Comparative study of noise in low-current Townsend discharge in nitrogen and argon

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Noise in a low-current Townsend discharge in argon and nitrogen is studied. Experiments were performed in a "semiconductor–gas-discharge" structure constituted by a short plane-parallel discharge gap and a high-resistivity photosensitive semiconductor electrode. The noise of optical emission from gas excited by the discharge was investigated with a photomultiplier. Experiments were done at the room temperature of the discharge structure. According to the obtained data, the noise of discharge glow in Ar is astonishingly low—similar to that earlier found for the cryogenic discharge in this gas. At equal time-average photon fluxes emitted by discharges in both gases, the noise of gas glow in nitrogen substantially exceeds the corresponding value for argon. A statistical processing of signals of glow brightness for the two gases revealed the origin of this difference: While the power spectral density of noise in nitrogen is specified by a band of frequencies with the increased density, in argon it is nearly constant in an extended frequency range. At the same time, intensity of noise is practically the same for both gases in the ranges of low and high frequencies. The relationship of the increased noise in nitrogen with a low critical current density for oscillatory instability of the Townsend discharge in this gas is considered.

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I. INTRODUCTION

Low-current stationary self-sustained discharges are promising in a large number of applications—for example, in low-power light sources at the lines of gas emission [1], in medicine [2,3], and for processing of semiconductor materials [4–6]. Thus, the authors of [6] have demonstrated application of a steady-state room-temperature Townsend discharge in a mixture of gases to produce a thin oxide layer on the surface of InAs. As a result, a complicated problem of preparation a high-quality dielectric layer on this compound semiconductor has been solved, which is an important issue in microelectronics.

In a set of applications of dc gas discharges—such as sources of light, converters of infrared (IR) images to the visible range of light [7], or gas-discharge microreactors applied in the precision processing of semiconductor wafers—one needs a stable and controllable operation of the gas-discharge medium.

A self-sustained discharge is accompanied by formation of a gas state which is far away from the thermodynamic equilibrium; in this relation, see, e.g., the recent review [8]. Being a strongly nonequilibrium system, a gas discharge device may be a source of an intensive noise over a broad band, from low frequencies to tens of GHz. The noise can be generated, in particular, due to the chaotic ionization processes in plasma of the positive column of the glow discharge [9,10]. A broad-band noise spectrum can be also produced by instabilities in the discharge region, which are accompanied by strong spatial-temporal current fluctuations [11]. Gas-discharge noise generators used, e.g., in microwave technology for calibration and tests of the electronic equipment have been developed on the basis of these phenomena [12].

It is of special interest to investigate noise produced by gas discharge in its simplest form, which is a stationary Townsend discharge. Statistics of fluctuations of current in Townsend discharges have been theoretically investigated for more than half a century; see [13–15] and references therein to earlier works. Regarding experimental work in this field, to date there are almost no relevant data. Such a situation may be related to the low stability of the spatially uniform stationary state of discharge in devices that are usually applied in experiments. Parallel-plate dc Townsend discharges are mainly studied applying setups with metal electrodes at parameters that provide a discharge operation near the minimum of the Paschen curve. At a rather large (centimeter size) distance d between electrodes, such devices may demonstrate a stable and spatially homogeneous regime [16,17]. However, their stability domain is rather narrow: increase in current density above some critical value j_{cr} is accompanied by current filamentation or oscillations. According to the results of theory (see [18]), the value of j_{cr} increases proportionally to d^{-3}. Therefore, one would expect a more stable operation of dc microdischarge devices as compared to setups with large values of d. Experiments demonstrate, however, that the stationary and uniform discharge mode is not observed at short gaps; in this relation see [19], where the corresponding data obtained at $d = 20$–$100\ \mu$m are presented. It has been found in the study [20] that the discharge mode becomes an oscillatory one at decreasing the gap length down to $d = 100$–$200\ \mu$m.

The stable spatially uniform Townsend discharge in a short-gap device can be observed when one electrode is prepared from a high-resistivity semiconductor material [21–23]. The presence of the high-resistivity planar electrode in such a semiconductor-discharge gap (SDG) structure suppresses the growth of "dangerous" fluctuations in the discharge process [20,22,24], whereas a small value of d provides the Townsend mode of the discharge up to a rather high current density.

