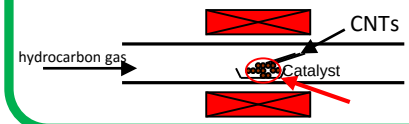
CNT synthesis

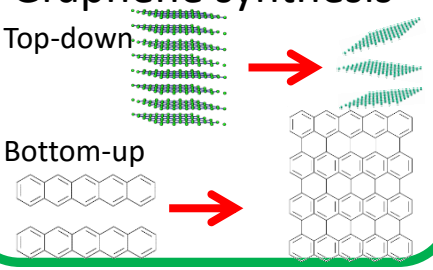
CVD reactor



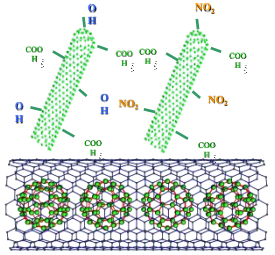
Graphene synthesis

Top-down

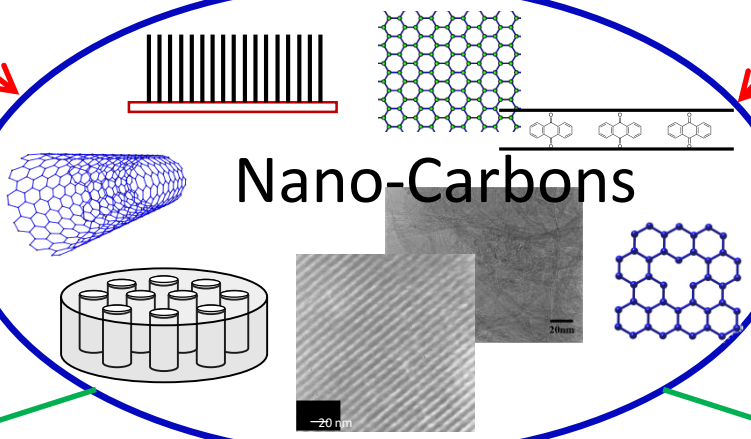
Bottom-up



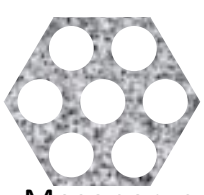
Chemical Modification



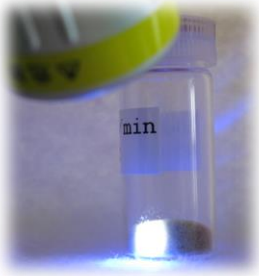
Nano-Carbons



Light-emitting

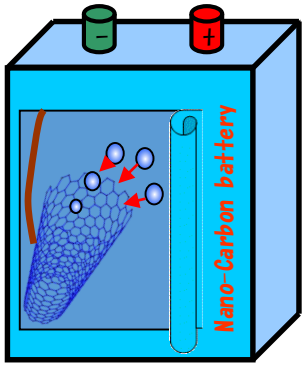


Mesoporus carbon-silica



Bright white light PL!

Energy Storage

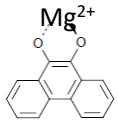


Batteries

Na+

✓ Low cost

Mg^{2+}



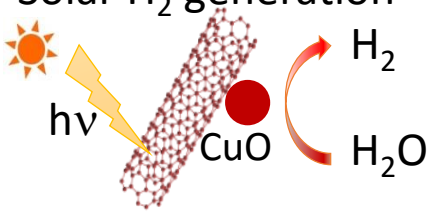
✓ High energy density

Capacitors

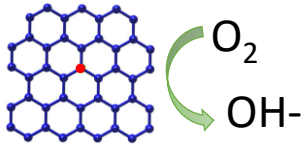
✓ High capacity

H_2 Energy

Solar H_2 generation



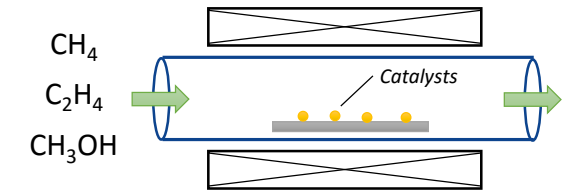
Rechargeable Fuel Cell



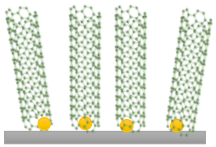
Synthesis of Nanocarbons

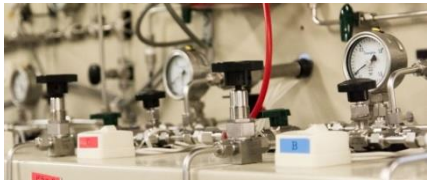
Carbon Nanotubes

Chemical Vapor Deposition (CVD)



