Solar Generation of Hydrogen using Titanium Oxide Nanoparticles: Impact of Size on Stability and Efficiency

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Objective

The aim of the current work is to study:

- The hydrogen generation efficiency of photoelectrodes with different particle sizes in 2 and 3 electrode systems
- The stability of the photoelectrode in the alkaline aqueous electrolyte by running a long term test under solar irradiation
- The kinetic aspects of photoelectrochemical cells based on different TiO_2 nanoparticle sizes

Introduction

Converting solar energy into fuels due to the great economic and environmental interests has received much attention lately. One of the capable technologies that would be able to produce a clean and cost-effective energy is solar photoelectrochemical (PEC) hydrogen production [1]. In a PCE when a photoelectrode illuminated with sunlight was immersed in an aqueous electrolyte, the photon energy was converted to electrochemical energy, which can directly split water into hydrogen and oxygen as seen in Figure 1 [2, 3]. TiO2 can utilize UV light due to its wide band gap.

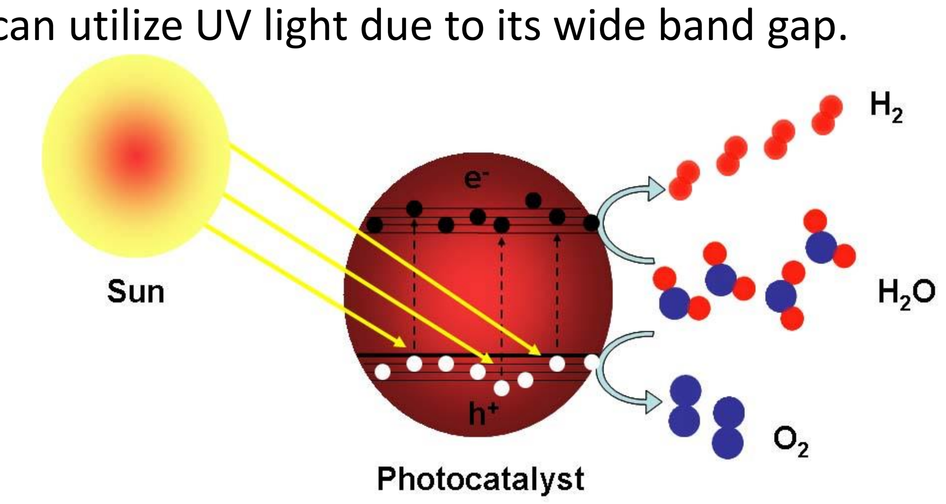


Figure 1. UV absorption by TiO_2

After the band gap excitation of TiO2, recombination of the photo-excited electron–hole might occur in a TiO2 particle which can impact the overall efficiency of the photocatalyst (Figure 2) [3]. Thus, transporting the charge is a key factor in determining the recombination rate of electrons-holes, and redox reactions rate which is related to the electrode particle size [4, 5].

