INTRODUCTION

The search for and development of new effective means enabling one to reduce the ignition time and control the process of combustion of high-velocity flows of fuel are currently central problems from the standpoint of development of modern aviation, in particular, as regards the optimization of operation of supersonic ramjet engine. One of new solutions to this problem is provided by the use of gas discharges of various types. Therefore, a new line of research has been intensively developing at present in the physics of plasma, namely, supersonic plasma aerodynamics. Relevant international conferences are held annually (International Workshops on Weakly Ionized Gases, American Institute of Aeronautics and Astronautics, USA: Colorado 1997, Norfolk 1998 and 1999, Anaheim 2001, Reno 2002–2008, Orlando 2009 and 2010; International Workshops on Magneto- and Plasma Aerodynamics for Aerospace Applications, Joint Institute for High Temperatures, Russian Academy of Sciences, Russia, Moscow: 1999, 2000, 2001, 2002, 2003, 2005, 2007, 2009, 2010; International Workshops on Magnetohydrodynamics for Aerospace Applications, Leninetz Holding Company, Russia, St. Petersburg: 2003, 2004, 2006, 2008). In so doing, it is suggested to use nonequilibrium gas-discharge plasma in hypersonic ramjet engine for reducing the time of ignition of fuel. One must find an optimal method for generating low-temperature nonequilibrium plasma with a view to studying the possibility of efficient utilization of gas discharge for initiating rapid ignition of high-velocity air–hydrocarbon flows. It was demonstrated in [1–11] that pulsed discharges existing at high values of reduced electric field lead to effective dissociation and heating of molecular gases, as well as to the production of a large number of excited particles and radicals. These facts are of importance when using gas-discharge plasma for rapid bulk ignition of chemically active mixtures.

Various types of electrode and electrodeless, volume and surface, self-sustained and non-self-sustained discharges are employed for this purpose at different research institutes, as well as various combinations of such discharges such as dc electrode discharges, high-voltage and low-voltage pulsed transverse and longitudinal electrode discharges, radio-frequency and microwave discharges, creeping, barrier, and surface discharges. DC electrode discharges, as well as pulse-periodic and rf discharges in supersonic air flow lead to strong erosion of electrodes and of the model surface and cannot be reliably reproduced in various experiments.

Of special interest from the standpoint of their effect on the processes of rapid ignition of air–hydrocarbon mixtures are microwave discharges, because they exist in a wide range of power and pressure, provide the possibility of generating plasma in free space, and are free of contamination of plasma by the products of erosion of bodies placed in this plasma. Microwave discharges are further characterized by high values of reduced electric field, which is very promising from the standpoint of rapid heating and ignition, in particular, of hydrocarbon mixtures.

The problem arose of searching for optimal methods of generating nonequilibrium plasma in a super-
sonic flow of gas. For this purpose, a microwave discharge of new type was suggested in [1], namely, a microwave discharge which is initiated by a surface wave on a dielectric body subjected to supersonic air flow. The basic properties of surface microwave discharge at low \((p < 1 \text{ torr})\) and medium \((p = 1–40 \text{ torr})\) pressures of air, where the electron-neutral molecule collision frequency is lower or of the order of the circular frequency of electromagnetic energy, are considered in detail in [1–11]. The dynamics of development of discharge at high pressures of air are studied in [12].

Now, we have investigated the evolution of gasdynamic perturbations arising under conditions of microwave discharge initiated by a surface wave on a dielectric body and the parameters of discharge at high (up to atmospheric) pressures of air.

