In-Situ Resources Production of Hydrogen Peroxide and Hydrogen Using Nano-enabled Optical Fibers

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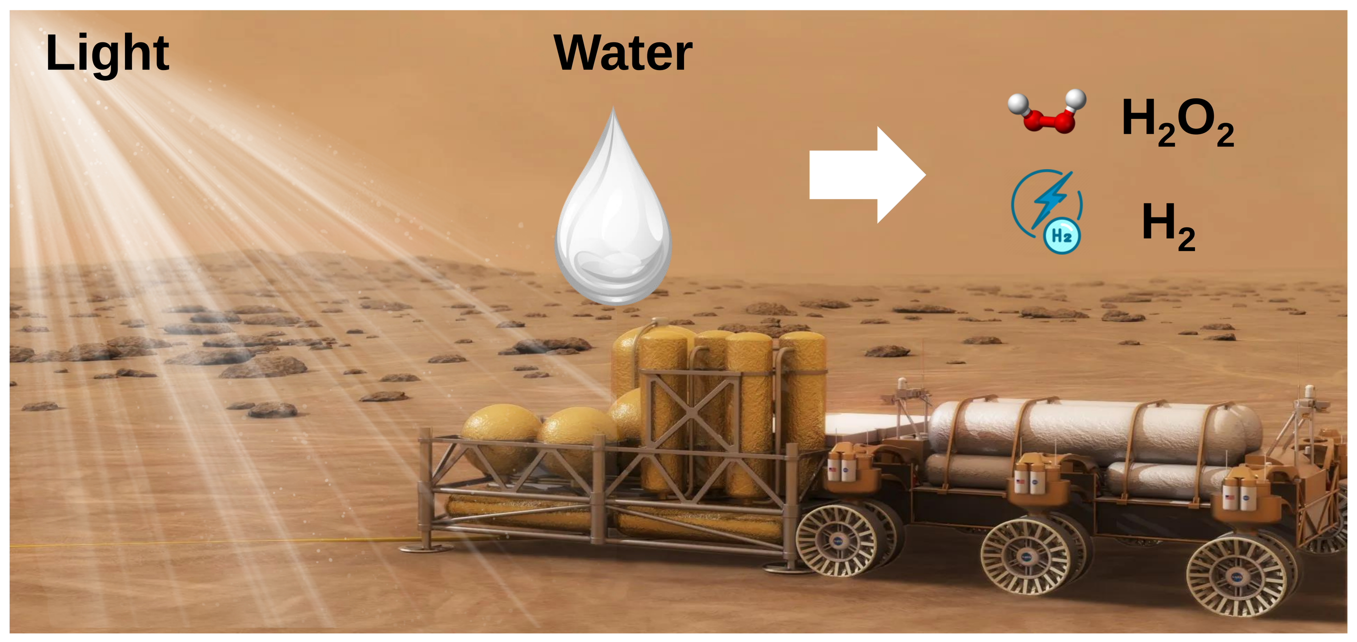
Nanosystems Engineering Research Center for Nanotechnology-Enabled Water Treatment

