CAS researches on next generation lithium batteries

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Beyond Li ion IX, PNNL, *20160524*

中国科学院未来先导专项
长续航动力学研究

Outline

1. Strategies of Li batteries
2. CAS-SPRP project on Li batteries
3. Highlight of SPRP progresses

中国科学院纳米先导专项
长续航动力锂电池

Battery everywhere, not very satisfied

Extended to two days

Triple distance

20-30 years life

Performances of batteries

Energy density
Power density
Cycle life
Service life
Energy effi.
Self-discharge
Safety
Durability
Cost
Environmental

Long operating time

Lighter batteries

High power density

transparent small flexible

J. Y. Peng, C. X. Zu, H. Li, *Energy Storage Sci. Tech.*, 2013, 2, 55-62

Status of EV battery

G1

Roadster

LCO/C
530Wh/L

Leaf

LMO/C
314Wh/L

Active E

LFP/C
297Wh/L

E150EV

LFP/C
297Wh/L

e6

LFP/C
245Wh/L

G2

Model S

NCA/C
685Wh/L

Leaf

LMO/C
440Wh/L

i3

NCM/C
344Wh/L

EV200

NCM/C
396Wh/L

秦EV

LFP/C
320Wh/L

G3

Higher energy density EV batteries ?

中国科学院纳米先导专项
长续航动力锂电池

Extend driving distance using HELB

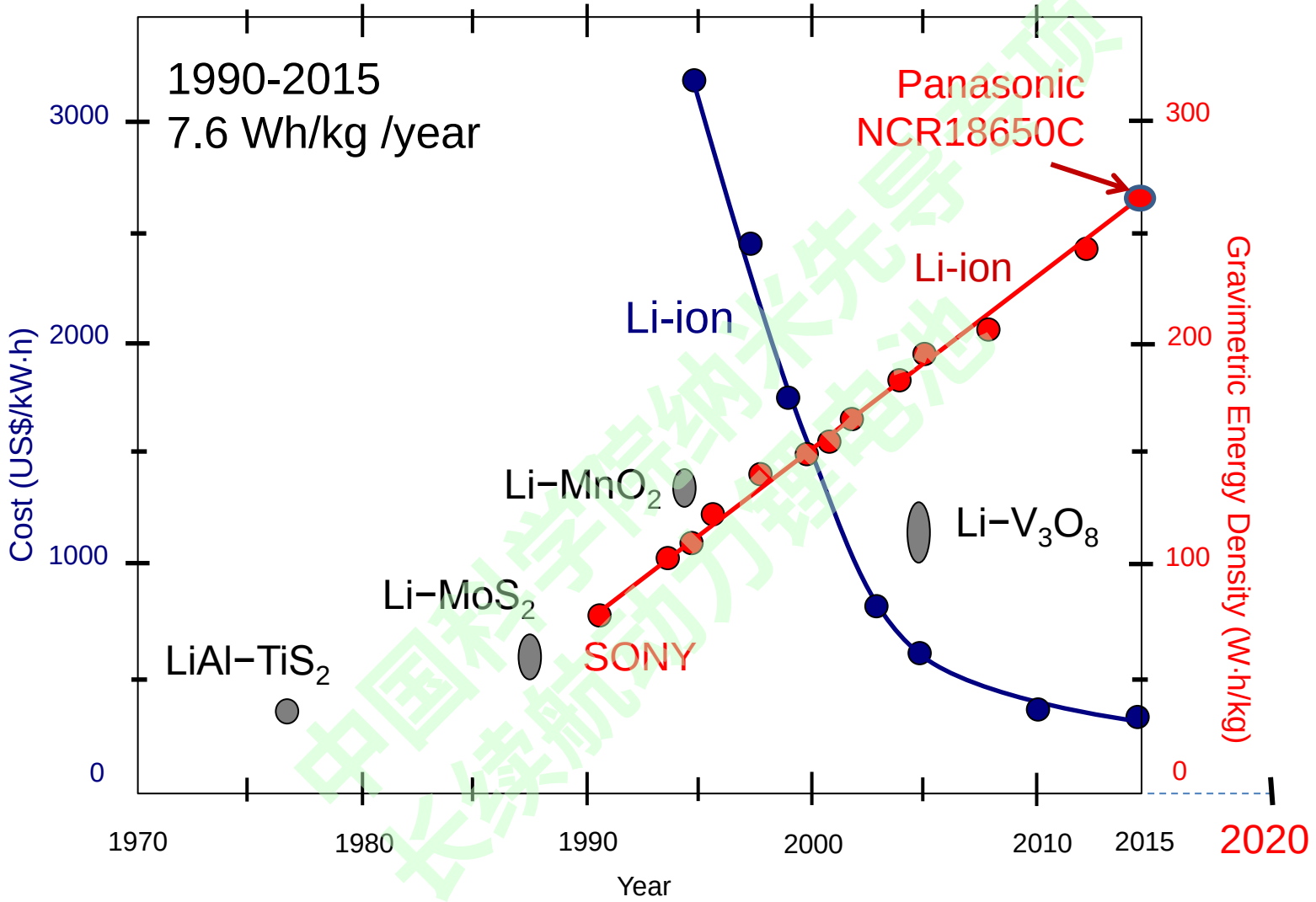
Model：EV200 (BJEV)
14kWh/1.29 ton
Guarantee：10 year
200, 000km
Volume of pack：220 L

Energy Wh/kg	Energy Wh/L	Energy /kWh	Weight /kg	Distance /km	Life/ Times
180	360	30.5	278	200	2000
300	600	66.0	314	470	900
400	800	88.0	314	628	650

- Current cell level：LG/SDI/CATL: 165-180 Wh/kg
- 2016-2017: 220-250 Wh/kg

中国科学院纳米先导项目
长续航动力锂电池

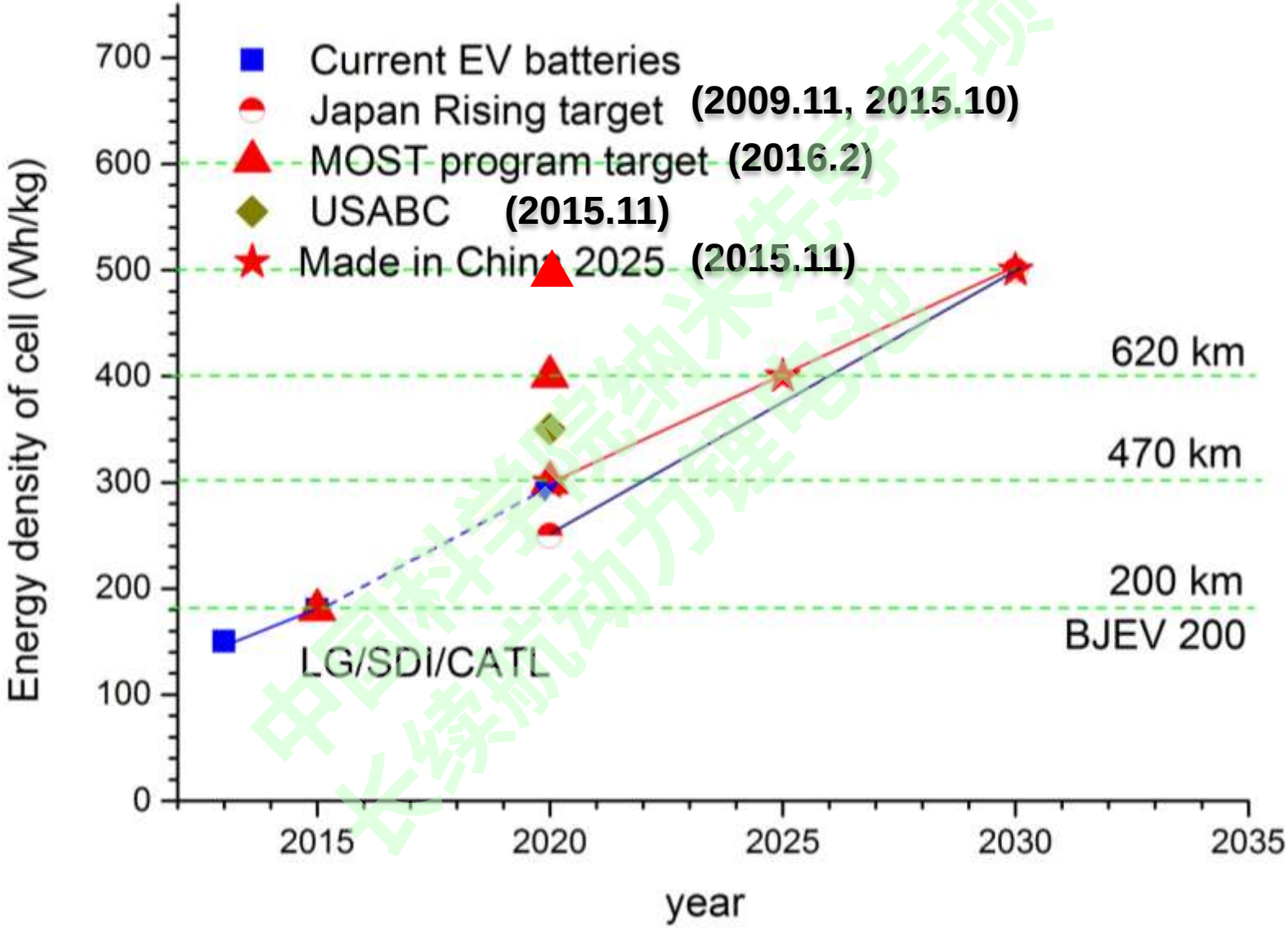
Energy density and Cost: history



Crabtree, Kocs, Trahey, MRS Bulletin, 2015, 1067

中国科学院纳米先导专项
长续航动力锂电池

Project targets: “number” game



中国科学院纳米先导专项
长续航动力锂电池

How to approach those targets?

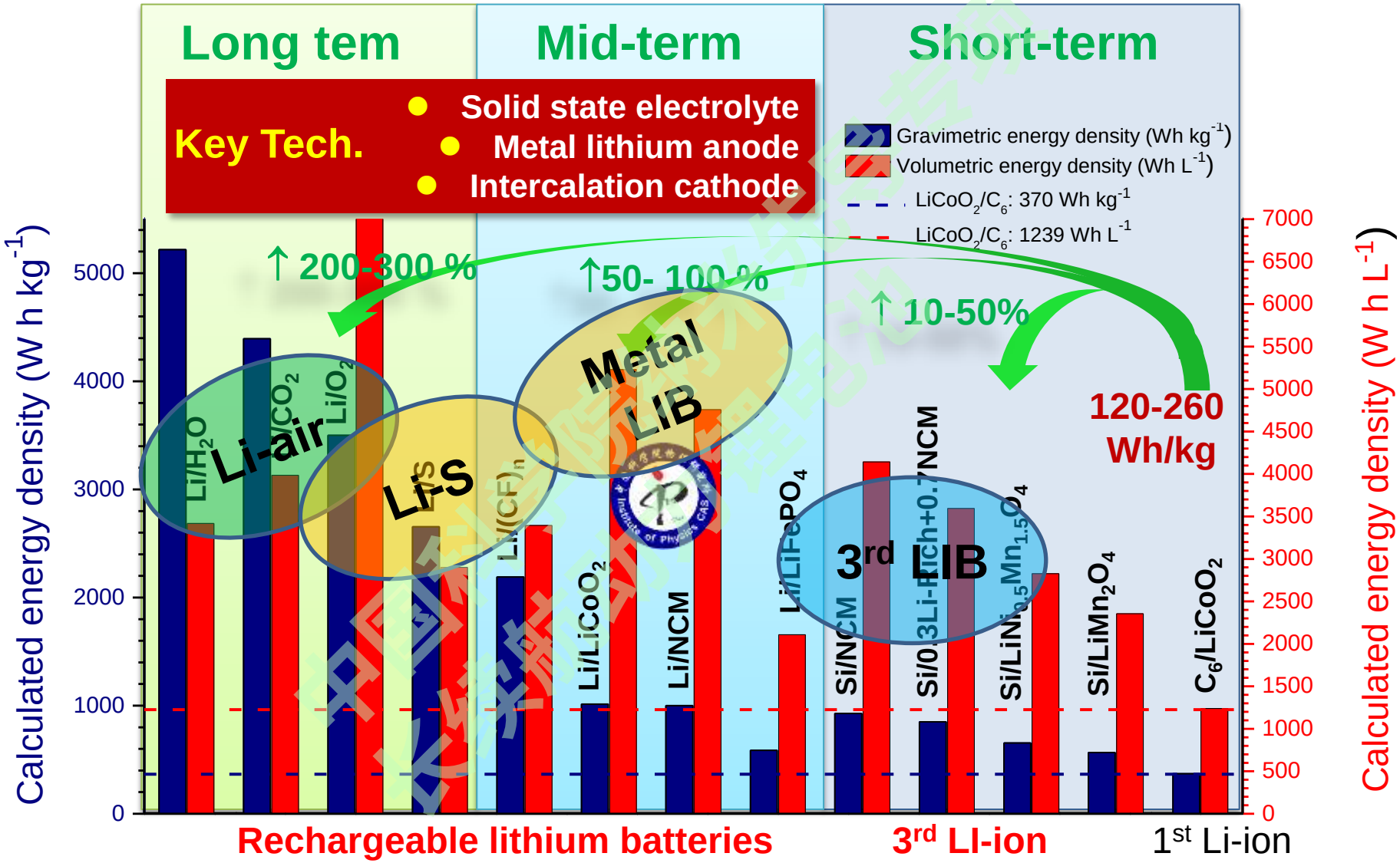
	Cathode	Anode	Electrolyte	Time	Market
1st	4.2V $LiCoO_2$	Coke	PC/DMC $LiPF_6$	1991-	CE
2nd	4.3 V $LiCoO_2$	NG AG $Li_4Ti_5O_{12}$	EC-DMC, $LiPF_6$	1994-	CE
	$LiMn_2O_4$,				EV
	$LiNi_{1/3}Co_{1/3}Mn_{1/3}O_2$				grid ,
	$LiFePO_4$				power tool
3rd	4.4-4.6 V $LiCoO_2$	Soft carbon Hard carbon SnCoC C@SiO_x C@Nano-Si/C C@Si-alloy/	**EC-DMC,** **$LiPF_6$** + VC, FEC, BP, ES, PS, LiBOB, LiTFSI, Silane, LiFSI, Ionic liquid…	2005-	CE EV HEV Grid Others
	$LiNi_{x\geq0.5}Co_yMn_zO_2$				
	$LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$				
	$LiFe_{1-x}Mn_xPO_4$				
	xLi_2MnO_3-$Li(NiCoMn)O_2$				
	$LiNi_{0.5}Mn_{1.5}O_4$				

4th generation?

