Threshold Conditions of Quasicontinuous Terahertz Optical Discharge in Gases

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***Abstract*—Threshold conditions of quasicontinuous terahertz optical discharge in five atmospheric gases were measured exactly by the Novosibirsk terahertz free-electron laser (THz NovoFEL) at wavelength of 130 μm (2.3 THz). Comparison of our breakdown data with the data in other experiments and calculations based on a classical theory of microwave electron heating was made. Accuracy of our experiment (± 20%) was much better than one of previous experiments in terahertz range.**

I. INTRODUCTION

THz optical discharge (TOD) was obtained on the THz NovoFEL in 2004 as one of the visual demonstrations of its high power [1]. Recently study of the phenomenon was resumed for definition of its possible user applications [2]. Threshold conditions of the TOD are very important both for the useful applications and for avoidance of the effect when it is parasitic and undesirable. On the other part the TOD is specific variety of gas discharge and threshold conditions are important for its theory [3].

II. RESULTS

Experimental Setup

In the experiments we used the THz NovoFEL radiation at wavelength of 130 mcm (2.3 THz) focused to minimal size by a parabolic mirror with focal length of 50 mm for axial and 100 mm for off-axis 90^0 focusing (Fig.1). Beam size in focal spot was measured by the THz Pyrocam III camera with a special zoom optical system (Fig.2). The experimental beam size exceeded the calculated one by 10 % only.

In time domain the laser radiation was a continuous train of 66 ps (FWHM) pulses (Fig.3) at the repetition frequency of 5.6 MHz. Form of the pulses was measured by our ultrafast Schottky diode detector [4]. As can see in Fig.3 the all NovoFEL pulses were practically similar. Some difference in amplitude of the pulses was taken into account because the TOD was produced by pulses of maximal power (color pulses in Fig.3) whereas for measuring of values of the power averaged pulse (black pulse in Fig.3) was used. We calculated absolute pulse power using CW NovoFEL power measured by our etalon sapphire calorimeter [5], averaged form of the pulses, and exactly known repetition period of the pulses.

Calibrated attenuator based on a metallic wire polarizer was used for smooth regulation of the input power. Wavelength of the NovoFEL radiation (130 mcm) was installed in the window of transparency of water vapor and was controlled by Fourier and grating spectrometers.

Threshold Conditions

Typical values of the CW and pulse power of the THz NovoFEL for the TOD production were about of 150 W and

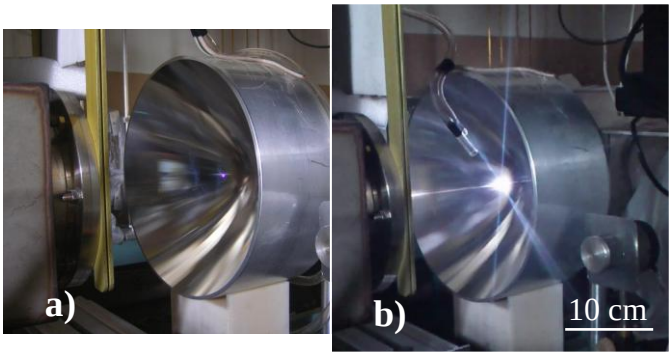

Fig. 1. Photo of the terahertz optical discharge in air (a) and argon (b) at the same THz NovoFEL power of 150 W.

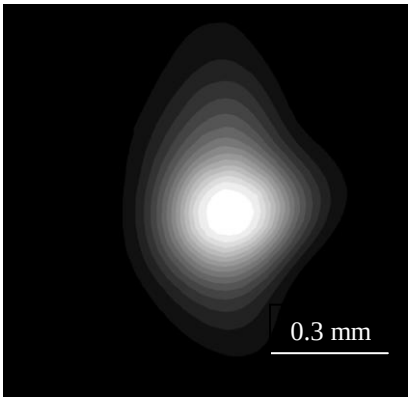

Fig. 2. Focal spot of the THz NovoFEL radiation after off-axis 90^0 focusing by the parabolic mirror. Difference between adjacent levels is 7%. Asymmetry of the outer levels is caused by asymmetry of the off-axis focusing.

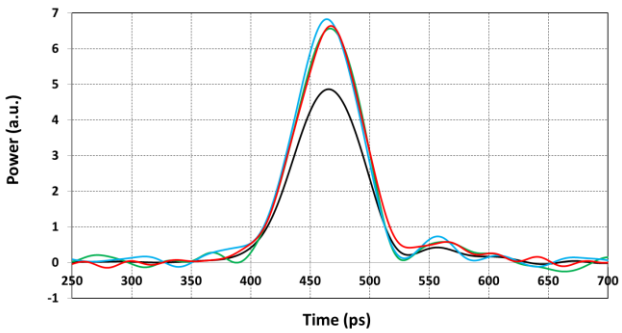

Fig. 3. NovoFEL pulses in the TOD experiment: pulses with maximal power (color lines) and averaged form of the 1000 pulses (black line).

of 0.4 MW accordingly. External view of the TOD was very different for different gases (Fig.1). The TOD in argon looked as intensive dazzling white plasma discharge while the TOD in air, CO_2, and N_2 had a view of week point discharge. The TOD in helium has a middle view (red plasma discharge of middle size).

