Control of Gas and Aqueous Phase Reactive Chemical Species by Air Surface Micro-Discharge

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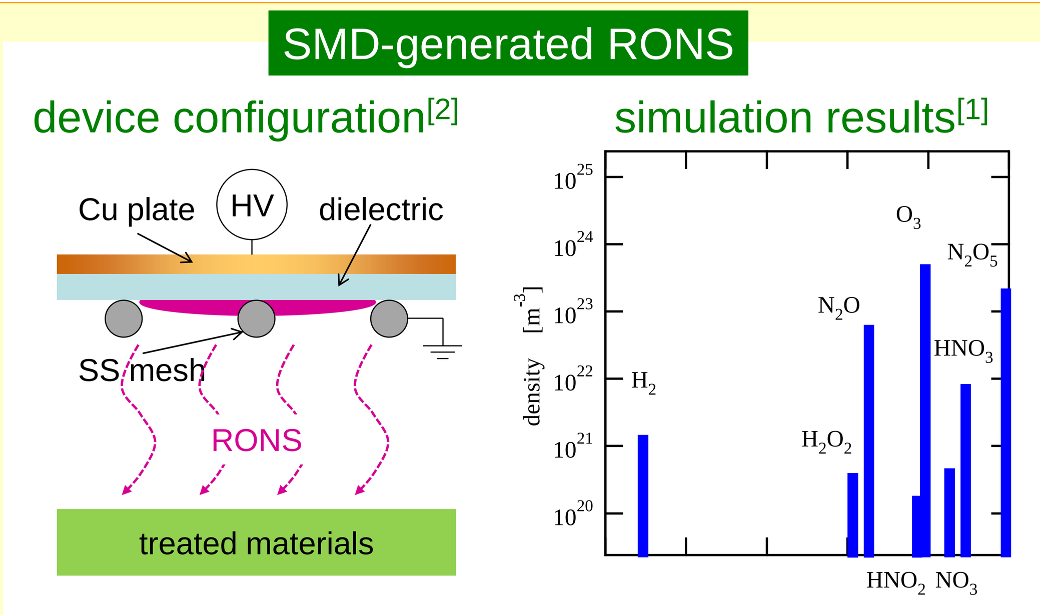
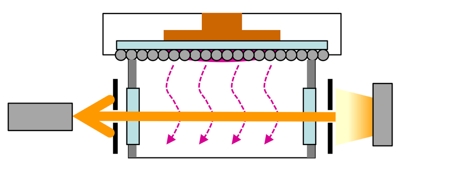
BACKGROUND

Reactive oxygen and nitrogen species (RONS) play different roles in the regulation of multiple cellular-level processes. Our previous numerical simulation [1] showed the major RONS generated by surface micro-discharge (SMD) [2] includes O_3, N_2O, N_2O_5, and HNO_3. A challenge is to control the plasma chemistry in the gas phase in such a way that the therapeutic potential can be realized. Also, aqueous-phase chemical reactions are thought to play crucial roles because cells and tissues to be treated are mostly immersed in or contact with water or other solutions. We demonstrate that distributions of SMD-generated chemical species can show surprising complexities through UV/FTIR absorption spectroscopy. In addition, we discuss the inactivation mechanisms of *E.coli* cells on agar plate and in liquid medium.

