ADVANCING BATTERY NANOTECHNOLOGIES

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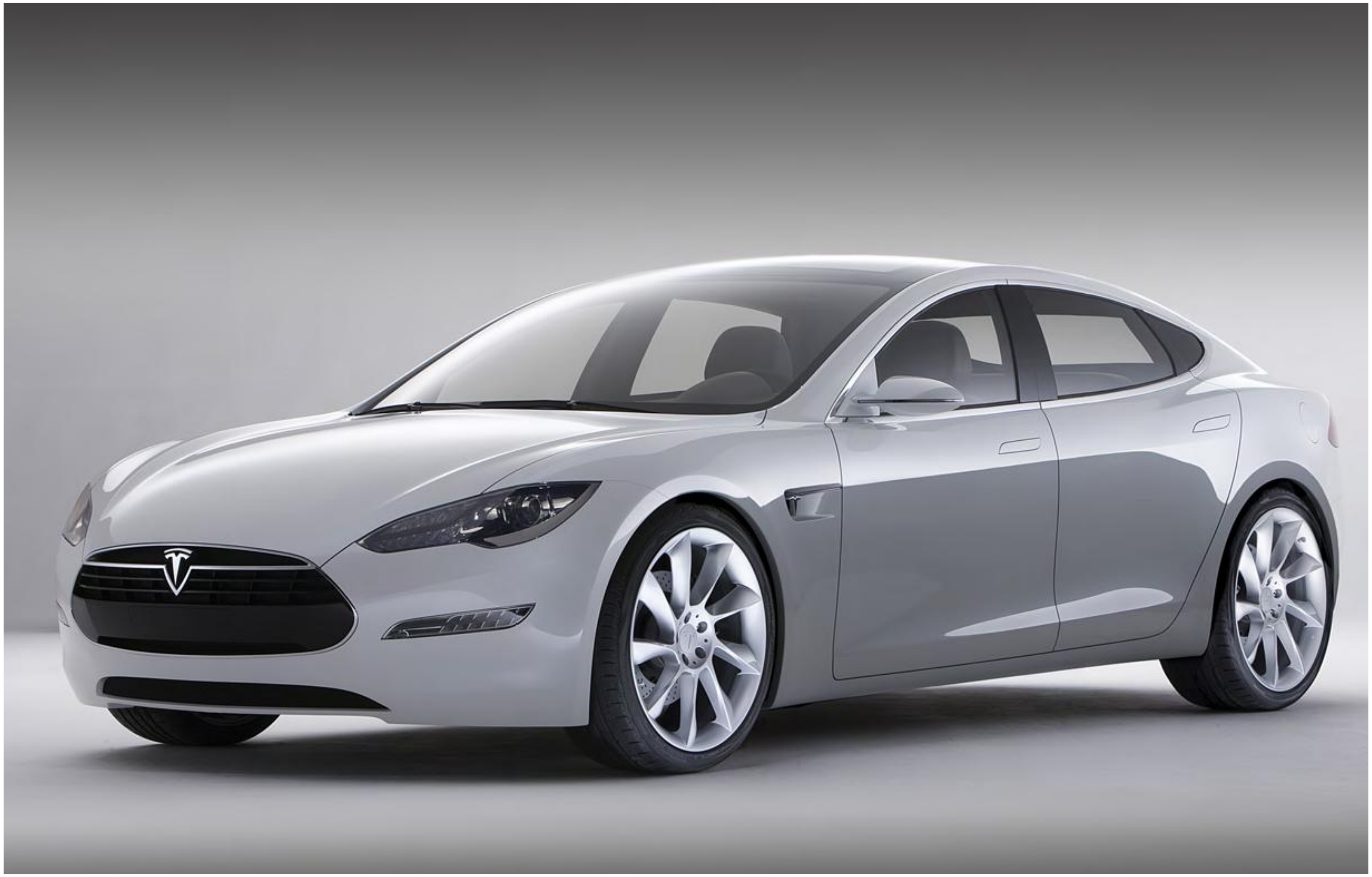
SHIFT Conference, 3rd December 2009

Maximum number of battery powered vehicles from world's resources

Lithium ion	12 billion vehicles
Pb Acid	2.2 billion vehicles
NiMH	1.8 billion vehicles
NiCd	0.049 billion vehicles

