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# AN ATTEMPT TO EXPLAIN THE OBSERVED DISCREPANCIES OF SOME PARAMETERS OF A XENON PLASMA COLUMN IN A FLASHTUBE

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The present stage of studies concerning the xenon plasma column in a flashtube is discussed. The conditions for the appearance of a quasistationary state were analysed. An explanation for the discrepancies observed is proposed basing on the analysis of a quasistationary state, conductivity and line spectra of xenon plasma, impurity and gas pressure of the atmosphere inside a flashtube, and the voltage-current characteristics of a discharge.

## *1. Introduction*

During the last decades impulse discharges in noble gases, especially in xenon, have been intensively studied both experimentally and theoretically. This is because of the properties of this type of plasma which allow one to apply the plasma as a very efficient light source [1–3]. Elaborating the true relations between different parameters of plasma is very difficult. Phenomena in a flashtube are extremely complicated and not stable in time and therefore, they are not fully recognized.

On the other hand, the lack of agreement between different works [4–8] further complicates the situation, because one can expect that the experimental data should agree with theoretical formulas, but they do not.

There are some works [9–14] whose authors have tried to construct a model of the quasistationary state of the plasma by avoiding the quickly changing phase of a discharge. In these models, the authors took account of the experimental relations between the parameters of a discharge and the plasma itself. They also had to use some approximations. As might be expected, the use of such models is restricted to plasmas that fulfill some preliminary assumptions.

Some calculations concerning the conductance of the xenon plasma using Spitzer's model have already been made and their results have been compared to the values experi-

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mentally determined [4, 15–16], thus showing that the model does not conform to xenon plasmas. The calculated values are about two times higher than those of the experiment. Some attempts, which have been made [8, 15, 16] to explain this, are not valid because the authors have not taken into account all the important factors connected with the properties of real plasmas.

It is a practical necessity in predicting the properties of the impulse xenon plasma forces to search for semiempirical formulas which would combine parameters of the plasma itself [6, 9–14]. The divergence of experimental data might be partially solved by using new measurement techniques featured by lower measurement error [15] and by studying other factors affecting the discharge and plasma parameters. It is thought that to these factors belong:

— the change in the composition of an atmosphere caused by thermic decay in the walls of a flashtube [2, 8, 17],

— the change of density of the plasma caused by gas dynamic processes connected with the high gradient of pressure [18],

— the initial conditions of a discharge [19–22].

The study of the influence of these factors on the characteristics of a discharge and the parameters of plasma has been intensively analysed during the past few years and partially analysed in this work.

## 2. *Quasistationary state of a discharge*

It is generally accepted that a quasistationary state of a discharge is achieved when plasma fills up the cross section of a flashtube. Its geometry is constant, displacement of the gas is practically absent and the energy released from the electric field in a volume of plasma and in a unit of time is equal to the energy transferred from the plasma to the surrounding area.

The results of many experimental works were obtained under the assumption that measurements were taken when the quasistationary state of plasma was achieved. The conditions for the existence of such a state was seldom analysed [4, 10, 13]. In short, the result of such an analysis might be formulated as follows. The existence of a quasistationary state of plasma is possible only when the duration time of the current impulse is longer than the relaxation time of basic processes which lead to the thermal and gas dynamic equilibrium in the entire volume of a discharge limited by the walls of a flashtube. The thermal equilibrium is reached when the distribution of a temperature gradient is established in the cross section of the plasma.

The distribution of the temperature gradient was experimentally determined by the authors of [4, 23, 24]. They stated that the ratio $T_r/T_m$ is a function of the ratio $r/r_0$, where $T_r$ is the temperature at a distance $r$, from the wall of a flashtube, $T_m$ is the temperature at a distance, $r_0$, from the wall of a flashtube, i.e., on the axis of a plasma column. The highest temperature gradient is observed only in the layer near the wall of a flashtube. The thickness of such a layer is equal to about $4 \cdot 10^{-2}$ of plasma cross section. Therefore, the xenon plasma column is considered to be thermally stable. The ratio $T_r/T_m$ during the

