. Thus if we suppose that i_{max} was determined by the surface temperature T ($T \sim I$) and the field strength E ($U \sim E$), $\ln(i_{max})$ must be a linear function of $\sqrt{U}$ [4]. As we can see in Fig. 8 the assumption of a thermoionic nature of the electron emission explains the results recorded in the experiment quite well. The main conclusions are :

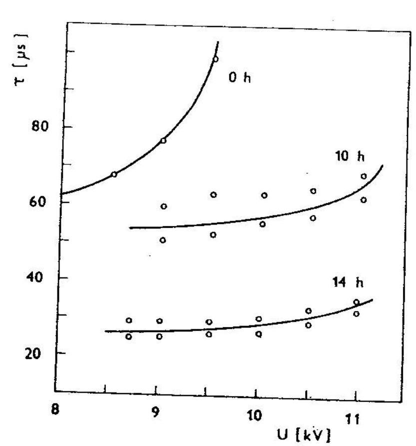

Fig. 5. Trichel pulse duration as a function of voltage for different conditions.

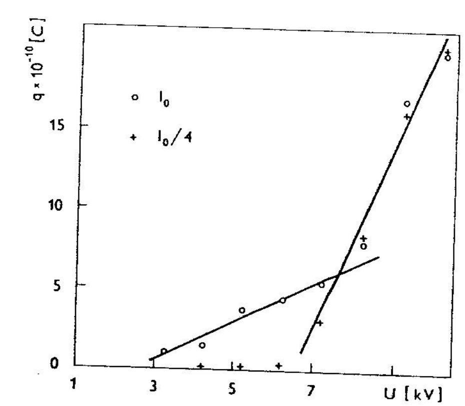

Fig. 6. Charge per pulse ($q = \int idt$) as a function of voltage for different intensities I.

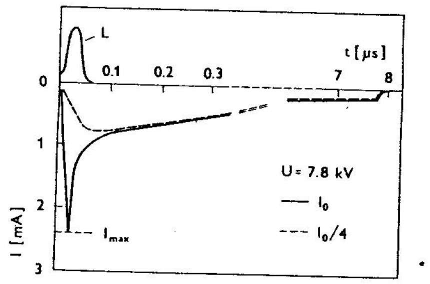

Fig. 7. Schematic representation of current pulses.

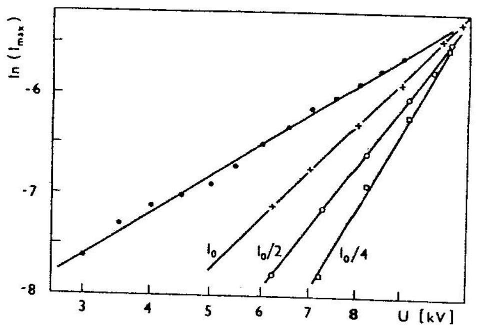

Fig. 8. Logarithm of the i_{max} as a function of $\sqrt{U}$ for different intensities I.

1. The magnitude of the first peak of the current pulse is the function of E and T.

2. It is possible to create typical Trichel pulses on voltages remarkably lower than the onset of a spontaneous one. Consquently the formation of a Trichel pulse is not determined only by ionization processes in the gas.

3. The role of the laser radiation diminishes with the voltage increase, near the spontaneous pulse onset the dependence of i_{max} on the radiation intensity (surface temperature) is weak.

4. The current pulse tail duration has a strong dependence on impurities.

V. DISCUSSION

Usually the formation of the Trichel pulse is explained by the gas ionization by electrons accelerated in the electric field. This model was used in Morrow's theory [5]. The existence of a step in the leading part of the current pulse was explained by a different influence of the γ_p and the γ_i mechanism [6]: at the beginning of the pulse γ_p is active, in the later stages it is replaced by a more effective γ_i mechanism. As a result of our measurements another explanation of the pulse formation is available. In [7] it is mentioned that field emission can play a role in pulse formation. Field emission is effective from the micropoints (or dielectric films) on the electrode surface [4]. As a result Joule heating of these irregularities and their explosion take place. Such a process is an effective source of electrons. We suppose that the step in the leading part of the current pulse as well as the "precursor" before the pulse [8] are due to explosive emission. Below the onset potential an additional source for electrode heating is needed (in our case - laser radiation).

The fact that for $t > 60$ ns the shapes of the Trichel pulses below and above the onset potential are the same indicates that ionization mechanisms in these stages do not differ. Recently the results of spectroscopical measurements of the Trichel pulses have been presented [9,10]: the ionization mechanism by the electron impact with the N_2 ground state is active only in the first ten nanoseconds, when the field strength near the point electrode is high enough, later ionization by means of the metastable *A*-state takes place. Consequently, the duration of the current tail is connected with the concentration of the *A*-state metastables. If the discharge occurs, a small amount of admixtures is released from the electrode surface. A possible maximum concentration of impurities is too low to stop the Trichel pulse by quenching the metastables. More realistic is an assumption that these admixtures (as it is shown in [11]), which have a lower ionization potential than N_2, modify the electron distribution function and as a result the rate coefficient of the *A*-state excitation diminishes: with an increasing admixture concentration the tail duration of the current pulse diminishes.

REFERENCES

[1] Korge, H., Kudu, K., Laan, M.: *3rd ISHVE*, paper 31.04, 1979.
[2] Popov, A. M., et al, Thermophys. High Temperatures USSR, vol. *27* (1989), 173.
[3] Korge, H., Laan, M., Susi, J., Acts Comment. Univ. Tartuensis, no. *824* (1988), 25. (in Russian).
[4] Korolev, Yu. D., Mesysts, G. A., in *Field emission and explosive processes in gas discharge*. Novosibirsk 1982 (in Russian).
[5] Morrow, R., Phys. Rev. *A32* (1985), 1799.
[6] Morrow, R., Phys. Rev. *A32* (1985), 3821.
[7] Černák, M., *Proc. 17 th ICPIG*, Contr.papers (1985), 573.
[8] Černák, M., Kaneda, T., and Hosakava, T., Jap. Appl. Phys. *28* (1989), 1989.
[9] Korge, H., Laan, M., Susi, J., *9 th ESCAMPIG*, Cont. papers (1988), 115.
[10] Korge, H., Kuusk, U., Laan, M., Susi, J., Plasma Phys. USSR, *17* (1991), 473.
[11] Apollonov, V., et al. Lett. Techn. Phys. USSR, *13* (1987), 1363.

Received October 18th, 1990
Accepted for Publication January 4th, 1991

ВЛИЯНИЕ ЛАЗЕРНОГО ИЗЛУЧЕНИА НА КОРОННЫЕ ИМПУЛЬСЫ

Исследованно влияние УФ лазерного излучения на коронные импульсы. В случае положительного острия получен одноканальный стример, который имел хорошую повторяемость как в пространстве так и во времени. В случае отрицательного острия формирование импульса при подпороговых напряжениях объяснимо термоэмиссией, при более высоких напряжениях – взрывной эмиссией.