Noise characteristics of Townsend discharge in the SDG structure were studied in [25] (see also Chap. 5 in [7]) with the aim to evaluate the sensitivity of the device operating as a converter of IR images. The discharge gap of the device of a thickness of 100 μm was filled with Ar. Experiments were done at a temperature T of the SDG structure near that of liquid nitrogen. The current density was changed in the range from 1 μA to 1 mA per cm^2. It was found that the photon noise of

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the discharge glow was equivalent to that produced by the flux of photons from an incandescent lamp. Such an astonishingly low noise of the gas glow in the device could be interpreted as being due to specific cryogenic conditions of the discharge.

It was also found that the spontaneous dynamics of the low-current Townsend discharge in nitrogen was significantly different from that characteristic for argon. Namely, a frequency band with increased amplitudes of noise was shown to exist in the emission of light from this gas [20,26]. This feature took place in the entire investigated temperature range (90–300 K), and a nonmonotonic dependence of the effect on T [27] was revealed. At an increase in the discharge current density j, the central frequency of this band shifted to higher values proportional to square root from j. The above effects in spontaneous dynamics of Townsend discharge in nitrogen can be interpreted in a model taking into account resonance properties of a discharge device [26,28,29].

The present work aims to compare noise properties of a spatially uniform steady state of the Townsend discharge in argon and nitrogen at the room temperature. Similar to the study [25], the experiments are carried out on a SDG structure. Light emitted by the gas-discharge gap is recorded by a photomultiplier (PMT). The method used is based on a statistical analysis of time series of the discharge glow for various interelectrode distances d, gas pressures p, and currents. In particular, we are interested to make a quantitative comparison of noise characteristics for the discharge in both gases, while having equal photon fluxes recorded by the photomultiplier.

It was found that the discharge in nitrogen produces a substantially stronger noise as compared to argon. Analysis of the experimental data shows that this effect is entirely due to the occurrence of the frequency band with increased noise power spectral density (PSD) in light emitted by the discharge in nitrogen. It is remarkable that, in the range of a uniform steady state, the glow dynamics of discharge in both gases can be described by Gaussian distributions of fluctuations. The increased value of noise in nitrogen is indicative of pronounced collective phenomena in discharge in this gas. Processes that are responsible for these features in dynamics of the Townsend discharge in nitrogen initiate the observed macroscopic oscillations in the structure at a comparatively low density of current. The discharge in argon remains stable in the range of current studied in the present work, while the discharge noise has no specific features and its spectrum is close to the spectrum of white noise.

II. EXPERIMENTAL DETAILS

The experimental procedure was similar to that used in [25,27,30–32]. The experiments were performed in a sandwichlike structure constituted by semiconductor and transparent electrodes separated by a dielectric spacer (Fig. 1). The aperture with diameter of 15 mm in the central part of the spacer forms the gas-discharge region. Thus, the area of the discharge region is $\sim$1.75 cm^2. The spacer thickness determines the interelectrode distance.

Wafers of single crystal semi-insulating gallium arsenide doped with chromium (GaAs:Cr) were used as semiconductor electrodes. The electrodes had the form of a disk 30 mm in diameter and $\sim$1 mm thick. A semitransparent electrical contact was fabricated in the form of a thin metal (Ni) film on one side of the semiconductor wafer by thermal evaporation in a vacuum. The surface resistance of the contact did not exceed 50 Ω/□. The resistance R_S of the semiconductor electrode could be changed in experiments by its illumination by an IR light source. The photoconductivity effect was due to photoionization of impurity centers in the semiconductor volume. An optical system used provided the uniform excitation of the electrode.

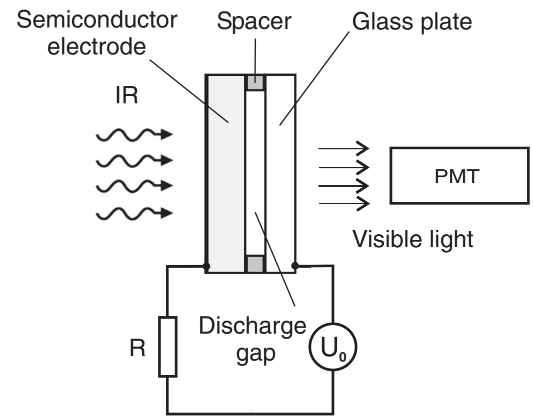

FIG. 1. Schematic presentation of the experimental setup. For the details, see text.