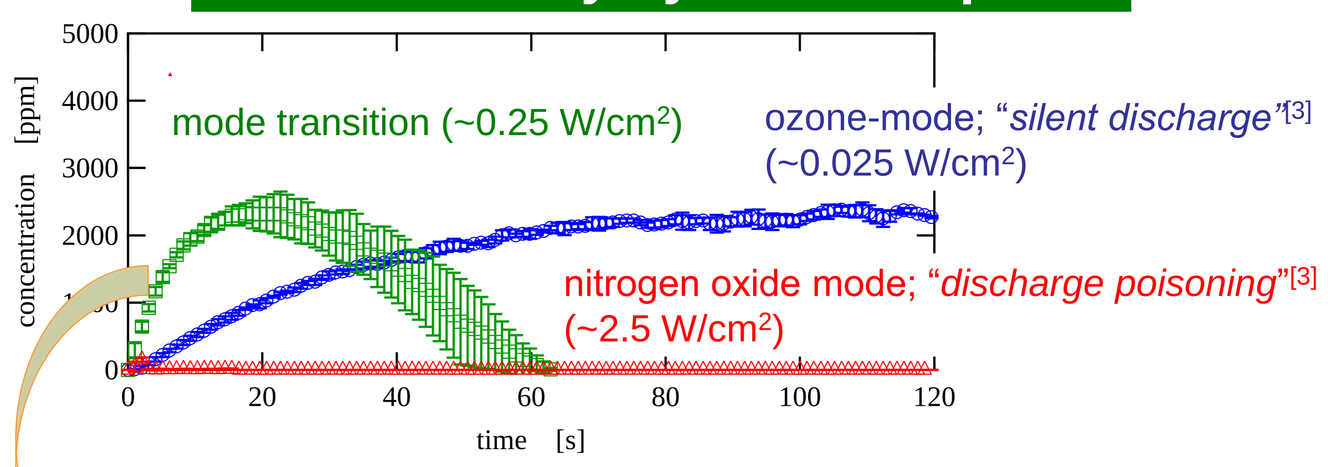


REACTIVE OXYGEN AND NITROGEN SPECIES IN GAS PHASE

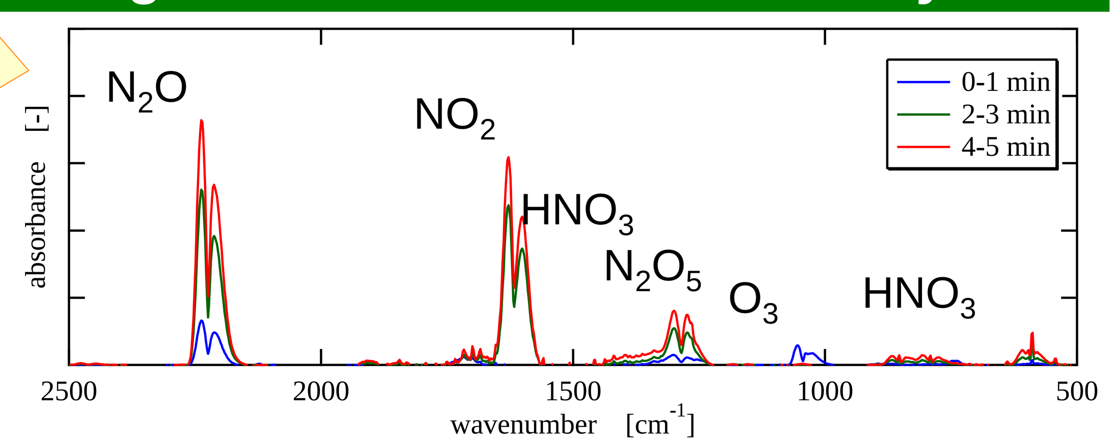


- power density: 0.03-3 W/cm^2
- gas gap: 10-40 mm
- device diameter: ~50 mm
- ambient air (30-40% humidity)

