Emission spectroscopy of atmospheric microplasma for biomedical application

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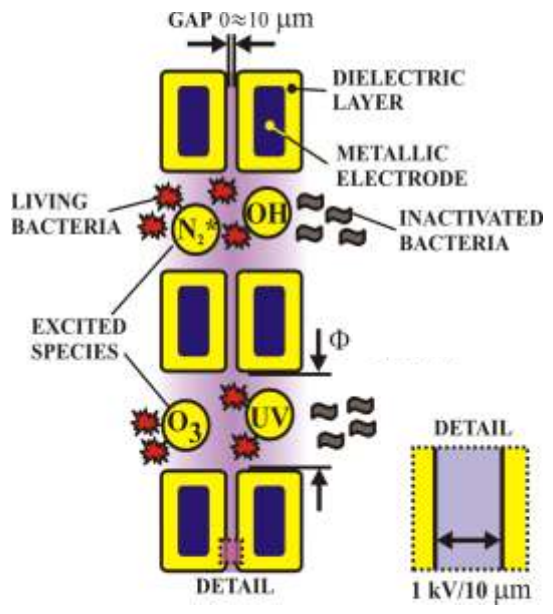
Introduction

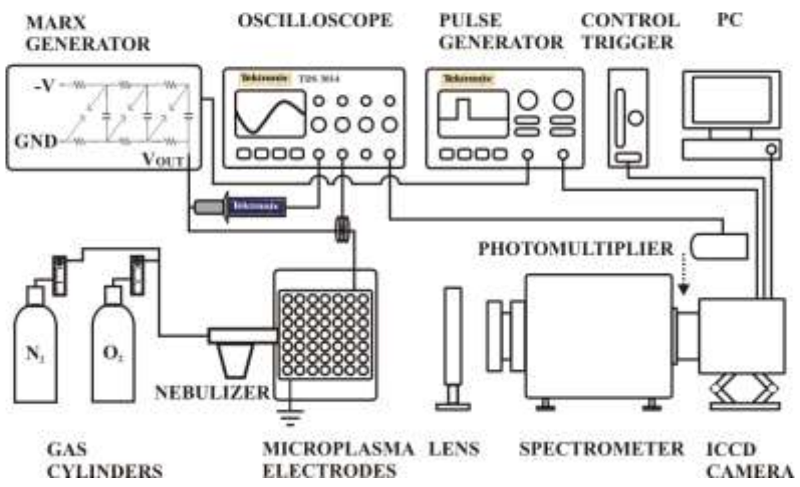
Microplasma can be found in many applications. In the last years, the technology was used also for biomedical applications. Although there is an interest for application driven research, microplasma phenomena are not fully understood.

Microplasma which is atmospheric pressure non thermal plasma could be used for the sterilization and inactivation processes of a wide spectrum of microorganism or removal of odors inside the houses or buildings. The factors which contribute to the inactivation and sterilization processes of bacteria such as generation of radicals and UV light, could be study with emission spectroscopy method.



Inactivation of bacteria by microplasma using carrier gas air or nitrogen containing water droplets

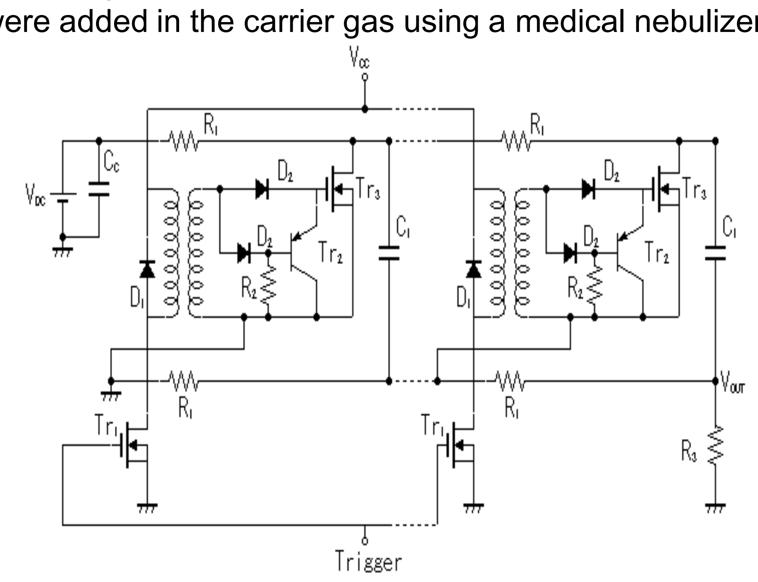
Experimental setup



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 gases used in experiments were N_2 with water droplets and air with water droplets. Experiments were carried out in atmospheric pressure and the gas flow rate was set at 5 L/min. Water droplets were added in the carrier gas using a medical nebulizer.



An experimental Marx Generator.

