Optical emission spectroscopy of plasma in waveguide-supplied nozzleless microwave source

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INTRODUCTION

Subject :

Spectroscopic study of electron number density and rotational and vibrational temperatures of selected heavy species in high flow rate atmospheric pressure microwave plasma

Motivation:

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

Determination of plasma parameters e.g. the plasma gas temperature from the rotational temperature of the heavy species [1]

Applications :

Gas processing:

production of hydrogen via hydrocarbons decomposition [2]

hazardous gas treatment [3]

MICROWAVE PLASMA SOURCE (MPS)

DESIGN

Waveguide-supplied
Nozzleless
Coaxial-line-based

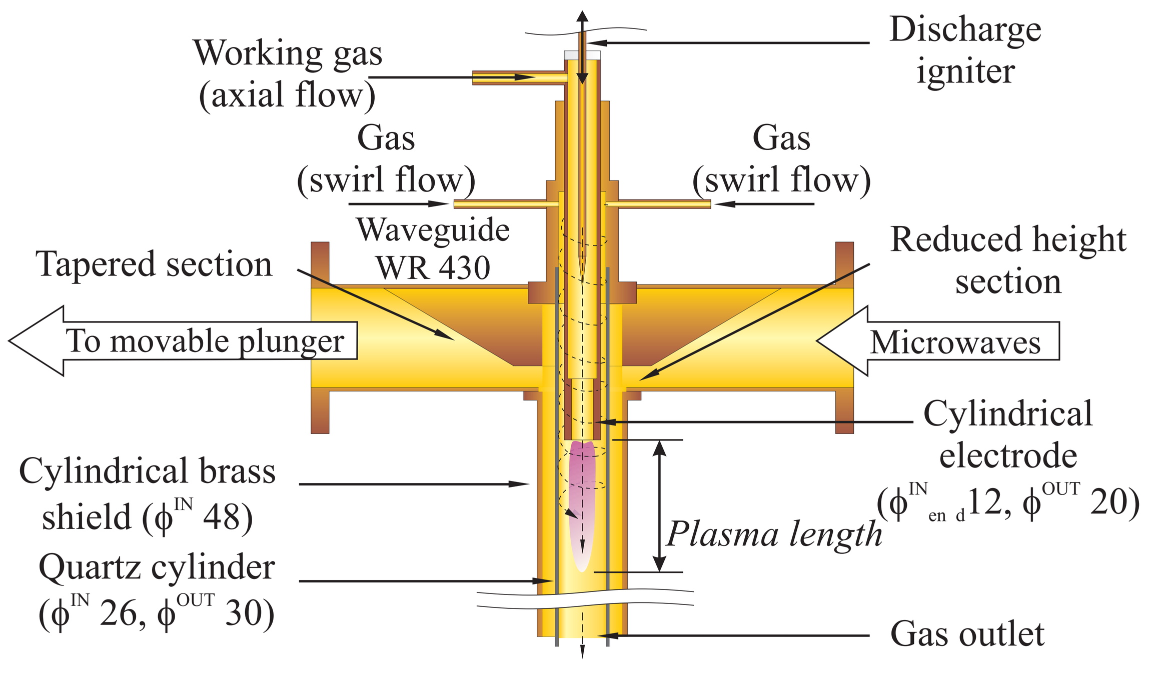
MICROWAVES

Frequency: 2.45 GHz
Power: 600 - 5500 W

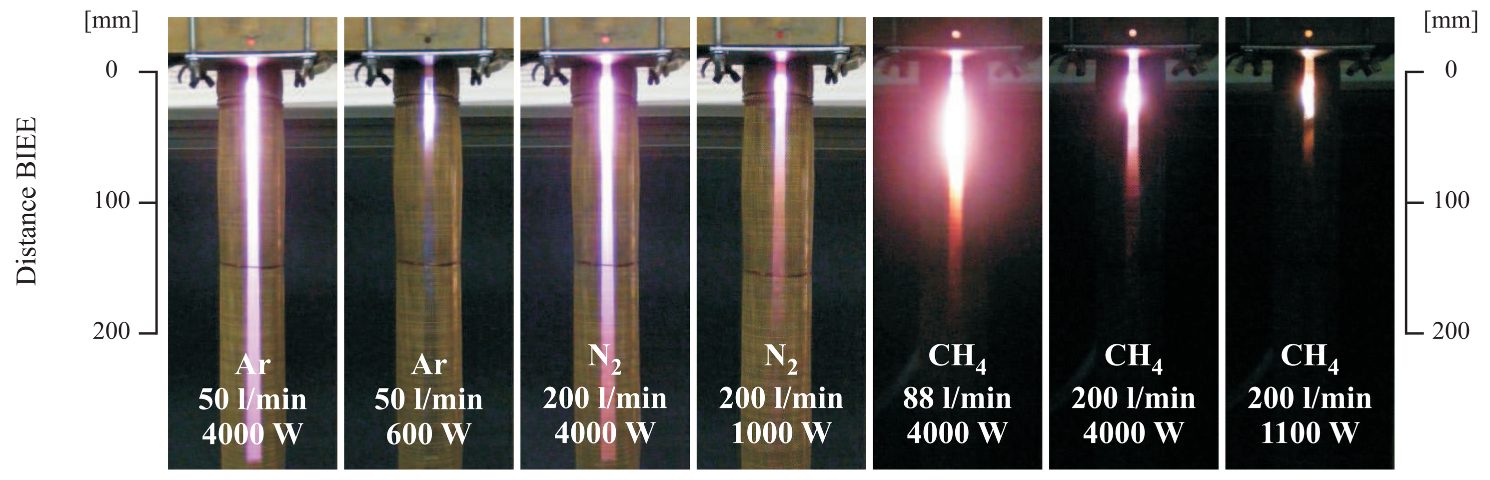
GAS FLOW

Swirl flow: N_2
(small amount of water vapor optionally added)
Flow rate: 50 l/min

