Lithium ion battery

Lithium

- Periodic Table Symbol: Li
- Atomic Weight: 3 (light!)
- Like sodium and potassium, an alkali metal. (Group 1 – #s 1 through 7)
- Highly reactive, with a high energy density.
- Used to treat manic-depression because it is particularly effective at calming a person in a "manic" state.
- The most electropositive (-3.04V versus standard hydrogen electrode

鋰離子電池的結構

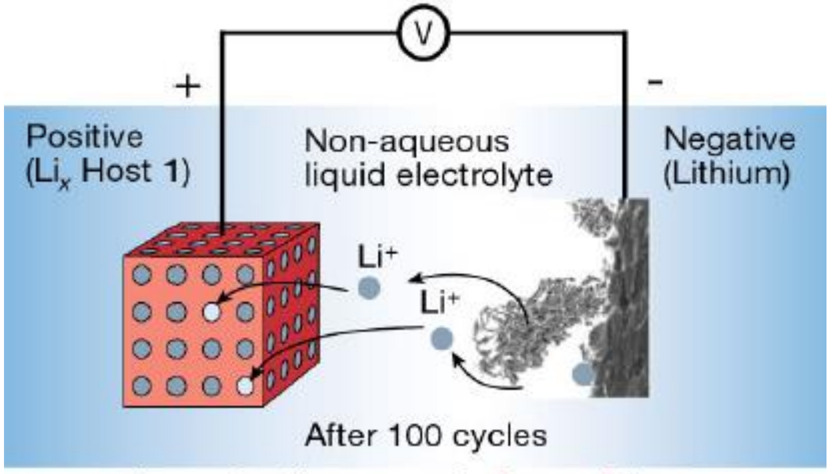
- 正極
- 活性物質($LiCoO_2$\$LiMnO_2$\$LiNi_xCo_{1-x}O_2$) 導電劑、溶劑、粘合劑、基體
- 負極 活性物質(石墨、MCMB) 粘合劑、溶劑、基體
- 隔膜(PP+PE)
- 電解液($LiPF_6$ + DMC EC EMC)
- 外殼五金件(鋁殼、蓋板、極耳、絕緣片)

Composition of Li-ion batteries

Electrode Component	Role	Anode(負極) Example	Cathode(正極) Example
Active Material	Reversibly stores chemical energy	Graphite	$LiCoO_2$ or LMO2
Binder	Stabilizes electrode coating (holds it together)	PVDF or SBR (Polyvinylidene fluoride)	
Current Collector	Supports electrode material Leads to electronic circuitry	Copper	Aluminum
Additives	Improves electrode performance	Carbon Black, Graphite	
Electrolyte	Li-ion transportation	**Salt:**LiPF6 + **Solvent:** Carbonates	

Lithium Ion Battery Development

- Pioneering work for the lithium battery bagan in 1912 by G. N. Lewis but it was not until the early 1970's when the first non-rechargeable lithium batteries became commercially availble
- In the 1970's Lithium metal was used but its instability rendered it unsafe



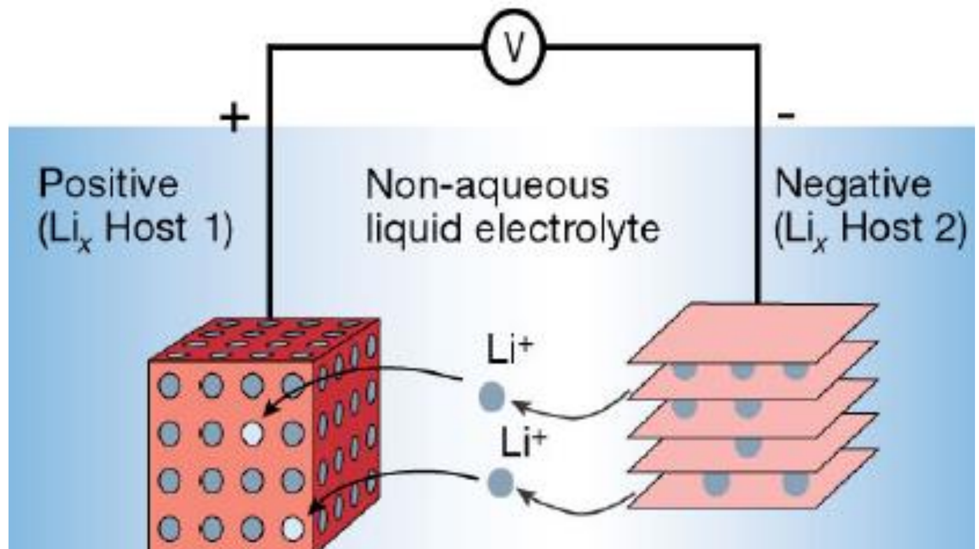
Schematic diagram of Li-metal battery

Why lithium-ion other than Lithium

- 鋰電池的負極採用金屬鋰，在充電過程中金屬鋰會在鋰負極上沉積，產生枝晶鋰，造成電池內部短路產生爆炸。
- 鋰離子電池則採用了碳材料代替純鋰做為負極。

Lithium Ion Battery Development

- Attempts to develop recharageable lithium batteries followed in the eithties, but failed due to safty problems
- The lithium ion battery has a slightly lower energy density than lithium metal, but it is much safer. Introduced by Sony 1991

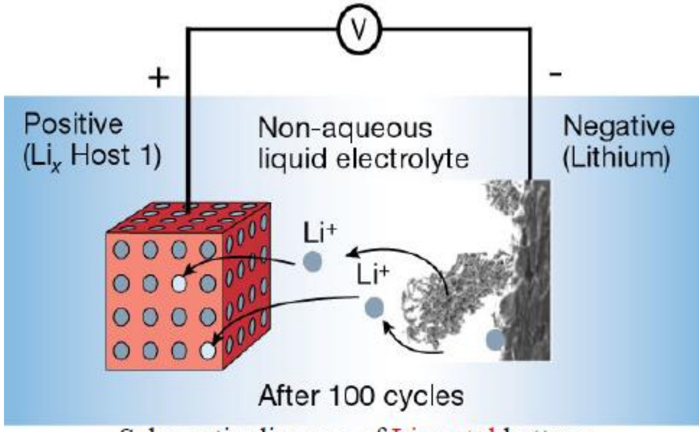


Schematic diagram of Li-ion battery

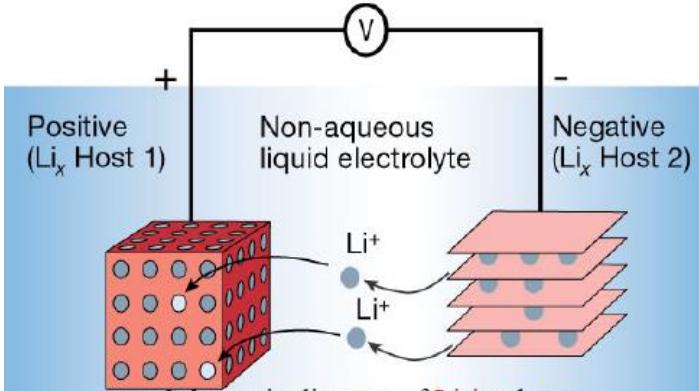
Lithium secondary battery

- A chemical intercalation reaction
- Intercalation is the reversible inclusion of a molecule between two other molecules

Ex: graphite intercalation compounds



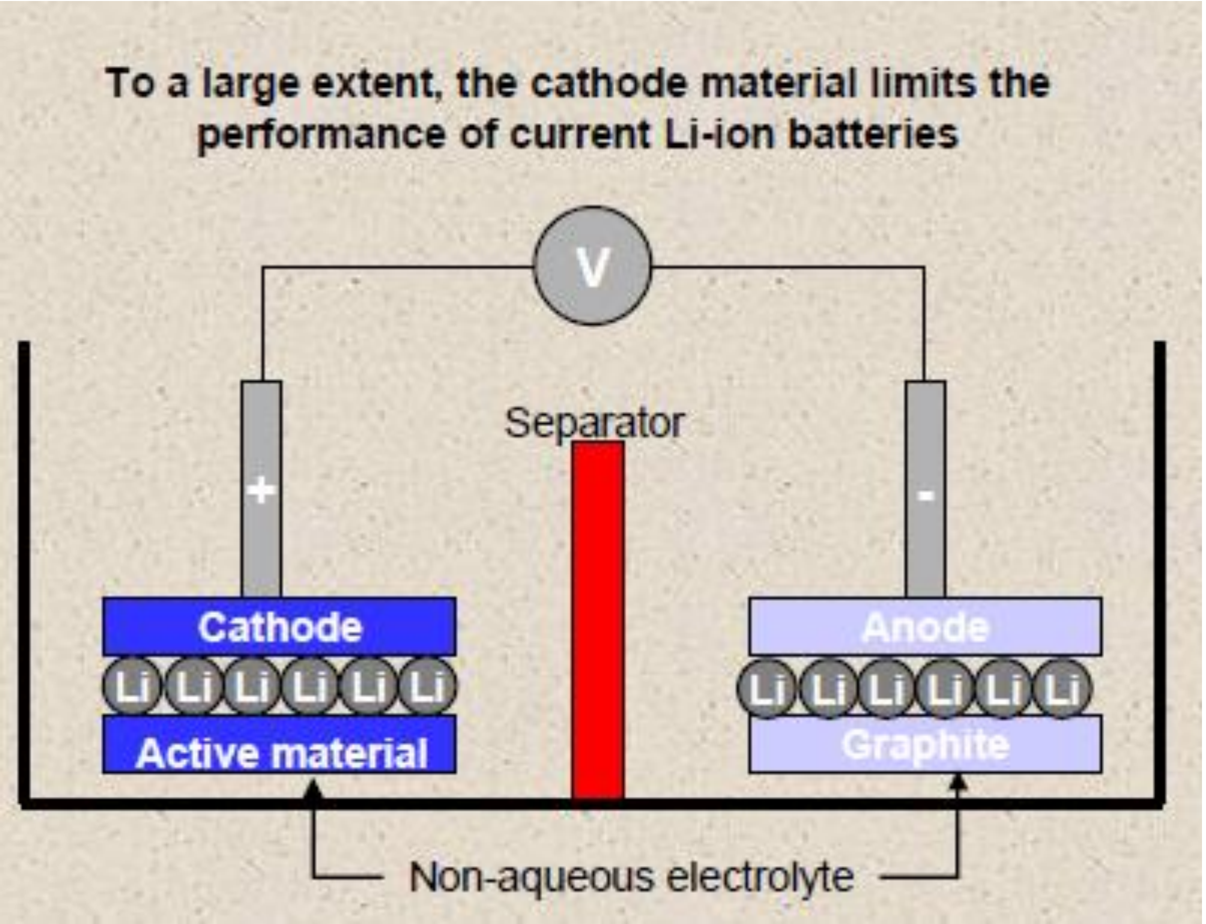
Schematic diagram of Li-metal battery



Schematic diagram of Li-ion battery

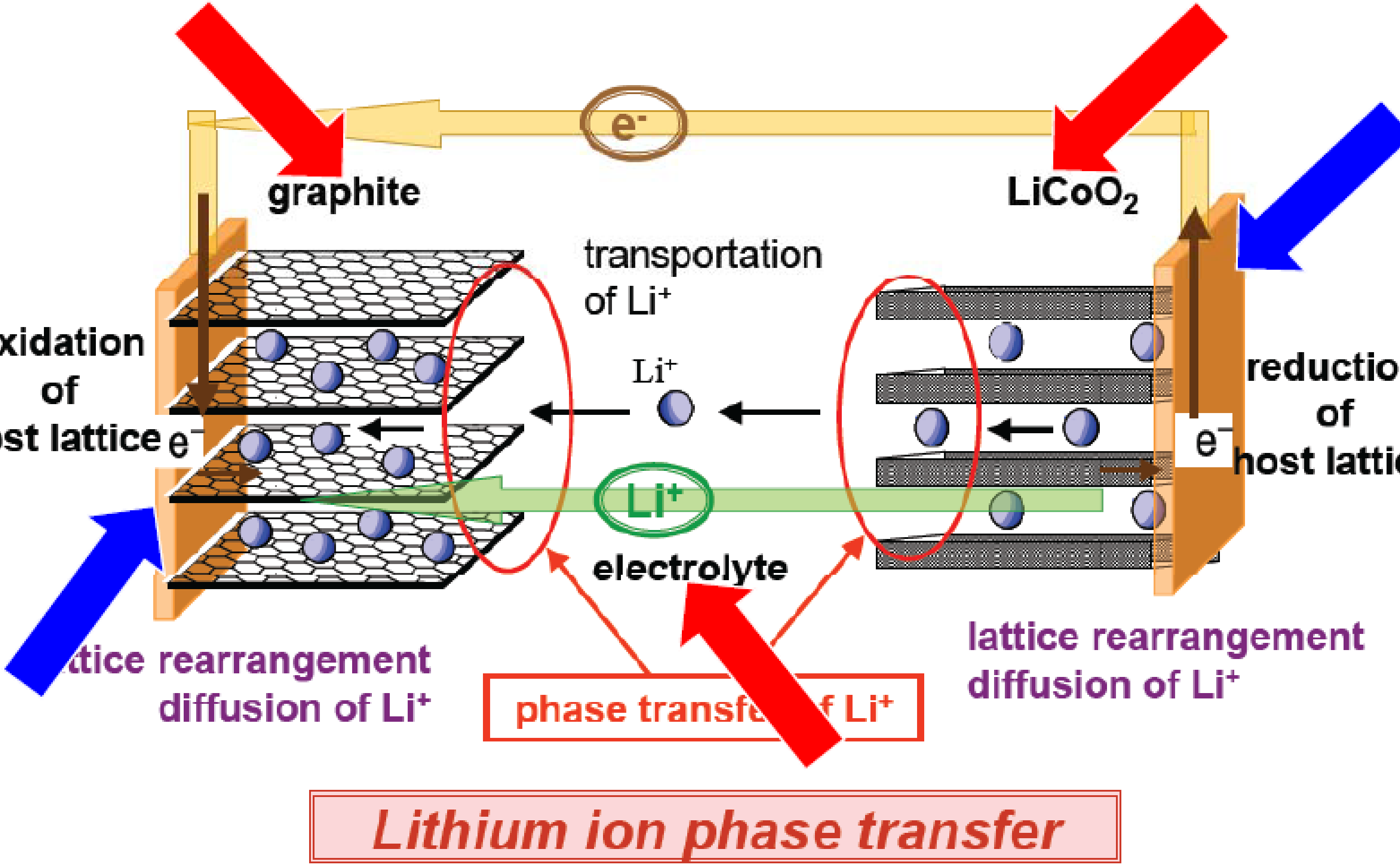
Armand, Nature, 2001

The operation principle of a Li-Ion battery



- During charging an external voltage source pulls electrons from the cathode through an external circuit to the anode and causes Li-ions to move from the cathode to the anode by transport through an liquid electrolyte.
- During discharge the processes are reversed. Li-ions move from the cathode through the electrolyte while electrons flow through the external circuit from the anode to the cathode and produce power.