B. Andersson and I. Rade, Transportation Research Part D 6 (2001) 297-324.

TESLA

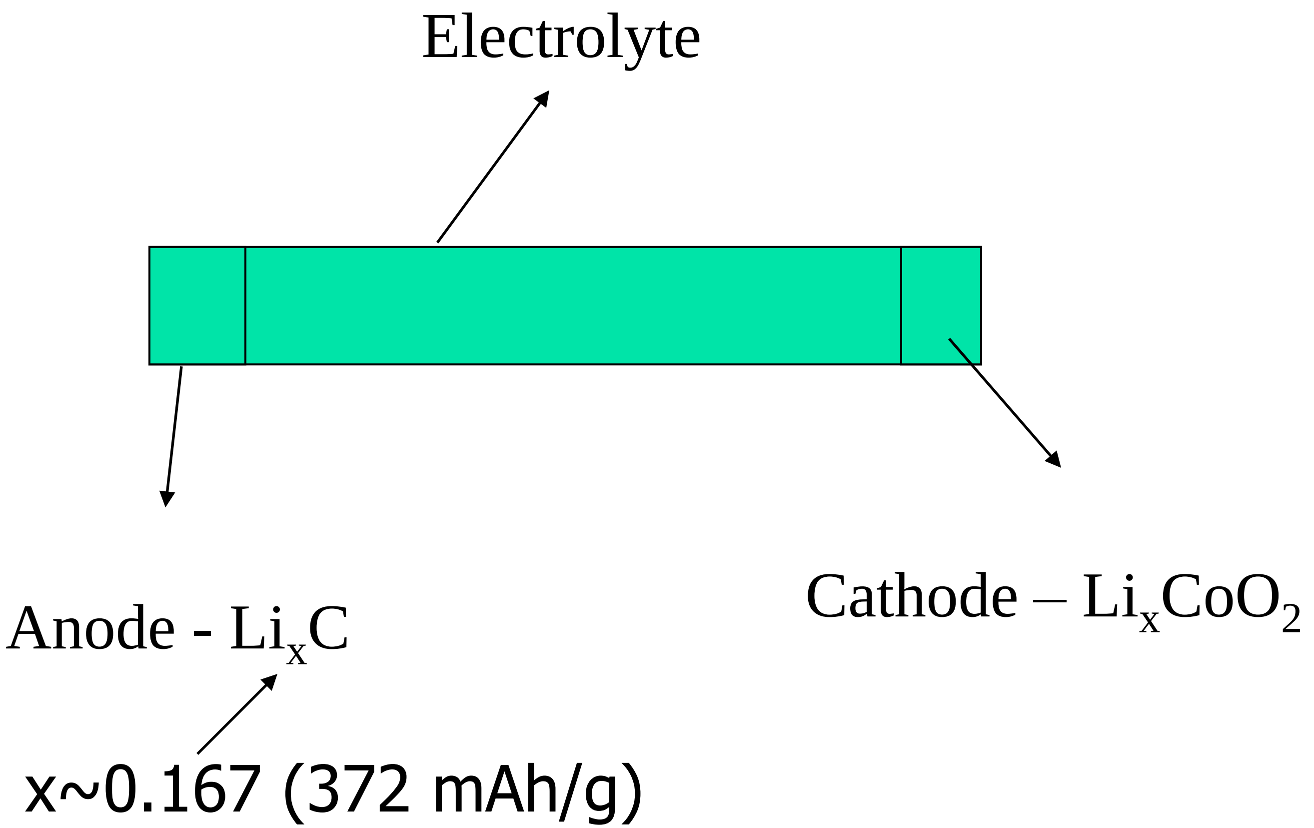


SPECIFICATION

- Up to 300 mile range
- 45 minute QuickCharge
- Charges from 120V, 240V or 480V
- 5 minute battery swap
- 0-60 mph in 5.6 seconds
- PURE electric
- 2X as efficient as hybrids
- Proven powertrain from leading EV manufacturer

Cost is $50,000!!

Li–ion Batteries



The battery functions by lithium intercalating into both materials

Possible improvements

- Electrolyte - change from liquid electrolyte to solid electrolyte (probably based upon a polymeric electrolyte)
- Cathode – move away from cobalt based cathode to nanosized materials, such as Li_xMnO_2 and $LiFePO_4$

