

Supporting Information

**Modulated III-V Triple-Junction Solar Cell Wireless Device for
Efficient Water Splitting**

Shinya Okamoto*, Masahiro Deguchi and Satoshi Yotsuhashi

Advanced Research Division, Panasonic Corporation, Sôraku-gun, Kyoto 619-0237, Japan

*E-mail: okamoto.shinya001@jp.panasonic.com

Tel: +81-774-98-2566

1. Materials

Pt plates (Nilaco), $\text{H}_2\text{PtCl}_6 \cdot 6\text{H}_2\text{O}$ (Wako Pure Chemical Industries, Ltd.), $(\text{CH}_3\text{COO})_2\text{Pb} \cdot 3\text{H}_2\text{O}$ (Wako Pure Chemical Industries, Ltd.) and H_2SO_4 (Wako Pure Chemical Industries, Ltd.) were used as received. Pure water ($>18 \text{ M}\Omega$) was obtained from a Direct-Q system (Millipore). An aqueous solution of KHCO_3 (3.0 M, Wako Pure Chemical Industries, Ltd.) was prepared as an electrolyte. A group III-V based triple-junction solar cell and IrO_2 coated on a SUS plate were purchased from Advanced Technology Institute and DAISO Engineering, respectively.

2. Simulated 1 sun illumination

A solar simulator (Asahi spectra, HAL-320W) was used as a light source to provide 1 sun illumination. Figure S1 shows the spectra of the simulated 1 sun illumination and standard solar light (AM 1.5), respectively.

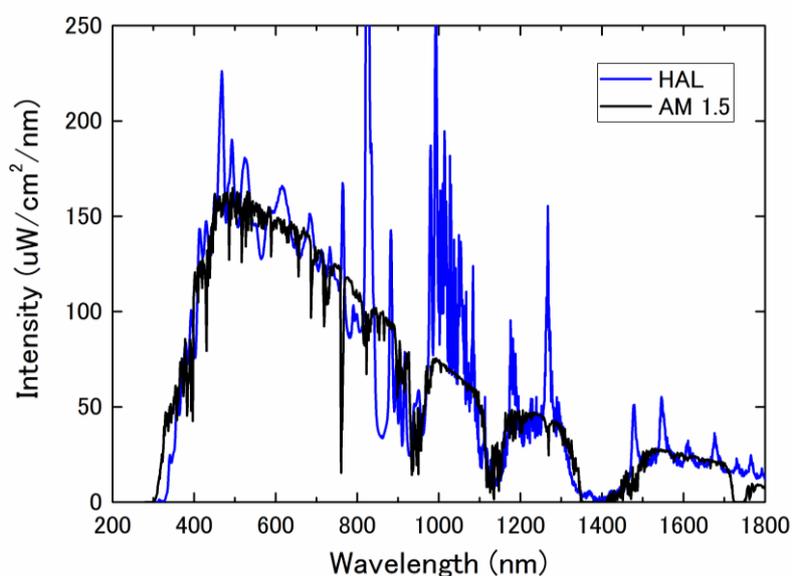


Figure S1. Spectra of simulated 1 sun illumination (blue) and standard solar light (black). We defined this spectrum of the solar simulator as 1 sun in this paper.