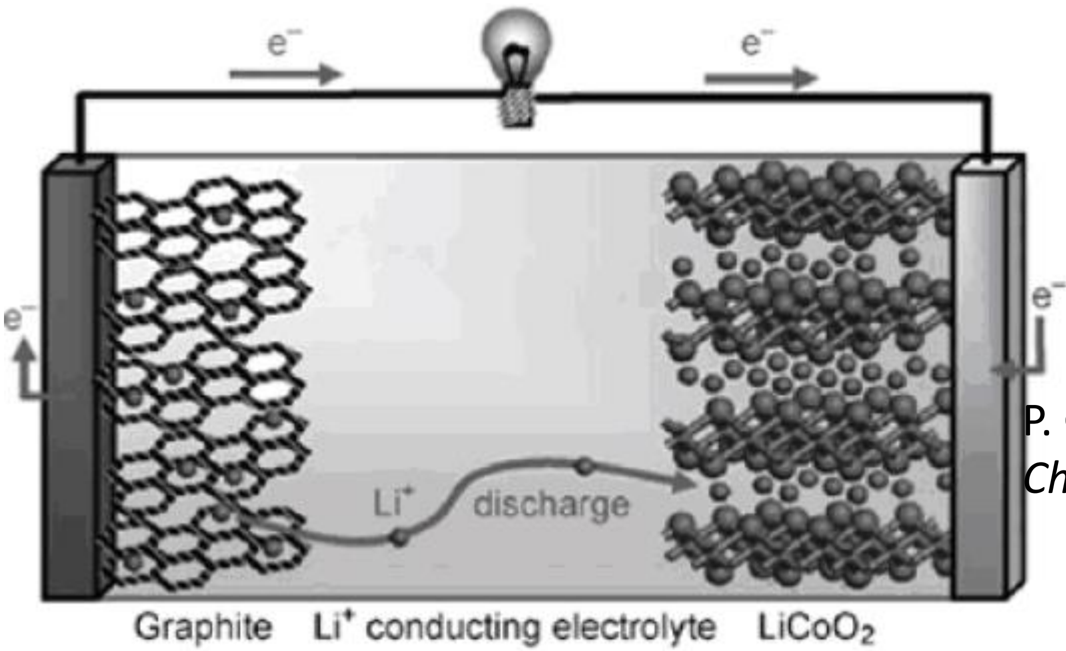
Intercalation process



充電時，鋰離子從LiCoO2脫出、Co+3氧化為Co+4; 放電池鋰離子則嵌入LiCoO2, 則Co+4 →Co+3

。換句話說，充電時由外界輸入能量而迫使鋰離子由低能量之正極材料往負極材料移動，而成為能量較高之狀態；而放電時，鋰離子將會自然地由高能量之負極材料移動至較低能量之正極材料之中，並同時對外釋出能量

Overall reaction of Li-ion battery



P. G. Bruce, B. Scrosati, J. M. Tarascon, *Angew Chem. Int. Ed.*, **2008**, 47, 2930

鋰離子二次電池充放電反應式：

ΔV

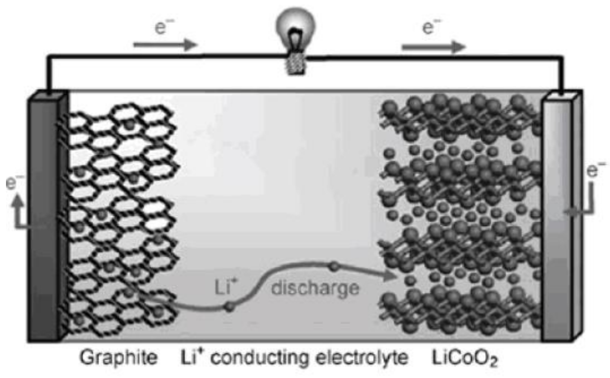
正極：$LiCoO_2 \rightarrow Li_{1-x}CoO_2 + xLi^+ + xe^-$

負極：$6C + xLi^+ + xe^- \rightarrow Li_xC_6$

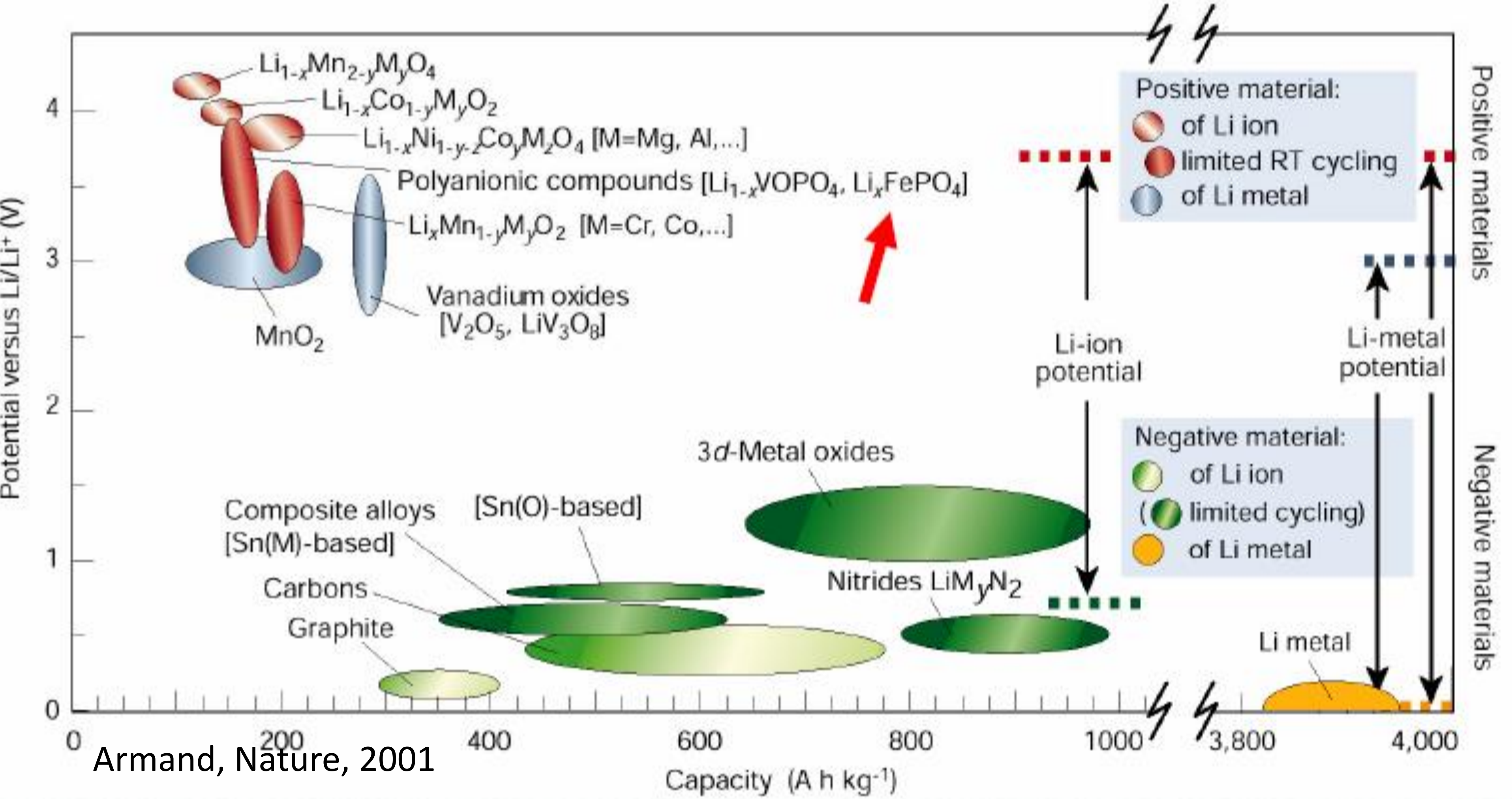
全反應：$6C + LiCoO_2 \rightarrow Li_xC_6 + Li_{1-x}CoO_2$

Charging Co+3->Co+4
discharging Co+4->Co+3

Rocking-chair tecnology



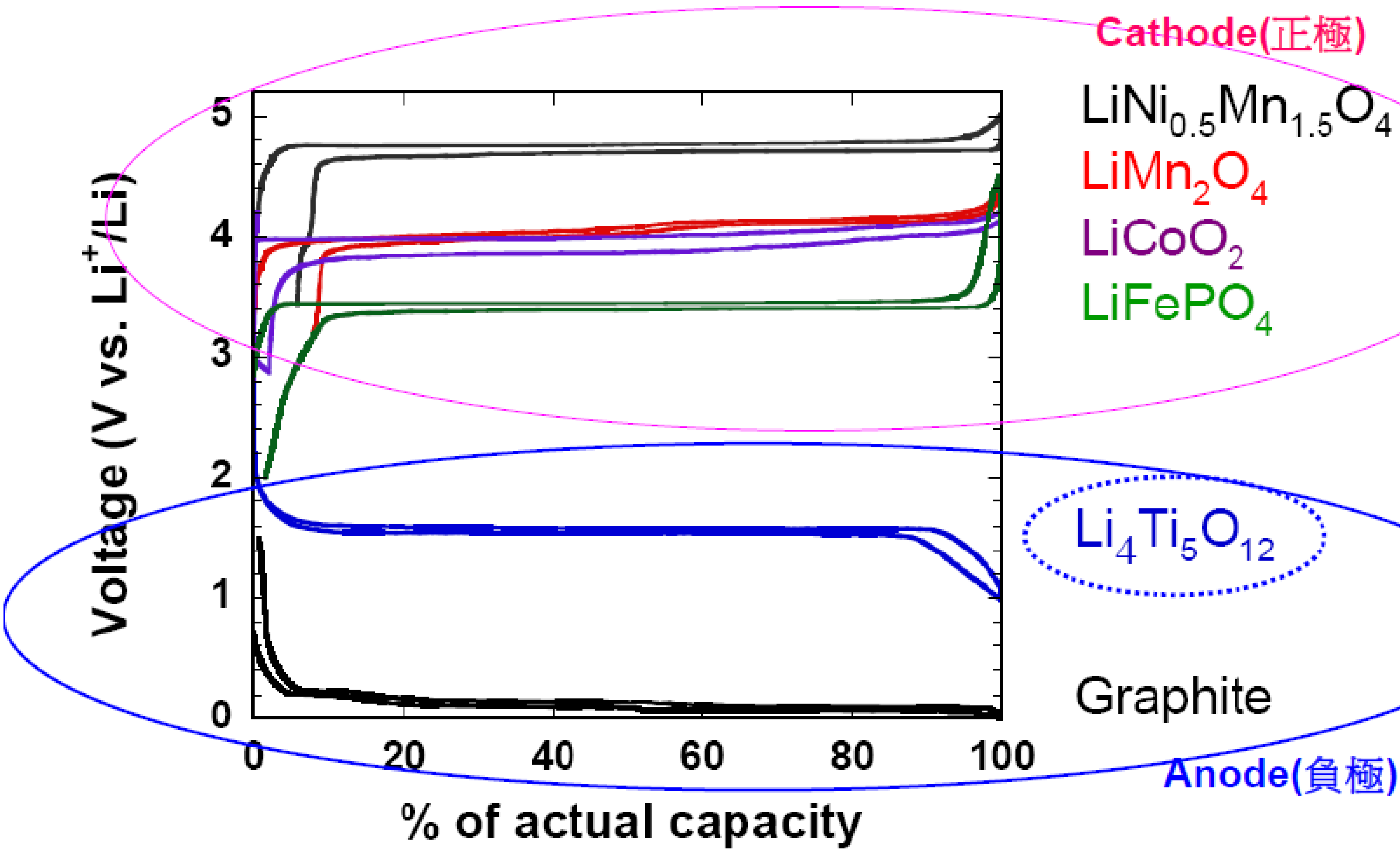
Combination of positive materials and negative materials for Lithium batteries



Armand, Nature, 2001

Voltage of a cell

V(battery)=V正 – V負

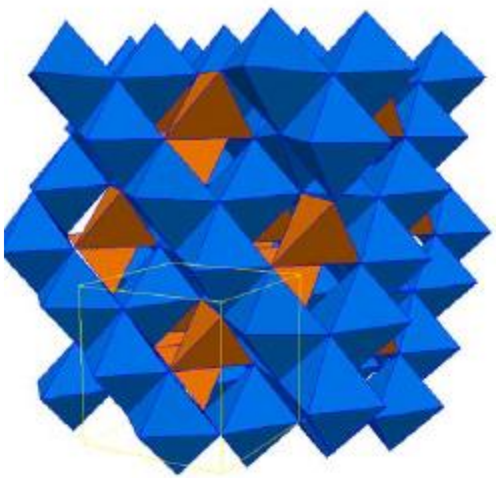


Capacity

$$\text{Total cell (mAh g}^{-1}) = \frac{1}{(1/C_A) + (1/C_c) + (1/Q_M)}$$
$$= \frac{C_A C_C Q_M}{C_A Q_M + C_C Q_M + C_A C_C}$$

where C_A and C_C are the theoretical specific capacities of the cathode and anode materials, respectively, and $1/Q_M$ is the specific mass of other cell components (electrolyte, separator, current collectors, case, etc.) in g mAh^{-1}. $1/Q_M$ will vary with cell geometry and dimensions, and will include any failure to obtain the theoretical capacity values and any other excess required, e.g., to provide excess cathode material for formation of the surface electrolyte interphase (SEI) film at the anode. For carbon, C_A is 372 mAh g^{-1}, and for $LiCoO_2$, C_C is 135 mAh g^{-1}. For the Sony 18650G8 cell (2550 mAh, 46 g), Q_M may be calculated to be 130.4 mAh g^{-1}. A similar calculation may be performed in terms of mAh cm^{-3}.

Cathode materials

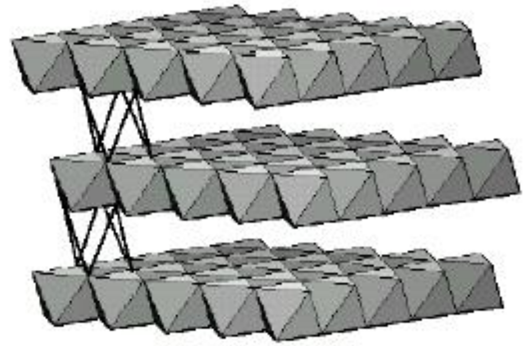


正方晶系

3D frameworks

Spinels

Fd3m



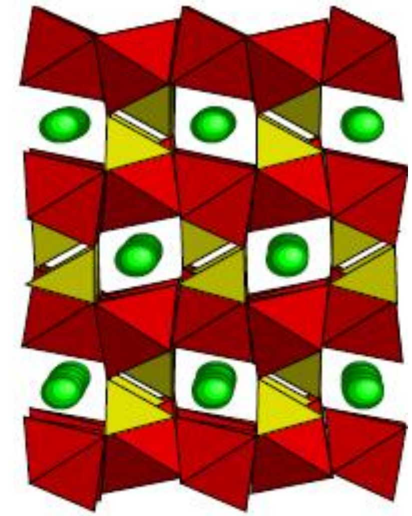
六方晶系

2D channel

Lamellar $LiCoO_2$

R3m

$LiFe^{II}PO_4$



斜方晶系

1D channel

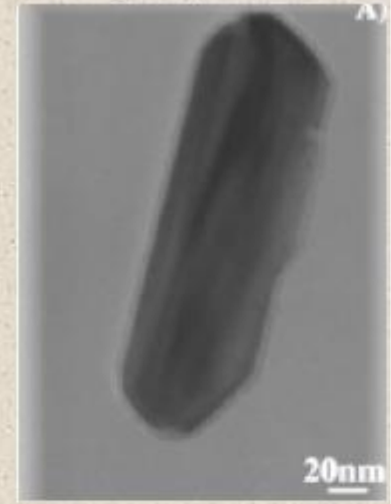
Olivine

Pnma

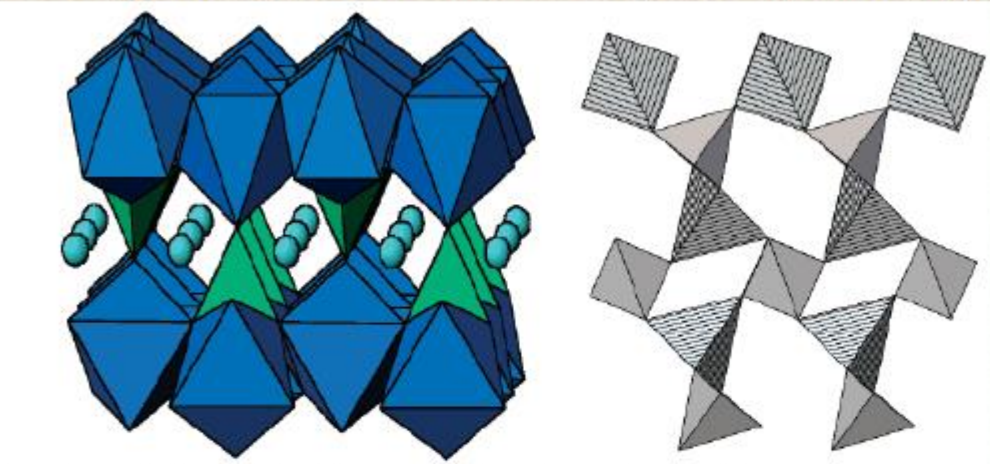
Cathode materials in Lithium-ion batteries

材料結構	鋰遷入/出空間	主要產品開發	理論電容量 (mAh/g)	預估電容量 (mAh/g)	平均工作電壓(V)	安全性	成本	主要產品應用
橄欖石 (Olivine)	1D	$LiFePO_4$	170	140-150	3.4	優	中	動力電池及大型電池
層狀氧化物 (layered Oxides)	2D	$LiCoO_2$ $Li(Co\text{-}Ni)O_2$ $Li(Ni\text{-}Mn)O_2$ $LiCo_{1/3}Ni_{1/3}Mn_{1/3}O_2$	273	160 180 160 190	3.6~3.7	尚可	高	小型電池 & 動力電池及大型電池
尖晶石 (Spinel)	3D	$LiMn_2O_4$	148	110	3.7	佳	低	動力電池及大型電池

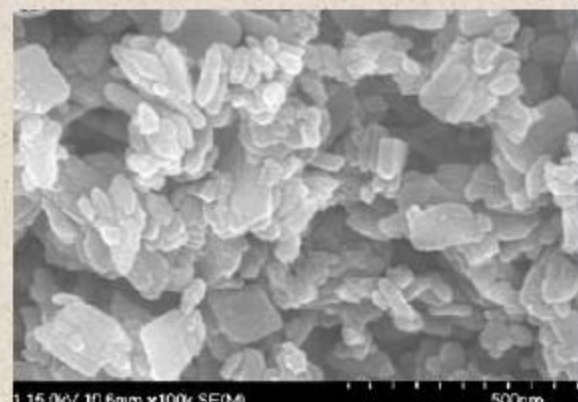
$LiFePO_4$ active material for lithium batteries



- Potentially low cost and plentiful elements;
- Environmentally benign;
- Theoretical capacity = 170 mAh/g
- Different synthetic methods: sol-gel, solid state, hydrothermal...

