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Investigation of Detection of Electromagnetic Radiation in The Plasma at The Constant Electric Field

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Abstract: The present paper deals on the investigation results of the detection of electromagnetic radiation in a glow discharge plasma of various gases. The voltage to the lamp is applied from a current source, providing a glow discharge in the lamp. It was shown that the detection efficiency depends strongly on the shape of the I-V characteristic of a gas-discharge lamp, as well as on the applied voltage (electric field). The different types of neon gas-discharge lamps were used as detectors. We also investigated the detection of a pulsed neodymium laser in air at an external electric field. Under the joint action of the laser pulse and the applied electric field, in the focusing region of the laser beam breakdown of air occurs. Thanks to the constant applied field, the created plasma behaves as a medium with a quadratic nonlinearity, which makes it possible to detect the electromagnetic radiation.

Keywords: Glow discharge plasma, nonlinear properties, laser-induced plasma.

1. Introduction

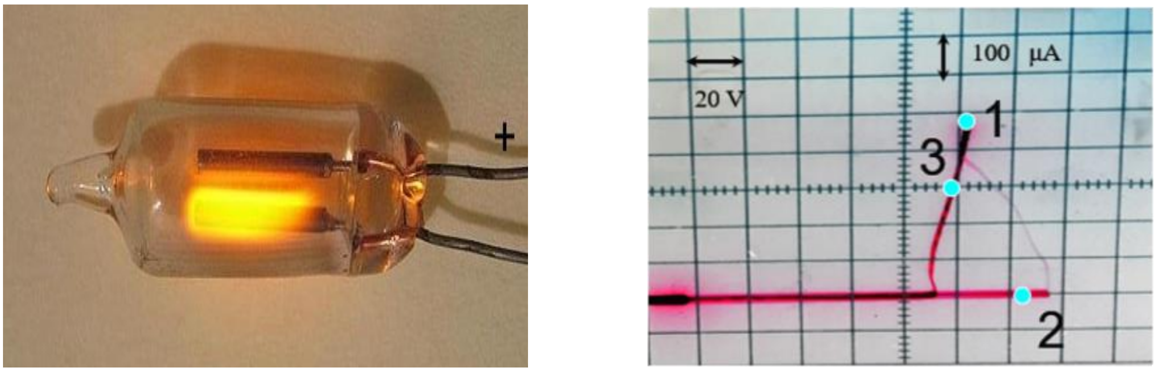
Gas-discharge lamps are widely used in various devices as indicators, light sources, noise sources, dischargers, etc., due to simplicity of design, reliability and low cost.
The nonlinear properties of gas-discharge devices are well known in the low-frequency region of electromagnetic waves. Their properties in the microwave and THz ranges have also been investigated by many authors (see, for example, [1–3]). Unlike nonlinear crystals, gas-discharge devices can withstand very high intensities of electromagnetic radiation, therefore, they can be successfully used as nonlinear elements for frequency conversion of high-power laser radiation.

In the last decades a lot of attention has been paid to the interaction of laser radiation with plasma, particularly, terahertz pulse generation in the laser-induced plasma from a series of noble gases, such as He, Ne, Ar, Kr, and Xe was systematically investigated [4-6]. Femtosecond laser pulses consisting of both a fundamental and its second-harmonic frequency were used for the terahertz generation [2-9]. Numerous works have appeared relating to the processes occurring in the atmospheric air under the influence of high power laser radiation. The powerful THz radiation was received from the femtosecond laser filament in air.

In gas-discharge devices, it is possible to arbitrarily increase the region of nonlinear interaction of electromagnetic wave with the plasma, thereby increasing the conversion efficiency.

We studied the features of the detection of laser radiation in a glow discharge plasma in neon gas-discharge lamps, as well as the detection of neodymium laser radiation in ambient air in the presence of an external constant electric field in present paper.

Various neon lamps with parallel electrodes were used as glow discharge detectors. The look and typical form of the I-V characteristics of the lamps used are shown respectively in Fig. 1a and 1b.



a. b.

Fig. 1. a. appearance of lamp, b. typical form of the I-V characteristics

We considered different operation modes of the lamp: glow discharge mode (points 1, 2 on the I-V characteristic) and standby mode (point 3, the lamp is closed until the laser pulse appears).

The block diagram of the experimental setup is shown in Fig. 2.

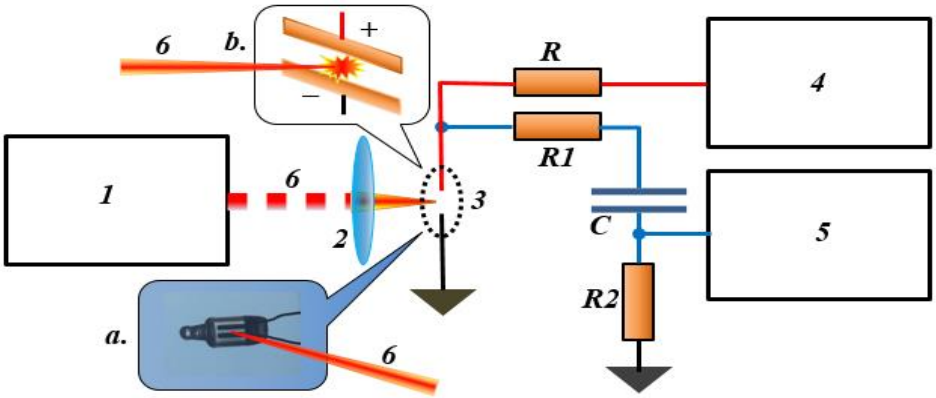


Fig. 2. 1-pulse neodymium laser, 2-lens, 3-plasma area (***a***. neon gas-discharge lamp, ***b.*** electrodes in ambient air), 4-adjustable high-voltage DC source, 5-oscilloscope Tektronix TDS 7102, 6-laser beam, R-ballast resistor, R1, R2, C-decoupling circuit with voltage divider.