3. Spectral response behavior of a III-V triple-junction solar cell

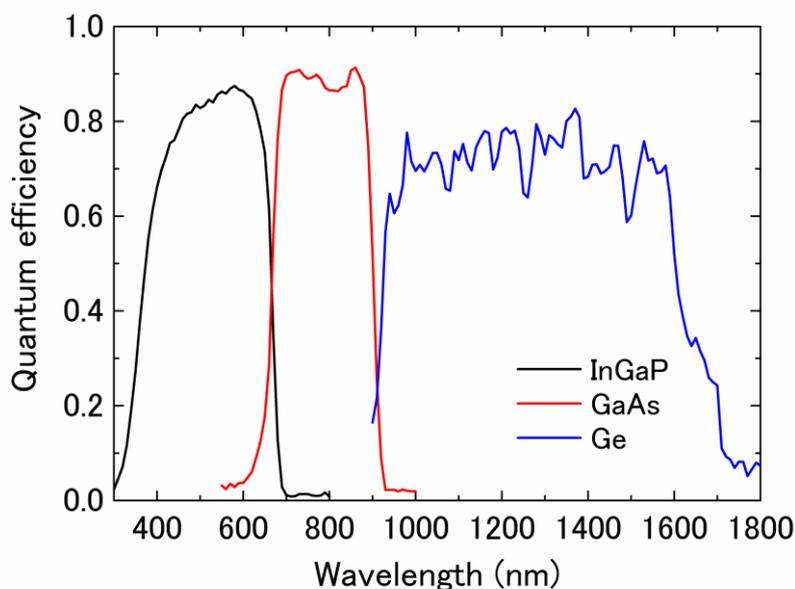


Figure S2. Spectral response behavior of a III-V triple-junction solar cell when light is illuminated through a quartz window.

4. Electrochemical measurements to investigate operating point

The surface electrode covered with Pt black was electrically contacted with a metallic holder using copper (Cu) tape and aluminum (Al) foil as shown in Figure S3a. The parts of the Cu tape and Al foil that were in the electrolyte in the electrochemical measurement were covered with epoxy resin. The back of the solar cell (6.25 cm^2) was attached to a glass plate. Thus, the surface electrode (cathode) was used as both a counter and reference electrode. In addition, a surface electrode that was not covered with Pt black was prepared as well for comparison. Figure S3b shows a photograph of the IrO_2 anode (6.25 cm^2). The IrO_2 anode was also electrically contacted with a metallic holder using Cu tape and Al foil, and the back of the anode was attached to a glass plate. The IrO_2 anode was used as the working electrode. The cathode and anode were immersed in 3.0 M KHCO_3 (aq).

The glass plate sides faced each other to form the structure of a wireless device. Electrochemical measurements to determine the operating point of this setup were performed in the electrolyte.

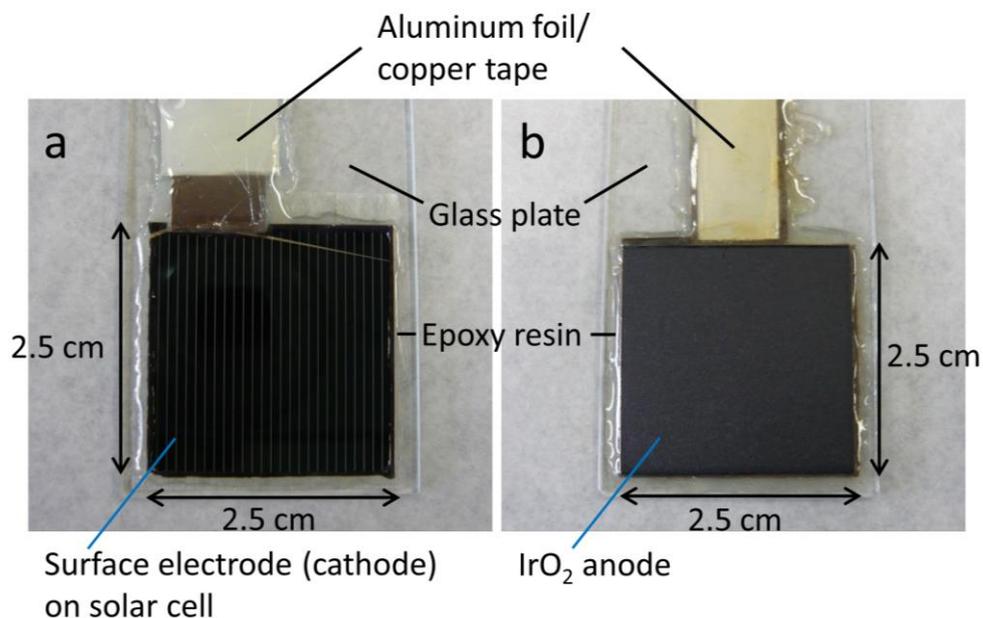


Figure S3. (a) Surface electrode (cathode) of the solar cell and (b) IrO₂ anode used for electrochemical measurements.

5. Dependence of the J-V performance of the III-V triple-junction solar cell on the path length of light in water

Figure S4 depicts a schematic diagram of the setup used to measure J-V performance. Containers of different sizes were placed between the solar simulator and solar cell in air. The containers were filled with water, and their width corresponded to the path length of light in water. This allowed us to investigate the effect of light path length in water on solar cell performance to verify the operation of the solar cell in water.