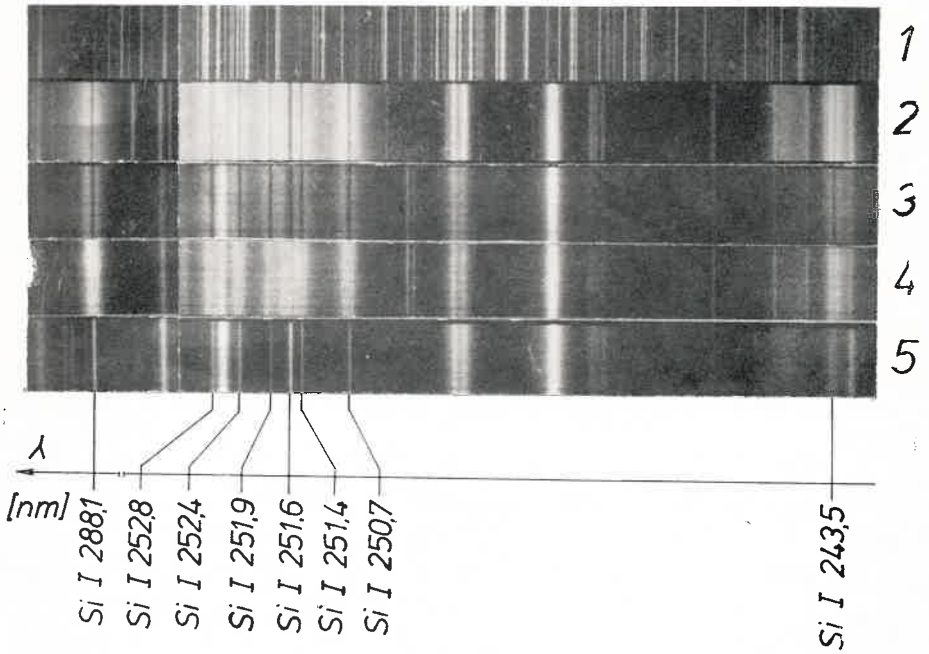

Fig. 1. Spectrum of iron arc — *1*. Spectra of xenon plasma obtained in the lamp with the constructive parameters: $d = 0.7$ cm, $l = 11$ cm, $V_b/V_p = 11$, $p_0 = 26.6$ kPa, and at the parameters of the discharges: *2* — $\tau = 1$, $j = 2.2$; *3* — $\tau = 1$, $j = 1.7$; $\tau = 3$, $j = 1.4$; *4* — $\tau = 3$, $j = 1.1$; $\tau = 1$, $j = 1.4$; *5* — $\tau = 1$, $0.6 \leqslant j \leqslant 1.3$; $\tau = 3$, $0.3 \leqslant j \leqslant 1.0$, where $j$ in kA/cm², $\tau$ in ms

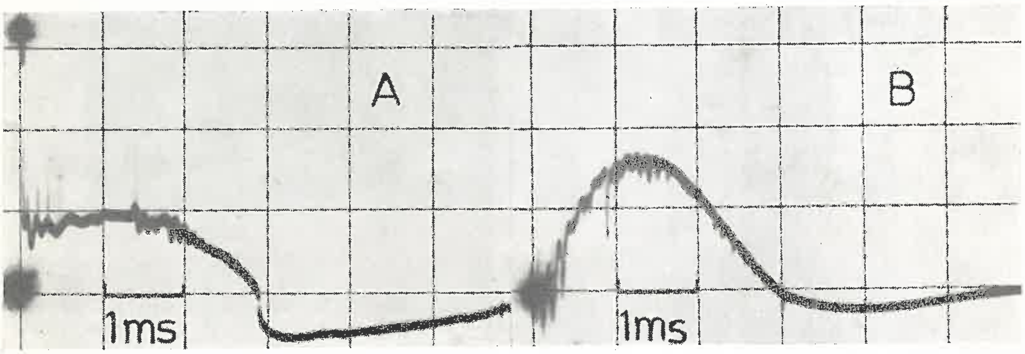

Fig. 4. Oscillograms of voltage A and current B of a discharge at $\tau$ = 3 ms and $j$ = 0.45 kA/cm$^2$ in the lamp as shown in Fig. 1

appreciable part of the duration time of a current impulse (about 0.5 $\tau$) depends somewhat on time. In this period the quasistationary state of the plasma is achieved.