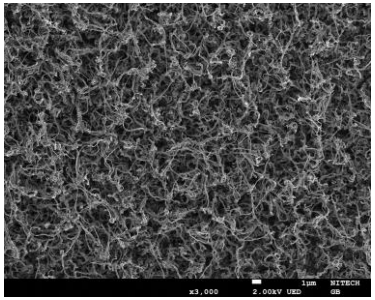
[After CVD]





Thermal CVD

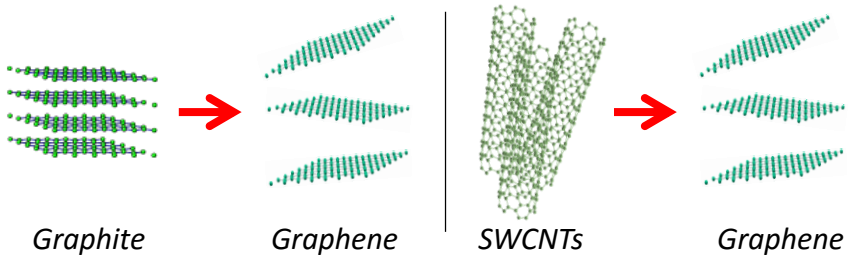
Plasma CVD



In addition to the simple carbon nanotubes, N-doped carbon nanotubes can also be prepared.

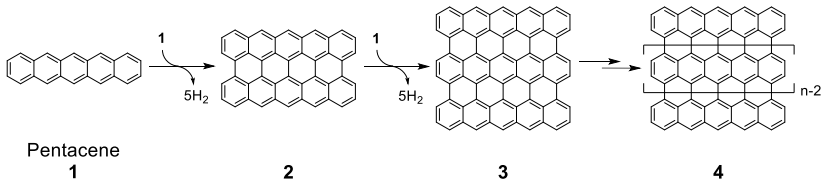
Graphene

Top-down approach



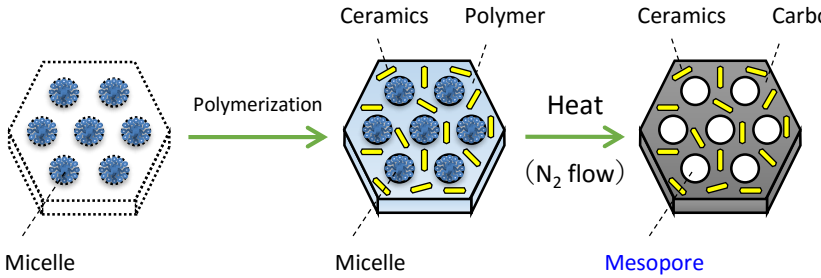
T. Inoue, S. Kawasaki, *et al. Jpn. J. Appl. Phys.* **50**, 01AF07 (2011).

Bottom-up approach



Y. Ishii, S. Kawasaki, *et al. Nanoscale* **4**, 6553 (2012).
T. Hayakawa, S. Kawasaki, *et al. RSC Adv.* **6**, 22069 (2016).