Ozone density by UV absorption



Nitrogen oxides at the transition by FTIR



A simplified fitting model

2 unknown variables
- n_{O3} and n_{NO}

3 fitting parameters
- n_O, T_{vmax}, τ_v

R1: $O + O_2 + M \rightarrow O_3 + M$

R2: $N_2(v) + O \rightarrow NO + N$

R3: $O_3 + NO \rightarrow NO_2 + O_2$

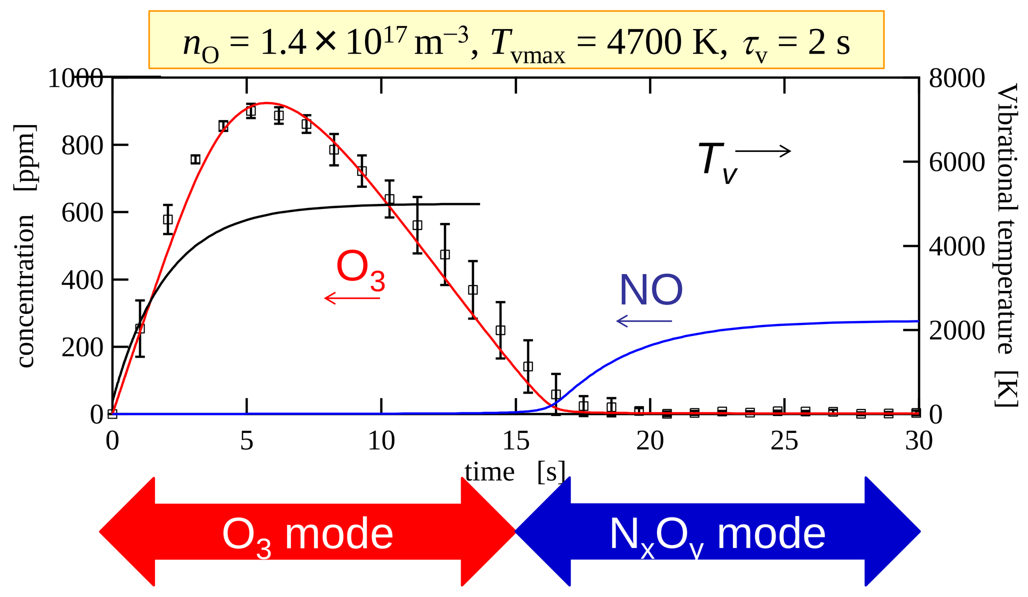
R4: $O + NO + M \rightarrow NO_2 + M$

$$\frac{dn_{O_3}}{dt} = k_1 n_M n_O n_{O_2} - k_3 n_{NO} n_{O_3} - \frac{n_{O_3}}{\tau_{dif}}$$

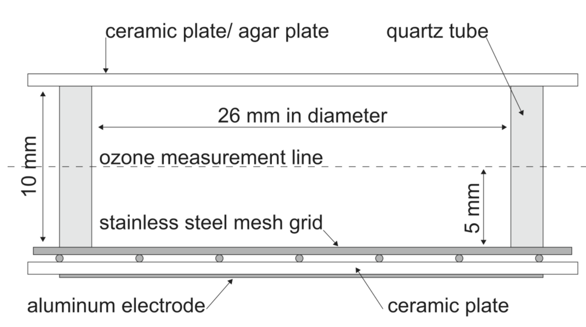
$$\frac{dn_{NO}}{dt} = k_2 n_{N_2(v)} n_O - k_3 n_{NO} n_{O_3} - k_4 n_O n_{NO} n_M - \frac{n_{NO}}{\tau_{dif}}$$

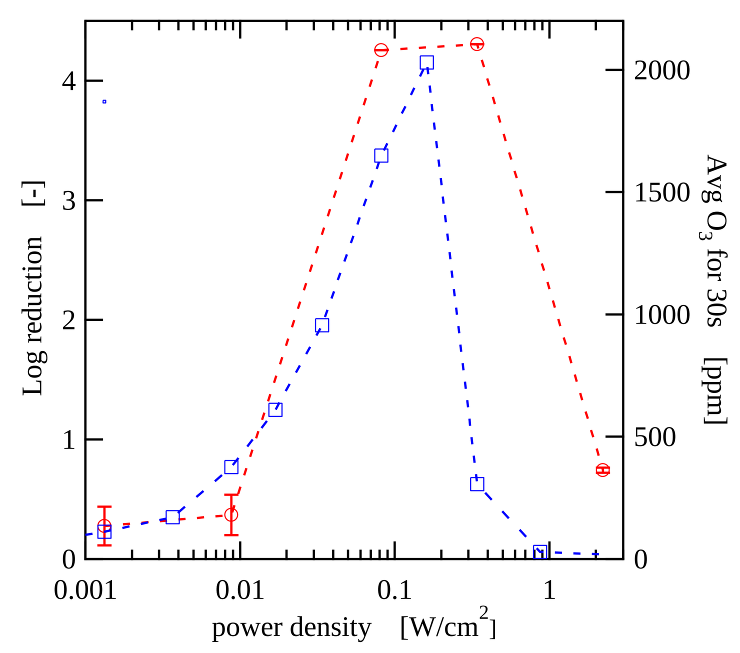
$$n_{N_2(v)} = n_{N_2} F_{v>12} = n_{N_2} \exp\left(-\frac{12\Delta\varepsilon_v}{kT_v}\right), \quad T_v = T_g + T_{vmax}\{1-\exp(-t/\tau_v)\}$$

