Air – Water Microwave

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Motivation
Plasma interaction with living matter ⇒ on the cutting edge of low-temperature plasma research

Microwave discharges driven by surface waves
Properties and advantages as sources of reactive species

Theoretical model of an air-water microwave plasma source (discharge & afterglow)

NO(X) flux in the afterglow plasma jet
Motivation

Plasma Medicine

Surface

Plasma Therapy

Biological
Motivation

Plasma Medicine

Surface

Plasma Therapy

Biological

Plasma <-> Living Matter
Plasmas can initiate, promote, control and catalyze complex biochemical processes in living matter.

Plasma biomedical applications need reliable and user-friendly plasma sources.
NO - Therapy
Nobel Prize in medicine and biology awarded in 1998 to R. F. Furchgott, L. J. Ignarro, and F. Murad for their work on the function of NO as a signal molecule
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- NO effects on wound healing and inflammatory processes
- Treatment of wound pathologies
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- NO effects on wound healing and inflammatory processes
- Treatment of wound pathologies
- Treatment of inflammatory and destructive illnesses:
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- NO effects on wound healing and inflammatory processes
- Treatment of wound pathologies
- Treatment of inflammatory and destructive illnesses:
  - pulmonology, phthisiology, traumatology and orthopedics, dentistry, gynecology, maxillofacial surgery, ophthalmology, dermatology, otorhinolaryngology, gastroenterology, etc.
Surface Wave Driven Plasma Source

Wave – to – plasma power transfer ⇒ physical basis of discharges sustained by surface waves

$f = 2.45$ GHz

Advantages:
⇒ compact, economical
⇒ electrodeless
⇒ large power density
⇒ high concentration of active species
⇒ follow the geometry of the guiding surface
Air – Water Plasma Source

\( f = 2.45 \, \text{GHz} \)

\[ \text{p} = 1 \, \text{bar} \]

\[ \text{[Air (98\%) - H}_2\text{O (2\%)]} \]

\[ \text{P} = 200 - 600 \, \text{W} \]

\[ \text{Q} = 500 – 2000 \, \text{scm} \]

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1D Self-consistent Model of the Air – Water Plasma Torch

✓ Maxwell’s equations;
✓ Dispersion equation for TM surface mode;
✓ Continuity equations for vibrationally excited states of ground state $N_2(X)$ molecules;
✓ Continuity equations for excited states of molecules and atoms [$N_2(A), N_2(B), N_2(C), N_2(a’), N^{(2D)}, N^{(2P)}, O_2(a), O_2(b), O^{(1D)}, O^{(1S)}$];
✓ Continuity equations for ions and electrons [$N_2^+, N_4^+, O^+, O_2^+, O_4^+, NO^+, NO_2^+, H_2O^+, H_3O^+, H_2^+, H_3^+, HN_2^+, NH_3^+, NH_4^+, O^-, O_2^-, O_3^-, H^-, OH^-, NO_2^-, NO_3^-]$;
✓ Continuity equations for ground state molecules and atoms [$N, O, O_3, NO, N_2O, NO_2, NO_3, N_2O_5, H_2O, H, H_2, OH, HO_2, H_2O_2, NH_3, NH_2, NH, HNO, HNO_2, HNO_3$];
✓ Gas thermal balance equation;
✓ Equation of mass conservation for the fluid as a whole.

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Air –Water Plasma Source

Gas Temperature Axial Variation

- $Q = 500$ sccm
- $\text{H}_2\text{O} = 2\%$

- $\text{H}_2\text{O} (2\%)$
- $P = 300$ W

- 2000 sccm
- 1000 sccm
- 500 sccm
Air – Water Plasma Source

\[ \text{NO}(X) \text{ axial variation} \]
[NO] vs. microwave power
$[O(^3P)]$ vs. microwave power
NO(X) generation

[NO] vs. total gas flow

Main Source Channels

N + O₂ → O + NO  
O + N₂ → N + NO

Main Loss Channels

NO + O → O₂ + N  
NO + N → N₂ + O

τ_{NO} > τ_R
Conclusions

♦ Surface wave driven plasma torch is a promising plasma source for biomedical applications;

♦ High population density of NO(X) in the afterglow plasma jet (up to 15 000 ppm) can be achieved;

♦ High population density of ground state atoms O(3P) can be reached in the discharge zone.
Thanks for your attention!