Emission Spectroscopy of Microplasma for NOx Removal Process

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Introduction

Microplasma can be found in many applications. In the last years, the technology was used also for NOx removal. Although there is an interest for application driven research, microplasma phenomena are not fully understood. Emission spectrometry is one of the methods to analyze plasma process.

The aim of this paper is to analyze the emission spectrum of the microplasma in a simulated exhaust gas.

Emission spectra of the microplasma discharge in N_2, NO and O_2 gas mixture was analyzed. The diagnosis of microplasma discharge was performed in order to understand the processes of NOx removal. An experimental Marx Generator was used as a pulsed power supply.

Temperature measurements are also carried out, which show the temperatures are specific for non-equilibrium plasmas.

Experimental setup

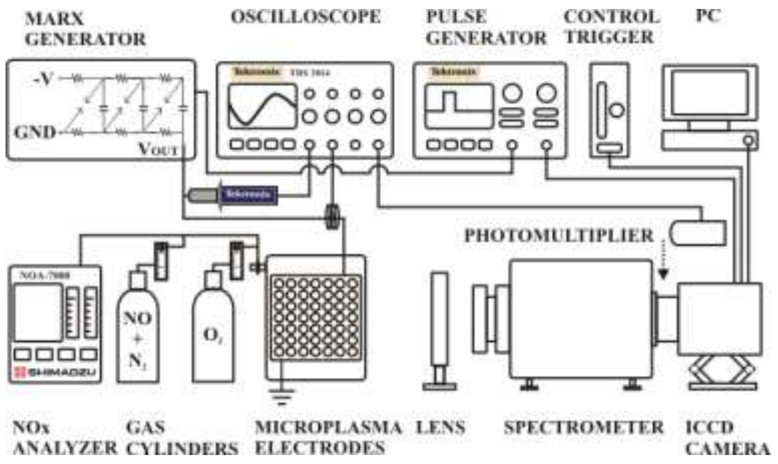

Fig.1 An experimental setup.

Emission spectra were measured by an ICCD camera, a spectrometer and by a photomultiplier tube. A pulse generator was used to trigger the Marx Generator and the ICCD camera.

Compositions of simulated gases used in experiments were N_2, NO 1000 ppm in N_2, and NO 950 ppm, O_2 5% in N_2. Experiments were carried out in atmospheric pressure and the gas flow rate was set at 2 L/min. Concentration of NO and NOx were measured by a NOx analyzer.

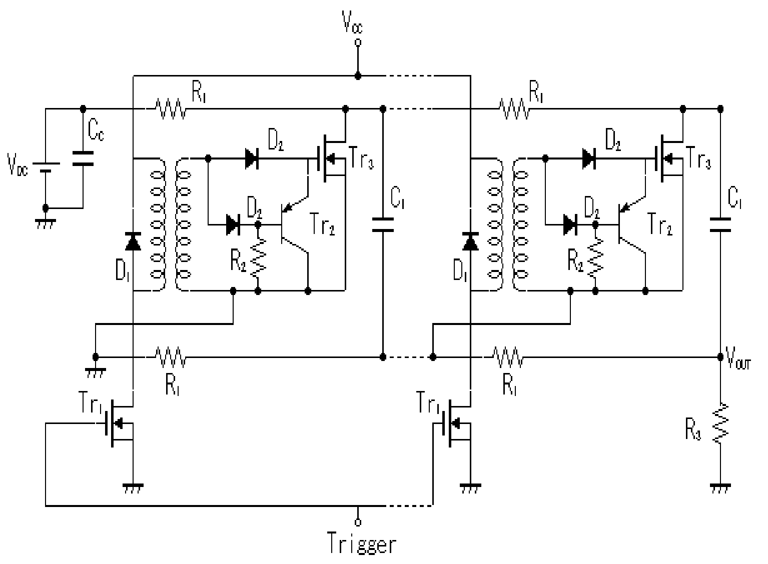

Fig.2 An experimental Marx Generator.