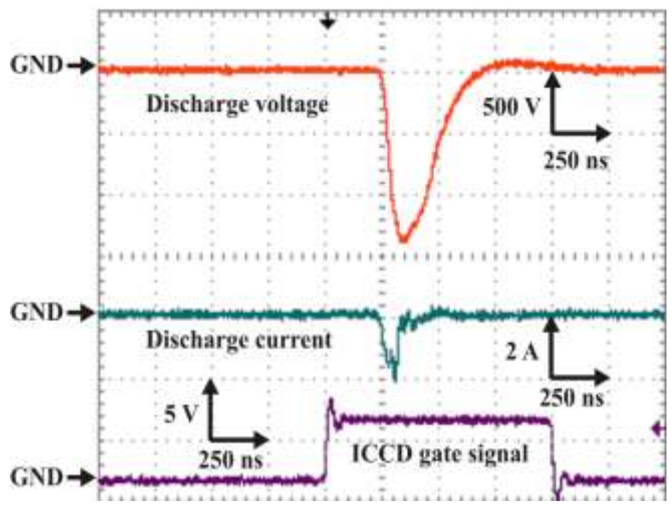
A Marx generator with 4 stages MOSFET switches: output voltage up to -1.8 kV peak (negative pulse, rise time 80 ns, pulse width 500 ns ~ 1 µs, frequency 1 kHz ~ 24 kHz).

Trigger signal for ICCD camera was set at 1 µs.

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).



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

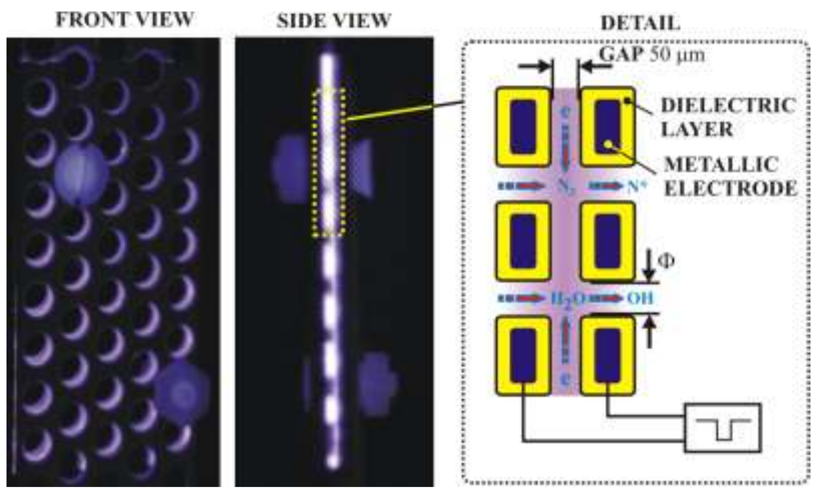
About microplasma

Microplasma electrodes are metallic electrodes covered with a dielectric layer.

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, which diameter is Ø 2mm and its aperture ratio of 36%. Discharge gap was set at 50 µm.