Introduction

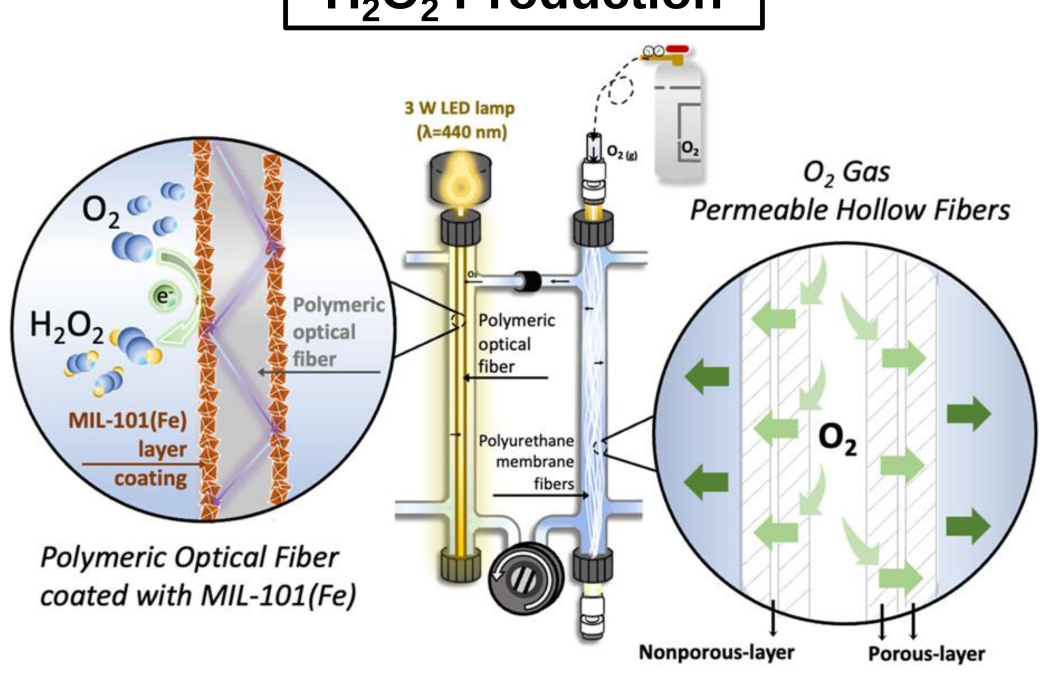
- We utilize Polymer Optical Fibers (POFs) equipped with visible-UV light LEDs that side-emit light to activate nanomaterials embedded in porous polymers on their surface. This approach provides an efficient method for producing hydrogen (H_2) and hydrogen peroxide (H_2O_2) from water.
- We also introduce a modified POF that integrates a photoelectrocatalytic (PEC) system, where the conductive and photocatalytic nanomaterial-coated POF acts as both a light delivery source and an optoelectrode.
- The POF and PEC-POF reactor designs demonstrate high physical flexibility and the ability to bundle hundreds of fibers, offering a significant surface area advantage over traditional flat glass plate photoelectrodes.
- This cost-effective, convenient, and eco-friendly technology is particularly suitable for in-situ H_2/H_2O_2 generation, making it ideal for in-situ resource utilization in space exploration.



NASA In-Situ Resource Utilization (ISRU) for deep space exploration

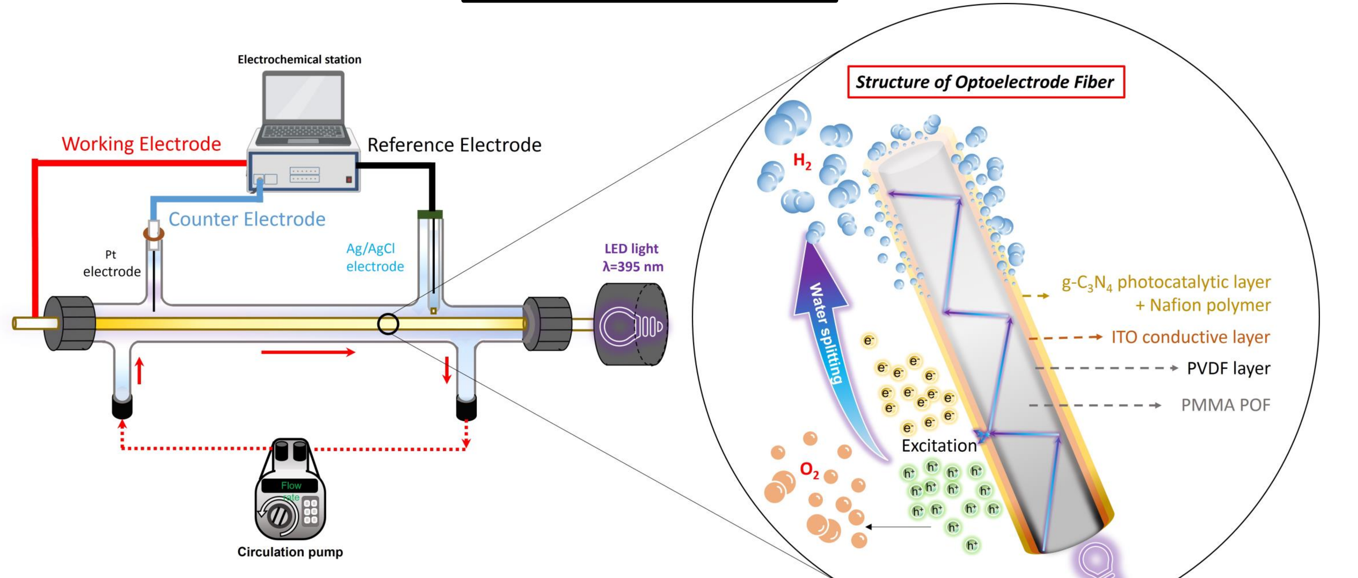
Reactor Set-up for H_2O_2/H_2 Production