A Marx generator with 4 stages MOSFET switches:
output voltage up to -1.8 kV peak (negative pulse, rise time 80 ns, pulse width 500 ns ~ 1 μs, frequency 1 kHz ~ 24 kHz).
Trigger signal for ICCD camera was set at 1 μs (Fig. 3).
Capacitors are charged in parallel connection at a given voltage *V* (500 V in this case).
MOSFET switches are closed, capacitors are discharging in series connection :
►output voltage 4 *V* (2 kV in this case).

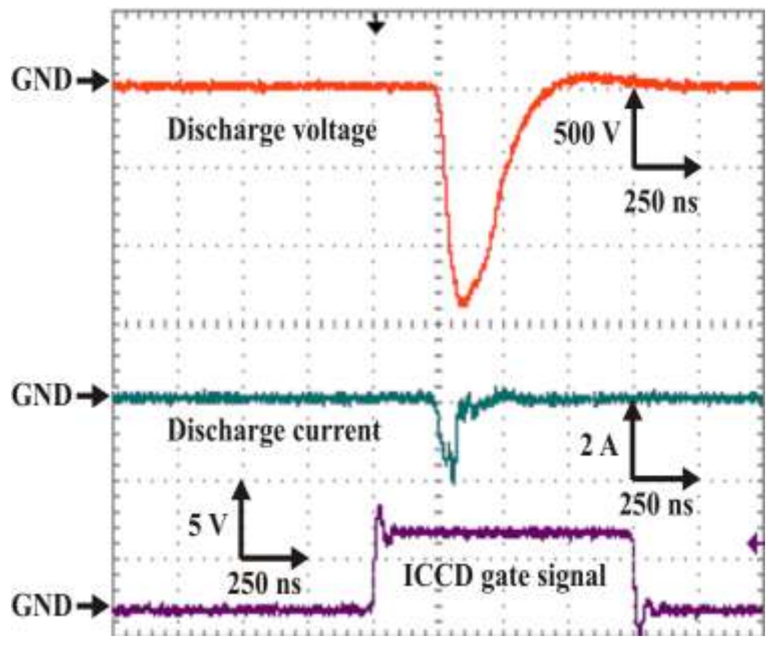

Fig.3 Waveforms of discharge voltage, discharge current and gate signal for ICCD camera.

About microplasma

Microplasma electrodes are metallic electrodes covered with a dielectric layer (Fig. 4).
Small discharge gaps (0~100) μm and assumed specific dielectric constant of $\varepsilon_r = 10^4$:
►a high intensity electric field (10^7 ~ 10^8 V/m) around 1 kV.
Electrode size was 20 mm versus 40 mm. Electrode has holes to flow for gas treatment, which diameter is Ø 2mm and its aperture ratio of 36%. Discharge gap was set at 50 μm.

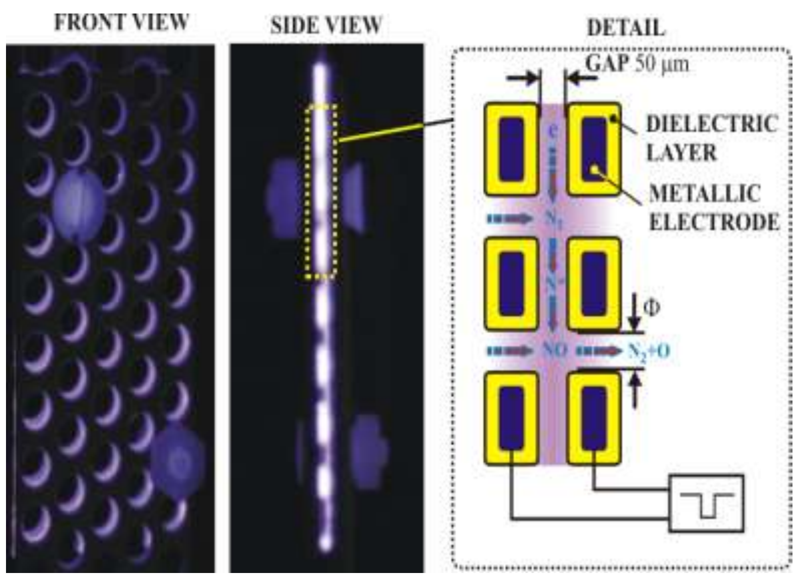

Fig.4 Microplasma electrodes.