Fei Luo, H. Li, JES, 2015

中国科学院纳米先导专项
长续航动力锂电池

Next, next and next: Si→ Li



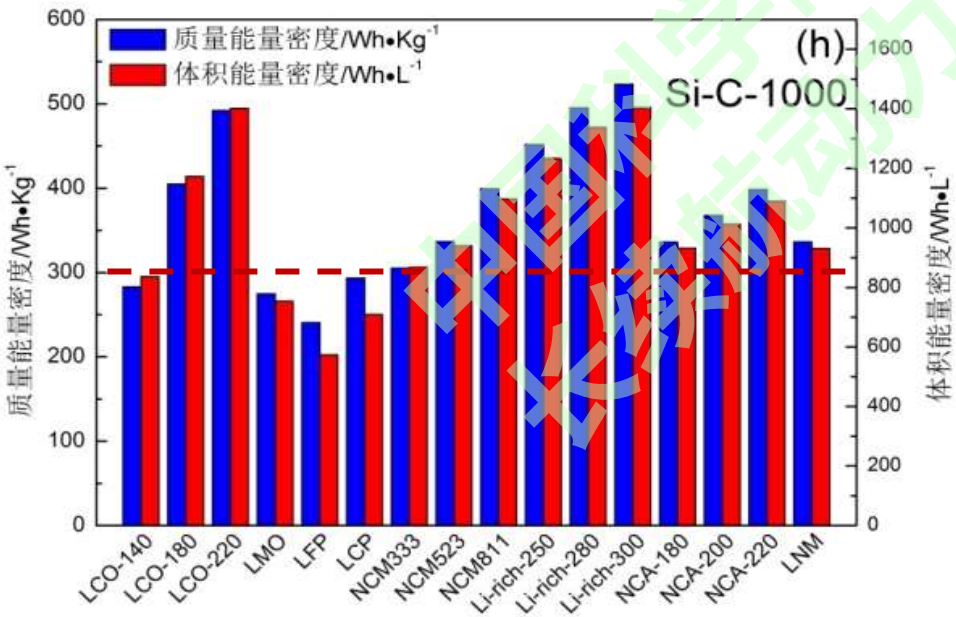
C. X. Zu, H. Li, *Energy Environ. Sci*, 2011, 4, 2614

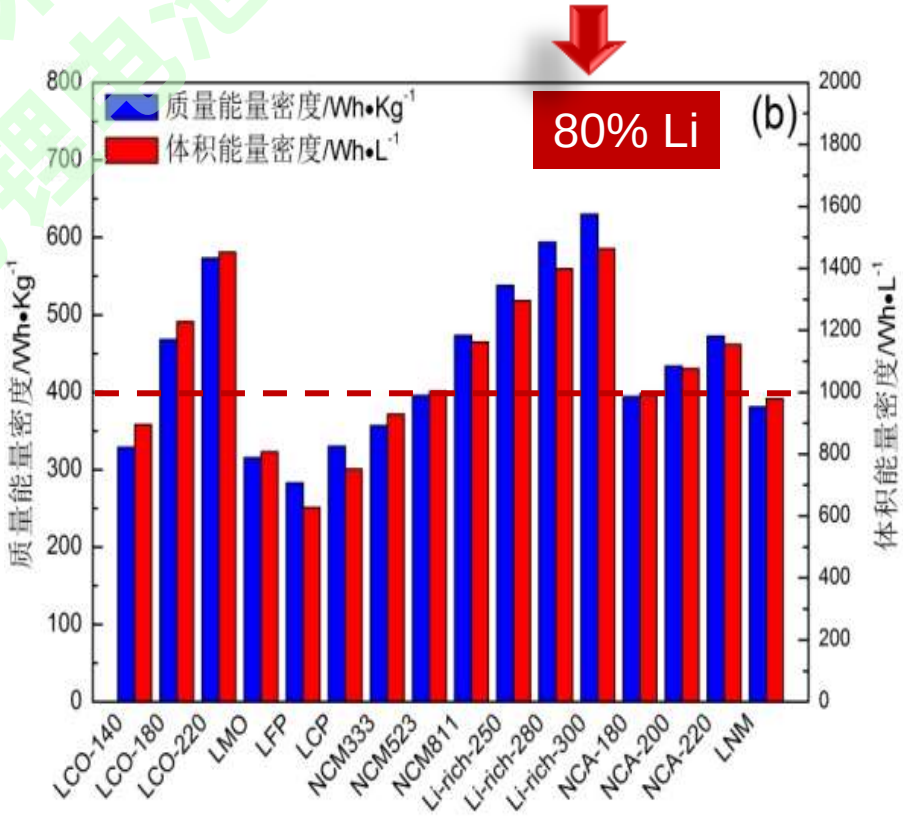
Fei Luo, H. Li, *JES*, 2015\

How to approach 300 Wh/kg?

Lithium ion batteries

- LCO： 200-240 mAh/g → 4.6V
- Li-rich：280-300 mAh/g → 2.2-4.6V
- N-rich (NCA， 811)：200-210mAh/g → 4.3 V
- Si：600-1000 mAh/g, η_1 ≥88-92%
- High voltage electrolyte
- Thinner inactive layers





中国科学院纳米先导专项
长效机动力锂电池

Calculated energy density of cell and 18650

Energy density	Graphite/ Li-rich-300	SC-400/ Li-rich-300	SiOx-420/ Li-rich-300	SiOx-1000/ Li-rich-300	Si-C-450/ Li-rich-300
Cell/Wh·kg^{-1}	409	382	432	523	443
Cell/Wh·L^{-1}	968	862	1068	1404	1105
18650/Wh·kg^{-1}	346	323	365	442	375

Energy density	Si-C-1000/ Li-rich-300	Si-C-2000/ Li-rich-300	LTO / LCO-220	Li/ Li-rich-300	Li 50%/ Li-rich-300
Cell/Wh·kg^{-1}	523	584	187	649	578
Cell/Wh·L^{-1}	1404	1645	512	1575	1206
18650/Wh·kg^{-1}	375	442	158	**558**	**533**

Cell：not including packing materials

Jiaoyang Wu, Ping Liu, Yongsheng Hu, Hong Li, Energy Storage Sci. Tech., 2016

中国科学院纳米先导专项
长续航动力锂电池

Outline

1. Strategies of Li batteries
2. **CAS-SPRP project on Li batteries**
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中国科学院纳米先导专项
长续航动力锂电池

SCI papers from countries on LIB

Web of Science , Key words: lithium + batteries

PEOPLES R CHINA	4051	38.102 %
USA	2276	21.407 %
SOUTH KOREA	1127	10.600 %
JAPAN	978	9.199 %
GERMANY	508	4.778 %
FRANCE	472	4.439 %
INDIA	374	3.518 %
SINGAPORE	338	3.179 %
AUSTRALIA	311	2.925 %
CANADA	249	2.342 %

2010-2012

PEOPLES R CHINA	8984	46.048 %
USA	3835	19.657 %
SOUTH KOREA	2033	10.420 %
JAPAN	1230	6.304 %
GERMANY	1170	5.997 %
SINGAPORE	691	3.542 %
INDIA	690	3.537 %
AUSTRALIA	578	2.963 %
FRANCE	552	2.829 %
CANADA	508	2.604 %

2013-2015

中国科学院纳米先导专项
长续航动力锂电池

- R&D on LIB researches are very active > 10000/year

Top 10 productive institutes on SCI papers

Web of Science , Key words: lithium + batteries

CHINESE ACAD SCI	540	5.079 %
CENT S UNIV	208	1.956 %
NANYANG TECHNOL UNIV	200	1.881 %
ZHEJIANG UNIV	191	1.796 %
TSINGHUA UNIV	190	1.787 %
ARGONNE NATL LAB	159	1.495 %
SEOUL NATL UNIV	148	1.392 %
UNIV SCI TECHNOL CHINA	146	1.373 %
NATL UNIV SINGAPORE	143	1.345 %
HANYANG UNIV	142	1.336 %

2010-2012

China: 5 Korea: 2
Singapore: 2 USA: 1

CHINESE ACAD SCI	1195	6.125 %
CENT S UNIV	478	2.450 %
TSINGHUA UNIV	403	2.066 %
NANYANG TECHNOL UNIV	395	2.025 %
ARGONNE NATL LAB	338	1.732 %
UNIV SCI TECHNOL CHINA	312	1.599 %
ZHEJIANG UNIV	279	1.430 %
NATL UNIV SINGAPORE	272	1.394 %
HARBIN INST TECHNOL	267	1.369 %
BEIJING INST TECHNOL	255	1.307 %

2013-2015

China: 7 Singapore: 2
USA: 1

Patents: Japan Top1 > 50%, Top 2: Korea, Top 3: China
World market share: Top 1: Korea, Top 2 China, Top 3: Japan

- Researches in China are not as effective as Japan and Korea in view of ratio of publication number/patent number

CAS Strategic Priority Research Program

"Industrial Nano-manufacturing Focus" SPRP project 2013.11.15-2018.6

- **Integrate** nanotechnologies for industries
- **Promote** the development of industrial manufacturing nanotech for new industries
- **Enhance** the capability to develop new technologies and set standard for some nanotech.

中国科学院纳米先导专项
长续航动力锂电池

Principles of **Strategic Priority Research Program**

1. Targets should be defined clearly (product based);
2. Results must be evaluated by the third party;
3. Innovations are used by industry;
4. Developed technologies are leading in China

Previous CAS vice director, Hejun Yin

中国科学院先导专项
长续航动力锂电池

"CAS Nano-Technologies" SPRP project

Strategic Nanotech.

Project 1：Lithium batteries for EV

Project 2：Green Nanoprinting Tech.

Promising Nanotechnology

Project 3：Nano for Energy, Environ. Health

Nano-materials in petroleum transport, chemical production, high voltage grid, deep clean of water, new medicines, diagnosis chips

Technologies Standards

Project 4：Nano-manufacturing standardization and infrastructure

中国科学院纳米先导专项
长续航动力锂电池

Main targets of CAS SPRP EV battery project

National target 2020
300 Wh/kg (cell)

2018

- Scale up new anode, cathode, electrolyte and separator and batteries
- Cell > 300 Wh/kg

National Target 2015
150 Wh/kg(pack)

2015

- Pilot production of nano-Si/C, LNM, High voltage electrolyte, separator, graphene ; integrated materials
- Pack > 150 Wh/kg, cell> 180 Wh/kg

2013.11

- Develop advanced materials for LIB ;
- Collaborate with top manufactures;
- Research on next generation Li batteries ;
- Build comprehensive battery analysis platform

中国科学院纳米先导专项
长效动力锂电池

CAS SPRP project: funding

~ 40 M$/5 year

- High Energy Li Batteries
  - Lithium ion Batteries — 60% Funding
    - HE Cathode
    - Nano-Si/C
    - 5V Electrolyte
    - 5V conductive additives
    - 5V separator
    - High safety cell/pack
  - Rechargeable Li batteries — 25% Funding
    - Solid LiB
    - Li-S
    - Li-Air
  - Analysis platforms — 15% Funding
    - Caffes
    - Nano-X

中国科学院纳米能量转换与长效动力锂电池专项

CAS SPRP project: PI Team

- 12 CAS institutes, 22 Principal Investigators
- 88 staffs, 300 team members (including students)

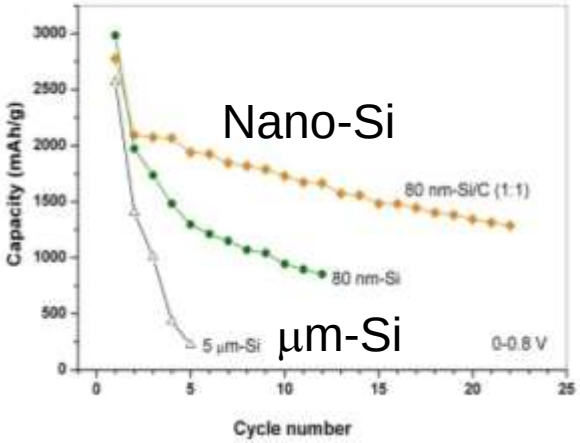
Dynamic management of SPRP program

Outline

1. Strategies of Li batteries
2. CAS-SPRP project on Li batteries
3. **Highlight of SPRP progresses**

中国科学院纳米先导专项
长续航动力锂电池

R&D on nano-Si/C anodes from IoP



H. Li et al, ESSL, 1999
Cited 275

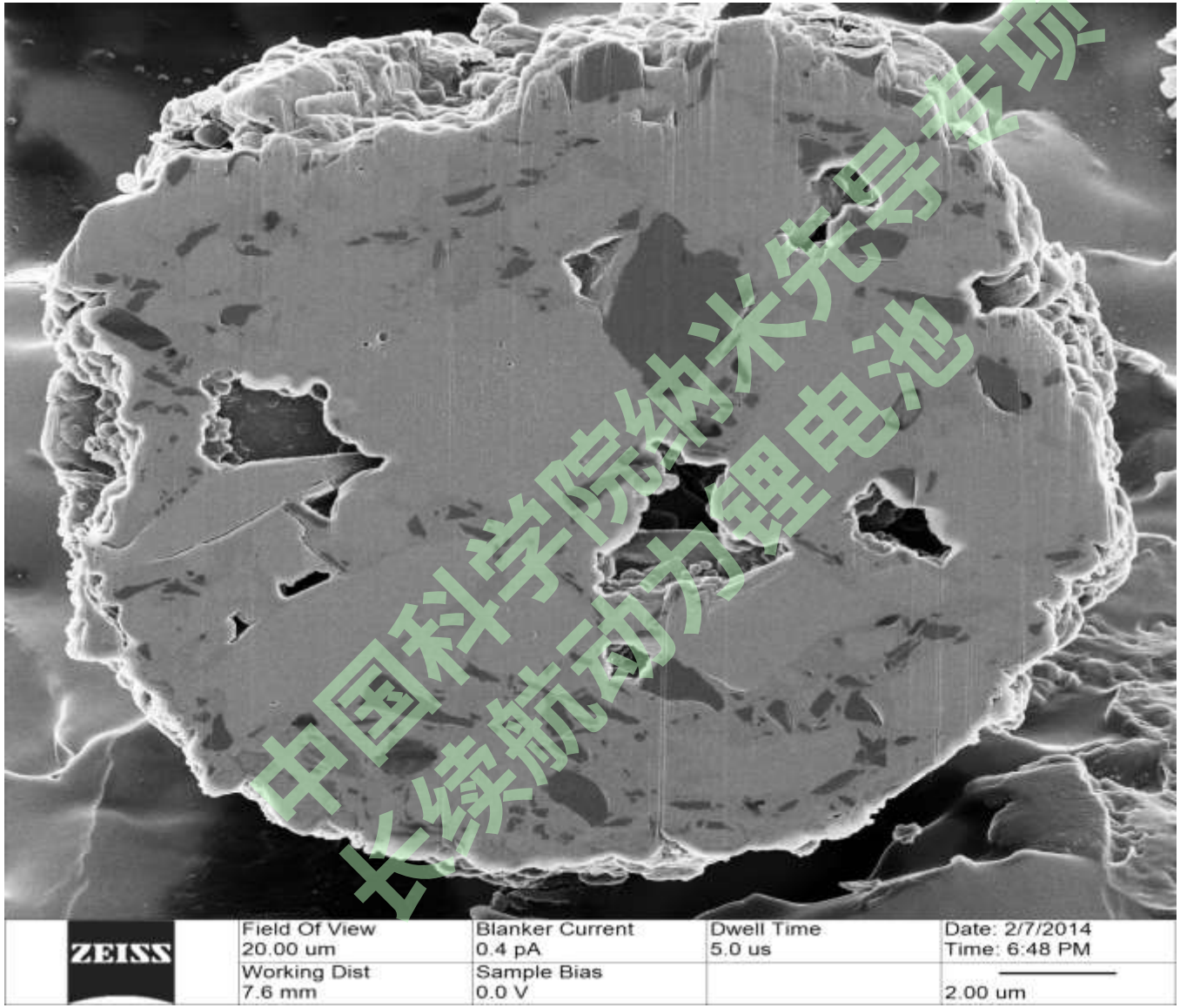
- Nano-Si: 1997, first team in world
- Sci. Problems: size effect, structure evolution, surface reaction, volume variation, alloy effect, mechanical properties
- Tec. Issues : Structure design, precursor, fabrication, processing, additive, binder, cathode matching ,volume, effi.,

