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SPECTROSCOPIC DIAGNOSTIC OF THE HE +H_2 PLASMA GENERATED BETWEEN CERAMIC ELECTRODES $BaTiO_3$

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A b s t r a c t. Emission spectroscopy diagnostic is the method that does not disturb the conditions of the plasma during the measurements of its parameters: gas temperature, electron temperature, electron number density etc.
In this paper we present the results of measurements of rotational temperature from the first negative band of the ionic nitrogen molecule (transitions N_2^+ (B-X)) in the dielectric barrier discharge under low pressure. The temperature of helium gas was determined from Doppler component of the HeI (501.6 nm) line. The electron concentration in the plasma was determined from the measured width of the hydrogen H_β line assuming that the line broadening is caused by linear Stark effect of electric microfields in plasma. Obtained results were discussed and compared with the data from earlier papers.

K e y w o r d s: dielectric barrier discharges, ionic nitrogen molecules, rotational temperature, gas temperature.

INTRODUCTION

Plasma generated in dielectric barrier discharges (DBD) has the unique properties therefore is the object of several applications and experimental and theoretical research [1, therein Ref.]. In our group we study spatial and spectral distributions of the light emitted from DBD source in different gas mixtures and pressures from 0.5 to 100 kPa. The light is observed in parallel to the surface of ceramic (or metal) plates ($BaTiO_3$) direction. The plasma source is supplied by generator alternating voltage with amplitude to 1200 V and frequencies from 50 to 10 kHz [2-4].

In this paper we present the results of measurements of rotational temperature from the first negative band of the ionic nitrogen molecule (transitions N_2^+ (B-X)) in the electric discharge under pressure 18 mmHg. Also the temperature of helium gas was determined from Doppler component of the He I (501.6 nm) line. The electron concentration in the plasma was determined from the measured width of the hydrogen H_β line assuming that the line broadening is caused by linear Stark effect of electric microfields in plasma. Obtained results were discussed and compared with the data from the earlier papers.

EXPERIMENT AND RESULTS

Figure 1 shows the experimental setup. The optical setup without interferometers but with photomultiplier P1 or optical multichannel analyser OMA-4 was used for measurements of intensity of molecular bands or wide line shape parameters and their intensities. The optical setup containing Fabry–Perot interferometer and Jamin interferometer was used during measurements of narrow line shape parameters.

The scheme of electric setup is presented on Fig. 2. Them oscilloscope with memory, voltage divider, capacitor with known capacities permitted monitoring of time courses of voltage and current and measurement of electrical charge transferring during one-half of the period.

In this experiment, source of plasma was supplied by voltage 500V with frequency 10 kHz. Distance between ceramic plates was 1 mm, pressure 18 mmHg. A mixture of helium and 5% hydrogen with trace amount of nitrogen was applied as working gas. The band was recorded with spectrograph equipped with a 561groves/mm grating and having a reciprocal dispersion of 0.734 nm/mm. Source image was projected on the slit of grating spectrograph PGS-2. The width of entrance and exit slit was 40µm. The photomultiplier RCA was used as a detector. Spectrum was recorded with Kipp & Zonen recorder.