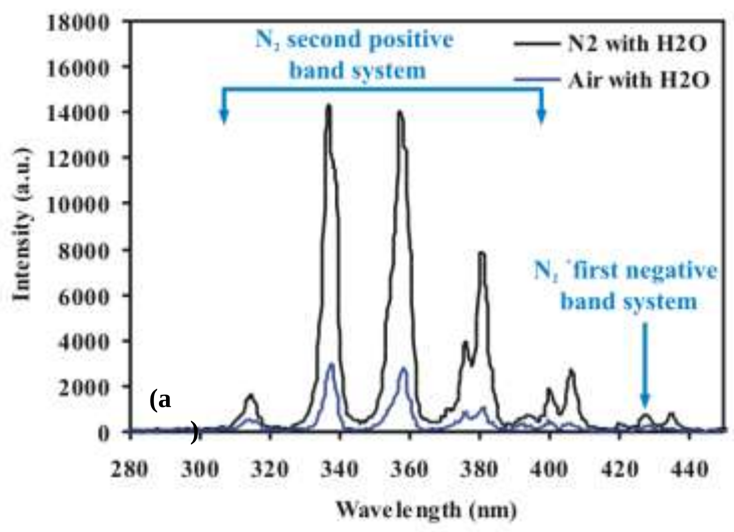


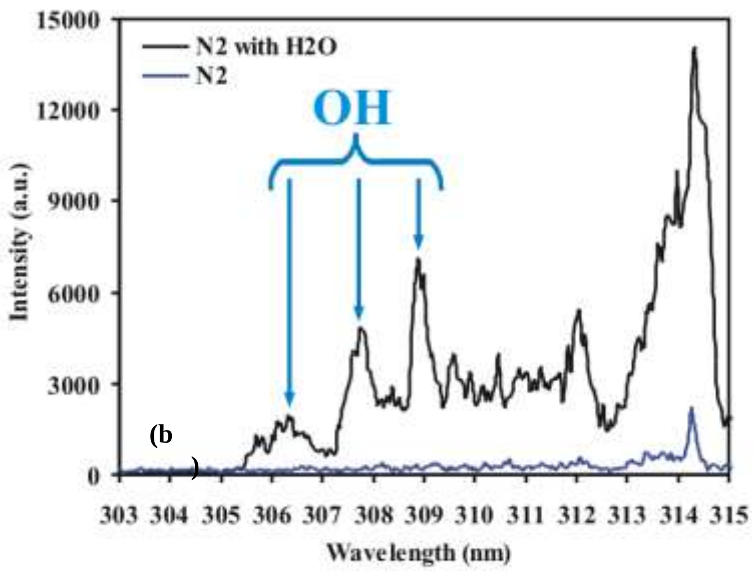
Microplasma electrodes.

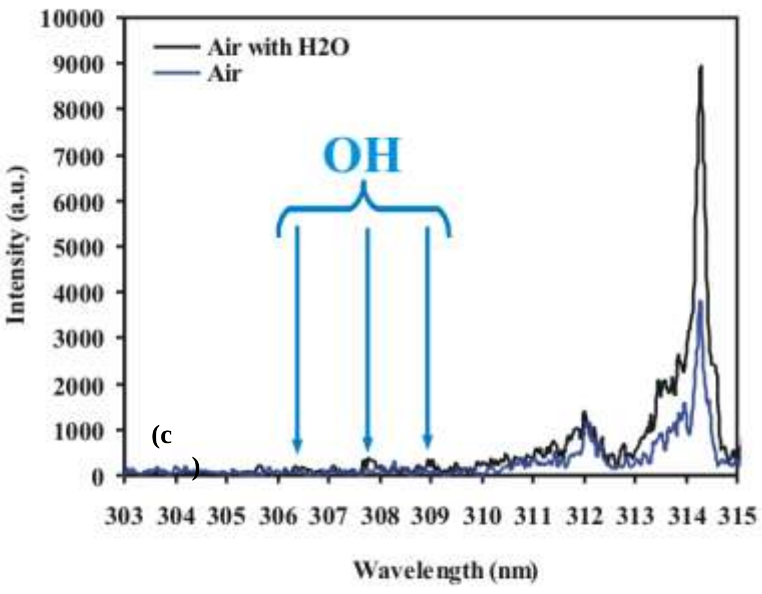
Emission spectrum of microplasma

Emission spectrum of the microplasma discharge was measured in N_2 gas, N_2 gas with water droplets, air and air with water droplets.

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.







Emission spectrum of microplasma discharge in (a) N_2 and air containing water droplets ; (b) N_2 and N_2 with water droplets; (c) air and air with water droplets.

Electron impact dissociation of H_2O leads to the production of H and OH radicals.

$e + H_2O \rightarrow e + H + OH$

Air which used as carrier gas with water droplets, leads to the generation of active species and ozone by microplasma.

$e + O_2 \rightarrow e + O(^3P) + O(^1D)$

$O + O_2 + M \rightarrow O_3 + M$

$O(^1D) + H_2O \rightarrow 2\,OH$

With oxygen in the carrier gas, any peaks of OH were not observed due to the quenching effect of oxygen atom and ozone.

$OH + O \rightarrow O_2 + H$

$OH + O_3 \rightarrow HO_2 + O_2$

List of detected systems and peaks for the microplasma in N_2 gas with water droplets

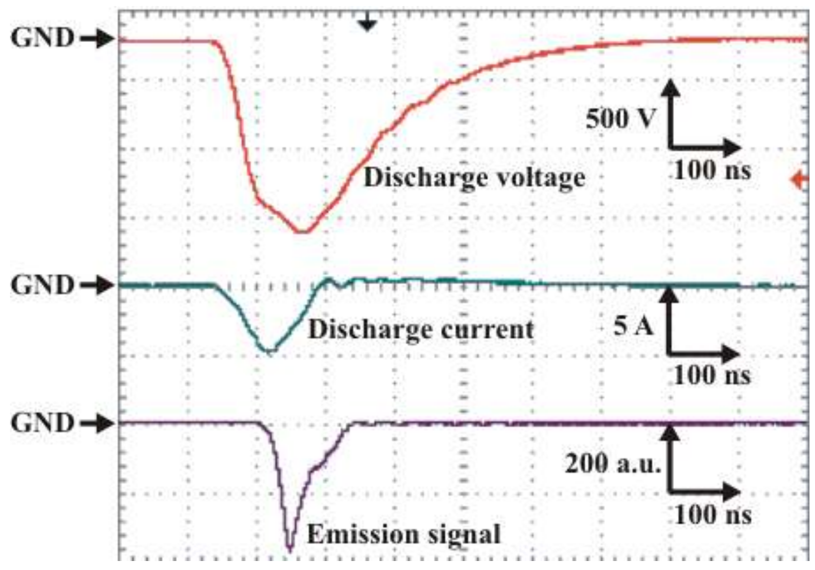
Species (system)	Transition	Peak Position (nm)
N_2 second positive	$C^3\Pi \rightarrow B^3\Pi$	315; 337.1; 357.7; 375.5; 380.5; 400.0
N_2^+ first negative	$B^2\Sigma_u^+ \rightarrow X^2\Sigma_g^+$	427.8
OH (3064 – Å system)	$A^2\Sigma^+ \rightarrow X^2\Pi$	306.4; 307.8; 308.9
H-γ	$^2P^0 \rightarrow {}^2D$	434.1

