Field-Driven Splitting of Pure Water based on Deep-sub-Debye-length Nanogap Cells

Y.F. Wang, S.R. Narayanan, W. Wu
University of Southern California, Los Angeles, CA 90089
wu.w@usc.edu

Hydrogen is a clean and renewable energy resource. Today, more than 90% of the industrially-produced hydrogen comes from steam reforming of natural gas, which are non-renewable and generate greenhouse gases as by-products. Water electrolysis can be a solution for a sustainable energy supply. However, only 4% of the industrial hydrogen production comes from water electrolysis, basically due to the low conversion efficiency. In this paper, we have demonstrated a novel method to achieve efficient pure water splitting based on our deep-sub-Debye-length nanogap cells, with efficiency that can be even better than 1 mol/L NaOH solution. This is the first time that even pure water can be efficiently electrolyzed.

For traditional water electrolysis in macro-system, electric field has been screened into double layer region due to high-concentration electrolyte added to increase water conductivity. The weak electric field inside bulk solution leads to slow ion transport and thus slow reaction rate. In our nanogap cells with pure water, double layer regions of cathode and anode are overlapped so that huge electric field can exist in the entire electrode gap. When the gap is small enough (Figure 1), the migration rate can be even larger than electron-transfer rate (a.k.a. chemical reaction), leading to much higher efficiency than traditional method. The high electric field enhances water ionization and ion transport. From a microscopic perspective, the conductivity of water has been enhanced "equivalently". We have named this process "virtual breakdown mechanism".

Figure 2 shows the schematic diagram and fabrication result of our metal-dielectric-metal sandwiched-like nanogap cells, achieved by common photolithography and low DC-bias nitride etching. The gap distance (or nitride thickness) has been down to 37 nm. I-V curve measurements based on our nanogap cells with pure DI water are shown in Figure 3. When gap distance shrank, the electrolysis current became larger due to higher electric field between two electrodes (Figure 3(a)). The threshold voltage around 1.5 V suggests that the energy efficiency is very close to 100% based on a thermoneutral potential of 1.48 V. Figure 3(b) shows currents saturated at fixed voltages when the gap distance became smaller, indicating electron-transfer limited reactions. The electrolysis of pure water and 1 mol/L NaOH solution were compared in Figure 4, both based on our nanogap cells. The different data dispersion indicates the different reaction locations for pure water and NaOH solution (Figure 4(b)). The electrolysis current from pure water was comparable to that from 1 mol/L sodium hydroxide solution, indicates more than 10^5-fold enhancement of equivalent conductivity of pure water.

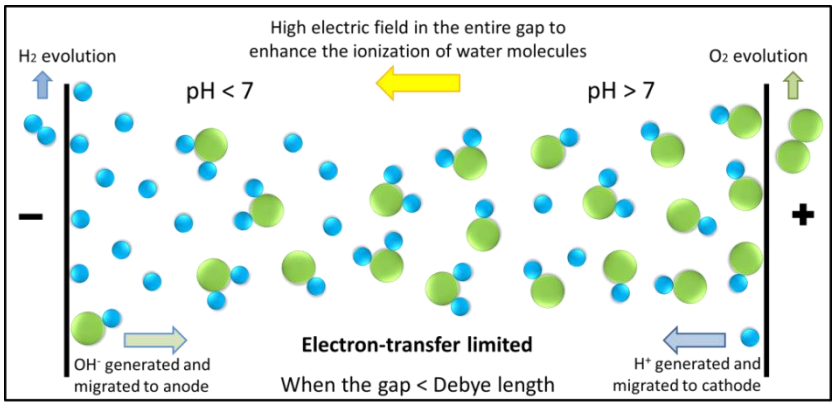

Figure 1. Schematic diagram of pure water splitting reactions in nanogap cells.

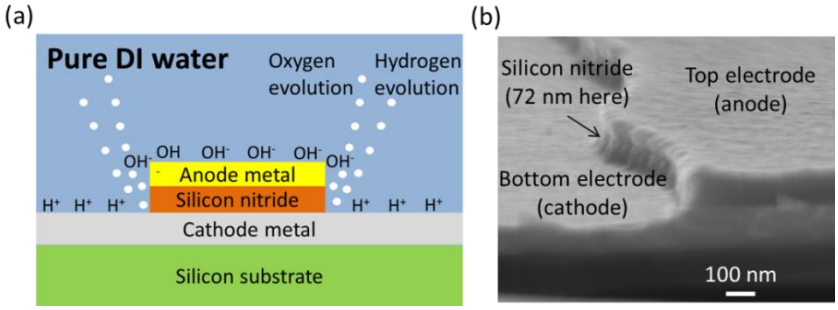

Figure 2. Schematic diagram and fabrication result of metal-dielectric-metal nanogap cells.

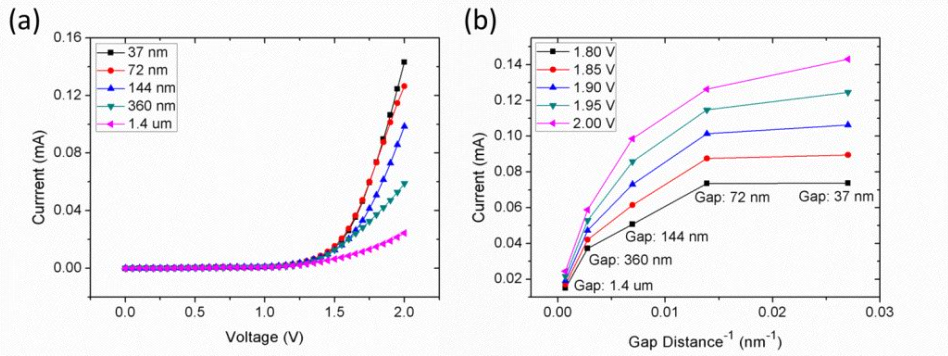

Figure 3. I-V curve measurements based on our nanogap cells with pure DI water.

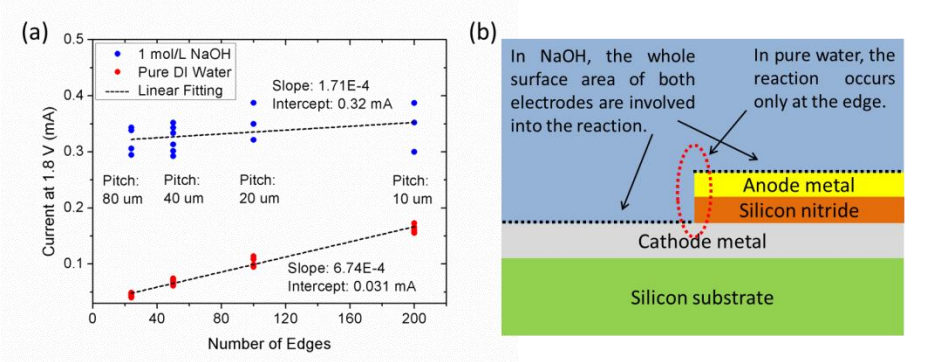

Figure 4. Comparison between pure water splitting and water splitting in 1 mol/L sodium hydroxide solution, both based on our nanogap cells.