

Karlsruhe Institute of Technology

Light, ECG and Plasma Technologies **Light Technology Institute** www.lti.kit.edu

# Plasma Water Activation with an Inductive Plasma **Torch at Atmospheric Pressure**

Generation of Reactive Oxygen and Nitrogen Species (RONS) by Plasma-Liquid Interaction

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## Motivation

#### Plasma Activated Water (PAW)

Hydrogen Peroxide  $H_2O_2$ 

 $NO_2^-$ 

 $NO_3^-$ 

Nitrite

Nitrate

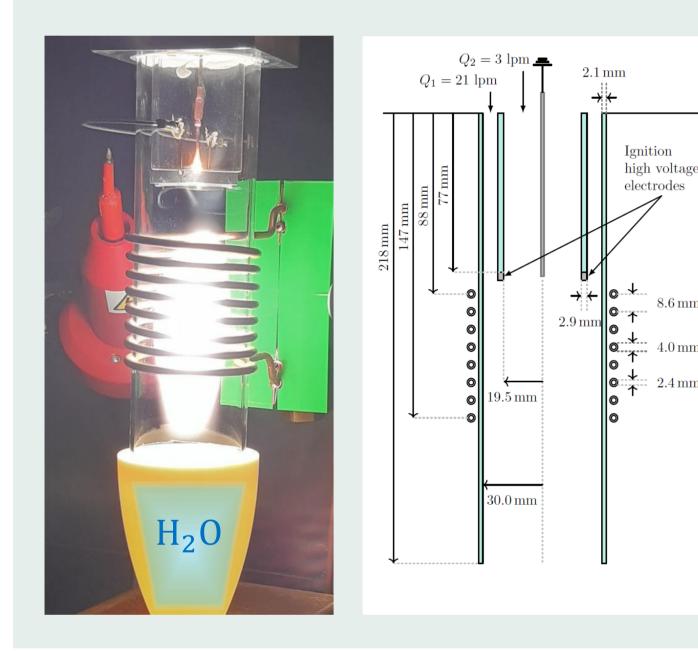
#### Application

- Biological Applications
- Food Industry
- Agriculture

#### Advantage of the Presented ICP-System

- Compact Design
- High RF- Efficiency (98%)
- High Power (>1 kW)

## **Torch System**



### Power Supply

SiC Based Resonant Converter [1]

3 MHz Excitation Frequency

1.2 kW Input Power

#### Parameter

 $2.4\,\mathrm{mm}$ 

 $e + N_2 \rightarrow e + N$ 

 $0 + 0_2 \rightarrow 0_3$ 

 $N + 0 \rightarrow N0$ 

 $NO + O \rightarrow NO_2$ 

 $NO_2 + O_3 \rightarrow NO_3$ 

 $e + 0_2 \rightarrow e + 0 + 0$ 

Used gas: Argon

Inner flow: 3 lpm

## Simulation

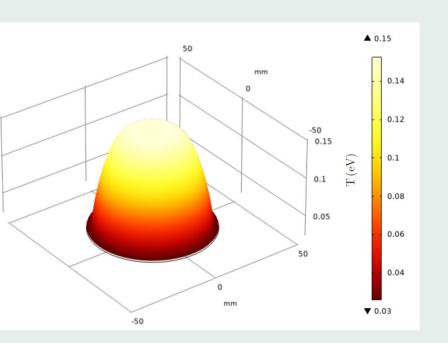
### Equilibrium Plasma Simulation

COMSOL Simulation of the Ar-Torch [2,3]

