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Research and development of battery technology in Australia

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The Australian National University

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Talk outline

- Introduction on lithium-ion batteries
- Mining of lithium in Australia
- Battery applications in grid and home storage in Australia
- Electric vehicles in Australia
- Sustainable beyond-lithium batteries
- Research landscape in Australia
- Projects in Battery Storage and Grid Integration Program at ANU

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Batteries enable a range of applications

Portable electronics

Power tools

Electrification of transport

Integration of renewables into grid and home energy storage

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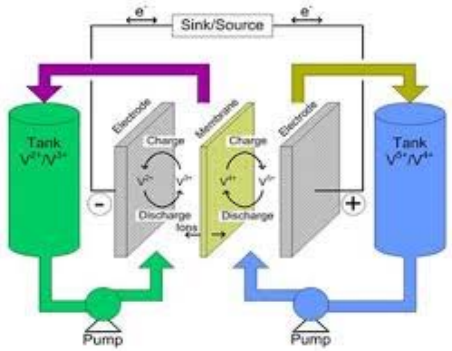
Lithium-ion battery as a dominant technology

Pb-acid batteries
(reliable technology, close to 100% recycling)
35-40 Wh/kg energy density

NiCd batteries
Energy density 40-60 Wh/kg



Flow batteries
(e.g., vanadium-redox, zinc-bromine)

External tanks;
capacity depends
on the size of tanks

Li-ion batteries
No or minimum maintenance
Energy density of 100-265 Wh/kg

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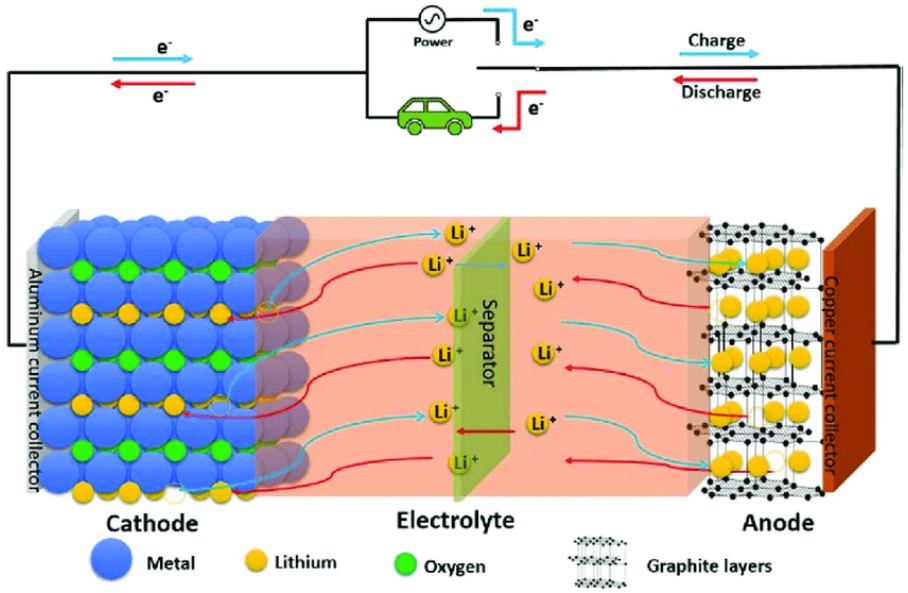
Li-ion battery – principle of operation



Reproduced from Liang et al., Solid State Ionics 2018

Commercialised battery type since 1991

Standard cathode:

$LiCoO_2$
$LiMn_2O_4$
$LiFePO_4$
$LiNi_xMn_yCo_zO_2$
$LiNi_xCo_yAl_zO_2$

Standard anodes:

Graphite
$Li_4Ti_5O_{12}$
Si-based anodes

Standard electrolyte: carbonate-based organic electrolytes

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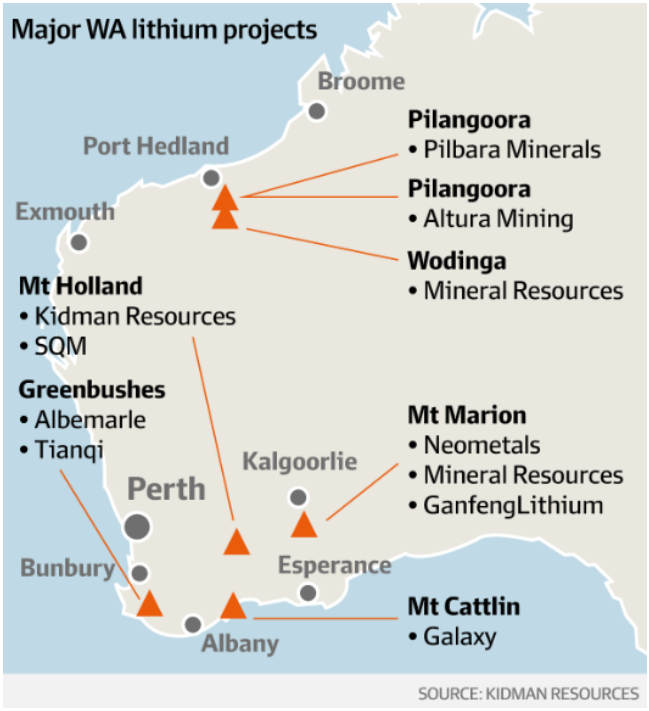
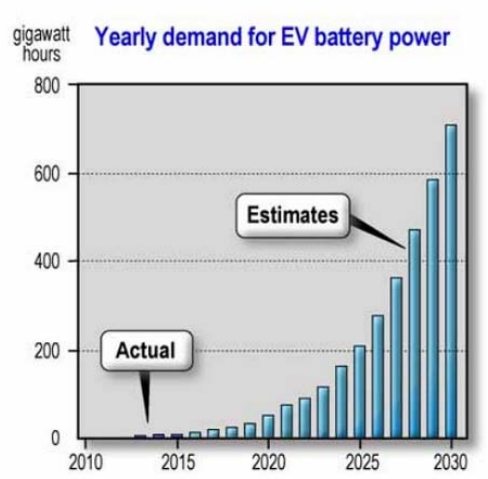
Mining of lithium in Australia



Currently up to 60% of lithium
is to be supplied from Western Australia



Hard rock (spodumene)

$LiAl(SiO_3)_2$

6 wt.% Li is a standard concentrate product to ship overseas

Production of lithium hydroxide, partnerships

Tianqi plant in Kwinana

24,000 tonnes per annum;
expansion to 48,000 tonnes p.a. is anticipated

Mineral Resources
Initial 10,000 tonnes p.a. capacity proposed

Albemarle

Plant of 60,000 – 100,000 tonnes p.a. is proposed

Partnerships with global EV companies and manufacturers of battery chemicals

Pilbara Minerals – with Great Wall Motors

Great Wall

Kidman Resources
- with Tesla and LG Chem

TESLA

LG Chem

Mineral Resources - with Jiangxi Ganfeng Lithium, Co.

GanfengLithium

Global lithium oversupply – 12 to 18 months

Australian supply overtakes demand (temporary)

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Large-scale batteries in the grid to support the penetration of renewables

Blackouts in the grid in SA in 2015 and 2016

Above: Damaged transmission lines in South Australia in 2016

- Blackouts are avoided
- 140 ms to engage (gas or steam generators take minutes to respond and adjust)
- A$40M p.a savings in frequency costs
- ~1.4 A$M profit in 2018 by power shifting

100 MW/125 MWh Tesla battery in Hornsdale, SA,
(launched in Dec 2017)

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Subsequent large scale grid battery projects

South Australia: 100 MW/300 MWh (Solar River Project, SA)
Victoria: 30 MW/30MWh (Ballarat, VIC)
Victoria: 30 MW/30 MWh (Gannawarra, VIC)
South Australia: 900 MW battery is planned (to supplement hybrid solar-wind plant)

100% electricity from renewable energy in Australian Capital Territory (ACT) in 2019

Royalla solar farm in ACT

- Grid battery project has been announced in Sep 2019
- 20 MW/40 MWh specification
- Provider to be selected by mid-2020, two years lag to build
- The battery will be able to power 25,000 homes for 2 hours

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Home battery storage to supplement PV

Australia is a global leader in solar cell installations in homes

10% of electricity generation capacity is behind the meter today

Up to 45% of electricity will be supplied in this way by 2040

2 million homes are now energy producers as well as consumers in Australia

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Residential batteries

Tesla Powerwall 2, 5 kW/13.5 kWh
A$11,700

Enphase battery, up to 3.38 kW/14.8 kWh
Cost depends on modular specification

Installation trends (data from 2017):

