Cutting-Edge Nanomaterials for Energy:

Solar Cell · Li^+ Battery

Byungwoo Park

Nanomaterials for Energy Group

http://bp.snu.ac.kr

Humanity's Top Ten Problems for the Next 50 Years

1. ENERGY
2. WATER
3. FOOD
4. ENVIRONMENT
5. POVERTY
6. TERRORISM & WAR
7. DISEASE
8. EDUCATION
9. DEMOCRACY
10. POPULATION

Prof. R. E. Smalley (1943 – 2005)

2003	6.5	Billion People
2050	8-10	Billion People

Nanoscale Control: Nanomaterials for Energy

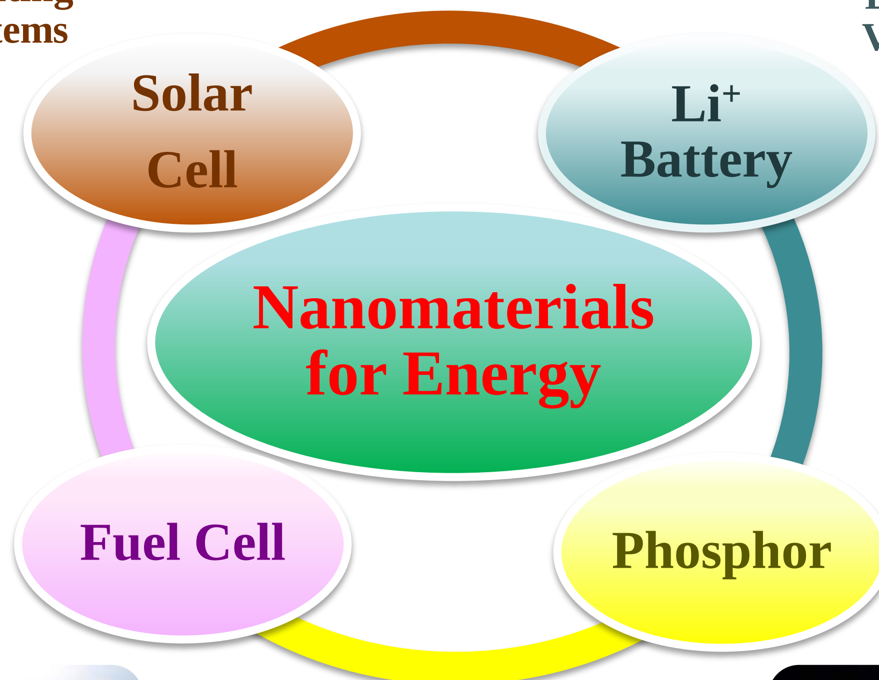
Water Pumping

Lighting Systems

Electric Vehicles

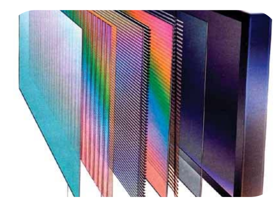
Laptops & Cell Phones

Portable Devices



Household Energy Storage System

Transportation



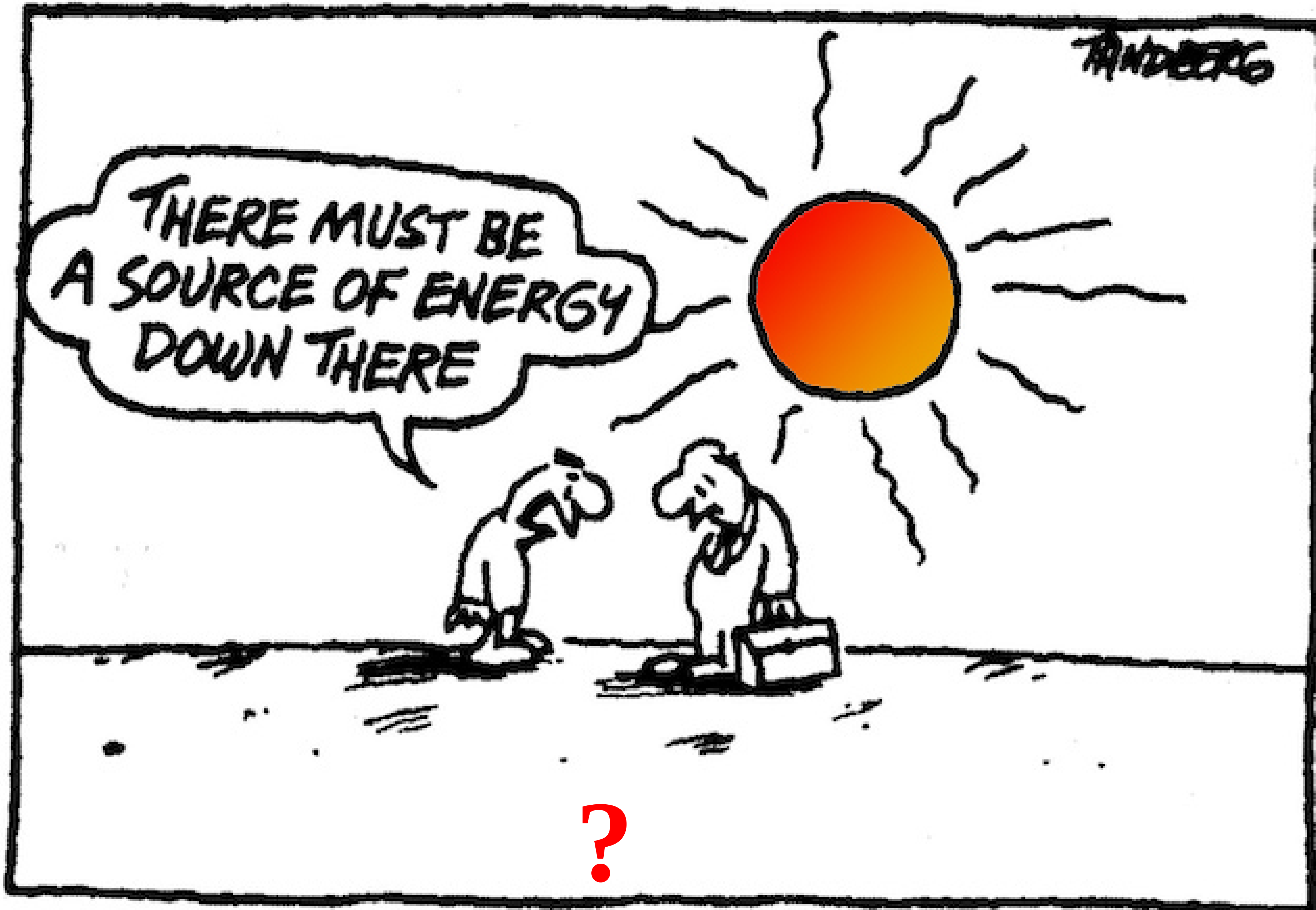
PDP

Portable Power Supply

Less Polluting Power Generation

Quantum Dot LEDs

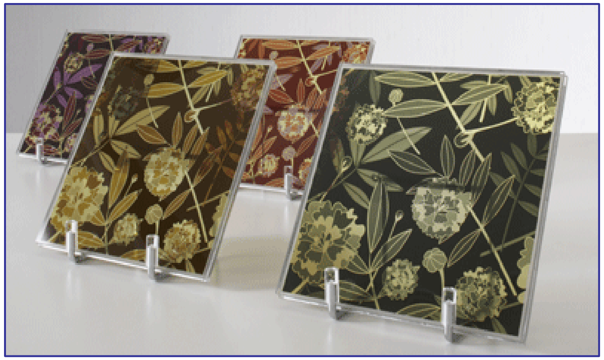
LCD TVs



http://foreconomicjustice.org/3989
/renewable-energy-development/

Semiconductor-Sensitized Solar Cells: from Quantum Dots to Quantum Rods

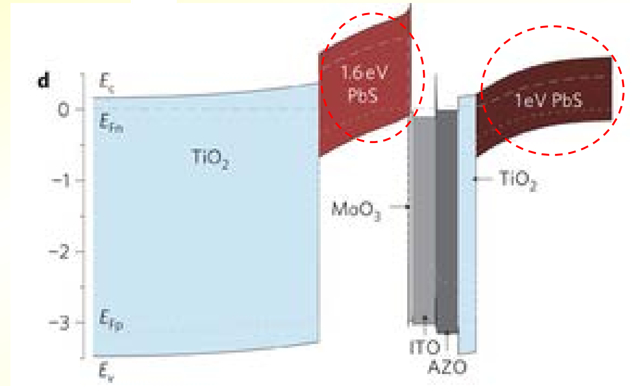
DSSC
KIST



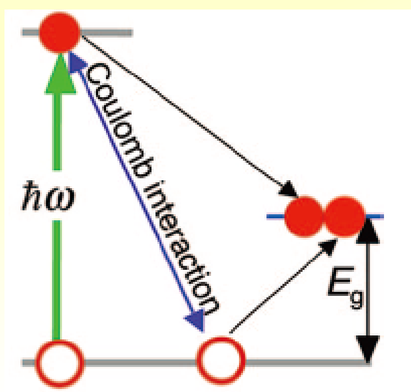
DSSC
SONY

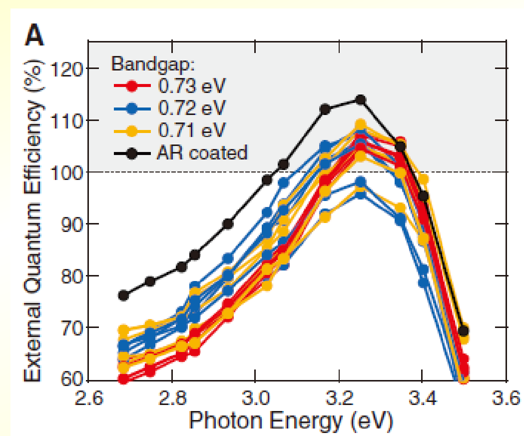
Advantages of Quantum-Dot-Sensitized Solar Cells