RESPONSE OF STOCKMARKET TO THE LAUNCH OF A123, A MIT SPIN OUT COMPANY WITH NANOSIZED $LiFePO_4$ TECHNOLOGY

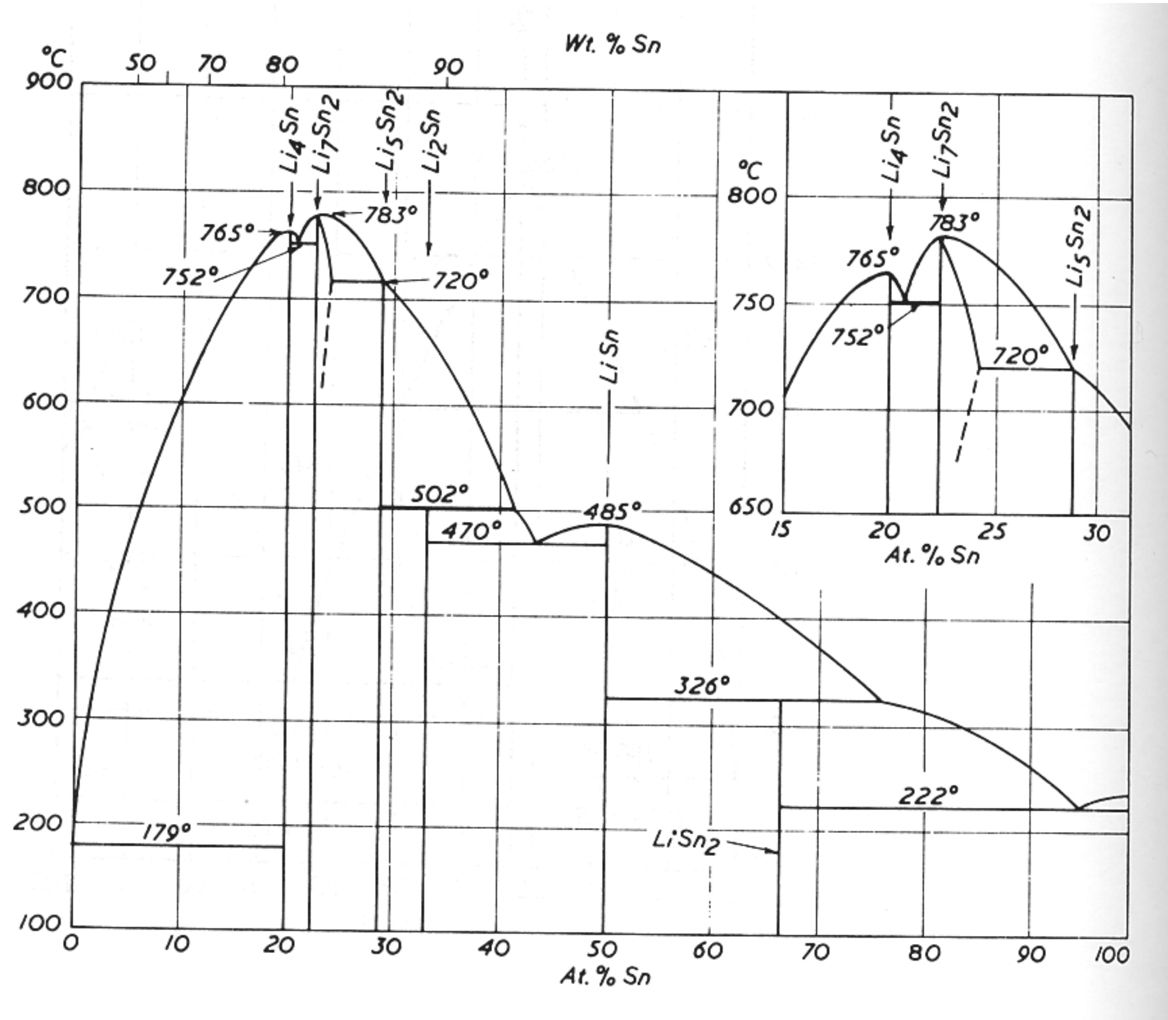
Nature News, 24th September 2009

Possible improvements

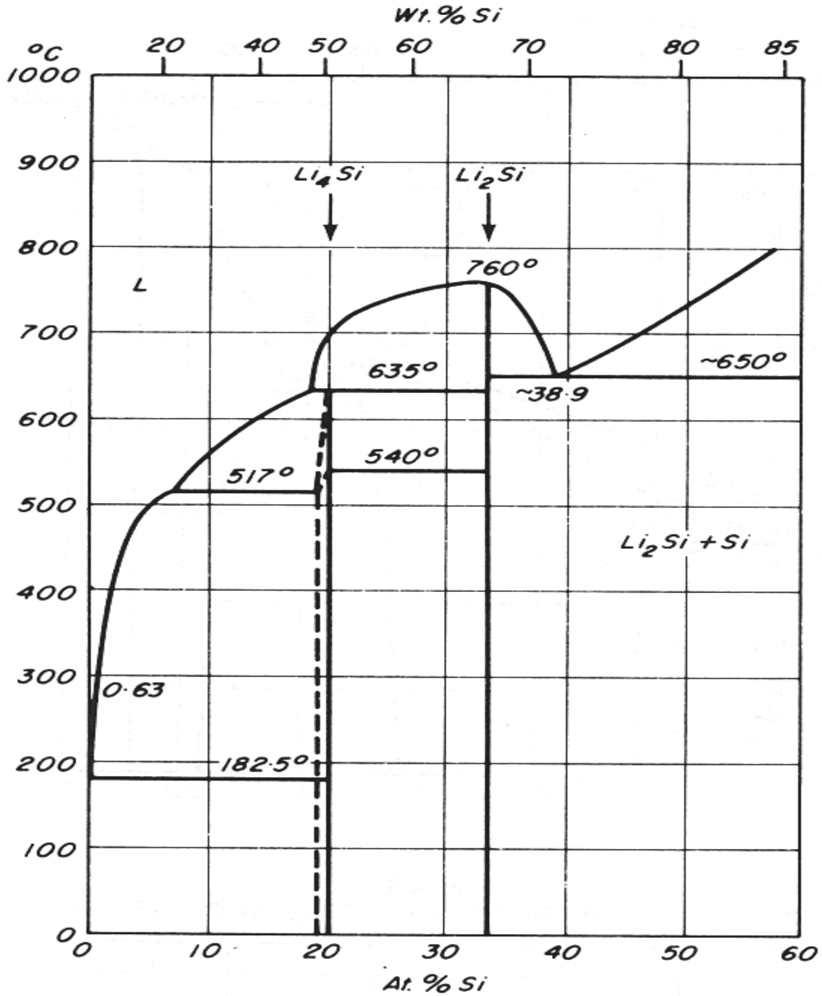
- Anode - increase capacity without sacrificing charge-discharge capabilities - increase the atom fraction of lithium in the anode from 0.167 to a much higher figure.

Intermetallic compounds as anode materials

C.J. Wen and R.A. Huggins, J. Electrochem. Soc., 126 (1979) C322



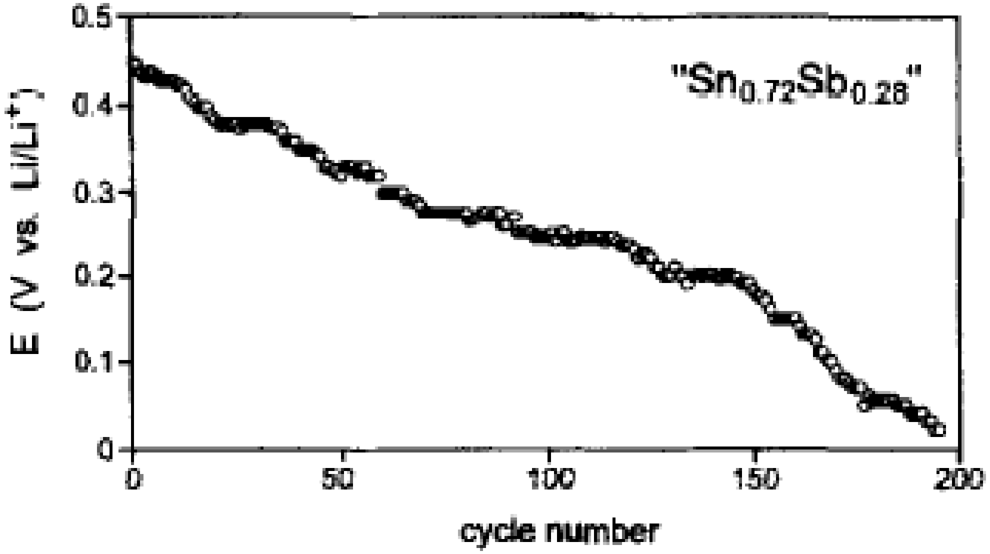
Lithium-silicon phase diagram



Capacity of various anode materials

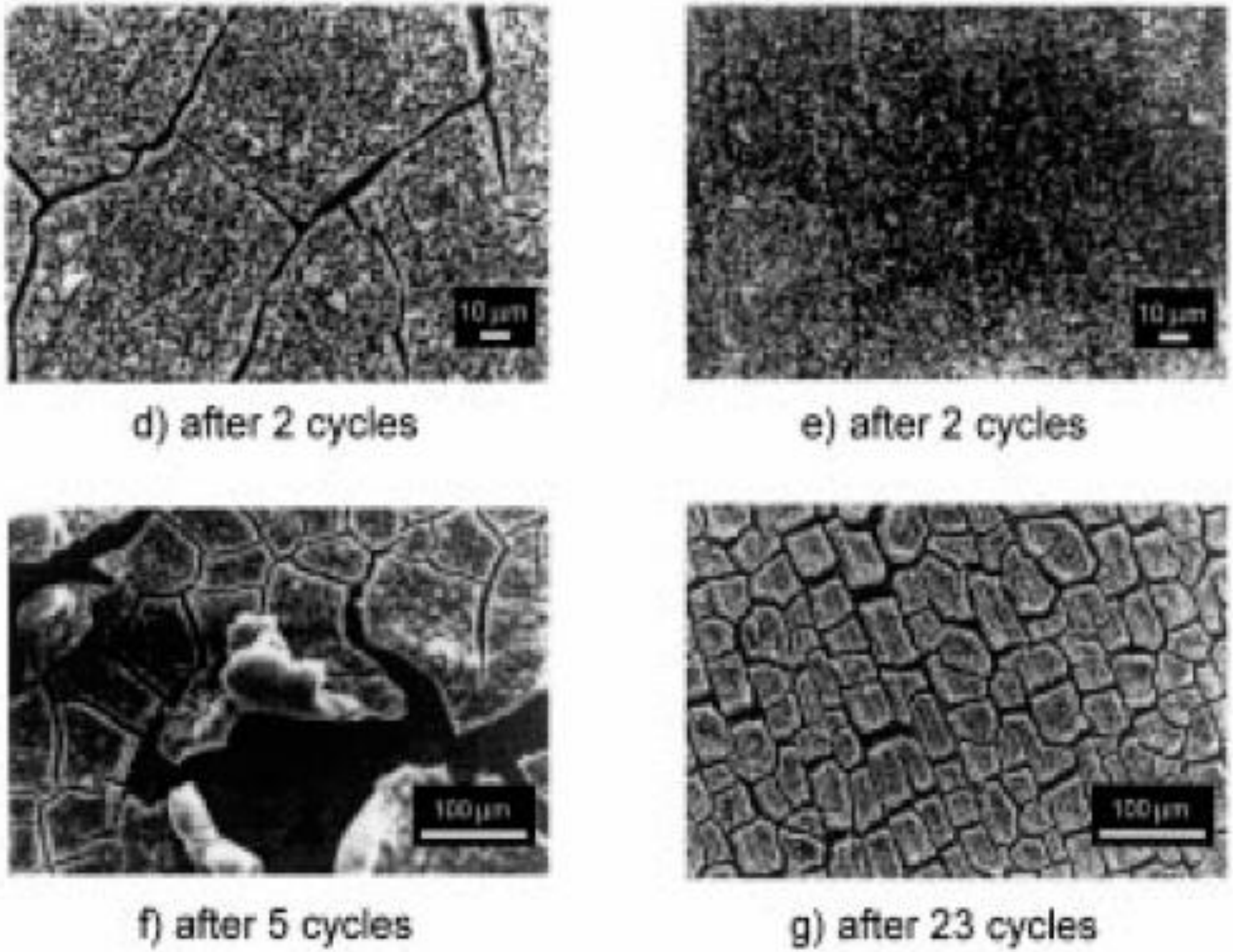
- $Li_{0.167}C$ ~ 370 mAh/g
- Li_4Sn ~ 700 mAh/g
- $Li_{4.4}Si$ ~ 2000 mAh/g

