

Variations of the Gas Temperature in He/N₂ Barrier Discharges

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For obtaining the gas temperature in the micro-discharge areas and in the ambient gas of dielectric barrier discharges in helium/nitrogen mixtures we have studied the rotational temperature of the emission of molecular nitrogen ions. The experimental set up was described in [1]. Shortly: the discharge cell consists of two flat parallel electrodes (6 x 6 cm²) covered by dielectric glass plates of 0.22 cm thickness. The gap between the dielectric plates was 0.15 cm. An ac-generator with a frequency of 19.7 kHz served as power supply. The applied voltage u and the current of the power supply i were measured by means of a digital oscilloscope TEKTRONIX 2440 either directly or via a matched 50 Ω resistor connected in series to ground. In these discharges the duration of a single micro-discharge is of the order of

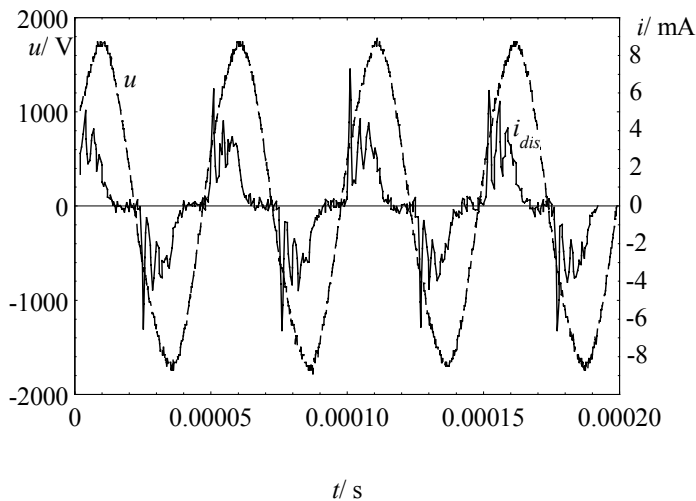


Fig. 1 Current and voltage of a DBD in He/N₂

800 ns, the number of micro-discharges in one cycle of the driving voltage (frequency 19.7 kHz) is of the order of 10 – see Fig. 1. In the helium/nitrogen mixture the excited state $N_2^+(B^2\Sigma_u^+)$ forms mainly by Penning ionisation and charge transfer. By averaging over the temporal variation of the gas temperature after ignition of a micro-discharge we calculated rotational spectra of the transition $N_2^+(B^2\Sigma_u^+ \rightarrow X^2\Sigma_g^+)$ using the reaction scheme for discharges in helium/nitrogen mixtures developed by J. M. Pouvesle et al. [2,3]. The reactions taken into account together with rate coefficients are given in Table 1 at the end of this contribution. Temperature variations of rate coefficients we took from [7 – 9].

The temperature variation for our experimental conditions ($p_{\text{He}}= 38.5 - 156 \text{ kPa}$, $p_{\text{N}_2}= 20 - 6500 \text{ Pa}$) we obtained by solving the Navier-Stokes equations

$$\frac{\partial \rho}{\partial t} = -\nabla \cdot (\rho \vec{V}) \quad (1)$$

$$\frac{\partial (\rho \vec{V})}{\partial t} = -\nabla p - \nabla \cdot (\rho \vec{V} \vec{V}) \quad (2)$$

$$\frac{\partial (c_v \rho T)}{\partial t} = \vec{j} \cdot \vec{E} - \nabla \cdot (\rho \vec{V} c_v T) - p \nabla \cdot \vec{V} + \nabla \cdot \Lambda \nabla T . \quad (3)$$

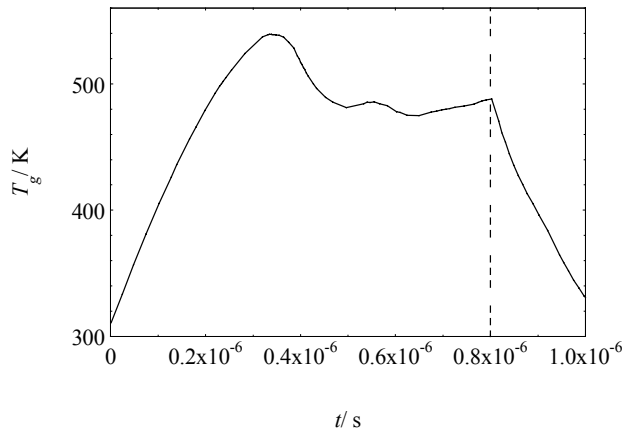
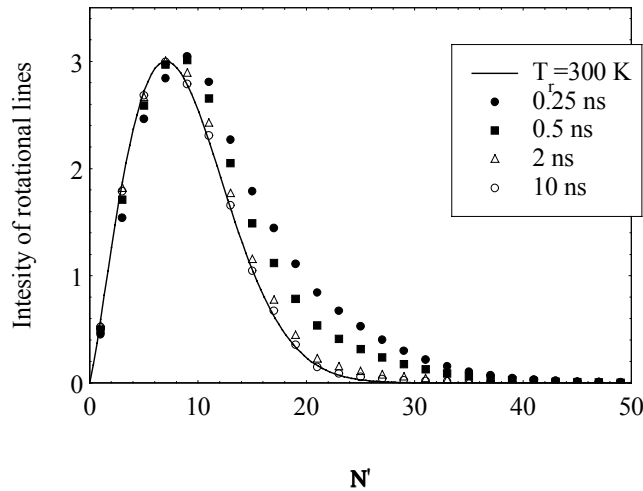