나노입자 크기조절을 통한 광흡수 조절



하나의 광자에 의한 다중 전자 생성

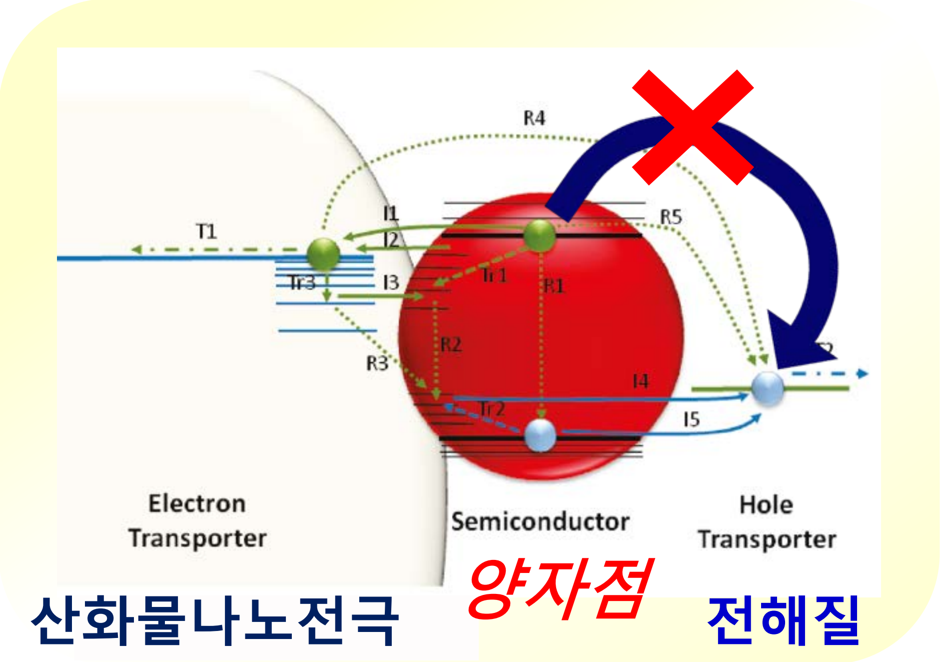




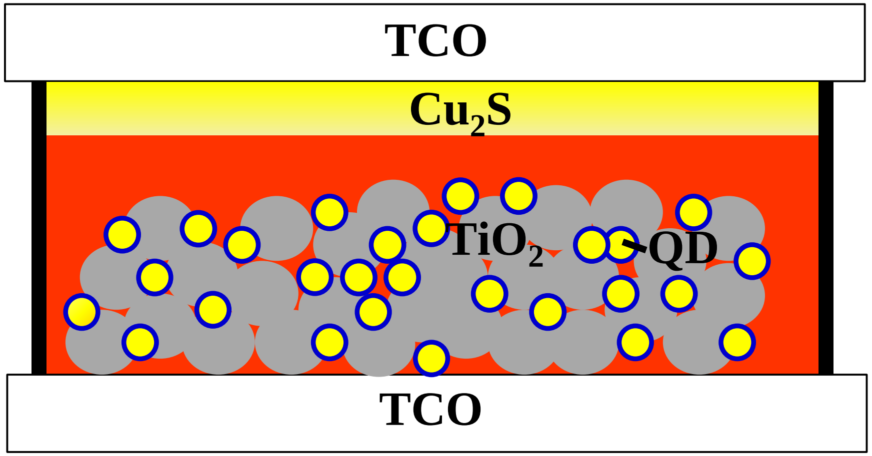
Nozik, *Science* (2011).

Suppression of Recombination: Coating of QD

양자점/전해질 계면처리



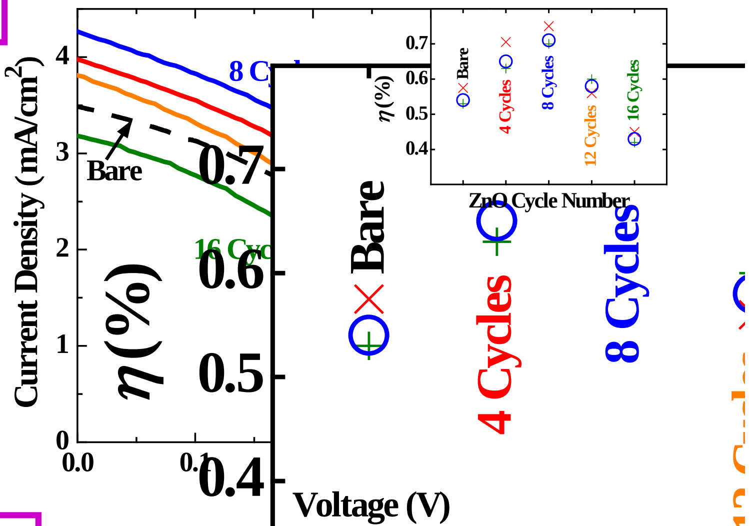
Core/Shell Structure



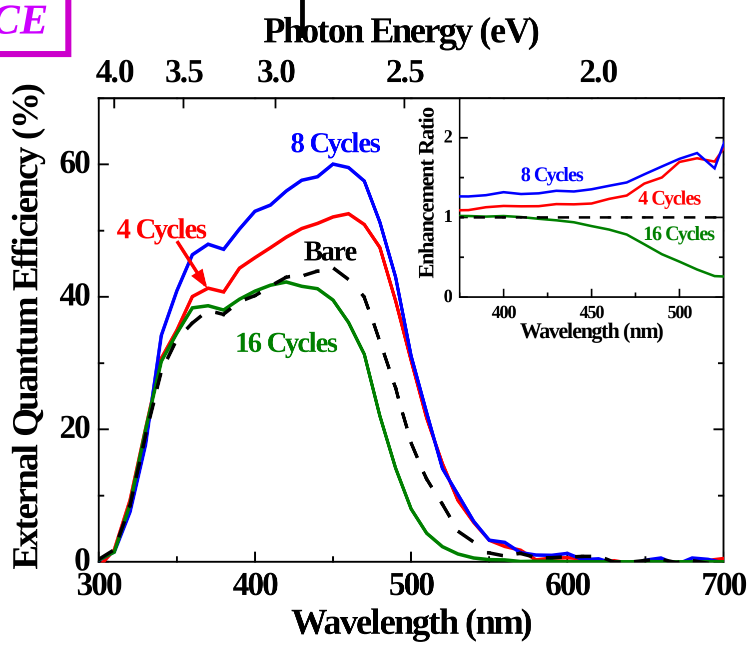
- ❖ 양자점의 전기화학적 안정성 확보
- ❖ Core/Shell 및 불순물 첨가를 이용한 밴드갭 조절
- ❖ 양자점 → 전해질로의 광전하 재결합 억제

