# **Supporting Information**

# Synthesising chain-like, interconnected Pt nanoparticles using tubular halloysite clay template for efficient counter electrode in dye-sensitised solar cells

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## S1. Experimental

## a. Preparation of HNT-Pt composite electrode:

Halloysite nanoclay  $(Al_2Si_2O_5(OH)_4 \cdot 2H_2O)$  is purchased from Sigma Aldrich and is used without further purification. A known amount of halloysite nanoclay is mixed with ethyl cellulose stock solution (ethyl cellulose + isoproponal) and added with mixture of 0.5 ml of deionized water and 5 ml of ethanol. This slurry was grinded for 30 minutes and kept at magnetic stirring for overnight. The resultant colloidal halloysite paste was dispersed onto conducting substrate by doctor blade technique. This coating was sintered at 450 °C for 30 minutes.

The platinum precursor solution of hydrogen hexachloroplatinate (IV)  $(H_2Pt(Cl)_6)$  in isoporponal was taken for Pt nanoparticle synthesis. In order to understand the Pt nanoparticle growth a known amount of Pt precursor solution (0.01 M, 0.03 M and 0.05 M) was spin coated onto assynthesised Pt-HT composite electrode as well as FTO substrate. Subsequently this electrode was sintered at 450 °C for 30 minutes. For comparative analysis, 0.03 M amount of Pt precursor solution was directly coated onto FTO substrate and repeated as described above sintering process. The as-synthesised Pt-HT composite electrodes are coined as *Pt-HT (x M)*, here x denotes the concentration of Pt precursor. For instance, Pt-HT (0.01 M) represents that the electrode was fabricated from 0.01 M of Pt precursor concentration.

## b. Characterization:

The surface morphology of the prepared electrodes was analyzed using scanning electron microscope (SEM) (Hitachi S-4800) and field emission transmission electron microscope (TEM), (JEOL JEM 2100F).

#### c. Assembly of DSSCs:

All the chemicals were received from Sigma Aldrich and used without further purification.

*Dye-sensitised* TiO<sub>2</sub> photoanode fabrication: The mesoporous TiO<sub>2</sub> layer of about ~6  $\mu$ m thickness was prepared on FTO substrate using commercially available TiO<sub>2</sub> paste (18 NR-T, Dyesol). A second layer of ~ 5- $\mu$ m in thickness was coated again using commercial ~200 nm light-scattering TiO<sub>2</sub> particles (WER 2-O, Dyesol) by doctor blade technique. Subsequently these coating was sintered at 450 °C for 30 minutes in ambient atmosphere. In order to avoid the back electron transfer from FTO substrate to electrolyte, a thin TiO<sub>2</sub> blocking layer was prepared in between TiO<sub>2</sub> photoanode and FTO layer by spin coating of 0.2 M di-isopropoxy titanium bis (acetylacetonate) solution in anhydrous ethanol and subsequent calcination at 450 °C. Following heat treatment, these electrodes were immersed in a dye solution (0.5 mM *cis*-diisothiocyanato-bis (2,2'-bipyridyl-4,4'-dicarboxylato) ruthenium (II) bis(tetrabutylammonium) (N719, Solaronix) in acetonitrile (ACN, Wako)/tert-buthyl alcohol (t-BuOH, Wako) (1/1, v/v) and kept at room temperature.

<u>Liquid type electrolyte</u>: The typical composition of liquid type electrolyte is 0.6M MPII (1methyl-3-propylimidazolium iodide), 0.03M  $I_2$ , 0.1M of GuSCN and 0.5M of tBP was mixture with acetronitrile/valeronitrile (85:15) solvent and it was loaded into the cell through capillary force.

#### c. Electrochemical Characterization:

The cyclic voltammogram (CV) of the as-synthesised electrodes (Pt-HT and Pt) were measured using three electrode cells with methoxypropionitrile solution of 10 mM LiI, 1 mM I<sub>2</sub> and 0.1 M LiClO<sub>4</sub>. (Scan rate: 50 mV s<sup>-1</sup>). The FRA-equipped PGSTAT-302N (Autolab, Netherlands,B.V) was utilized for all electrochemical measurements. Electrochemical impedance measurements were carried out (using symmetry cell configuration) under light illumination (100 mW cm<sup>-2</sup>) using a potentiostat (Autolab) equipped with a frequency response analyzer (FRA) in the frequency range of 0.1 Hz–1000 kHz. The results were analyzed with an equivalent circuit

model for interpreting the characteristics of the DSSCs.

# **S2. Surface morphology**



**Figure S2.** SEM images of (a) HNT-Pt (0.01 M); (b) HNT-Pt (0.03 M); (c) HNT-Pt (0.05 M) coating onto FTO substrates and (d) Pt film coated directly onto FTO by spin coating.

# **S3.** Morphology analysis



**Figure S3.** HRTEM images of Pt nanoparticle coated on HT prepared from different Pt precursor concentration (a) 0.01 M; (b) 0.03 M and (c) 0.05 M.

## **S4.** Photovoltaic device – reproducibility



**Figure S4.** Histogram plots of DSSCs assembled with different counter electrodes and their corresponding JV parameters (a) open circuit potential (b) current density (c) fill factor and (d) efficiency. Note that in each batch three devices are fabricated and obtain the results from JV plots.

# **S5. Impedance analysis**



**Figure S4.** (a) Dummy cell configuration of Pt/electrolyte/Pt for impedance measurement, and (b) equivalent circuit used for simulation.