The typical value of R_S was in the range 10^5–10^6 Ω. A glass plate covered with a conducting tin oxide layer transparent in the visible spectral range was used as the second electrode of the device. With this structure applied, it was possible to obtain a stable spatially uniform steady-state Townsend discharge, which enabled studies of its properties at different experimental parameters. We remark that even a rather long exposure of a semiconductor electrode to the Townsend discharge produces no destructive changes of its surface. These data have been obtained by using the method of atomic force microscopy to investigate exposed surfaces of GaAs electrodes [5].

The structure under study was placed in a closed chamber having input and output windows. The input window served to illuminate the photodetector by the IR light from an incandescent lamp that was powered by a stabilized source of dc voltage. The output window was used to provide recording the discharge glow intensity with a photomultiplier tube (PMT). The chamber volume could be filled with argon or nitrogen at a certain gas pressure p, whose value was measured with a CAP 100 vacuum gauge (ILMVAC GmbH). The purity of used gases was 99.99%.

The investigated structure was powered by a Stanford Research Systems Model PS 325 voltage source. The discharge current and, accordingly, the gas glow brightness observed at a supply voltage U_0 exceeding the discharge sustaining voltage were defined by the U_0 value and electrode resistance. The current was measured with using a load resistance $R = 1$ kΩ.

The spatial uniformity of the discharge was monitored with a Pieper FK 7512-IQ charge-coupled device (CCD) camera. The gas glow dynamics was studied with a FEU-38 PMT. The signal of PMT was recorded with a LeCroy 7300A

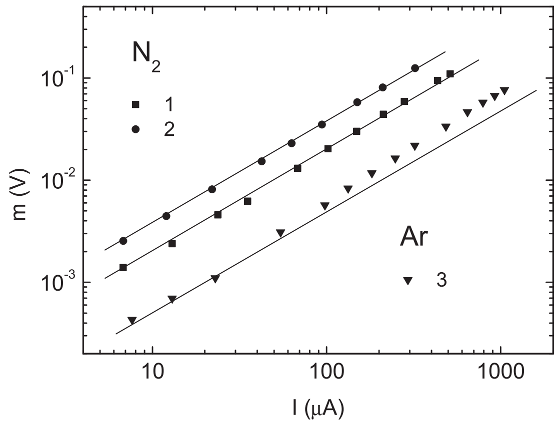

FIG. 2. Examples of dependencies of the time-average PMT signal on current in the SDG structure. (1) $d = 0.1$ mm, $p = 120$ hPa; (2) $d = 0.26$ mm, $p = 46$ hPa; (3) $d = 0.18$ mm, $p = 50$ hPa. The straight lines correspond to the linear rise in the gas brightness with increasing current in the structure.

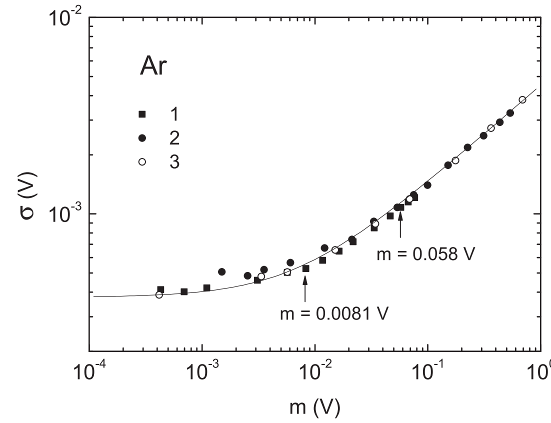

FIG. 3. Dependencies of the standard deviation of the PMT signal on its time-average value. Full symbols represent the data for the glow of a discharge gap filled with argon: (1) $d = 0.18$ mm, $p = 50$ hPa, and (2) $d = 0.84$ mm, $p = 100$ hPa. Open circles (3) correspond to recording light from an incandescent lamp. The solid curve shows dependence (1) that approximates sets of experimental points (see text).

oscilloscope at the sampling frequency of 50 MHz and 10^5 points in a recorded time series. The noise characteristics of the discharge in Ar and N_2 were compared with the data obtained in experiments where the PMT cathode was illuminated by an incandescent lamp powered by a battery. In all experiments, the PMT feeding voltage as well as diaphragm aperture on its entrance window were kept fixed.

