Fundamentals of plasma-surface interactions in sustainable plasma applications

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Abstract: Low-temperature plasmas integrated with catalysis offer a pathway for renewable energy storage and industrial electrification. This study explores plasma-induced processes using a micro-cavity plasma array and an RF-driven plasma jet, emphasizing reactive species generation, catalytic efficiency, and phase separation in biocatalysis. Advanced diagnostics reveal key roles of charges, electric fields, and surface interactions, guiding optimized reactor designs.

1. Introduction

The integration of low-temperature plasmas with catalysis has recently gained attention as a method to store renewable energy in chemical forms, potentially facilitating the electrification of industry in response to the climate crisis. Although the combination of traditional catalysts with non-equilibrium plasmas has demonstrated promising synergies, much of the research remains empirical. Studies indicate that atmospheric pressure plasmas, with their distinctive non-equilibrium properties and surface interactions, can enhance classical catalysis. However, understanding the underlying mechanisms is challenging due to the complexity of diagnostics and analysis in these reactors.

2. Methods

Here, we use a planar micro-cavity plasma array [1] to investigate plasma-surface interactions regarding surface charges, electric fields, and reactive species. The discharge reactor consists of hundreds of discharge cavities with a diameter of ~100 µm. The plasma is operated in Helium with admixtures of reactive gases such as oxygen, n-butane, or CO_2 and excited using a kHz bipolar voltage. To analyze the effect of different plasma species and processes as well as the catalyst material and surface temperature on conversion, we use electrical measurements [2], emission and absorption spectroscopy as well as FTIR and modeling approaches.

To investigate particle separation, transport, and energy efficiency, we will use an RF-driven atmospheric pressure plasma capillary jet [3]. To analyze the transport of reactive species in a liquid medium, spectrophotometric approaches are used and compared to MD simulations [4].

3. Results and Discussion

In this presentation, we will discuss the influence of different plasma species on processes and how they can affect the performance of plasma-catalytic reactions.

First, the role of charges and electric fields is illustrated at the example of the micro-cavity plasma array. The resulting temporal and spatial generation of reactive species is investigated. We will analyze the effect of excitation schemes and surface temperature on the conversion rates and absolute species densities.

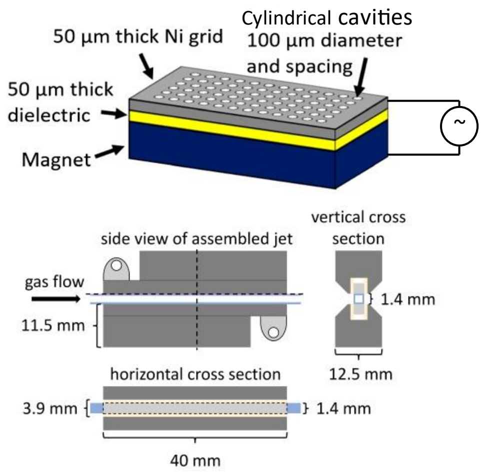

Fig. 1. Schematics of the two discharge reactors used in this study: Micro cavity plasma array (top) and atmospheric pressure capillary jet source (bottom).

Second, for more complex applications we present a biocatalysis setup. Here, catalysis is performed based on enzymes submerged in an aqueous solution. Thus, effective separation between plasma effluent and the catalysis phase is possible. We will analyze the production and transport of H_2O_2 in the gas and liquid phase to tailor the catalytic reaction.

4. Conclusion

Understanding plasma catalysis requires detangling complex plasma-surface processes. To investigate the effects separately, dedicated reactor setups and tailored diagnostic techniques are required.

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References

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