Emission spectrum of microplasma

Emission spectrum of the microplasma discharge was measured in N_2 gas, in NO 1000 ppm/N_2 as balance gas and in NO 950 ppm and O_2 5% in N_2 balance.
Spectrum were obtained at discharge voltage -1.4 kV, rise time of 80 ns, pulse width of 500 ns, and discharge frequency of 1 kHz.

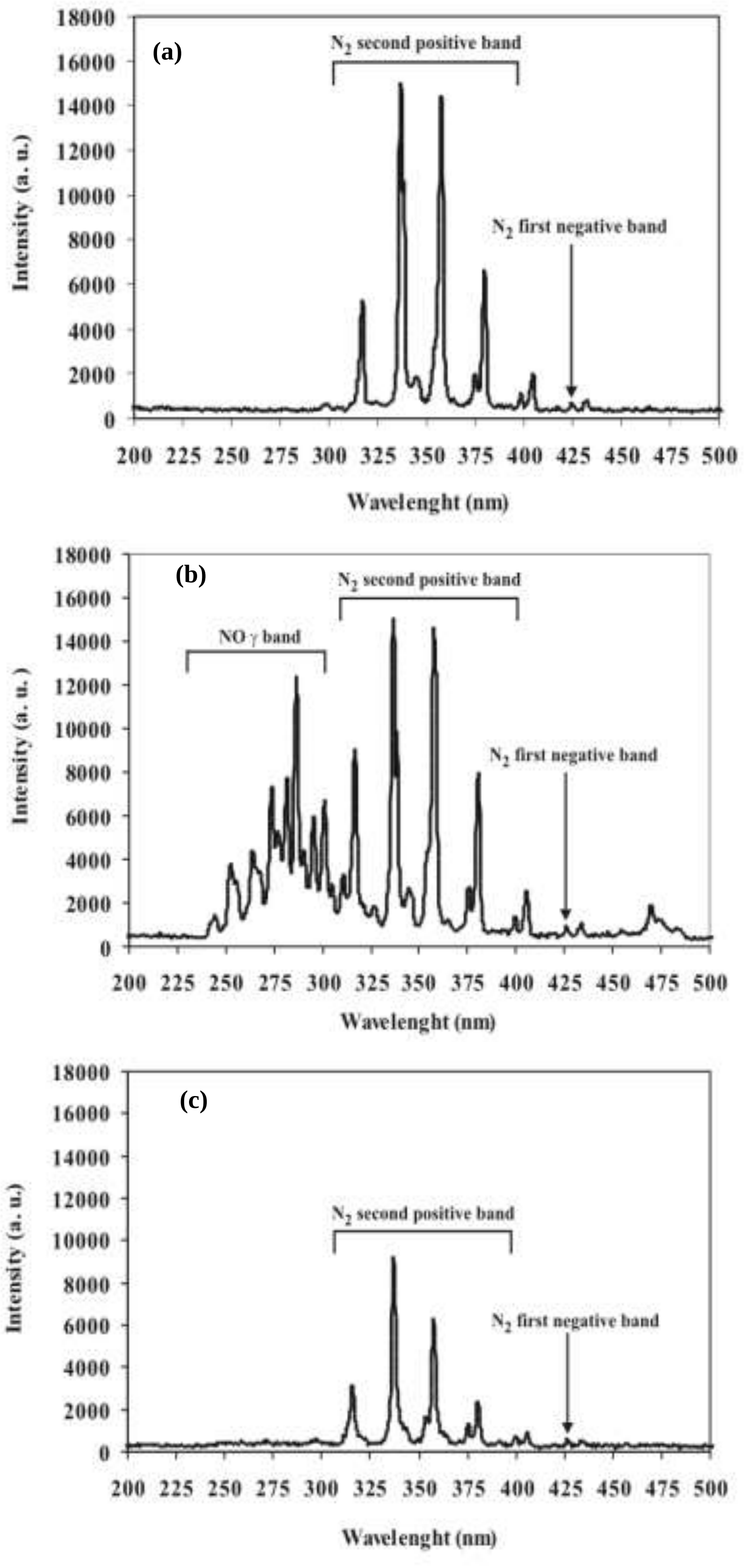

Fig.5 Emission spectrum of microplasma discharge (a) in N_2; (b) in NO 1000 ppm/N_2 as balance gas; (c) in NO 950 ppm and O_2 5% in N_2 balance.

