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Noncovalent Functionalization of Single-Walled Carbon Nanotubes Using Aqueous-Dispersed Platinum Nanoparticles for Hydrogen Production by Water Electrolysis

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Abstract

We report that an aqueous-dispersed platinum nanoparticle (PtNP) acts as a dispersant for single-walled carbon nanotubes (SWCNTs) through noncovalent functionalization. A PtNP/SWCNT suspension in water is used to fabricate a cathode of a polymer electrolyte membrane (PEM) electrolyzer by spray coating. The PEM electrolyzer exhibits hydrogen (H_2) production with PtNP on the order of microgram.

1. Introduction

H_2 production by water electrolysis is a promising strategy for obtaining clean energy. A PEM electrolyzer for water electrolysis contains Nafion as a PEM between an anode and cathode (Fig. 1); oxygen (O_2) and proton (H^+) at the anode are produced by oxidation of water and H_2 is produced at the cathode by reduction of H^+ transmitted through the PEM. Platinum (Pt) has an excellent catalytic property for H_2 production in the cathode; however, it is a noble and expensive metal. Therefore, reducing the use of Pt is an important issue for effective utilization and cost reduction of the noble metal.

In this study, we demonstrate that the aqueous-dispersed PtNP can suspend hydrophobic SWCNT without surfactant in water (Fig. 1). The PtNP/SWCNT suspension provides the cathode of the PEM electrolyzer using the spray-coating method. The PtNP/SWCNT cathode with the microgram-scale PtNP was found to produce H_2 by water electrolysis.

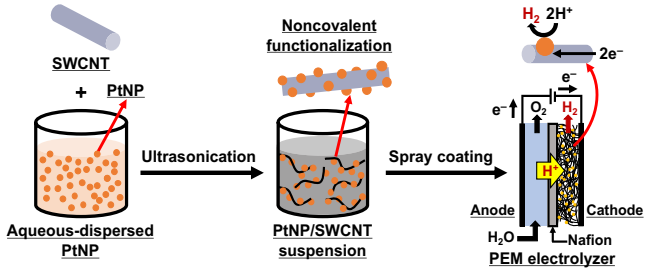

Fig.1 PEM electrolyzer for H_2 production using a PtNP/SWCNT suspension prepared through noncovalent functionalization.

2. Experiment

An aqueous-dispersed PtNP was prepared from high-purity Pt by solution plasma processing.[1] A mixture of SWCNTs (2 mg) and the aqueous-dispersed PtNP (0.1 g L^{-1}, 10 mL) was sonicated for 30 min, yielding a PtNP/SWCNT suspension (0.5:1 (*w*/*w*)) (Fig. 2a(i)). Different ratios (0.5:1, 1:1, 2:1 (*w*/*w*)) of PtNP/SWCNT suspensions were prepared. Dispersion behavior of PtNP/SWCNT was observed using transmission electron microscopy

(TEM). Thermogravimetric analysis (TGA) was used to estimate loading amounts of PtNPs in PtNP/SWCNT composites Com_x (x: 6, 16, 32). Current-voltage characteristics and H_2 and O_2 production rates for the PEM electrolyzer were evaluated using a potentiostat and mass flow meter. Device stability of the PEM electrolyzer was investigated by chronopotentiometry.

3. Results and discussion

The TEM image of PtNP/SWCNT composite showed that PtNPs with the average particle size of 11 nm were immobilized on the surface of SWCNT (Fig. 2a(ii)). The TGA results revealed that loading amounts of PtNPs in PtNP/SWCNT of 0.5:1, 1:1, and 2:1 (*w*/*w*) are 6 (Com_6), 16 (Com_{16}), and 32 (Com_{32}) μg_{Pt} cm^{-2}. The PEM electrolyzer with the Com_6 cathode reached a current density of 547 mA cm^{-2} at 2 V and 25 °C. Mass activity, ratio of the current to the loading amount of PtNP, was 91,100 A g^{-1} for Com_6 at 2 V (Fig. 2b). The mass activity for commercial Pt/C (2.8 mg_{Pt} cm^{-2}) was 325 A g^{-1}, indicating that Com_6 is the highly efficient catalyst for H_2 production. The production rates for H_2 and O_2 from the PEM electrolyzer using the Com_6 cathode were 15.6 and 7.2 mmol h^{-1} at 2 V, suggesting that the stoichiometric production of H_2:O_2 = 2:1 (mol/mol) occurs by water electrolysis (Fig. 2c). Furthermore, this PEM electrolyzer exhibited hydrogen production for 150 h without degradation at 100 mA cm^{-2} and 25 °C (Fig. 2d).