The relation between the initial conditions of a discharge and the time needed to fill up the cross section of a flashtube, when $T_r/T_m$ is quite stable, was determined [13]:

$$t = 26dp_0^{1/2}E_0^{-3/2}, \tag{1}$$

where $t$ is in s, $d$ is the inside diameter of a flashtube in m, $p_0$ is the initial pressure of gas in Pa and $E = U_0/l$ is the initial intensity of the longitudinal electric field in V/m. Usually $p_0$ and $E_0$ belong to the following ranges: $1\ \text{kPa} \leqslant p_0 \leqslant 10^2\ \text{kPa}$; $5 \cdot 10^{-3}\ \text{m} \leqslant d \leqslant 4 \cdot 10^{-2}\ \text{m}$; $3 \cdot 10^3\ \text{V/m} \leqslant E_0 \leqslant 10^5\ \text{V/m}$. The $t$-values calculated for extreme conditions using formula (1) are equal to $10^{-3}$ s and $2 \cdot 10^{-7}$ s, respectively.

As it can be seen, $t$ may be higher than the duration time of a current impulse or it may be comparable to the relaxation time of different processes (about $10^{-6}$ s, [4] leading to the establishment of an equilibrium in the plasma.

However, the use of formula (1) as a criterion is limited. The authors of [19–21] determined that the velocity of a discharge propagation cannot be higher than the velocity of a shock wave. Both velocities depend on $dJ/dt$ ($J$ is the intensity of current). For $dJ/dt \approx 10^8$ A/s their value is about $3 \cdot 10^2$ m/s, but for $dJ/dt \ll 10^8$ A/s the difference between these velocities is high enough to inhibit the discharge propagation down to 20 m/s by a shock wave reflected from the wall. This causes prolongation of the time required to fill up the entire volume of a flashtube by the plasma.

The use of formula (1) is also limited by the method of initiation of a discharge. For $U_0 > U_s$, where $U_s$ is the voltage of selfinitiation, the discharge develops in many different channels [22]. This causes a shortening of the time needed to fulfill the volume of a flashtube by a plasma. When $U_0 < U_s$ the development of a discharge depends on the method of leading in an ignition electrode. In paper [19] the construction of an electrode where a wire is rolled on a tube was described. By using the above construction, a discharge is initiated at the inside surface of the tubing parallel to the ignition electrode.

The discharge develops from the wall (starting diameter 0.1 mm) to the axis of a flashtube fulfilling its cross section in the initial phase ($t \approx 1/4\tau$) of the discharge. The brightness of the discharge is about the same in the full cross section of the flashtube. Installing an ignition electrode along the wall, parallel to the axis of a flashtube causes an establishment of the plasma column near the wall along the electrode. The interaction of the shock wave reflected from the wall of a flashtube with the developing discharge leads to a lowering of its velocity, vibration of the dividing layer and withdrawal of the discharge up to the ignition electrode. Thus, the discharge is divided into two parts by a cooler layer of the gas which may be filled by the plasma only, when one uses a sufficient capacity of a capacitor battery. At the divided phase of a discharge, the plasma occupies 70–80% of the full volume of a flashtube. The time calculated from formula (1), needed to establish the quasistationary state, is equal to 0.12 ms and is two times less than the time experimentally measured by the photographic technique [21].

The gas dynamic equilibrium features a stable distribution of particle density in the plasma column. In a flashtube where $V_b/V_p > 0$, where $V_b$ is the volume behind the electrodes, $V_p$ is the volume between the electrodes, and when $dJ/dt \gg 0$, the high gradient of pressure causes a compression of the gas out of $V_p$. However, this process vanishes when $dJ/dt \leqslant 0$. Then the concentration of xenon atoms in the volume of the discharge is nearly stable. The return of the compressed gas to the volume $V_b$ occurs in about $10^2$ ms [7]. It is generally accepted that a relative change in the concentration of particles in the volume $V_p$ is given by an exponential relation with a ratio of $V_b/V_p$, and is independent of the maximum current density of a discharge [18]. No one has presented this in an analytical form.