List of detected systems and peaks for the microplasma in air with water droplets

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; 400.0
N_2^+ first negative	$B^2\Sigma_u^+ \rightarrow X^2\Sigma_g^+$	427.8

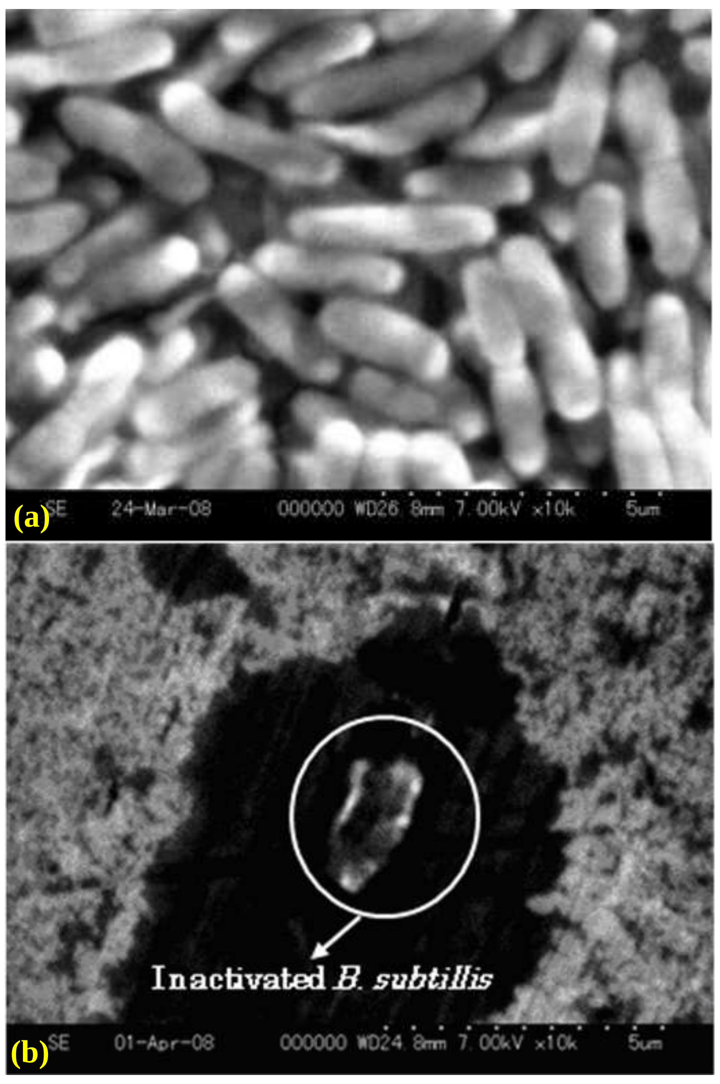
Excitation of nitrogen molecules in the ground state by direct electron impact and spontaneous radiation of formed excited state of nitrogen:

▸the lifetime of photomultiplier signal of N_2 SPS was about 40 ns



Waveforms of discharge voltage, discharge current and emission signal of microplasma (N_2 SPS 337.1 nm) in N_2 with water droplets.

Active radical species have etching effect to break the bacteria cell wall, and UV affects DNA directly to cut their structure



Images of B. subtilis by SEM a) Living B. subtilis (x 10000); (b) Sterilized B. subtilis by nitrogen plasma (x10000).

Conclusion

1)Analysis of emission spectrum shows

▸ N_2 SPS, N_2 FNS, OH 3064 – Å system and H-γ band system for the microplasma discharge in N_2 gas with water droplets.

▸ N_2 SPS, N_2 FNS, and H-γ band system for microplasma discharge in air with water droplets with lower intensities comparing with emission spectrum of microplasma discharge in N_2 with water droplets due to the quenching effect of oxygen atom and ozone.

2)Lifetime of emission signal measured by a photomultiplier tube corresponding to wavelength 337.1 nm of N_2 SPS was about 40 ns.