Multiphysics: Heat Flow, Fluid Dynamics, Magnetic Fields, Equilibrium Discharge

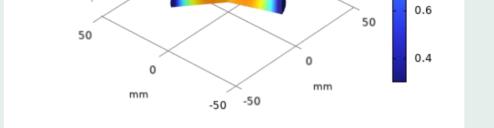
### Result

Temperature in the Power Coupling Area ≈ 2200 K



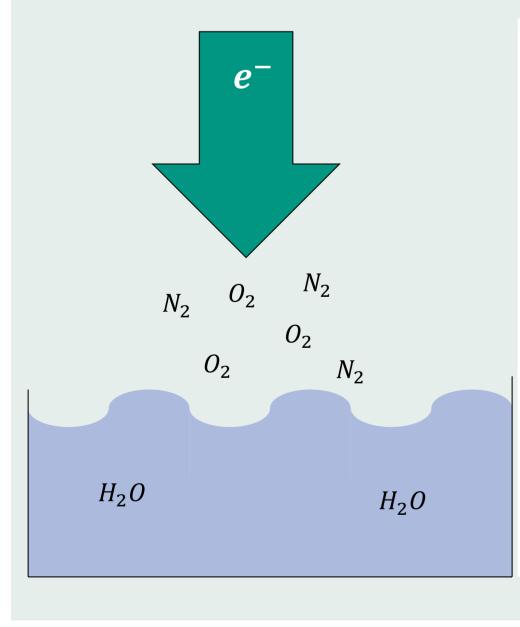
Sheath flow: 21 lpm

Pointed at DI-Water in a Distance of 10 mm



Electron Temperature at the Torch Outlet ≈ 0.15 eV

## Reactions



Electron Collision Dissociation of N<sub>2</sub> and O<sub>2</sub> at the Plasma-Atmosphere-Impact Region

- Nitrite and Nitrate Components Reacting with Water
- Hydroxide Generation by Electron Water Interaction
  - $NO_2 + NO_2 + H_2O \longrightarrow NO_2^- + NO_3^- + 2H^+$ 
    - $e + H_2 0 \longrightarrow OH + H + e$

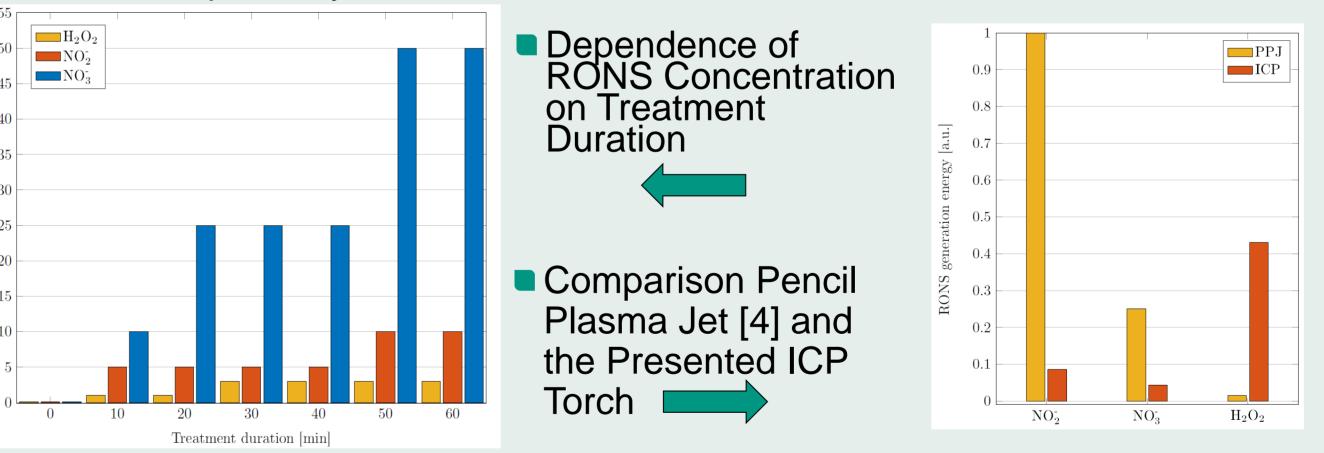
#### $OH + OH \rightarrow H_2O_2$

## Measurements

#### Method

mm

Colorimetric Measurement of the RONS Concentration using Quantofix Test Strips every 10 Minutes.



## Conclusion

#### RONS-Generation

## References

[1] Eizaguirre, Santiago; Gehring, Tim; Denk, Fabian; Simon, Christoph; Kling, Rainer: Argon ICP plasma torch at atmospheric pressure driven by a SiC based resonant converter operating in MHz range. PCIM Europe digital days 2020, Poster, 7-8.07.2020

High RNS Generation Compared to Similar Technologies

#### Improving RNS Generation Rate

Further Increase in RNS Production through ICP Nitrogen Plasma

Stable Plasma Operation with 20% N<sub>2</sub> in Ar Tested at 3 MHz and 1.2 kW

[2] COMSOL Multiphysics v. 6. www.comsol.com. COMSOL AB, Stockholm, Sweden.

[3] Xue, S.; Proulx, P.; Boulos, M.I. Extended-field electromagnetic model for inductively coupled plasma. Journal of Physics D: Applied Physics 2001, 34, 1897–1906. https://doi.org/10.1088/0022-3727/34/12/321.

[4] Rathore, V.; Nema, S.K. The role of different plasma forming gases on chemical species formed in plasma activated water (PAW) and their effect on its properties. Physica Scripta 2022, 97, 065003. https://doi.org/10.1088/1402-4896/ac6d1b.

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