Basing on the above, one can state that the existence of a quasistationary state of a discharge depends on the initial parameters of a discharge, the conditions of initiation and the feeding parameters. At present, the general mathematical formula which would predict the existence of a quasistationary state and hold true in all cases does not exist. However, it should be noted that the quasistationary state of a discharge is achieved for a relatively long period of time (about 0.5 $\tau$) on the descending part of the current characteristic. The existence of the state is more likely at longer duration time ≈ 1 ms, with the proper initiation of a discharge and with a properly valued longitudinal electric field.

In this work the conditions of the experiments were selected in order to make measurements in the quasistationary state of a discharge, and thus they take into account the conclusions from the above discussion.

## 3. *Experimental procedure*

Flashtubes which were used for this experiment were 0.3 cm and 0.7 cm in diameter, 8 cm and 11 cm high. Their $V_b/V_p$ ratio was equal to 40 and 11, and they were filled with spectral purity xenon under a pressure of 13.3 kPa and 26.6 kPa, respectively. Electrodes were placed in such a way as to provide a free flow of gas between an electrode and a wall. Flashtubes were treated with a vacuum and they were tested with some empty runs. The gas impurity absorber was sprayed within a flashtube behind the electrodes. Current and voltage measurements were taken with an oscillograph, a calibrated resistor with small inductance, and a voltage divider having a specially selected value of RC. The ignition electrode was reeled onto the outside surface of a flashtube. Flashtubes were fed from the battery of capacitors with a capacity equal to 650 μF and a voltage of 2.5 kV through the series on inductance ranged from $10^{-2} - 10^{-3}$ H.

The parameters of a discharge were changed in the following ranges. The duration time of a discharge was 1–3 ms, the density of the current was 0.3–3 kA/cm², the growth of the current $dJ/dt$ was $10^5$–$10^6$ A/s, and the relative intensity of the longitudinal initial electric field $E_0$ was 0.18–0.6 V/m Pa. The spectra of xenon plasma were recorded in the spectral range of 200–600 nm and in a direction perpendicular to the axis of a flashtube.

## 4. *Results*

The estimation of both the change in pressure and the ratio of the quartz evaporation from the wall of a flashtube was obtained at a current density $j$ = 3 kA/cm² and the duration time of the current impulse $\tau$ = 3 ms. The method of comparing the known volume filled with xenon at an initial pressure of 13.3 kPa to that of a flashtube was used. The presence of oxygen within the reference volume and in a flashtube was checked using the control amount of impurity absorber. The increase of pressure within a flashtube after one impulse under the above conditions was equal to 3500 Pa. The rate of quartz evaporation from the wall of a flashtube was calculated to be 0.4 mm/s.

A darkening of a flashtube around electrodes was also observed. The discharge part of a flashtube was not darkened because of the squeezing effect caused by the rapid growth of pressure during a discharge. This has been observed for both ratios of $V_b/V_p$.

Some cracks on the inside surface of a flashtube were observed and their number increased after every impulse, and finally, after about 30 impulses the flashtubes exploded.

Some of the spectra of the discharges which were used to calculate the topics discussed below were recorded using the photografic technique. Some of them are in Fig. 1.

The results of measurements of the conductivity of the xenon plasma in relation to the density of the current for the quasistationary state of a discharge are shown in Fig. 2. The results from other authors are included in the same figure for comparison. The calculations were made with the assumption that the voltage gradient along the axis of a flashtube is constant, and the voltage fall near the electrodes is equal to 15–20 V [4, 24, 25].