Fig. 2 Calculated time dependence of the temperature in the micro-discharge area. The dotted line indicates the end of the active discharge ($p_{\text{N}_2} = 1300 \text{ Pa}$, $p_{\text{He}} = 99.7 \text{ kPa}$).



Here p is the thermodynamic pressure, V the advective (or convective) velocity, Λ the thermal conductivity, c_v the heat capacity, j the current density, E the electric field and ρ the mass density. Fig 2 shows as an example the calculated time dependence of the temperature in a micro-discharge area.

Modelling the rotational relaxation process we found under these conditions the rotational spectra of the nitrogen molecular ions to be within 2 ns in thermal equilibrium with the surrounding

Fig. 3 Calculated rotational lines in the $\text{N}_2^+(\text{B}^2\Sigma_u^+, v_B = 0) \rightarrow \text{N}_2^+(\text{X}^2\Sigma_g^+, v_X = 0)$ spectra ($p_{\text{He}}=101 \text{ kPa}$) for different effective lifetime of the $\text{N}_2^+(\text{B}^2\Sigma_u^+)$ state (initial temperature 1000 K, temperature of the ambient gas 300 K)

gas – see Fig. 3.

Experimentally we obtained the rotational temperatures of molecular nitrogen ions by high-resolution optical emission spectroscopy. Rotational temperatures at different nitrogen pressures measured and calculated in the way described above are presented in Fig. 4. The best agreement of the measured and calculated values was obtained by using the following fit parameters: ambient gas temperature 310 K, 10 current pulses during one half period of the

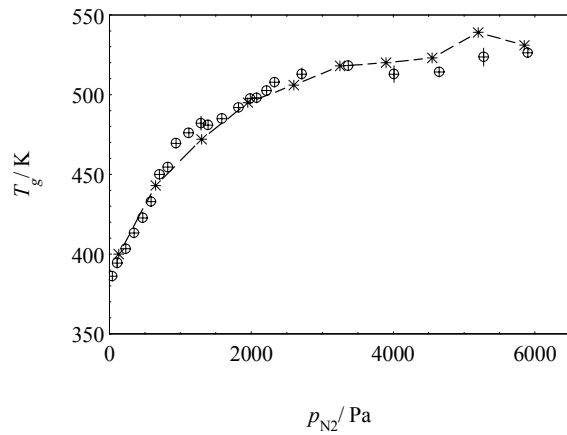


Fig. 4 Rotational temperature of the $N_2^+(B^2\Sigma_u^+, v_B = 0) \rightarrow N_2^+(X^2\Sigma_g^+, v_X = 0)$ transition measured in He/ N_2 mixtures of constant total pressure $p = 101$ kPa versus the nitrogen partial pressure (\oplus - experiment, $-*$ - best fit to model).

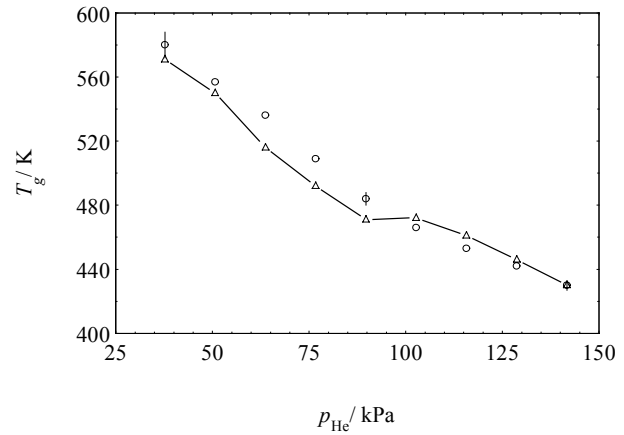


Fig. 5 Rotational temperature of the $N_2^+(B^2\Sigma_u^+, v_B = 0) \rightarrow N_2^+(X^2\Sigma_g^+, v_X = 0)$ transition measured in He/ N_2 mixtures with constant nitrogen partial pressure $p_{N_2} = 1300$ Pa versus the helium partial pressure (\circ - experiment, $-\Delta$ - best fit to model).