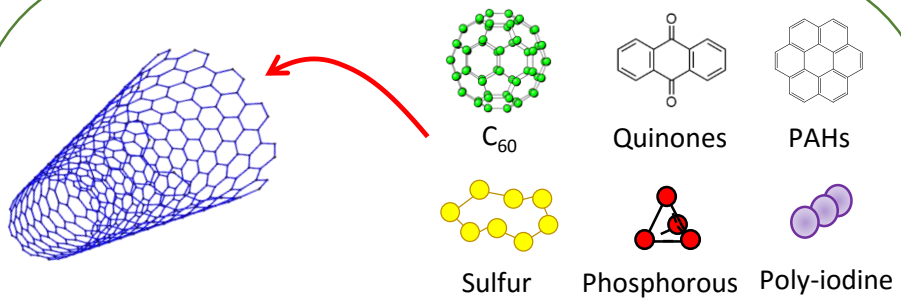
Mesoporous Carbons



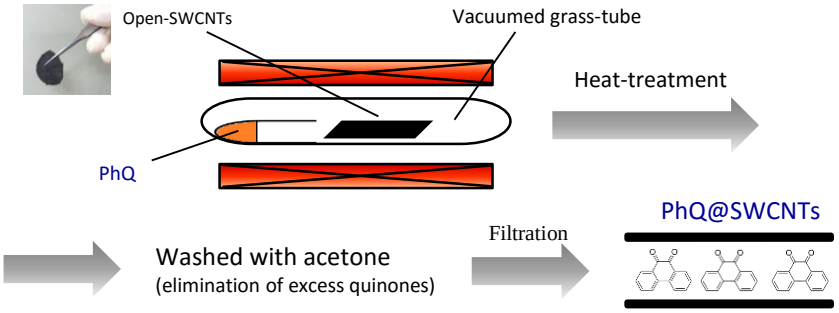
Y. Ishii, S. Kawasaki, *et al. Mater. Express* **2**, 23 (2012).
Y. Ishii, S. Kawasaki, *et al. Jpn. J. Appl. Phys.* **50**, 01AF06 (2011).
Y. Ishii, S. Kawasaki, *et al. J. Phys. Chem. C* **117**, 18120 (2013).

Modification of Carbon Nanotubes

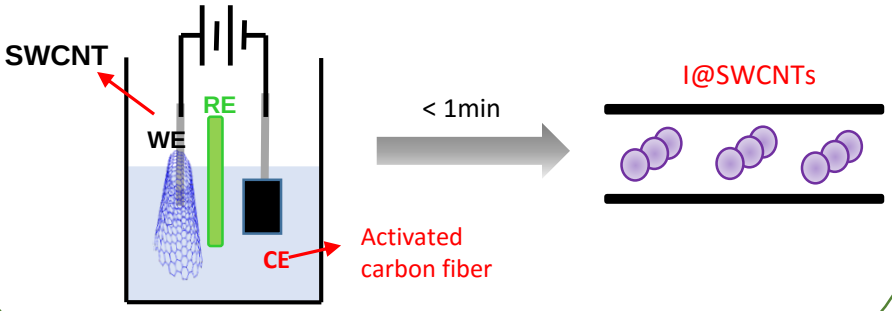
Encapsulation



Evaporation Method

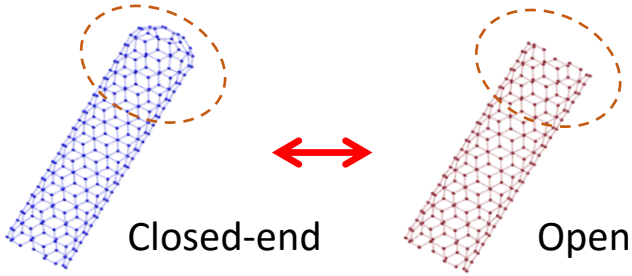


Electrochemical Method



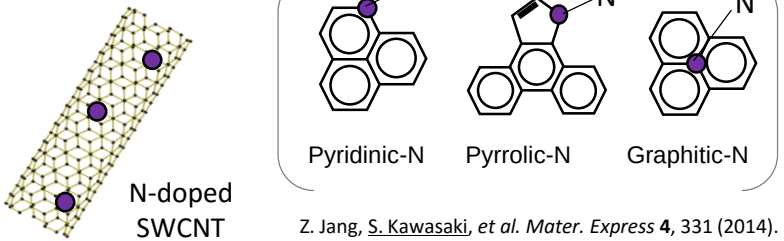
H. Song, S. Kawasaki, *et al. Phys. Chem. Chem. Phys.* **15**, 5767 (2013).

