A graphene-carbon nanotube hybrid for high performance proton exchange membrane fuel cells (PEMFC)

Kien-Cuong Pham a,b,*, Daniel H.C. Chua a, David S. McPhail b, Cecilia Mattevi b and Andrew T.S. Wee a,d

a NUS Graduate School for Integrative Sciences and Engineering (NGS), National University of Singapore, Singapore
b Department of Materials, Imperial College London, London, UK
c Department of Materials Science and Engineering, National University of Singapore, Singapore
d Department of Physics, National University of Singapore, Singapore

* Email address: phamkien@nus.edu.sg or k.pham11@imperial.ac.uk

1. Introduction and objective

Proton Exchange Membrane Fuel Cell (PEMFC) is a suitable renewable energy technology for transportation. 1,2
- Combustion engine: C6H12 + O2 → CO2 + H2O + heat
- PEMFC: H2 + O2 → H2O + heat + electricity

Hydrogen tank

2. Method

1. Direct growth of carbon nanotubes (CNT) on Toray carbon paper using the thermal chemical vapour deposition (CVD) method
2. Direct growth of graphene onto the CNT scaffold, forming the graphene–carbon nanotube hybrid (G–CNT), using the radio frequency plasma enhanced chemical vapour deposition (PECVD) method
3. Deposition of platinum on the G–CNT hybrid at an ultra–low loading of 0.04 mgPt/cm², using the magnetron sputtering method
4. Assembling into the membrane electrode assembly (MEA) of the PEMFC

Scheme 1. Schematic illustration of the Pt/G–CNT cathode fabrication process and (inset) the structural comparison of the Pt/G–CNT cathode (left) and the conventional carbon black–based cathode (right).

3. Results and Discussions

4. Conclusions and future work

- The direct growth of the G–CNT hybrid on carbon paper is reported
- The hybrid combines the advantages of an ultra–high density of active graphene edge planes with the porous structure of CNT scaffolds in a single material
- The G–CNT hybrid suggests an effective structure to better utilise the Pt catalyst material and to reduced the required Pt loading in PEMFC Future work:
- Characterisation of the G–CNT hybrid’s 3D structure
- Study the effect of the G–CNT hybrid on the durability of PEMFC

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References


Microstructural characterisation of the Pt/G–CNT hybrid with SEM and TEM
- The resulting material retains the overall structure of the G–CNT hybrid, with the thickening of the leaf–like features due to the deposition of Pt
- Crystalline Pt nanoparticles attach densely on the surface of the G–CNT hybrid, especially along the graphene edges

Figure 3. (a) SEM and (b) TEM micrograph of the Pt/G–CNT hybrid, and (c) HR–TEM micrograph of the hybrid in the region outlined by the black square in figure (b).

Graphene–Carbon Nanotube hybrid

- Directly grow graphene onto CNT structure
- Expose numerous edge planes
- Remain porous

Carbon Nanotube

Graphene

Carbon fibre

Graphitic nanomaterials

Carbon nanotubes: Porous but expose basal graphitic plane

Graphene: Active edge planes but restacks due to the 2D morphology

Protein exchange membrane fuel cell (PEMFC) is a suitable renewable energy technology for transportation. 1,2
- Combustion engine: C6H12 + O2 → CO2 + H2O + heat
- PEMFC: H2 + O2 → H2O + heat + electricity

Challenges of the catalyst layer
- Low Pt utilisation due to the too small pore size of the carbon black support
- Carbon corrosion in the carbon black due to the low crystallinity

Desirable catalyst support 1
- Highly graphitic, high electrical conductivity
- High surface area and porous, preferably 20–40 nm pore sizes
- Exposure of graphitic edges

Log and Fe sputtered Toray carbon paper

Growth of CNTs

PECVD growth of graphene

Assembled in MEA

Pt/G-CNT electrode in MEA

Pt nanonparticles

Nafion ionomer

Polarisation performance of the Pt/G–CNT–based cathode
- Remarkable improvement over carbon black and CNT supported Pt catalysts throughout the current density range
- ~20% higher power density on the carbon black supported Pt, and a great improvement over the CNT supported Pt
- Reduce the required Pt loading

Figure 4. Polarisations measurements of MEAs with Pt/G–CNT, Pt/VXC72 and Pt/CNT cathodes.