Spectroscopic measurements in plasma generated by waveguide-supplied coaxial-line-based nozzleless microwave source

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Introduction

SUBJECT :

Spectroscopic study of rotational temperature of OH radicals and electron number density in high flow rate atmospheric pressure argon microwave plasma

MOTIVATION :

Development of microwave plasma technology at atmospheric pressure and high gas flow rates

The gas temperature can often be inferred from the rotational temperature of the heavy species of the gas [1-2]

APPLICATIONS :

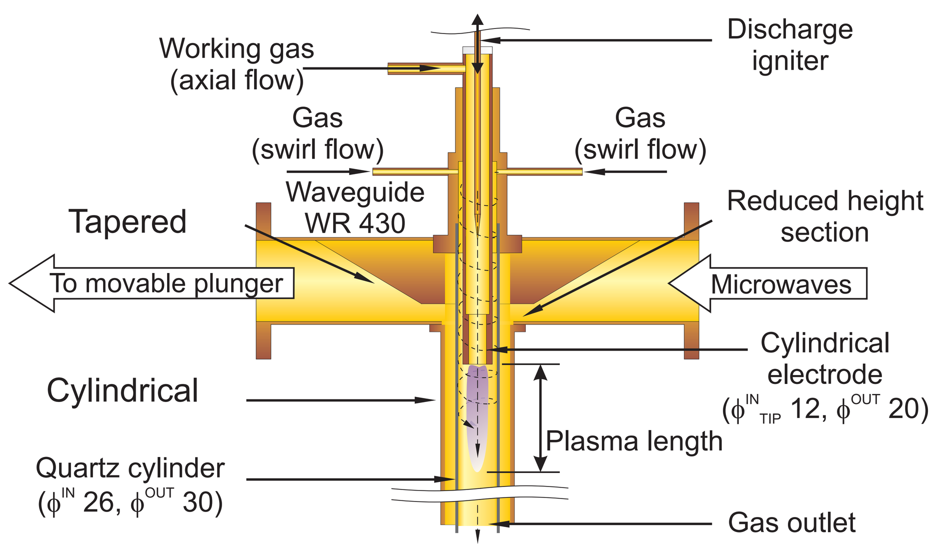
Gas processing:
production of hydrogen via hydrocarbons decomposition [3]
hazardous gas treatment [4]

Microwave Plasma Source (MPS)

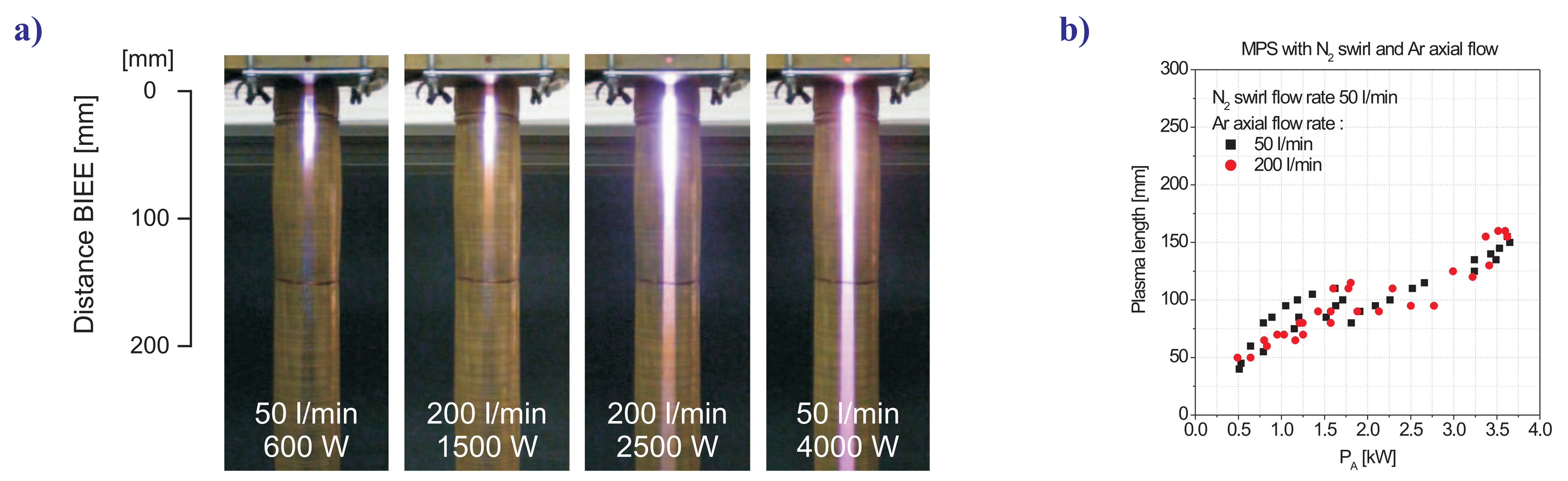
MICROWAVES
Frequency: 2.45 GHz
Powers: 600 - 4000 W