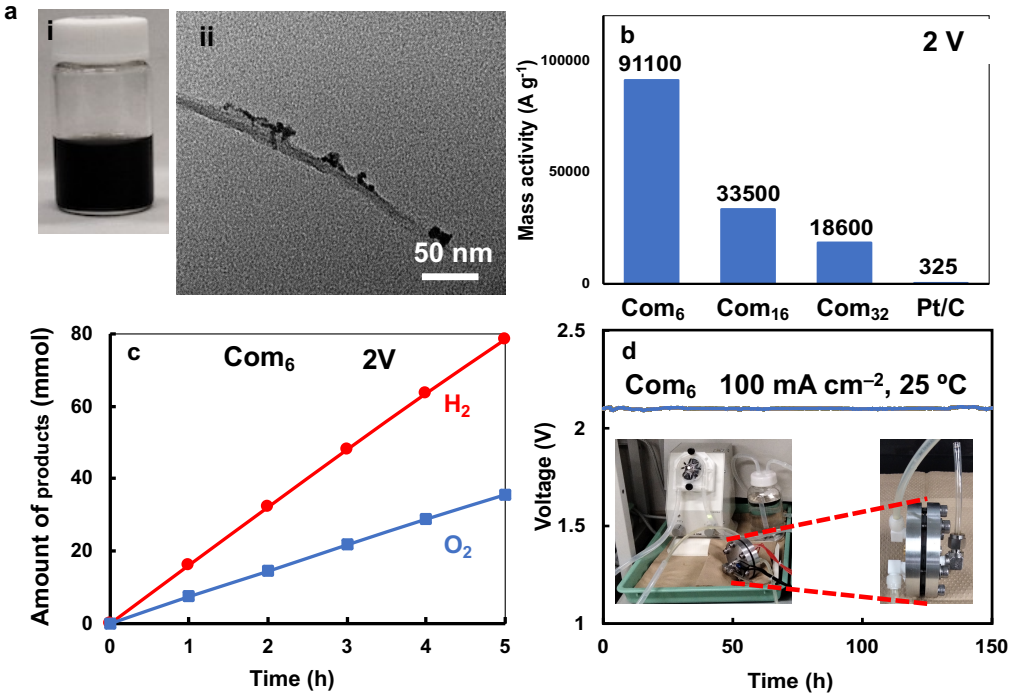

Fig.2 (a) (i) Photograph of aqueous suspension of PtNP/SWCNT (0.5:1 (*w*/*w*)). (ii) TEM image of PtNP/SWCNT (0.5:1 (*w*/*w*)). (b) Mass activities of PEM electrolyzers containing Com_x (x: 6, 16, 32) and Pt/C at 2V. (c) H_2 and O_2 evolution of the PEM electrolyzer including the Com_6 cathode at 2 V. (d) Chronopotentiometric response of the PEM electrolyzer with the Com_6 cathode at 100 mA cm^{-2} and 25 °C. Inset shows photographs of the evaluation apparatus and the PEM electrolyzer.

4. Conclusions

The aqueous-dispersed PtNP enabled the surfactant-free SWCNT suspension in water. The PEM electrolyzer fabricated from the PtNP/SWCNT suspension brought the high mass activity and stable device operation even with the low loading amount of PtNP. We believe that our results are the promising method to reduce the amount of the noble metal Pt.

Reference

1) G. Horiguchi and Y. Chikaoka, H. Shiroishi, S. Kosaka, M. Saito, N. Kameta, and N. Matsuda, J. Power Sources, 382, 69-76 (2018). DOI: https://doi.org/10.1016/j.jpowsour.2018.02.017