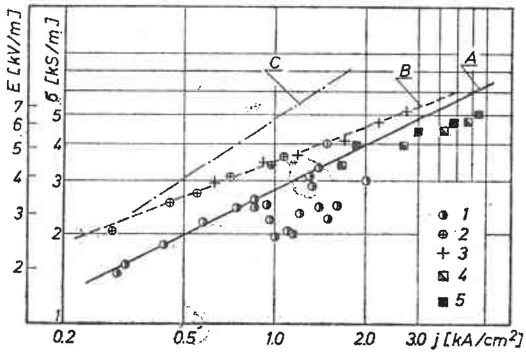

Fig. 2. The conductance ($\sigma$) of the xenon plasma column in a flashtube and the relative intensity of the longitudinal electric field ($E_0$) vs current density of a discharge ($j$). The lines A and C were drawn according to results from [24] and [5], respectively. The line B shows results of the present work obtained here for the lamp as in the caption for Fig. 1 and $\tau = 3$ ms — points 2, $\tau = 1$ ms — points 3. The points denoted as 1 result from [8]. Four and five result from [15] at $p_0 = 53.2$ kPa, and 26.6 kPa, respectively. $E$ is related to $\sigma$ as follows: $\sigma = 0.783\,E$, [24]

The relation between the pressure in the flashtube and the current density of the discharge with or without considering a squeezing effect were calculated. The results given above and the results of other authors are shown in Fig. 3.

The current and voltage measurements of the discharge were made using an oscillograph and some of the oscillograms are shown in Fig. 4.

A significant rise in the initiation voltage was observed with an increasing degree of the gas impurity in a flashtube. The influence of the amplitude of the ignition impulse exerted on the current-voltage characteristics of a discharge was also observed.

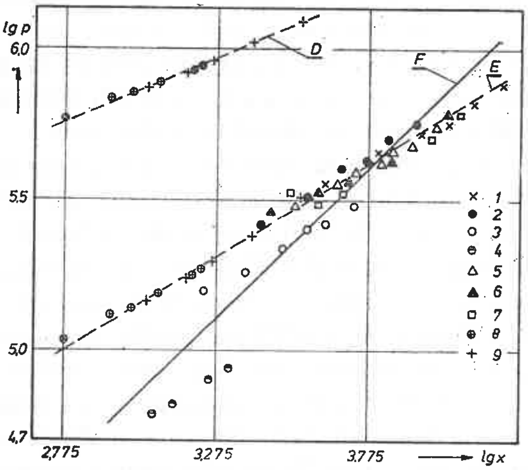

Fig. 3. Pressure $p$ of gas within a flashtube as the function of parameter $x$ where $x = j^{0.8}p_0^{0.6}r_0^{0.4}$. Points 1–7 and the straight line, F, result from [32]. Points 8–9 are the results of this work. The straight line E was drawn according to equation (8) using equation (7); D was drawn according to E but without using equation (7)

## 5. *Discussion*

The heating of the wall of a flashtube is caused mostly by the absorption of ultraviolet light [26, 27]. The formula $W_0 = 10^{-16}\,T^5$ W/cm$^2$ gives the radiation energy falling on the area unit of the wall of a flashtube at proper temperatures such as $10^4$ K $\leqslant T \leqslant 2 \cdot 10^4$ K. At these temperatures the evaporation rate of quartz from the wall of a flashtube becomes highly significant. Taking into account that the amount of material evaporated from the wall of a flashtube is proportional to both $W_0$ given by the above formula, and the duration time $\tau$ of a current impulse of a discharge, and accepting that $T = 8.45 \cdot 10^3\,j^{0.29}$ [28], one can obtain at different $j$ values:

$$p_2 = p_1(j_2/j_1)^{1.45}\tau_2/\tau_1 \text{ Pa}, \tag{2}$$

where $p_1, p_2$ are the partial pressures of Si or $O_2$ particles in the flashtube. The $p_1$ values may be derived from the present work (see Section 4), or [29].

In [29] the author studied the pressure broadening of some Si I lines in the impulse discharge obtained in a quartz capillary ($d = 1.5$ mm, $l = 15$ mm) using a capacitor battery (0.05 µF, 26 kV). The capillary was filled with $SiF_4$ gas with an initial pressure chosen from the following range: 400 Pa $\leqslant p_0 \leqslant$ 46.7 kPa. The author of [29] had observed that the Si I line $\lambda = 288.1$ nm starts to broaden at $p_0 \geqslant 930$ Pa. This broadening increases with a rise in the $SiF_4$ pressure, but the line was not merged with the continuous spectrum even at the maximum pressure.