GAS FLOW
Swirl flow: N_2 or Ar
Flow rate: 50 - 200 l/min
(small amount of water vapour optionally added)

Axial flow: Ar
Flow rate: 50 - 200 l/min

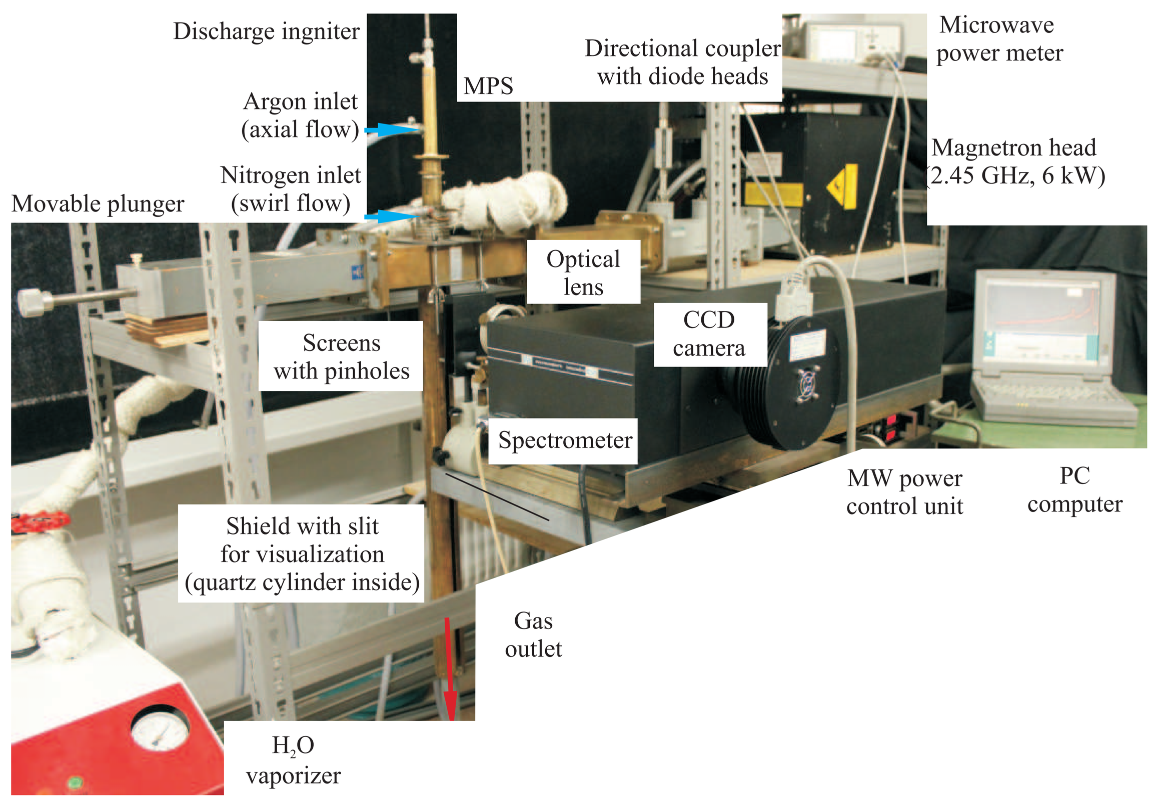


The sketch of MPS



a) Argon microwave plasmas, b) the length of argon plasma (measured from electrode) as a function of microwave absorbed power P_A ($P_A = P_I$(incident) - P_R(reflected)) for different axial flow rates