Axial flow: Ar, N_2, CH_4
Flow rate: 50 - 200 l/min

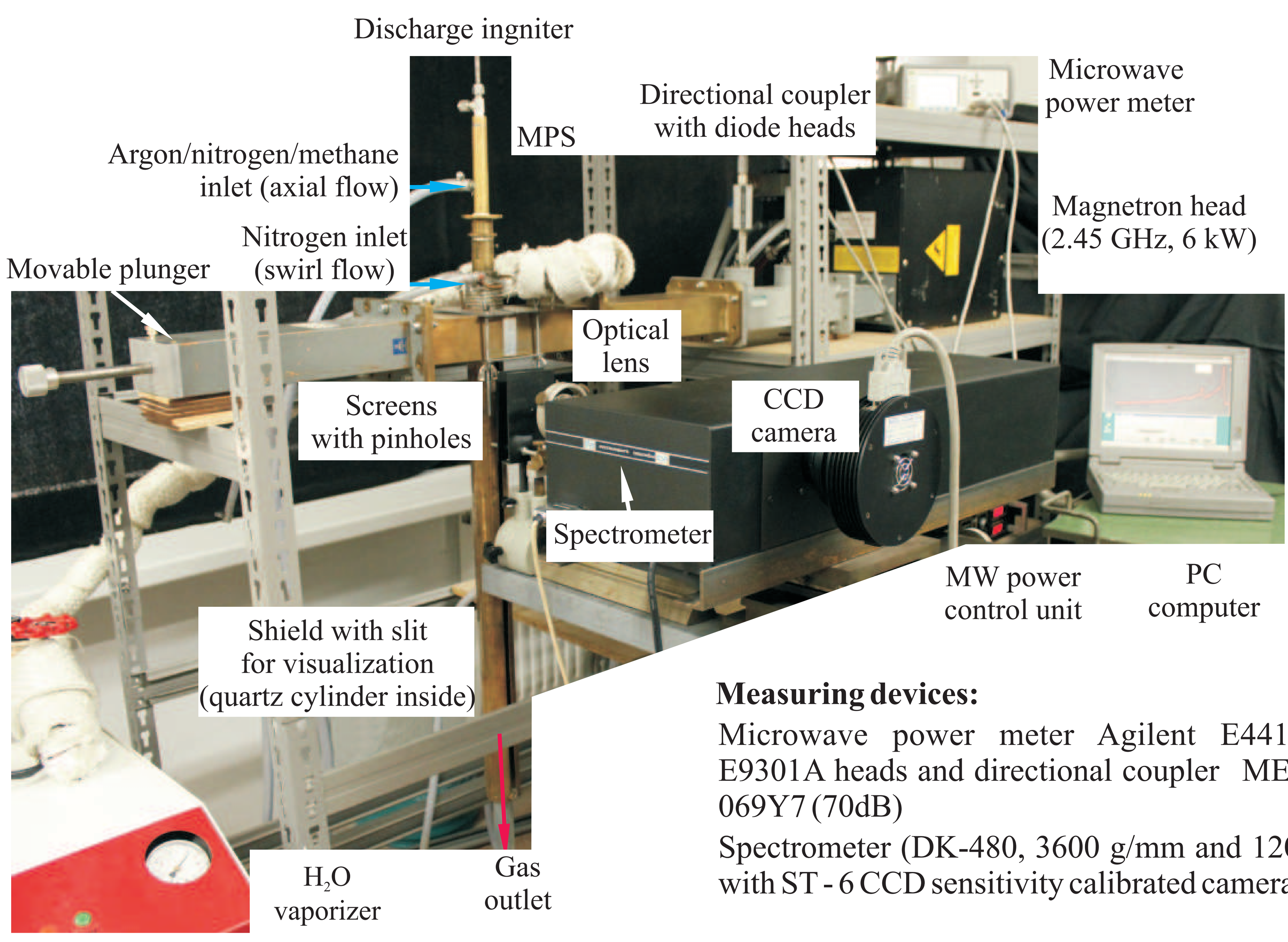


The sketch of MPS



Microwave plasmas for Ar, N_2 and CH_4 at different microwave absorbed powers and axial gas flow

EXPERIMENTAL SETUP



Measuring devices:

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

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

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

