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Mechanistic studies of H_2 production from H_2O using a low power Al/Al_2O_3 microplasma chip reactor

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The transition to a H_2-based energy economy is considered an important step towards the alleviation of fossil fuel environmental effects. The current work demonstrates that plasmachemical water reactions within microplasma channels produce significant H_2. The mechanisms underlying these reactions are studied to optimize H_2 production efficiency. Chemical processes are characterized using a variety of gaseous measurement, optical characterization, and surface analysis techniques. The results demonstrate that the plasmachemical reactions deposit regular aluminium oxide and aluminium hydroxide structures along the walls of the microplasma channels. However, the electrical characteristics of the microplasma device are completely retained after more than 160 minutes of plasma reactions despite nanoparticle growth within the microchannels. Thus, microplasma chip reactors may have potential to aid the transition to a global H_2 economy.

Hydrogen is an ideal fuel because of its ultra-high energy density, lack of harmful combustion byproducts, and availability in common sources like water. However, H_2 lacks global adoption as a fuel because virtually all H_2 is synthesized from fossil fuels through expensive and energy-intensive industrial processes such as methane steam reforming.[1] Alternatively, small amounts of hydrogen can be made on-demand through water electrolysis, but this process is similarly energy intensive, requires high electrolyte concentrations, and its non-specific reactions can produce harmful reaction byproducts. As an example of non-specificity, water electrolysis can emit chlorine gas when chloride ions are present in solution.[2] Despite these limitations, the numerous applications of on-demand H_2 fuel encourages research to produce it at low cost and high efficiency.

Microplasmas are an emerging technology with promising potential for hydrogen production.[3] Microplasmas are micrometer-scale ionized gases. In contrast to traditional macroscale plasma apparatuses, microplasma chips use nanoporous materials with microscale channel dimensions to reduce dielectric breakdown voltages. These chips can operate at room temperature and pressure, and provide molecular excitation via weakly ionized nonthermal plasma.[4] Powers on the order of 1 W can excite nonthermal plasmas.[5]

Microplasma chips can produce H_2 on-demand at high efficiency and specificity using H_2O as fuel, as the current work demonstrates. The chips are modularly parallelizable, suggesting large amounts of H_2 can be created at high efficiency, and thus have significant industrial potential.[6] On-site hydrogen sources are needed for a wide variety of energy applications including hydrogen filling stations, fuel cells, and hydrogen energy storage.[7] Efficient and low power production of H_2 from H_2O would eliminate global dependence on fossil fuels.

References

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