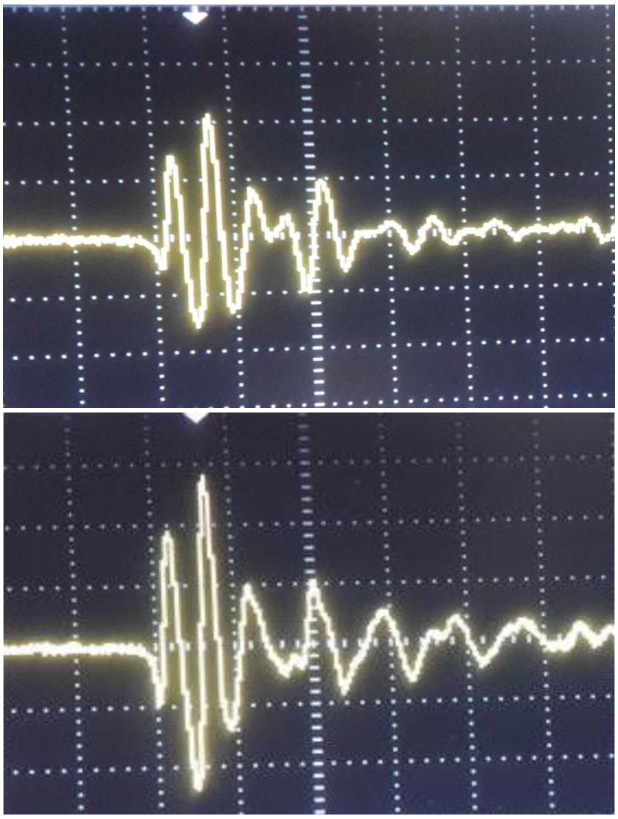
The operating point on the I-V characteristic of the lamp was chosen by feeding a constant voltage to the gas discharge lamp 2 through the ballast resistor R. The YAG: Nd laser radiation was focused in the interelectrode region of the lamp.

The detected signal was taken from the anode of the gas-discharge lamp through a decoupling and voltage divider circuit (R1, R2, C), and was supplied to the Tektronix TDS 7102 oscilloscope.

When the distance between the side walls of the lamp exceeds the interelectrode distance *L*, and the operating point is selected in the region of the glow discharge (point 1 according to the I – V curve), a flat discharge is realized. Since the characteristic size of the Faraday dark space in this case does not depend on the gas pressure, the glow discharge turns out to be essentially non-uniform. If at the same time the interelectrode distance does not exceed the characteristic size of the near-electrode layers the current-voltage characteristic of the lamp is non-linearly increasing [10]: $U \sim L^{3/2} J^{1/2}$, or $J \sim U^2$, where J is the lamp current density.

At the operating point 2, close to the threshold of a glow discharge, under the influence of electromagnetic radiation, a discharge occurs in the lamp, and because of the region of negative resistance according to the I-V curve, the operating point jumps from 2 to 3.

Oscillograms of the corresponding detected signals (change in voltage on the lamp when exposed to a laser pulse) are shown in Fig. 4.



a. b.

Fig. 4. Oscillograms of the detected signals: a. corresponding to the operating point 1 (see Fig. 1b), b. corresponding to the operating point 2.

The comparison shows that the detection efficiency strongly depends on the shape of the I-V curve of the gas-discharge lamp, as well as on the applied bias voltage (electric field). In the case of the choice of operating point 2 due to a sharp change in the anode current under the action of laser radiation, the detected signal is more than one and a half times stronger than the signal obtained in the first case.

The detection of a laser pulse in plasma of atmospheric air is also of interest.

In this paper, we investigated the detection of radiation from a relatively low-power pulsed neodymium laser (peak power $\sim 0.7MW$) in atmospheric air plasma. It should be noted that laser radiation with a specified power is unable to independently initiate air breakdown, however, when combined with external electrostatic and laser fields, it is possible to initiate breakdown.

The laser beam is focused on the interelectrode space by means of a short-focus lens($d \approx 1mm$) (see Fig. 4.) with an electrostatic field of strength $E_0 \approx 2000kV/m$ (the interelectrode voltage $U_0 \approx 2kV$). With the combined effect of a laser pulse and an electrostatic field in the region of the beam focusation, air breakdown occurs. In the case when the plane of polarization of the laser radiation coincides with the direction of the electrostatic field, a nonlinear polarization of the plasma occurs $P_{NL} \sim \left(E_m \cos\omega_1 t + E_0\right)^3$, which is responsible for the optical rectification of the laser pulse.

We measured the change in voltage on the electrodes induced by the breakdown of air in the interelectrode gap. The registration scheme is the same (see Fig. 2.). The signal magnitude was $\sim 150V$ at $R_1 = 100kOm, R_2 = 10kOm, C = 0.1\mu F$.

When the polarization plane of the laser beam is rotated by 90^0, the minimum value of the electrostatic field at which air breakdown occurs increases about 1.6 times. At the same value of the laser power $(0.7MW)$, the amplitude of the detection signal (change in voltage on the electrodes) also increases $(\sim 1.4 times)$. This is explained by the fact that due to the breakdown of air, the interelectrode resistance decreases abruptly, as a result the voltage across the electrodes drops to almost zero. Consequently, the magnitude of the detected signal depends mainly on the initial voltage on the electrodes.

In conclusion, we note that the results obtained in present work can be used to convert the frequency of laser radiation in the plasma. Particularly, they can be used to generate THz pulses in ambient air using relatively low-power femtosecond lasers that are unable to independently initiate the breakdown of air.

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