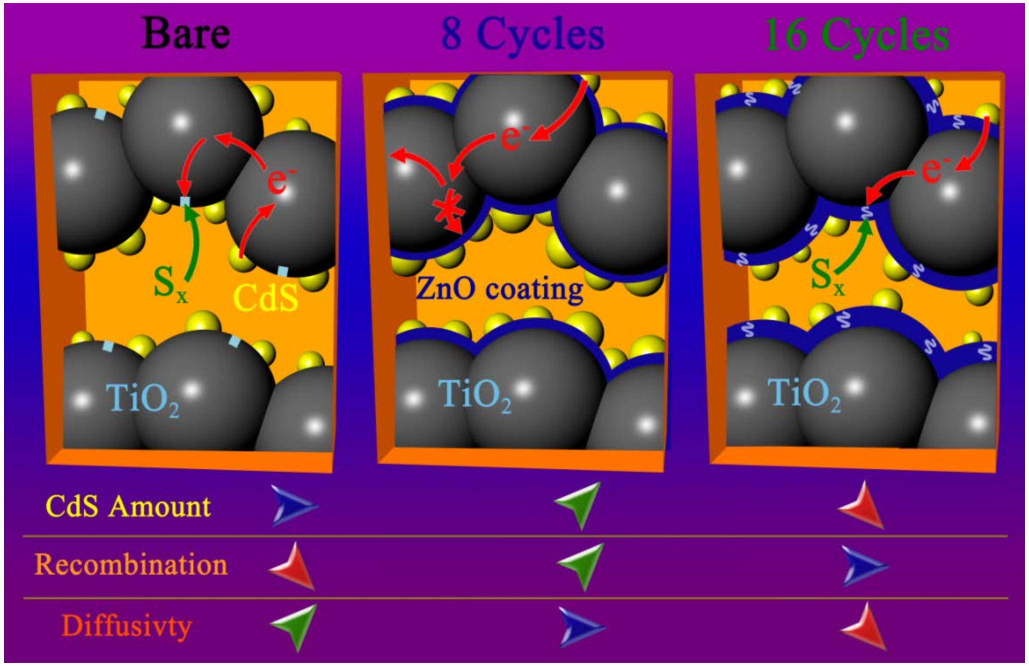
ZnO Passivation on TiO_2 Electrode in QDSC

J-V



IPCE

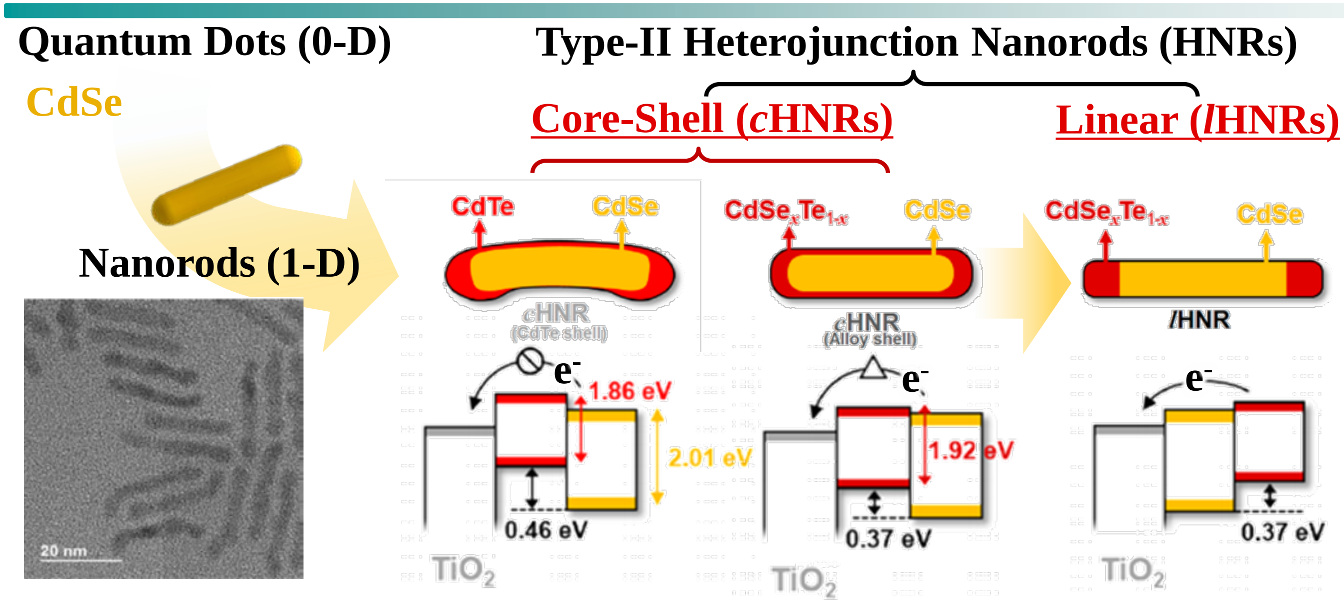


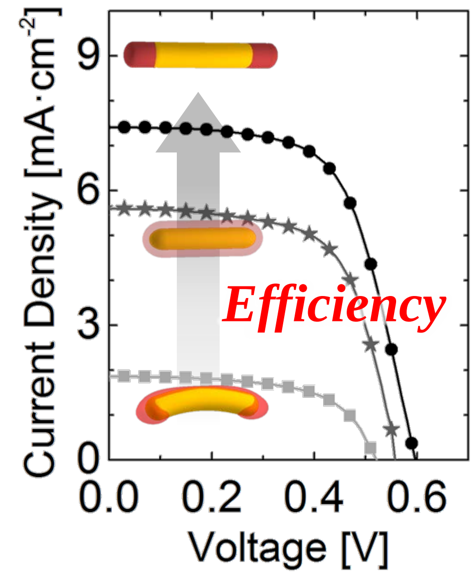


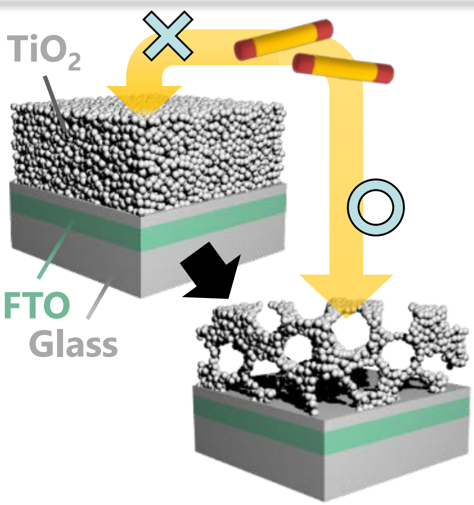
- **Recombination of carrier electrons is significantly diminished by the ZnO layer.**
- **Enhanced adsorption behavior of CdS quantum dot.**

➢ H. Choi, J. Kim, C. Nahm, C. Kim, S. Nam, J. Kang, B. Lee, T. Hwang, S. Kang, D. J. Choi, Y.-H. Kim, and B. Park, *Nano Energy* (2013).

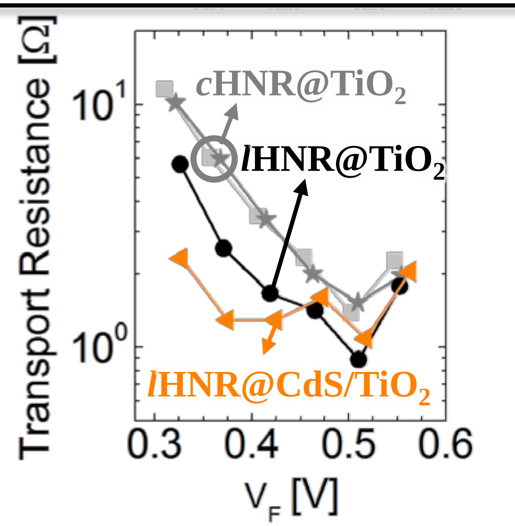
Type-II Heterojunction Nanorods for Solar Cells