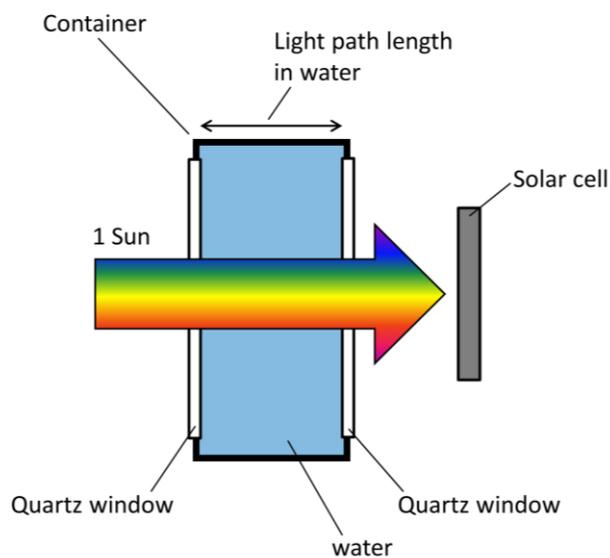


Figure S4. Schematic diagram of the experimental setup used to measure the dependence of solar cell performance on the light path length of water.

6. Fabrication of a wireless device

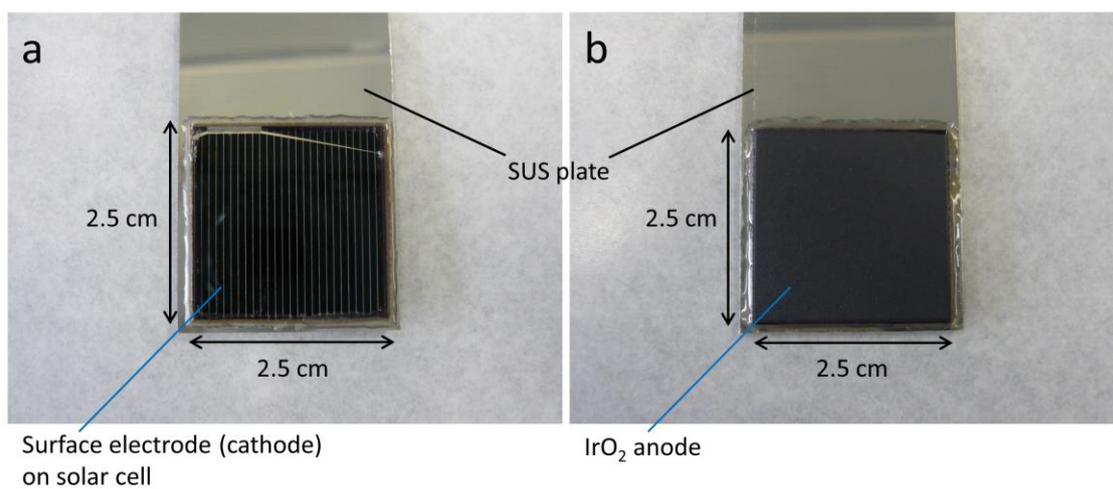


Figure S5. Photographs of the (a) light receiving surface side and (b) IrO₂ anode side of the wireless device.

7. Experimental setup for solar-driven water splitting in a wireless device

A photograph of the operating wireless device for solar-driven water splitting without external bias is presented in Figure S6. The path length of light in water can be adjusted by moving the device holder.