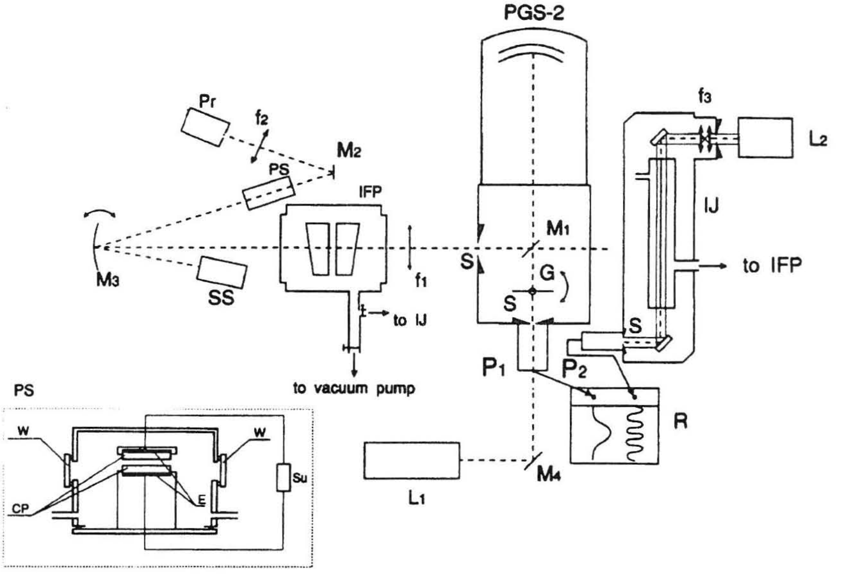

Fig. 1. Experimental setup; projector (Pr), lenses (f1, f2, f3), mirrors (M1, M2, M3), lasers (L1, L2), Farby-Perot interferometer (IFP), Jamin interferometer (IJ), grating (G), two-channel recorder (R), slits (S), plasma source (PS), standard source (SS), photomultipliers (P1 or OMA4, P2), spectrograph (PGS-2), windows (W), ceramic plates (CP), electrodes (E), supply (Su).

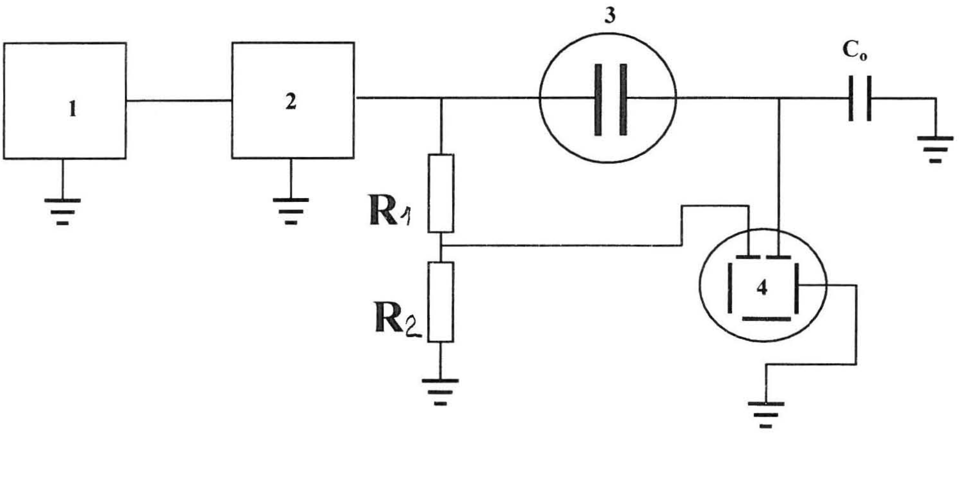

Fig. 2. Electric setup scheme. 1-generator, 2-amplifier, 3-plasma source, 4-oscyloscope.

Figure 3 shows observed emission spectra of N_2^+ ($B\ ^2\Sigma_u^+ - X\ ^2\Sigma_g^+$). The wavelength of particular lines of band was determined from:

$$\lambda_l = 388.865 + \Delta X_l * D, \quad (1)$$

where ΔX_l is distance of a given line from position of helium line HeI 388.865 nm, D is a reciprocal dispersion determined from position and wavelength of HeI line and a N_2^+ 391.44nm band head.