Typical performance of lithium-tin anodes



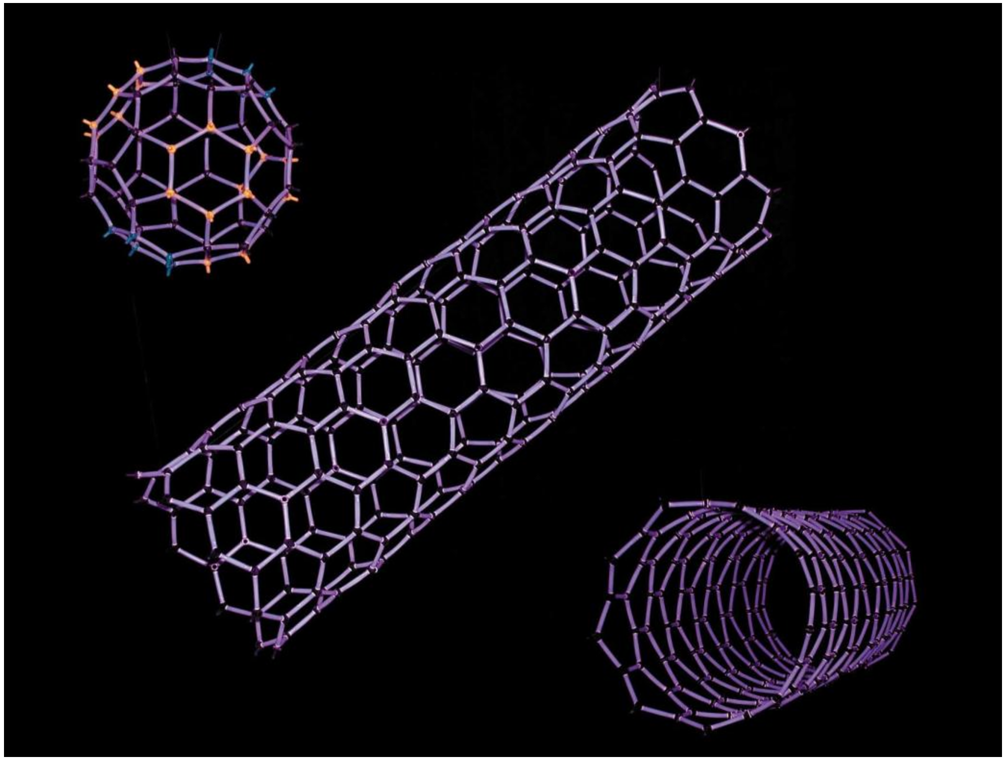
J.O. Besenhard et al., J. Power Sources 68 (1997) 87

CHANGE IN MICROSTRUCTURE ON CHARGE-DISCHARGE CYCLING



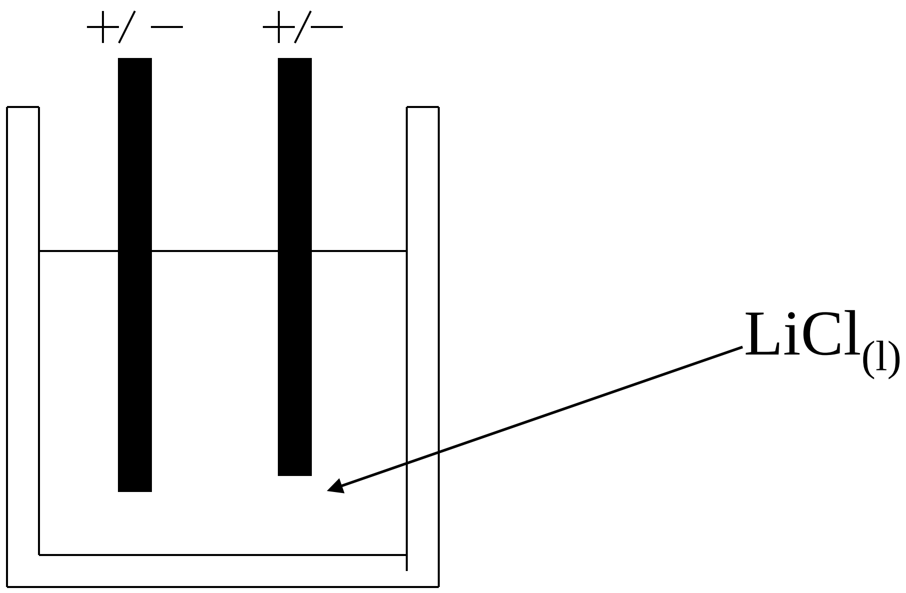
M. Winter and J.O. Besenhard, Electrochem. Acta 45 (1999) 31