Edge Structure



A. Al-zubaidi, S. Kawasaki, *et al. Phys. Chem. Chem. Phys.* **14**, 16055 (2012).

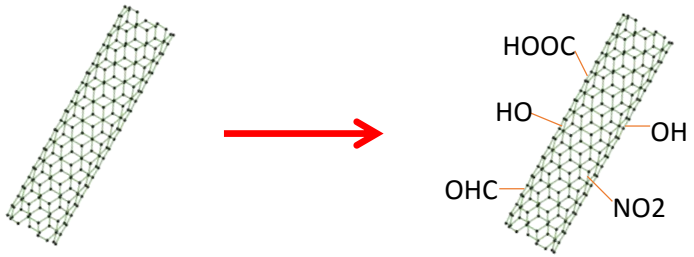
Atomic Substitution



Z. Jang, S. Kawasaki, *et al. Mater. Express* **4**, 331 (2014).

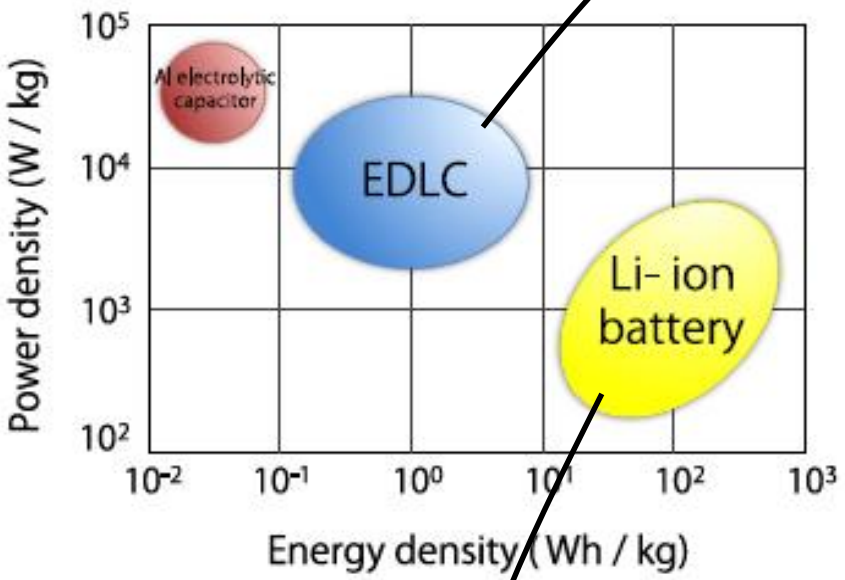
Z. Jang, S. Kawasaki, *et al. Mater. Express* **4**, 337 (2014).

Surface Functionalization



I. Mukhopadhyay, S. Kawasaki, *et al. J. Nanosci. Nanotech.* **10**, 4089 (2010).

Energy Storage Devices



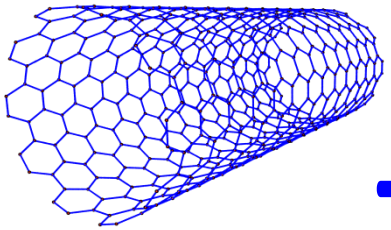
Electric double layer capacitor (EDLC)

✓ Low capacitance…

Li-ion battery (LIB)