$n_O = 1.4\times10^{17}$ m^{-3}, $T_{vmax} = 4700$ K, $\tau_v = 2$ s



Bactericidal effect

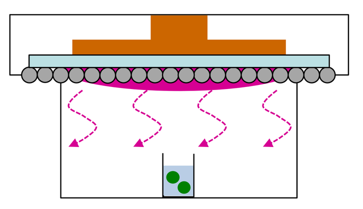




Positive correlation between ozone density and inactivation rate of E.coli cells

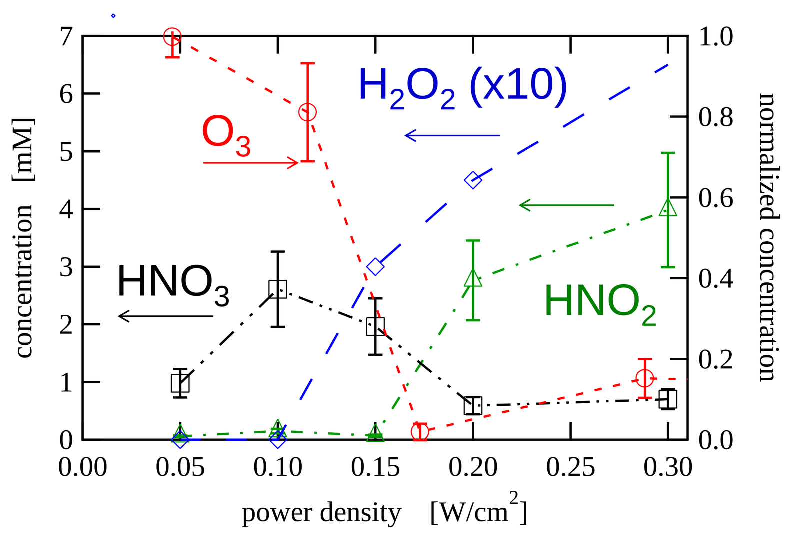
REACTIVE OXYGEN AND NITROGEN SPECIES IN AQUEOUS PHASE

Short-term effect

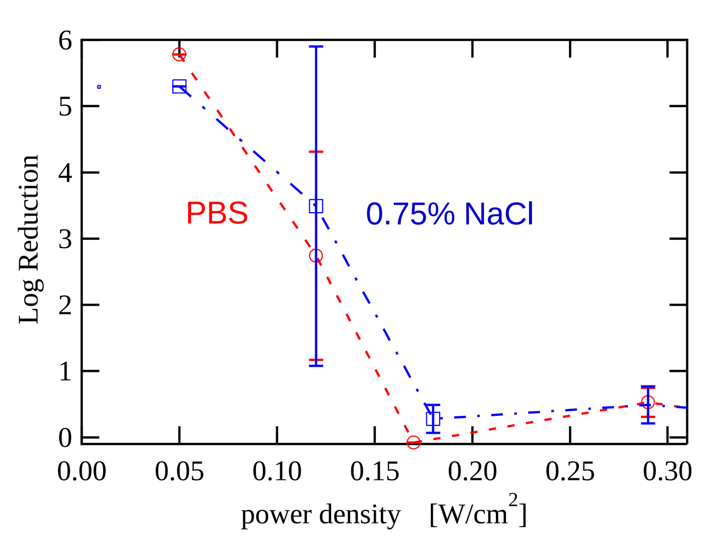


- power density: 0.05-0.3 W/cm^2
- exposure time: 5 min
- E. coli: ~10^7 cfu/ml
- O_3: indigo method
- H_2O_2: electrochemical probe
- HNO_2/HNO_3: UV absorbance