H_2O_2 Production



H_2O_2 production experiments were conducted in a dual-fiber system consisting of a photocatalyst-coated polymeric optical fiber and an O_2-permeable hollow fiber bundle. An LED source (λ = 440 nm, 3 W) was supplied on the top of the POF, while compressed pure O_2 was supplied to the fiber bundle. H_2O_2 samples were taken and evaluated using a colorimetric method.

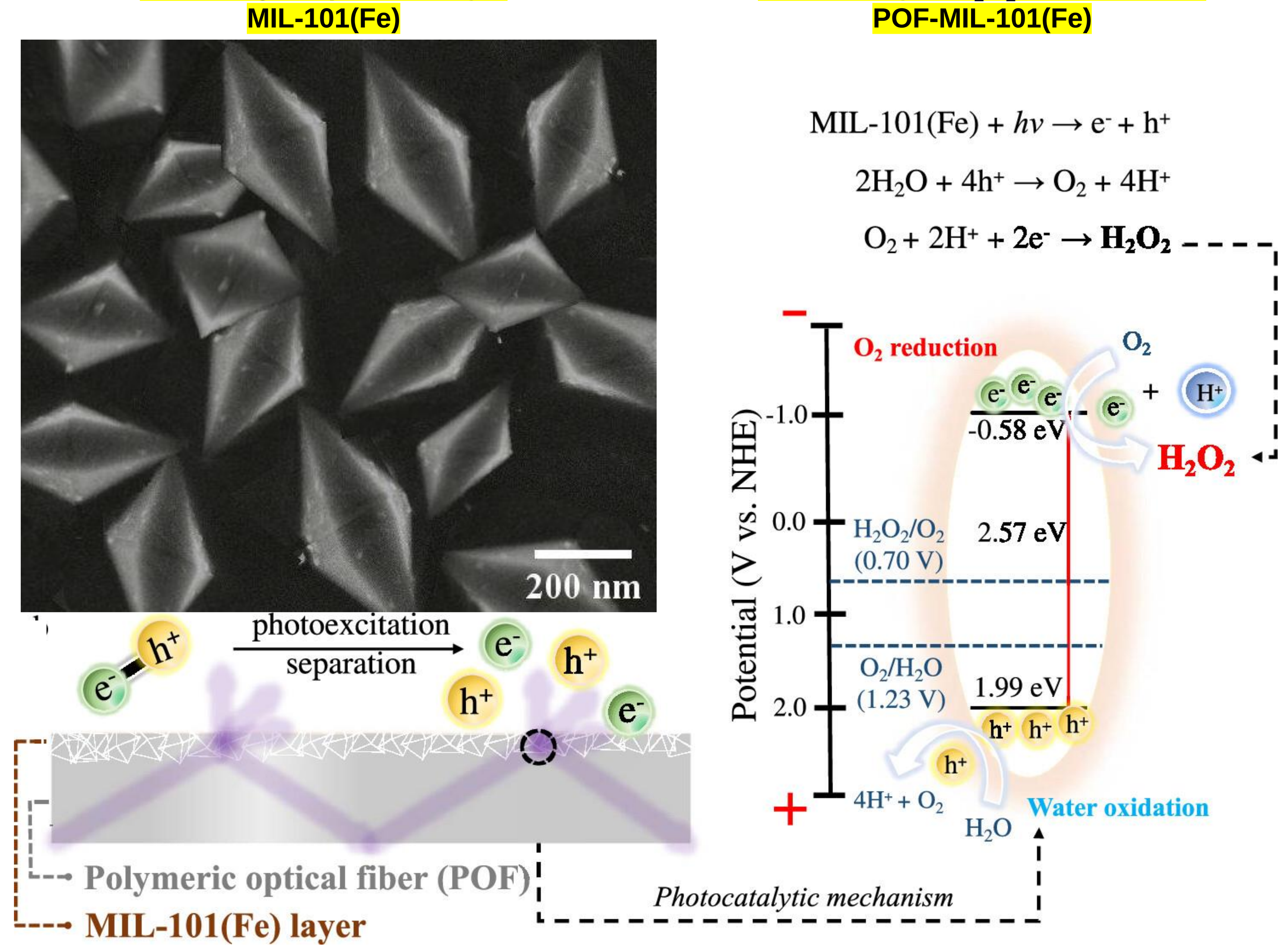
H_2 Production



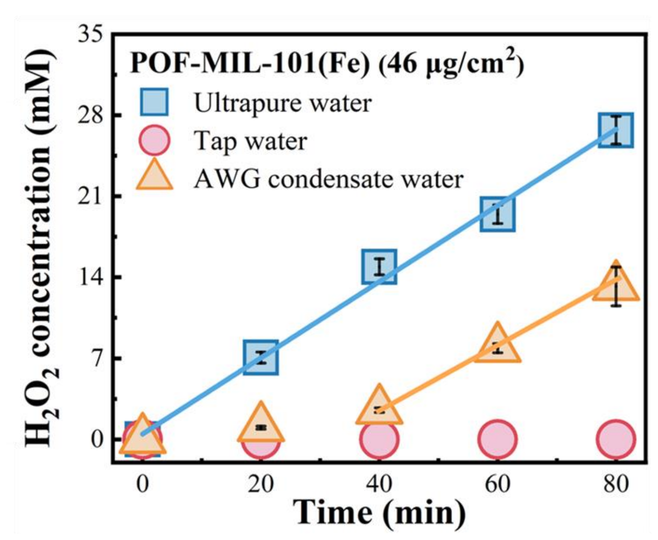