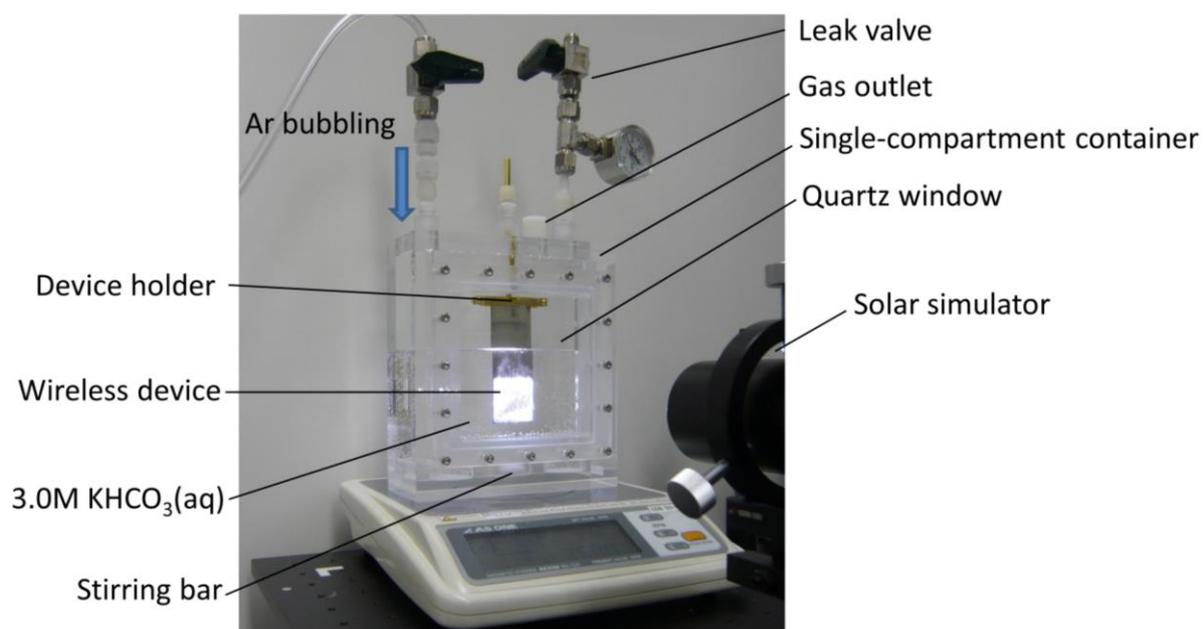


Figure S6. Photograph of the operating wireless device.

8. Calculation of solar-to-hydrogen conversion efficiency

The solar-to-hydrogen conversion efficiency (STH) of the device was calculated as follows.

$$\text{STH} = (\text{Produced amount of hydrogen} \times \Delta G) / \text{Light input}$$

ΔG = Change in Gibbs free energy for water splitting to hydrogen under standard-state conditions

$$\text{Produced amount of hydrogen} \times \Delta G = 177.1 \mu\text{mol} \times 237 \text{ kJ/mol}$$

$$= 41.97 \text{ J}$$

$$\text{Light input} = 100 \text{ mW/cm}^2 \times 6.25 \text{ cm}^2 \times 600 \text{ s}$$

$$= 375.0 \text{ J}$$

$$\text{STH} = 100 \times 41.97 / 375.0 = 11.2\%$$

Assuming that 2.20 V is necessary for the operation, STH conversion efficiency is calculated to be 15.8% from the solar cell efficiency of 28.2% as described below.

$$\text{STH conversion efficiency} = (\text{solar cell efficiency}) \times 1.23\text{V} / 2.20\text{V}$$

$$= 15.8\%$$

The difference between our experimental result and the calculated one may be caused by the light scattering due to bubbles generated from the surface electrodes.

9. H₂ and O₂ evolution in the wireless device

H₂ and O₂ evolution in the wireless device under 1 sun illumination was investigated 6 days after the measurement shown in Figure 7 in the main text. Figure S7 reveals that the evolution of H₂ and O₂ increased linearly with the light irradiation time. In addition, stoichiometric evolution of H₂ and O₂ was also observed.