2016: 6,750 installations
2017: 20,000
2018: 40,000 (forecast)

- Australia is arguably #1 country in uptake of residential storage
- Efficient energy use at home is enabled
- Home battery can be used to support the grid (Bruny Island trial)
- Expected to be a common part of electricity grid in Australia

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Slow adoption of electric cars in Australia

- 0.5% of cars on road in 2018
- <1% of new vehicle sales
- emissions are likely to increase until 2029 due to limited sales of Evs
- only 4% of sales are forecasted by 2023
- In 2019 sales of EVs declined, only 0.2% of new cars (Bloomberg)

27 EV models for sale in Australia
(216 in China and 96 in Europe)

EV fleet – about 5,000 cars
(global fleet - ~2 million cars)

International context:

Britain and France – end sales of petrol cars by 2040

India – only electric cars sold by 2030,

China – more than 20% by 2025 to be EVs of plug-in vehicles

Slow EV uptake: infrastructure or policy?

One of the successful global fast charger manufacturing companies is Australian (projects in UK, Norway)

QLD: Electric Super Highway (stations between Brisbane and Cairns, 17 locations); State-owned Ergon Energy utility identified 100 places for charging stations in the network with surplus capacity (charging initially free)

Western Australia – 70 charging stations in Perth

Adelaide – 40 (**all data from 2017**)

Need for national programs and policy

- Cost premium for EVs in Australia of A$8,000 – A$12,000
- Relaxed emission requirements for vehicles in Australia

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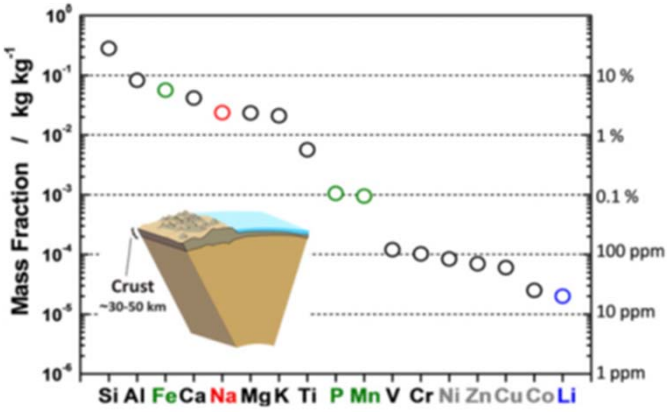
Sustainability: post-lithium battery chemistries

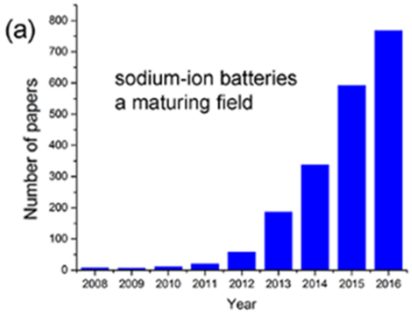


Abundance of elements (Yabuuchi, Komaba, Sci. Technol. Adv. Mater. 15, 043501, 2014)

Low abundance of Li and geographic localisation (Chile, Bolivia, China, Australia)

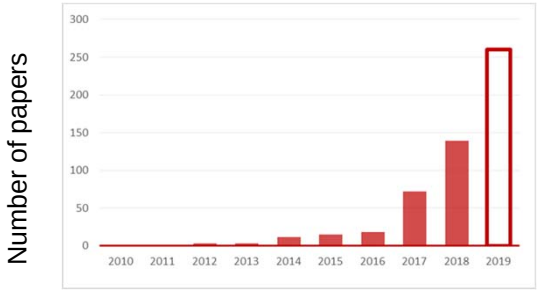
Na, K are about 700 times more abundant and available everywhere