Open pore structure for HNR infiltration



CdS Pretreatment for Improved Electron Transport

Nanorod Morphology Tuning

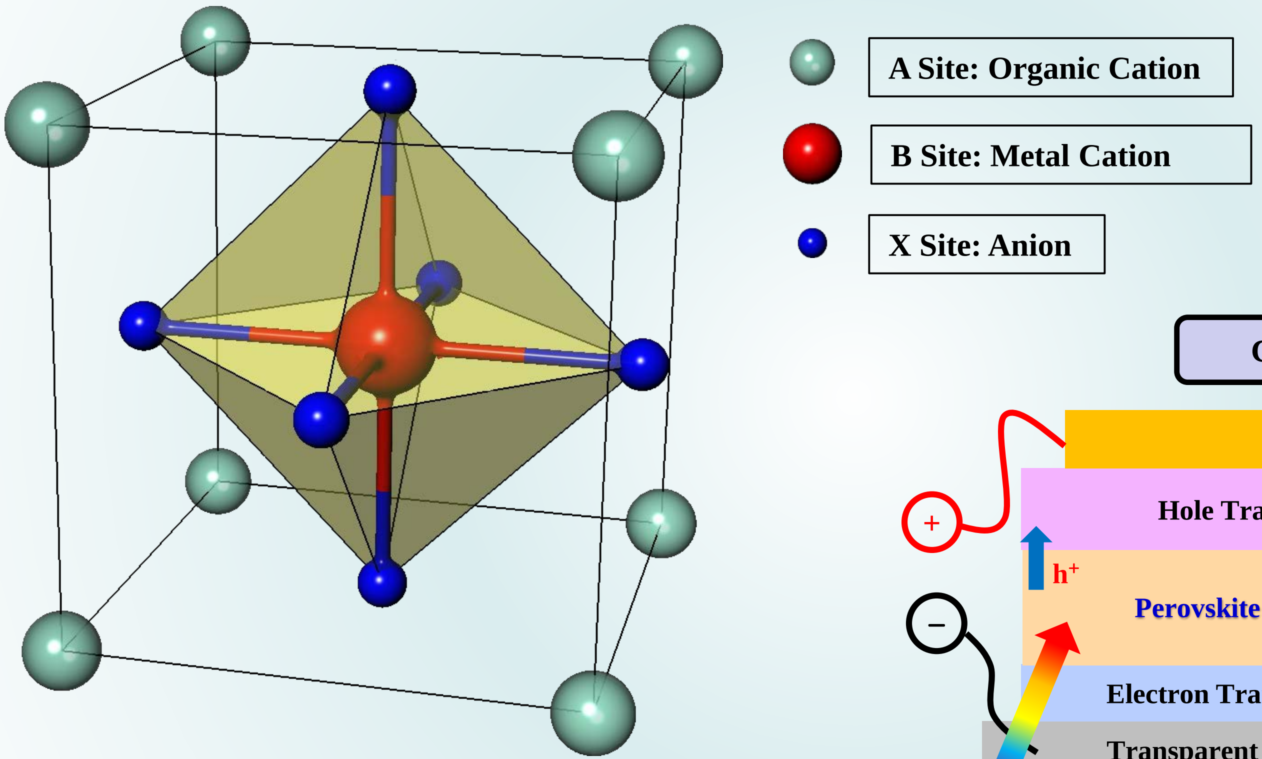
&

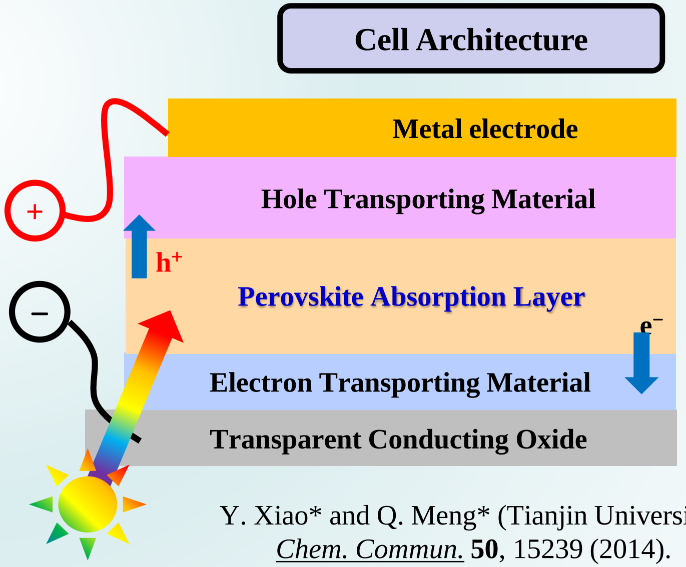
Electrode Property Modification

- S. Lee,+ J. C. Flanagan,+ J. Kang, J. Kim, M. Shim, and B. Park, *Sci. Rep.* (2015).
- S. Lee,+ J. C. Flanagan,+ B. Lee, T. Hwang, J. Kim, B. Gil, M. Shim, and B. Park, *ACS Appl. Mater. Interfaces.* (2017).

Organo-Metal Halide Perovskite Solar Cells

ABX_3 Perovskite Unit Cell

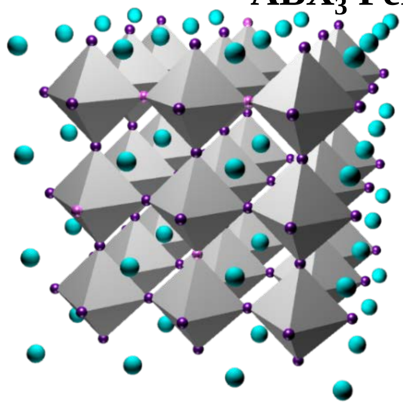




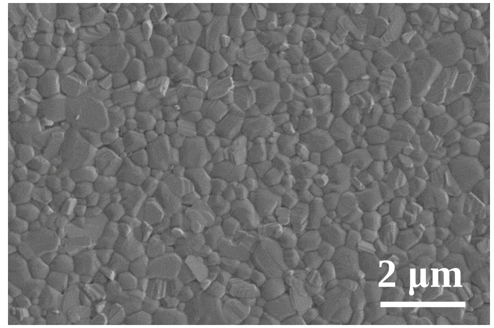
Y. Xiao* and Q. Meng* (Tianjin University), *Chem. Commun.* **50**, 15239 (2014).

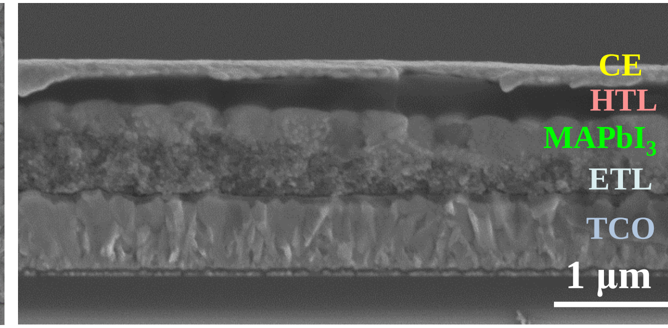
Perovskite as the Next Generation Photovoltaics

ABX_3 Perovskite



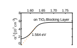
A: $CH_3NH_3^+$, $HC(NH_2)_2^+$, Cs^+, . .
B: Pb^{2+}, Sn^{2+}, . .
X: I^-, Br^-, Cl^-, . .

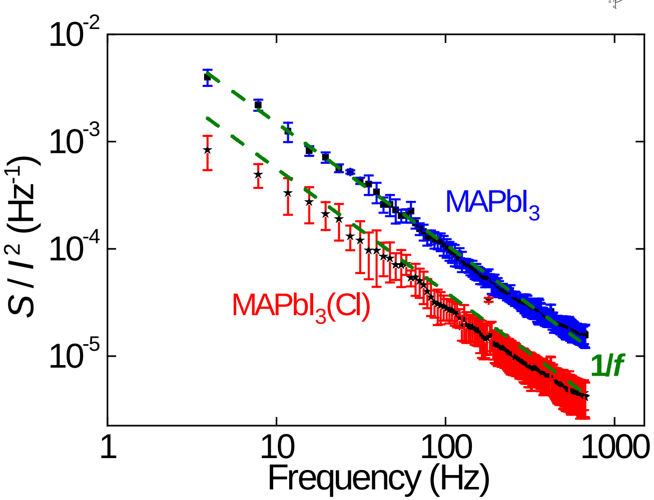


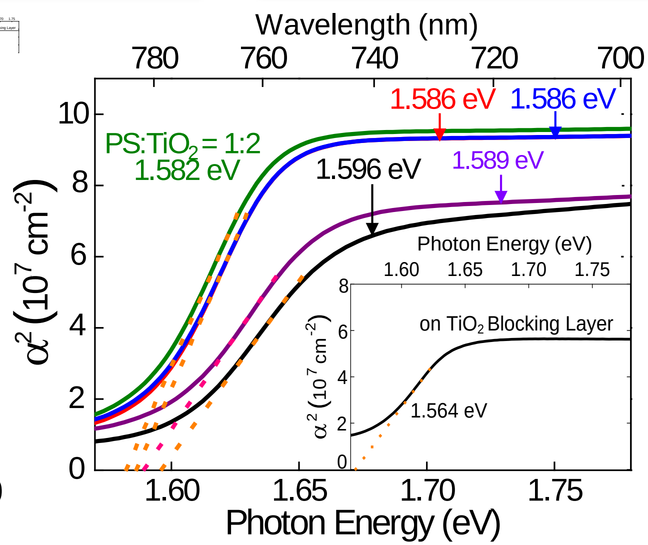


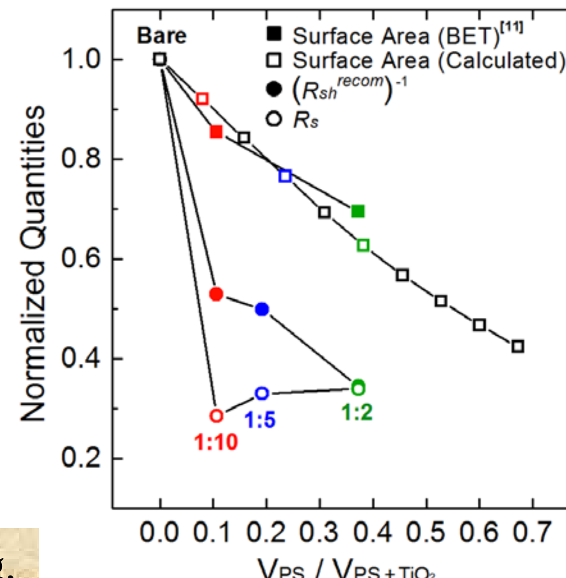
Power Conversion Efficiency of 22.1%
(from *National Renewable Energy Laboratory*)

Nanostructure control of organolead halides perovskite for performance improvement.