Carbon nanotubes as containers for tin



M.W. Macklin and D.J. Fray, USP 7189476

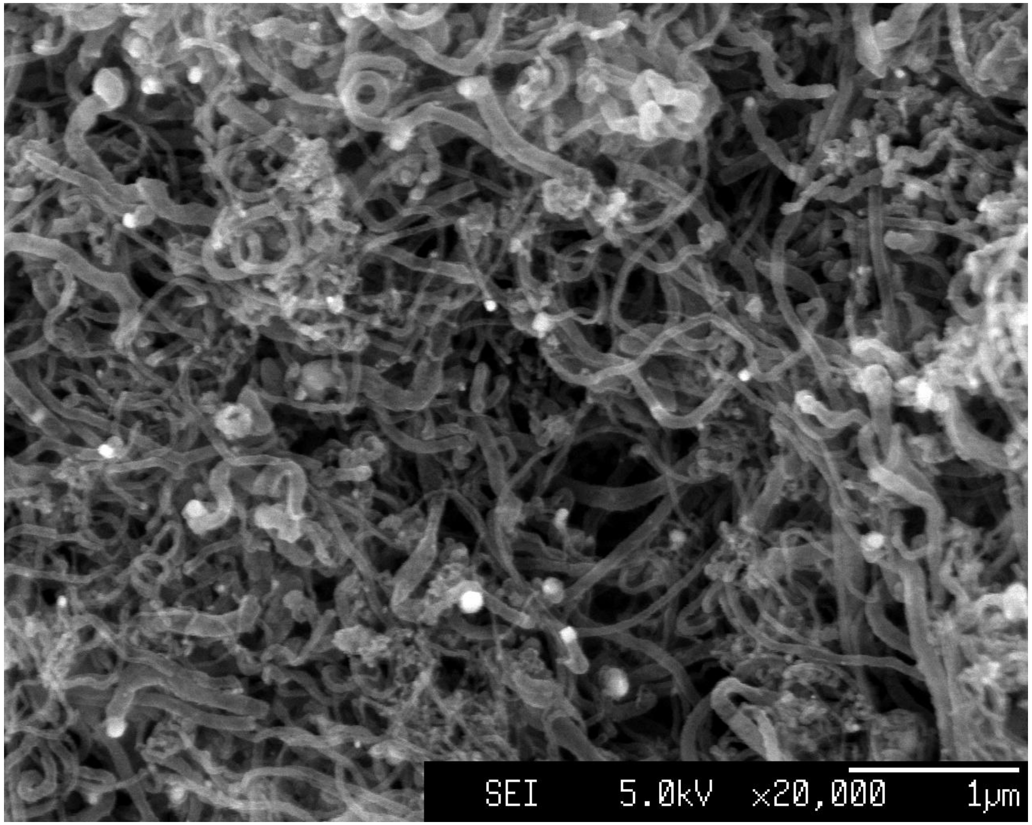
Continuous electrochemical method for synthesising carbon nanotubes