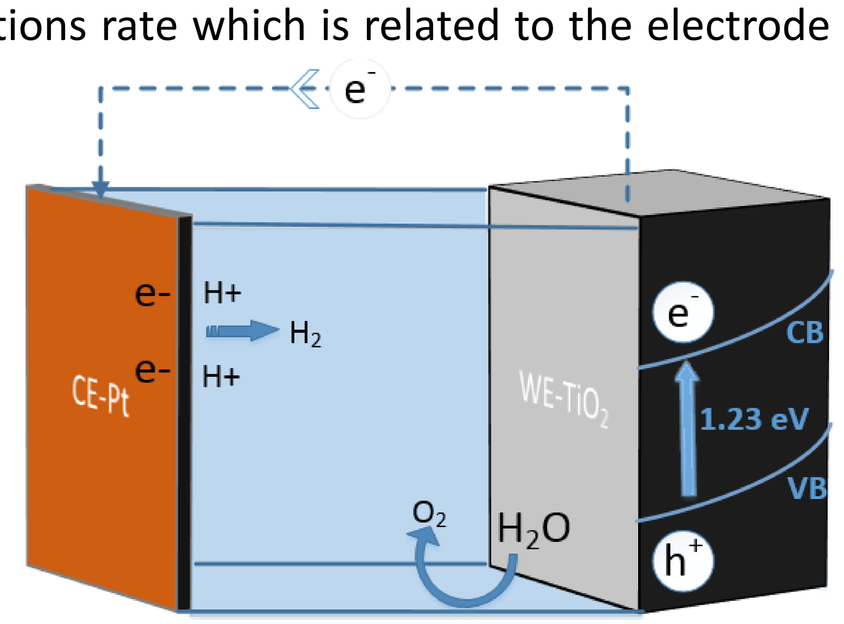


Figure 2. PEC performance.

Methodology

Anatase TiO2 particles of 5, 18, and 30 nm in diameter and Rutile of 30, 50, and 100 nm (Purity ≥99+%) were used for making TiO2 thin films using doctor-blading method [4]. Microstructural and phase characterization of TiO2 powders were studied using XRD as see in Figure 3. A commercial PEC cell device "PECC2- Zahner Germany" with a volume of 7.2 cm3 was used to study the photoelectrochemical behavior of TiO2 electrode (Figure 4).