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[3] M. Jasinski, M. Dors, J. Mizeraczyk: Plasma Chem. Plasma Process. **29** (2009), 363
[4] http://www.sri.com/psd/lifbase/
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[9] http://www.specair-radiation.net

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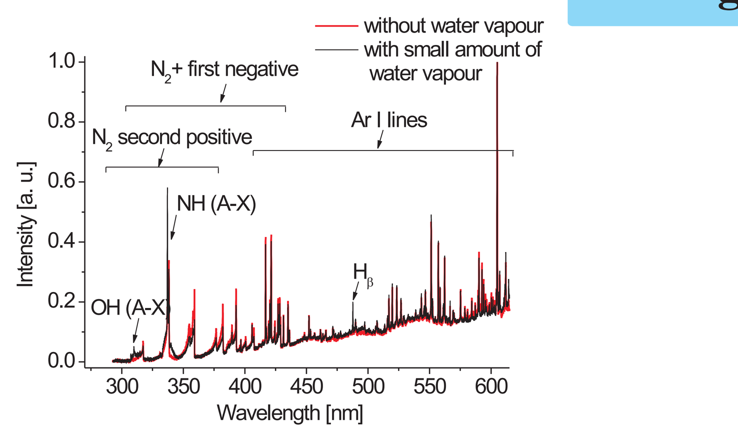
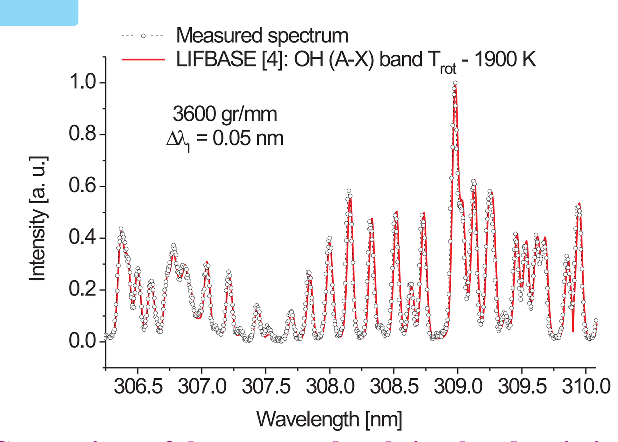
RESULTS