H_2 production experiments were conducted in a batch reactor comprising a cylindrical electrochemical cell containing a 0.2 M Na_2SO_4 electrolyte at pH 6.8. The optoelectrodes were activated using a monochromatic UV-light LED (λ = 395 nm, 2.18 W), and a bias potential of 1.2 V vs Ag/AgCl was applied. Gas phase samples were collected over time, and the amounts of H_2 were quantified using GC-MS (Shimadzu 2010).

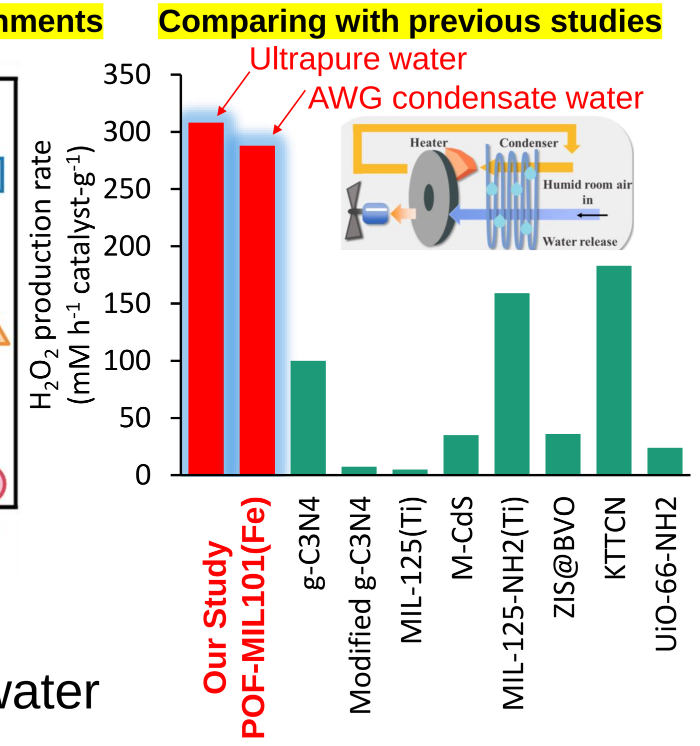
H_2O_2 Production in a Dual Optical/Membrane Fiber Reactor and Effects of Water Quality