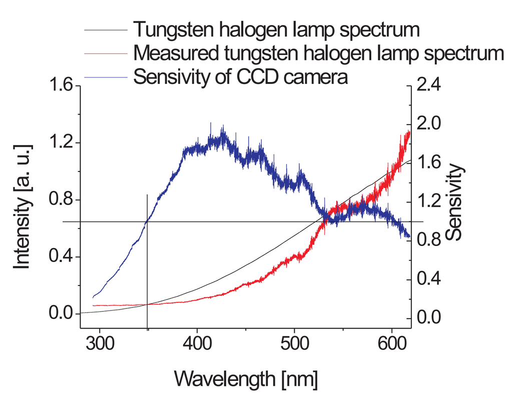
Experiments



Measuring devices:

Microwave power meter Agilent E4419B with E9301A heads and directional coupler MEGA IND. 069Y7 (70dB)

Spectrometer (DK-480, 3600 g/mm and 1200g/mm) with ST - 6 CCD sensitivity calibrated camera



The experimental setup for spectroscopic study of argon microwave atmospheric pressure plasma at high flow rates

Rotational temperature of OH radicals

- **Gas temperature can often be inferred from the rotational temperature of the heavy species of the plasma [1, 2]**
- **The rotational temperatures of OH radicals were determined by comparing the measured and simulated spectra in LIFBASE [5] program**
- **Method described by Izzara [1], based on analyzing intensities of two groups of unresolved rotational lines of the OH (A-X) band, was also used**

Electron number density

- **The electron number density in the argon plasma was determined using the Stark broadening of H_β spectral line**
- **Voigt function was fitted to the measured H_β:**

$$\Delta\lambda_V = \frac{\Delta\lambda_L}{2} + \sqrt{\frac{\Delta\lambda_L^2}{4} + \Delta\lambda_G^2} \quad [6]$$

$\Delta\lambda_V$ - Voigt FWHM, $\Delta\lambda_L$ - Lorentzian FWHM, $\Delta\lambda_G$ - Gaussian FWHM

- **Broadening mechanisms:**

$$\Delta\lambda_L = \Delta\lambda_W + \Delta\lambda_S$$
$$\Delta\lambda_G^2 = \Delta\lambda_D^2 + \Delta\lambda_I^2 \quad [6]$$

$\Delta\lambda_W$ - Wan der Waals, $\Delta\lambda_S$ - Stark, $\Delta\lambda_W$ - Doppler, $\Delta\lambda_S$ - Instrumental, $\Delta\lambda_G$ - Natural, $\Delta\lambda_R$ - Resonance - neglected [6]

$$\Delta\lambda_D = 7{,}16\times10^{-7}\times486.13\times\sqrt{T}$$
$$\Delta\lambda_W = 6{,}48\times10^{-22}T^{-0{,}7}\frac{p}{k} \quad [7]$$