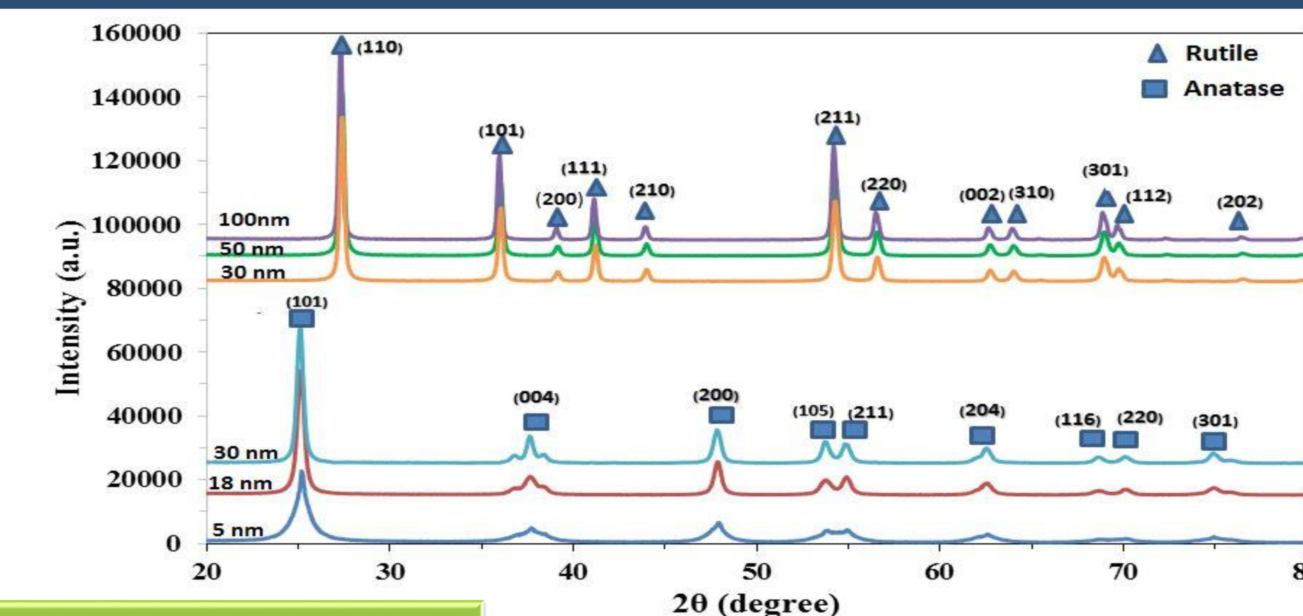
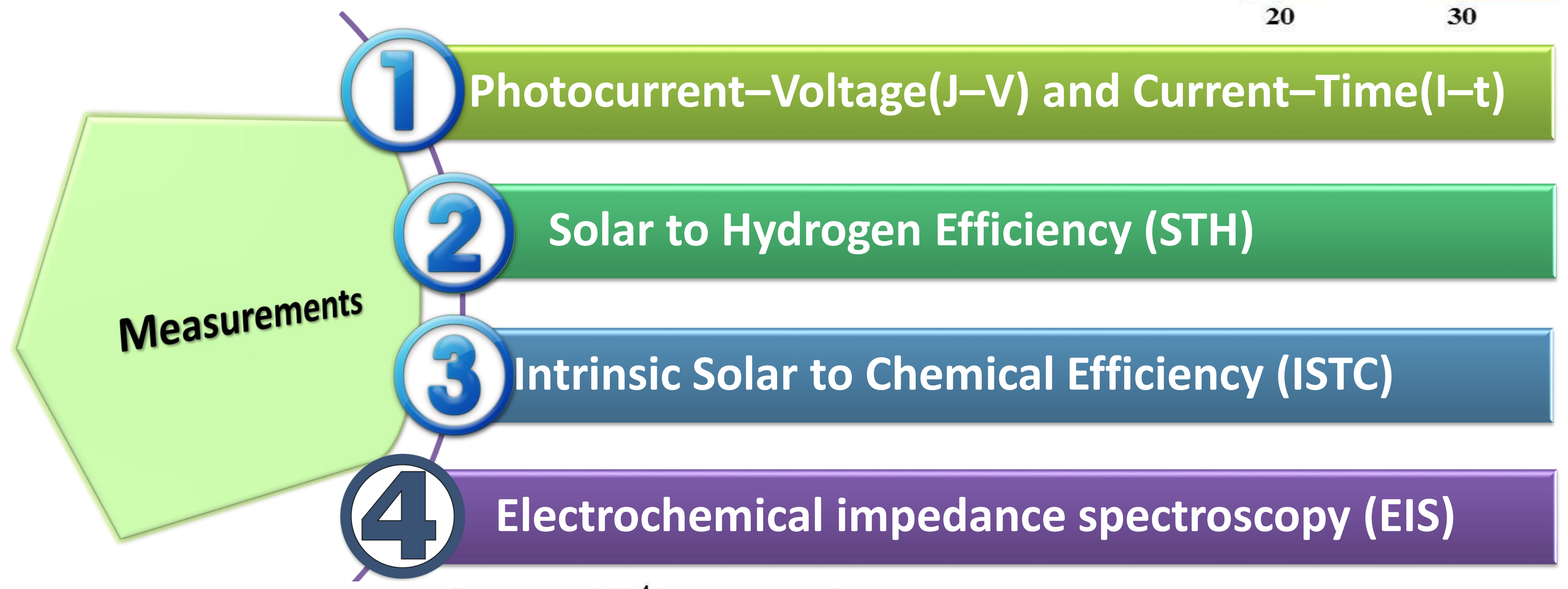


Figure 3. XRD patterns of TiO_2 powders.



$$ISTC = \left[\eta_{el}\frac{J_{photo}\left(\frac{mA}{cm^2}\right) * V_{photo}\,(V)}{P\,\left(\frac{mW}{cm^2}\right)}\right]_{AM1.5G} \qquad \mathrm{STH} = \left[\frac{|J_{SC}\,(mA/cm^2)| * 1.23\,(V) * \eta_F}{P\,(mW/cm^2)}\right]_{AM1.5G}$$