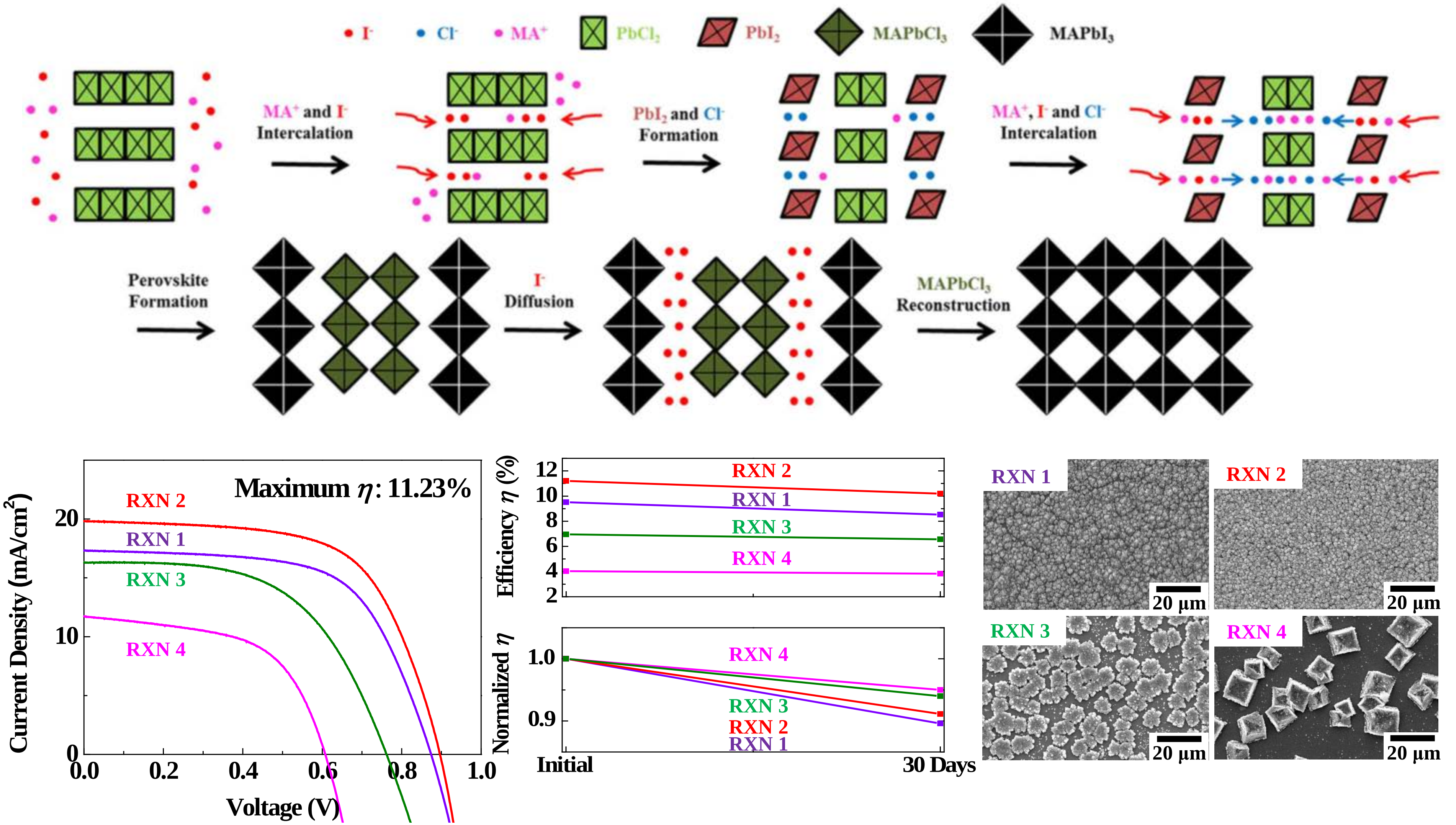






➢ T. Hwang, D. Cho, J. Kim, J. Kim, S. Lee, B. Lee, K. H. Kim, S. Hong, C. Kim, and B. Park, *Nano Energy*, **26**, 91 (2016).

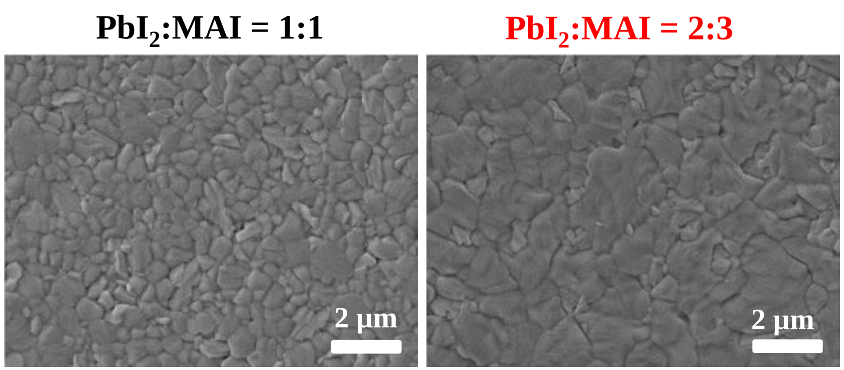
Mechanism Control in the Perovskite Solar Cells



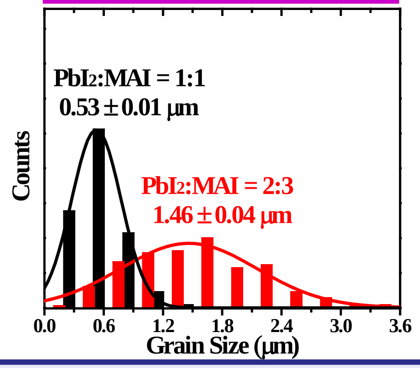
➤ J. Kim, T. Hwang, S. Lee, B. Lee, J. Kim, G. S. Jang, S. Nam, and B. Park, Sci. Rep. (2016).

The Effects of Excess CH_3NH_3I on Perovskites

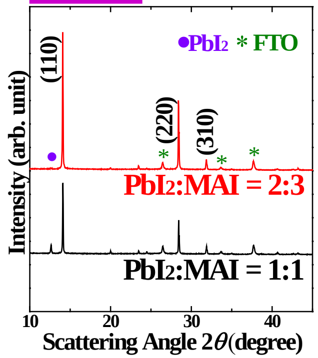
Toluene Dripping in the Non-Stoichiometric Precursor



Grain Size Distribution

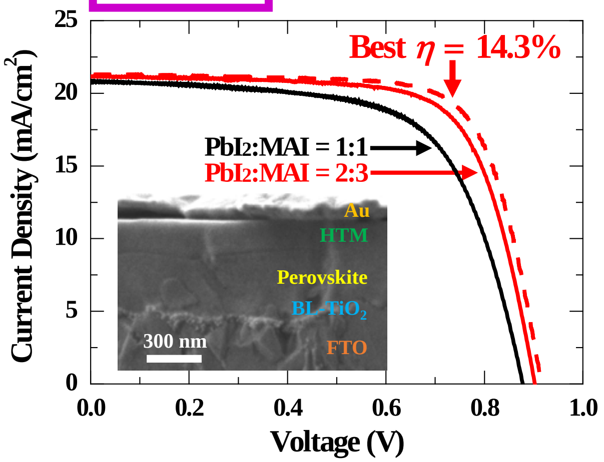


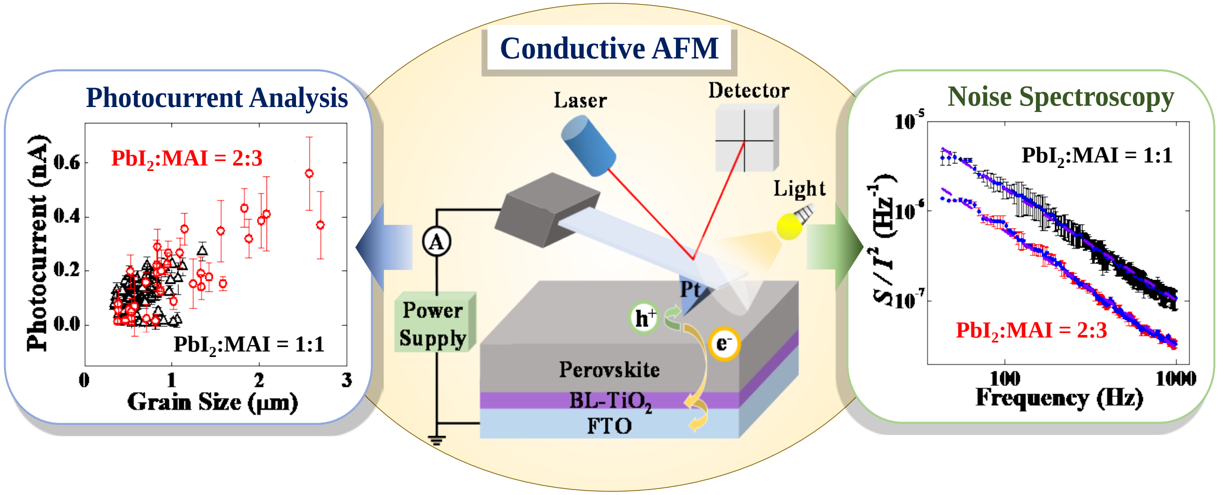
XRD



- **Toluene dripping during spinning of the excess CH_3NH_3I containing precursor.**
  → Enlarged grain size and improved crystallinity with perfect film coverage.