✓ Unsafe…
✓ High cost…
✓ Low capacity…
✓ Low temperate operation is hard…

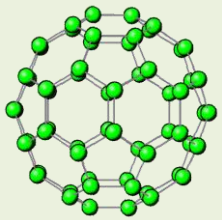
SWCNT Encapsulation Systems

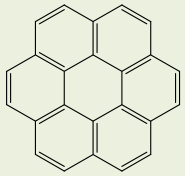


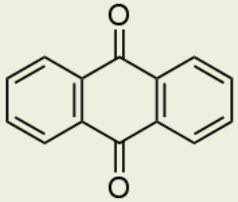
Nanotube

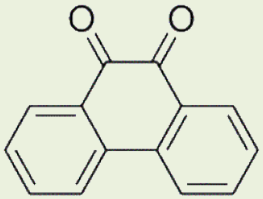
+

Functional Molecules

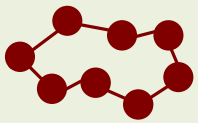


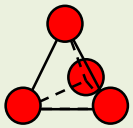




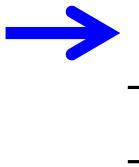


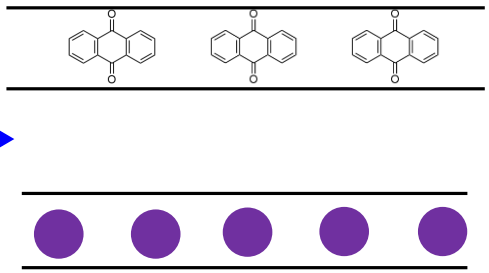
quinones

S 

P 

I 





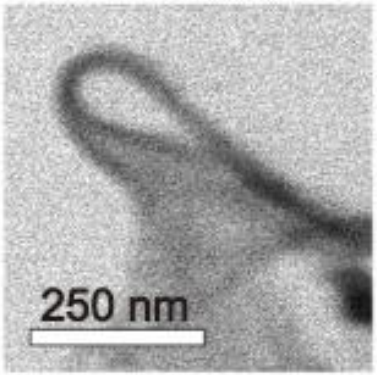
Activities in Kawasaki's Lab.

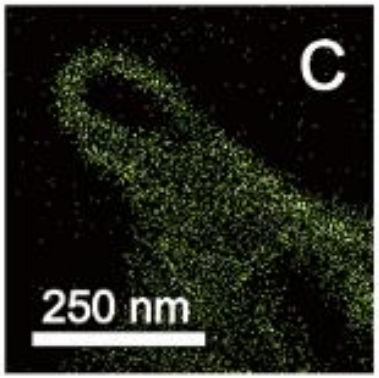
LIB	Next generationLIB	Post LIB
✓ High capacity anode • Organic molecules @SWCNT • Graphenes • P@SWCNT • Improve low temperature property	✓ Li-organic cells • OM@SWCNT ✓ all solid batteries • iodine@SWCNT	✓ Metal-air cells • Hetero-atom doped SWCNTs ✓ Dual-SWCNT cells • Thin metal SWCNTs ✓ Li-S batteries • sulfur@SWCNTs ✓ Na-ion batteries • P@SWCNT ✓ Multi Valent ion batteries • PhQ@SWCNT