applied voltage and a micro-discharge radius of $28\mu\text{m}$. Measured and calculated values of the rotational temperature versus the helium pressure for a constant nitrogen partial pressure $p_{N_2} = 1300$ Pa are presented in Fig. 5. We used here the same values of the fit parameters as in the case of Fig. 4. In both cases the agreement between experiment and model is very good.

References

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Table 1

Reaction	Rate constant at $T = 300$ K	Reference
$\text{He}^+ + 2 \text{He} \rightarrow \text{He}_2^+ + \text{He}$	$k_3 = 1.5 \cdot 10^{-31} \text{ cm}^{-6} \text{ s}^{-1}$	[3]
$\text{He}_2^+ + \text{N}_2 \rightarrow \text{N}_2^+(\text{B}^2\Sigma_u^+) + 2 \text{He}$	$k_6 = 8.3 \cdot 10^{-10} \text{ cm}^{-3} \text{ s}^{-1}$	[3]
$\text{He}^* + \text{N}_2 \rightarrow \text{N}_2^+(\text{B}^2\Sigma_u^+) + \text{He}$	$k_7 = 7.6 \cdot 10^{-11} \text{ cm}^{-3} \text{ s}^{-1}$	[3]
$\text{N}_2^+(\text{B}^2\Sigma_u^+) \rightarrow \text{N}_2^+(\text{X}^2\Sigma_g^+) + h\nu$	$k_8 = 1.5 \cdot 10^{-7} \text{ cm}^{-3} \text{ s}^{-1}$	[4]
$\text{He}^+ + \text{N}_2 \rightarrow \text{products}$	$k_9 = 1.2 \cdot 10^{-9} \text{ cm}^{-3} \text{ s}^{-1}$	[5]
$\text{He}^+ + \text{N}_2 + \text{He} \rightarrow \text{products}$	$k_{10} = 2.2 \cdot 10^{-29} \text{ cm}^{-6} \text{ s}^{-1}$	[3]
$\text{He}_2^+ + e \rightarrow \text{He}^* + \text{He}$	$k_{11} = 9 \cdot 10^{-9} \text{ cm}^{-3} \text{ s}^{-1}$	[2]
$\text{He}_2^+ + \text{N}_2 \rightarrow \text{products}$	$k_{12} = 2.7 \cdot 10^{-10} \text{ cm}^{-3} \text{ s}^{-1}$	[3]
$\text{He}_2^+ + \text{N}_2 + \text{He} \rightarrow \text{N}_2^+(\text{B}^2\Sigma_u^+) + 3 \text{He}$	$k_{13} = 1.0 \cdot 10^{-29} \text{ cm}^{-6} \text{ s}^{-1}$	[3]
$\text{He}_2^+ + \text{N}_2 + \text{He} \rightarrow \text{products}$	$k_{14} = 3.4 \cdot 10^{-30} \text{ cm}^{-6} \text{ s}^{-1}$	[3]
$\text{He}^* + \text{N}_2 \rightarrow \text{products}$	$k_{15} = 1.4 \cdot 10^{-10} \text{ cm}^{-3} \text{ s}^{-1}$	[3]
$\text{He}^* + \text{N}_2 + \text{He} \rightarrow \text{N}_2^+(\text{B}^2\Sigma_u^+) + \text{He}$	$k_{16} = 1.7 \cdot 10^{-30} \text{ cm}^{-6} \text{ s}^{-1}$	[3]
$\text{He}^* + \text{N}_2 + \text{He} \rightarrow \text{products}$	$k_{17} = 1.7 \cdot 10^{-30} \text{ cm}^{-6} \text{ s}^{-1}$	[3]
$\text{N}_2^+(\text{B}^2\Sigma_u^+) + e \rightarrow \text{N} + \text{N}$	$k_{18} = 1.75 \cdot 10^{-7} \text{ cm}^{-3} \text{ s}^{-1}$	[6]
$\text{N}_2^+(\text{B}^2\Sigma_u^+) + \text{N}_2 \rightarrow \text{products}$	$k_{19} = 3.7 \cdot 10^{-10} \text{ cm}^{-3} \text{ s}^{-1}$	[7]