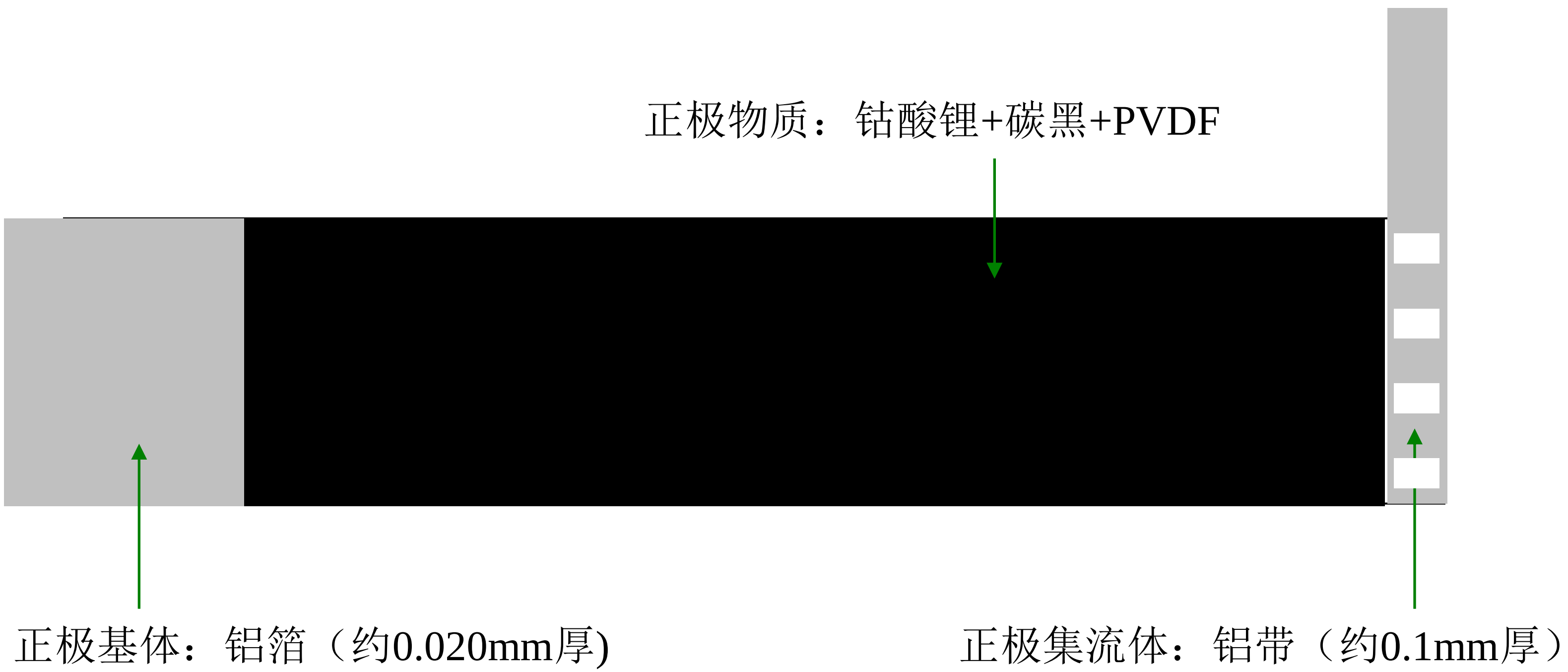


Structures of orthorhombic $LiFePO_4$ and trigonal quartz-like $FePO_4$.



Source: M. Stanley Whittingham. Chemical Reviews, 104 (2004) 4271-4301; R. Dominko,et al. Journal of The Electrochemical Society, 152 (2005) A607-A610; Bo Jin et al. J Solid State Electrochem (2008) 12:1549–1554.

锂离子电池结构——正极



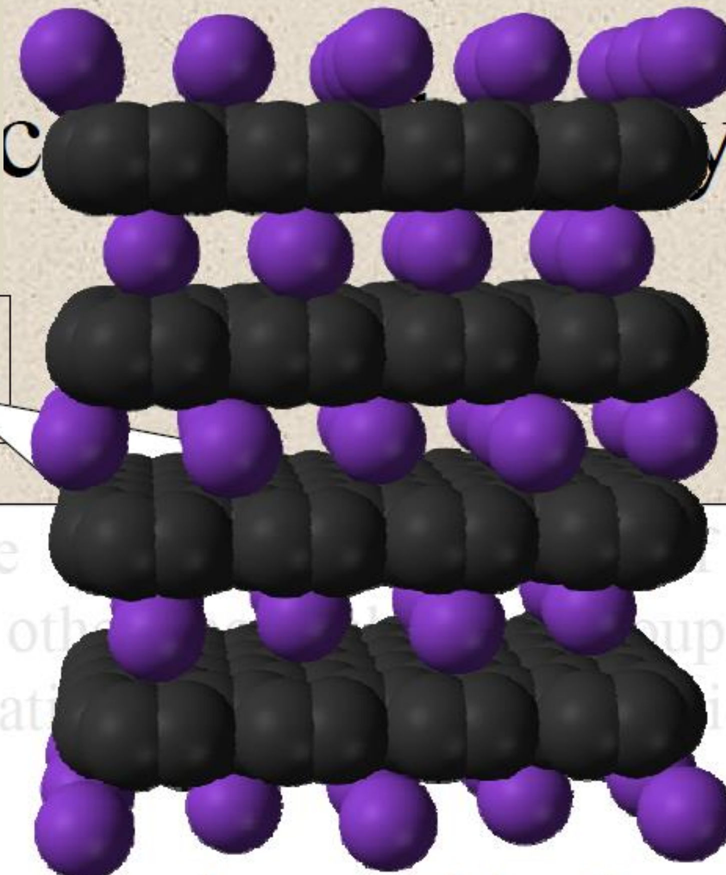
Editor: Frank　Veken_Baowang

Cathode Materials Challenges

- The most desirable cathode materials are strong oxiding agents that can react with and decompose organic electrolytes
- In extreme cases, problems with internal shorts or improper voltages can trigger exthermic reactions, leading to thermal runaway and catastropic falure

Anode materials: Carbon

1972 Define the concept of chemical intercalation



In chemistry, intercalation is the ... a molecule (or group) between two oth... ups). Examples include DNA intercalat... ion compounds, etc.

Graphite intercalation compounds are complex materials where an atom, ion, or molecule is inserted (intercalated) between the graphite layers. In this type of compound the graphite layers remain largely intact and the guest species are located in between

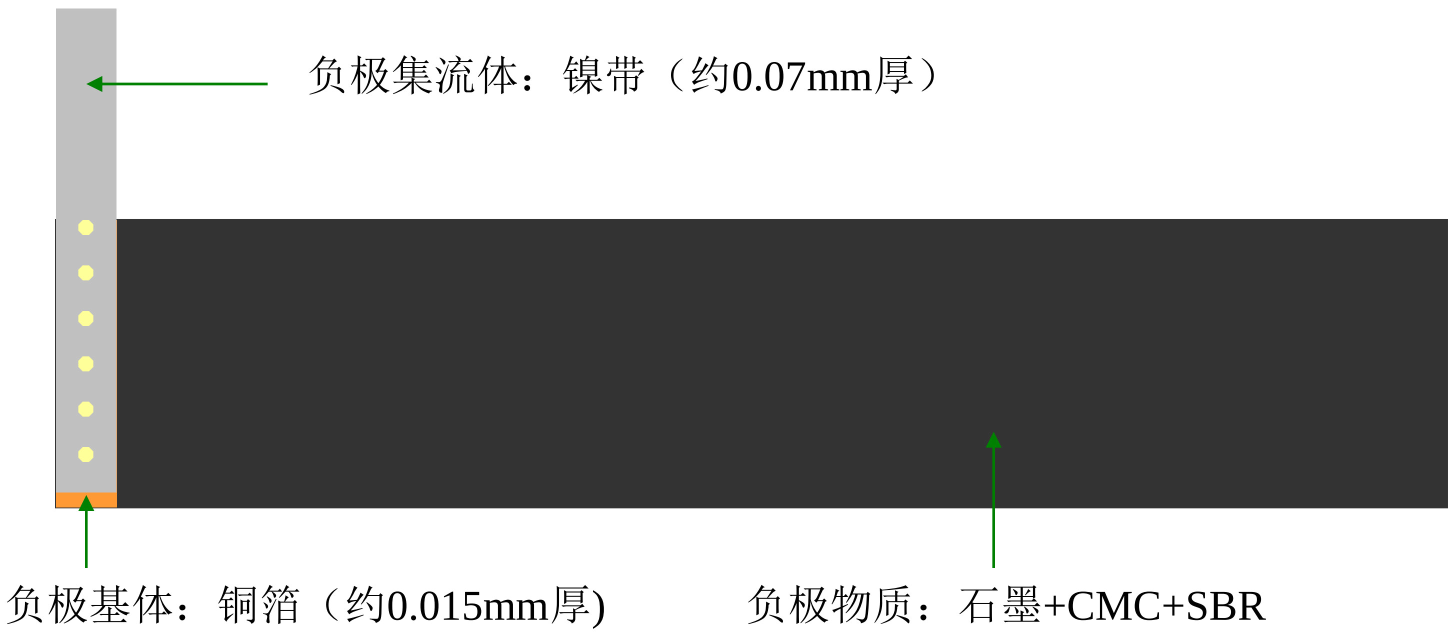
However, its theoretical capacity (LiC_6) is only 372 $mAhg^{-1}$

Figure:Space filling model of potassium graphite KC8 (side view) from: http://en.wikipedia.org/wiki/Graphite_intercalation_compound

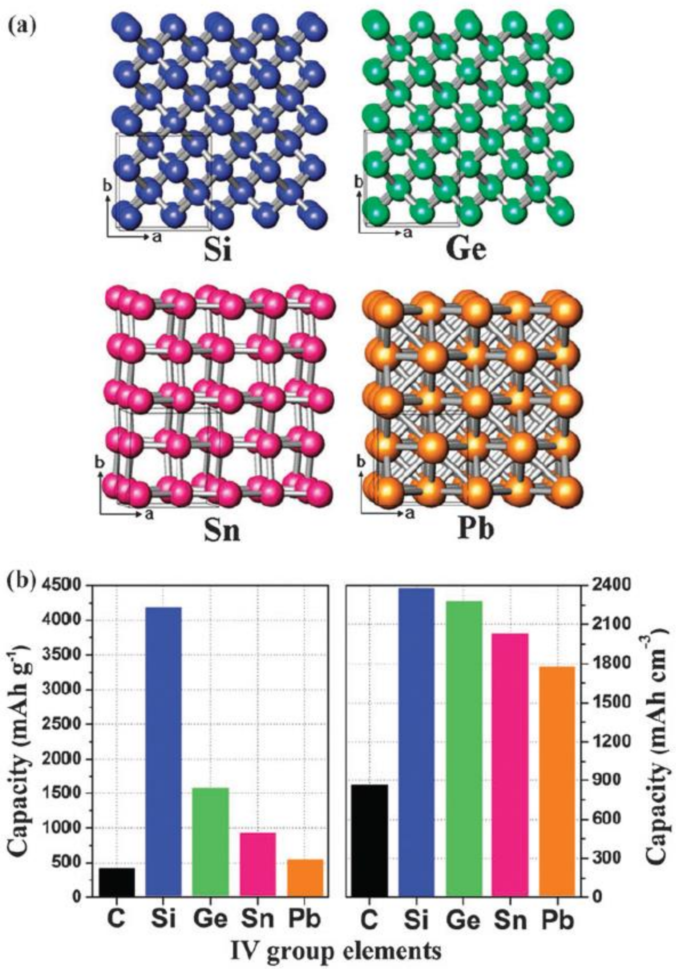
Anode materials

Anode material	Fully lithiated material	Theoretical Specific capacity (mAh/g)	Volumetric capacity* (mAh/cm^3)
Al	LiAl	993	1374
Sb	Li_3Sb	660	1881
Sn	$Li_{22}Sn_5$	994	2025
SiO	$Li_{15}Si_4$	>2000	~200
Si	$Li_{15}Si_4$	3579	2200
$Li_4Ti_5O_{12}$	$Li_7Ti_5O_{12}$	175	350
C, graphite	LiC_6	372	760

锂离子电池结构——负极



Li-alloy based anode materials for Li secondary batteries



During discharge:

$$\text{Si (crystalline)} + x\text{Li}^+ + xe^- \rightarrow \text{Li}_x\text{Si (amorphous)} + (3.75 - x)\text{Li}^+ + (3.75 - x)e^- \quad (1)$$

$$\rightarrow \text{Li}_{15}\text{Si}_4 \text{ (crystalline)} \quad (2)$$

During charge:

$$\text{Li}_{15}\text{Si}_4 \text{ (crystalline)} \rightarrow \text{Si (amorphous)} + y\text{Li}^+ + ye^- + \text{Li}_{15}\text{Si}_4 \text{ (residual)} \quad (3)$$

CSR, 2010

Anode capacity for total specific capacity

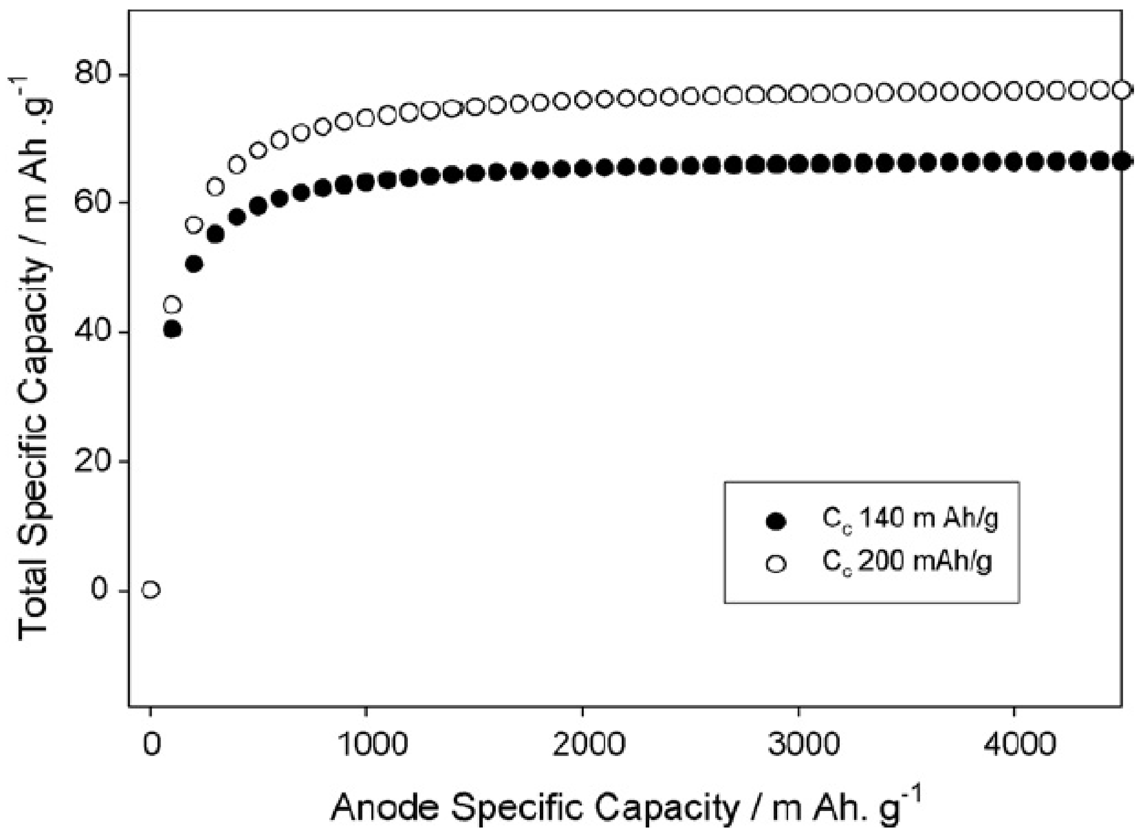
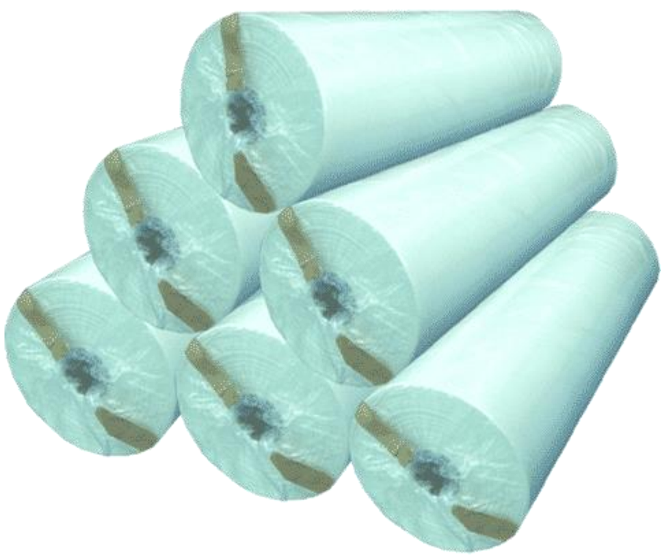


Fig. 1. Total capacity of 18650 Li-ion cell as a function of anode capacity (C_A), including masses of other required internal components and case. Capacities of cathodes considered were 140 and 200 mAh g^{-1}.