SEM image of photocatalyst MIL-101(Fe) | **Photocatalytic H_2O_2 mechanism of POF-MIL-101(Fe)**



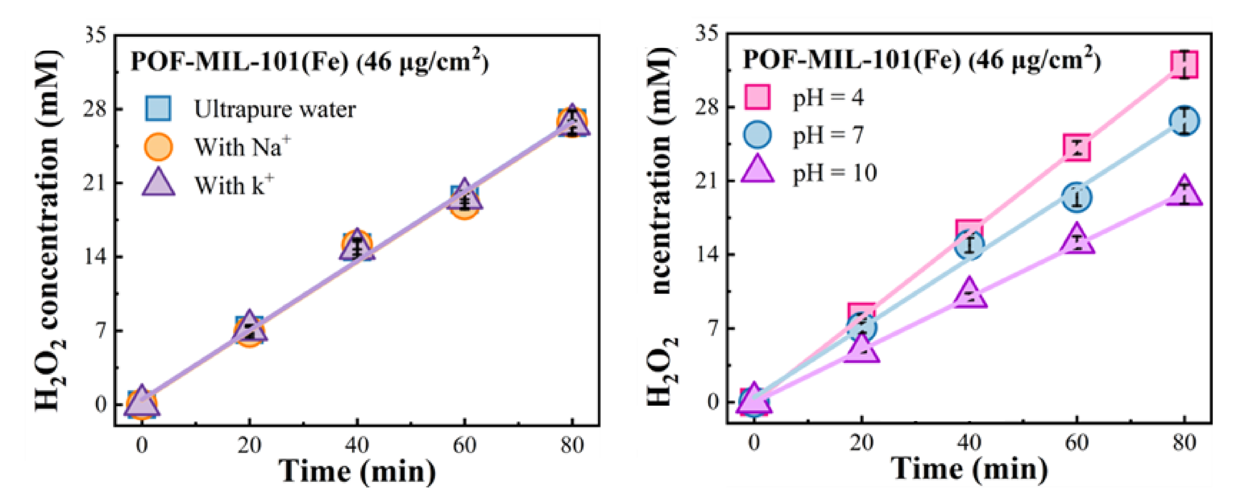
H_2O_2 Production in Diverse Water Environments | **Comparing with previous studies**



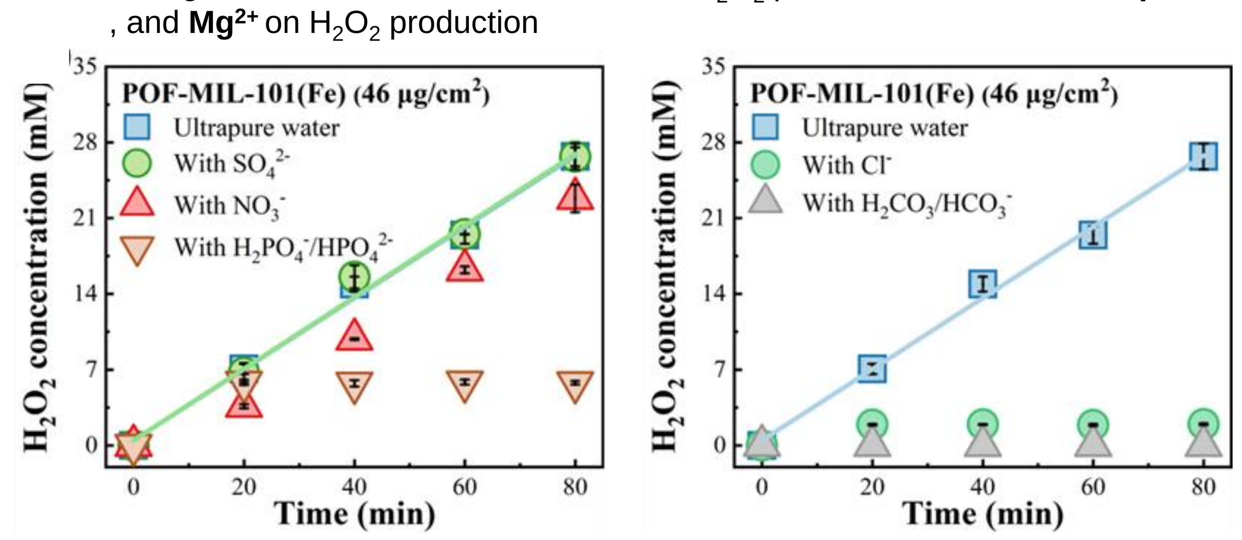


✔ Ultrapure water
✔ AWG condensate water
✘ Tap Water

Effects of Water Quality



No significant effect Na^+, K^+, Ca^{2+}, and Mg^{2+} on H_2O_2 production | H_2O_2 production is favorable at **pH = 4**