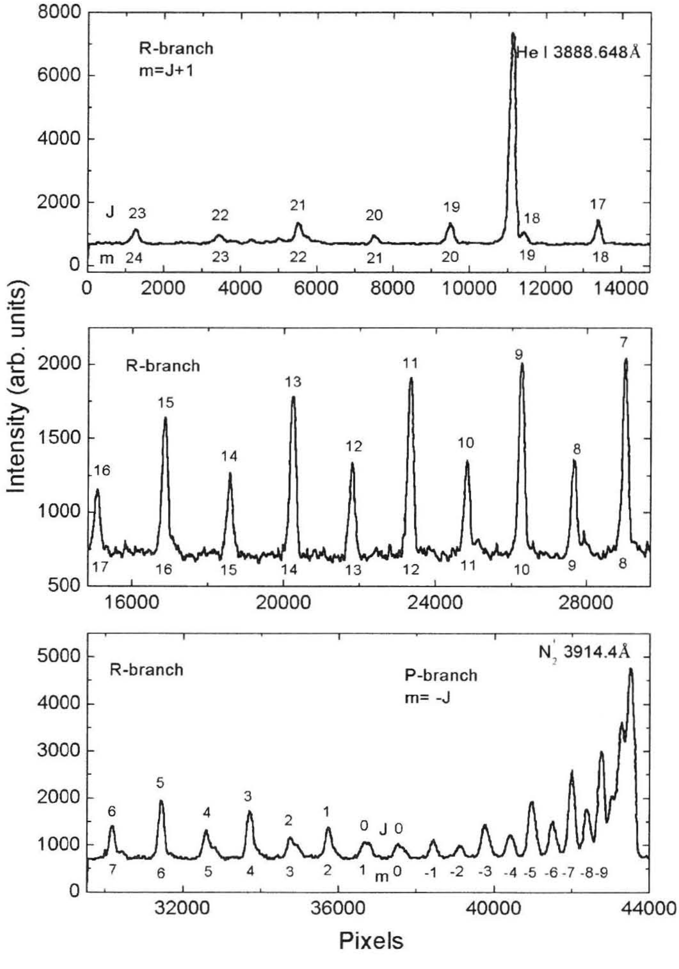

Fig. 3. Emission spectra of N_2^+ $B^2\Sigma_u^+$ - $X\ ^2\Sigma_g^+$.

General information about molecular spectra, especially the Fortrat parabola for the specified type of molecule, and intensity distribution of lines in a given branch, are helpful in identification of bands. Allotment of J values to spectral lines was controlled using several methods: 1) by creating Fortrat parabola (Fig. 4), 2) by method using Déslandres formula for branches P and R. [5]

$$\nu = c+d*m+e*m^2, \tag{2}$$

where: c, d, e – constances

$e = B' - B''$, $d = B' + B''$

$m = J'$ for branch P, $m = J'+1$ for branch R,

B' – a spectroscopic constant for upper vibrational level,

B''- a spectroscopic constant for lower vibrational level.

From an analysis of first derivative

$$\Delta\nu/ \Delta m = d+2e*m$$

and second derivative

$$\Delta^2\nu/ \Delta m^2 = 2e$$

of wave numbers of lines in branch R for $\Delta m = 1$, were calculated average values of constants: 2e= 0.32, d =4.22, B' = 2.27, B'' = 1.95. The smallest scatter of constant 2e was obtained for J≥15 and data for these quantum numbers were taken into account. The analyse of band for the small quantum numbers J causes difficulties, because there is a big density of lines close to the band head and lines in branch P and R are superpositoned. Therefore by determination of rotational temperature only the well identified part of branch R, not perturbed by branch P was used.

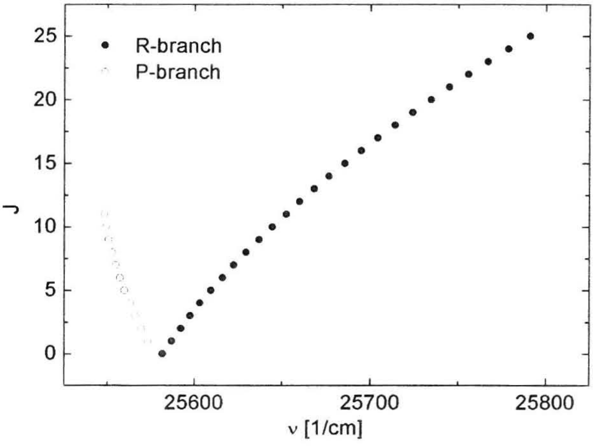

Fig. 4. Fortrat parabola for a N_2^+ $B^2\Sigma_u^+$ - $X\ ^2\Sigma_g^+$.

Rotational temperature was determined with graphical method from line intensity distribution in branch R of transition N_2^+ $B^2\Sigma_u^+$ - X $^2\Sigma_g^+$ at wavelength of band head 391.44 nm. Line intensity distribution is given by [5]

$$I= C_{em}\, P\, \nu^4 \exp [-E_r/kT], \qquad (3)$$

where: I – line intensity, C_{em} – constant for given band, P – transition probability, E_r – rotational energy, T – rotational temperature.

After segregation of particular values, grouping constants for given band and taking a logarithm of both sides we obtained the expression:

$$\log I^w - \log[\nu^4 (J'+J''+1)] = -[B'J'(J'+1)hc/2.303kT] - \log D, \quad (4)$$

where $I = I^w * K$, I^w- relative line intensity, K- recalculation units factor, D – constant for given band.

The plot in coordinates $y = \log I^w - \log[\nu^4 (J'+J''+1)]$, $x = E_r = B'J'(J'+1)\, hc$, is shown on Fig. 5.