Electro Acta

隔離膜

- 材質:單層PE(聚乙烯)或者 三層複合PP(聚丙烯) +PE+PP
- 厚度:單層一般為0.016~0.020mm 三層一般為0.020~0.025mm



電解液

- 性質: 無色透明液體,具有較強吸濕性。
- 應用: 主要用於可充電鋰離子電池的電解液,只能在乾燥環境下使用操作(如環境水分小於20ppm的手套箱內)。
- 規格: 溶劑組成 DMC:EMC:EC =1:1:1 (重量比) $LiPF_6$ 濃度 1mol/l
- 品質指標: 密度(25℃)g/cm3 1.23±0.03 水分(卡爾費休法) ≤20ppm 游離酸(以HF計) ≤50ppm 電導率(25℃) 10.4±0.5 ms/cm

Electrolyte challenges:

- Liquid electrolyte （LiPF6/EC+DMC)
- Problems: leakage, non-flexibility of the cells, side reactions with charged electrodes
- Explosions

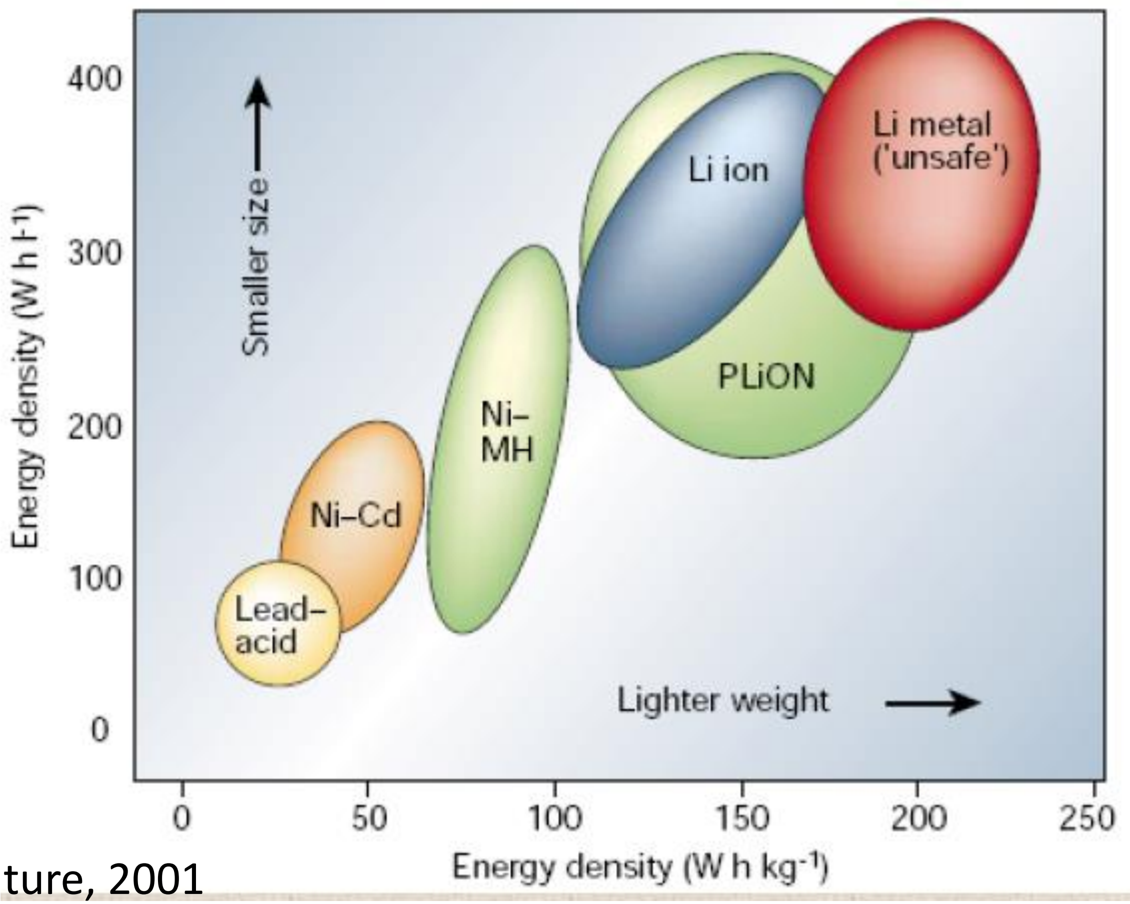
新型電解液

- 非水溶液系，如離子溶液
- 化學和電化學穩定性好，與電極材料和集流體以及隔離膜不發生反應
- 較高的離子導電性
- 沸點高、冰點低（在-40~70C保持液態）
- 高熱穩定性
- 較寬電化學視窗

Lithium-Ion and Lithium-Ion Polymer Batteries

- Great energy-to-weight ratio (~160 Wh/kg compared to 30-80 Wh/kg in NiMH)
- No memory effect.
- Slow self-discharge rate.
- Battery will degrade from moment it is made.
- Protection circuits are required to protect the battery.
- Li-Ion Polymer batteries are significantly improved.
  - Higher energy density.
  - Lower manufacturing costs
  - More robust to physical damage
  - Can take on more shapes.

Comparison of the different battery technologies in terms of volumetric and gravimetric energy density.



Armand, Nature, 2001

表 1：鋰離子電池/鎳鎘電池/鎳氫電池主要性能比較

參數/電池種類	鋰離子	鎳鎘	鎳氫
單位重量能量密度（W－Hr/kg）	90	40	60
單位體積能量密度（W-Hr/l）	210	100	140
額定電壓（V）	3.6	1.2	1.2
充電次數	1000	1000	800
自放電率（%/月）	6	15	20

Disadvantages of Li-Ion

EXPENSIVE -- 40% more than NiCd.

DELICATE -- battery temp must be monitored from within (which raises the price), and sealed particularly well.

REGULATIONS -- when shipping Li-Ion batteries in bulk (which also raises the price).

- Class 9 miscellaneous hazardous material
- UN Manual of Tests and Criteria (III, 38.3)

Schematic drawing of Li-ion batteries

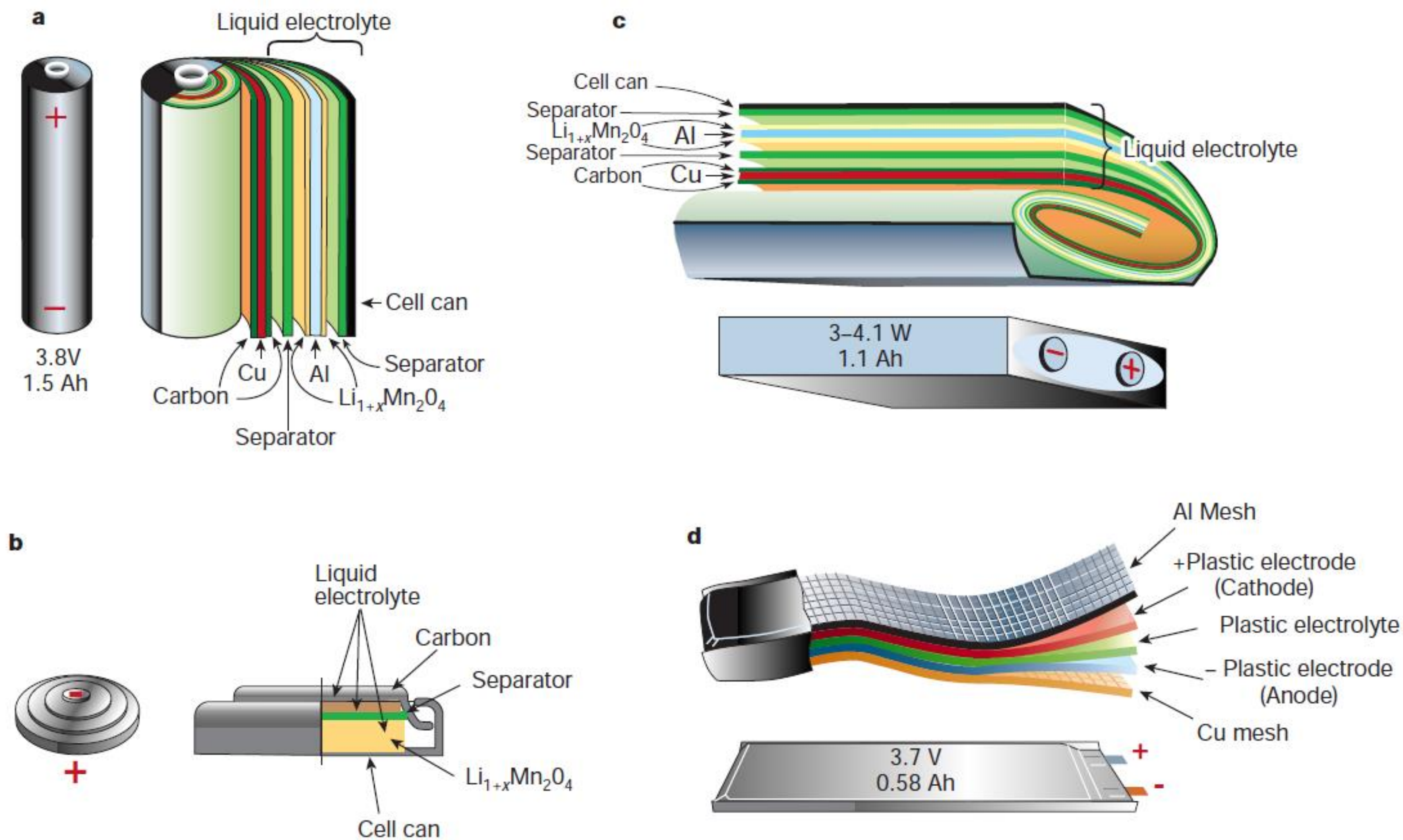


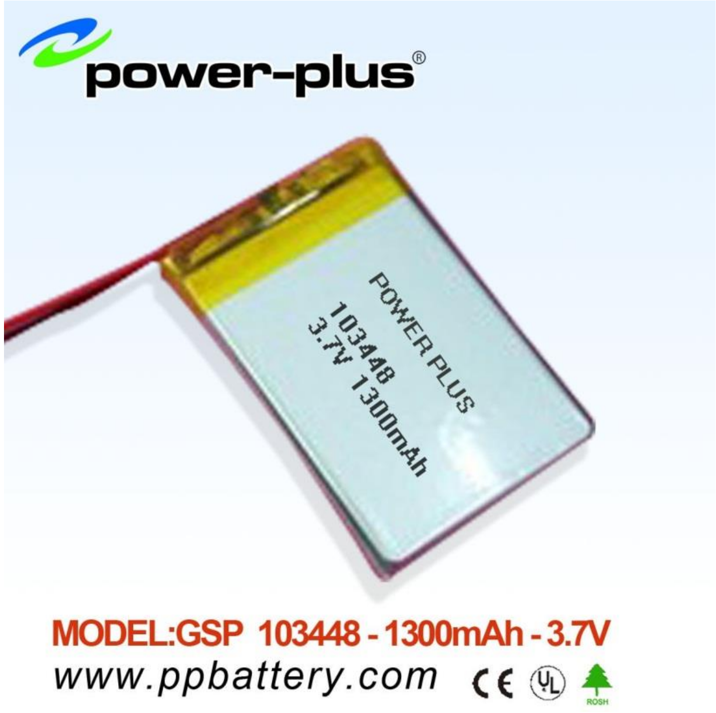
Figure 4 Schematic drawing showing the shape and components of various Li-ion battery configurations. **a**, Cylindrical; **b**, coin; **c**, prismatic; and **d**, thin and flat. Note the unique flexibility of the thin and flat plastic LiION configuration; in contrast to the other configurations, the PLiION technology does not contain free electrolyte.

Types of lithium-ion batteries

- 圓柱型：5位數 前兩位為直徑，後兩位數為高度。18650 型電池，直徑18mm, 高度65mm

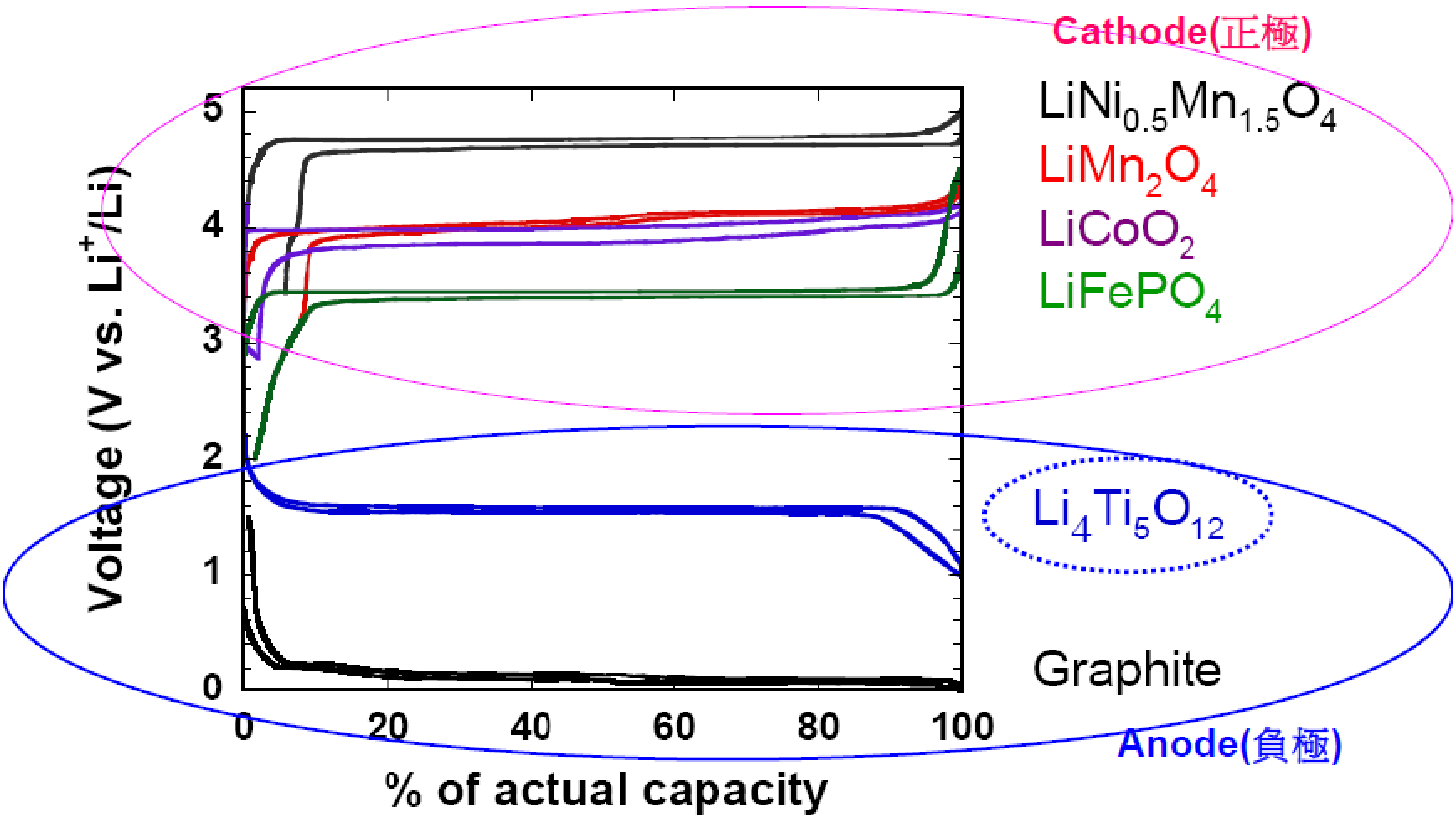
Types of lithium-ion batteries

- 方形：六位數。前兩位電池厚度、中間兩位為電池寬度，後面兩位為電池長度。083448：厚度8mm、寬度:34mm、長度48mm



Voltage of a cell

V(battery)=V正 – V負



Capacity

$$\text{Total cell (mAh g}^{-1}) = \frac{1}{(1/C_A) + (1/C_c) + (1/Q_M)}$$
$$= \frac{C_A C_C Q_M}{C_A Q_M + C_C Q_M + C_A C_C}$$

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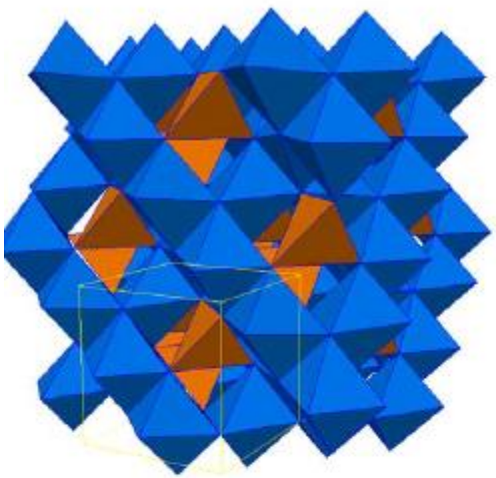
Cathode materials