The analysis of spectra 4 and 5 (shown in Fig. 1) allowed to state that the pressure broadening of silicon lines such as $\lambda = 288.1$ nm as well as others which were not investigated in [29] suddenly appear after reaching the following parameters: $j = 1.1$ kA/cm$^2$ for

$\tau = 3$ ms and $j = 1.4$ kA/cm$^2$ for $\tau = 1$ ms. Generally, the lines are broadened symmetrically. When the value of $j$ increases, the silicon lines can even be reversed (see spectrum 2 and 3, Fig. 1). The broadening discussed above is not caused by an interaction between atoms of silicon and electrons, because the electron broadening is proportional to the electron density, i.e., to the $j$-value as well [30, 31]. Thus, this cannot occur quickly. The partial pressure of oxygen $p_2$ after one impulse was calculated to be 3950 Pa at the following conditions: $p_1 = 930$ Pa, $j_1 = 3$ kA/cm$^2$, $\tau_1 = \tau_2 = 3$ ms (formula (2)). The experimentally determined $p_2$-value is equal to 3500 Pa. The difference between these two values is within experimental error. The calculations made using formula (2) for $\tau_1 \neq \tau_2$ (see spectrum 4–5, Fig. 1) do not agree with the experimental data. It is very likely that the poor agreement in this case is caused by some omission in a factor in formula (2) which should in some way represent the light absorption coefficient of the surface of the wall as function of the change in light intensity. There is no mathematical expression for this fact in the literature. However, it has been possible to take this into account in formula (2) using the following assumption. That is, the necessary partial pressure of silicon is obtained when the minimum energy $W_0$ is absorbed on the surface of the wall of a flashtube. When a change of absorption coefficient occurs as a function of $W$, the following expression may be obtained $W_0 = Aj^{1.45}\,\tau^x$, where $A$ is constant in the $j$-range studied. The exponent factor, $x$, was calculated using some parameters of the discharge shown in spectrum 4, Fig. 1. Formula (2) may be written as follows:

$$p_2 = p_1 \left(\frac{j_2}{j_1}\right)^{1.45} \left(\frac{\tau_2}{\tau_1}\right)^{0.32}. \tag{3}$$

Using relations $p = nkT$, $T = 8.45 \cdot 10^3\, j^{0.29}$, [28], and the experimental data $p_1 = 930$ Pa, $j_1 = 1.1$ kA/cm$^2$, $\tau_1 = 3$ ms, $T_1 = 300$ K, one can obtain a formula which allows him to calculate the partial pressure of silicon and oxygen in a flashtube in the quasistationary state of the discharge

$$p_3 = k \cdot 1.6 \cdot 10^4 j^{0.42} \tau^{0.32} \text{ Pa}, \tag{4}$$

where $k = 1$ for Si, and $k = 2$ for O, as well as after the decay of plasma

$$p_4 = 570 j^{1.45} \tau^{0.32} \text{ Pa}, \tag{5}$$

where in (4) and (5) $j$ is the maximum current density in kA/cm$^2$.

The expression above gives the value of the pressure of the gas impurity in a flashtube as a function of the present work discharge parameters within the error of 20%.

From equation (3) there follows a lack of a low limit of the $j$-value at which the evaporation rate of a wall would equal zero. This agrees well with the experimental data, as the trace of silicon atoms in the plasma was found even at $j = 0.3$ kA/cm$^2$ (spectrum 5, Fig. 1). This can be explained on the basis of the absorption of light by the surface layer of a wall, having a thickness less than $10^{-2}$ cm [26, 27], heated to temperature high enough to cause evaporation.

