Physical basis and actual applications of a new form of high-power microwave discharge in high-pressure gases

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Abstract: The first results of the use of a subthreshold microwave discharge (self supporting – non-self sustained (SNSS) discharge) excited by a microwave beam as a basis for the method of plasma chemical purification of the urban air environment from environmentally hazardous pollution are presented. For samples of air taken from the real atmosphere of the Moscow high efficiency of simultaneous reduction of the content characteristic of the modern big city of harmful substances supplied to the atmosphere by urban transport and industry have been shown.

Keywords: microwave discharge, plasmachemistry, megalopolis atmosphere cleaning

The solution of the most difficult task of maintaining a high environmental quality of life in modern megacities would certainly be facilitated by the development of a method of cleaning the urban atmosphere from a significant number of impurities, the source of which is urban transport, gas emissions from industrial production, thermal power plants, waste disposal enterprises, etc. The complexity of the problem lies in the significant differences in its composition of emissions, the need to simultaneously withdraw from the air pollution of a number of environmentally hazardous components, the unpredictability of the place and time of a number of sources of pollution, etc. All of the above makes it extremely difficult to develop a universal technology for cleaning the urban air environment. At present, the absence of a method of solving such a complex and urgent problem in the technique of environmental protection determines the interest in the form of the microwave discharge discovered and studied in the General Physics Institute of RAS (GPI) - **a self supporting – non-self sustained** (SNSS) discharge excited by essentially subthreshold microwave beams in gases of high (up to atmospheric and above) pressure. Typical photography of SNSS discharge is shown on the Fig. 1. Gas discharges of this kind in the air (as well as in the medium of almost any gas and gas mixture) are a system of thin (transverse size ≤ 100 μm) plasma channels ("filaments") with a high concentration of electrons ($n_e \approx 10^{16} - 10^{17}$ cm^{-3}), extremely high gas temperature ($T_g \approx 3000 - 7000$ K), high electronic temperature ($T_e \leq 5$ eV). Such a specific and unusual discharge structure determines the unique plasmachemical properties, which allow us to count on the SNSS-discharge as the basis of the method for solving the above environmental problem.

Fig. 1

In fact, we are talking about the involvement of a new trend in the chemistry of plasma**: plasmachemistry of unusual plasma formation (SNSS discharge),** which is a set of "microexplosive" areas. The effect on the gas medium can be considered in this case a sequence of two reactors: a super-fast heating reactor and a fast cooling reactor.

The main results presented in this report are primarily related to the solution of environmental problems in the modern metropolis related to gas emissions of transport, emissions of landfills, emissions of metallurgical industries and heating plants.

In the described in this report experiments are the first samples of the air intakes of the characteristic of the modern metropolis air environments demonstrated the ability to restore the ecological purity of the city atmosphere with the help of SNSS discharges. Turning to the problem of energy efficiency of the use of "self supporting non – self sustained " discharge for these purposes, it is possible-on the basis of the experiment conducted in this work-to offer an approximate (requiring further clarification) value of the price of purification of one m^3 of air. Let us assume for this purpose that the processing of gas volumes is carried out with the help of a Gyrotron, similar to the one used in the experiment described in this report, but acting in the pulse-periodic mode, in which the parameters of the microwave pulse correspond to the parameters of single pulses used in this work. Mode Gyrotron in the proposed process may be the following: the frequency of sending pulses of f = 20 Hz, pulse duration τ_{MW} = 4 ms , the impulse power Pi = 250 kW, Then the average power of microwave radiation will be about 20 kW, and energy cost of treatment:

$$\eta \approx 2{,}8 \text{ kWh} / m^3$$

This rather high cost of processing can be justified by a set of specific properties inherent in the SNSS-discharge and significantly expanding the possibilities of the method of cleaning the urban atmosphere based on it. Among the features of the SNSS-discharge, making its application very promising, are the following:

- The possibility of excitation under the action of a microwave beam in the air, in gases and gas mixtures of atmospheric (and higher) pressure without the involvement of vacuuming systems and energy-consuming initiators;
- The existence of the SNSS in the form of an ionization wave propagating towards microwave radiation and capturing significant amounts of the processed gas medium;
- Possibility of simultaneous removal (purification) of a wide range of environmentally harmful impurities from the treated gas;
- At the same time with "chemical" cleaning implementation of highly effective disinfection of the processed gas environment;
- The possibility of excitation of the SNSS-discharge both in closed volumes and in free air space at the surface of the earth and at relatively large distances from it, etc.

Conducting experiments that specify the energy price of microwave exposure to polluted urban atmosphere, and conducting technical and physical analysis of the problem of plasma-chemical electric discharge restoration of environmental safety of the urban environment are the main objectives of studies of GPI.

Potential applications of the sub-threshold microwave discharge are shown in Figures 2-4.

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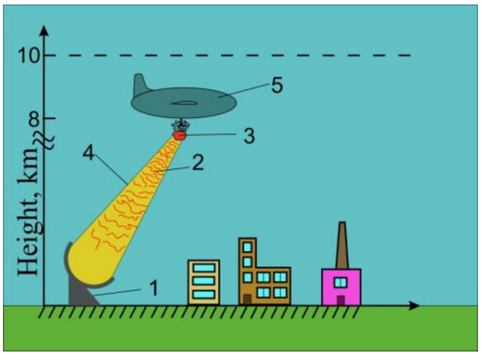

Fig.2. Schematic of atmospheric cleaning system. 1-gyrotron and MW antenna; 2-SNSS discharge;3-initiator; 4-MW beam;5-pilotless vehicle

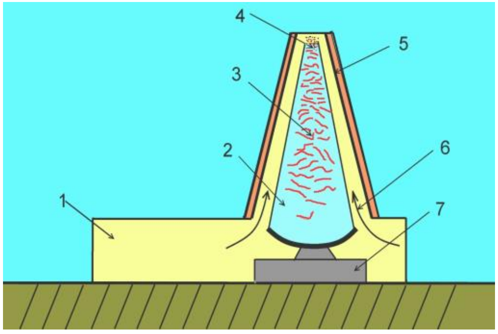

Fig. 3. Industrial gas ejection cleaning. 1-plant building; 2-MW beam; 3-SNSS discharge

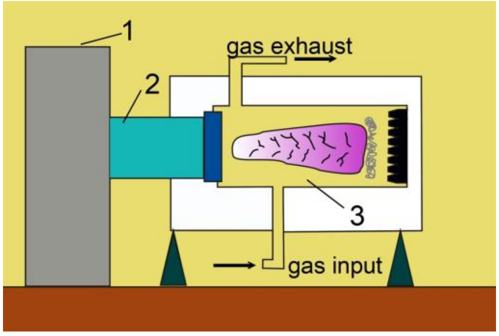

Fig. 4. Cleaning of the gas environment in the workshop.
1-gyrotron; 2-microwave beam; 3-plasmachemical reactor.