Table 1. List of detected systems and peaks for the microplasma in N_2 gas

Species (system)	Transition	Peak Position (nm)
N_2 second positive	$C^3\Pi \rightarrow B^3\Pi$	315; 337.1; 357.7; 375.5; 380.5; 400
N_2^+ first negative	$B^2\Sigma_u^+ \rightarrow X^2\Sigma_g^+$	427.8

Table 2. List of detected systems and peaks for the microplasma in NO 1000 ppm/N_2 as balance gas

Species (system)	Transition	Peak Position (nm)
N_2 second positive	$C^3\Pi \rightarrow B^3\Pi$	315; 337.1; 357.7; 375.5; 380.5; 400
N_2^+ first negative	$B^2\Sigma_u^+ \rightarrow X^2\Sigma_g^+$	427.8
NO γ band	$A^2\Sigma^+ \rightarrow X^2\Pi$	226.9; 237; 247.9; 259.6; 260.1; 271.5; 285

Table 3. List of detected systems and peaks for the microplasma in in NO 950 ppm and O_2 5% in N_2 balance.

Species (system)	Transition	Peak Position (nm)
N_2 second positive	$C^3\Pi \rightarrow B^3\Pi$	315; 337.1; 357.7; 375.5; 380.5; 400
N_2^+ first negative	$B^2\Sigma_u^+ \rightarrow X^2\Sigma_g^+$	427.8

In NO 950 ppm and O_2 5% in N_2 balance. intensities of peaks are lower than those measured for nitrogen, due to the quenching effect of O_2 .Weak peaks were also measured for the NO γ band. That could be explained by presence of O_2 molecules to oxidize to remove NO molecules.
Excitation of nitrogen molecules in the ground state by direct electron impact:
►the lifetime of photomultiplier signal of N_2 SPS was about 40 ns
NO γ band is excited by the collision of N_2 metastable states:
►process of light emission of NO γ band (260.1 nm) is longer, thus the lifetime of photomultiplier signal for NO γ band was about 2 μs (Fig. 8).