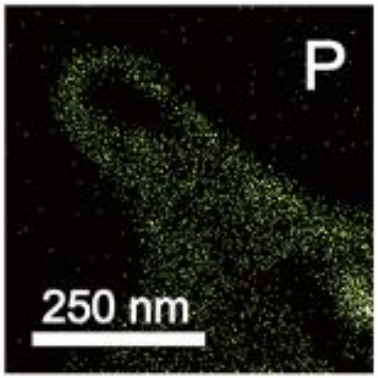
Inorganic molecules @ SWCNTs

P@SWCNTs

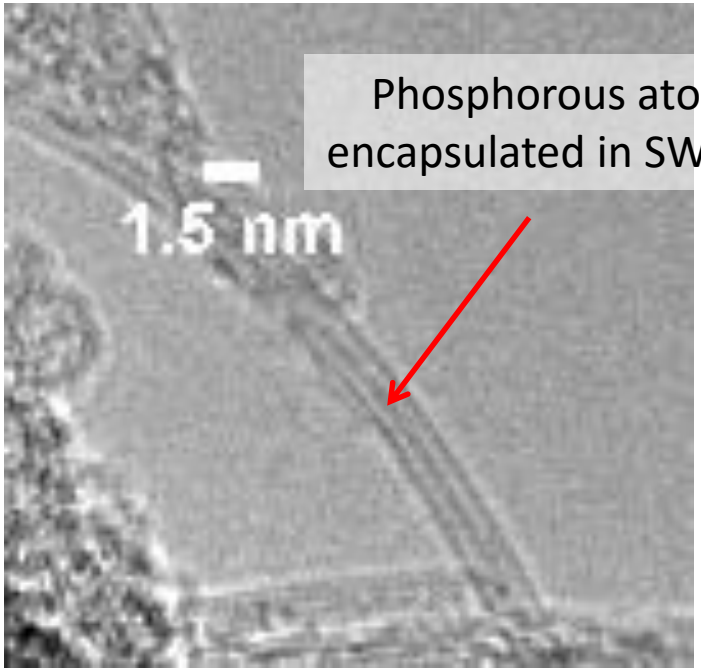
STEM-EDX map







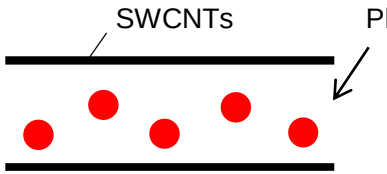
High resolution TEM



P@SWCNTs

Inorganic molecules @ SWCNTs

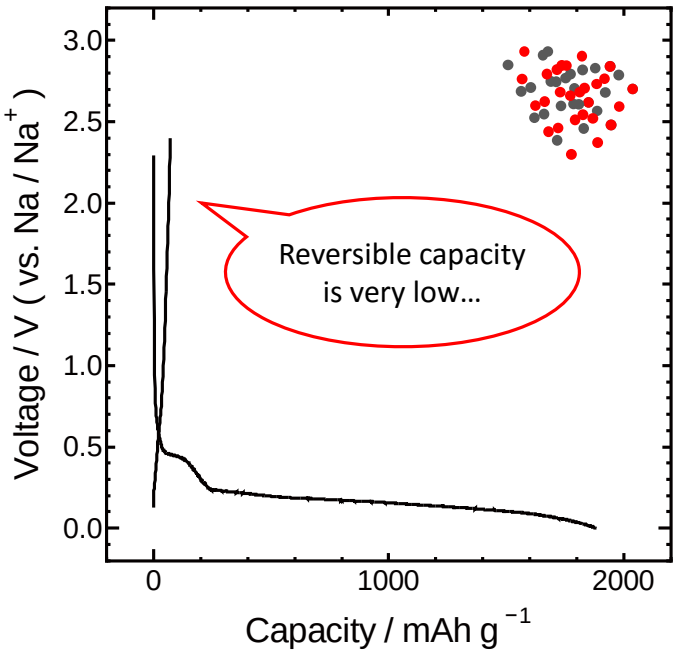
Sodium-ion Battery



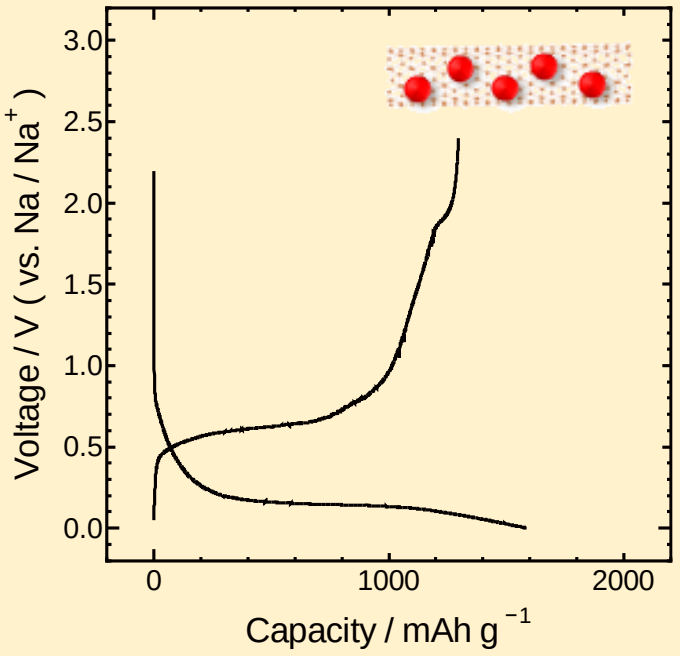
Electrolyte: 0.5 M $NaClO_4$ / EC + DEC (1 : 1 v)

Note) Measured without binder and conductive additives.