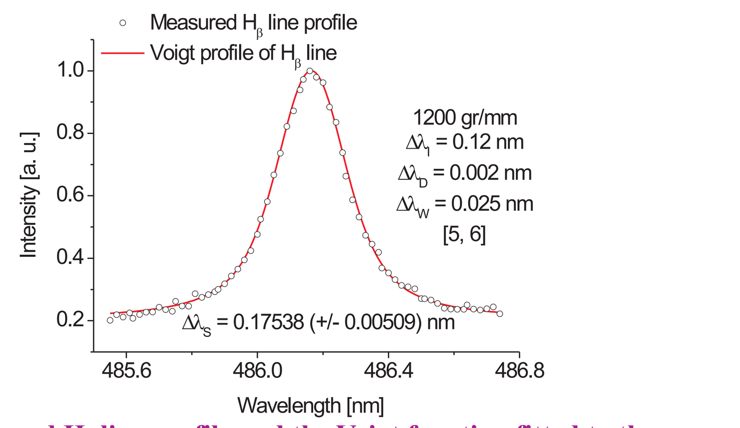
Argon



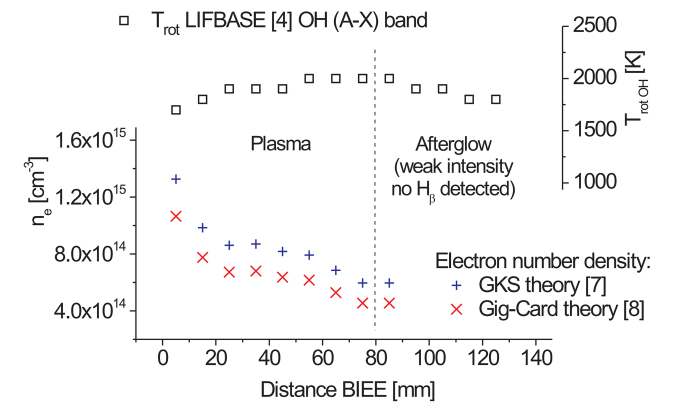
Measured emission spectrum of argon plasma (P_A – 1 kW, argon flow rate - 50 l/min, 25 mm below the electrode end)



Comparison of the measured and simulated emission spectra of OH(A-X) in argon plasma (P_A – 1 kW, argon flow rate - 50 l/min, 25 mm below the electrode end)

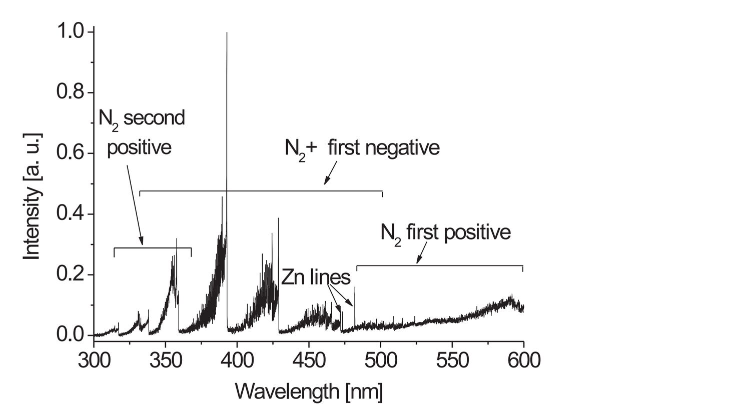


Measured H_β line profile and the Voigt function fitted to the experimental points (P_A - 1 kW, argon flow rate - 50 l/min, 25 mm below the inner electorode end)

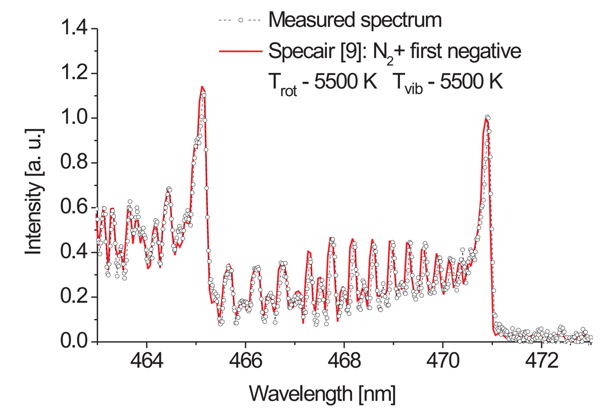


Measured rotational temperatures of OH radicals and electron number density as a function of distance below inner electrode end (Distance BIEE) (P_A - 1 kW, argon flow rate - 50 l/min)