J-V Curve

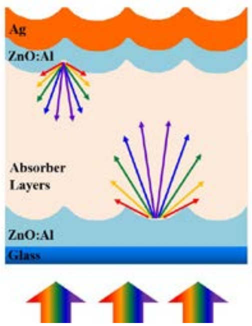


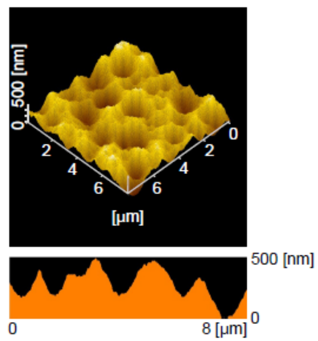


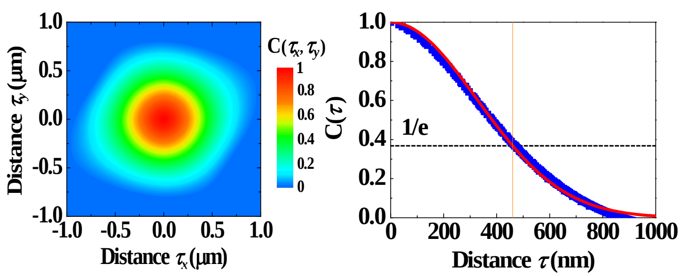
- B. Lee, S. Lee, D. Cho, J. Kim, T. Hwang, K. H. Kim, S. Hong, T. Moon, and B. Park, *ACS Appl. Mater. Interfaces* (2016).

Light Trapping by Surface-Textured ZnO Layer

➢ **Light trapping for thin-films solar cells.**

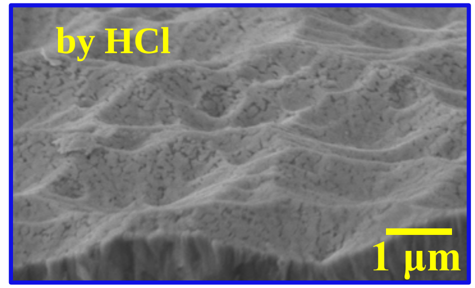


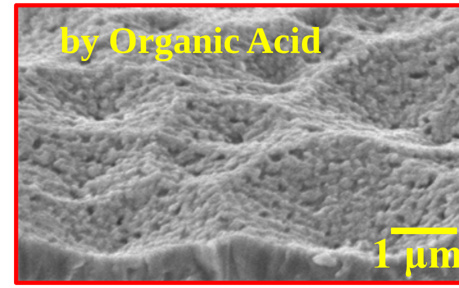


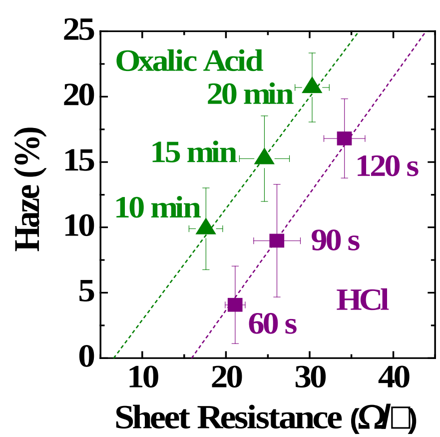


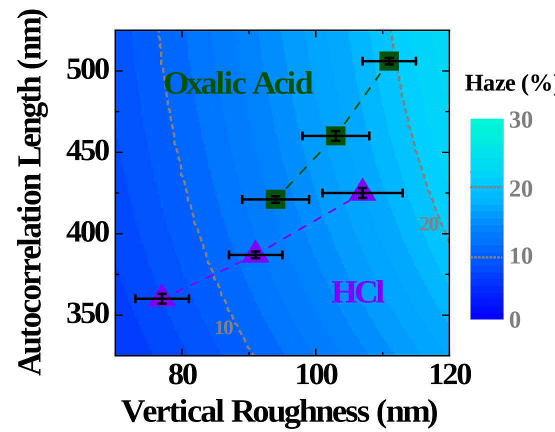
σ_{rms} = 103 ± 5 nm, a_{corr} = 460 ± 3 nm