III. EXPERIMENTAL RESULTS

We investigated in the experiments how noise of the discharge glow depended on the intensity of light emitted by the discharge and current of the device. The glow intensity of a gas was evaluated by measuring the voltage drop on the PMT load resistance, U_{pmt}. Figure 2 presents examples of how the time-average PMT signal depends on the device current for certain parameters of the discharge region. The data were obtained for a fixed electrode resistance and varied voltage U_0 feeding the structure. The time-average brightness m was found by an appropriate processing of the time series being recorded, $U_{\mathrm{pmt}}(t)$. For the case in which the SDG structure is filled with nitrogen, the experimental parameters were chosen so that the pd product remained approximately the same ($\sim$1.2 hPa cm). It can be seen that the gas glow intensity for the discharge in nitrogen depends linearly on the current of the device. In the case of argon, this dependence somewhat deviates from linearity at increased currents. With the interelectrode distance made larger at a certain fixed current, the gas brightness grows for both gases. It is noteworthy that the discharge in the structure remains spatially uniform in the whole range in which the current varies in Fig. 2. The high stability of the spatially uniform discharge (confirmed by observations of the discharge gap with a CCD camera) makes it possible to study how the noise characteristics of this state depend on the current density.

We characterize the discharge noise by the standard deviation σ of the PMT signal from its average value m. The magnitude of σ was calculated as a square root of the value of the autocorrelation function of the PMT signal, $R(\tau)$, at $\tau = 0$ by processing the time series $U_{\mathrm{pmt}}(t)$ with TISEAN v 3.0.0 mathematical software package [33].

Figure 3 presents examples of how σ depends on the time-average PMT signal m for the case of gap filled with argon at different values of pd product. The figure also shows the dependence $\sigma(m)$ for the case in which the PMT cathode is illuminated with an incandescent lamp, instead of the emission from the gas discharge. The solid line in the plot shows the analytical dependence $\sigma(m)$ approximating the whole set of experimental points:

$$\sigma(m) = k(m + I_B)^{1/2}, \tag{1}$$

where k and I_B are constants obtained by fitting the calculated curve to the experimental points. I_B can be regarded as a signal due to the additional apparatus noise (see also [25]).

It can be seen in Fig. 3 that dependencies $\sigma(m)$ obtained in different conditions of discharge in argon and with light from the incandescent lamp nearly coincide. Only at low discharge glow intensities, the PMT signal noise somewhat exceeds the noise observed under exposure of the PMT cathode to the incandescent lamp. Thus, light emitted by the discharge in argon is characterized by noise that is not higher than that produced by a thermal source of radiation. This is observed at widely varying gas glow intensity. We remark also that the experimental procedure applied in the present study cannot be used to quantify the intrinsic parameters of the discharge noise in argon under studied conditions.

When the SDG structure is filled with nitrogen, different discharge noise properties are observed, compared with the case of argon. Figure 4 shows the $\sigma(m)$ dependencies measured in the system with interelectrode distances of 0.1 and 0.26 mm under nitrogen pressures of 120 and 46 hPa, respectively. Thus, the pd product remained fixed in the case under consideration. The figure also shows the result of a run in which the PMT recorded light emitted by the incandescent lamp.

Data presented in Fig. 4 show that the discharge noise exceeds in this case the intrinsic noise of the measuring

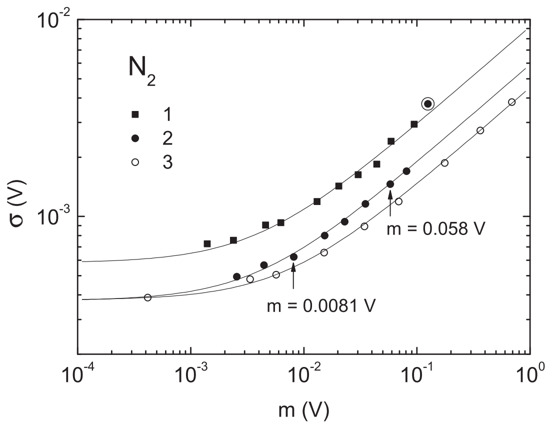

FIG. 4. Dependencies of the standard deviation of the gas glow signal on its time-average value obtained in two conditions of filling the discharge gap by nitrogen at $pd \approx$ const (full symbols): (1) $d = 0.1$ mm, $p = 120$ hPa, and (2) $d = 0.26$ mm, $p = 46$ hPa. The open circles (3) represent the data for light from the incandescent lamp. The solid curves correspond to the results of fitting of the approximating dependence (1) to experimental data.