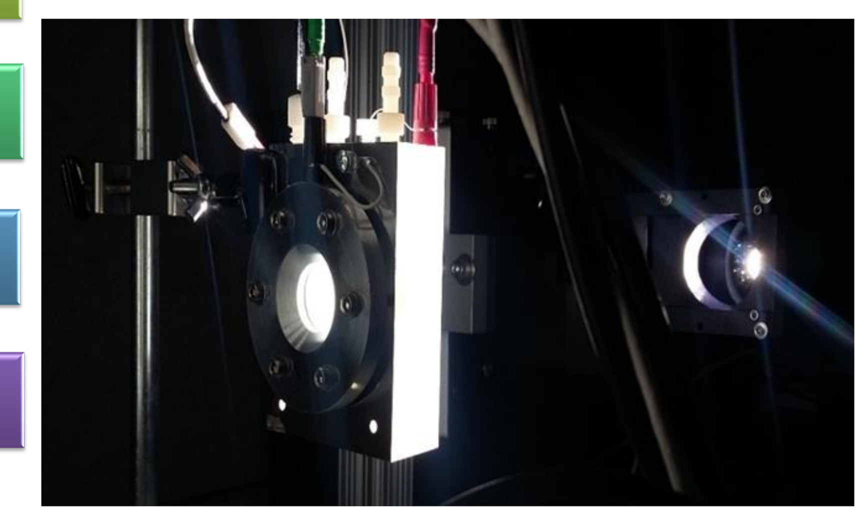


Figure 4. Illumination cell by solar simulator.

Results and Discussions

Photocurrent–Voltage(J–V)

The behavior of the 5 nm TiO_2 thin film on generating photocurrent was different compared to the other electrodes (Figure 5).

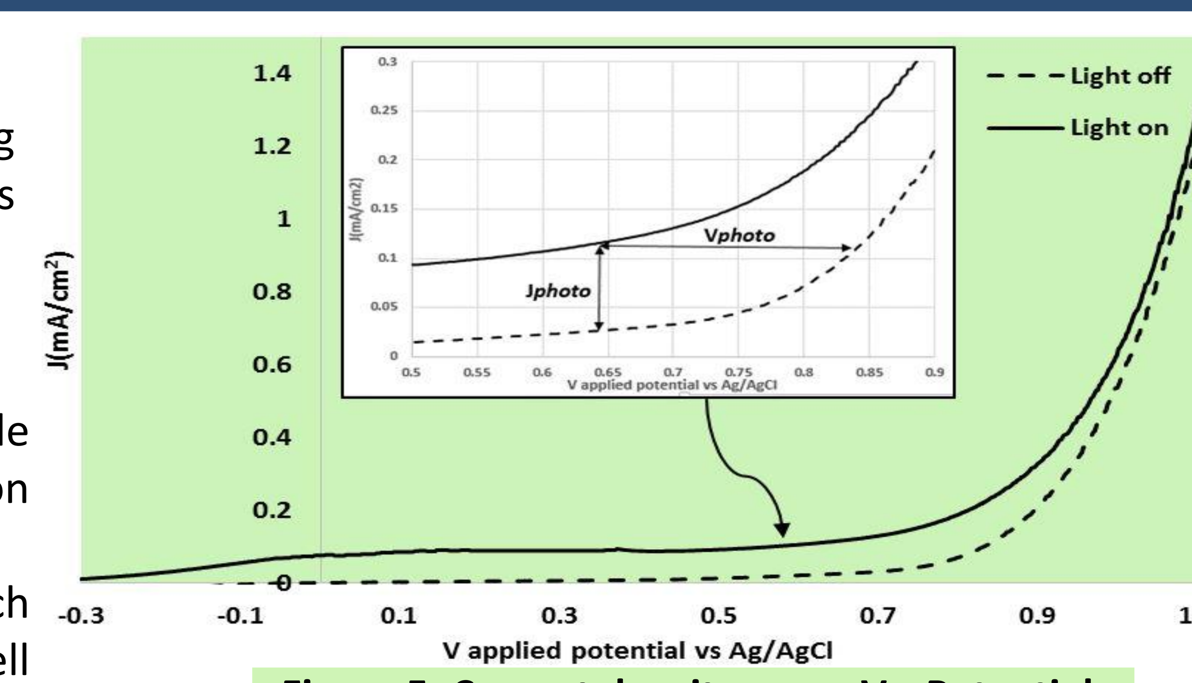


Figure 5. Current density curve Vs. Potential.