According theory the real threshold radiation parameter for shot pulse laser at a definite wavelength is the product of pulse intensity and pulse duration [1, 3, 6]. Experimental threshold beam intensities for our 66 ps pulses at wavelength of 130 mcm are shown in Fig.4. The thresholds of breakdown are universal most useful parameters while the thresholds of maintenance are depended on plasma conditions and frequency of pulse repetition. The lowest breakdown threshold has argon though difference between thresholds of the all atmospheric gases was not great. Much more difference was observed for thresholds of maintenance of plasma discharge. The lowest threshold of maintenance has also argon because this TOD produces the most intensive plasma. It can be noted that the threshold of maintenance can be strongly increased in our experiment due to plasma oscillations.

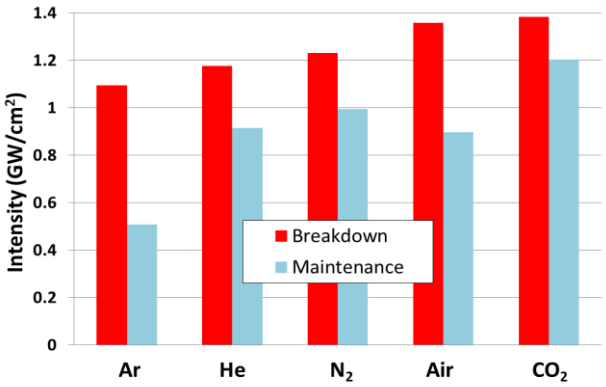

Fig. 4. Thresholds of breakdown and maintenance of the TOD in different gases for 66 ps pulse duration of the THz NovoFEL at wavelength of 130 μm and pulse repetition frequency of 5.6 MHz.

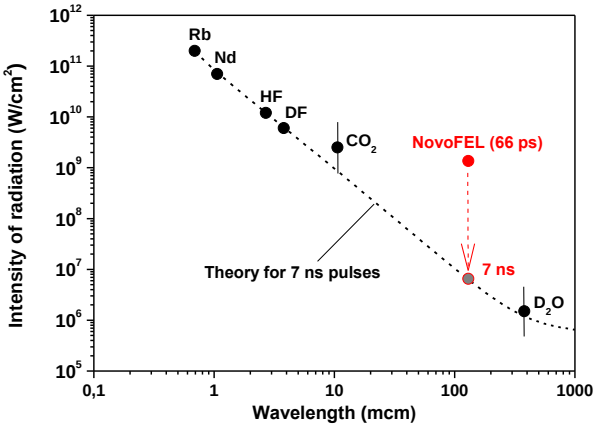

Fig. 5. Comparison of experimental intensities of breakdown in air for different lasers (points) and theory (dash line). Black points are data from the papers [3, 6] for lasers with 7 ns pulse duration. Red point is the original NovoFEL measurement, grey point with red contour is a scaling for 7 ns pulse.

In the intensive argon TOD 100 % gas-dynamics auto-oscillations at frequencies 100-200 kHz were observed [2]. Since period of the auto-oscillations is much longer than a plasma relaxation time they can strongly increase the threshold of maintenance of the argon TOD.

As can see from Fig.4 the all thresholds of maintenance are lower than thresholds of breakdown. It means that there is plasma bridging between pulses in the all TOD though visible light radiation in point TOD (N_2, Air, CO_2) has view of absolutely separated pulses [2].

We found also close to fourfold decreasing of NovoFEL breakdown power by creation of standing wave in the focus of our parabolic mirror. In the case additional small plane metallic mirror was installed in the focus. Such situation can be place in practice when laser radiation is focused in a metallic surface.

The Fig.5 illustrates comparison of our data with previous experiments obtained by other pulse lasers [3, 6], and theory. We used improved theory [1] analogical conceptions in [3, 6] based on a classical theory of microwave stochastic electron heating [7]. After scaling to 7 ns pulse our data are in good agreement with the previous experiments and theory. The accuracy of our experiment (± 20 %) is much better than in previous THz experiments (order of value). It is obtained thank to both better pulse form and pulse reproducing in the NovoFEL compared to CO_2 and H_2O lasers and more careful measuring of the all laser parameters.

III. Summary

Exact measurements of the thresholds of breakdown and maintenance of the TOD in different atmospheric gases were made. The thresholds of breakdown are in good agreement with the calculations based on a classical theory of microwave stochastic electron heating in the discharge.

IV. Acknowledgements

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