IoP-CAS 18 years R&D on nano-Si/C anodes

1997	2002	2005	2008	2010	2012-2013
Nano-Si First patent	Aggolmeration Amorphous alloy SEI	C/Si Core/shell Peanut Rice-glue-ball	Surface coating New binder New additives	New precursors Volume variation Mechanical Full cell	Initial Effi. Volume New electrode Bifunctional binder
2000-3500 mAh/g	→	600 mAh/g	→	800 mAh/g	→ 450-600 mAh/g

Patents: ZL97112460.4, ZL 200410030990.x, ZL 200410090700.0, ZL 200410098618.2, ZL200510082822.x , CN201010034008.1, CN201310254509.4, CN201410003424.3, CN201410003365.X…

Dense Walnut-like nano-Si/C anode materials



中国科学院纳米先导专项
长续航动力锂电池

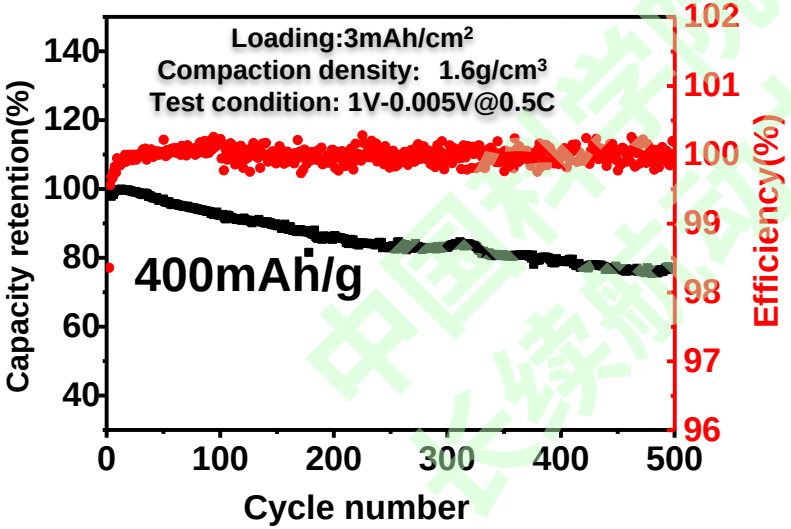
Si: 6-15 wt%
Tap density
1.0 g/cm^3
BET
<1 m^2/g

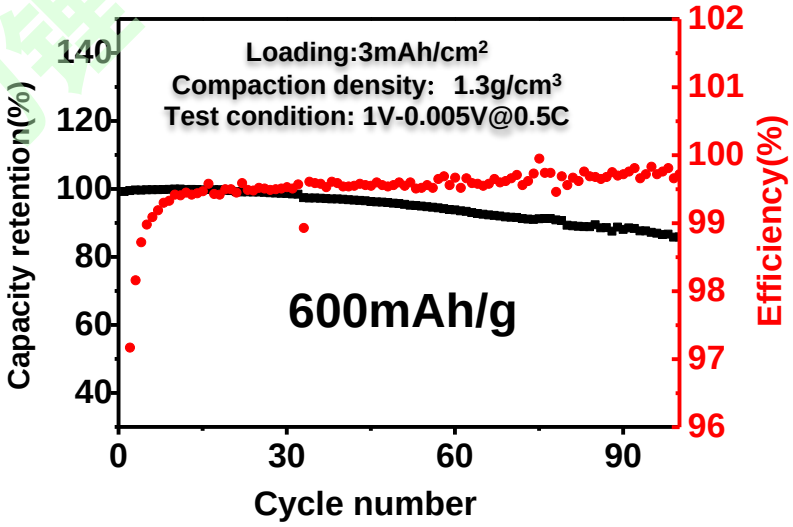
Crystallinity of nano-Si, size and distribution are essential

Nano-Si/C—Solutions

Our key solutions:

- **Homogeneous dispersion in carbon matrix**
- **Introducing compatible graphite to release stress**
- **Sophisticated surface coating and spherical**





中国科学院纳米能源专项
长续航动力锂电池

Technology progress in 2015

Optimization of precusor

Upgradation of pilot

Short-term : 450mAh/g

A 500kg-pilot production line

Medium and long term : 600-800mAh/g

Establishment of full cell Experimental line

Technology breakthrough for fabricating stable and dense material

中国科学院纳米先导专项
长续航动力锂电池

Si/C Full Cell Types

- Cylinder: 18650 and 20650
- Pouch cell: nonaqueous electrolyte gel-type
- VDA: Al can
  SS can

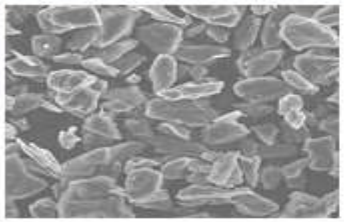
- HE $LiCoO_2$
- Li-rich
- $LiNi_{0.5}Mn_{1.5}O_4$
- NCM (532, 622, 811)
- NCA
- LFMP

中国科学院纳米先导专项
长续航动力锂电池

Si-anode product (Produced in Zichen)

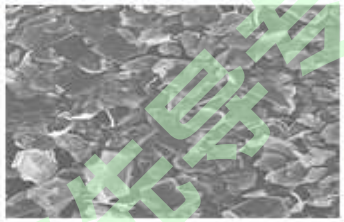
产品中心 Products

当前位置：首页 > 产品中心



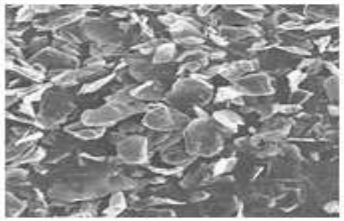
Si/C composites —380mAh/g

类　　别：硅碳
适用范围：高容量的聚合物电池，圆柱电池，方型电池等
应用领域：3C EV 储能



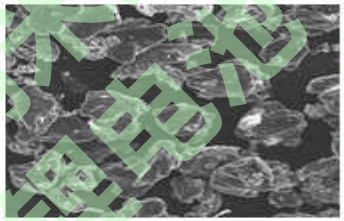
Si/C composites —400mAh/g

类　　别：硅碳
适用范围：高容量的聚合物电池，圆柱电池，方形电池等
应用领域：3C EV 储能



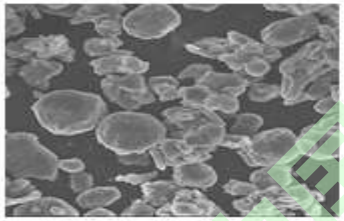
Si/C composites —420mAh/g

类　　别：硅碳
适用范围：高容量的聚合物电池，圆柱电池，方形电池等
应用领域：3C EV



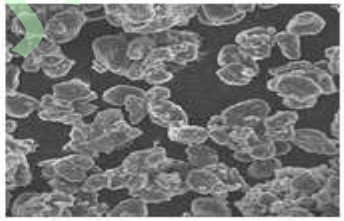
Si/C composites —450mAh/g

类　　别：硅碳
适用范围：超高容量的聚合物电池，圆柱电池
应用领域：3C



Si/C composites —600mAh/g

类　　别：硅碳
适用范围：超高容量的圆柱电池
应用领域：3C 特殊领域



Si/C composites —950mAh/g

类　　别：硅碳
适用范围：超高容量的圆柱电池
应用领域：3C 特殊领域

注：中国科学院物理研究所提供硅基材料技术支持。

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中国科学院纳米先导专项
长效动力锂电池

http://www.jxzichen.com/products

Zichen is the main anode supplier (80%) for Iphone 6 and 6plus

Issues on nano-Si/C anode

Problems	Possible solution	status
Volume expansion	Control capacity	✓
	Material structure design	✓
	Electrode structure design	✓
	Battery structure design	✓
Cracking and agglomeration	Low particle size	✓
	Isolated particles	✓
	Surface coating	✓
SEI	Low surface area	✓
	Surface coating	✓
	SEI additives	✓
	Optimize binder	✓
Volumetric capacity	Dense particle	✓
	Low surface area	✓
Mechanical property	Tuning composition	✓
	Shape control	✓
	Structure control	✓
Cost issue for scaling up	Precursor optimization	✓
	Nano-Si: new technique	✓
	Technique optimization	✓

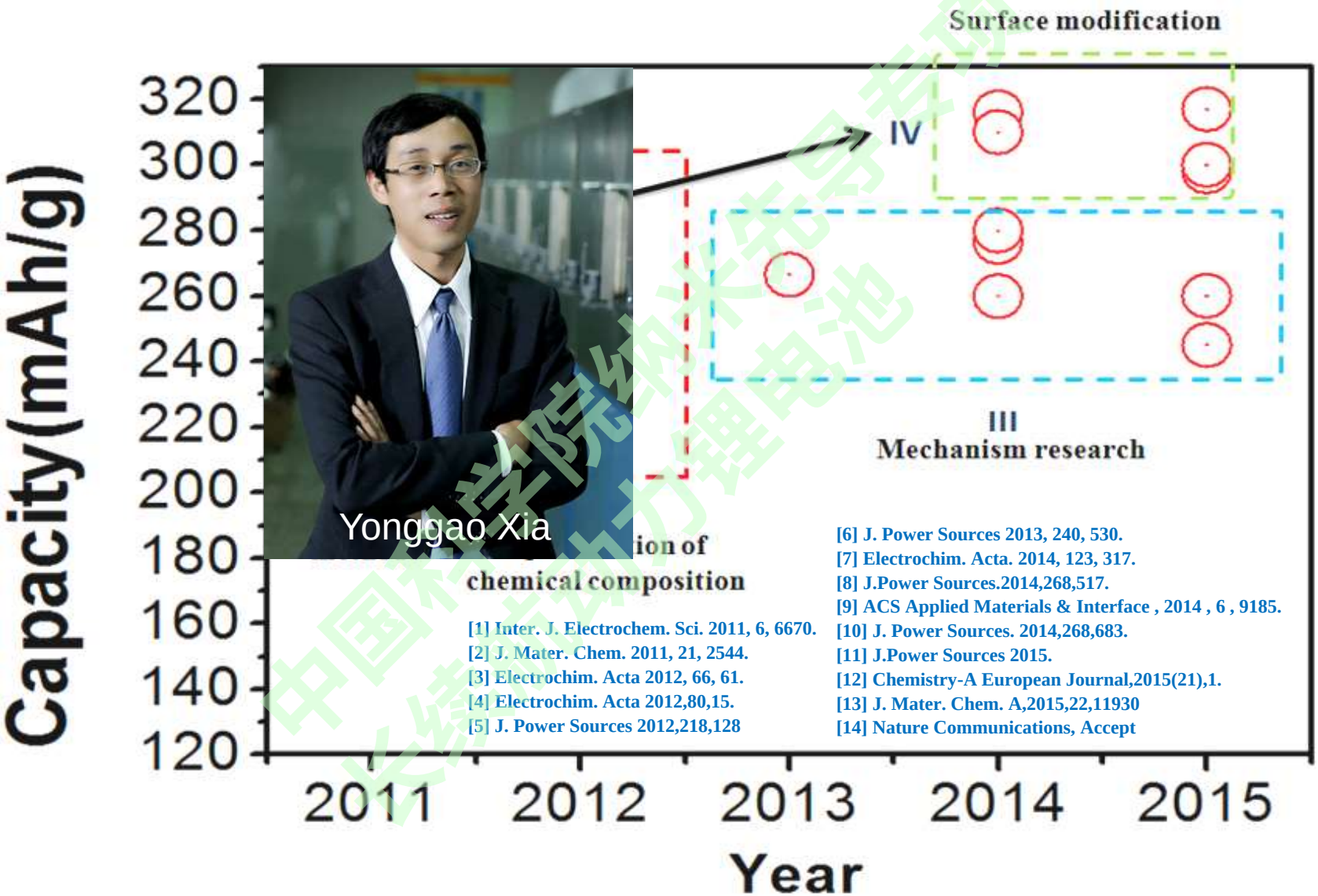
Advantages

- High columbic efficiency
- Good cycle
- High pressing density
- Robust
- Free of prelithiation
- Low cost
- Easy scaling

Disadvantages

- Moderate rate
- < 1000 mAh/g
- Volume change

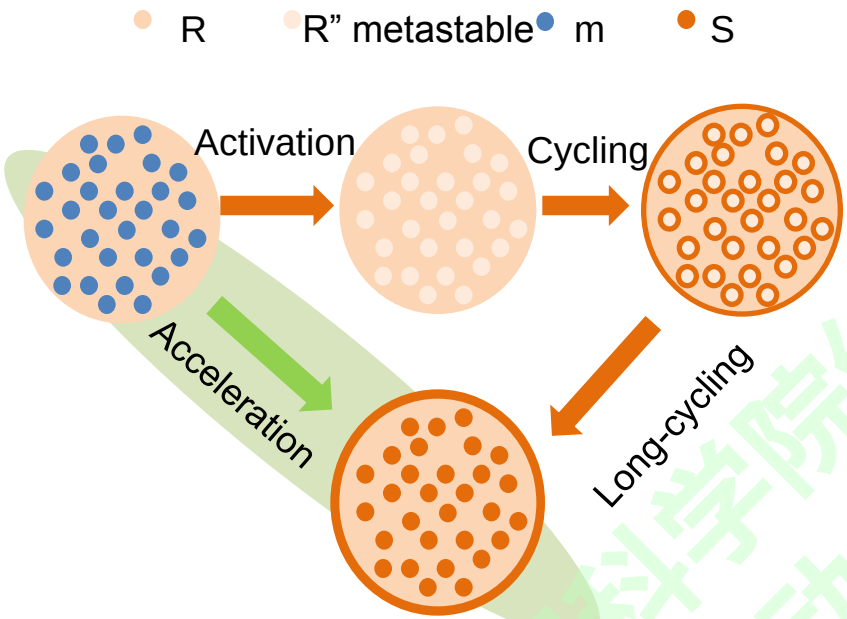
Research Progress in NIMTE on Li-rich cathode