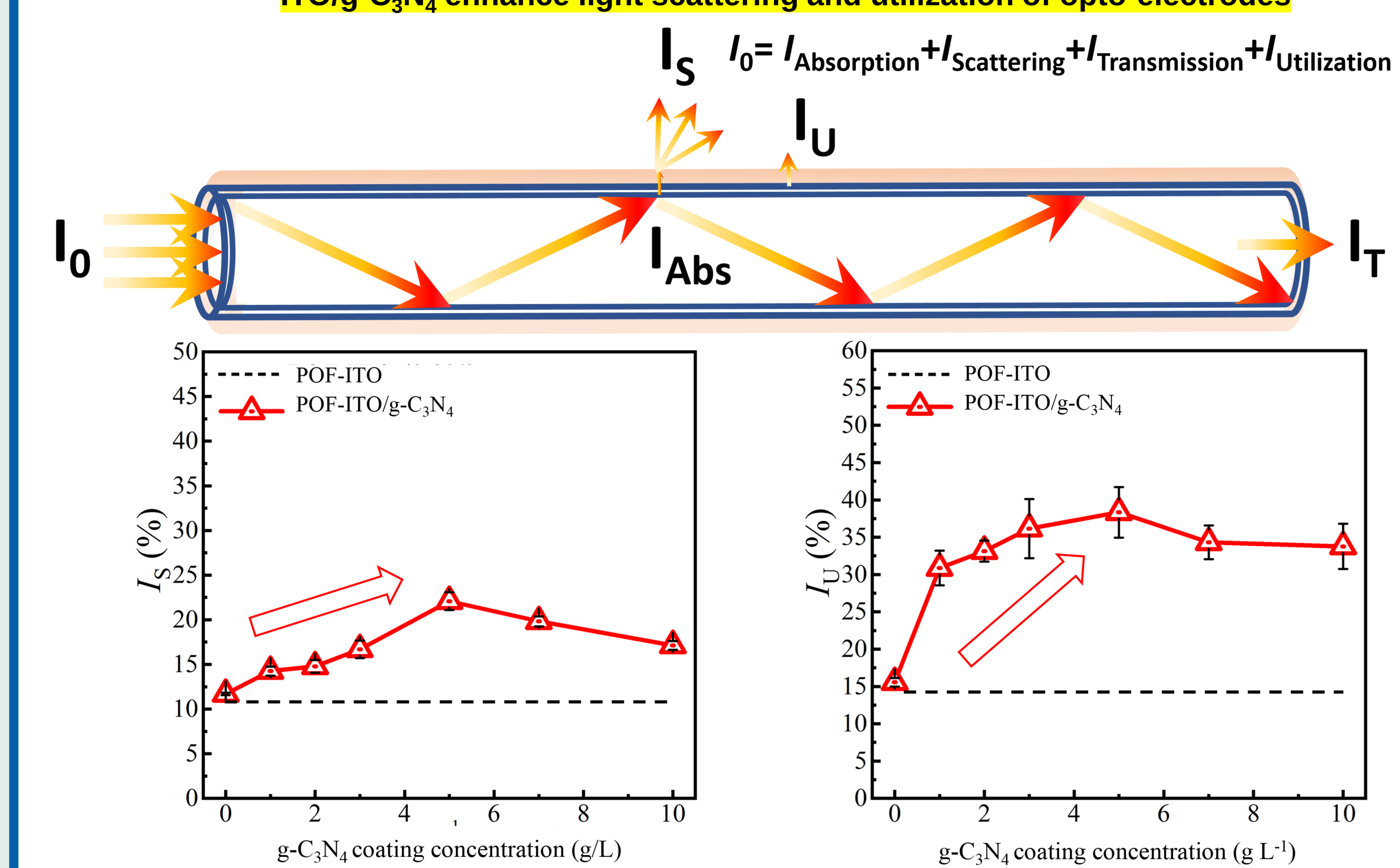


No significant effect of **SO_4^{2-}**
Slight inhibitory effect of **NO_3^-**
Inhibitory effect of **$H_2PO_4^-/HPO_4^{2-}$**

