Red Flashes in Air

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Abstract—A red flash in a low-pressure air discharge is experimentally studied. Optical radiation, double electric probes, and the electric current of the pulsed plasma that is generated against a low-current stationary discharge are measured. The experimental data are analyzed.

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1. INTRODUCTION

The results of a model experimental study of the air discharge can be found in [1, 2]. The observed red flashes are similar to the flashes (sprites) that are generated in the upper atmosphere [3–14]. The flashes are caused by the vortex acoustic flow in the tube due to the air inlet. The flashes are not generated when pure nitrogen or oxygen are substituted for air. A video camera is used to record the generation and decay of pulsed plasma objects. The flash duration and the spectral structure of the plasma radiation correspond to the sprite parameters. It is demonstrated in [2, 15] that the red-sprite emission in the ionosphere can be classified as superluminescence caused by acoustic waves [16, 17].

In this work, we experimentally study the red flash in a low-pressure air discharge; measure the optical radiation, double electric probes, and the electric current of the pulsed plasma in the presence of the background stationary discharge; and analyze the data.

2. EXPERIMENTAL SETUP

Figure 1 demonstrates the scheme of the experimental gas-discharge setup, which contains a quartz tube (1) with an inner diameter of 6 cm. The interelectrode distance is 40 cm. The power supply is provided by a high-voltage dc source (7). The tube is evacuated using a forepump (5). The PMT (2) measures the variation in the optical radiation of the pulsed plasma. The double

Fig. 1. Scheme of the experimental setup: (1) quartz discharge tube, (2) PMT, (3) double electric probe, (4) 25-fps video camera, (5) vacuum pump, (6) computer, (7) high-voltage dc power supply, (8) gas inlet, (9) electrodes, (10) manometer, (11) isolating transformer, (12) spectrograph, and (13) diodes.
electric probe (3) makes it possible to trace a variation in the electron density with time. The video camera (4) is used to record the processes of the plasma formation and decay. The PMT and probe signals are fed through an isolating transformer (II) and a sound card to a computer (6). An inlet (8) is used to radially deliver gas to the tube, which is needed for the generation of the pulsed plasma. The tube pressure is measured using a mercury manometer (10). The spectrograph (12) allows us to study the plasma spectra.

3. SOFTWARE

The PC input and storage of the electric signals of the double electric probes, PMT, and resistor R (used to determine variations in the discharge current) are realized using a sound card that serves as a 16-bit ADC with the passband 20 Hz–44 kHz (Fig. 2). This method of data input is simpler and more convenient than the conventional approach involving an ADC. An isolating transformer (II) protects the computer from the high-voltage signal of the gas-discharge circuit and separates this signal from the electric components of the setup (Fig. 1). An RC circuit connected to the sound-card input rejects the dc signal. It can be demonstrated that the signal is differentiated with respect to time when the signal frequency is lower than 1/RC. Consider the ac input signal \( V_{in}(t) \) of the RC circuit. The output signal at the resistor R is \( V_{out} \). The frequency of the input signal is \( \omega \). At low frequencies (\( \omega \ll 1/RC \)), the capacitor is charged to a level close to \( V_{in} \), so that the capacitor voltage is \( V_{C} \approx V_{in} \).

For \( \omega \ll 1/RC \) or \( R \ll 1/\omega C \) and

\[
V_{in} = IZ = \sqrt{R^2 + \left(\frac{1}{\omega C}\right)^2},
\]

we have \( V_{in} \approx 1/(\omega C) = V_{C} \) and, hence,

\[
V_{out} = V_R = IR = R \frac{dV_R}{dt} = R \frac{d}{dt} CV_C \approx RC \frac{d}{dt} V_{in}.
\]

Thus, the output signal represents a time derivative of the input signal multiplied by time constant RC. To computer control the experiments and to store the data, we create two computer codes using LabView 8 and MathLab 7. The experimental data are delivered to the computer using the sound card.

The first computer code (Capture2) is employed to deliver the analog signal to the computer using the sound card. The data obtained using Capture2 are processed using the Viewer&Editor code. To accurately determine the external signal, we take into account the differentiation effect on the signal with a frequency of lower than 20 Hz. With allowance for the aforesaid, note that the developed computer codes must be able to integrate the signal and to filter out noise.

To determine \( x(t) \) and integral signal \( y(t) \) using LabView 8, we calculate each pulse as

\[
y_i = y_{i-1} + x_i dt,
\]

where \( dt \) is the time difference between two signals that depends on the chosen sampling rate.

To filter out noise in the measured signal, we employ the BIKh and KIKh digital filters [24, 25] in the Viewer&Editor code.

Figure 3 shows the computer-recorded electric signal corresponding to variations in the discharge current. The solid line results from the filtering using the BIKh filter and the integration of the input signal. The curve that contains noise corresponds to the absence of filtering and integration.

Figure 4 demonstrates an oscillogram that corresponds to variations in the discharge current in air and that is obtained in the absence of filtering and integration (as in the case of the computer signal (solid line)). The coincidence of the curves indicates that the computer reproduces signals in the absence of significant distortions.

4. EXPERIMENTAL RESULTS

We experimentally study the air discharge. At a pressure of 0.05 mmHg, which corresponds to the sprite formation in the upper atmosphere, we generate a stationary discharge (in the tube with an inner diameter of 6 cm) at a current of 8 mA and a voltage across the electrodes of 2000 V. Under such conditions, the mean electron concentration in the discharge deter-