$$Li_{(graphite)} = Li_{(graphite)}$$

D.J. Fray, C. Schwandt and A. Dimitrov USP 2008105561

Carbon nanotube product

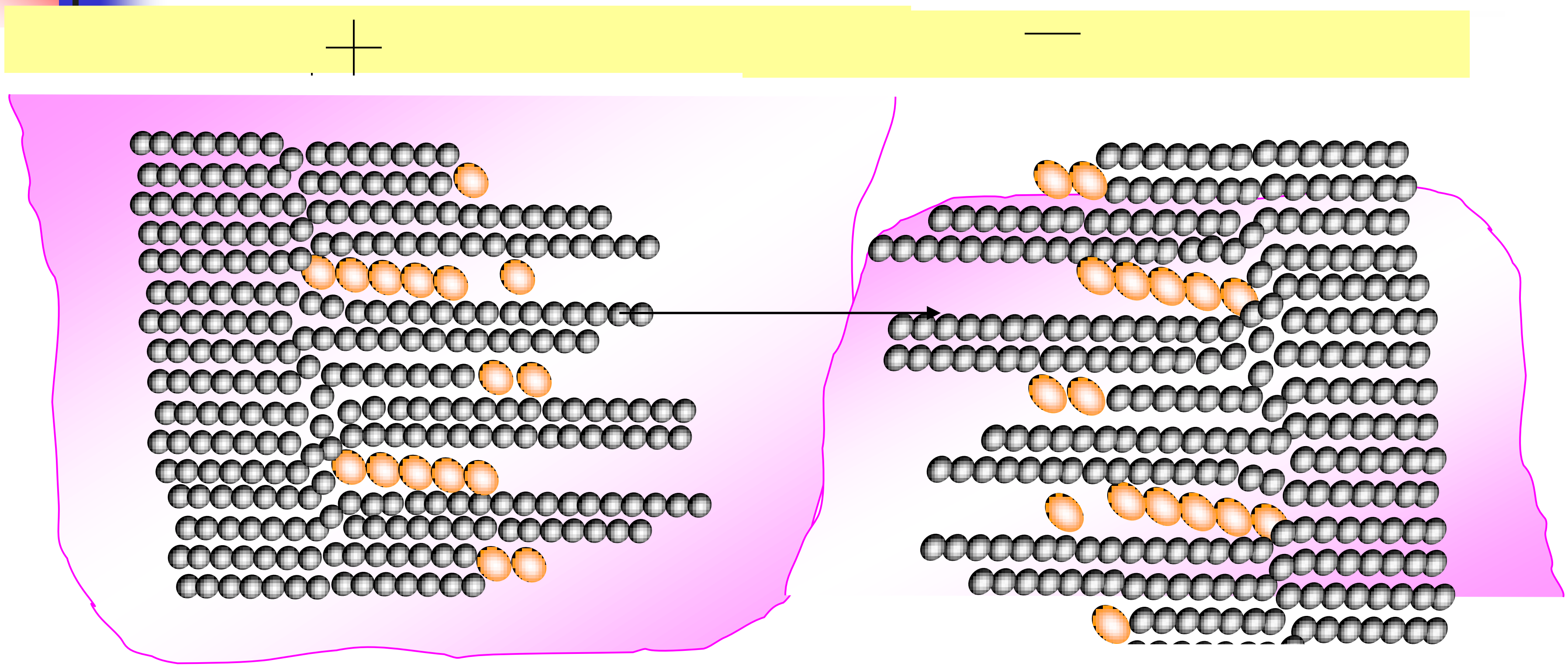


R. Das Gupta, Ph.D thesis, University of Cambridge 2009

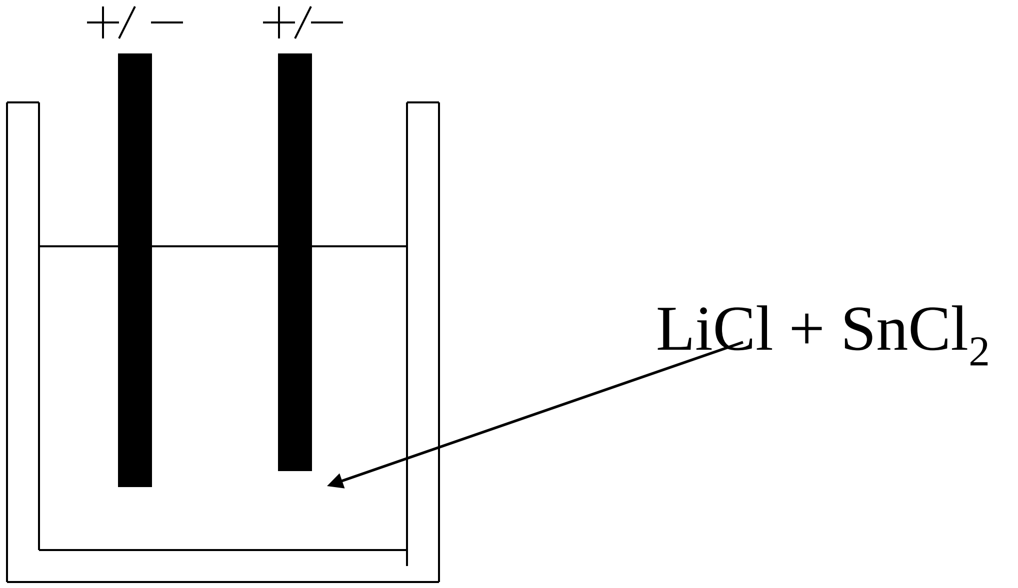
Advantages of Molten Salt Route for Preparation of Carbon Nanotubes

- 1000 times faster than catalytic route
- No entrapped catalyst particles
- Graphite \$1/kg
- Electricity \$1/kg
- Washing, etc \$1/kg
- Depreciation \$1/kg
- Labour \$1/kg
- Costs should be below \$10/kg (100 times cheaper than carbon nanotubes sold via the internet)

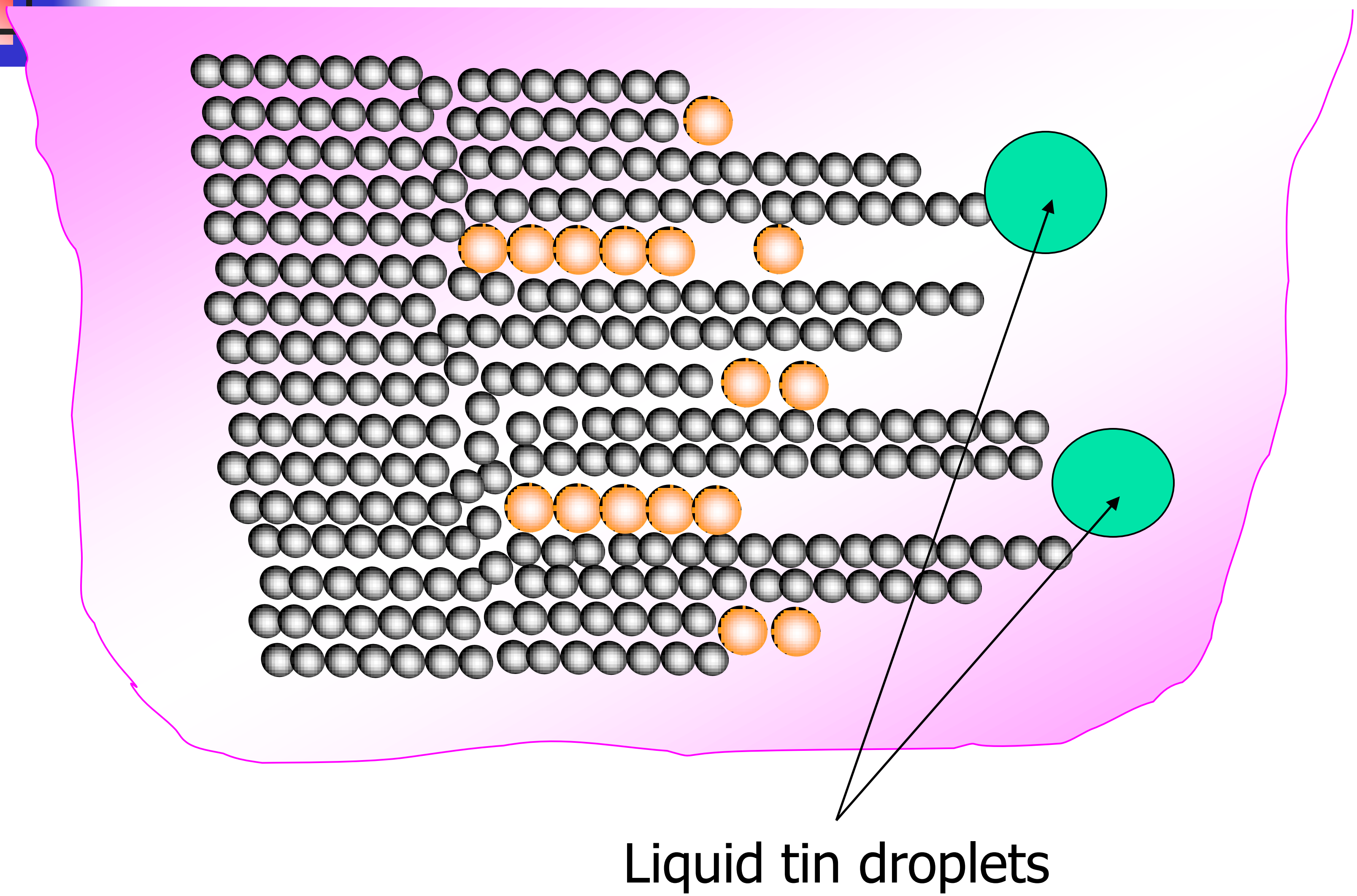
Intercalation mechanism for formation of carbon nanotubes