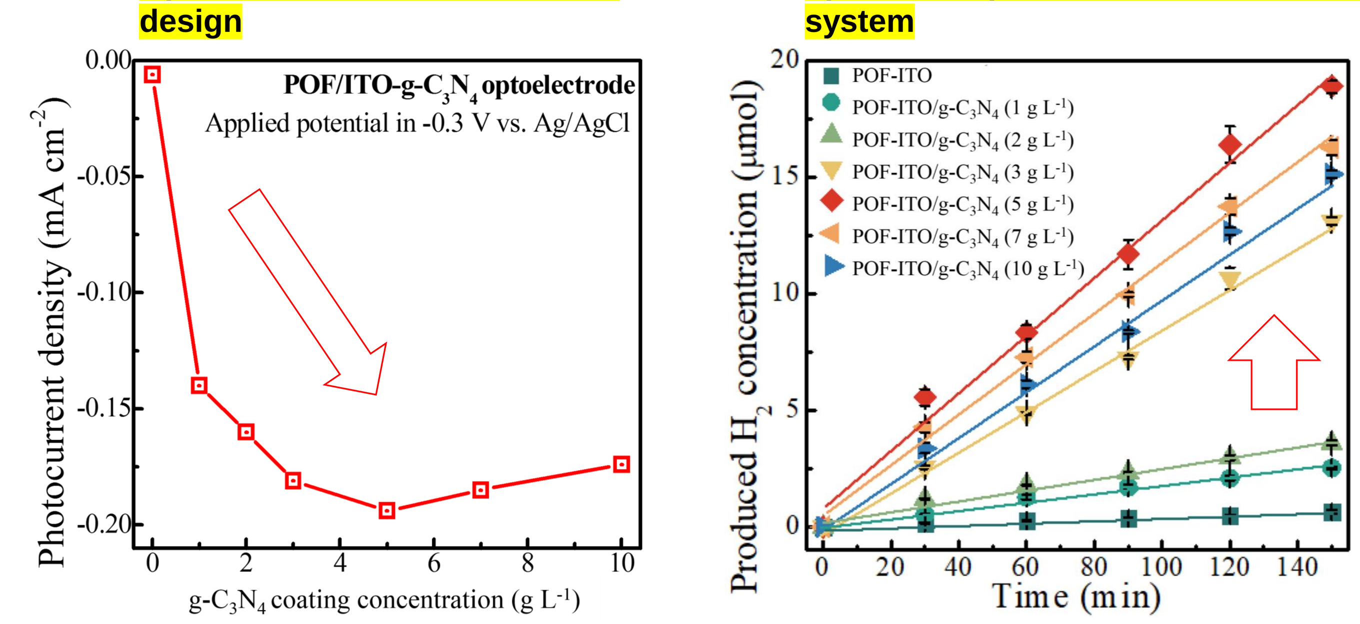
Inhibitory effect of **Cl^-**
Inhibitory effect of **H_2CO_3/HCO_3^-** on H_2O_2 production

H_2 Production in PEC-POF Systems: Flexible Fiber Opto-electrodes with Integrated g-C_3N_4-ITO Layers