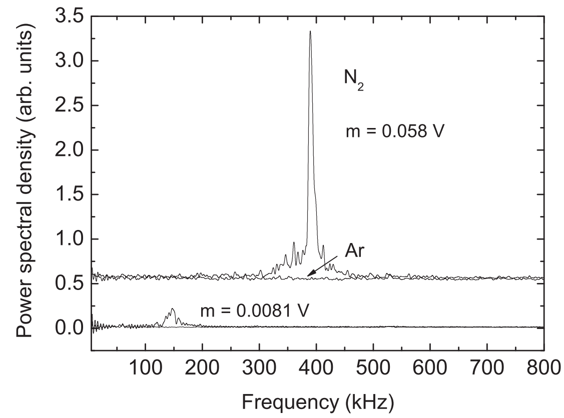

FIG. 5. Spectral distributions of the noise power density for discharge glow in argon and nitrogen at the same time-average PMT signal $m = 0.058$ and 0.0081 V.

apparatus. According to these data, the noise intensity is not a universal function of the product of the gas pressure by the gap length: at $d = 0.1$ mm, the noise exceeds that for $d = 0.26$ mm. The solid curves in Fig. 4 show analytical dependencies of the standard deviation of the PMT signal on its average value, obtained similarly to those for the corresponding curve in Fig. 3 by fitting the coefficients of the approximating dependence (1) to sets of experimental points. Comparison of the data in Figs. 3 and 4 demonstrates that the discharge in nitrogen is characterized by a stronger noise than that in the case when the gap is filled with argon.

The difference between the characteristics of the discharge-generated noise in the gases under study is revealed by a statistical analysis of the time series of PMT signals. One of characteristics of the fluctuation process is the power spectral density $S(f)$. As is known, this function reflects the kinetics of the processes responsible for the observed noise and the contribution of the components of the energy spectrum of fluctuations to the experimentally measured standard deviation. The PSD function $S(f)$ and the correlation function of the time series, $R(\tau)$, are related by the Fourier transform (Wiener-Khinchin theorem) [34]:

$$S(f) = 2\int_0^\infty R(\tau)\cos(2\pi f\tau)d\tau, \tag{2}$$

where f is frequency in Hz and τ is the time in seconds.

Figure 5 presents examples of spectra $S(f)$ for both gases. The data are found from the recorded time series of PMT signals by using the above formula. The processed time series refer to the same values of the time-average gas glow brightness m for both gases, which are 0.0081 and 0.058 V. The corresponding states of the system are marked by the arrows in Figs. 3 and 4.

The data in Fig. 5 show that the noise power spectral density significantly differ in nitrogen and argon at the same time-average gas glow intensities. In the case of N_2, the spectrum has a frequency band with the increased intensity. It is at a maximum in the frequency ranges near the central frequencies, f_0, which are ≈150 and ≈400 kHz, for the average values $m = 0.0081$ and 0.058 V, correspondingly. For Ar, the spectral noise density is nearly frequency independent and resembles so called "white" noise. It is characteristic that branches of the $S(f)$ functions coincide for both gases at low and high frequencies.

The dispersion σ^2 of a random process can be defined as the integral of the power spectral density over all frequencies [34]:

$$\sigma^2 = \int_0^\infty S(f)df. \tag{3}$$

Thus, the increase in the discharge noise in nitrogen, compared with argon, is due to the specific features of the discharge glow dynamics in this gas, which contains a rather broad band with increased power spectral density of noise.

As shown previously [31,32], an increase in the discharge current in nitrogen is accompanied by a shift of the central frequency f_0 in the noise spectrum to higher values. This behavior is also observed in Fig. 5. We point out that the spectrum of the signal is strongly transformed at a current exceeding a certain critical value I_{cr}: a narrow peak appears there in place of a broad band with increased amplitudes of spectral components. This change of the dynamics indicates that the system passes to the oscillation mode after I_{cr} is reached (see [31,32]). At $I \geqslant I_{\mathrm{cr}}$, value of σ steeply grows, see point with highest value of m on the curve (2) in Fig. 4. It is noteworthy that oscillations of the discharge glow in the nitrogen-filled gap of a parallel-plate SDG structure may occur in the mode spatially uniform over area [35].