T - temperature, p - pressure, k - Boltzmann constant

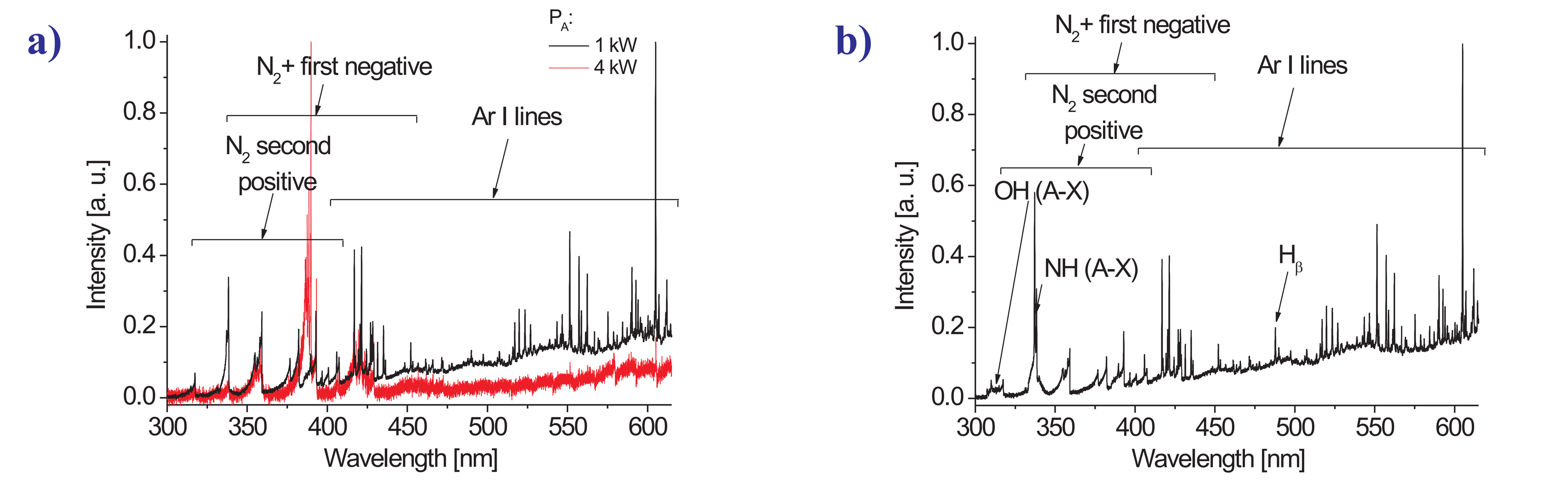
$\Delta\lambda_S$ - Instrumental - measured with low-pressure Hg-Ne calibration lamp

- **Formulas used for electron number density calculation:**

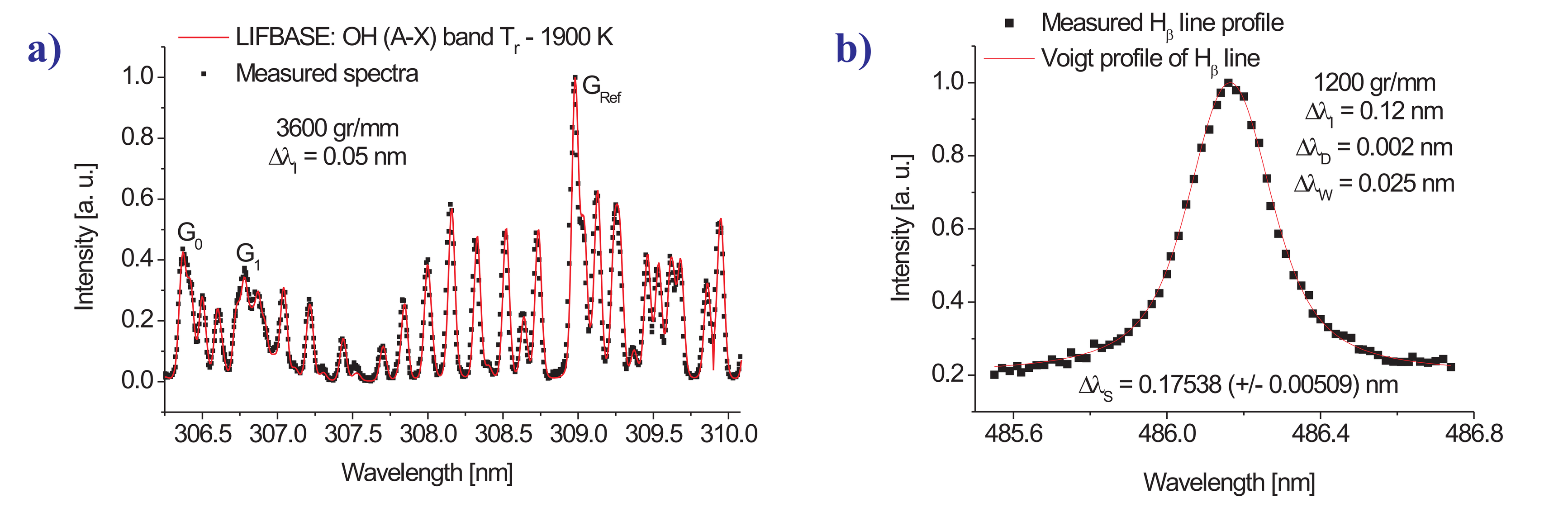
GKS theory:
$n_e = 1.09\cdot10^{16}\cdot[\Delta\lambda_S(H_\beta)]^{1.458}$ [cm^{-3}] [8]