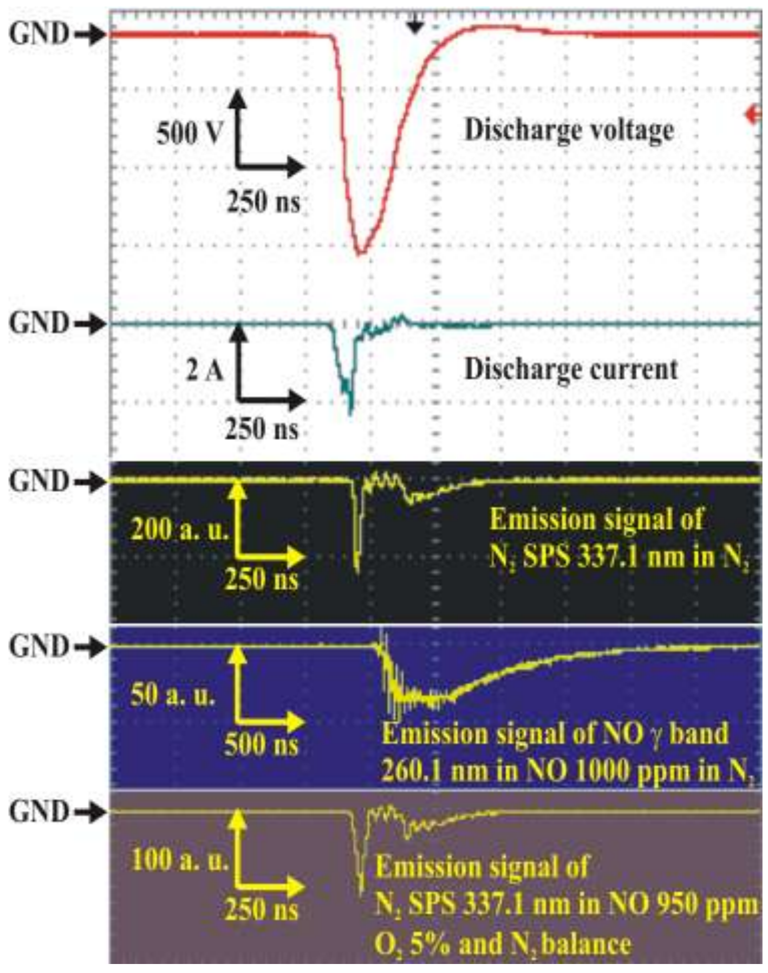

Fig.8 Waveforms of discharge voltage, discharge current and emission signal of microplasma (N_2 SPS 337.1 nm and NO γ band 260.1 nm) in N_2, NO 1000 ppm / N_2 as balance gas and in NO 950 ppm and O_2 5% in N_2 balance .

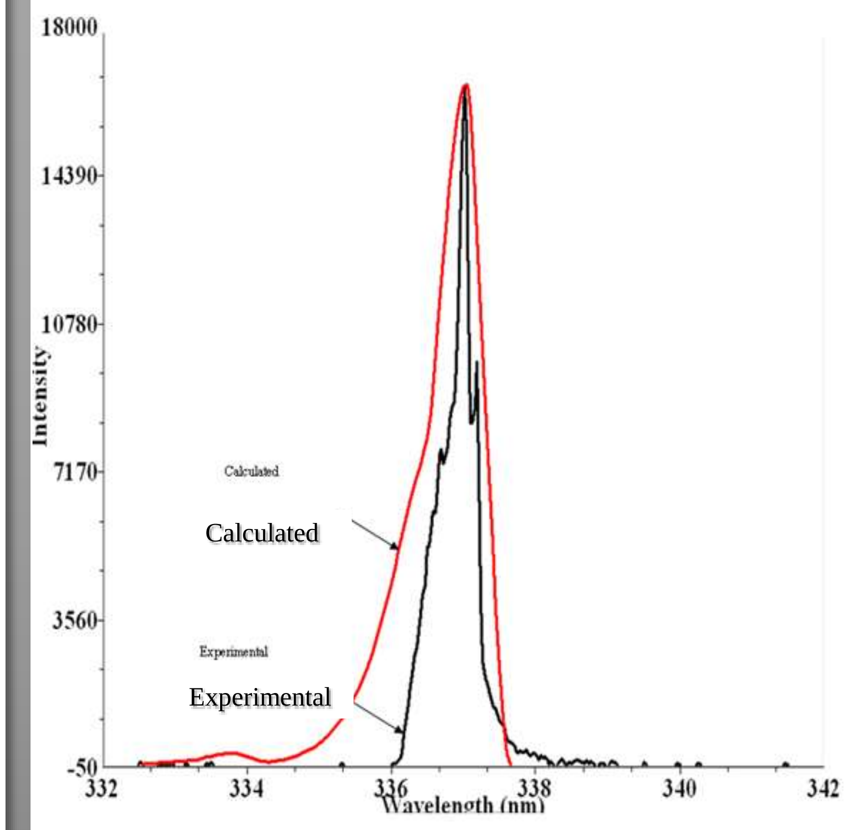

Fig.9 Determination of microplasma temperatures for N_2 SPS (337.1 nm).

Table 4. List of temperatures for microplasma discharge in N_2 gas.

Temperature	Value (K)
Rotational	360
Vibrational	3100
Translational	360
Electronic	8200

Conclusion

1)Analysis of emission spectrum shows
N_2 SPS, N_2 FNS for microplasma in N_2 gas.
N_2 SPS, N_2 FNS and NO γ band. for the microplasma in NO 1000 ppm in N_2 and N_2 SPS, N_2 FNS, with lower intensities comparing with emission spectrum of microplasma in N_2 for NO 950 ppm and O_2 5% in N_2.
2)Lifetime of emission signal measured by a photomultiplier tube corresponding to wavelength 337.1 nm of N_2 SPS was about 40 ns. Lifetime of emission signal of NO γ band was about 2 μs, due to the excitation of N_2 metastable states.
3)Temperature estimation of microplasma discharge show high electron and vibrational temperatures and low rotational and translational temperatures. These temperatures are specific for non-equilibrium plasmas.