Analysis of the time series of the gas glow signals shows that, in the subcritical region, i.e., at $I < I_{\mathrm{cr}}$, the statistical aspects of the glow dynamics of the discharge region remain close to the Gaussian distribution despite the fact that the frequency spectrum of the signal being recorded significantly changes with increasing current. This can be seen in Fig. 6, which shows examples of probability distribution function (PDF) for fluctuations in the discharge glow, obtained under various experimental conditions. The squared normalized

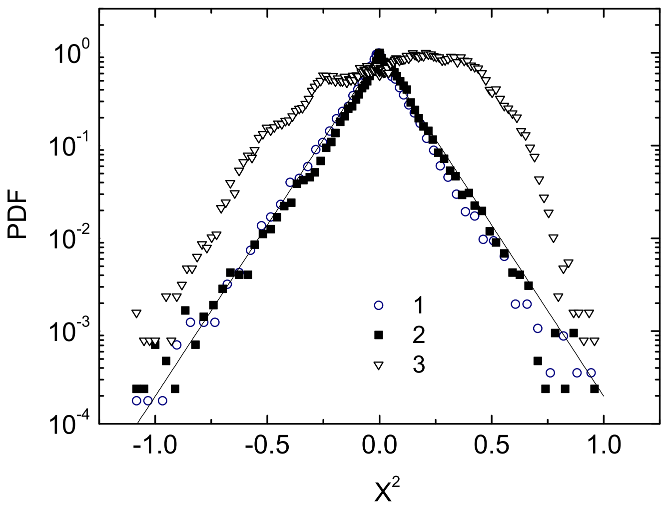

FIG. 6. Probability distribution functions for fluctuations in the discharge glow in an SDG structure. (1) discharge in Ar, $d = 0.18$ mm, $p = 50$ hPa, $I = 248$ μA; (2),(3) discharge in N_2, $d = 0.26$ mm, $p = 46$ hPa, (2) $I = 234$ μA, (3) $I = 307$ μA. The solid lines correspond to the Gaussian distribution of the probability density. The distributions are normalized to the maximum probability density.

difference of the PMT signal and its average value

$$X = [s(t) - m]/[s(t)_{\max} - s(t)_{\min}] \tag{4}$$

is plotted along the horizontal axis of the graph. The solid curve in the figure shows the Gaussian distribution of the probability density. In accordance with the obtained results, the distributions are Gaussian for the discharge in nitrogen for the current varying within the subcritical region. At a current $I = 307$ μA, which exceeds the critical value for the oscillatory instability—see Fig. 4 where the corresponding point is marked by a circle—the distribution strongly differs from that of a Gaussian type.

For argon, the probability distribution function remains Gaussian up to the maximum currents used in experiments ($\sim$1 mA; see Fig. 3). To conclude this section, we emphasize that the probability distribution function of fluctuations in the stable state of the discharge has the same form for both gases despite that the $S(f)$ spectrum for nitrogen has a specific feature.

IV. DISCUSSION OF RESULTS

We studied the noise of glow of the microdischarge region for discharges in nitrogen and argon at the room temperature. A parallel-plate gas-discharge structure was used, in which one of electrodes is made of a high-resistivity semiconductor (SDG structure). The method used yields information about the noise of the spatially uniform state of the Townsend discharge, while changing discharge region parameters and current.

It was found that the noise properties of the discharge in Ar and N_2 are markedly different. The power spectral density of the discharge noise in Ar has no specific features in an extended frequency range and is close to the so called "white noise" spectrum. This conclusion is based on a comparison of the results obtained by studying light emitted by the discharge region and an incandescent lamp. It is remarkable that the noise intensity of the Townsend discharge in Ar at the room temperature is essentially the same as observed for a cryogenic ($T \approx 85$ K) discharge [25].