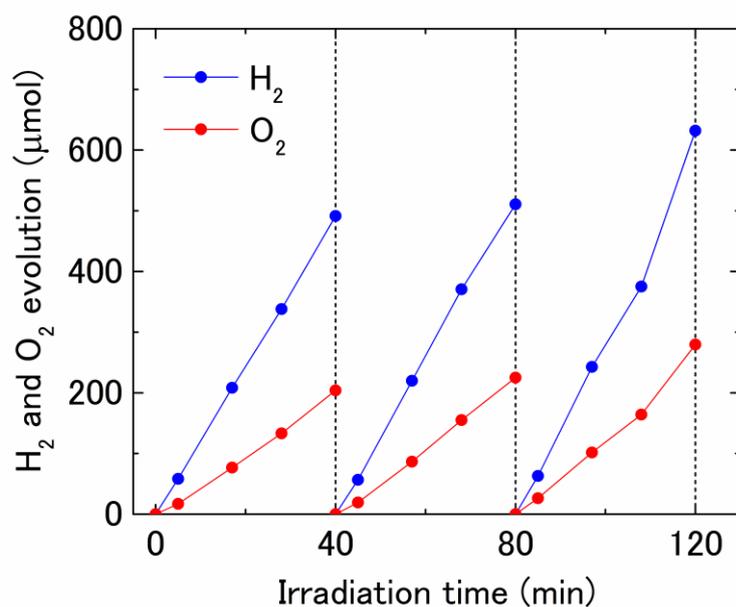


Figure S7. The dependence of H₂ and O₂ evolution in the wireless device under 1 sun illumination on irradiation time 6 days after the measurement shown in Figure 7.

10. Stability and durability in the wireless device

To investigate the stability and durability of the device, solar-driven water splitting under simulated 1 sun illumination without an external bias in a two-electrode configuration was performed in 3.0 M KHCO_3 (aq). Figure S8 shows the photocurrent time profile. Figure S9 shows optical microscope images of the surface of the wireless device (a) before and (b) after solar-driven water splitting experiment.

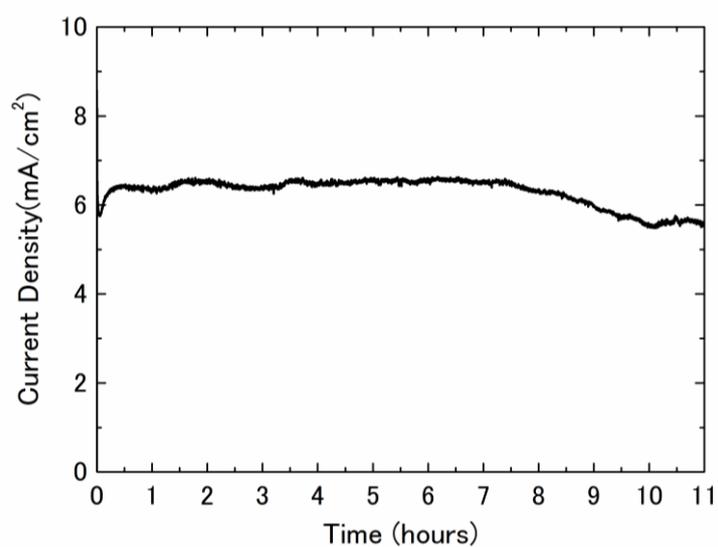


Figure S8. Photocurrent time profile in a two-electrode configuration under 1 sun illumination in 3.0 M KHCO_3 (aq).

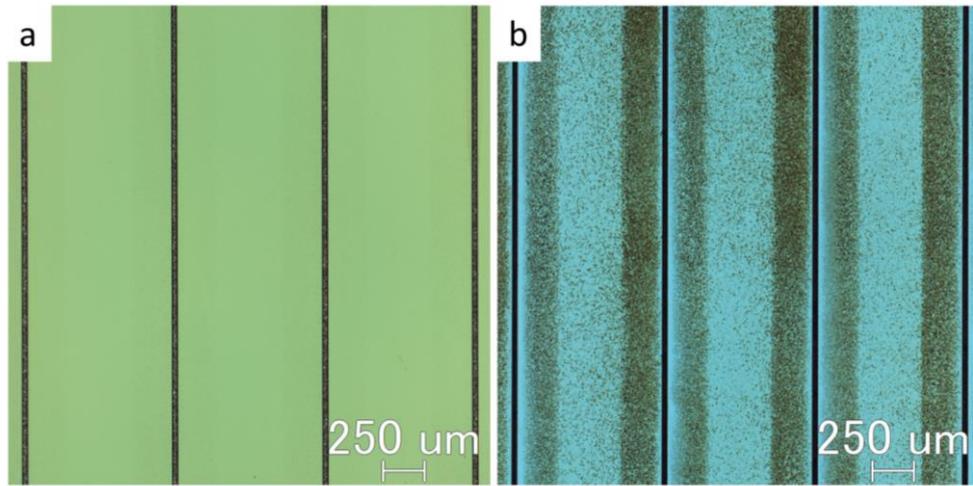


Figure S9. Optical microscope images of the surface of the wireless device (a) before and (b) after solar-driven water splitting experiment.