Gig-Card theory:
$n_e = 10^{16}\cdot[\Delta\lambda_S(H_\beta)]^{1.5}$ [cm^{-3}] [9]

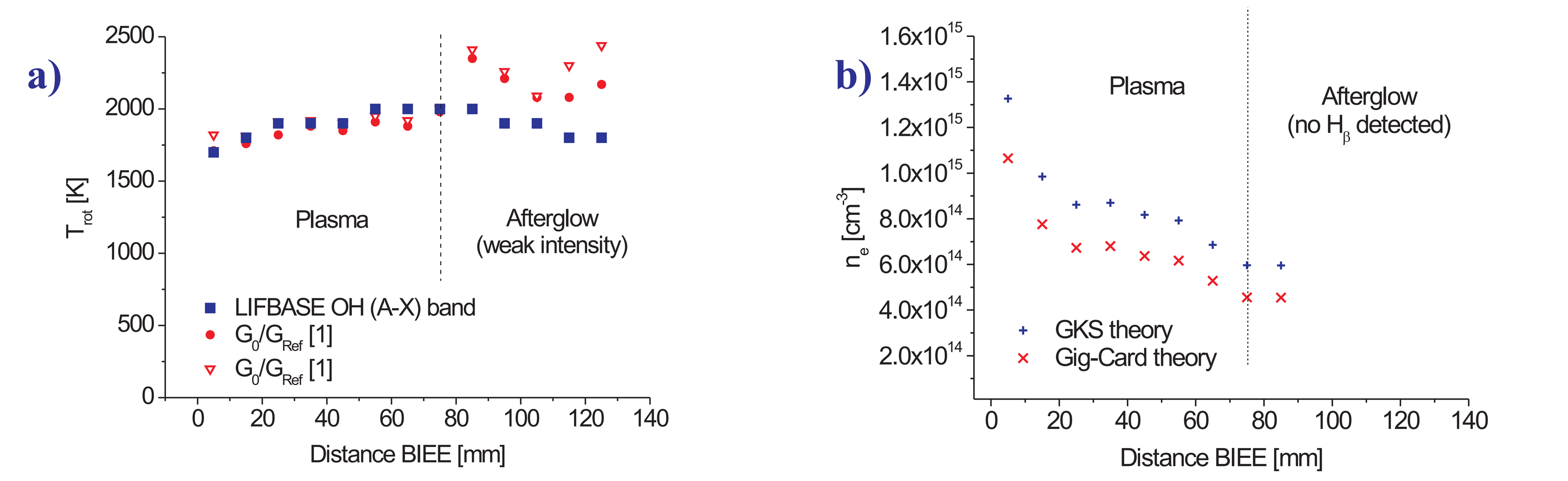
Results



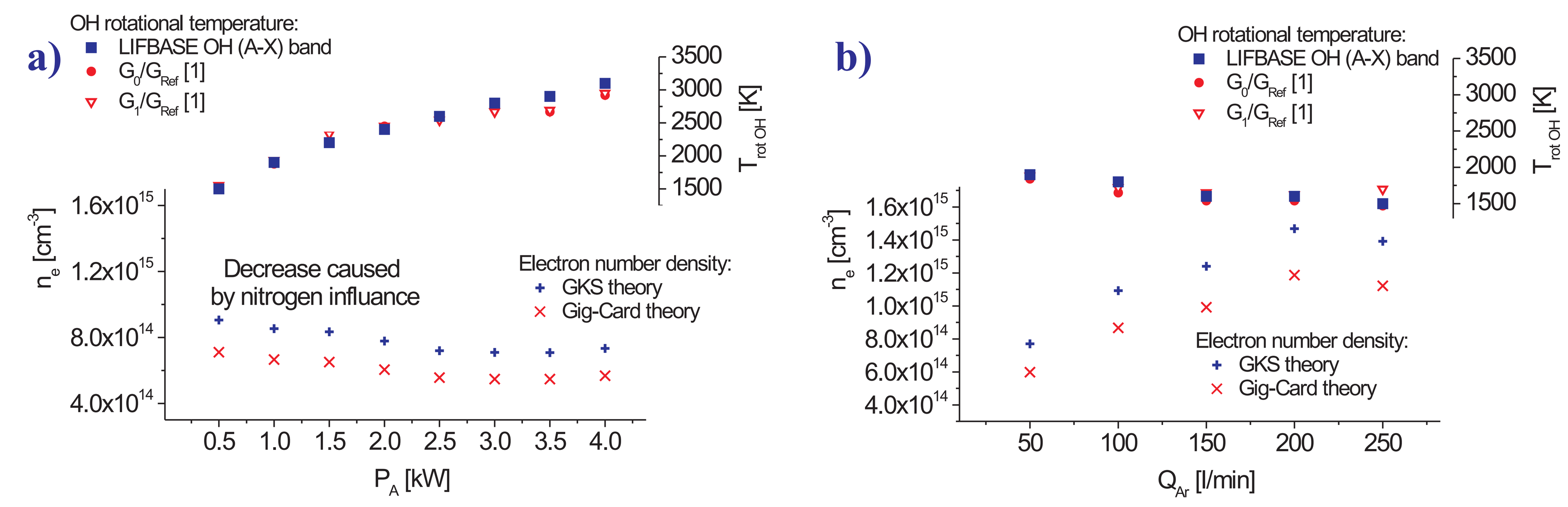
Measured emission spectrum of argon microwave plasma without water vapour (a) and with small amount of water vapour added to swirl flow (b) (P_A - 1 kW [4 kW - red], axial Ar flow rate 50 l/min, swirl N_2 flow rate - 50 l/min)



a) Comparison of the measured and simulated in LIFBASE program [7] emission spectra of OH (A-X) rotational band in argon microwave plasma, b) Measured H_β line profile and the Voigt function fitted to the experimental points (P_A - 1 kW, axial Ar flow rate 50 l/min, swirl N_2 flow rate - 50 l/min, 25 mm below the inner electorode end)



Measured rotational temperatures of OH radicals (a) and electron number density (b) as a function of distance below inner electrode end BIEE (P_A - 1 kW, axial Ar flow rate - 50 l/min, swirl N_2 flow rate - 50 l/min)



Rotational temperatures of OH radicals and electron number density measured 25 mm below inner electrode end as a function of microwave absorbed power P_A (axial Ar flow rate 50 l/min) (a) and axial Ar flow rate Q_{Ar} (P_A - 2 kW) (b)

Summary

- Obtained rotational temperatures of OH radicals ranged from 1500 to 3100 K, depending on location in argon plasma, microwave absorbed power and argon axial flow rate
- Obtained electron number density ranged from $5.5 * 10^{14}$ to $1.4 * 10^{15}$ cm^{-3}, depending on location in argon plasma, microwave absorbed power and argon axial flow rate
- Stable operation and wide range of parameters makes MPS attractive tool for different gas processing at atmospheric pressure and high flow rates

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