Trends in publication numbers in sodium and potassium-ion batteries



Na-ion

K-ion

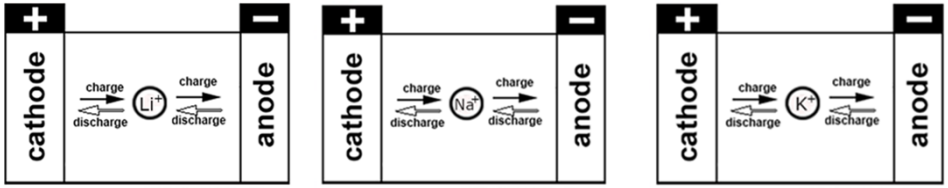


Comments on feasibility of beyond-lithium batteries

Plating/stripping potentials for sodium and potassium, V vs lithium

Na	+0.3
K	-0.1

The same “rocking chair” principle



- Identify anodes that operate at low potentials vs Na or K

  Na examples: hard carbons, phosphorus
  K examples: graphite

- Identify cathodes that operate at high potentials vs Na or K

  Na examples: $NoCrO_2$, $Na_3V_2(PO_4)_2F_3$

  K examples: $K_2Mn[Fe(CN)_6]$,

- Optimise electrolytes, additives and binders

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Australia: competitive research landscape

Major research universities

GROUP OF EIGHT AUSTRALIA

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THE UNIVERSITY OF WESTERN AUSTRALIA

MONASH University

THE UNIVERSITY of ADELAIDE

THE UNIVERSITY OF MELBOURNE

UNSW SYDNEY

THE UNIVERSITY OF QUEENSLAND AUSTRALIA

THE UNIVERSITY OF SYDNEY

- ~20 research-intensive universities
- some form of battery research probably in each
- Not necessarily coordinated, a lot of competition

Other universities with significant battery research

UNIVERSITY OF WOLLONGONG AUSTRALIA

DEAKIN UNIVERSITY

UTS UNIVERSITY OF TECHNOLOGY SYDNEY

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Commonwealth Scientific and Industrial Research Organisation (CSIRO)

Includes battery research facility in Melbourne (Clayton area)

- Electrolytes
- Battery prototyping (e.g., pouch cell fabrication)
- Battery characterisation
- Testing battery modules for integration with PV

Successful technologies Commercialised in the past:

UltraBattery

Cap-XX, Co.

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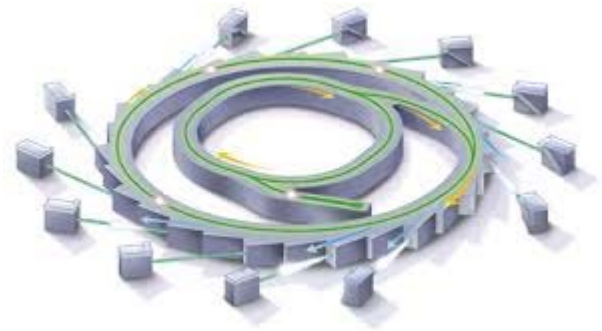
Australian synchrotron (Melbourne)



Access is based on competitive rounds of proposals

Useful beamlines:

- Powder diffraction (used a lot for in-situ battery characterisation)
- Infrared microspectroscopy
- Small and wide angle x-ray scattering (SAXS/WAXS)
- X-ray absorption spectroscopy (XAS)
- Soft x-ray spectroscopy (XPS, NEXAFS)

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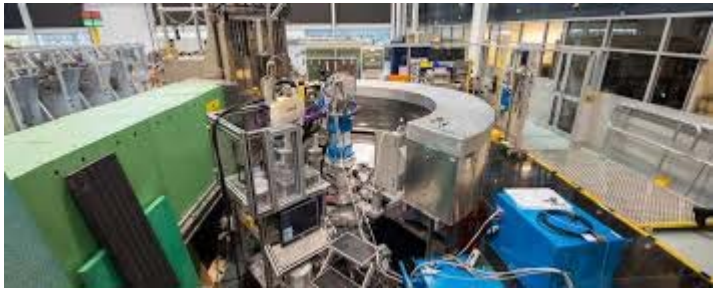
ANSTO Neutron Diffraction facility (Sydney)