A rapid change of the chemical composition of plasma while $j$ increases is also predicted by formula (5). When the ratio $n_1/n_0 \approx 0$, where $n_1$ and $n_0$ are the concentrations of impurity atoms and xenon atoms, respectively, every rise in the concentration of atoms with a lower ionization potential in plasma leads to a rise in the electron density and conductance of plasma as well. When the next condition is fulfilled, where $n_1/n_0 > 0$, the plasma is cooled because its energy is used to dissociate $SiO_2$ molecules and excite the atoms coming from the impurities. The electron density decreases because of the formation of $O^-$ ions [8]. All of these processes, as well as a rise in the density of plasma leads to a lowering in conductance.

From the shape of curves A and B and the coincidence of points 4 and 5 (Fig. 2), it follows that the initial difference caused by the difference in pressure of pure xenon disappears at a $j$ range of 3–5 kA/cm$^2$. According to formula (4) the real pressure of gas impurities within a flashtube can be even several times higher than the pressure before the initiation of a discharge because of the existence of silicon and oxygen atoms. This is why the plasma can not be studied as pure xenon plasma. This assumption has not been made in several experimental and theoretical works.

The increase in the conductance of plasma for a small $j$ (curve B, Fig. 2) is caused by a significant lowering of the gas pressure (up to 80%) which can be explained by a squeezing effect. The results obtained are in good agreement with those of other authors [4, 5] for $p_0 \leqslant 13$ kPa. The rapid fall in the conductance of the plasma studied in [8] (points 1 in Fig. 2) is caused by the rapidly coming $Al_2O_3$ and $SiO_2$ vapours into the plasma from a wall in a cylindrical flashtube made of $Al_2O_3$ and $SiO_2$ having a ratio $V_b/V_p$ nearly equal to zero.

The possible influence of parameter $V_b$ on the other plasma parameters is shown in Fig. 3, which was drawn based on calculations of gas pressure using the following formula (derived from [32])

$$p = 1.7 \cdot 10^3 j^{0.8} p_0^{0.6} r_0^{0.4} \text{ Pa}, \tag{6}$$

and the relations $p = kT(n_0 + n_e)$; $T = 8.45 \cdot 10^3 j^{0.29}$, [28]; $n_e = 3.1 \cdot 10^{17} j$, [31]; $j$ is in kA/cm$^2$, $r_0$ is in cm and $T$ in K.

The straight line P which was drawn without taking into account a squeezing effect differs significantly from the other results. For points 8 and 9 the real xenon concentration in the volume of a discharge was determined from the relation

$$n_0 = n_0 \left(1 - f\left(\frac{V_b}{V_p}\right)\right), \tag{7}$$

where the value of $f(V_b/V_p)$ for $V_b/V_p = 11$ was determined from [10, 18]. The calculated from formula (6) $p$-values agree very well with the experimentally determined values reported by others (see points 1, 2, 5–7 in Fig. 3). Points 8 and 9 can be approximated by the following straight line denoted as E

$$p = 1.8 \cdot 10^3 \cdot j^{0.5} p_0^{0.38} r_0^{0.25} \text{ Pa}. \tag{8}$$

Some current-voltage characteristics are shown in Fig. 4. In these characteristics one can see the voltage vibrations with the periods of 0.1 ms and 0.5 ms for $\tau = 3$ ms. For $\tau = 1$ ms, the vibrations having a period equal to 0.25 ms was observed. The existence of such vibrations is connected with the values used for the longitudinal electric field $E_0$, which causes a relatively small increase in current of about $10^5$–$10^6$ A/s. Because the initial shape of discharge reproduces the shape of a spiral ignition electrode, the shock wave which results, interacts with a discharge along the axis of the flashtube as well as in the perpendicular direction.

This process leads to the vibration on a surface of a developing discharge, i.e., the vibrations of voltage and current. When the intensity of a longitudinal electric field increases, the vibration amplitude decreases because the difference between the velocities of a developing discharge and a shock wave vanishes with an increase of $dJ/dt$. In such a case the interaction between a developing discharge and a shock wave begins when a discharge is more developed. Thus, the effect caused by the same vibrations is relatively smaller.

