TEMPERATURE TIME DEPENDENCE IN NITROGEN PULSE
EXCITED MICROWAVE DISCHARGE

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A detailed analysis of the population of the N₂ vibrational states for the N₂ (C³Π_u, X¹Σ⁺_g) electronic states has been carried out. Quantitative spectral and microwave measurements of vibrational temperatures and electron densities were performed for 2400 MHz non-isothermic pulsed discharges in flowing nitrogen at pressures (60–2700) Pa. From the time dependent peak intensities of the second positive system of N₂, the temperature of neutral gas during the h.f. pulses has been determined.

INTRODUCTION

The microwave discharges excited at pressures between (60 – 13 × 10³) Pa are frequently utilized as plasma flow chemical reactors. The neutral gas temperature is well above the room temperature, but a remarkable disequilibrium between electronic, vibrational, rotational and translational temperatures causes some difficulties in the diagnostics for systems of chemical interest. Nitrogen was chosen as the working medium because of its thermochemical properties which are well known; from the experimental viewpoint, nitrogen is ideal to be employed, since techniques are available to measure its vibrational temperatures.

The coupled relaxation of free electron, nitrogen vibrational and translational temperatures is an important phenomenon in high-enthalpy nonequilibrium plasma flows [1–4]. The basic difficulties encountered when comparing the spectroscopically determined values of vibrational temperatures with the corresponding quantities of the ground electronic state, are mentioned and the time resolved dependences of the translational gas temperature during the microwave pulses are evaluated.

The present paper is devoted to spectroscopic and microwave investigation of pure nitrogen flowing in a discharge apparatus. The measured time resolved dependences of N₂ (C³Π_u – B³Π_g), N₂⁺ (B²Σ⁺_u – X²Σ⁺_g) molecular band intensities and electron densities were determined to predict the variation of the nitrogen vibrational and translational temperatures during the h.f. pulses.

EXPERIMENT

A schematic drawing of the apparatus is given in Fig. 1.

Fig. 1. A schematic drawing of the apparatus. 1 – power supply for klystron generator, 2 – magnetron generator (2400 MHz), 3 – oscilloscope, 4 – spectrophotometer, 5 – klystron generator, 6 – ferrite insulator, 7 – attenuator, 8 – detector of microwave signal (λ = 0.8 cm), 9 – cylindrical cavity resonator, 10 – oscilloscope, 11 – discharge tube.

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The discharge tube of fused silica with i.d. of 12–13 mm was placed in the microwave cavity resonator. Pure nitrogen (70 ppm of O₂, 20 ppm of CO, CO₂) was introduced at a fixed flow 2·9 cc/s (60 Pa), 7·6 cc/s (260–2700 Pa). The pressure range investigated varied from 60 Pa (0·5 torr) to 2700 Pa (20 torr). Emission from the discharge was observed through a circular window \((D = 5 \text{ mm})\) in the microwave cavity resonator and analyzed by means of an Optica Milano spectrophotometer. A grating with 600 lines/mm in the first order has been used. Light signals were detected with an I P 28 photomultiplier and recorded at selected amplification by a Tektronix 549 Storage Oscilloscope. The medium band width of the observed spectra used for the measurements 3·2 Å has been applied.

Either a reduced or an enlarged image of the source could be focused on the plane of the spectrophotometer slit.

The discharge tube was first exhausted to the pressure 0·1 Pa \((5 \times 10^{-4} \text{ torr})\). By a system of needle valves the required pressure and gas flow was established. The pressure was measured by a LKB - Autovac vacuumeter.

Power output of the magnetron generator operating at 2400 MHz was 200 W in the continuous exploitation but the measurements were performed in pulsation regime. The duration of the rectangular pulse was 1·5 ms; the frequency of pulsation was 300 Hz.

To determine the time dependence of the electron density during the h.f. pulse the microwave method has been applied. The microwave signal \((\lambda = 0·8 \text{ cm})\) of a constant amplitude from the klystron generator was fed through the discharge plasma in the cavity resonator. The transmitted signal was observed on the screen of an oscilloscope. The absorption of the microwave signal is proportional to the electron density of the observed plasma. For the required purposes the relative measurements of electron density are sufficient.

**SPECTRAL AND MICROWAVE OBSERVATIONS**

The time resolved band intensities of \(N_2 \left( C^3 \Pi_u - B^3 \Pi_g \right)\), \(N_2^+ \left( B^2 \Sigma_u^+ - X^2 \Sigma_g^+ \right)\) systems and electron density during the pulses of h.f. energy are presented in Figs. 2, 3, 4, 5. The pulses of h.f. energy were strictly rectangular. The time dependence of the electron density shows a small deviation from the rectangular form after the breakdown only — Fig. 3. At the beginning of the h.f. pulse the intensity of \(C^3 \Pi_u - B^3 \Pi_g\) bands with \(v' = 0, 1, 2\) shows a very high peak and a subsequent decay — Figs. 2, 3, 4, 5. With growing vibrational quantum number \(v'\) the initial peak diminishes and within the pressure range \((60-270) \text{ Pa}\) it was not observed at all for \(v' = 4\) or greater — Figs. 2, 3, 4.

The relative peak intensities depend on the vibrational quantum number in the upper electronic state and on the gas pressure in the discharge tube. At 60 Pa the intensity of the \((v' = 4, v'' = 2)\) band has no initial peak, but at 700 Pa a pronounced peak after the breakdown is observable — Figs. 2, 5.

Very similar effects have already been observed in the spectra of pulse excited unipolar h.f. discharge [5].

The explanation of the above measured effects can be performed on the basis of a detailed analysis of the excitation processes and temperature ratios.

The time resolved intensity of the \(N_2^+ \left( B^2 \Sigma_u^+ - X^2 \Sigma_g^+ \right) (0, 0)\) band (Fig. 1, 2) shows that the processes of ionization, excitation and heating reach the steady state after \(10^{-4}\) sec.