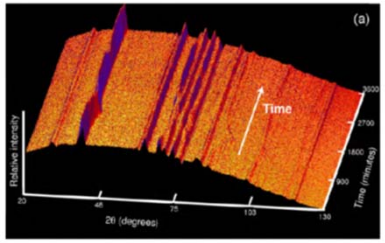


Echidna, high resolution neutron diffractometer

Wombat, high intensity powder diffractometer

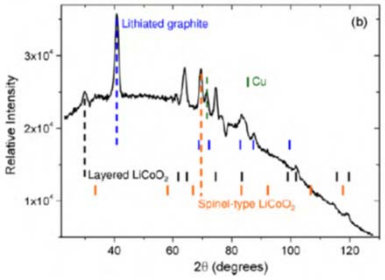
Access is based on competitive rounds of proposals

- **Crystallographic information on materials**
- **In-situ battery analysis**



Example:
commercial prismatic graphite-$LiCoO_2$ cell

Sharma et al., J. Power Sources, 2010



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Australian National Fabrication Facility

National fabrication network for micro- and nanofabrication

Nodes:

Australian Capital Territory (ANU)
Victorian Node (MCN)
NSW
South Australia
Queensland
Materials Node
Optofabrication Node

ANFF

Melbourne Centre for Nanofabrication (Victorian Node)

- Various thin film and pattern fabrication techniques
- Relevant characterisation facility
- Largest clean room in Australia

Useful for micro-battery fabrication and preparing customised in-situ cells, electrode coatings

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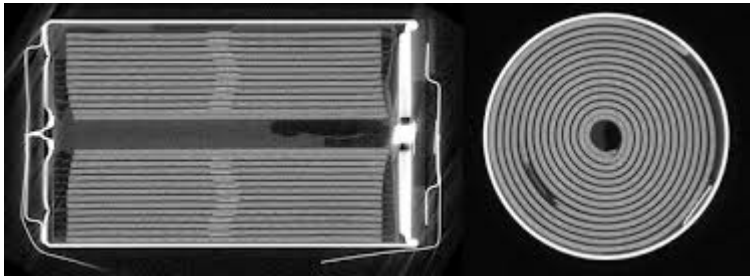
National Laboratory for X-ray Micro Computed Tomography (The Australian National University)

ANU supercomputer facility can be used for calculations

In principle capabilities (currently in discussion with laboratory's staff):

- Visualisation of the structure of batteries
- Changes in batteries upon abuse and cycling
- In-situ visualisation may be possible



Micro-CT scan of a cylindrical battery (literature example)

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Battery Storage and Grid Integration Program (BSGIP) at ANU

Battery Storage and Grid Integration Program

Established in 2018 at ANU with support from the Australian Capital Territory government

Cross-college, cross-school program

- Research School of Electrical, Energy and Materials Engineering (ANU College of Computer Science and Engineering)
- Research School of Chemistry (ANU College of Science)

BSGIP Energy Storage

BSGIP Data and Analytics

BSGIP Devices, Optimisation and Control

BSGIP Regulation, Markets and Models

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BSGIP: integration of batteries in grid and home storage

- **Economic assessment of battery integration**

Collection of information on electricity use in households with installed PV and batteries

Possible principles for future energy tariffs

Scenarios of peer-to-pear energy trading

- **Social aspects**

Social attitudes to battery installations at home and energy sharing

How people feel towards these innovations and barriers in society

- **Control algorithms and software**

Smart control of batteries installed with PVs in homes

Collection of information on grid parameters (frequency, voltage) and control of these within the desired operational envelopes

- **Distribute Energy Resources Laboratory**
  (project launched in Sep 2019, under construction)

Simulation of electricity use in a residential street with solar panels and battery integration

Development and test of technologies and control systems needed for Australia's future energy system

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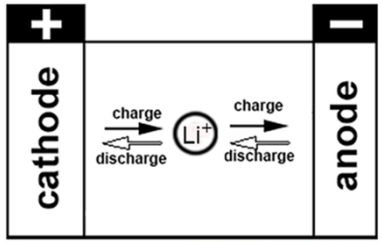
BSGIP: Post-lithium metal-ion batteries

Battery materials and devices laboratory
(operates in Research School of Chemistry)

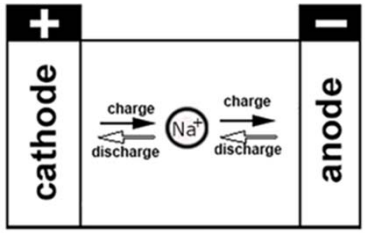
Focus on post-lithium metal-ion batteries