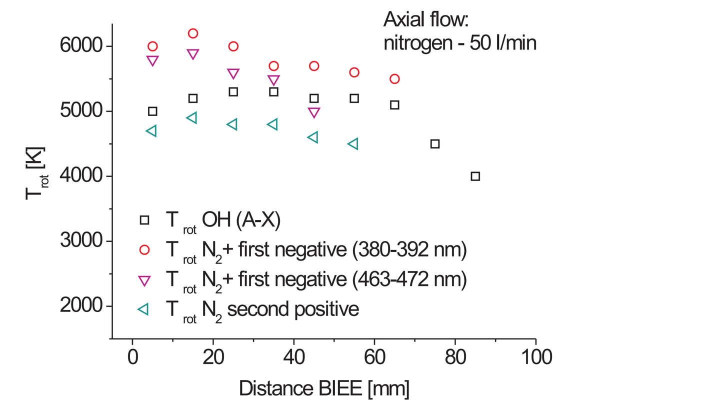
Nitrogen



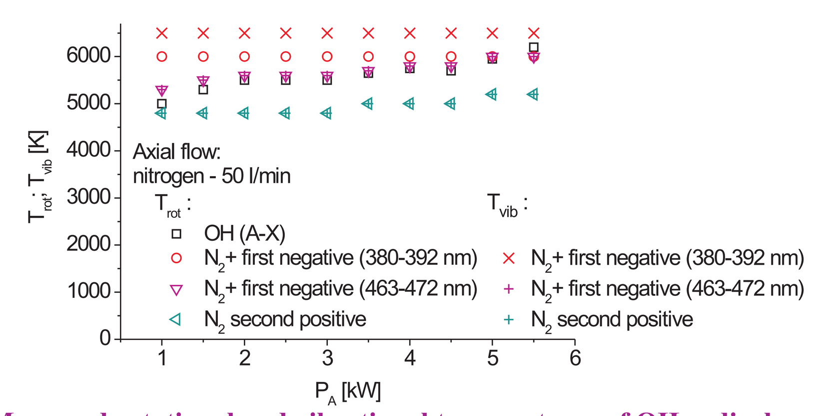
Measured emission spectrum of nitrogen plasma (P_A – 4 kW, nitrogen flow rate - 50 l/min, 25 mm below the electrode end)



Comparison of the measured and simulated emission spectra of N_2+ first negative system in nitrogen plasma (P_A – 2 kW, nitrogen flow rate - 50 l/min, 25 mm below the electrode end)

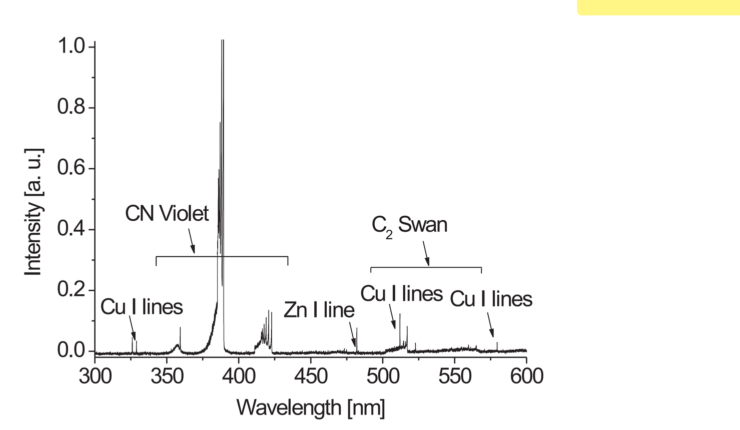


Measured rotational temperatures of OH radicals, N_2+ ions and N_2 molecules as a function of distance below inner electrode end (Distance BIEE) (P_A - 2 kW, nitrogen flow rate - 50 l/min)

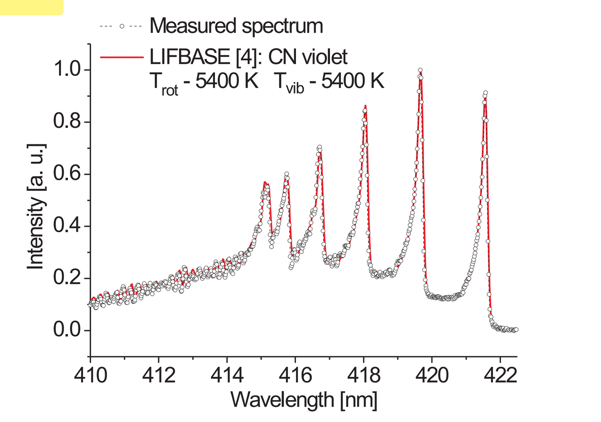


Measured rotational and vibrational temperatures of OH radicals, N_2+ ions and N_2 molecules as a function of microwave absorbed power P_A (nitrogen flow rate - 50 l/min, 25 mm below the electrode end)