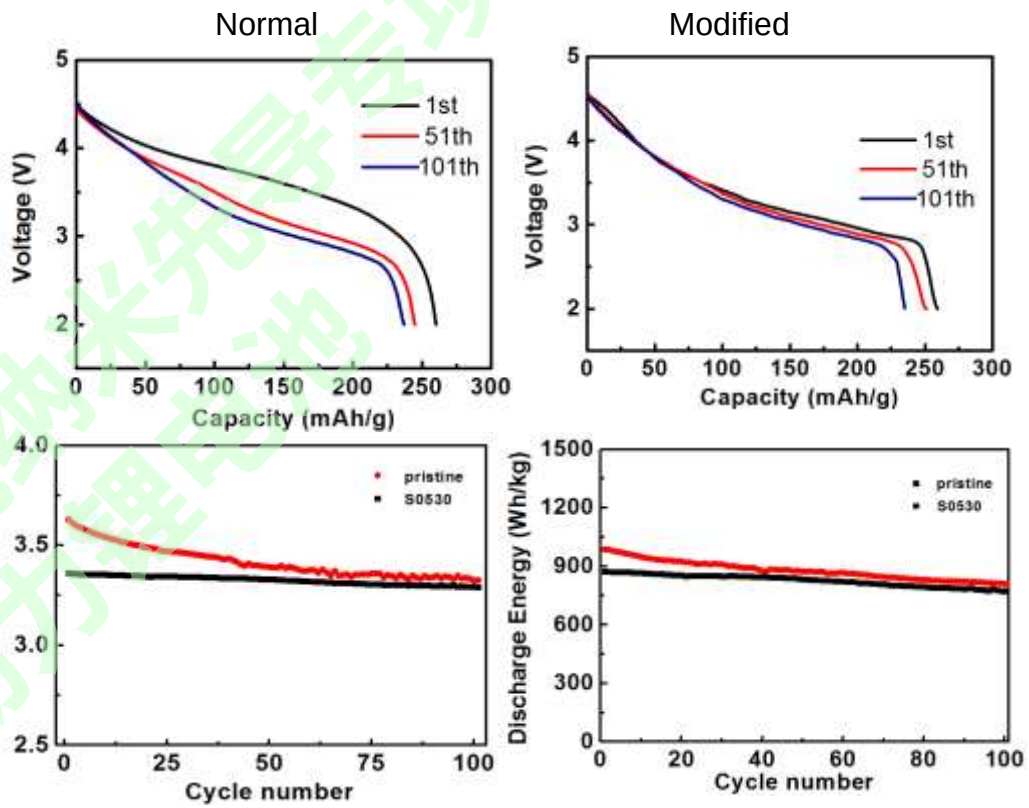


[1] Inter. J. Electrochem. Sci. 2011, 6, 6670.
[2] J. Mater. Chem. 2011, 21, 2544.
[3] Electrochim. Acta 2012, 66, 61.
[4] Electrochim. Acta 2012,80,15.
[5] J. Power Sources 2012,218,128
[6] J. Power Sources 2013, 240, 530.
[7] Electrochim. Acta. 2014, 123, 317.
[8] J.Power Sources.2014,268,517.
[9] ACS Applied Materials & Interface , 2014 , 6 , 9185.
[10] J. Power Sources. 2014,268,683.
[11] J.Power Sources 2015.
[12] Chemistry-A European Journal,2015(21),1.
[13] J. Mater. Chem. A,2015,22,11930
[14] Nature Communications, Accept

中国科学院纳米先导专项
长续动力锂电池

CAS progress on Li-rich cathode

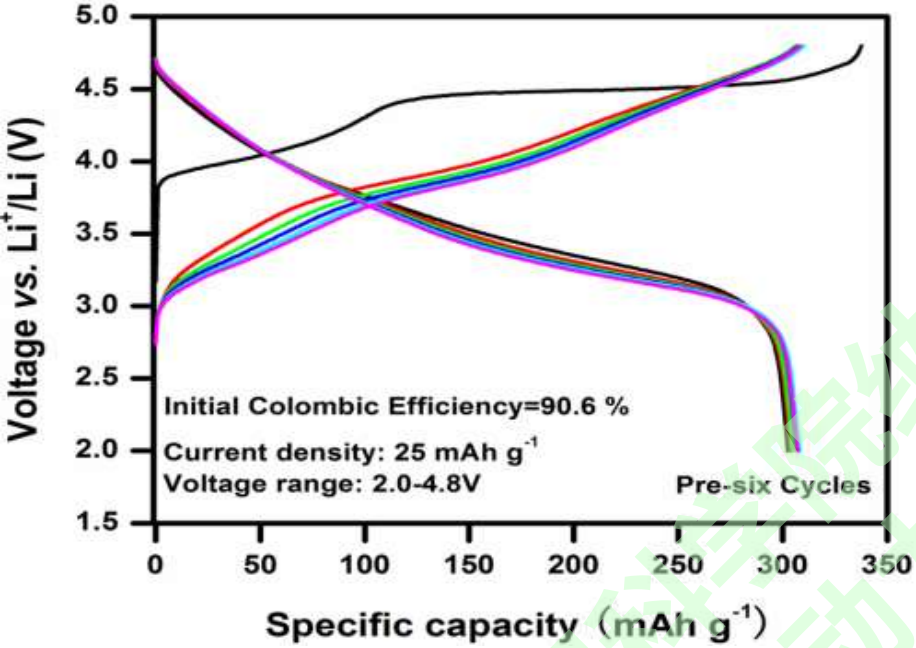


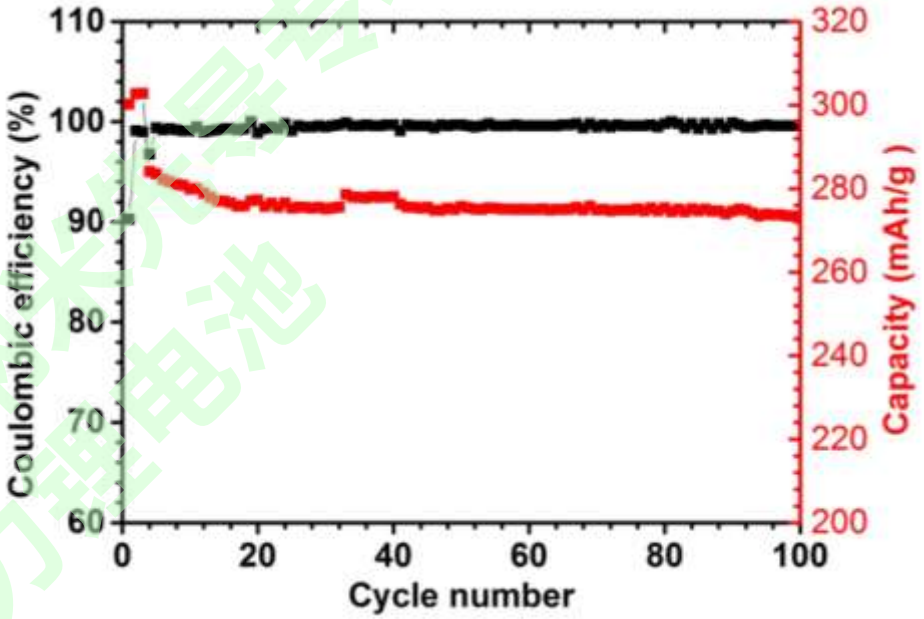


➢ Voltage decay : from rock-salt to spinel, directly

中国科学院纳米先导专项
长续航动力锂电池

Cycle life of Li-rich cathode





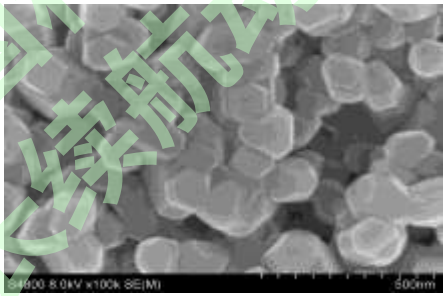
- RT , 0.2C
- 302 mAh/g
- 100 cycle, 91%

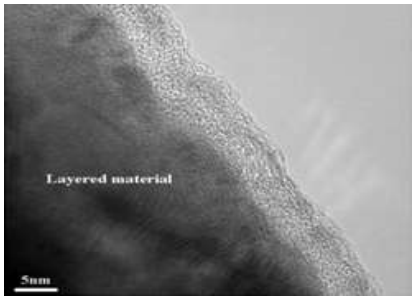
中国科学院纳米光量专项
长续航动力锂电池

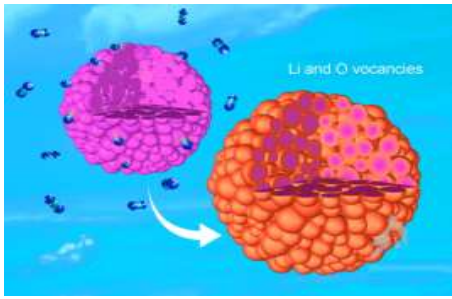
Researches on Li-rich cathode

Time		2013.7	2014.7	2015.7
Scale		Gram level	Kg gram	100kg gram
Test	Capacity above 3.0V （0.1C)	230 mAh/g	260 mAh/g	270 mAh/g
	Initial Effi.	86	88	89
	10th Effi.	99.0	99.2	99.6
	20th capacity retention	89.2%	96%	98%

Solutions





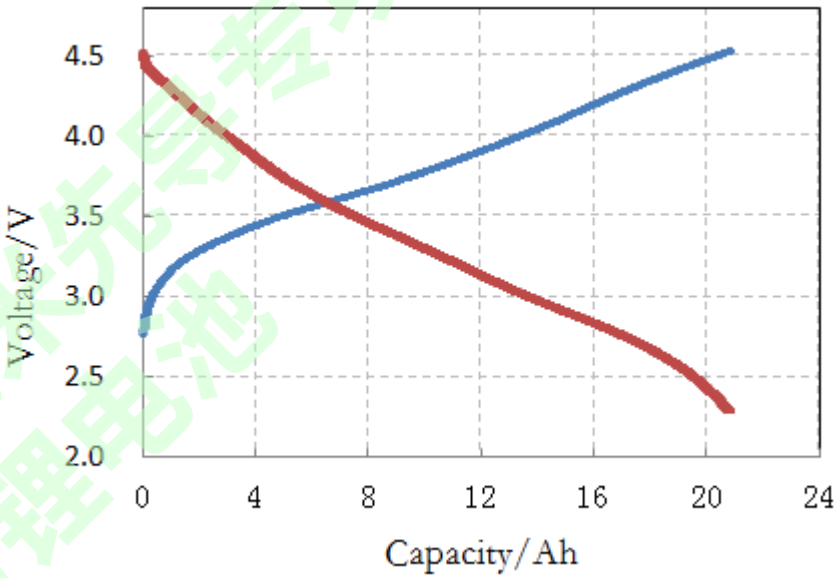


composition **Surface coating** **Gradient**

Yonggao Xia, Ningbo Institute of Industry Technology, CAS

中国科学院纳米先导专项
长续航动力锂电池

Li-rich Cathode / Si-C 900

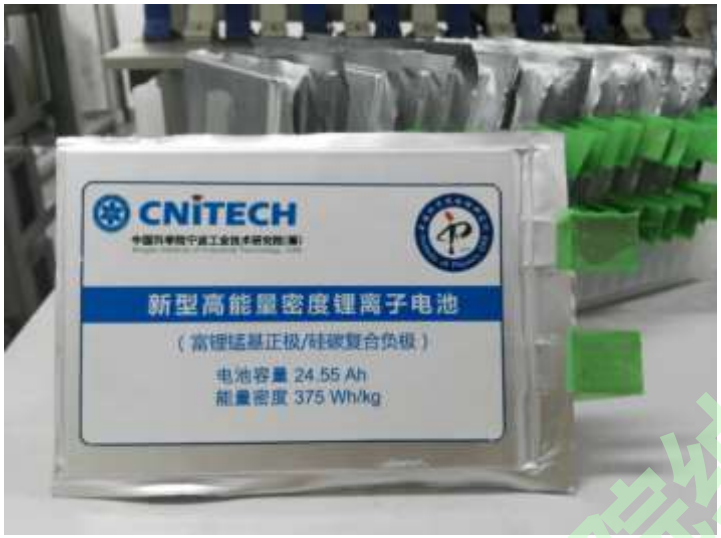


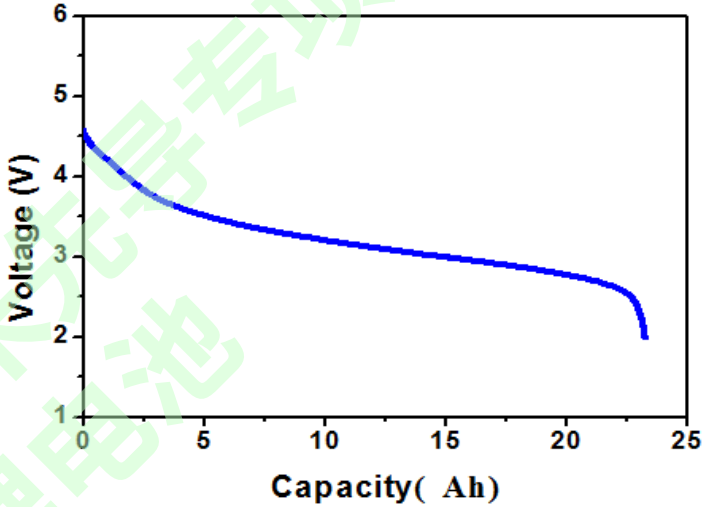
	Battery Capacity	ICE	Average voltage	Battery Energy	Battery Weight	Current rate	Discharge capacity	Energy density
Design value	15.2Ah	--	3.4V	73.83Wh	210g	0.1C/0.1C	260mAh/g	246Wh/kg
Cell-1#	22.5Ah	81%	3.28V	73.83Wh	226.1g	0.1C/0.1C	259mAh/g	327Wh/kg
Cell-2#	22.2Ah	84%	3.24V	72.8Wh	226.1g	0.1C/0.1C	260.5mAh/g	322Wh/kg

Yonggao Xia's team and Hong Li's team

中国科学院纳米先导专项
长续航动力锂电池

Li-rich Cathode / Si-C 2500





	Battery Capacity	ICE	Average voltage	Battery Energy	Battery Weight	Energy density
Design value	25.7Ah	--	3.28V	84.3Wh	208.1g	405Wh/kg
Cell-1#	24.55Ah	79%	3.17V	77.8Wh	207.6g	375Wh/kg