Bulk P + Carbon Black
(Simple Mixture)



P @ SWCNTs
（Encapsulation System）

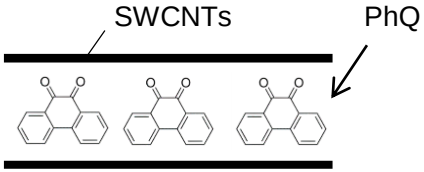


Y. Ishii, S. Kawasaki, *et al. AIP Adv.* **6**, 035112 (2016).

P@SWCNTs electrodes store Na-ion reversibly. (High reversible capacity)

Organic molecules @ SWCNTs

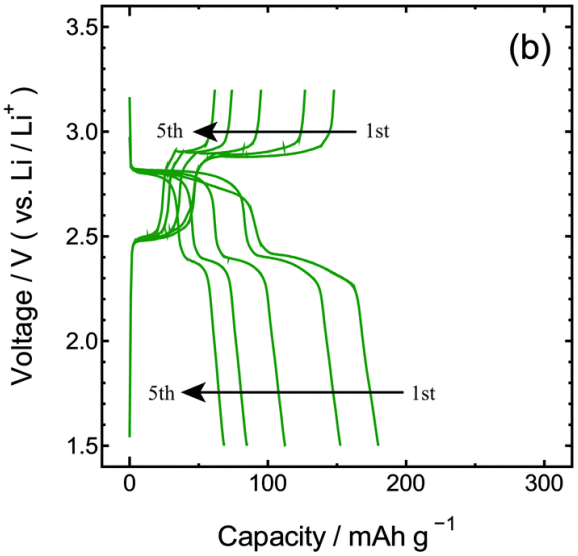
Lithium-ion Battery



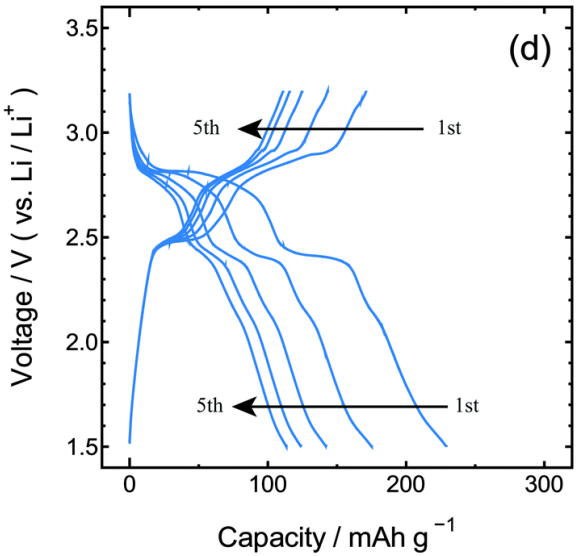
Electrolyte: 1.0 M $LiClO_4$ / EC + DEC (1 : 1 v)

Note) Measured without binder and conductive additives.

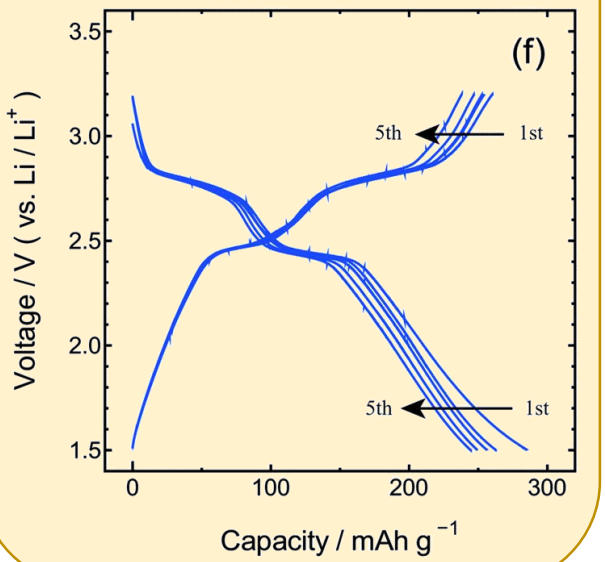
PhQ + Carbon Black
(Simple Mixture)