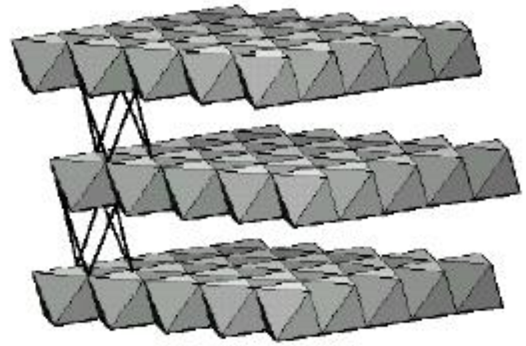


正方晶系

3D frameworks

Spinels

Fd3m



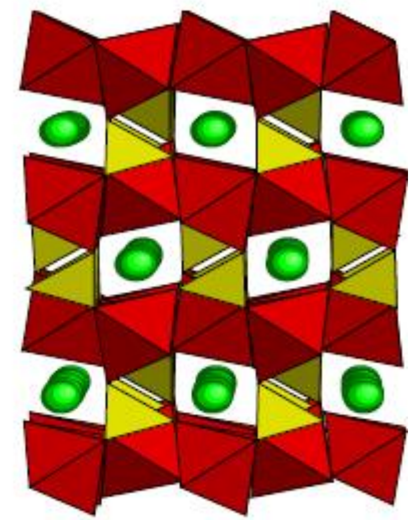
六方晶系

2D channel

Lamellar $LiCoO_2$

R3m

$LiFe^{II}PO_4$



斜方晶系

1D channel

Olivine

Pnma

Cathode materials in Lithium-ion batteries

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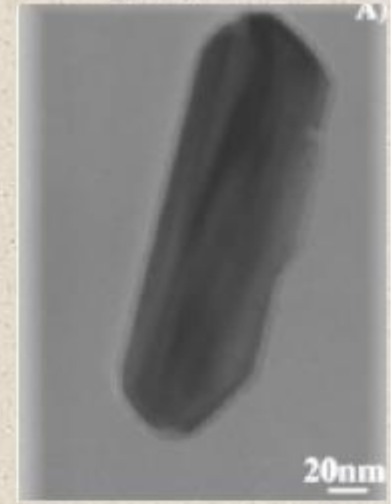
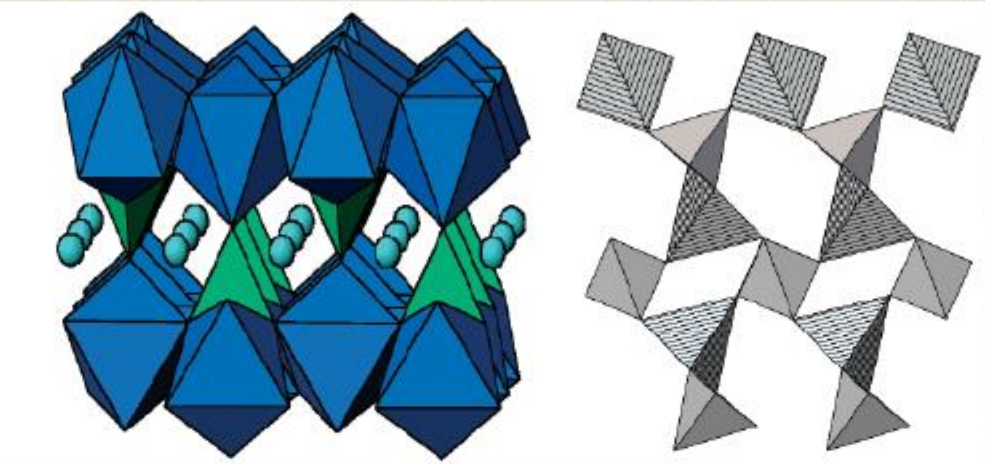
尖晶石 (Spinel)	3D	$LiMn_2O_4$	148	110	3.7	佳	低	動力電池及大型電池

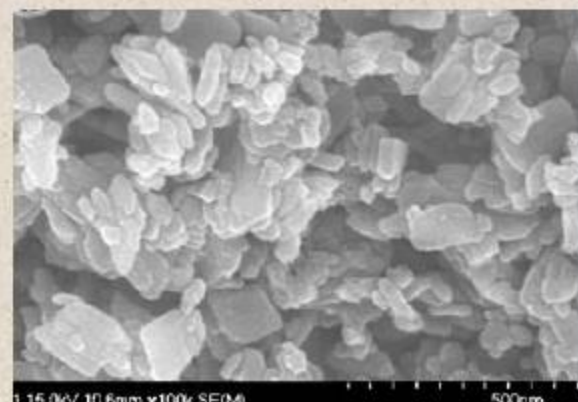
$LiFePO_4$ active material for lithium batteries

- Potentially low cost and plentiful elements;
- Environmentally benign;
- Theoretical capacity = 170 mAh/g
- Different synthetic methods: sol-gel, solid state, hydrothermal...



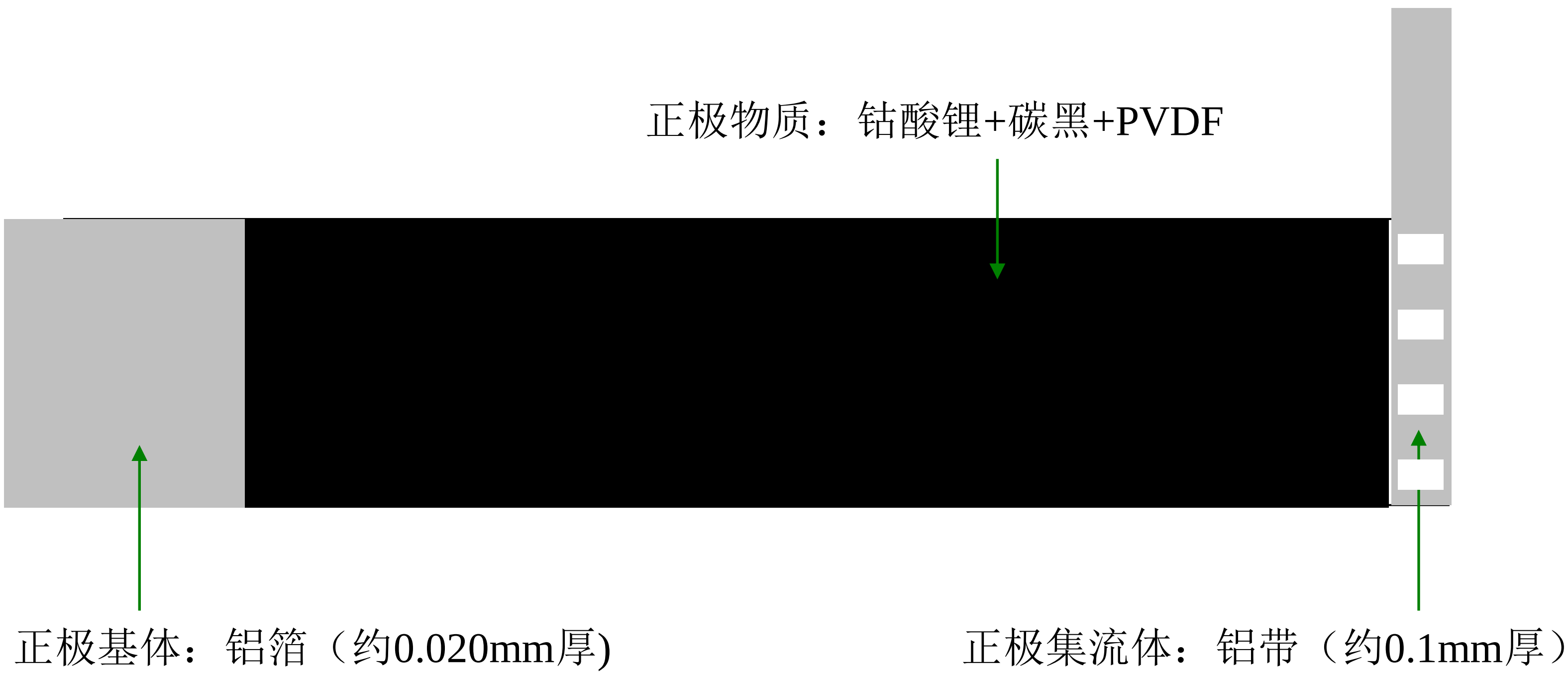


Structures of orthorhombic $LiFePO_4$ and trigonal quartz-like $FePO_4$.



Source: M. Stanley Whittingham. Chemical Reviews, 104 (2004) 4271-4301; R. Dominko,et al. Journal of The Electrochemical Society, 152 (2005) A607-A610; Bo Jin et al. J Solid State Electrochem (2008) 12:1549–1554.

锂离子电池结构——正极



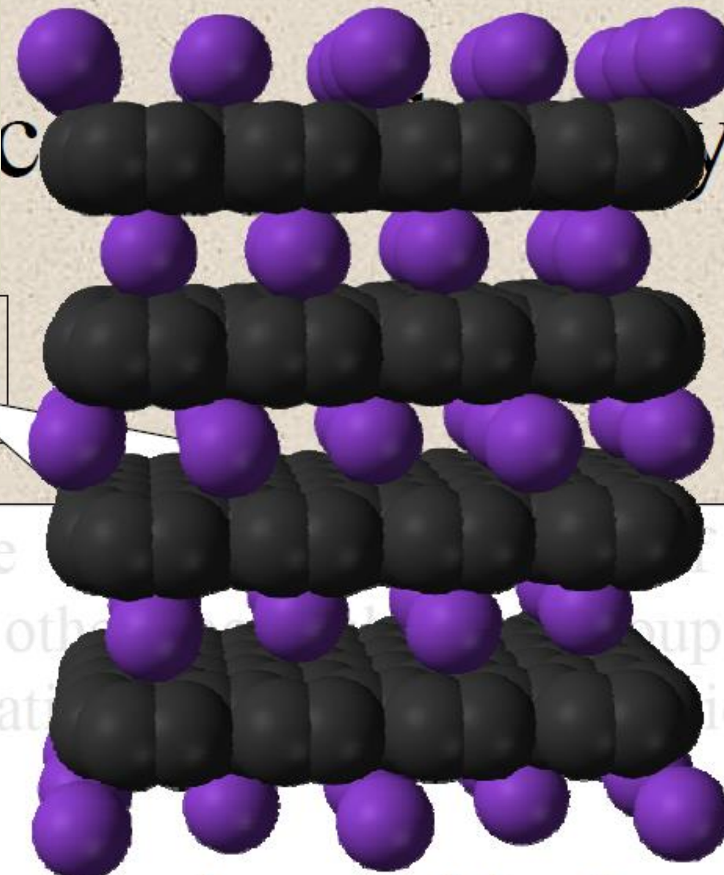
Editor: Frank Veken_Baowang

Cathode Materials Challenges

- The most desirable cathode materials are strong oxiding agents that can react with and decompose organic electrolytes
- In extreme cases, problems with internal shorts or improper voltages can trigger exthermic reactions, leading to thermal runaway and catastropic falure

Anode materials: Carbon

1972 Define the concept of chemical intercalation



In chemistry, intercalation is the ... a molecule (or group) between two oth... ups). Examples include DNA intercalat... ion compounds, etc.

Graphite intercalation compounds are complex materials where an atom, ion, or molecule is inserted (intercalated) between the graphite layers. In this type of compound the graphite layers remain largely intact and the guest species are located in between

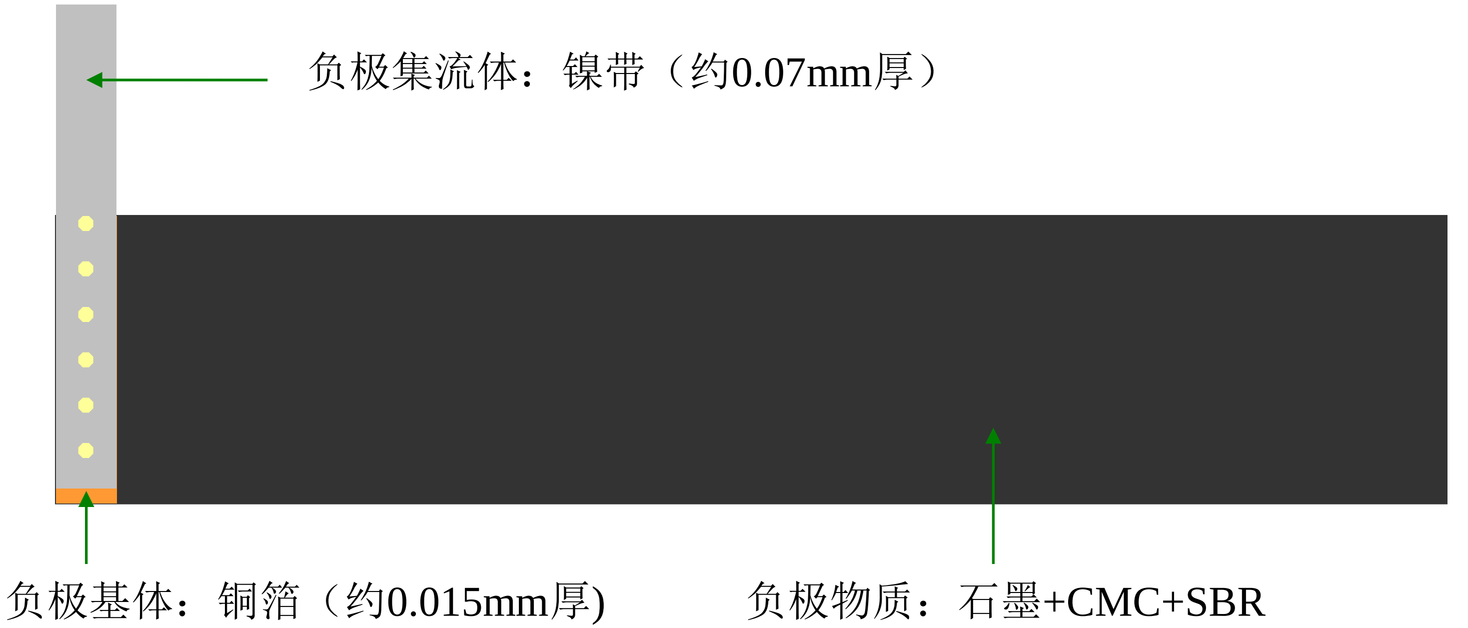
However, its theoretical capacity (LiC_6) is only 372 $mAhg^{-1}$

Figure:Space filling model of potassium graphite KC8 (side view) from: http://en.wikipedia.org/wiki/Graphite_intercalation_compound

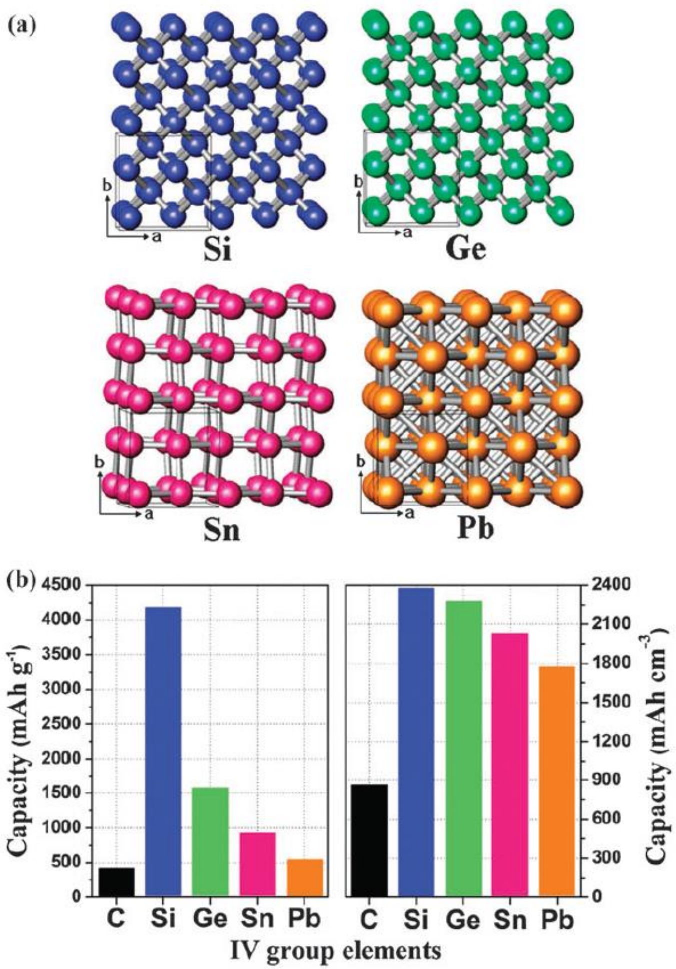
Anode materials

Anode material	Fully lithiated material	Theoretical Specific capacity (mAh/g)	Volumetric capacity* (mAh/cm^3)
Al	LiAl	993	1374
Sb	Li_3Sb	660	1881
Sn	$Li_{22}Sn_5$	994	2025
SiO	$Li_{15}Si_4$	>2000	~200
Si	$Li_{15}Si_4$	3579	2200
$Li_4Ti_5O_{12}$	$Li_7Ti_5O_{12}$	175	350
C, graphite	LiC_6	372	760