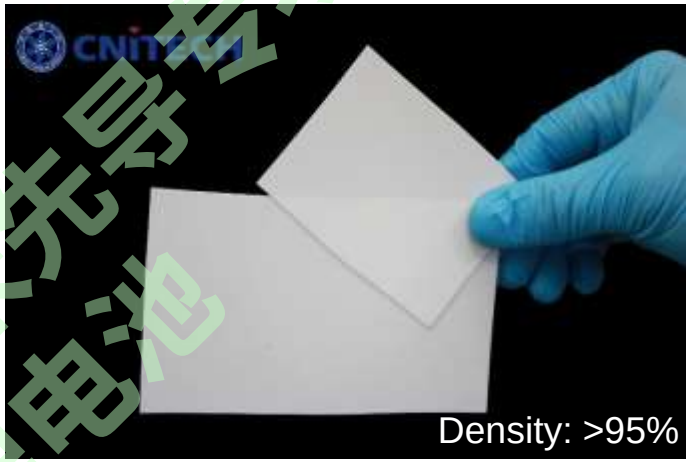
375 Wh/kg and 577 Wh/L

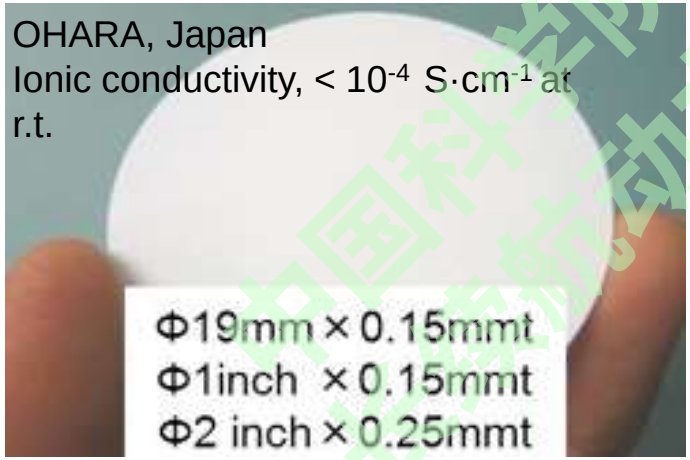
Yonggao Xia's team and Hong Li's team

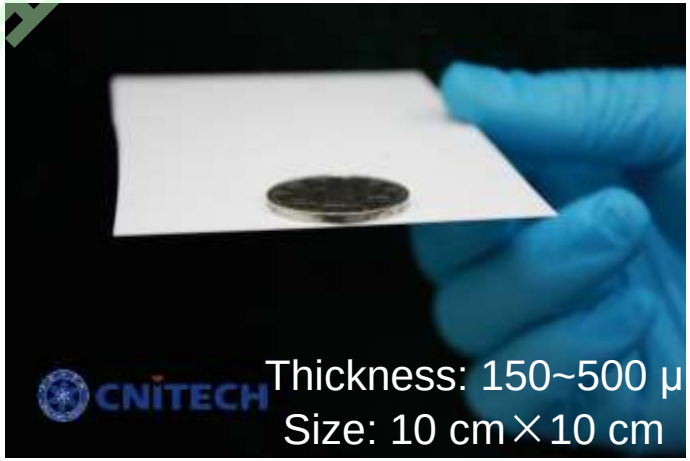
中国科学院纳米先导专项
长续航动力锂电池

Solid electrolyte: LISICON

- **LISICON, Xiaoxiong Xu' team in CNITECH, CAS**







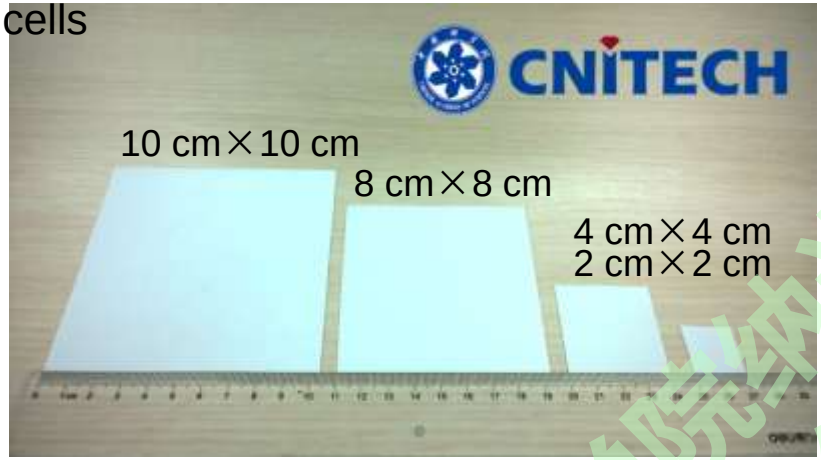
- Ionic conductivity: 4.5×10^{-4} S·cm^{-1} at r.t., >10^{-2} S·cm^{-1} at 90 ^{o}C,
- Series of thickness with designed size.

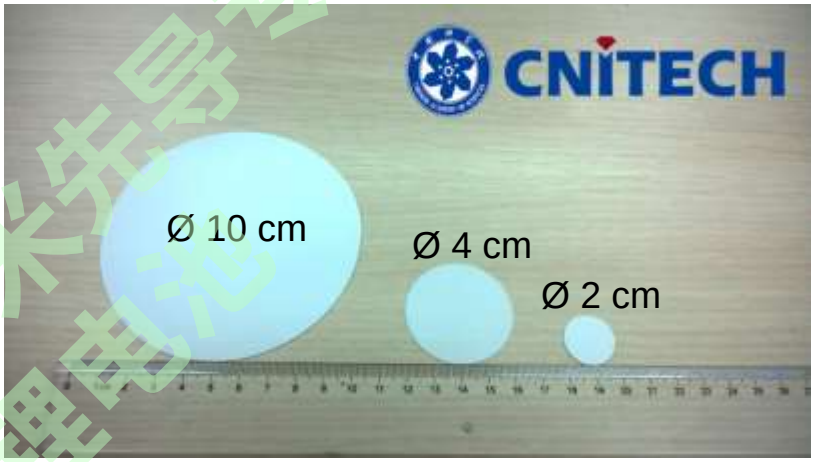
中国科学院纳米先导专项
长寿命动力锂电池

Solid electrolyte: LISICON

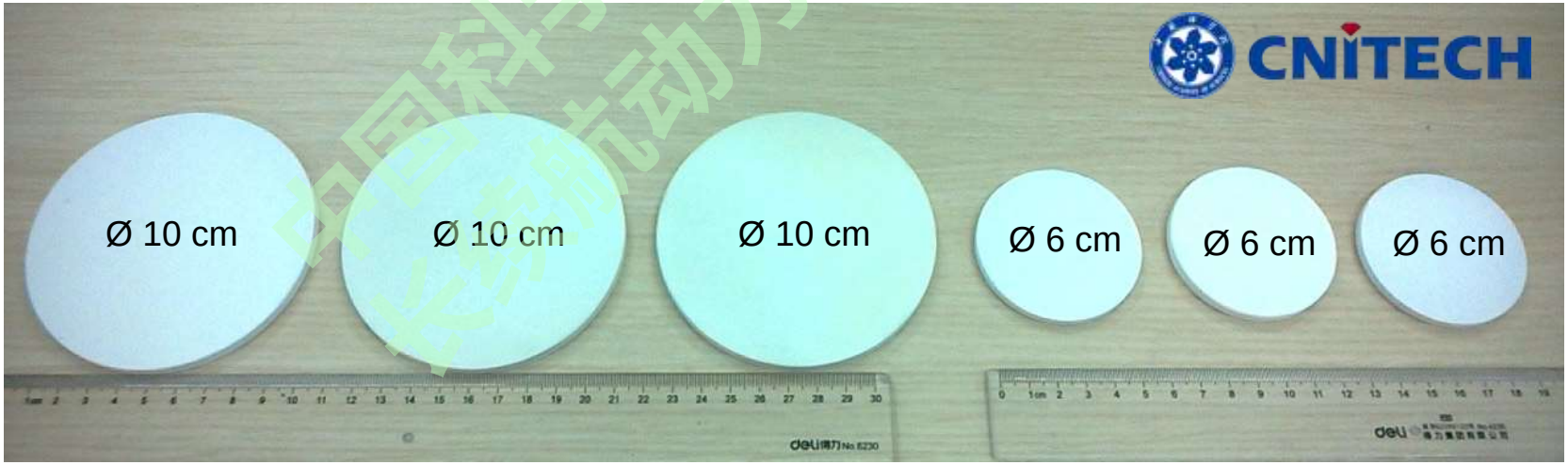
- **LISICON, Dense oxide solid electrolytes from CNITECH, CAS**

1. Thin films with thickness range of 150~500 μm for solid lithium-ion, solid Li-S and Li-air cells





2. Targets with thickness range of 5~10 mm



Xiaoxiong Xu' team in CNITECH, CAS

中国科学院纳米先导专项
长春航动力锂电池

Developed thio-LISICON, sulfide solid electrolytes

	Composition	Material phase	Ionic conductivity ($S \cdot cm^{-1}$ @ r.t.)	E_a (eV)	Stable against Li-metal
①	$80Li_2S\text{-}20P_2S_5$	Glass-ceramics	5.77×10^{-4}	0.31	No
②	$75Li_2S\text{-}25P_2S_5$	Glass-ceramics	4.02×10^{-4}	0.25	Yes
	$75Li_2S\text{-}(25\text{-}x)P_2S_5\text{-}xP_2O_5$	Glass-ceramics	8.03×10^{-4}	0.22	Yes
③	$70Li_2S\text{-}30P_2S_5$	Glass	0.81×10^{-4}	0.34	Yes
		Glass-ceramics	9.31×10^{-4}	0.21	No
		Ceramics	2.82×10^{-4}	0.37	No
	$70Li_2S\text{-}(30\text{-}x)P_2S_5\text{-}xLi_3PO_4$	Glass-ceramics	1.87×10^{-3}	0.20	Yes
	$70Li_2S\text{-}(30\text{-}x)P_2S_5\text{-}xP_2O_5$	Glass-ceramics	2.63×10^{-3}	0.19	No
①	$Li_{3.25}Ge_{0.25}P_{0.75}S_4$	Ceramics	2.11×10^{-3}	0.30	No
②	$Li_{10}GeP_2S_{12}$ @sintered	Ceramics	11.5×10^{-3}	0.25	No
	$Li_{10}GeP_2S_{12}$ @wet chem.	Ceramics	5.69×10^{-3}	0.26	No
	$Li_{10}GeP_2S_{12}$	Glass-ceramics	1.67×10^{-4}	0.45	No

X-X. Xu, *et al*. *Chem. Mater.*, 23 (2011) 3798; X-X. Xu*, *et al*. *Solid State Ionics* 274 (2015) 8; *ibid* 270 (2015) 61; X-X. Xu*, *et al*. *J. Power Sources* 284 (2015) *ibid* 206; 273 (2015) 389; *ibid* 301 (2016) 47; *ibid* 307 (2016) 724; X-X. Xu*, *et al*. *J. Electrochem. Soc.*, 163 (2016) A96. CN201310465226.4; CN201310535524.6; CN201310536009.X; CN201410188063.4; CN102544580B

中国科学院纳米能源专项
长效能动力推进会

LISICON-based all solid batteries

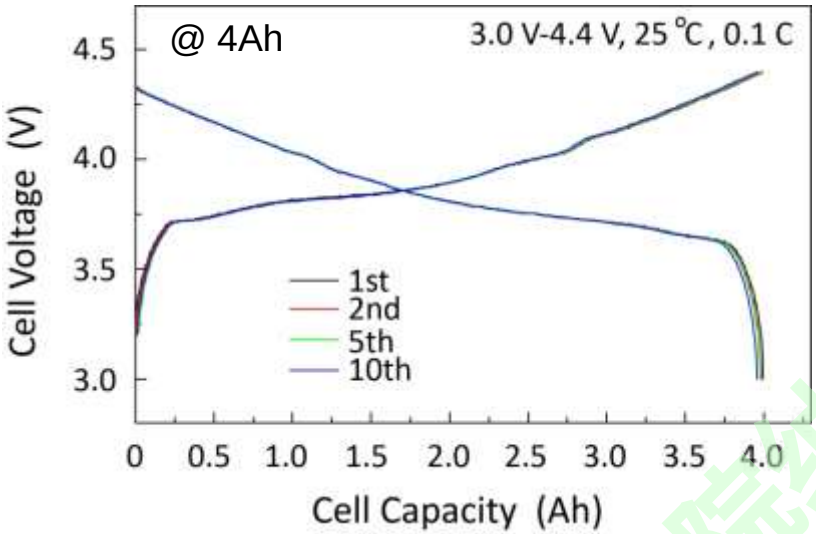
中国科学院纳米先导专项
长续航动力锂电池

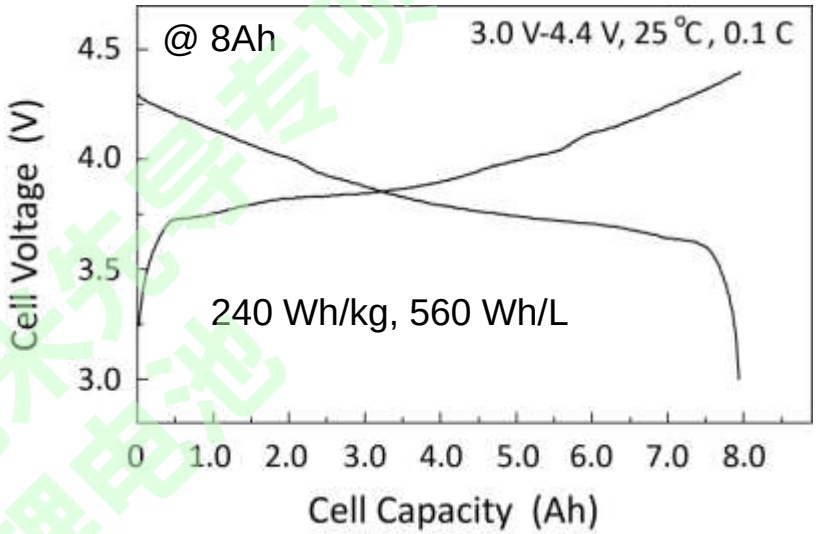
All-solid-state lithium (ion) cells, Cathode/LISICON/In or Cathode/LISICON/Coated-Li

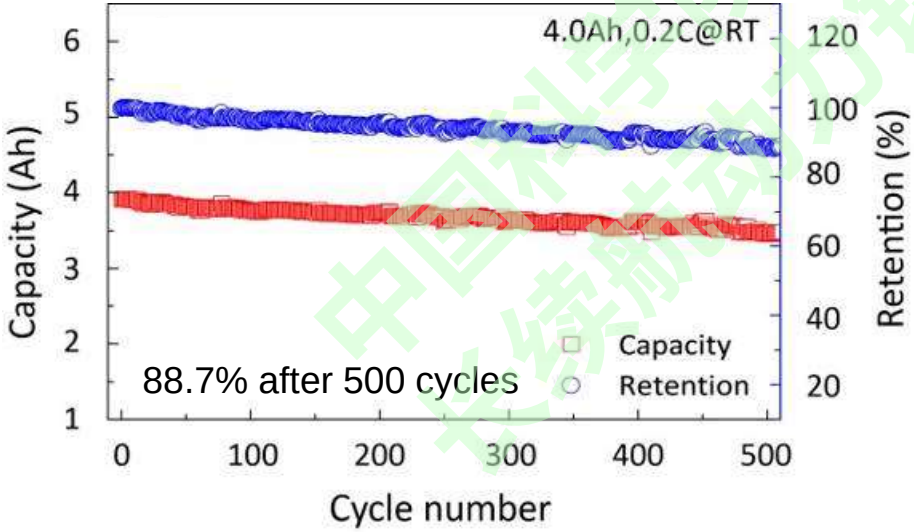
- LFP, LVP, LCO, NCM, NCA and Li-rich oxide could act as the positive material.