PhQ + SWCNTs
(Simple Mixture)



PhQ @ SWCNTs
（Encapsulation System）



Y. Ishii, S. Kawasaki, *et al. Phys. Chem. Chem. Phys.* **18**, 10411 (2016).

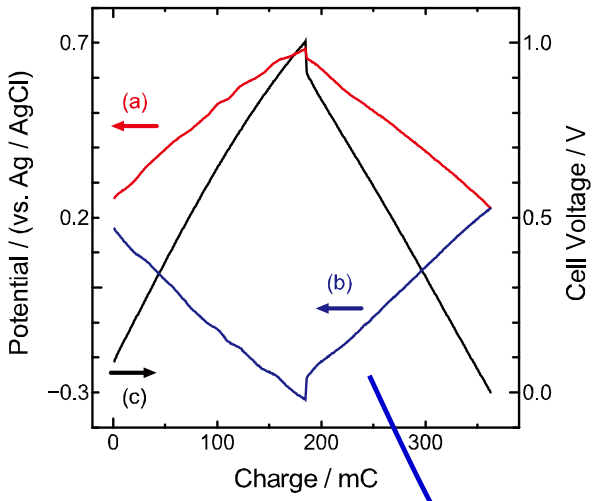
Cycle performance was dramatically improved by the encapsulation!

Iodine molecules @ SWCNTs

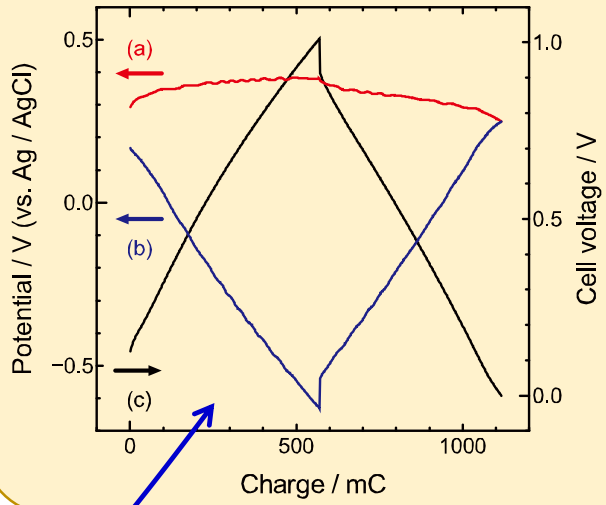
Redox Capacitor

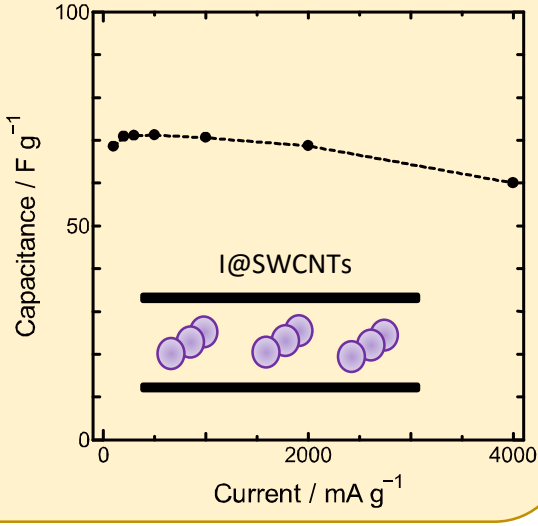
Y. Taniguchi, S. Kawasaki, *et al. J. Nanosci. Nanotech.* in press. [doi: 10.1166/jnn.2016.13006]

Conventional EDLC



Redox capacitor using electrochemical iodine encapsulation reaction of SWCNTs





Energy density was dramatically increased!

(20.7 F/g, 2.4 Wh/kg ---> 67.2 F/g, 7.8 Wh/kg)