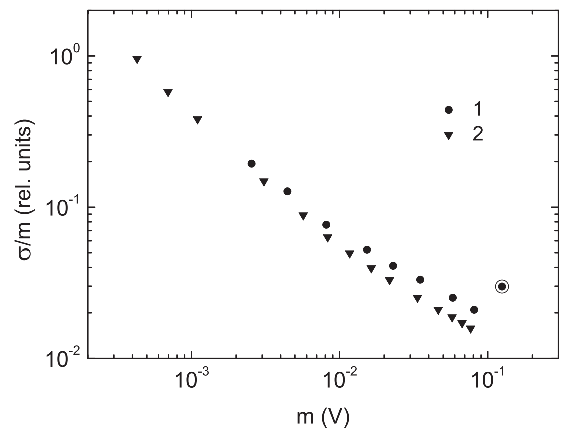

FIG. 7. The ratio of the standard deviation of the PMT signal to its time-average value as dependent on the time-average value. (1) discharge in N_2, $d = 0.26$ mm, $p = 46$ hPa; (2) discharge in Ar, $d = 0.18$ mm, $p = 50$ hPa.

In the case of a discharge in nitrogen, the power spectral density of noise shows a band with increased power [20]. In the experiments of the present work, this band lies, depending on current, in the frequency range 200–800 kHz. This specific feature of the spectra is observed at any currents corresponding to the stable spatially uniform state of the discharge. Experiments demonstrate that, at equal time-average fluxes of photons recorded by the PMT, the noise of the discharge glow in nitrogen substantially exceeds that in argon. It is found that this difference is due to the above-mentioned feature in the noise spectrum of this gas.

For a uniform stationary discharge, the relative role of fluctuations in the gas glow should decrease with increasing a time-average luminescence intensity. Just such a behavior of discharge in the stability domain can be seen in data of Figs. 3 and 4 and is directly illustrated by Fig. 7. The change in the ratio σ/m with increasing m is shown there for both gases for some chosen experimental parameters. Curves (1) and (2) in the figure correspond to curve (2) in Fig. 4 and curve (1) in Fig. 3, respectively. We remark that the σ/m ratio steeply increases for the discharge in nitrogen at reaching the instability point; see the point with the highest m value on curve (1).

Despite the difference between the noise spectra, the amplitude distributions of gas glow fluctuations are similar for both gases in the discharge stability domain and correspond to the Gaussian distribution. This pattern suggests that the fluctuations in the glow intensity in the discharge gap are statistically independent in both cases. This similarity in the probability distribution function is observed until the current density for the discharge in nitrogen reaches a critical value $j_{\rm cr}$. With further increase in current, the discharge there enters the oscillatory mode.

It is known that stability of a spatially homogeneous stationary discharge in nitrogen is relatively low; see [19,30].

The effect is commonly associated with the occurrence of negative differential resistance (NDR) of the discharge. Some models suggest that the NDR of the Townsend discharge is due to accumulation of positively charged ions in gas [36–38] and is especially pronounced at the right-hand branch of the Paschen curve. The quantitative analysis of the problem for the discharge in nitrogen [29] has demonstrated, however, that the effect of ion accumulation is too weak to explain the observed low values of j_{cr}.

Another theoretical approach to the problem of oscillation instability of Townsend discharges takes into account a possible dependence of secondary electron emission on the electric field at the cathode (or the current density) [29,39,40]. This effect can be also responsible for formation of the discharge NDR. By introducing a certain hypothetical dependence $\gamma(j,E)$, one can obtain in theory a relatively small j_{cr}, which corresponds to that observed in an experiment at a given set of parameters of a studied device. Explanation of the effect through involving the electrode processes is, however, not satisfactory: The theoretical interpretation of observed j_{cr} as dependent on experimental parameters requires the appropriate selections of functional dependencies of coefficient $\gamma(j,E)$. In other words, to reproduce a variation of j_{cr} at changing parameters of an experiment—e.g., at changing d while keeping pd fixed—one has to use a set of *ad hoc* functions $\gamma(j,E)$.

The above discussion raises an important issue of defining in an experiment the NDR of a Townsend discharge, which is an attribute of the static current-voltage characteristic of the discharge gap. The values of NDR of the discharge in nitrogen and corresponding critical current densities for the oscillation instability were calculated in the theoretical investigation [29]. One of the important results of the cited work is establishing the analytical dependence of j_{cr} on the NDR of the gap and dynamics of the discharge process there.