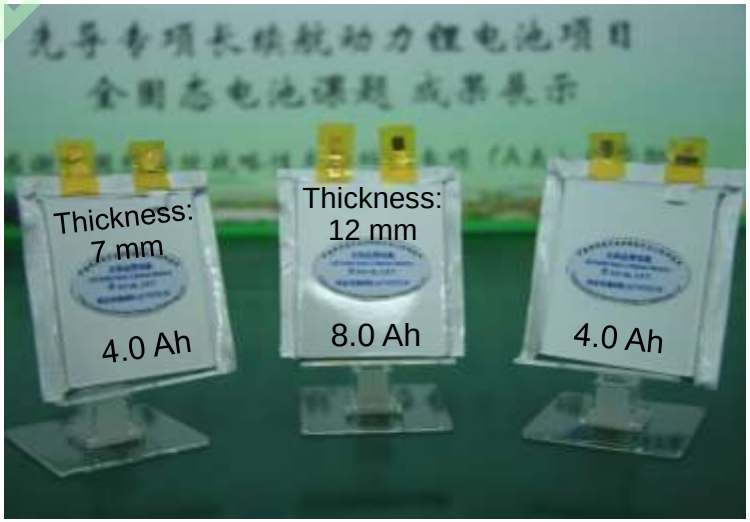
Xiaoxiong Xu' team in CNITECH, CAS

●Solid-state lithium battery









Xiaoxiong Xu' team in CNITECH, CAS

中国科学院纳米先导专项
长续航动力锂电池

$Li_{6.4}La_3Zr_{1.4}Ta_{0.6}O_{12}$(LLZTO) electrolytes

陶瓷粉

陶瓷片

陶瓷流延薄膜

Powders preparation: 10-100 kg；

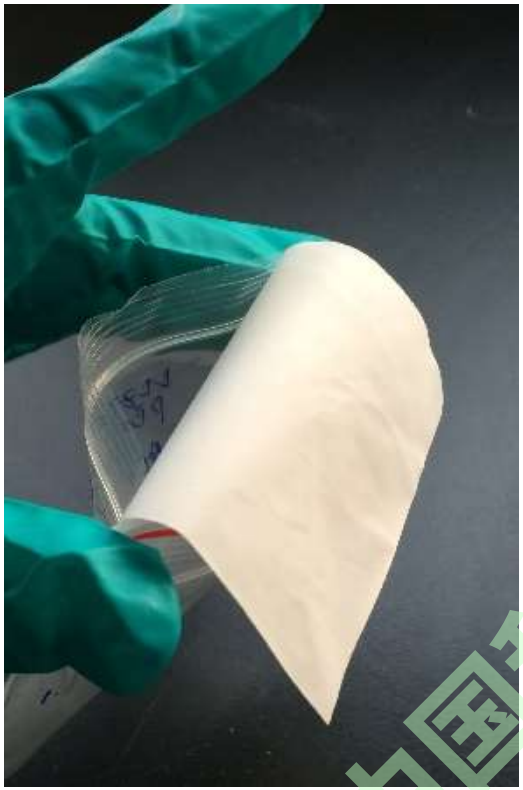
Ceramic conductivity:
1.6×10^{-3} S cm^{-1} @ 30°C

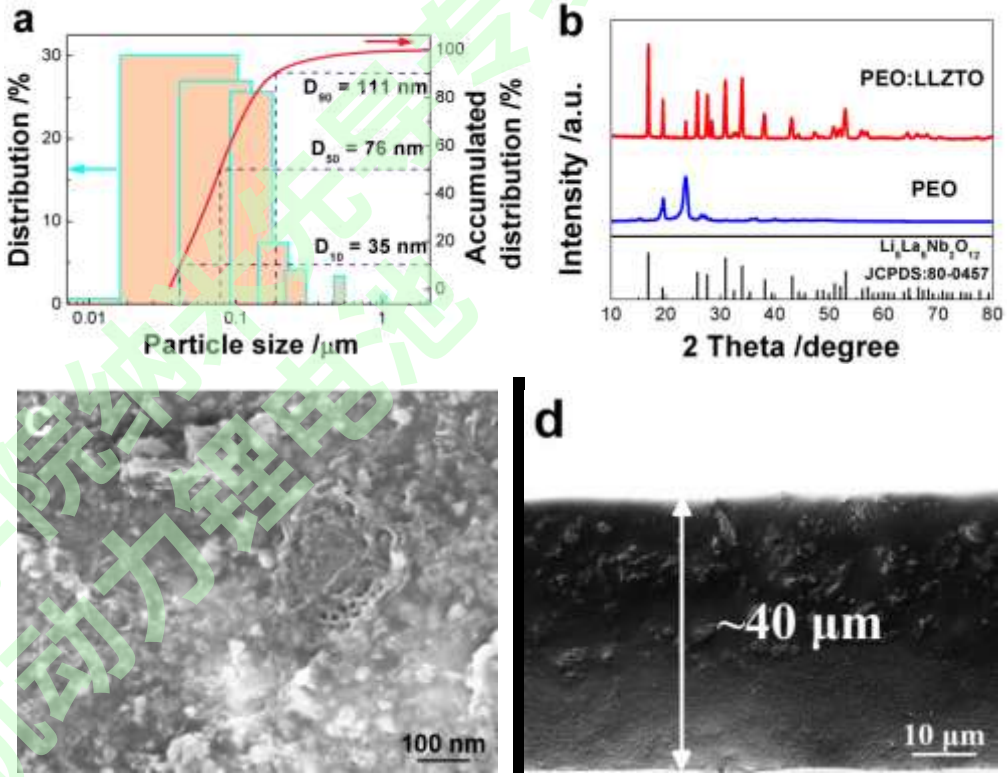
Chin. Phys. B 22 (2013) 078201; Solid State Ionics 253 (2013) 76-80; J. Power Sources 248 (2014) 642-646；Electrochim. Acta 180 (2015) 37-42

Prof. Xiangxin Guo's team in Shanghai Institute of Ceramics

中国科学院纳米先导专项
长续航动力锂电池

Membrane electrolytes: PEO + LLZTO





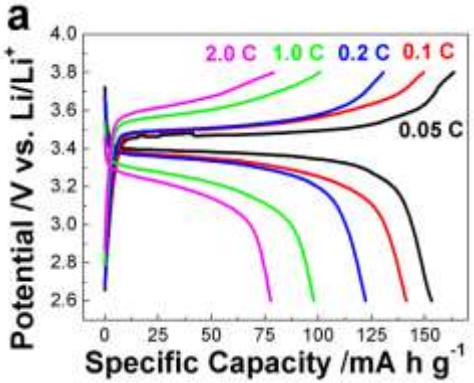
Self standing and flexible membranes

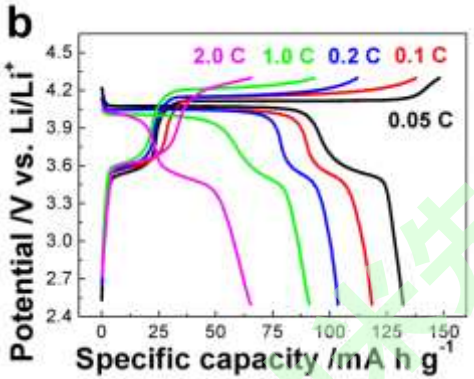
D_{50}: 76 nm, D_{90}: 111 nm
Membrane thickness: 40 μm

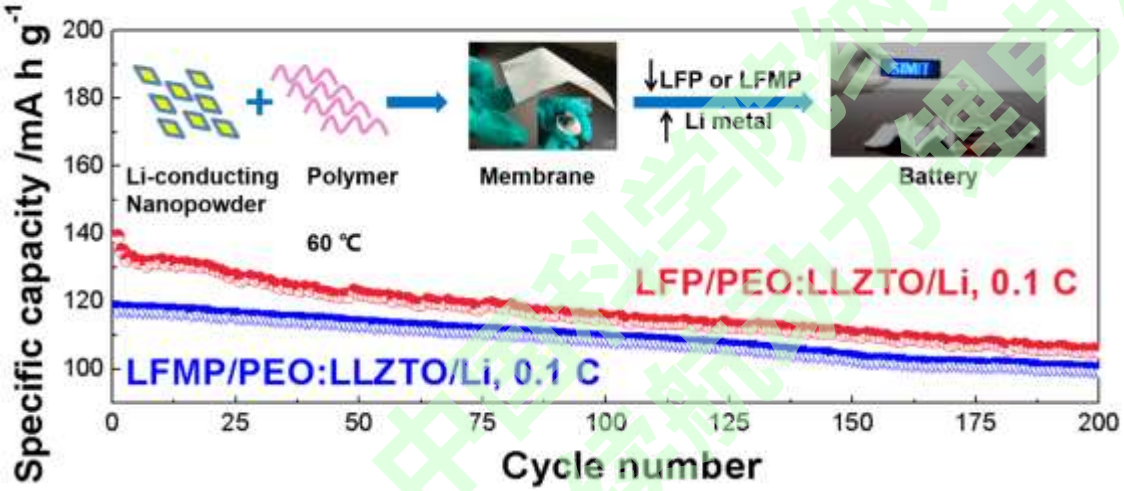
Prof. Xiangxin Guo's team in Shanghai Institute of Ceramics

中国科学院物理研究所 长续航动力锂电池专项

Cell performance: Li/PEO:LLZTO/$LiFePO_4$ & Li/PEO:LLZTO/$Li(FeMn)PO_4$







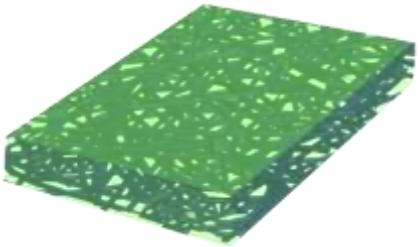
0.1 Ah cells @ 0.1C & 60°C
LFPO: 328 Wh/kg & 552 Wh/L
LFMPO: 385 Wh/kg & 578Wh/L
(excluding package weight)

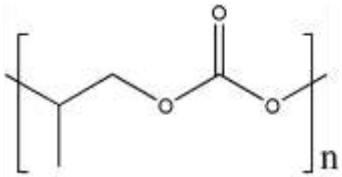
Specific capacity @ 0.05C
LFPO: 153 mAh/g
LFMPO: 132 mAh/g

J.X. Zhang, N. Zhao, Z.F. Di, X.X. Guo &H. Li et al. (submitted)

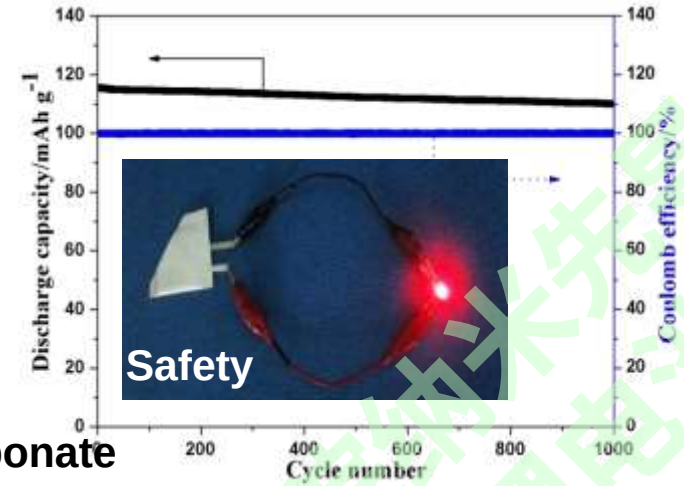
Prof. Xiangxin Guo's team in Shanghai Institute of Ceramics

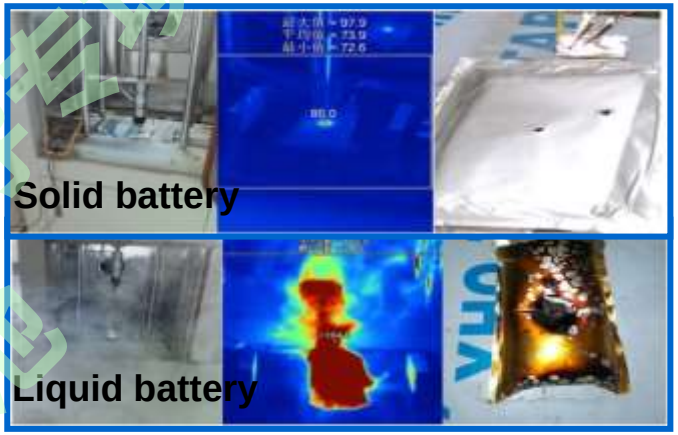
Poly (propylene carbonate) based solid-state polymer lithium battery at ambient temperature





Poly (propylene carbonate





Samples	Ionic conductivity at 25 °C	Electrochemical window	Mechanical strength
poly (ethylene oxide)	2×10^{-5} S/cm	3.8 V	<1 MPa
Poly (propylene carbonate)	4.2×10^{-4} S/cm	4.6 V	>26 MPa

Adv. Energy Mater., 2015, *5*, 1501082. *J. Electrochem. Soc*., 2013, *160*, A1341.

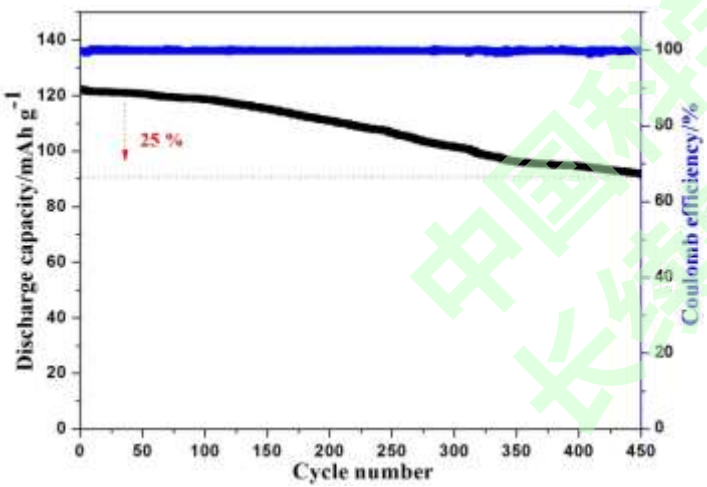
PCT patent，application number：PCT/CN2016/072104

Prof. Guanglei Cui's team in QIBBT, CAS

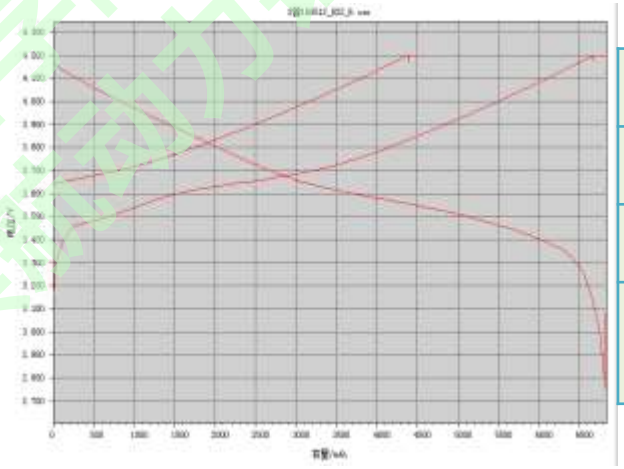
中国科学院纳米先导专项
长续航动力锂电池

PPC-based polymer lithium batteries

- Energy density: 249 Wh/kg
- Cycling stability: 450 cycles
- Apply for 12 invention patents
- Signed a cooperation agreement with Zhongtian Technology Co., Ltd.