Texturing by Organic Acid





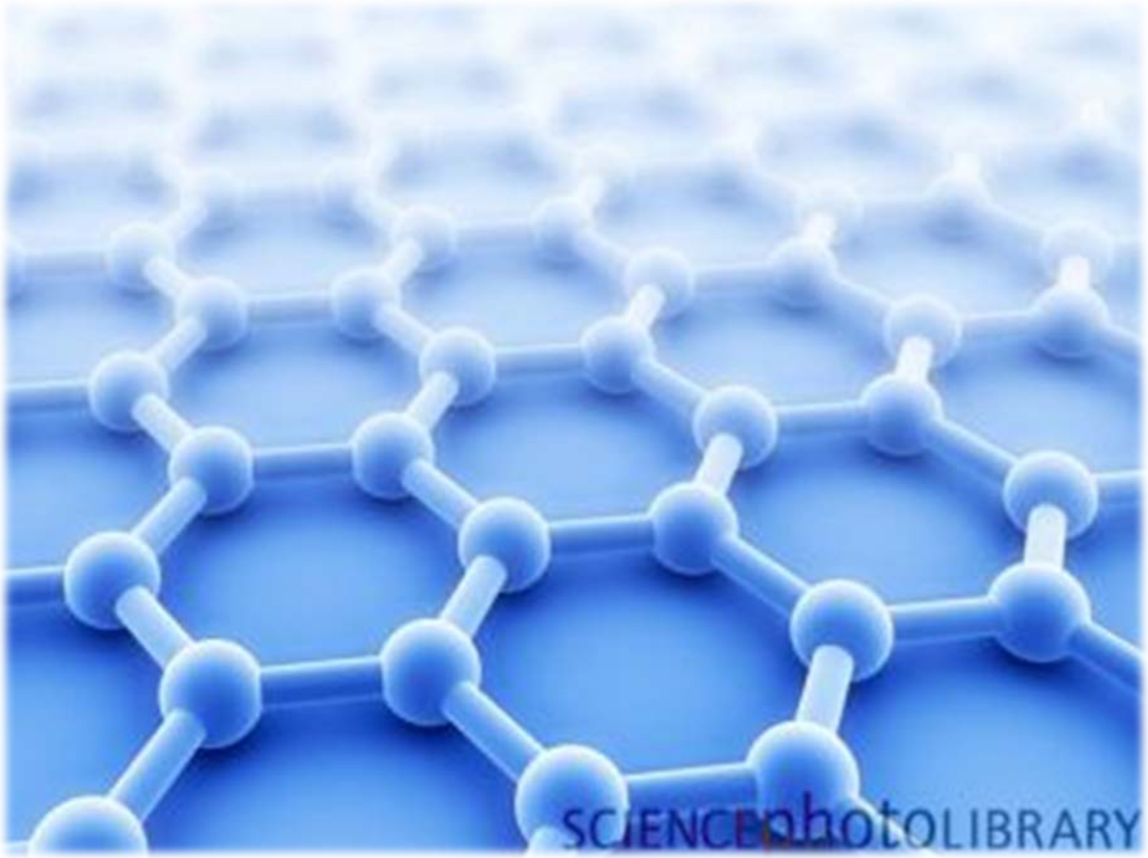




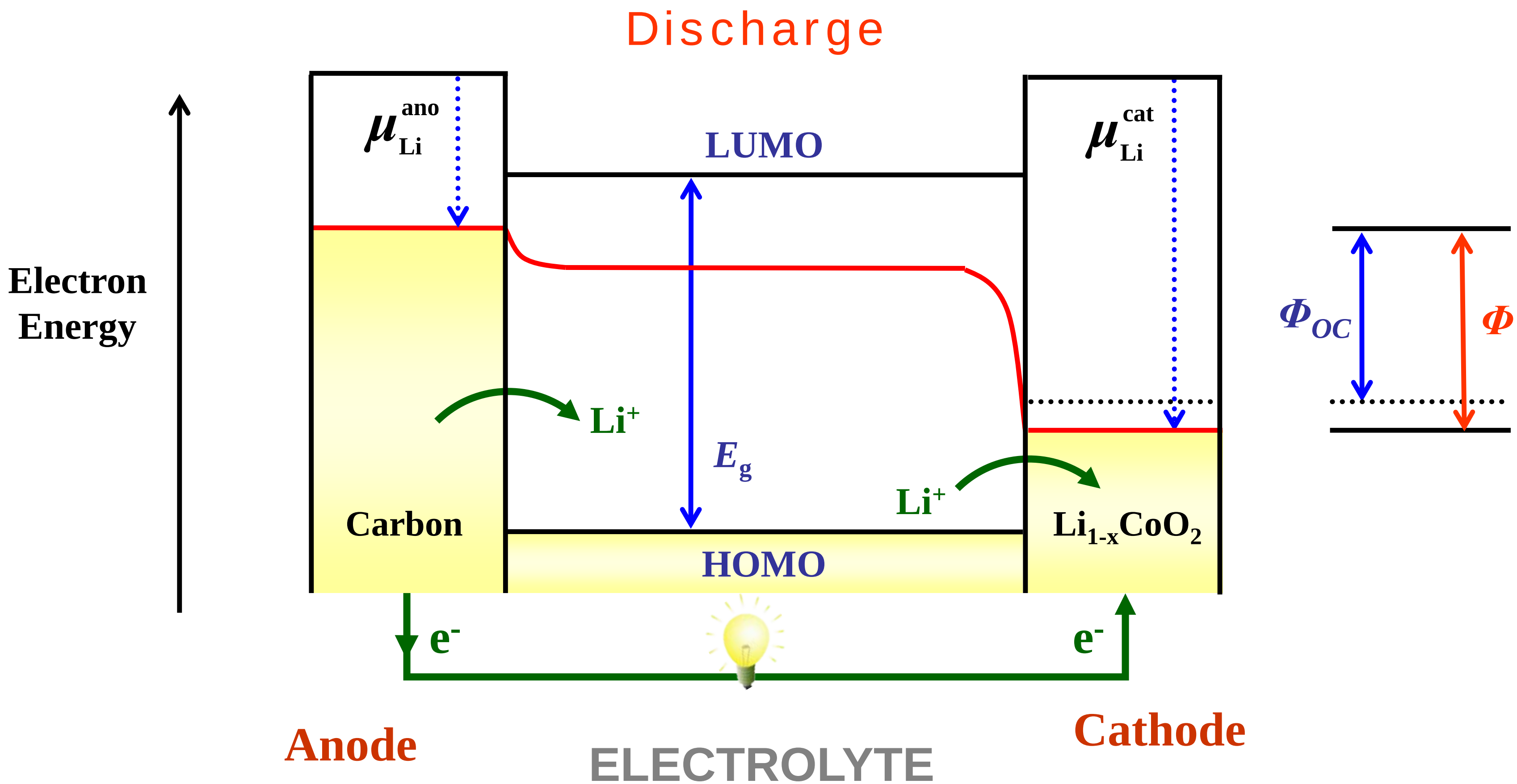
- **Superior light scattering with maintaining transparency and resistance.**
- **Due to effective crater formation with less amount of overall vertical etching.**

➢ W. Lee, T. Hwang, S. Lee, S.-Y. Lee, J. Kang, B. Lee, J. Kim, T. Moon, and B. Park, *Nano Energy* (2015).

Electrode Materials for Li-Ion Battery



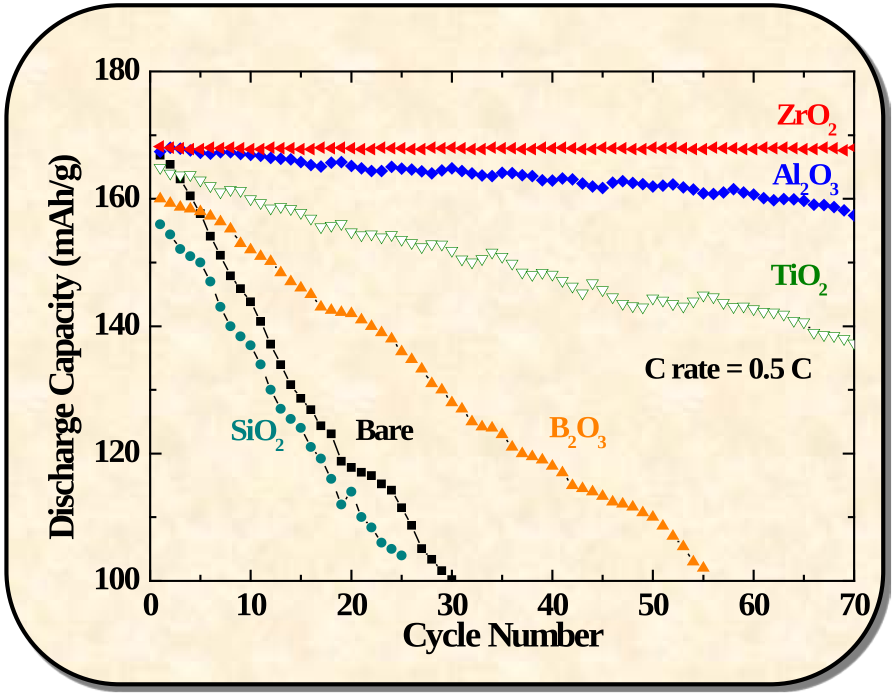
Electrode Materials for Li-Ion Battery



- Capacity (Volume + Mass)
- Rate Capability
- Stability
- Safety
- Cost

Solution?

Novel Electrochemistry by Nanoscale Coating



The following communications are "Very Important Papers" in the opinion of two referees. They will be published shortly. Short summaries of these articles can be found on the *Angewandte Chemie* homepage at the address http://www.angewandte.com

❖ **Improved electrochemical properties by nanoscale metal-oxide coating**

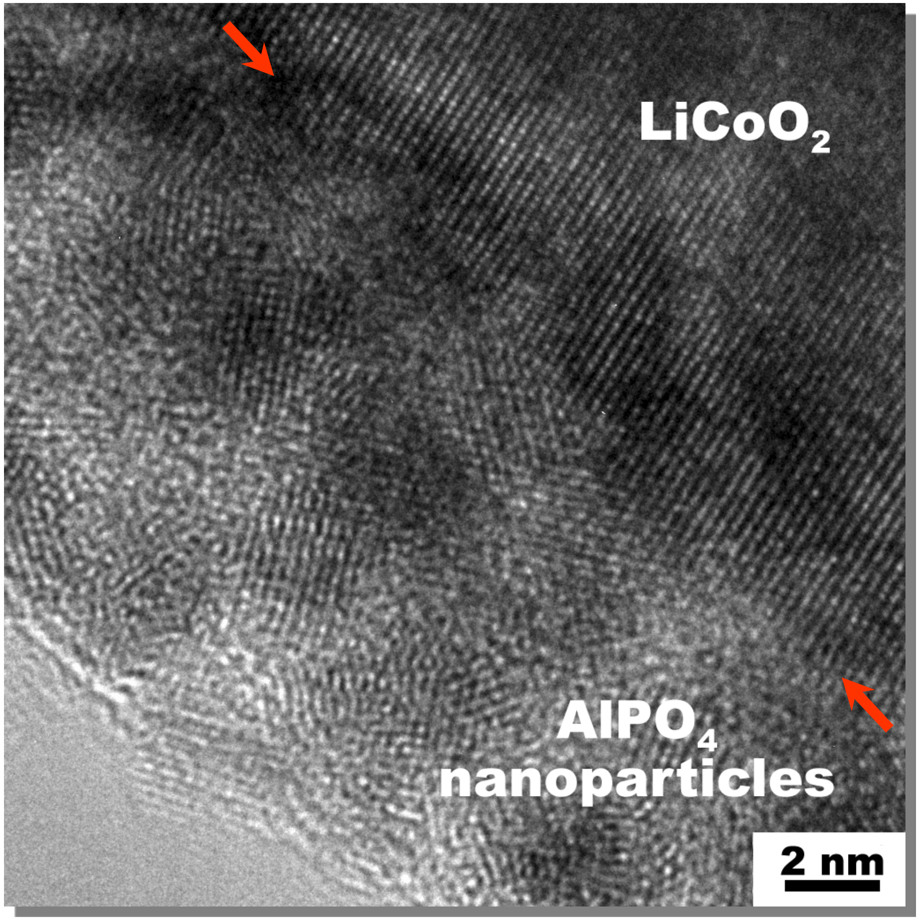
- J. Cho, Y. J. Kim, T.-J. Kim, and B. Park, *Angew. Chem. Int. Ed.* **40**, 3367 (2001). **[Times Cited: 488]**
- J. Cho, Y. J. Kim, and B. Park, *Chem. Mater.* **12**, 3788 (2000). **[Times Cited: 476]**