**EXPERIMENTAL SETUP AND DIAGNOSTIC METHODS**

The experimental setup described in [7] was employed for measuring the parameters of surface microwave discharge plasma at high pressures of air and attendant gasdynamic perturbations. The setup includes a vacuum chamber, a magnetron oscillator, a system for microwave energy input into the chamber, a system for evacuation and bleeding-in of gas, and a diagnostic system. The vacuum system made possible investigations in a wide range of air pressures from 1 to 760 torr. When studying the properties of surface microwave discharge at atmospheric pressure, the vacuum hood was removed and the experiments were performed in free space. A pulsed magnetron oscillator of centimeter wavelength range was used as the source of microwave radiation. The magnetron exhibited the following characteristics: the wavelength \(\lambda = 2.4 \text{ cm}\), the pulsed microwave power released to the circuit \(W < 100 \text{ kW}\), the pulse duration \(\tau = 5–200 \mu\text{s}\), the pulse repetition rate \(f = 1–100 \text{ Hz}\), and the duty factor in the repeating pulse mode \(Q = 1000\); in so doing, the average power did not exceed 100 W. A surface microwave discharge was initiated on a quartz antenna of 115 mm long. The rectangular waveguide circuit, via which the microwave power was delivered to the magnetron, was filled with SF\(_6\) gas at a pressure of 4 atm in order to preclude electric breakdown within this waveguide circuit.

For measuring the gas temperature, the radiation spectrum of plasma of surface microwave discharge was recorded using an AvaSpec-2048-2-DT two-channel spectrograph (made by Avantes) and DFS-12 and MDR-23 monochromators (reciprocal linear dispersions of 0.5 and 1.3 nm/mm, respectively). The plasma radiation from a certain cross section of discharge was projected onto the entrance slits of spectral instruments using a system of light guides, lenses, and mirrors.

At low and medium pressures of air, the gas temperature under condition of surface microwave discharge was determined using a spectroscopic method based on recording the distribution of intensities of fully or partly resolved lines of rotational structure of molecular bands. The gas temperature was determined using the band \((0,2)\) with edge wavelength \(\lambda = 380.5 \text{ nm}\) of the second positive system of nitrogen. The intensity of glow of molecular bands of the second positive system of nitrogen abruptly decreases with increasing air pressure; therefore, it becomes impossible under these conditions to obtain a fully resolved rotational structure of molecular spectrum. This is associated with the fact that, firstly, the spectral lines in plasma are strongly broadened because of various mechanisms and, secondly, the spectrum must be recorded in the experiment using a wide entrance slit of spectral instrument because of low intensity of the signal being investigated; this likewise leads to strong broadening of spectral lines being recorded.

In spite of the great diversity of physical systems in which some or other random processes are generated, the overwhelming majority of the latter may be described using relatively few mathematical models. In so doing, the model must correctly include the basic physical characteristics. We used the Gauss profile as the broadening function. The thermal motion in plasma with Maxwellian velocity distribution leads to the Gauss process. A wide entrance slit must be used in recording weak signals. In so doing, the main contribution to the spread function of the spectral instrument is made by broadening due to finite width of the entrance slit. This results in a strong variation of the spread function which is transformed from Gaussian to trapezoidal function with the half-width proportional to the width of entrance slit.

In the case of fully or partly unresolved rotational structure of molecular bands, the foregoing method of measuring the gas temperature cannot be employed. In this case, the gas temperature was determined by comparing the measured molecular spectrum with the model spectrum of unresolved rotational structure calculated for preassigned values of gas and vibrational temperatures and for the given spread function of the spectral instrument.

In the present study, under conditions of high pressures of air \((p > 100 \text{ torr})\) where the intensity of the band \((0,2)\) with edge wavelength \(\lambda = 380.5 \text{ nm}\) of the second positive system of nitrogen becomes insufficient for measuring \(T_g\), the simulation was performed for different sequences of molecular bands of cyan \((0,0)\) with edge wavelength \(\lambda = 388.3 \text{ nm}\) and \((1,1)\) with edge wavelength \(\lambda = 387.1 \text{ nm}\). The distribution with respect to rotational and vibrational levels was assumed to be Boltzmann distribution. Computer codes for the calculation of spectra were employed and, separately, those for the calculation of the Hanle–London factors. The calculations were per-