Cycle performance



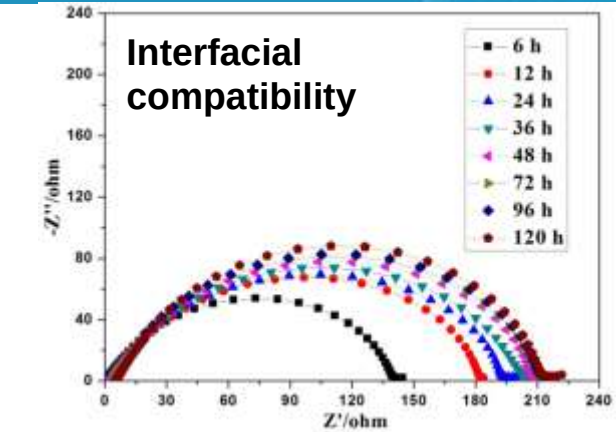
Charge/discharge curve

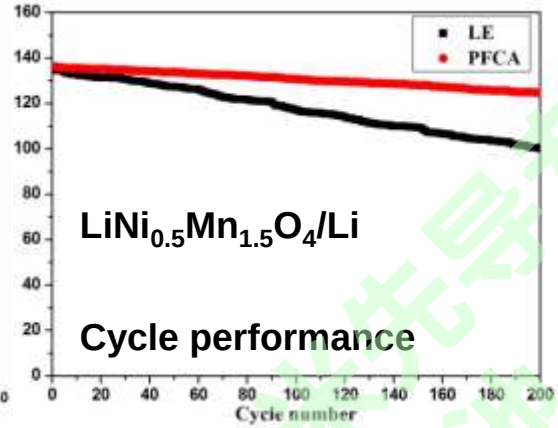
Capacity	6.82Ah
Voltage	3.65 V
Weight	100 g
Energy density	249 Wh/Kg

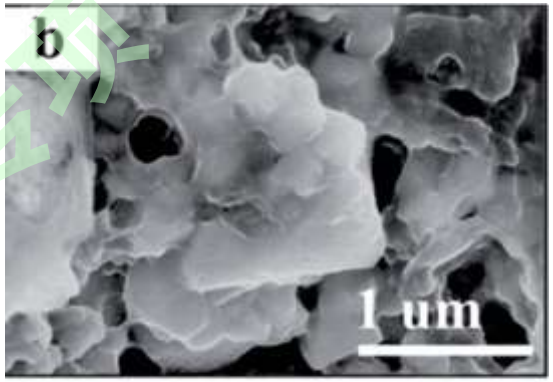
Prof. Guanglei Cui's team in QIBBT, CAS

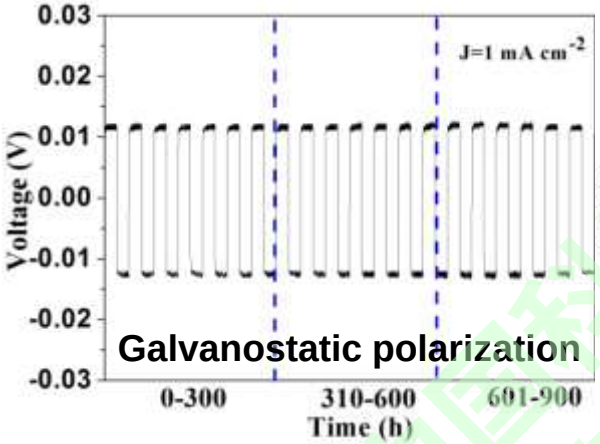
中国科学院纳米先导专项
长续航动力锂电池

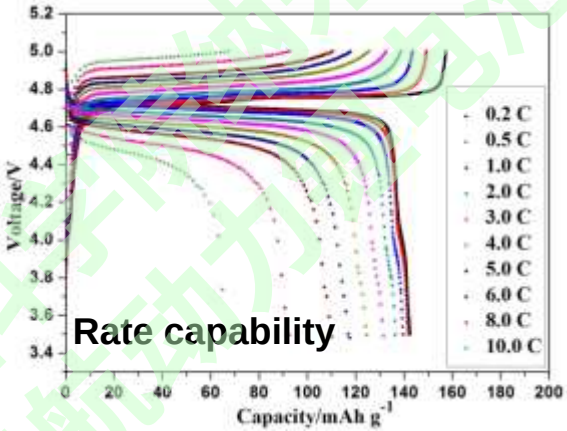
Poly(cyanoacrylate) electrolyte for 5 V lithium battery

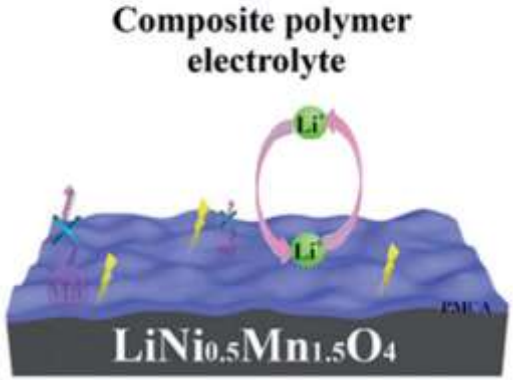












Enhance the interfacial compatibility, improve the electrochemical window, protect lithium anode, improve cycle stability and safety

Chem.Mater., 2015, *27*, 2189; *J. Mater. Chem. A*, 2015, *3*, 22552

Prof. Guanglei Cui's team in QIBBT, CAS

High energy density Li-S batteries

3Ah@350Wh/kg

2013.10

15Ah@430Wh/kg

2014.10

30Ah@519Wh/kg

2015.06

12kWh Li-S/PV

2015.01

2013.07

10Ah@380Wh/kg

2014.06

100Wh
@~250Wh/kg

2015.06

1000Wh
@~300Wh/kg

2015.08

37Ah Li-S: 556 Wh/kg, 1KWh Li-S: 332Wh/kg

Cycle number < 20 cycles for 37 Ah, ~ 100 cycles for 5-8Ah

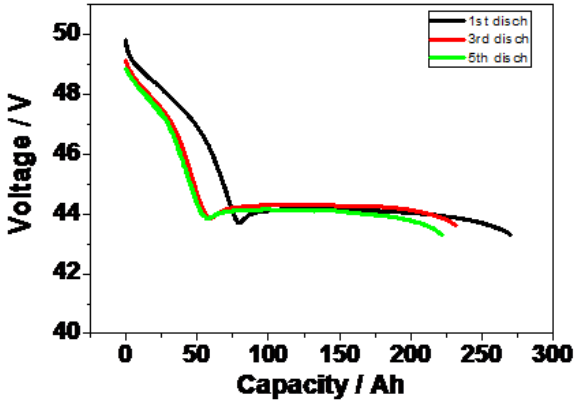
Jian Chen, Dalian Institute of Chemical Physics, CAS
Xiaodong Wu & Liwei Chen, Suzhou Institute of Nanotech, CAS

中国科学院纳米技术与纳米仿生研究所
长续航动力锂电池

Development of Li-S Battery Pack

12 kWh Li-S battery pack and demonstration system with PV

- **The first demonstration system of LiS battery in China**



T ↑ **Control and monitor** ↑ **V**

Charge

Discharge

12kWh LiS Battery Pack

- **270Ah@12.1kWh**
- **Columbic efficiency>96%**
- **Energy efficiency>90%**

中国科学院纳米先导专项
长续航动力锂电池

Jian Chen, Dalian Institute of Chemical Physics, CAS

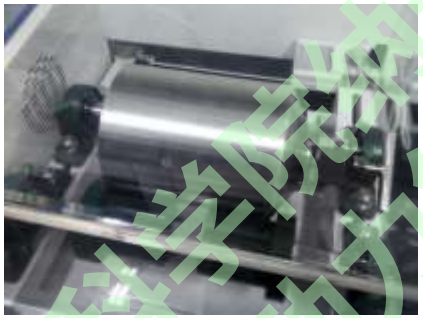
Li-O_2 batteries

2012: 80 Wh/kg

2013: 150 Wh/kg

2014: 360 Wh/kg

2015: 526 Wh/kg

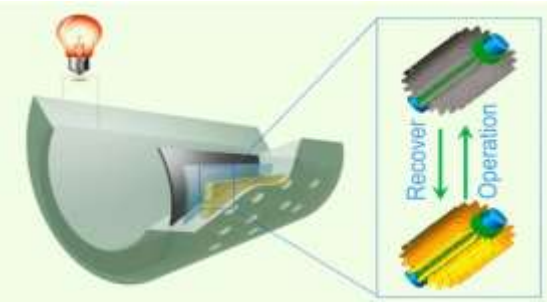


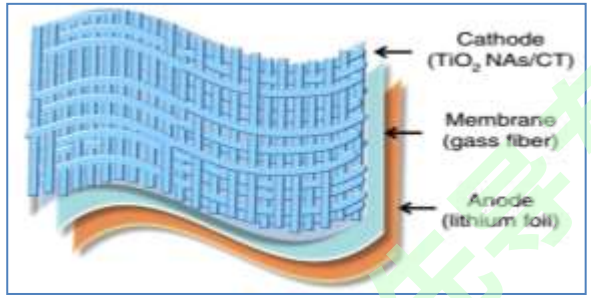
- 5Ah Li/O_2 cell: 526 Wh/kg; 51Ah Li/O_2 pack: 360 Wh/kg
- Cyclic performance is very poor < 10 cycles
- Cyclic performance is poorer for Li/air batteries

Team of Xingbo Zhang
Changchun Institute of Applied Chemistry

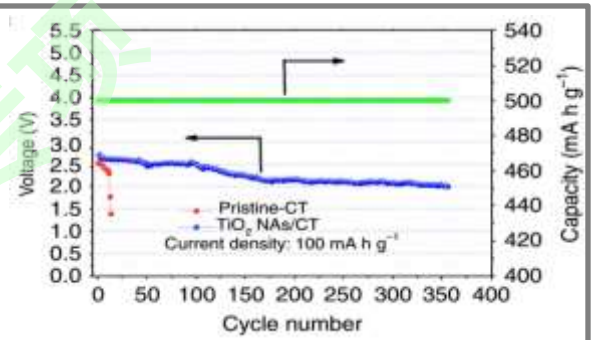
中国科学院纳米特别专项
长效动力锂电池

First Flexible Li–O_2 Battery



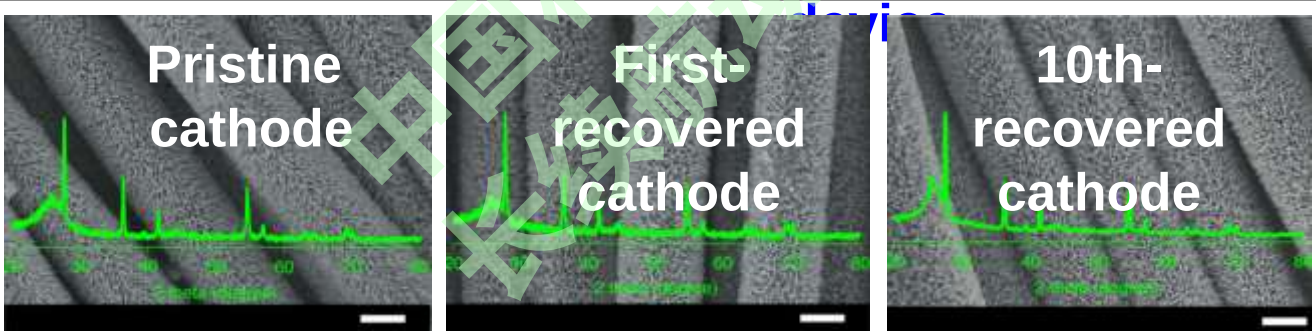


Scheme for fabrication flexible Li–O_2 battery



Cycling Stability

The bending and twisting properties of the Li–O_2 battery device

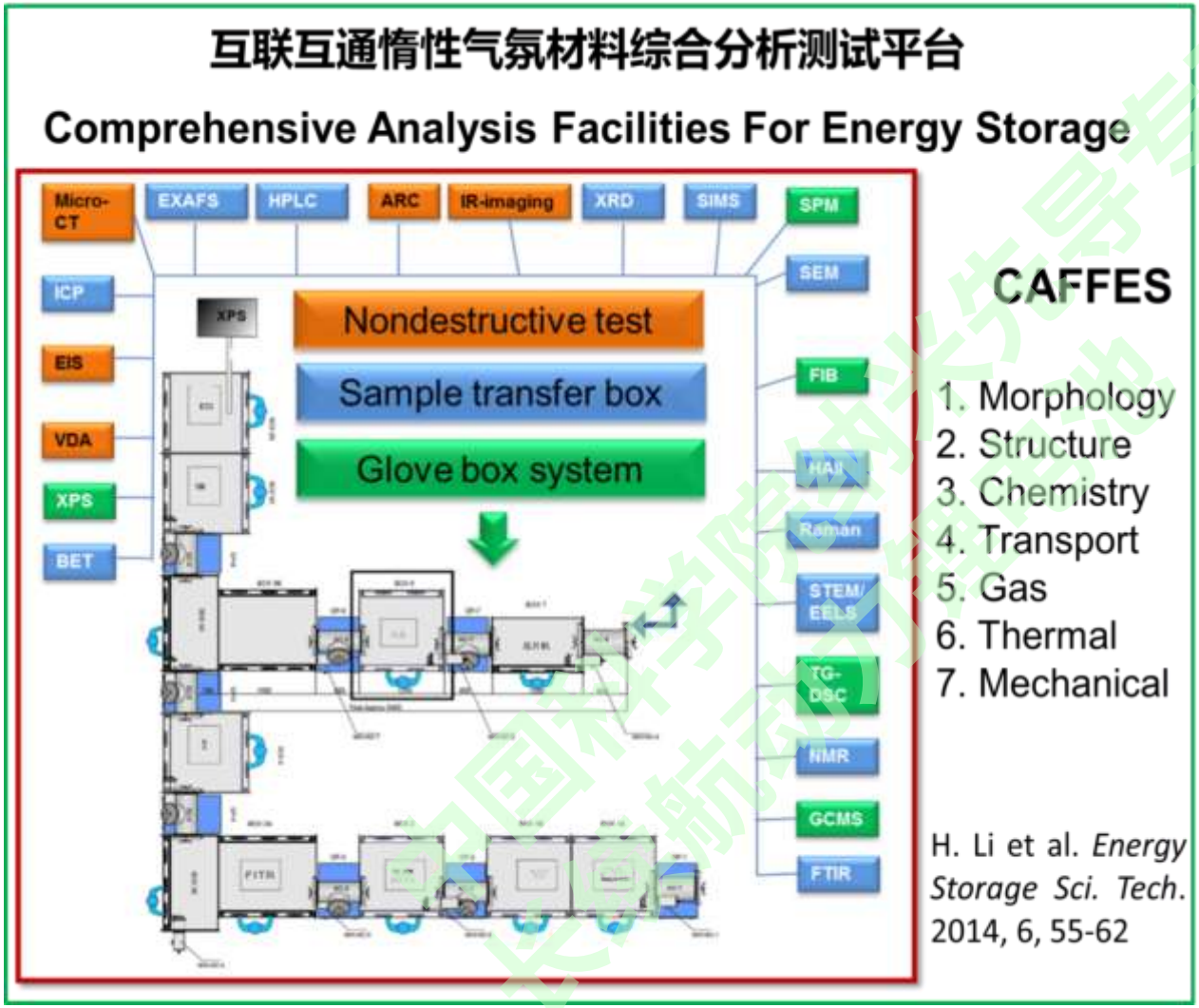


Excellent recoverability

Team of Xingbo Zhang,
Changchun Institute of Applied Chemistry,CAS

Nat. Commun, 2015, 6, 7892.