Current–Time(I–t)

The behavior of charge carriers dynamics of each electrode was evaluated by running I-t test under backside illumination (Figure 6).

The majority carries (electrons) need small diffusion to reach the interface than the minority carrier (holes) when the cell illuminated from the backside as shown in Figure 7. Therefore, having larger particle size make charge transport much easier as reported by Docampo et al. [5]

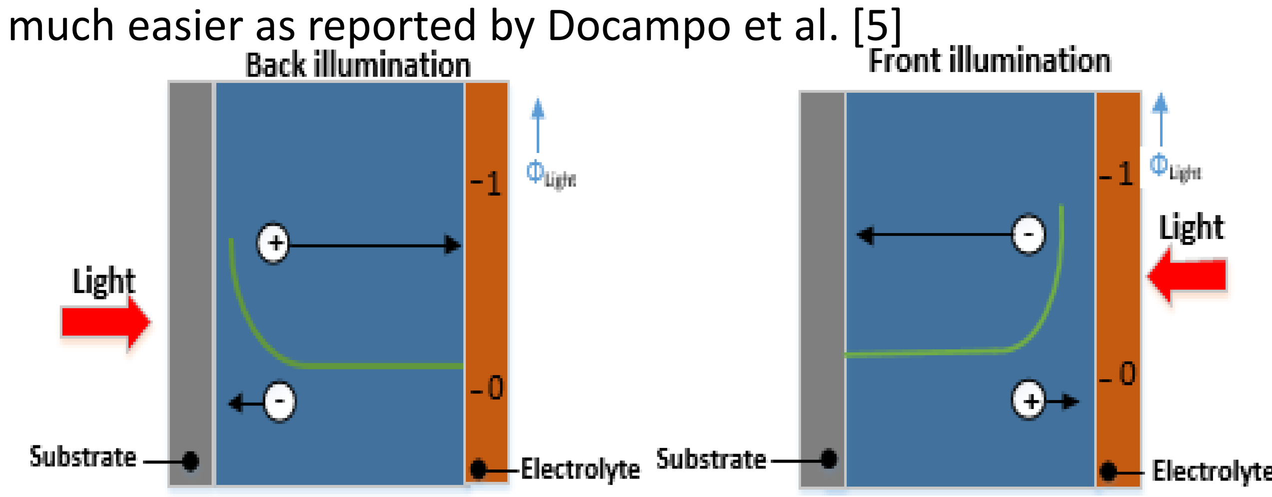


Figure 7. Illumination of the difference between front- back-side.