For some discharges the vibration did not appear after the rise of the initiation impulse power. This might be explained if one thinks of the discharge developing process in a statistical way, i.e., the probability for the development of a discharge in many different channels simultaneously and at a relatively small impulse power is almost equal to zero. With the increase in power of the initiation impulse, there occurs a rise in the probability of multichannel development, thus such a discharge becomes observable especially using a spiral ignition electrode. The discharge in a relatively short time fills the entire cross section of a flashtube. The interaction between the developing plasma and a shock wave exists only at the beginning phase of a discharge and the vibration of a current-voltage characteristics does not appear in the quasistationary state.

The method for leading the ignition electrode was emphasized previously [19–21]. However, these authors did not study the influence of the spiral electrode pitch, the kind (periodic, aperiodic) and the amplitude of the ignition impulse power exerted on the initiation and behaviour of a discharge.

Taking the above into account, it appears possible to explain why the different kinds of a discharge had been observed [33]. These authors had initiated discharges using a spiral ignition electrode.

Knowing that the discharges studied in this work had a very small vibration in current-voltage (Fig. 4), and that the capacity of the capacitor battery was relatively high, one can assume with a high probability that the measurements were taken in the quasistationary state of a discharge. Criterion (1) was fulfilled.

Many Xe II and only a few of the strongest Xe I lines (450 nm, 473,4 nm) were found in the line spectra of the plasma (Fig. 1). While $j$ increased from 0.3 to 2.2 kA/cm$^2$, the intensities of the continuous spectrum and Xe II lines also increased. The relative change in the intensity of the Xe I lines was approximately 25%. The explanation for this is that the Xe I lines are emitted while $j \approx 0$, i.e., at the final phase of a discharge. This phase of a discharge is repeatable regardless of its previous phases.

The study of plasma while $j \gg 0$ using the Xe I lines is limited to the outer cool layer of plasma only, while the use of the Xe II lines largely contains information concerning the center of a discharge.

## 6. *Conclusion*

The fact is that there exists a quantitative and qualitative change of the chemical composition of plasma during a discharge. The lack of considerations of this fact is the reason for the existing discrepancies among the theoretical and experimental works. This change was observed at current densities as low as 1–1.5 kA/cm$^2$. With an increase of the $j$-value, the change increases rapidly. Repeating a discharge at $j \geqslant 3$ kA/cm$^2$ induces a different chemical composition of the plasma than that of the first discharge, because for $V_b/V_p \approx 0$, the gas pressure inside a flashtube after one discharge may be even more than twice as high as the one at the beginning. Formulas (4) and (5) permit one to estimate the gas impurity pressure in a flashtube during the quasistationary state and after the decay of the plasma.

If $V_b/V_p > 0$, it is necessary to consider the dynamic gas processes. The studies of plasma in the quasistationary state should follow the studies of the initial conditions of its existence in every different case. It can be stated that such conditions are fulfilled if the duration time of a discharge is about 1 ms, at which criterion (1) is simultaneously fulfilled, and when a discharge begins in several different channels. This happens when the voltage between the electrodes is higher than the selfinitiation voltage.

If one initiates a discharge using an additional electrode, one finds a discharge which evenly fills the cross section of a flashtube if the electrode is reeled spirally on a flashtube and if the amplitude of the ignition impulse is at a high value. Then, reaching a quasistationary state is the more likely, with the simultaneously fulfilled criterion (1), the higher is the capacity of the feeding battery.

If one initiates a discharge using an additional electrode parallel to the axis of a flashtube one obtains, from the very beginning, single, pushed to the wall near the ignition electrode, initial channel of a discharge. The interaction of such a developing discharge with a shock wave causes an approach to a quasistationary state in about twice the time of the one calculated using formula (1). In this case, the possibly high capacity of feeding battery is especially important.

Single ionized xenon lines are emitted mainly from the central part of a discharge, whereas the neutral xenon lines are emitted by the plasma during the decay phase, i.e., $dJ/dt \approx 0$. Thus, the analysis of plasma in the quasistationary state using the XeI lines gives information only concerning the relatively cool, outer surface of a discharge.

An accurate analysis of all the published data concerned with the determination of the cause of the discrepancies observed is not yet possible because there are not enough data concerning the experimental conditions.

As shown from the above discussion, such conditions are especially important to investigate all the complicated processes involved with impulse discharges in flashtubes.

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