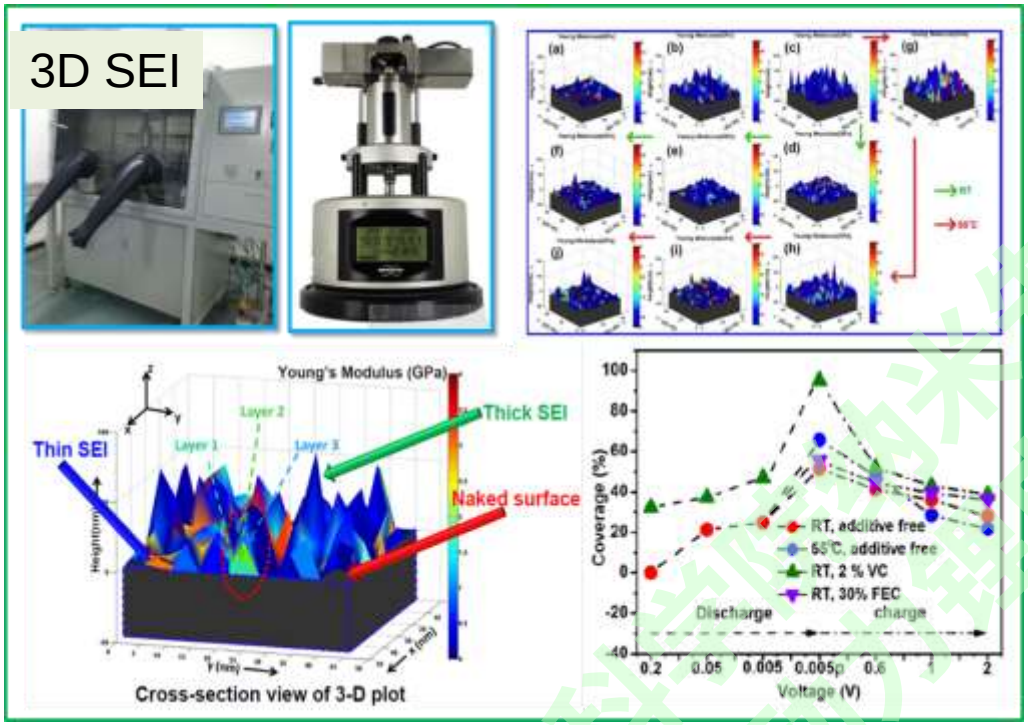
LIB comprehensive analysis platform



CAS CAFFES platform

Caffes: （2014-2016） Open for the world

A few results obtained from CAFFES



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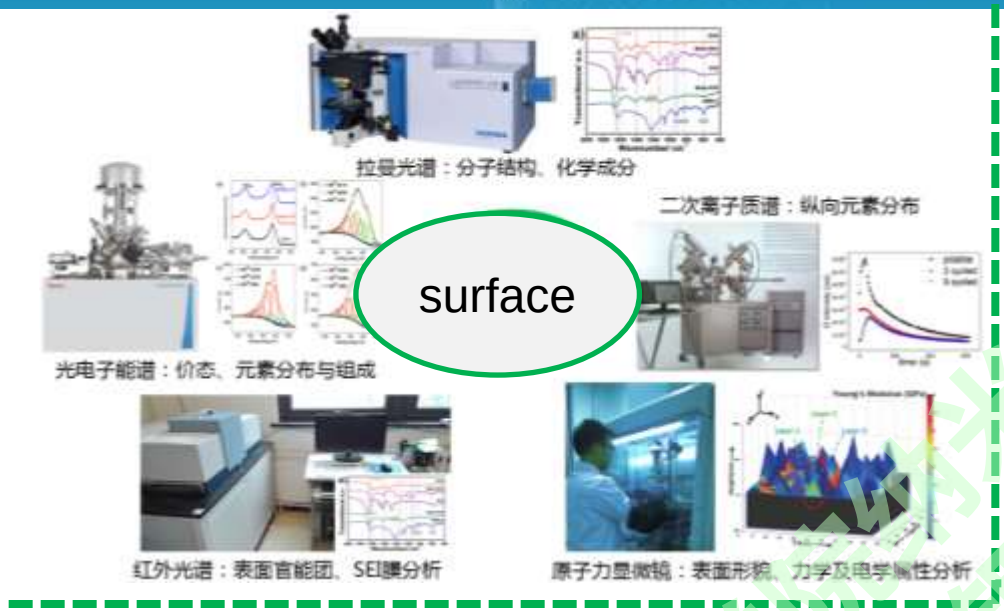
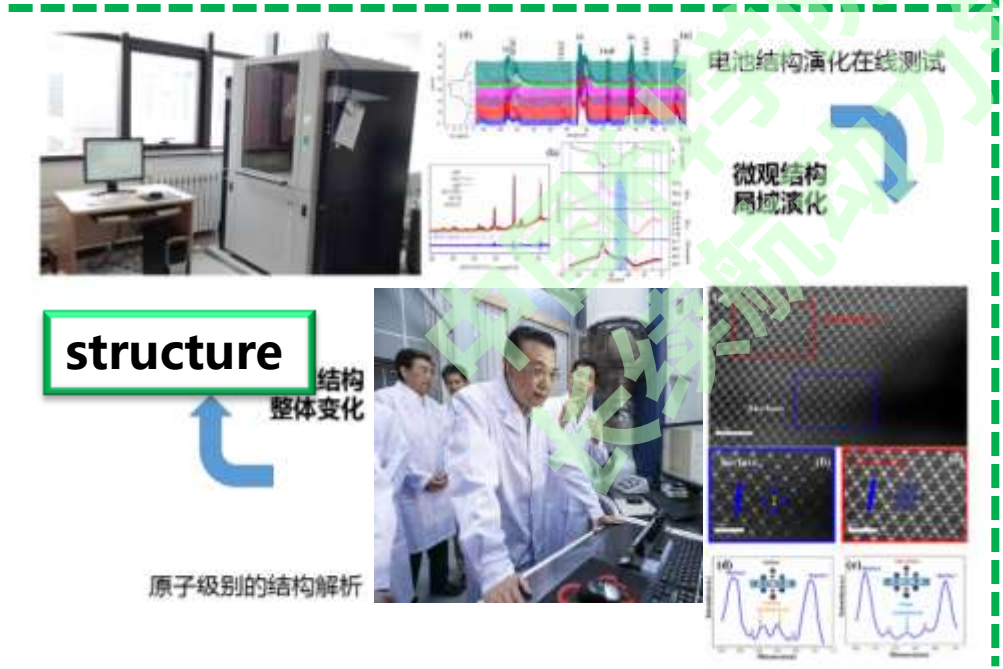
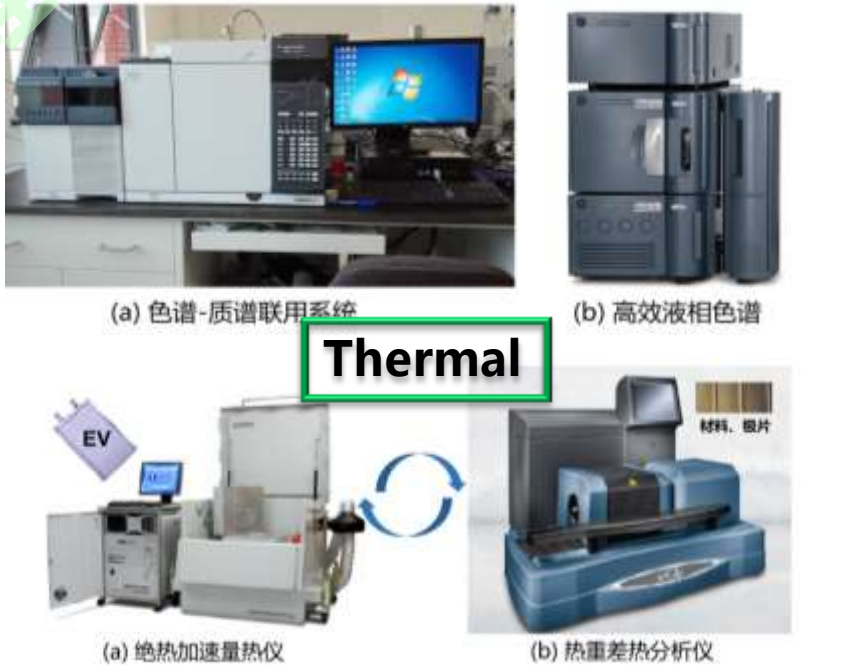
CAFFES: functions







Summary 1: CAS EV battery project

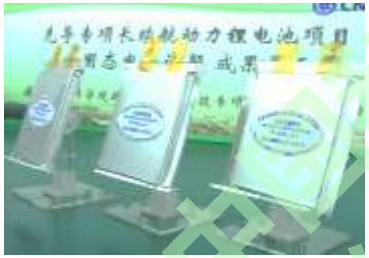
2015.12

375 Wh/kg
LIB

556 Wh/kg Li-S

526 Wh/kg Li-air

High energy EV battery



240Wh/kg
Solid Li batteries

EV cell facility

Analysis platform

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Summary 2: tendency of lithium batteries

Weight ratio of liquid in cell

nonaqueosu | gel | Semi-solid | solid | All solid

55°C — 80°C — 150 °C — safety

Ratio of metal lithium in anode

Li-ion | Prelithiated | Composite Li | Metallic lithium

High energy density

250 Wh/kg — 300 Wh/kg — 350 Wh/kg — 400Wh/kg — 500 Wh/kg

Cycle life

500 — 1000 — 1500 — 2000 — 5000 — 10000

TRL5 — TRL6 — TRL7 — TRL8 — TRL9

Time

2016 — 2017 — 2018 — 2019 — 2020 — 2021 — 2022

Next: half-solid lithium batteries (HSLB)

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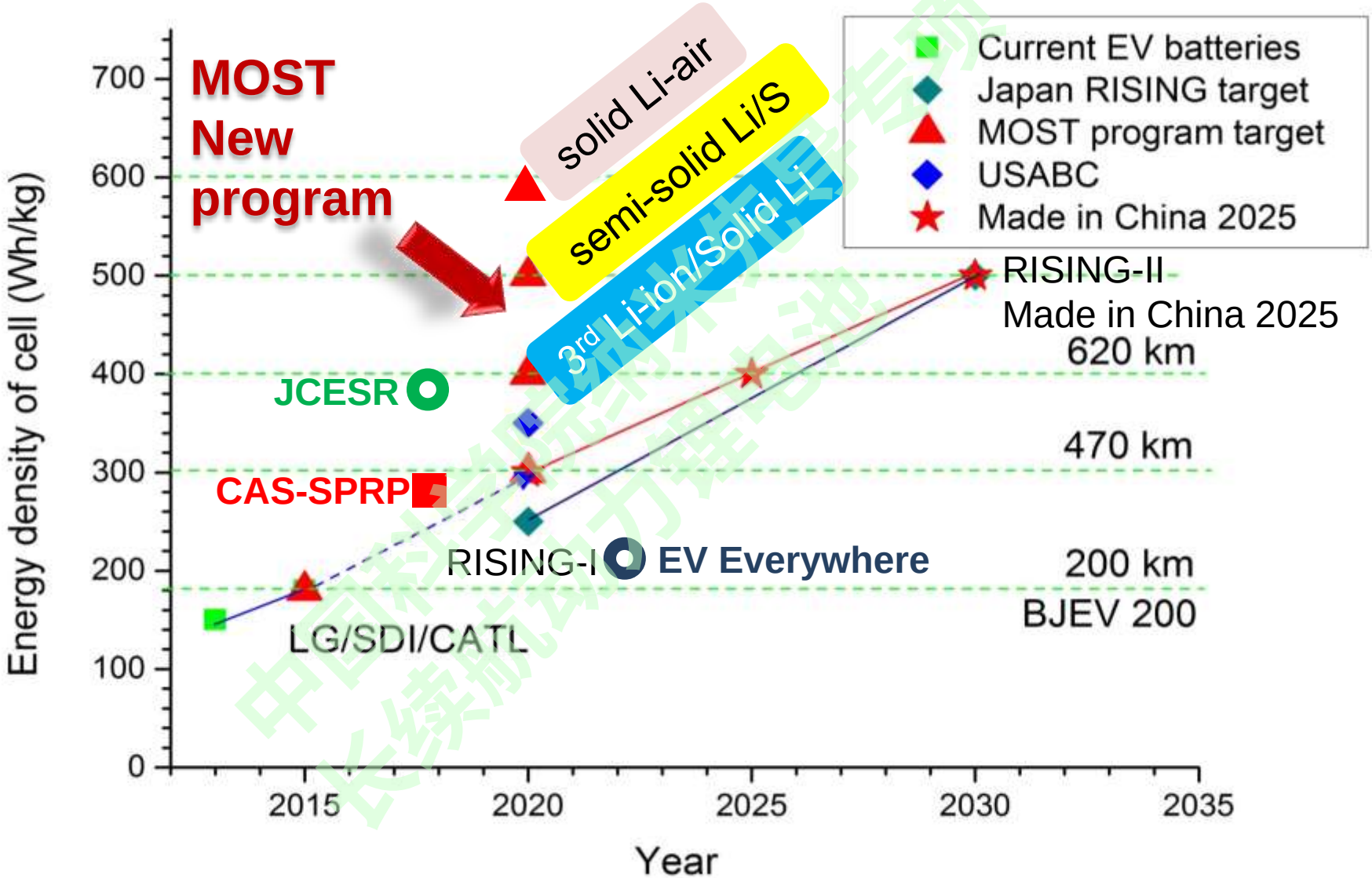
Summary 3: new program targets comparison



BJEV: Beijing Electric Vehicles Company Model: EV 200: 14kWh/100km/1.3 ton

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- National Natural Science of Foundation of China
- Ministry of Industry and Information Technology
- Beijing Municipal Science and Technology Commission
- Ministry of Finance
- State Intellectual Property Office
- Shanghai Synchrotron Radiation Facility

- All CAS team members over 12 institutes (~ 300 members)
- Industry partners over 23 companies
- National and international collaborators…

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Thank you for your attention !
Collaboration is welcome!

海内存知己，天涯若比邻

Long distance separates no bosom friends

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