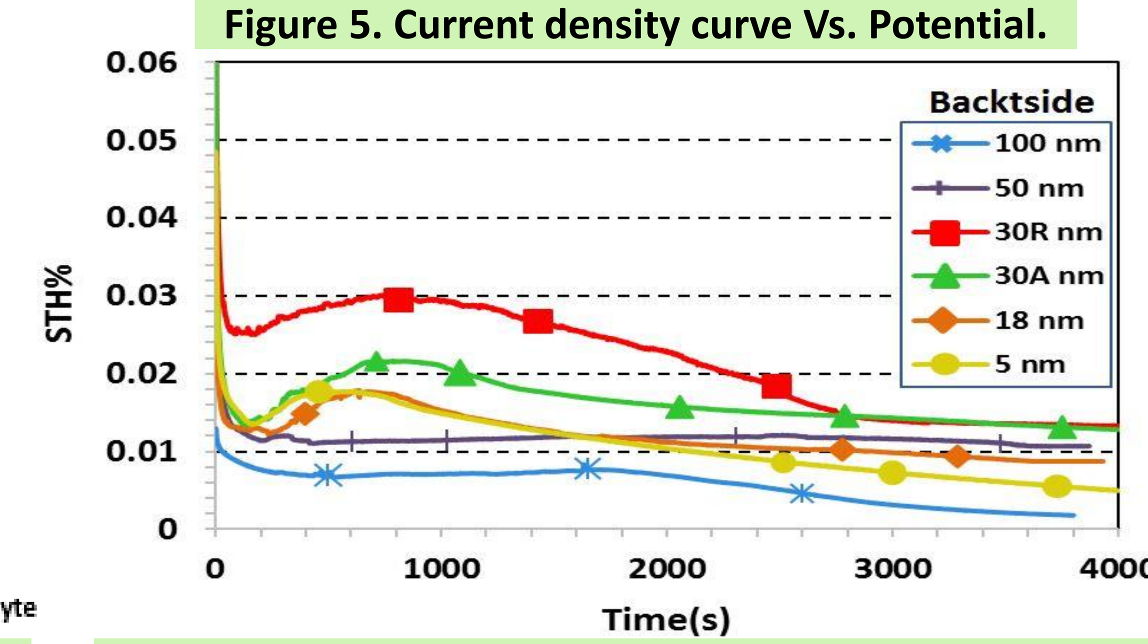


Figure 6. STH efficiency versus time(s) under zero bias.

ISTC Efficiency- Electrochemical Impedance

The ISTC efficiency of photoelectrodes shown in Figure 8. The 5 nm particles size has the highest ISTC efficiency near the zero-bias potential vs. Ag/AgCl (1.42 mW/cm² at the potential of 1.03 V vs. RHE).

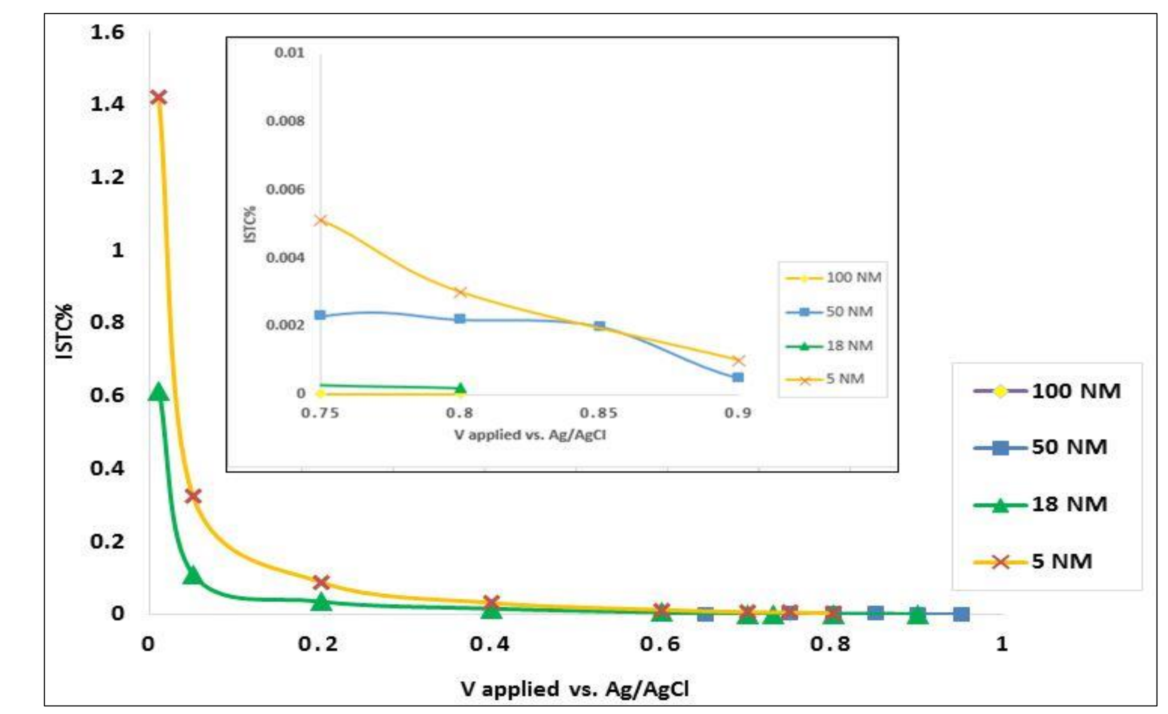


Figure 8. ISTC efficiency vs. Applied potential for 100 ,50 ,18 , and 5 nm.