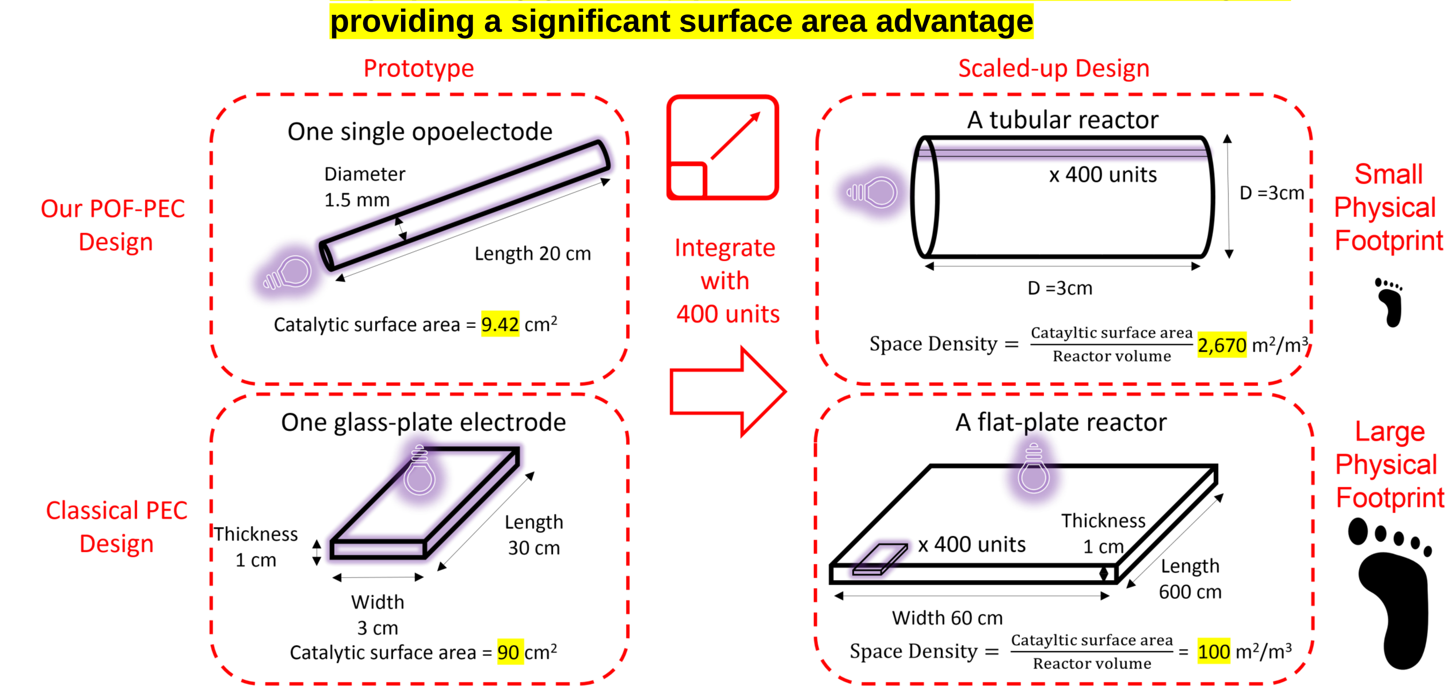
ITO/g-C_3N_4 enhance light scattering and utilization of opto-electrodes



Improved photoconductivity of Opto-electrode in the PEC-POF design | **Boosted hydrogen evolution rate from optimized Opto-electrode in PEC-POF system**



High packing geometry potential for PEC-POF reactor designs, providing a significant surface area advantage



Conclusion

- The dual-fiber system, integrating with a metal-organic framework (MOF) catalyst-coated optical fiber (POF-MIL-101(Fe)) and O_2-based hollow-membrane fibers, achieved a remarkable H_2O_2 yield (308 ± 1.4 mM h^{-1} catalyst-g^{-1} in ultrapure water)
- Notably, atmospheric water-generated condensate water emerged as a promising alternative for light-driven in-situ H_2O_2 production.
- The unique inside-out light delivery approach in the PEC-POF design significantly enhanced light utilization (24-fold larger than bare POF) and achieved high photocurrent density (0.2 mA cm^{-2}), leading to rapid hydrogen production rate of 344 μmol h^{-1} g^{-1}, up to 15 times higher than most existing reactor designs.
- Our optoelectrode system also offered a geometric space capacity of 2,670 m^2 m^{-3}, >25 times larger than conventional flat-electrode PEC designs.

References

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3. Fu, H., Wang, T.-H., Doong, R.-A., Lai, Y.-J. S., Garcia-Segura, S., Zhao, Z., & Westerhoff, P. (2024). Boosting hydrogenproduction via water splitting: An ITO plus g-C3N4 nanomaterial enabled polymer optical fiber design. *ACS mater. lett.*,6(4), 2267-2275.