锂离子电池结构——负极



Li-alloy based anode materials for Li secondary batteries



During discharge:

$$\text{Si (crystalline)} + x\text{Li}^+ + xe^- \rightarrow \text{Li}_x\text{Si (amorphous)} + (3.75 - x)\text{Li}^+ + (3.75 - x)e^- \quad (1)$$

$$\rightarrow \text{Li}_{15}\text{Si}_4 \text{ (crystalline)} \quad (2)$$

During charge:

$$\text{Li}_{15}\text{Si}_4 \text{ (crystalline)} \rightarrow \text{Si (amorphous)} + y\text{Li}^+ + ye^- + \text{Li}_{15}\text{Si}_4 \text{ (residual)} \quad (3)$$

CSR, 2010

Anode capacity for total specific capacity

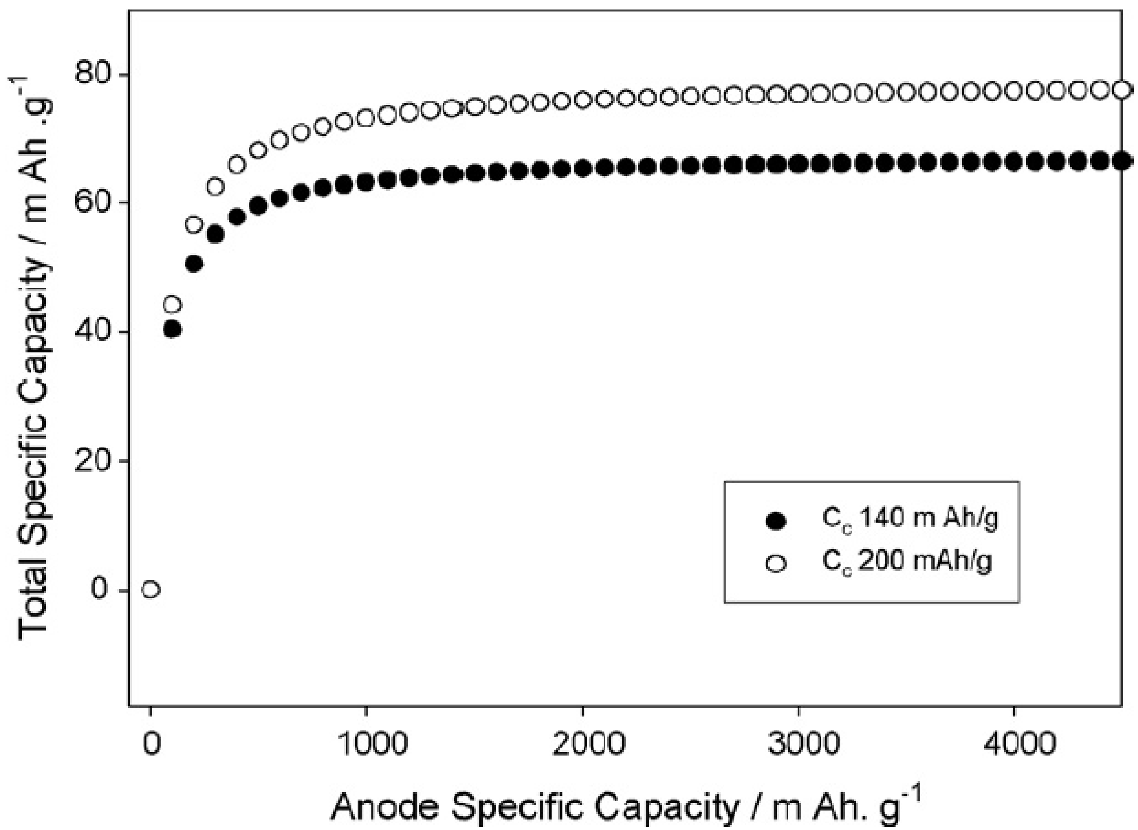
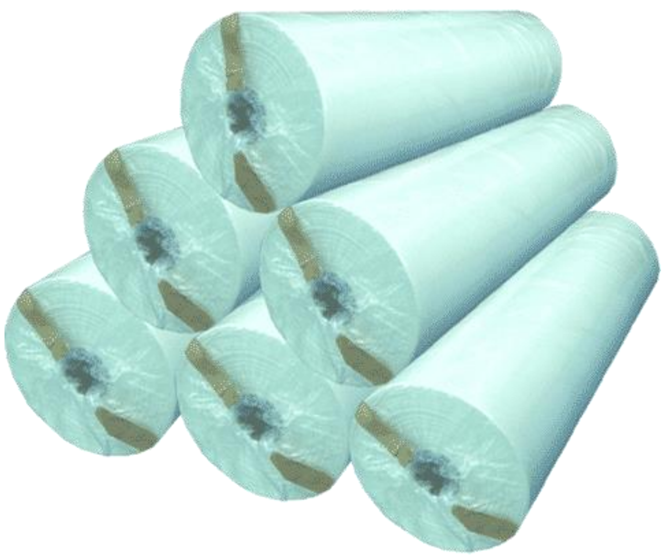


Fig. 1. Total capacity of 18650 Li-ion cell as a function of anode capacity (C_A), including masses of other required internal components and case. Capacities of cathodes considered were 140 and 200 mAh g^{-1}.

Electro Acta

隔離膜

- 材質:單層PE(聚乙烯)或者 三層複合PP(聚丙烯) +PE+PP
- 厚度:單層一般為0.016~0.020mm 三層一般為0.020~0.025mm



電解液

- 性質: 無色透明液體,具有較強吸濕性。
- 應用: 主要用於可充電鋰離子電池的電解液,只能在乾燥環境下使用操作(如環境水分小於20ppm的手套箱內)。
- 規格: 溶劑組成 DMC:EMC:EC =1:1:1 (重量比) LiPF6濃度 1mol/l
- 品質指標: 密度(25℃)g/cm3 1.23±0.03 水分(卡爾費休法) ≤20ppm 游離酸(以HF計) ≤50ppm 電導率(25℃) 10.4±0.5 ms/cm

Electrolyte challenges:

- Liquid electrolyte （LiPF6/EC+DMC)
- Problems: leakage, non-flexibility of the cells, side reactions with charged electrodes
- Explosions

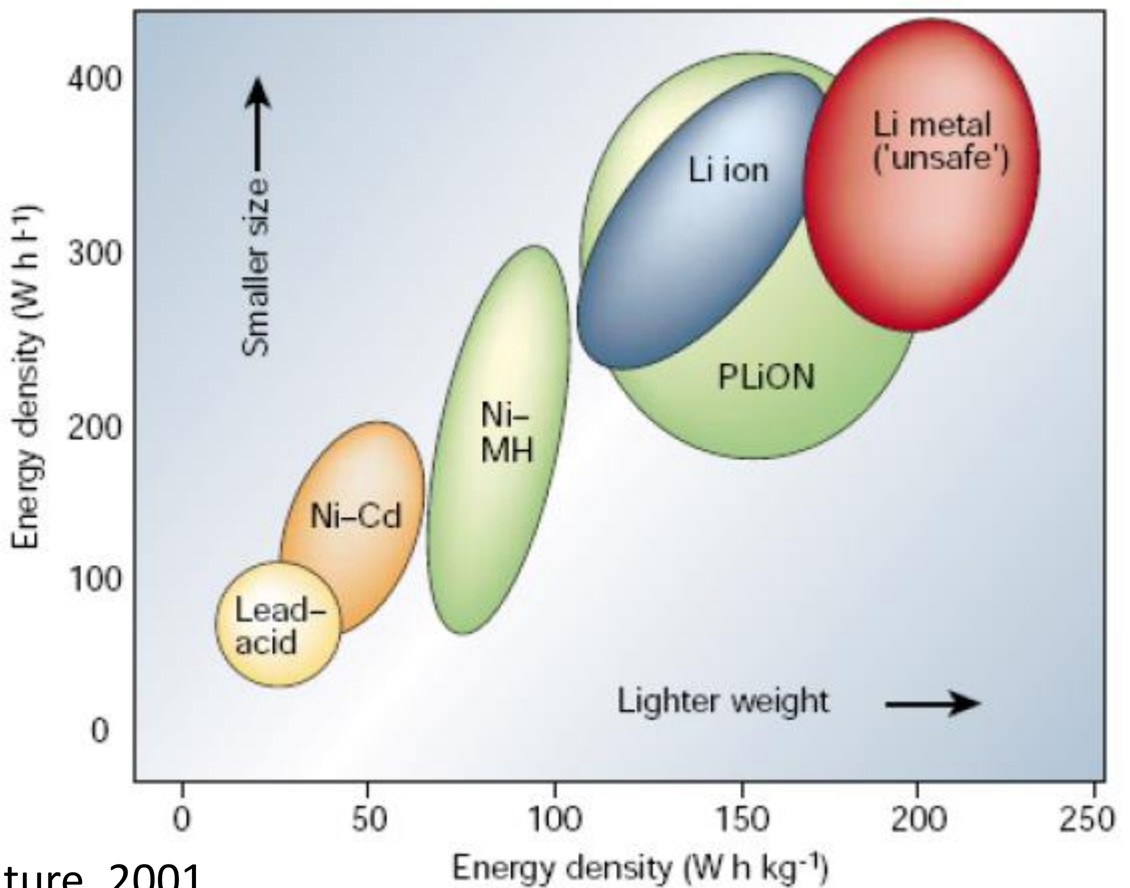
新型電解液

- 非水溶液系，如離子溶液
- 化學和電化學穩定性好，與電極材料和集流體以及隔離膜不發生反應
- 較高的離子導電性
- 沸點高、冰點低（在-40~70C保持液態）
- 高熱穩定性
- 較寬電化學視窗

Lithium-Ion and Lithium-Ion Polymer Batteries

- Great energy-to-weight ratio (~160 Wh/kg compared to 30-80 Wh/kg in NiMH)
- No memory effect.
- Slow self-discharge rate.
- Battery will degrade from moment it is made.
- Protection circuits are required to protect the battery.
- Li-Ion Polymer batteries are significantly improved.
  - Higher energy density.
  - Lower manufacturing costs
  - More robust to physical damage
  - Can take on more shapes.

Comparison of the different battery technologies in terms of volumetric and gravimetric energy density.



Armand, Nature, 2001

表 1：鋰離子電池/鎳鎘電池/鎳氫電池主要性能比較

參數/電池種類	鋰離子	鎳鎘	鎳氫
單位重量能量密度（W－Hr/kg）	90	40	60
單位體積能量密度（W-Hr/l）	210	100	140
額定電壓（V）	3.6	1.2	1.2
充電次數	1000	1000	800
自放電率（%/月）	6	15	20

Disadvantages of Li-Ion

EXPENSIVE -- 40% more than NiCd.

DELICATE -- battery temp must be monitored from within (which raises the price), and sealed particularly well.

REGULATIONS -- when shipping Li-Ion batteries in bulk (which also raises the price).

- Class 9 miscellaneous hazardous material
- UN Manual of Tests and Criteria (III, 38.3)

Schematic drawing of Li-ion batteries

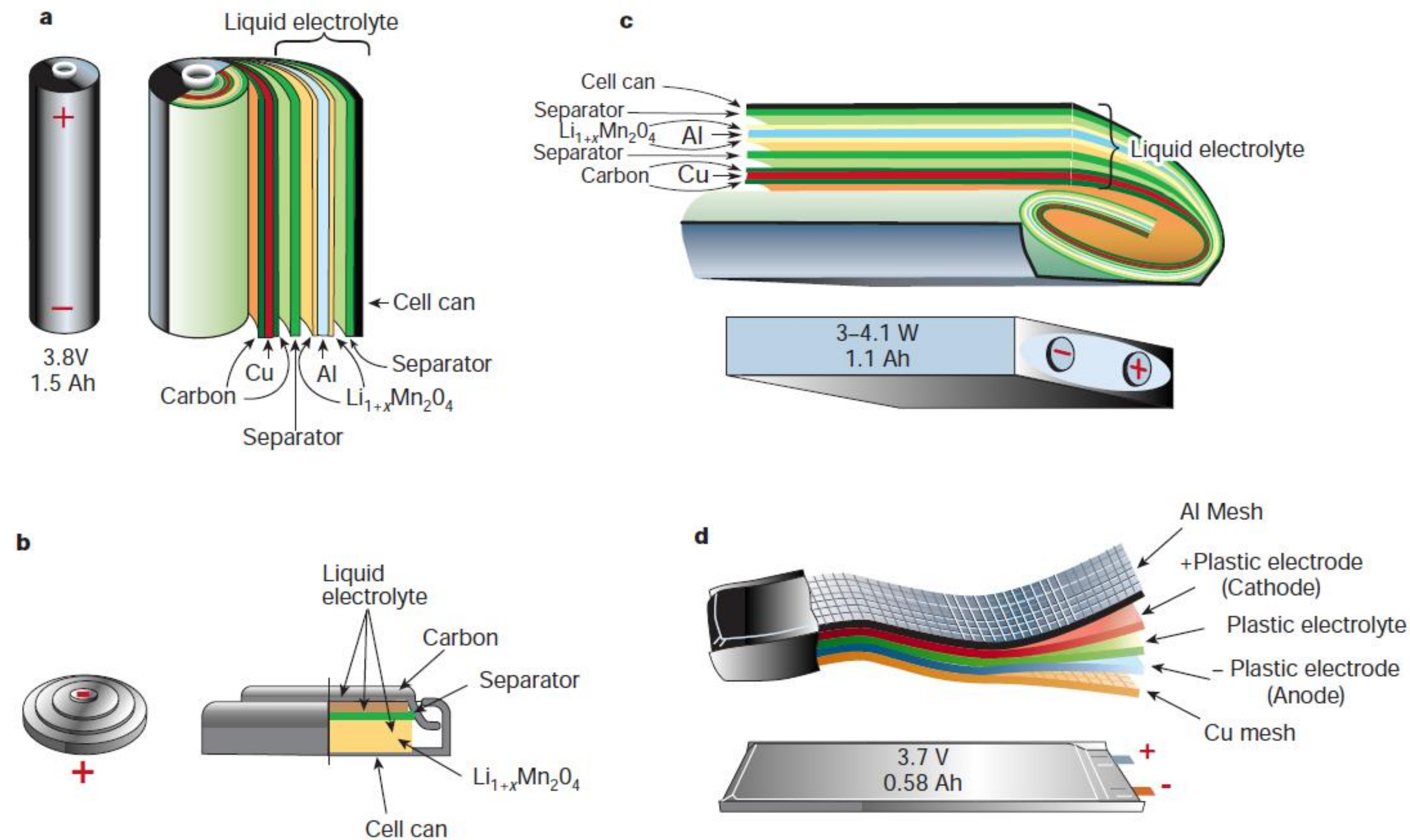


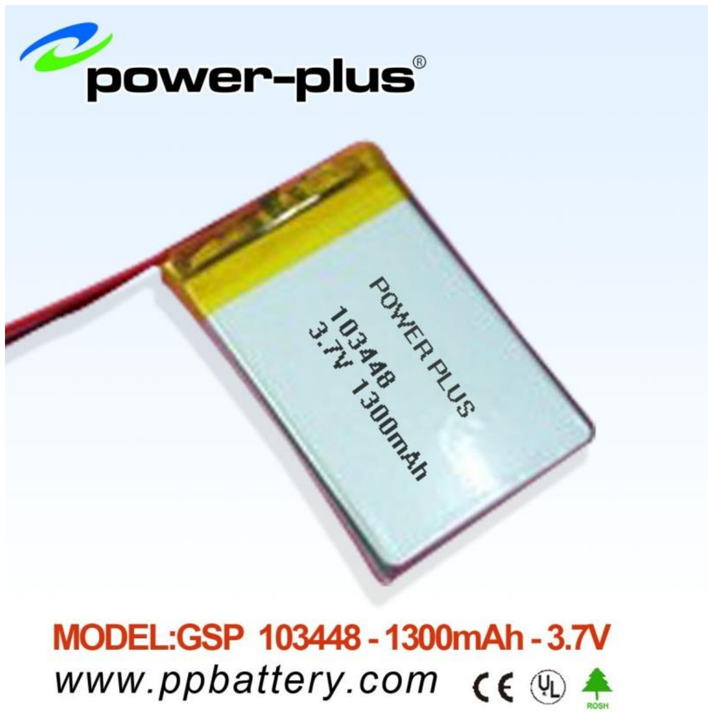
Figure 4 Schematic drawing showing the shape and components of various Li-ion battery configurations. **a**, Cylindrical; **b**, coin; **c**, prismatic; and **d**, thin and flat. Note the unique flexibility of the thin and flat plastic LiION configuration; in contrast to the other configurations, the PLiION technology does not contain free electrolyte.