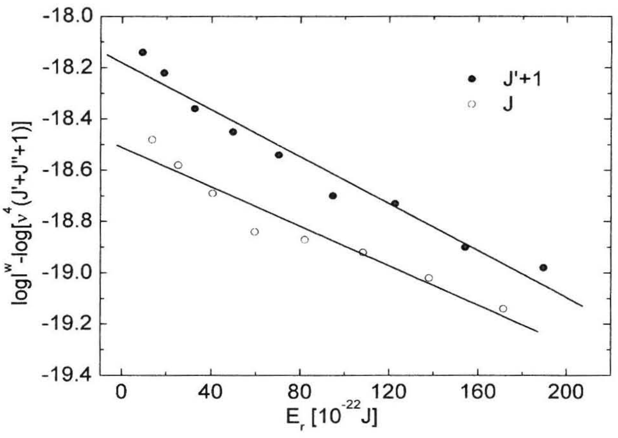

Fig. 5. Boltzmann plot for rotation temperature determination.

The upper and lower straight lines refer to line with higher intensity and to line with lower intensity, respectively. The lines were fitted to experimental data using last squares method. The ratio of intensities for nitrogen molecule is like 2:1 that is in agreement with experimental data within experimental error. The rotational temperatures determined from the slope of the straight lines are T_{rg} = 690±50 K, T_{rd} = 820±80 K, respectively.

The final result is the average temperature T_r= 730±30 K.

For comparison the gas temperature T_g = (510±30) K was determined from Gauss component of Voigt profile of HeI line (501.6nm). Because width of helium line in our experiment conditions was only 0.004 nm, the method of crossed dispersions of PGS-2 spectrograph and Fabry-Perot interferometer (IT-30) was used. The spectrum was scanned by change of pressure in system of two coupled pressure F-P and Jamin interferometers. Jamin interferometer was used to scale the spectrum.

The dispersion interval of F-P interferometer was λ = 0.021 nm, width of apparatus profile $\delta\lambda_a = 7x10^{-4}$ nm, and dispersion interval of IJ is $\Delta\lambda = 4x10^{-4}$ nm. Half width of Doppler component was determined by fitting of the experimental line He I profile to Voigt profile using the last squares method. The temperature was calculated from the known expression

$$\Delta\lambda_{1/2}=7.2x10^{-7}\,\lambda\,(T/M)^{1/2}, \qquad (5)$$

where λ is wavelength of specified line, T is temperature in K, and M is the emitter atomic weight.

The difference between the rotational temperature and the gas temperature is possible to explain by different excitation and relaxation processes of particular components of investigated plasma. Due to very fast Pening ionisation processes [6]:

$$He^* + N_2 \rightarrow N_2^+(B^2\Sigma_u^+) + He,$$

ionic nitrogen molecule is created, He* is metastable helium atom excited to level 2^3S_1 or 2^1S_0.

Bibinov [6] presumes that molecular ions of nitrogen are created in initial phase of microdischarge that can explain much higher rotational temperature of nitrogen molecule ions in comparison to neutral plasma components. This conclusion is consistent also with our experimental results.

The electron concentration (n_e=1.4*10^{14} cm^{-3}) was also determined from halfwidth of hydrogen H_β line. Obtained electron concentration is higher in comparison to earlier paper data [7] ($n_e \approx 10^{13}$ cm^{-3}), where electron concentration was determined from helium line intensity, in assumption of collision-radiation model to generated plasma. We think, that discrepancies of electron concentrations are due to the splitting Stark components by outside electric field, that predominant contribution to hydrogen lines broadening parameters has in comparison with line broadening caused by inner plasma microfields [2]. Therefore determination of electron concentration from halfwidth of hydrogen lines, which gives very good results for electric arc plasma, can give incorrect results for the barrier electric discharges plasma.

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DIAGNOSTYKA SPEKTROSKOPOWA PLAZMY $He+H_2$ GENEROWANEJ POMIĘDZY ELEKTRODAMI CERAMICZNYMI Z $BaTiO_3$

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S t r e s z c z e n i e. W prezentowanej pracy podajemy rezultaty pomiarów temperatury rotacyjnej uzyskanej dla jonu molekuły azotu (przejścia N_2^+ (B-X)) w wyładowaniu barierowym pod niskim ciśnieniem. Gazem roboczym była mieszanina helu i 5% wodoru ze śladową ilością azotu. Temperatura helu była wyznaczana z składowej linii Dopplera HeI (501.6 nm). Stężenie elektronów w plazmie było wyznaczane z pomiarów szerokości połówkowej linii H_β Otrzymane rezultaty były porównywane z danymi z wcześniejszych prac.

S ł o w a k l u c z o w e: wyładowania barierowe, jony molekuły azotu, temperatura rotacyjna, temperatura gazu.