An attempt to evaluate the NDR of the steady state microdischarge in nitrogen at the instability point was made in our study [31]. In experiments, the Townsend discharge in the SDG device was investigated. To analyze collected experimental data on j_{cr}, the theory [29] was applied. Here, without going into detail, we make a stress on the next results obtained in [31]: (i) NDR values at instability points are found to be essentially lower as compared to those theoretically determined in [29] for given experimental parameters. (ii) The threshold current density for the oscillation instability is approximately the same for the left- and right-hand branches of the Paschen curve. (The corresponding data have been obtained at the same voltage that ignites the Townsend discharge.)

In our opinion, these results suggest that a common interpretation of low stability of the stationary Townsend discharge in nitrogen as being due to the NDR effect may be incorrect. An alternative explanation of the phenomenon of emerging macroscopic oscillations in the considered spatially distributed (parallel-plate) device can be the synchronization of local (oscillating) microdischarges in the gap.

Low-current gas discharges are known to demonstrate resonances in their behavior, which is due to the presence of capacitances in a studied device and to the pseudoinductive nature of the free carrier multiplication in the discharge region [15,26,29,40]. So, at proper parameters that define dynamics of the discharge process, a discharge structure may show features that are characteristic for an oscillator. It is also established that the stochastic processes in multiplication of free carriers in the gap may induce spontaneous discharge dynamics that reveals its oscillatory properties [15,26].

In a parallel-plate microdischarge device (that is, in a device where the lateral dimension $D \gg d$), the discharge process can be considered through dynamics of an ensemble of local oscillators. The behavior of such a system depends on both properties of individual oscillators and their coupling with each other.

The interaction of local oscillators of a spatially extended system is known to provide their phase synchronization and, in this way, formation of collective dynamics of the system. Such scenarios of self-organization of spatially distributed nonlinear media are at present intensively studied in systems of different nature; see, e.g., [41,42]. We believe that just this mechanism of generation of large-amplitude oscillations is observed in the studied microdischarge device using nitrogen. The dynamics of local oscillators can be coupled through the lateral propagation of light in the UV spectral range. The short-range coupling of the discharge process in the gap can be also provided by propagation of the electric potential along the semiconductor-discharge interface [43].

In the frame of the qualitative model discussed above, the formation of excess noise in the nominally stationary state of discharge in nitrogen (that is, at $j < j_{cr}$) can be interpreted supposing that spatial correlations in dynamics of local oscillating microdischarges persist also at a small current density. However, spatially distant microdischarges remain almost independent of each other within the space of the parallel-plate structure. This gives the observed distribution in fluctuations of the gas glow; see Fig. 6. It is characteristic that the excessive noise and, presumably, correlations in space-time dynamics of the discharge are observed over the entire range of variation of current density, up to its critical value j_{cr} for the appearance of macroscopic oscillations.

The growing interaction between the microdischarges with increasing current density seems finally to give rise to the coherent discharge oscillations, when a certain critical value I_{cr} is reached [20]. We stress again that such a hypothetical scenario of formation of the collective behavior of the system is not related to the presence of the discharge NDR. When using language of the nonlinear dynamics, transition from a noisy state to the ordered oscillation state may be specified as a phase transition in the spatially extended system. In the case of discharge in argon, effects of this kind seem to play a substantially less important role. As a consequence, a discharge there exhibits no specific features in the noise spectrum and is characterized by a low noise level. As a result, it remains stable in the whole range of currents used in the experiments. At present, it remains unclear what processes in the studied gases define the difference in their spontaneous dynamics.

It is remarkable that the noise intensity of a spatially homogeneous stationary Townsend discharge in argon and nitrogen (outside the band around the resonance frequency for the case of nitrogen, i.e., at low and high frequencies) is practically the same; see Fig. 5. On the other hand, noise of photon flux emitted by the discharge in Ar is almost identical to that observed in experiments where the incandescent lamp is used as a light source. It can be concluded therefore that the Townsend discharge in nitrogen at the high and low frequencies is also characterized by the noise intensity close to that which is specific for a thermal radiation source in the respective frequency bands. In our opinion, the phenomenon of low noise in light emission from Ar excited by the Townsend discharge in the SDG structure can be applied in sources of low-noise emitters of light on lines of radiation of this gas.

To conclude, we emphasize that the method used in the current work makes it possible to study noise properties of dc Townsend discharges in mircodischarge devices at using different gases. In this context it is of interest to establish, in particular, whether the specific features of the discharge dynamics in nitrogen can be manifested in discharges in other gases, both atomic and molecular.

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