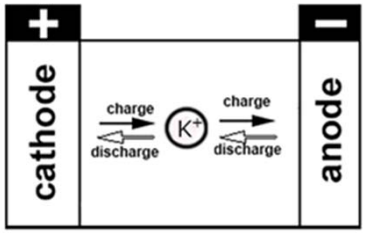
- Na-ion batteries
- K-ion batteries
- Ca-ion batteries (to commence in 2020)

Enabling transition
from Li-ion batteries



to more sustainable chemistries





FEATURE ARTICLE
Potassium-Ion Batteries

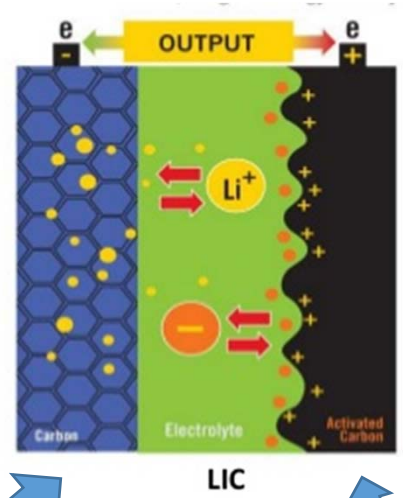
ADVANCED FUNCTIONAL MATERIALS
www.afm-journal.de

Potassium-Ion Battery Anode Materials Operating through the Alloying–Dealloying Reaction Mechanism

*Irin Sultana, Md Mokhlesur Rahman, Ying Chen, and Alexey M. Glushenkov**

(talk on Oct 9, EEM symposium)

BSGIP: lithium-ion capacitors



LIC

Battery electrode

(usually lithiated graphite or lithium titanate)

Capacitive electrode

(activated carbon)

Concept proposed by Amatucci in 2001

Commercialised in 2011 in Japan

Charge-discharge profiles of a capacitor (triangular charge-discharge profiles)

BUT High energy density

REVIEW
Sodium-ion Capacitors
ADVANCED SUSTAINABLE SYSTEMS
www.advsustainsys.com

Cell Configurations and Electrode Materials for Nonaqueous Sodium-Ion Capacitors: The Current State of the Field

Alexey M. Glushenkov and Amanda V. Ellis*

Australian National University

BSGIP: dual-ion batteries

Joint project with University of Münster, Germany

Australian National University

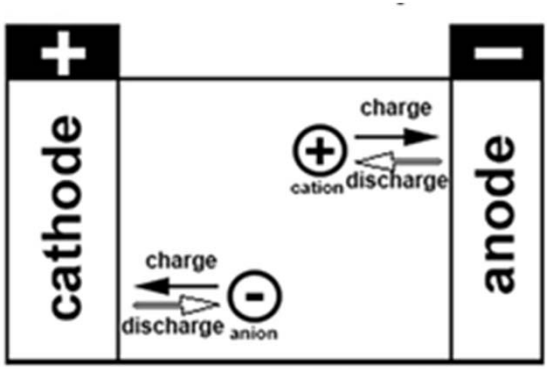
WWU MÜNSTER

Supported by an initial grant from

UNIVERSITIES AUSTRALIA

DAAD

Operating principle



- Graphite is a possible cathode material
- Co, Ni use can be avoided in Li-based batteries
- Na and K-based dual-ion batteries are possible

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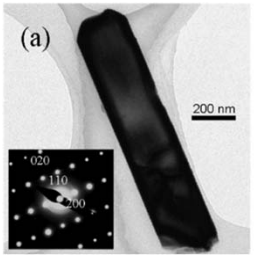
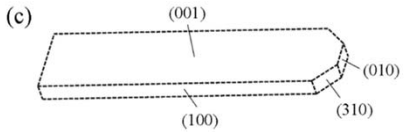
BSGIP: Application of TEM analysis to battery materials

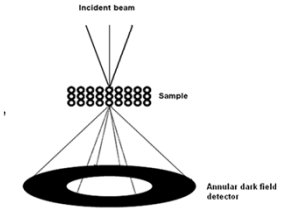
(talk on Oct 9, EEM symposium)