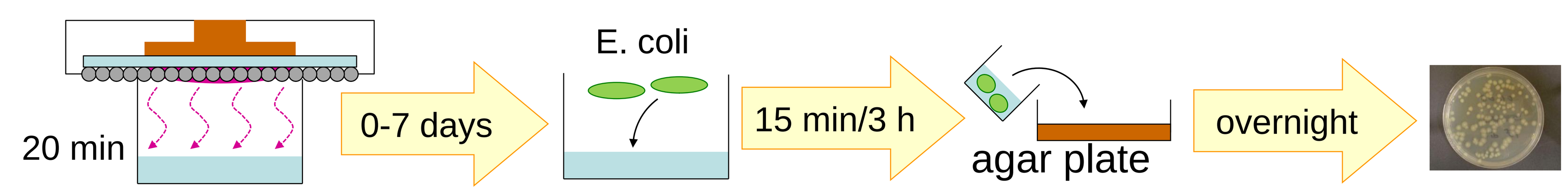
RONS distributions in PBS



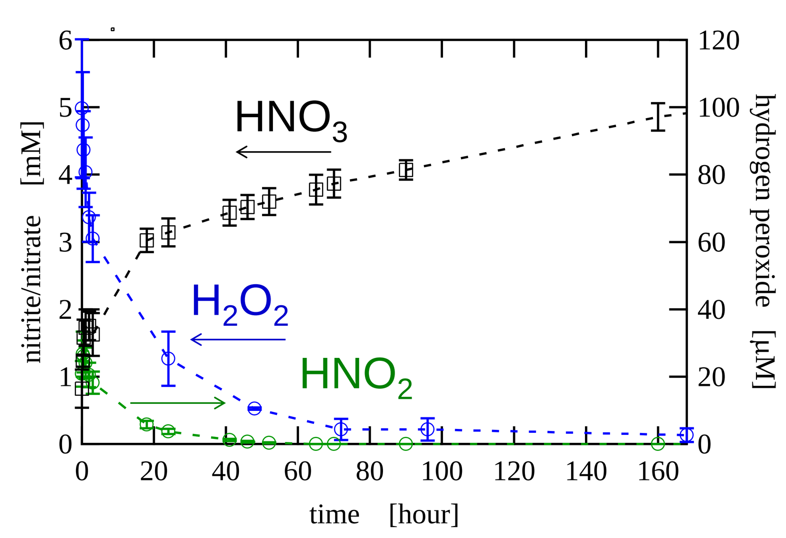
Inactivation of E. coli



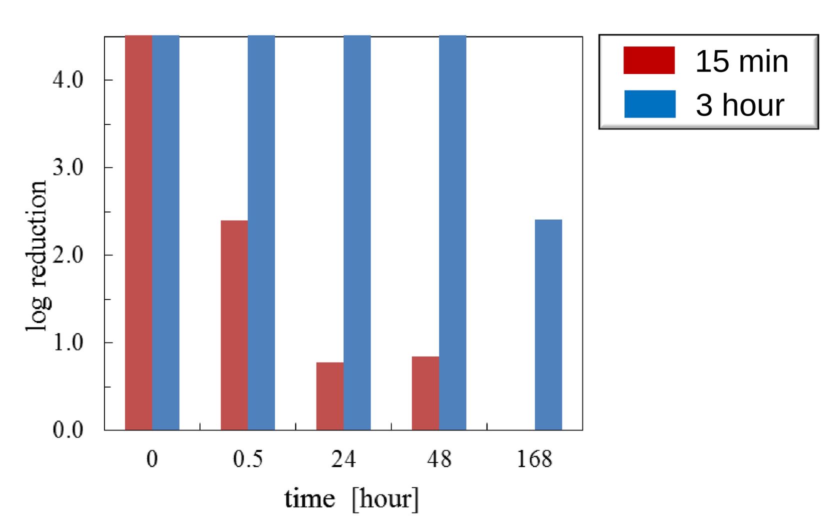
Long-term effect [5]



RONS distributions in PBS



Inactivation of E. coli



CONCLUDING REMARKS

- ✓ SMD shows surprisingly dynamic and transient behavior of RONS.
- ✓ Power density is a key parameter to control the distributions of RONS.
- ✓ We observed positive correlation between ozone and inactivation rate of *E. coli* in gas phase.
- ✓ The short-term bactericidal effect in liquid phase can be explained by ozone, whereas nitrites and nitrates appears to be important for long-term sterilization efficacy.

REFERENCES

[1] Y. Sakiyama, et al., *J. Phys. D* (submitted)

[2] G. Morfill, et al., *New J. Phys.* **11** (2009) 115019

[3] U. Kogelschatz, et al., *Ozone Sci. Eng.* **9** (1987) 195

[4] R. Sander, Max-Planck Institute of Chemistry (1999)

[5] M. Traylor, *J. Phys. D* **44** (2011) 472001

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