Types of lithium-ion batteries

- 圓柱型：5位數 前兩位為直徑，後兩位數為高度。18650 型電池，直徑18mm, 高度65mm

Types of lithium-ion batteries

- 方形：六位數。前兩位電池厚度、中間兩位為電池寬度，後面兩位為電池長度。083448：厚度8mm、寬度:34mm、長度48mm

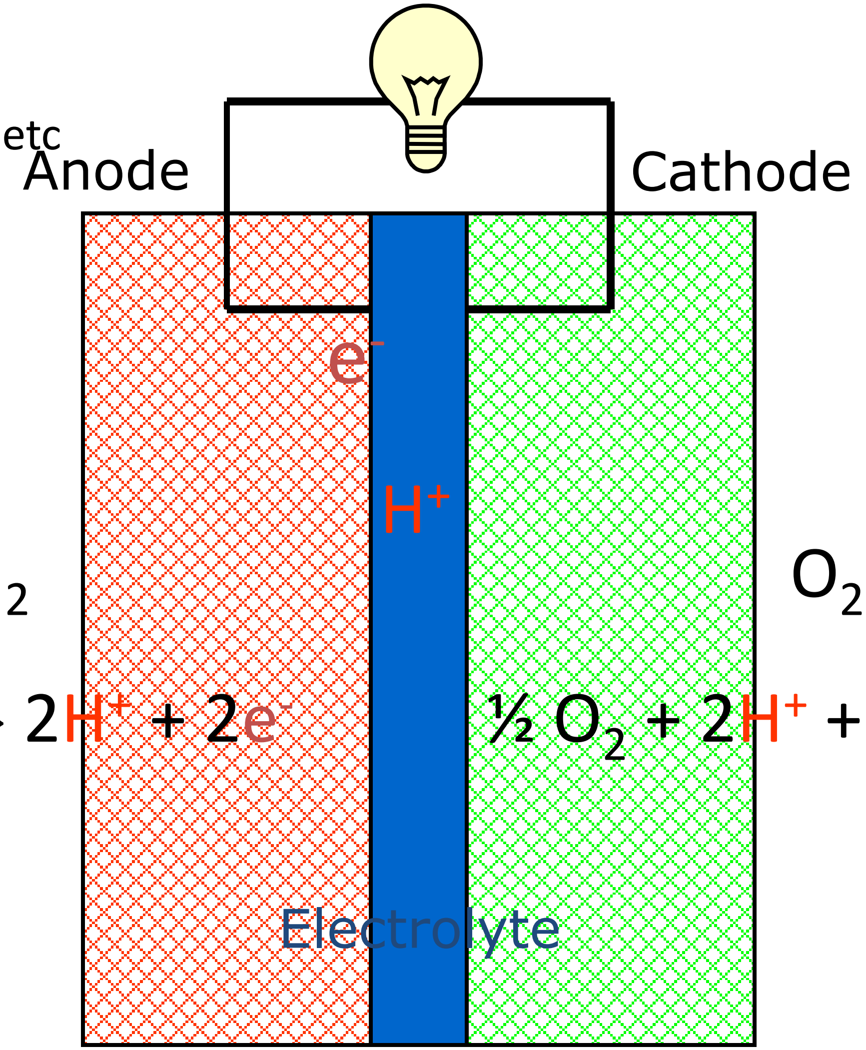


燃料電池 (Fuel Cell)

- 電池經由外界源源不絕提供可產生反應的物質，藉此持續產生能量。
- 燃料電池電極本身不具活性物質，只是個電催化元件。
- 燃料電池獲得未發生化學反應的物質（燃料）的供應，並製造出電能後，就會將發生過化學反應的物質排出，不會囤積在電池內部，只要能持續提供燃料，即可持續的製造出電能

Fuel Cell: Principle of Operation

Catalysts:
Platium, oxide, carbon etc



H_2 O_2

Supply $H_2 \rightarrow 2H^+ + 2e^-$

$\frac{1}{2} O_2 + 2H^+ + 2e^- \rightarrow H_2O$ Supply

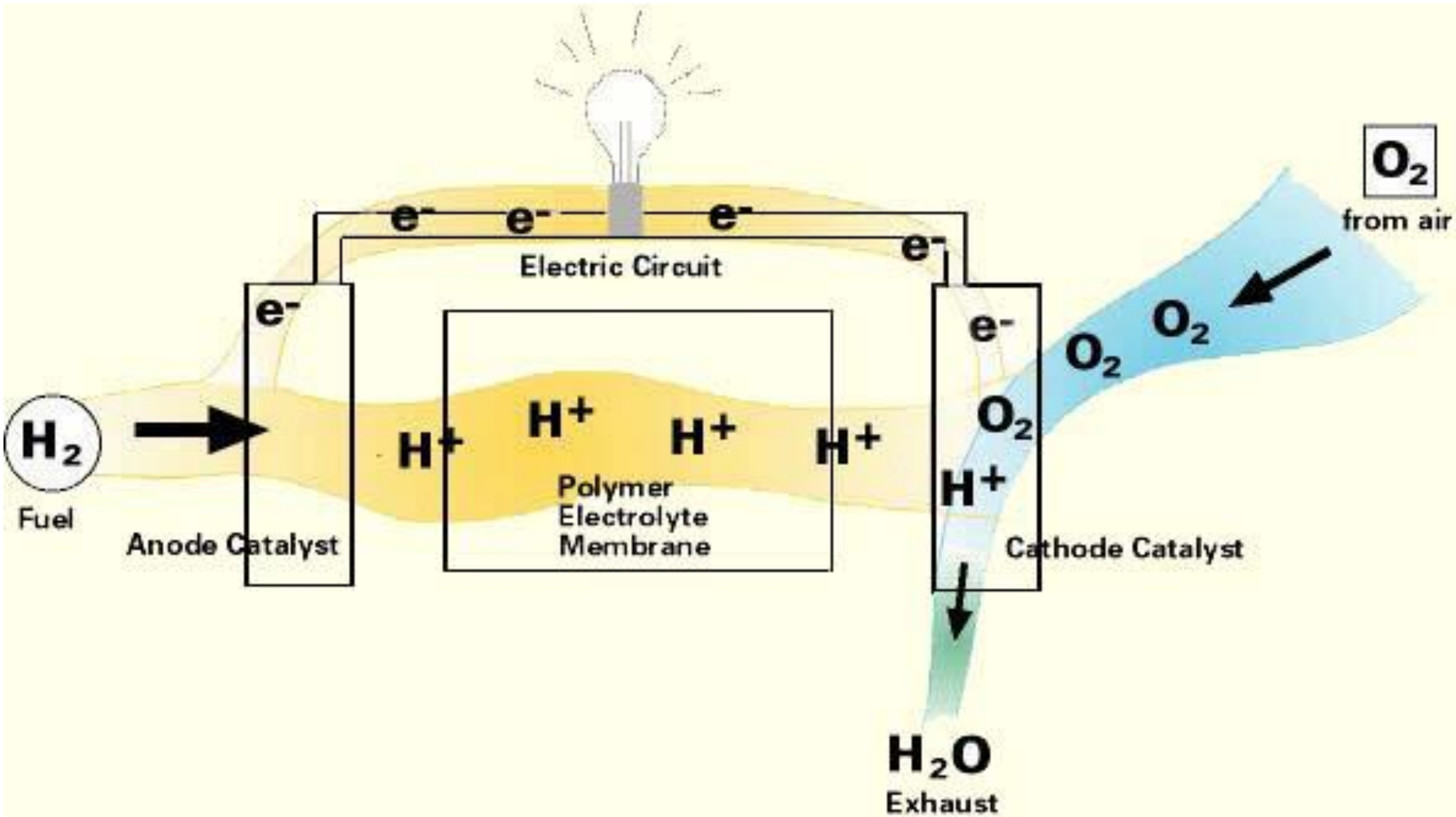
Overall: $H_2 + \frac{1}{2} O_2 \rightarrow H_2O$

燃料電池發展史

1800	
Schoenbein (1838)	發現燃料電池原理
Grove (1839)	發明燃料電池 (當時稱作「氣體電池」)
1850	
Mond and Langer (1889)	「氣體電池」正名為「燃料電池」
1900	
Reid (1902)	提出鹼性燃料電池概念 (專利)
Schmid (1923)	提出氣體擴散電極概念
Heise (1932)	開發出以蠟為疏水劑之疏水電極
1950	
Bacon (1959)	開發出可工作之 6 kW 鹼性燃料電池
Allis-Chalmers (1959)	開發出鹼性燃料電池農用曳引機
GE, Grubb and Niedrach (1960)	開發出「Grubb-Niedrach 燃料電池」
GE, Gemini Space Mission (1962)	應用高分子電解質燃料電池於雙子星太空任務
GE and Union Carbrid (1965)	應用 Teflon® 於疏水氣體擴散電極
P&W, Apollo Space Mission (1965)	應用鹼性燃料電池於阿波羅太空任務
Dupont (1972)	杜邦開發出 Nafion® 質子交換膜
P&W, TARGET (1967-1976)	普惠主導「目標」之磷酸燃料電池開發計畫
Moonlight Project (1981-1992)	「月光計畫」── 日本首度進行之燃料電池開發計畫
Jet Propulsion Laboratory (1992)	JPL 首度將 Nafion® 膜應用於直接甲醇燃料電池
Ballard Power System (1993)	巴拉德推出質子交換膜燃料電池電動車
CaFCP (1998)	「加州燃料電池夥伴聯盟」成立
2000	
Toyota & Honda (2002)	以租用方式正式推出燃料電池乘客車
Hydrogen Fuel Initial (2003)	美國政府推出「自由車」燃料電池電動車發展計畫
Freedom Fuel (2003)	美國政府推出「燃料解放」氫能發展計畫
International Partnership for the Hydrogen Economy (2003)	17 個國家地區組成氫能經濟國際合作組織

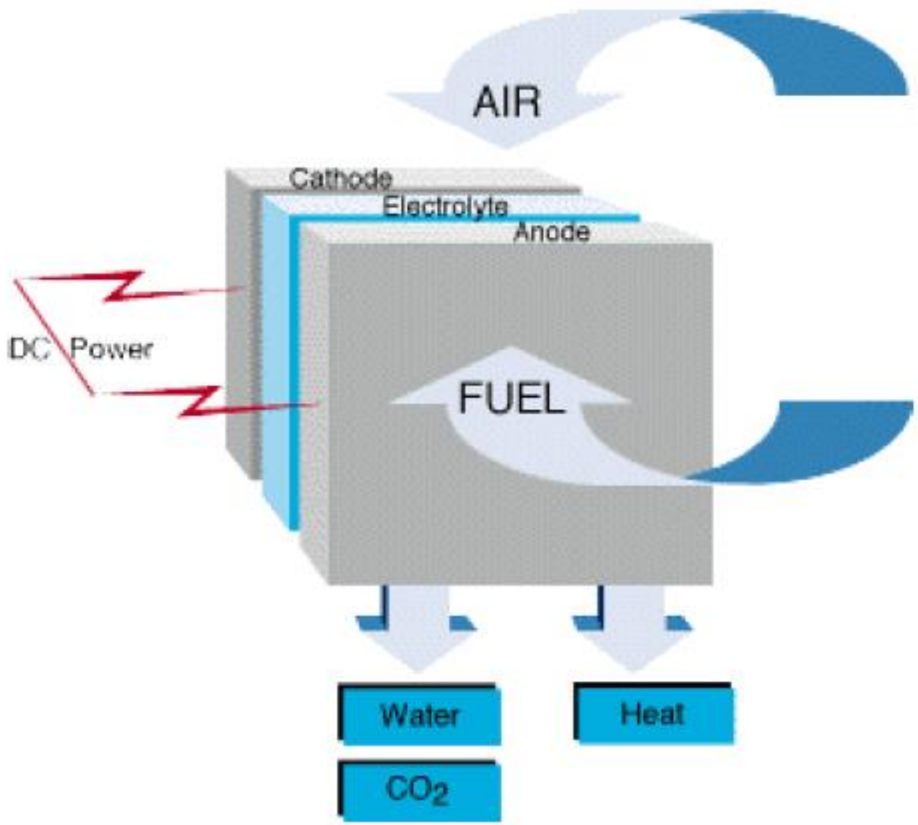
黃鎮江 燃料電池

How does a Fuel Cell work?