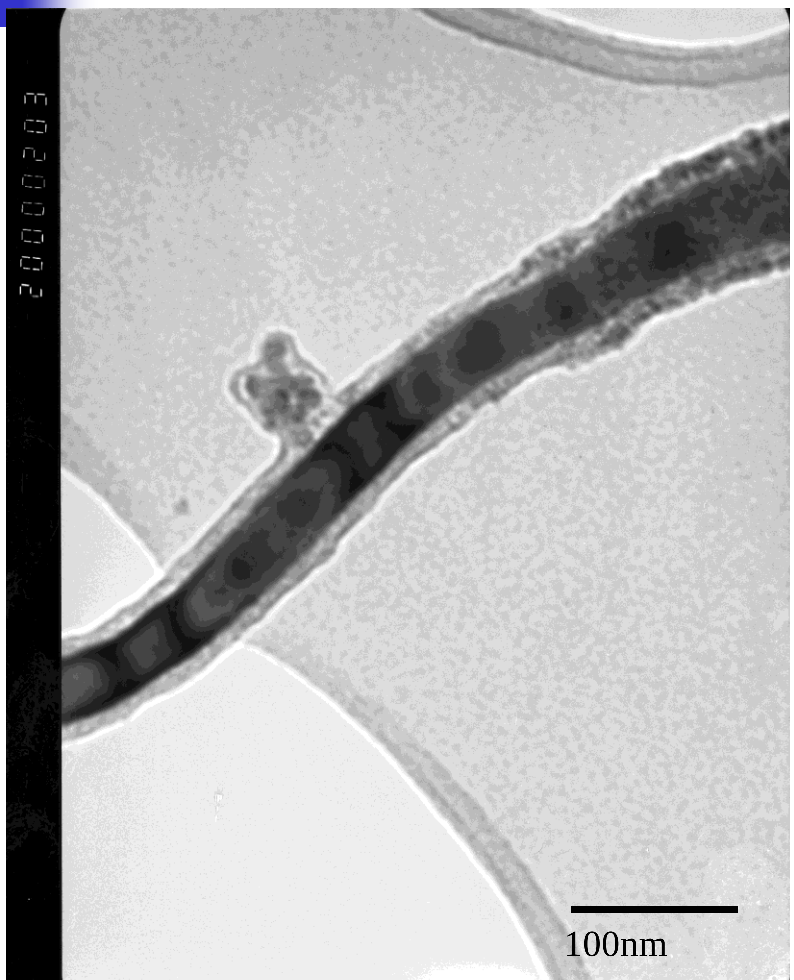
Schematic of current reversal cell for producing tin-filled carbon nanotubes