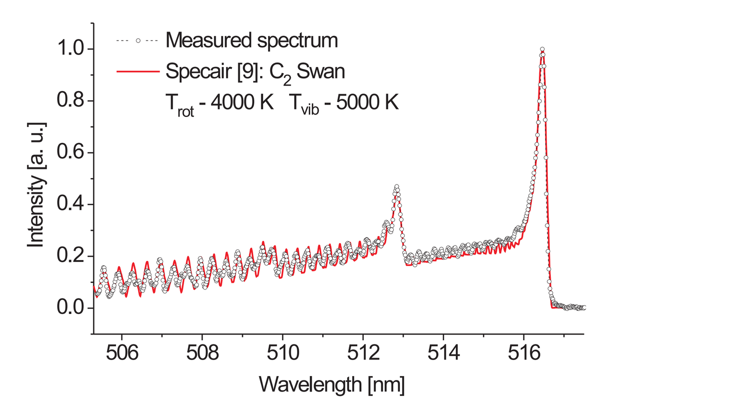
Methane



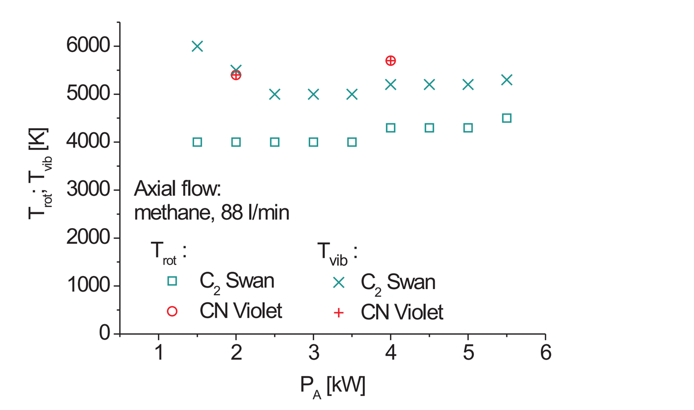
Measured emission spectrum of methane plasma (P_A – 3 kW, methane flow rate - 88 l/min, 15 mm below the electrode end)



Comparison of the measured and simulated emission spectra of CN Violet system in methane plasma (P_A – 2 kW, methane flow rate - 88 l/min, 15 mm below the electrode end)



Comparison of the measured and simulated emission spectra of C_2 Swan system in methane plasma (P_A – 2 kW, methane flow rate - 88 l/min, 15 mm below the electrode end)



Measured rotational and vibrational temperatures of CN and C_2 molecules as a function of microwave absorbed power P_A (methane flow rate - 88 l/min, 25 mm below the electrode end)

SUMMARY

- Obtained electron number density in argon plasma ranged from $5.5 * 10^{14}$ to $1.4 * 10^{15}$ cm^{-3}, depending on the location in the plasma, the microwave absorbed power and argon flow rate.
- In argon plasma the rotational temperature of OH radicals ranged from 1500 up to 3100 K depending on the location in the plasma, the microwave absorbed power and argon flow rate.
- In nitrogen plasma rotational and vibrational temperatures ranged from 4000 to 6000 K and from 4500 to 6500 K, respectively, depending on the location in the plasma, the microwave absorbed power and nitrogen flow rate. OH radicals and N_2+ ions provided comparable results. N_2 molecules in all cases provided sligtly lower temperatures. The rotational and the vibrational temperatures of N_2+ ions and N_2 molecules were in equilibrium in nitrogen plasma.
- In methane plasma rotational and vibrational temperatures ranged from 4000 to 5700 K and from 5000 to 6000 K, respectively, depending on the microwave absorbed power. CN molecules provided higher rotational temperature than C_2 molecules. The vibrational and the rotational temperatures of CN molecules were in equlibrium. In case of C_2 molecules in such plasma the vibrational temperature were 10 – 30 % grater than the rotational.
- Stable operation with various gases as well as wide range of parameters make MPS an attractive tool for different gas processing at atmospheric pressure and high flow rates.
- MPS was successfully used for hydrogen production via hydrocarbon conversion [2] and for Freon destruction [3] owing to high plasma gas temperature.