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To cite this version:

Sylvain Iséni, Ronan Michaud, Philippe Lefaucheux, Volker Schulz-von Der Gathen, Goran B Sretenovic, et al.. Spectroscopic study of the neutral gas temperature of silicon based DC MHCD in various gases close to atmospheric pressure. 13th Frontiers in Low-Temperature Plasma Diagnostics, May 2019, Baf Honnef, Germany. 2019. hal-02131666

HAL Id: hal-02131666
https://hal.science/hal-02131666
Submitted on 24 May 2019

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Spectroscopic study of the neutral gas temperature of DC MHCD in various gases close to atmospheric pressure

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**Motivation**

Micro hollow gas discharges (MHCD) have been of high interest to produce highly ionized gas while keeping the gas temperature close to room temperature. This study focuses on the accurate measurement of the gas temperature in and out the cavity, operated in different regimes, by means of space resolved optical emission spectroscopy. Two approaches are applied depending on the gas mixture (He, Ar, N2):

- analysis of the profile of resonant atomic lines taking into account the Van der Waals broadening,
- analysis of the relative population distribution of ro-vibrational N2(C-B) bands.

Limitations of the latter approach will be discussed specifically. Heat transfer and temperature gradient will be discussed with regard to the geometry and the material properties of the present MHCD design.

**Source plasma – micro-cavity plasma (MHCD)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>He, Ar, N2</td>
</tr>
<tr>
<td>Pressure</td>
<td>66 atm</td>
</tr>
<tr>
<td>Polarity</td>
<td>Positive or negative</td>
</tr>
<tr>
<td>Power</td>
<td>0.2 mW to 150 mW</td>
</tr>
</tbody>
</table>

**Experimental conditions:**

- Powered in DC,
- Polarity: positive or negative,
- ≥ 0.2 mW to 150 mW,
- Gas pressure 0.26 atm to 1.2 atm,
- Gas: He / Ar / N2,
- MHCD arrays, e.g. 32 × 32 micro-cavities.

**Imaging optical emission spectroscopy**

Front image of a single MHCD (100 µm diameter). Integration of the whole spectrum.

**Resonance broadening and rotational temperature of N2(C-B)**

The pressure broadening contributes to the Lorentzian full width at half maximum (FWHM) of the line, $\Delta v$. At atmospheric pressure, $\Delta v$ is dominated by the resonance broadening with a minor contribution due to the van der Waals interactions. Thus, $\Delta v \approx \Delta v_{\text{res}} + \Delta v_{\text{vdw}}$, with

$$\Delta v_{\text{res}} = K(0,1) \sqrt{\frac{\beta \cdot T}{\hbar \cdot \Omega \cdot \hbar^2 \cdot n \cdot N}}$$

$$\Delta v_{\text{vdw}} = 8.18 \cdot 10^{12} \lambda_0^2 (\alpha R)^{2/5} \left( \frac{T}{\mu} \right)^{3/10} \cdot N$$

A detailed analysis of the line profile is used to determine $T_{rot}$.

With reasonable assumptions, $T_{rot}$ is often considered to be equal to the rotational temperature of diatomic molecules, e.g. N2. The relative spectral intensity $I_J/J''$ of transitions from two different vibrational states (J'' → J') reads

$$I_J/J'' \propto N \nu_s \nu_{rot} \exp \left( \frac{-hc}{k_B T_{rot} F(J')} \right)$$

- Spectral simulation based on molecular constants of N2(C^3Π) determined for $J \leq 25$.
- Fitting routine using only four parameters and two optimization passes; computed confidence interval of 95 %, e.g. uncertainties.

**Trot temperatures inside/outside the MHCD**

- $T_{rot}$ measured with line profile analysis.(0.66 atm).
- Significant thermal differences between He and Ar.
- Discrepancies between $T_{rot}$ and $T_{rot}$ => is N2(C-B) in equilibrium in He...?

**Focus on the temperature gradient...**

- $T_{rot}$ in He (0.66 atm).
- $T_{rot}$ in Ar (0.66 atm).
- $T_{rot}$ front corresponds to the light from the negative glow (the brightest ionized volume) above the cathode sheath.
- Si substrate acts as a heat sink while the SiO2 plays the role of a thermal isolation with the anode surface.

**Comparison Trot N2(C-B) in MHCD and in guided ionization waves**

- $T_{rot}$ in pure DC MHCD.
- $T_{rot}$ in guided ionization waves at atmospheric pressure (APPJ).

**Concluding remarks**

- Higher $T_{rot}$ and $T_{rot}$ outside the cavity than inside => heat flux disturbed by SiO2 layer.
- Closer to atmospheric pressure, is $T_{rot}$ of N2(C-B) in equilibrium in He discharge...?
- Iseni S, et. al., 2019 On the validity of neutral gas temperature by emission spectroscopy in micro-discharges close to atmospheric pressure, PSST, 2019, in press.

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