Figure 9 shows a decrement of the internal resistance related to the electron transportation in the TiO_2/electrolyte interface which causes the improvement of the cell efficiency. It shows that the charge transfer resistance only in the electrode with 30 nm particle size changes by varying the applied potential to the electrode.

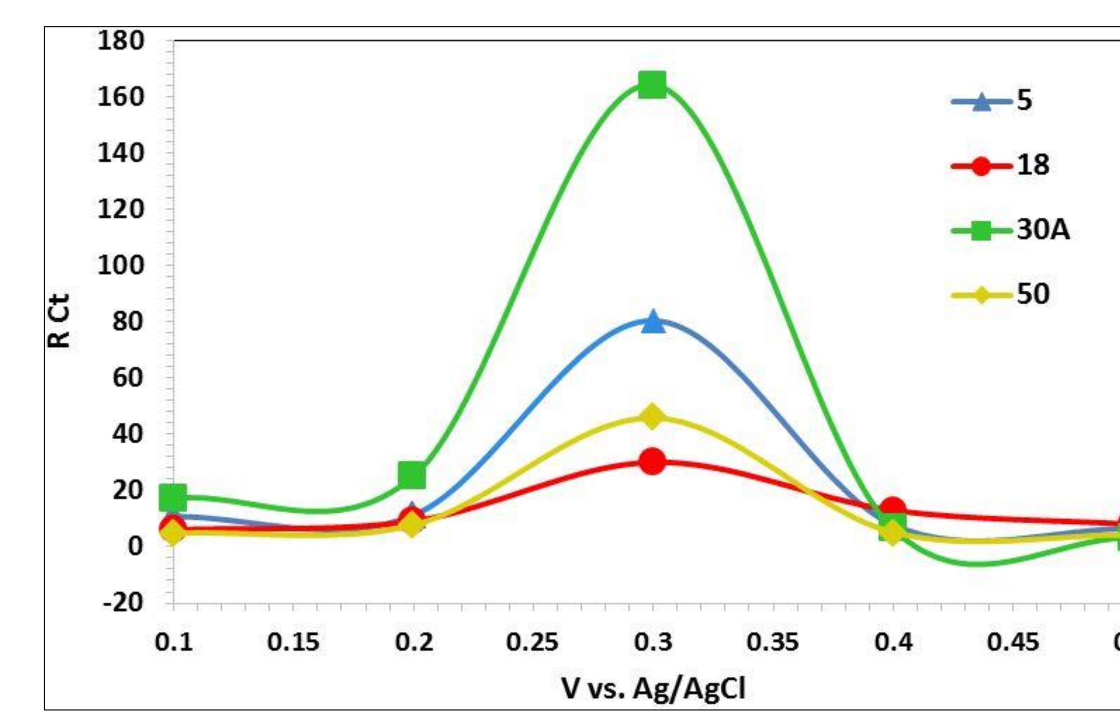


Figure 9. Charge transfer resistance Vs. Potential.

Conclusion/Further work

In term of cell efficiency for hydrogen production without any external bias, the particle size of 30 nm exhibited the highest solar to hydrogen (STH) efficiency. The EIS values show that the 30 nm particle size had a better charge transportation efficiency. Further investigations is needed to characterize the effect of particle sizes on the charge recombination rate which directly affect the cell efficiency.

CONTACT INFORMATION

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