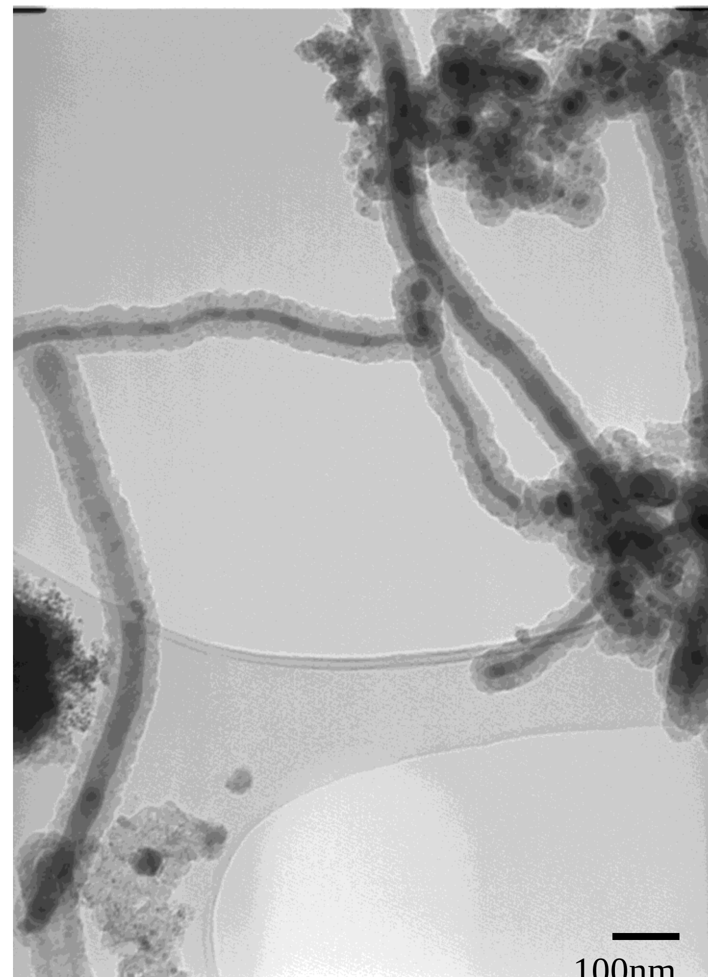


Intercalation- extrusion mechanism

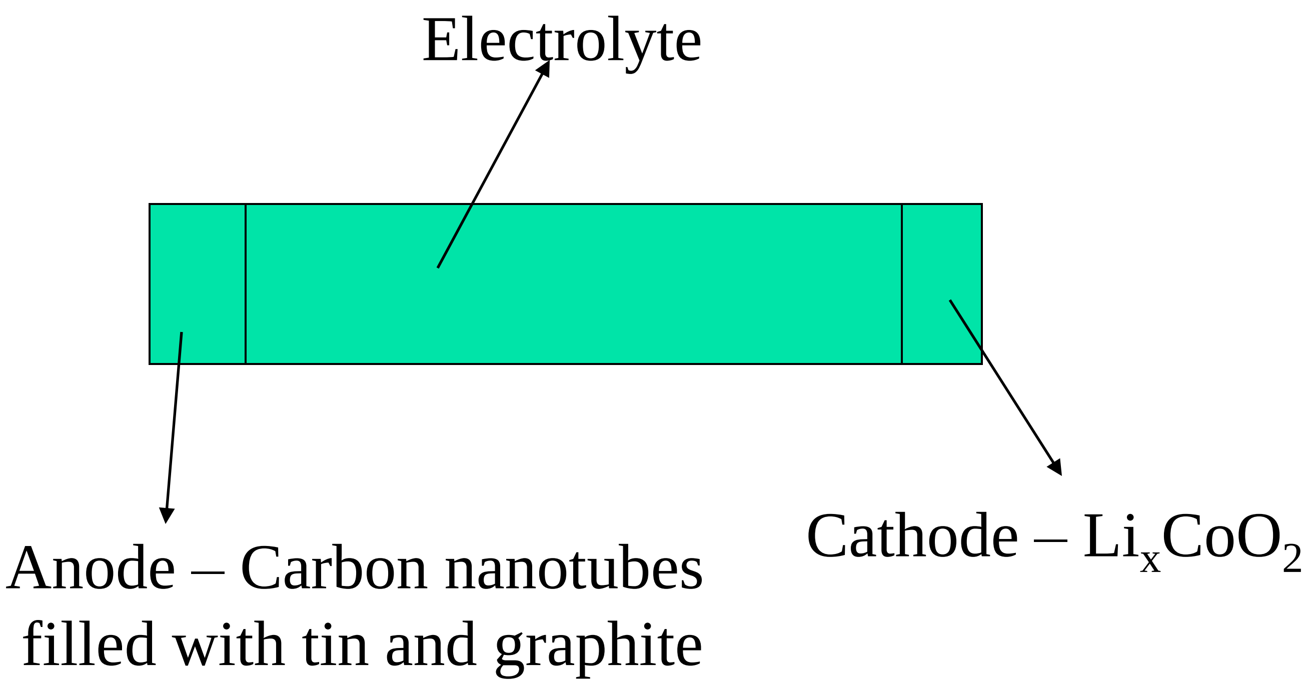


TIN FILLED CARBON NANOTUBES

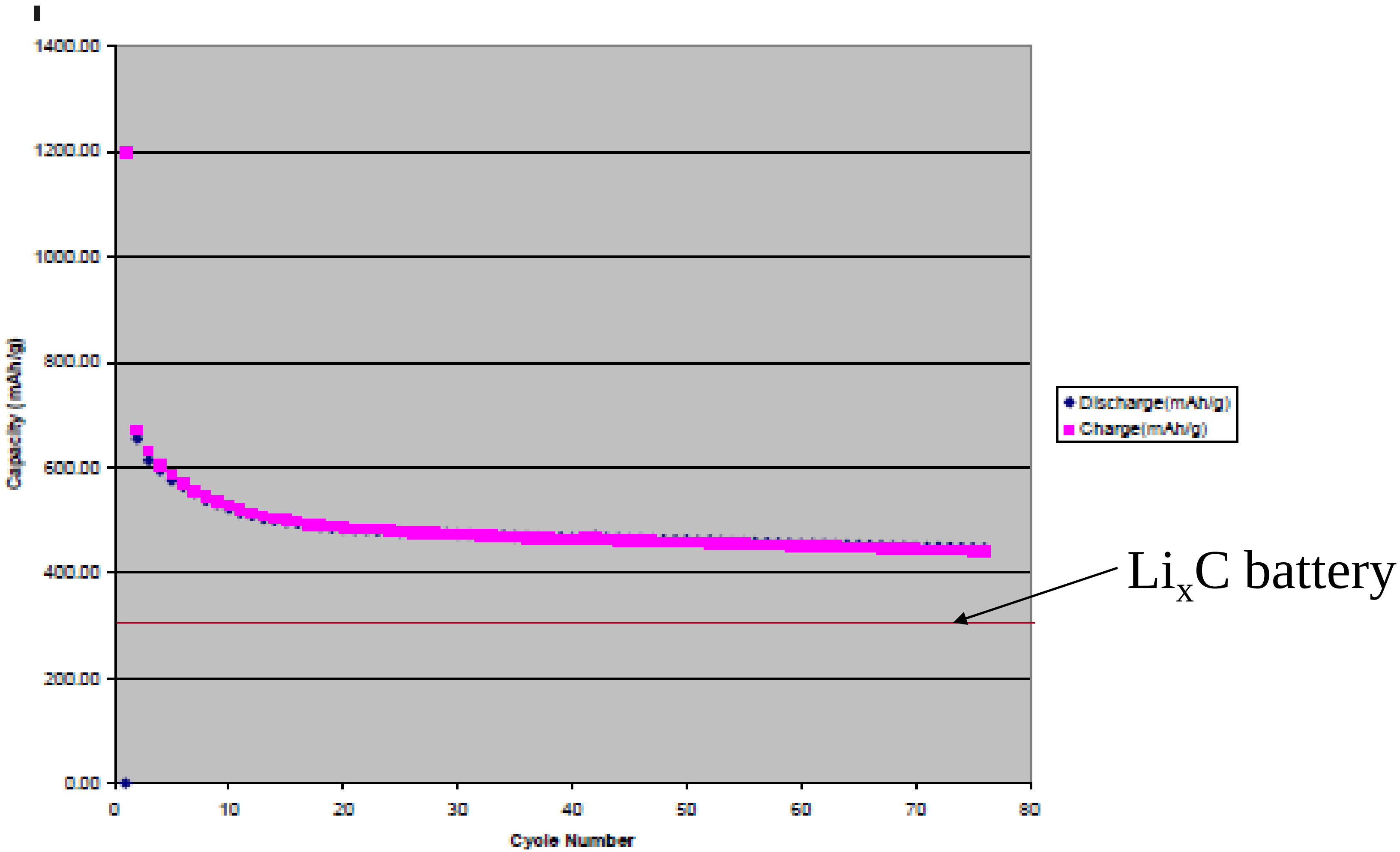




Li–ion Battery

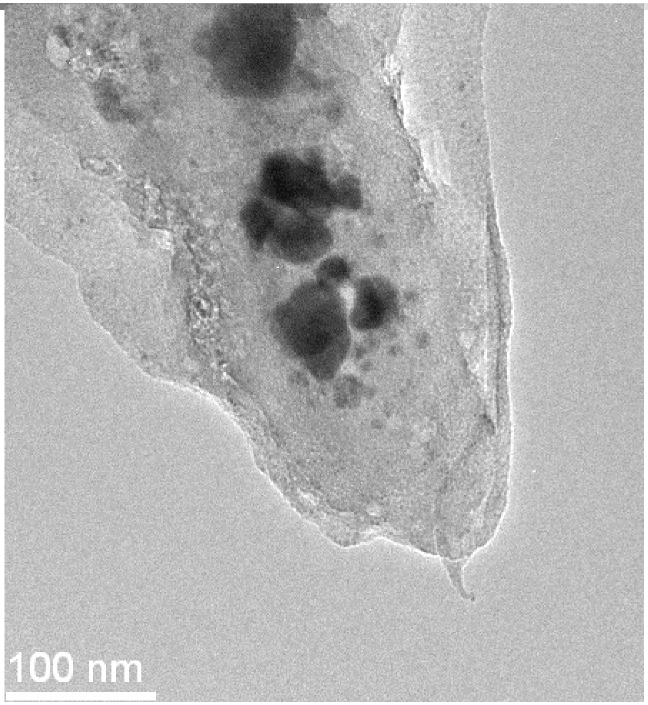


Experiments performed at NRC, Canada



CHARGE - DISCHARGE CYCLES FOR Li_xSn BATTERY

Tin filled carbon nanotube after many charge-discharge cycles



R. Das Gupta, Ph.D thesis, University of Cambridge 2009

The technology is being developed by Electrovaya, Canada and an application has been made for funds to create a spin-out company in Cambridge

CONCLUSIONS

- Plenty of lithium resources for Li-ion batteries
- Capacity of anode and cathode needs to be increased and the charge-discharge time decreased
- Move to nanosized particles with large surface areas and short diffusion distances
- A company to exploit this technology is being created in Cambridge