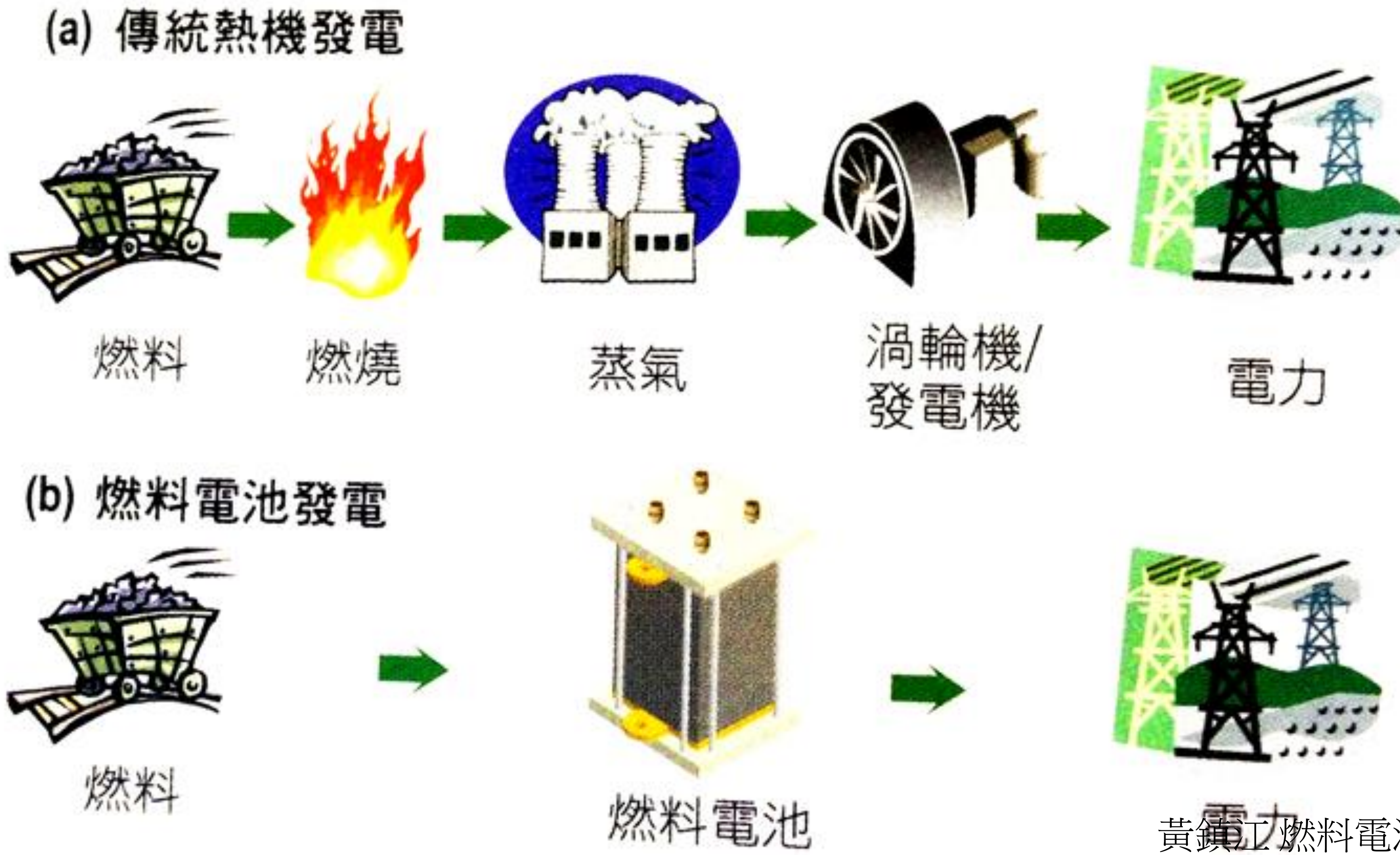


How a fuel cell function

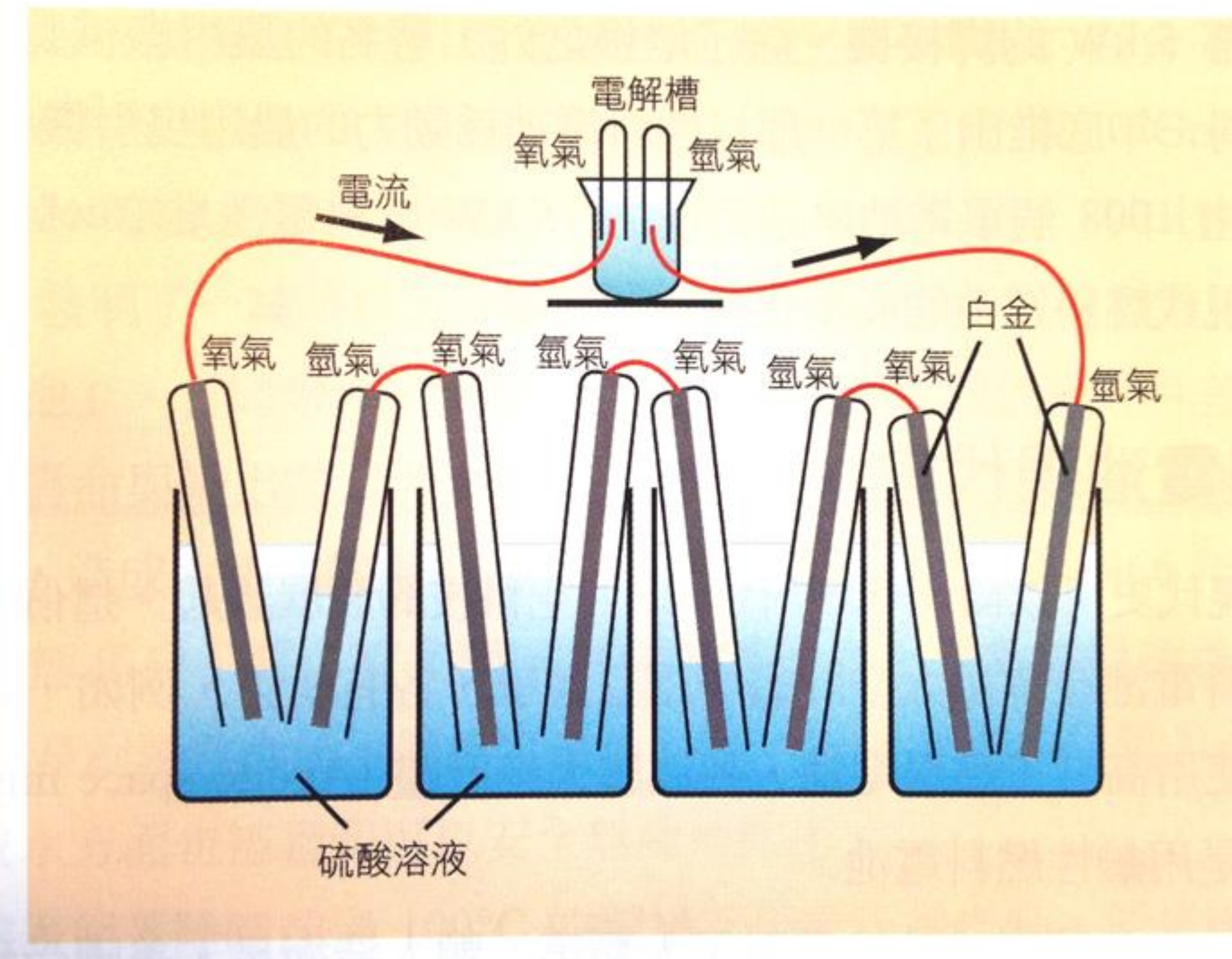
- Unlike battery, fuel cell does not run down or require recharging.
- Fuel cell consists of two electrodes sandwiched around an electrolyte.
- Encouraged by catalysts, H_2 (fuel) and O_2 (air) occur anodic and cathodic reaction (with electrons create a separate current) then generate electricity, water and heat by chemical reaction.



燃料電池與傳統熱機的火力發電比較

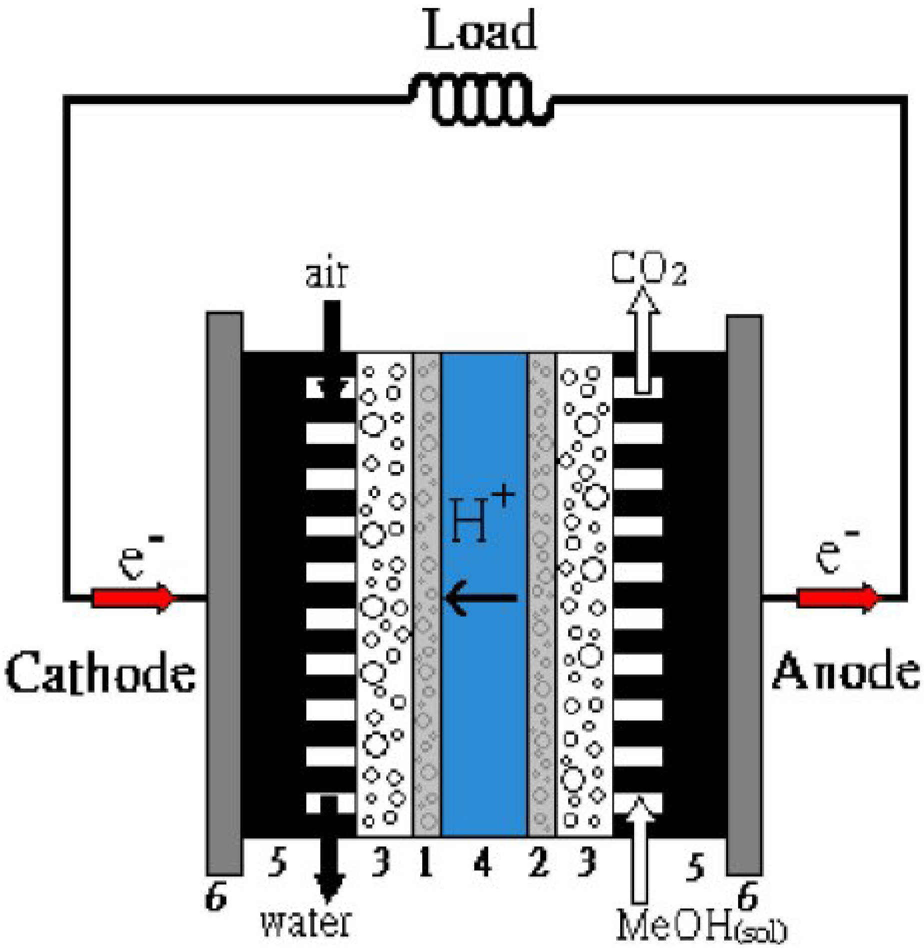


Willam R. Grove 進行的氣體電池實驗



黃鎮江 燃料電池

DMFC, direct methanol fuel cell



Anode

$$CH_3OH + H_2O \rightarrow CO_2 + 6H^+ + 6e^-$$

Electrolyte

Cathode

$$3/2\ O_2 + 6H^+ + 6e^- \rightarrow 3H_2O$$

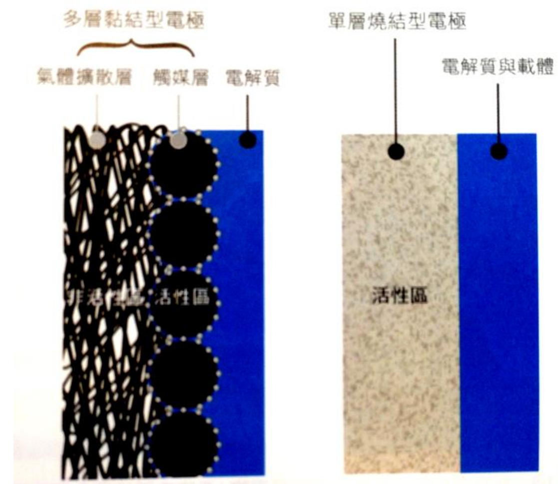
Overall

$$CH_3OH + 3/2\ O_2 \rightarrow CO_2 + 2H_2O$$

觸媒與多孔氣體擴散電極

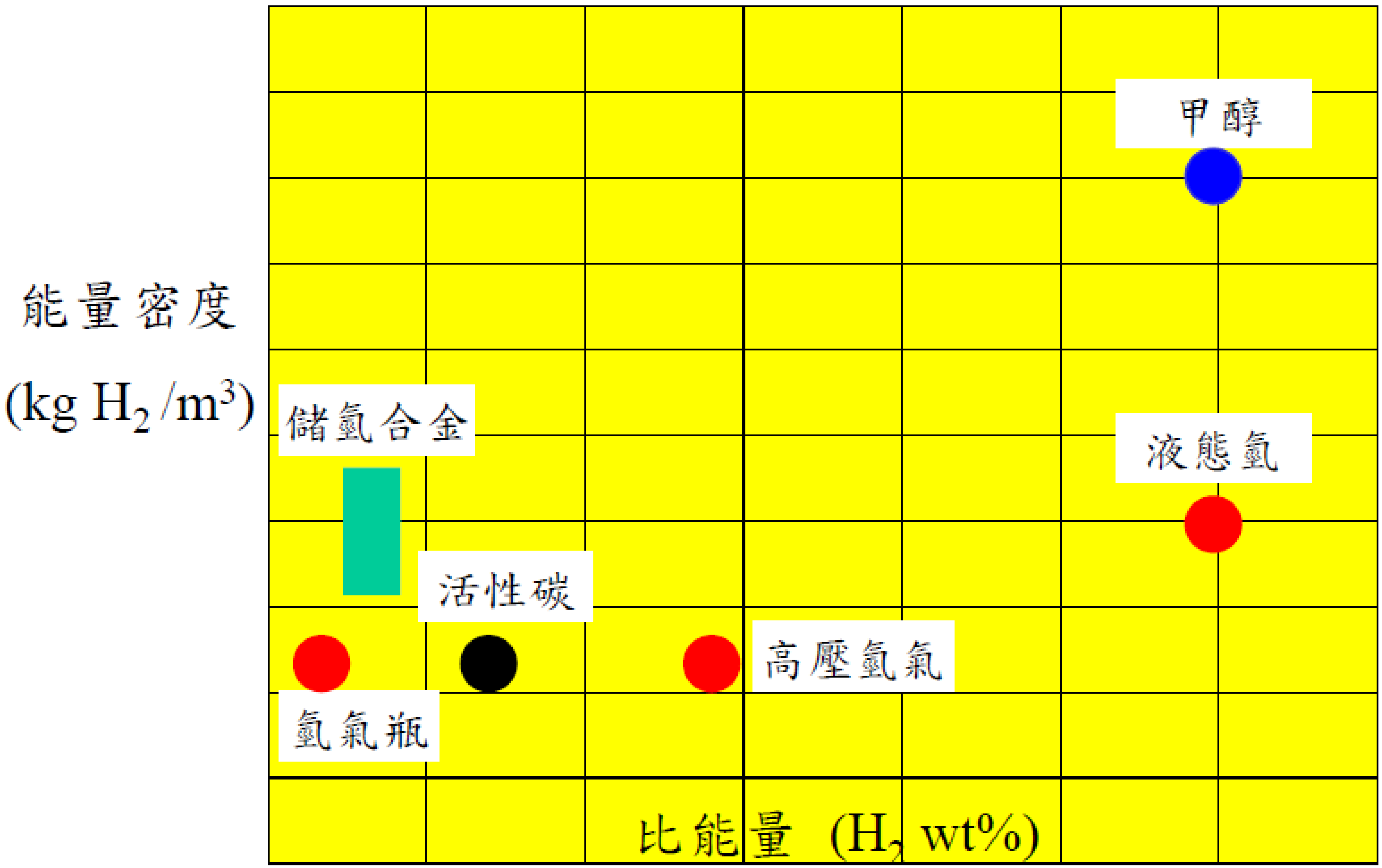
表 1-5 燃料電池使用觸媒電極結構之比較

種類	AFC	PEMFC	PAFC	MCFC	SOFC
陽極觸媒	雷尼鎳、鉑/碳	鉑/碳	鉑/碳、鉑釕/碳	鎳-鉻合金、鎳-鋁合金	鎳/YSZ
陰極觸媒	雷尼鎳、鉑/碳	鉑/碳	鉑/碳	鋰化-氧化鎳	摻鍶錳酸鑭
電極結構	單層雷尼鎳電極或多層黏結型電極	多層黏結型電極	多層黏結型電極	單層燒結型電極	單層燒結型電極



- 主要可分為單層燒結型電極以及多層的黏結型電極
- 單層：將金屬觸媒與電解質之混合粉末以燒結方式製作多孔結構
- 多層：在高分散型觸媒內填加黏結劑 (PTFE)後黏貼至氣體擴散層上。擴散區為非活性區

燃料電池用燃料系統之比較

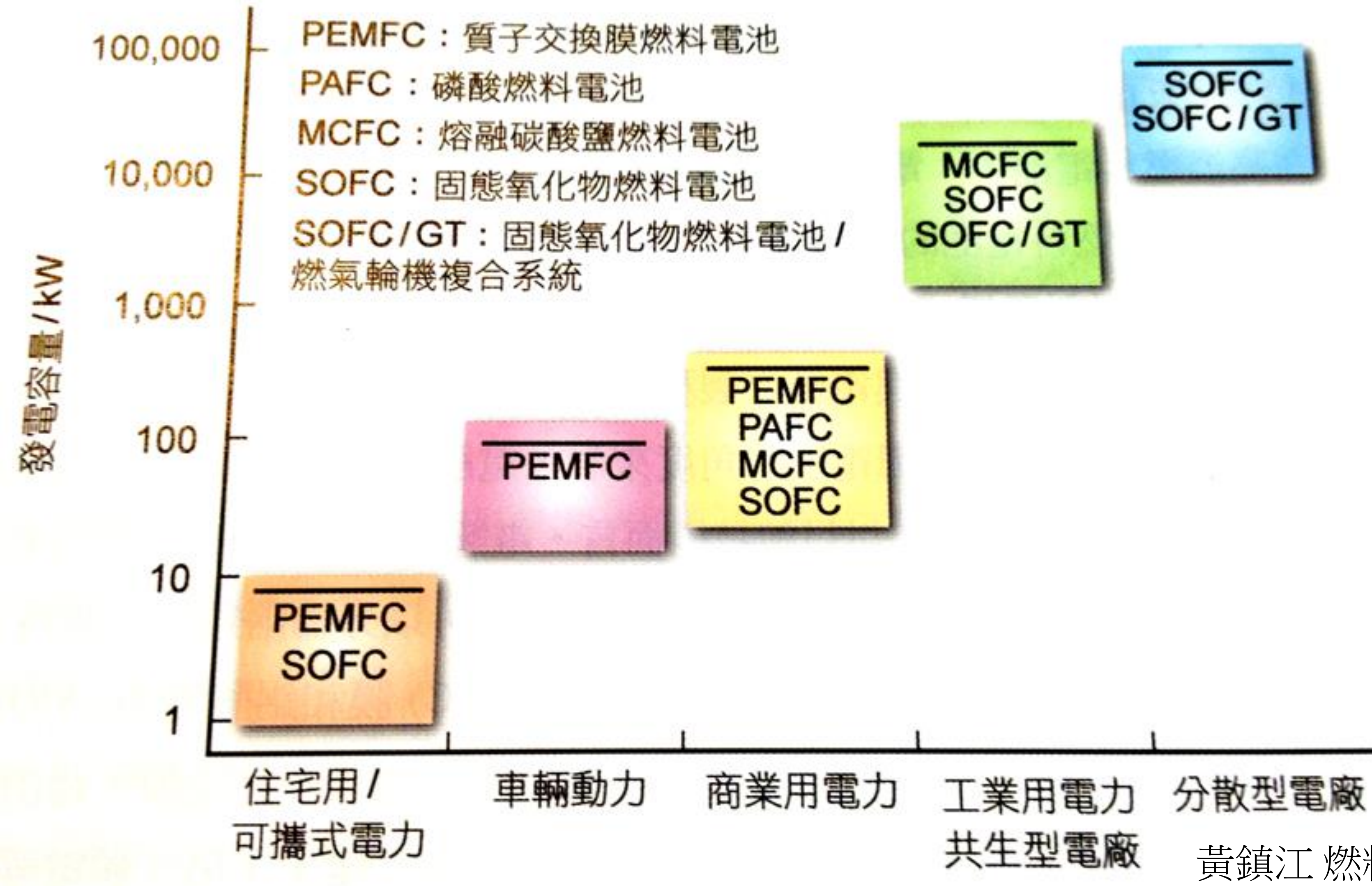


燃料電池的分類

- 依電解液性質可分為五類

1) 鹼性燃料電池 （ alkaline fuel cell,AFC)
2) 磷酸燃料電池 (phosphoric acid fuel cell, PAFC)
3) 質子交換燃料電池 (proton exchange membrance fuel cell, PEMFC)
4) 溶融碳酸鹽燃料電池 (molten carbonate fuel cell, MCFC)
5) 固態氧化物燃料電池 (solid oxide fuel cell, SOFC)

燃料電池發電容量與適用範圍



黃鎮江 燃料電池

燃料電池特點

- 效率高：目前工作的燃料電池效率可達40-60%,平均單位質量燃料所產生的電能，僅次於核能
- 噪音低：結構簡單且沒有運轉機件
- 污染低：氫氣為主要燃料。
- 進料廣：只要含有氫原子的物質都可以當作燃料來源，包括天然氣、石油、燃煤、酒精、甲醇。
- 用途多：可提供的電力範圍在1W~1000MW間

Fuel Cell