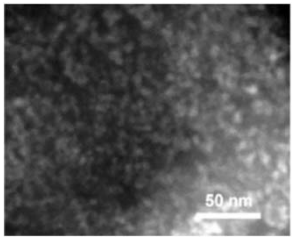
Imaging and diffraction



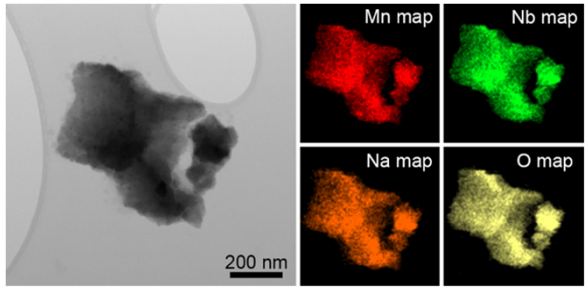


Scanning TEM

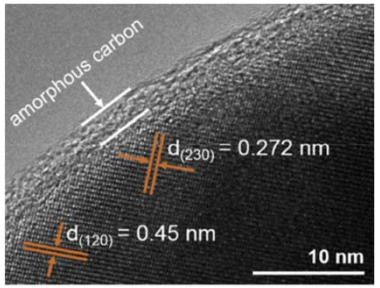




EDX analysis and mapping



High resolution TEM



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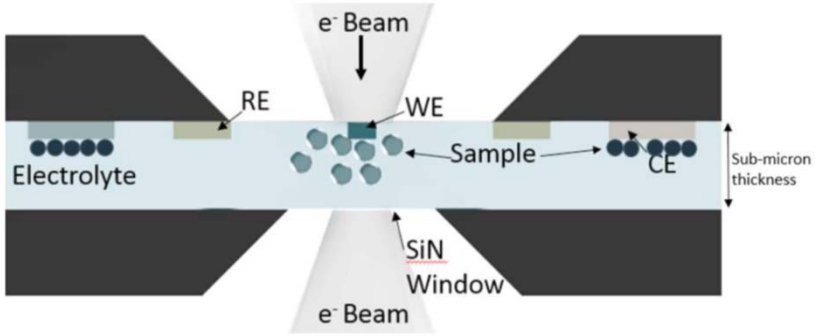
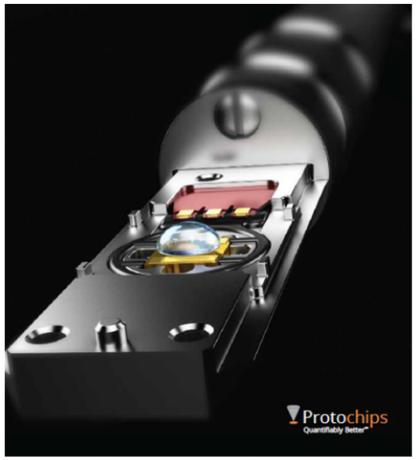
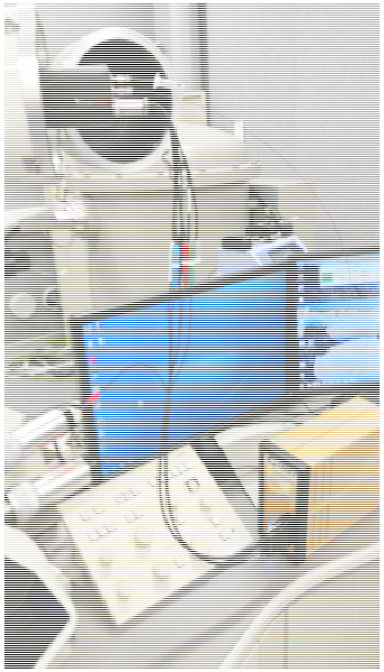
BSGIP: in-situ TEM/electrochemistry in liquid cells

A schematic of a three-electrode liquid cell



Reproduced from
Wheatcroft et al., Energy Procedia 151 (2018) 163





- Operation with actual battery electrolyte, realistic conditions
- Possibility to study full cells
- Observation of metal plating/stripping, electrode behaviour and SEI

Summary

- Lithium-ion batteries are dominating major applications
- Mining industry in Australia is actively targeting spodumene and lithium hydroxide production
- Australia is a global leader in battery installations in grid and at home
- In contrary, the uptake of electric vehicle in Australia is lagging that in Europe, the US and China
- A brief overview of research landscape in Australia has been provided
- The Australian National University has launched Battery Storage and Grid Integration Program in 2018