Metal-Phosphate Nanoparticle-Coated $LiCoO_2$

Bare $LiCoO_2$

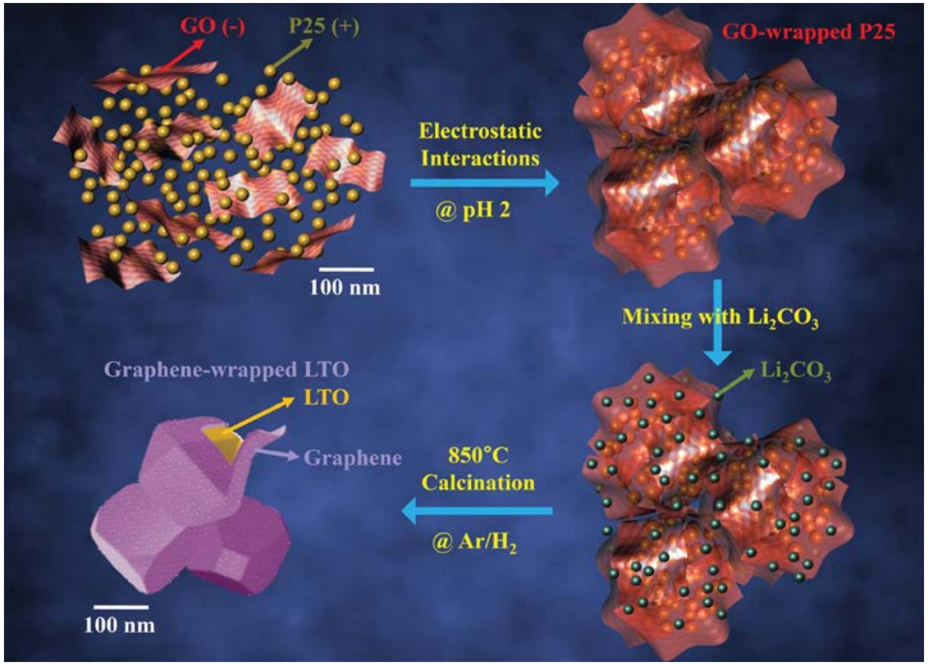
$AlPO_4$-Coated $LiCoO_2$

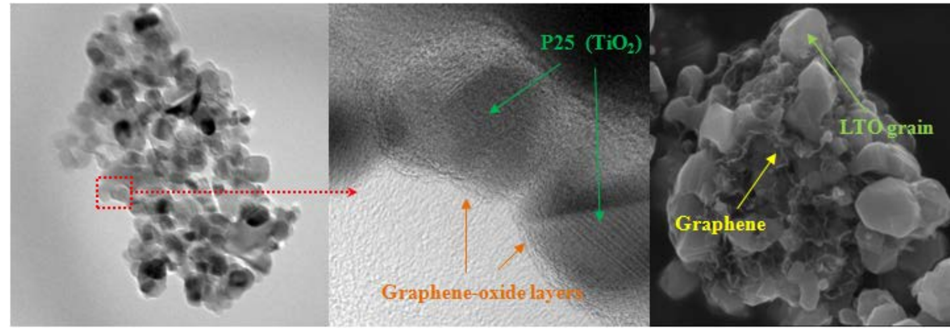
- J. Cho, Y.-W. Kim, B. Kim, J.-G. Lee, and B. Park *Angew. Chem. Int. Ed.* (2003). **[Times Cited: 282]**
- E. Kim, D. Son, T.-G. Kim, J. Cho, B. Park, K.-S. Ryu, and S.-H. Chang *Angew. Chem. Int. Ed.* (2004).
- C. Kim, M. Noh, M. Choi, J. Cho, and B. Park *Chem. Mater.* (2005). **[Times Cited: 469]**

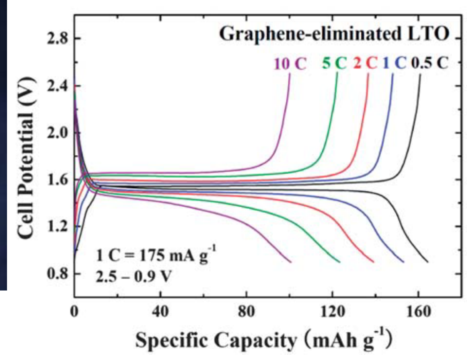


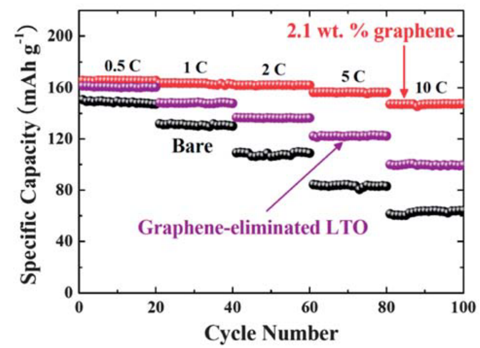
$AlPO_4$ nanoparticles (~3 nm) embedded in the coating layer (~15 nm)

Graphene Wrapping on Single-Crystal $Li_4Ti_5O_{12}$







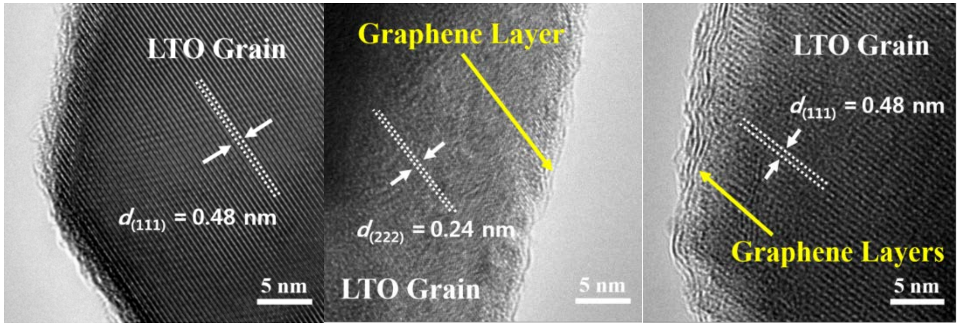


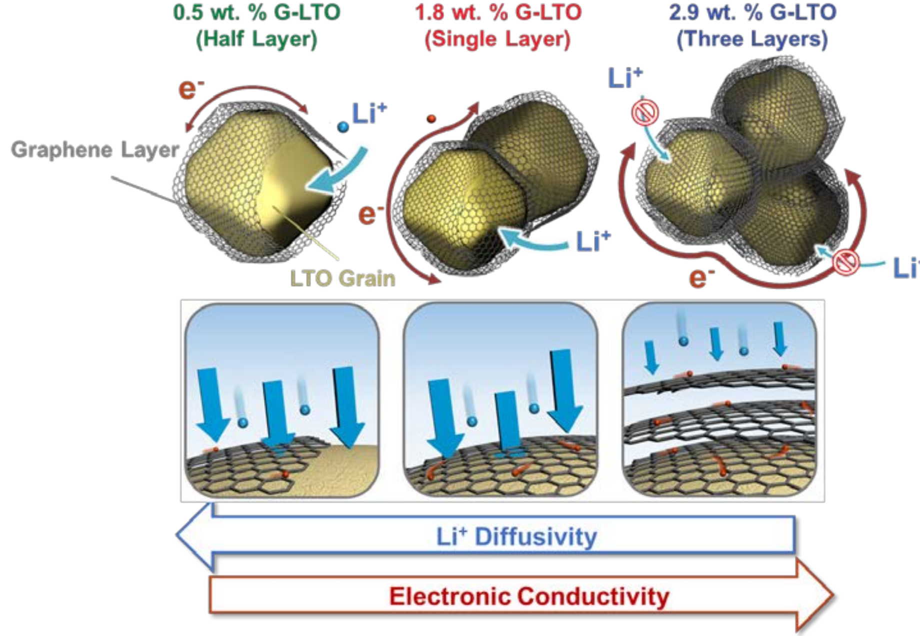
- ✓ Self-assembly of TiO_2 (P25) and GO by electrostatic interactions.
- ✓ Conformal coating of RGO on the individual LTO grains during solid-state reaction ($5TiO_2 \rightarrow Li_4Ti_5O_{12}$, ($\Delta V \cong 32\%$)).
- ✓ The graphene-wrapped LTO manifested an excellent specific capacity at a lithiation/delithiation of 10 C after 100 cycles.

➢ Y. Oh,[+] S. Nam,[+] S. Wi, J. Kang, T. Hwang, S. Lee, H. H. Park, J. Cabana, C. Kim, and B. Park, *J. Mater. Chem. A* (2014). **[Inside Back Cover]**

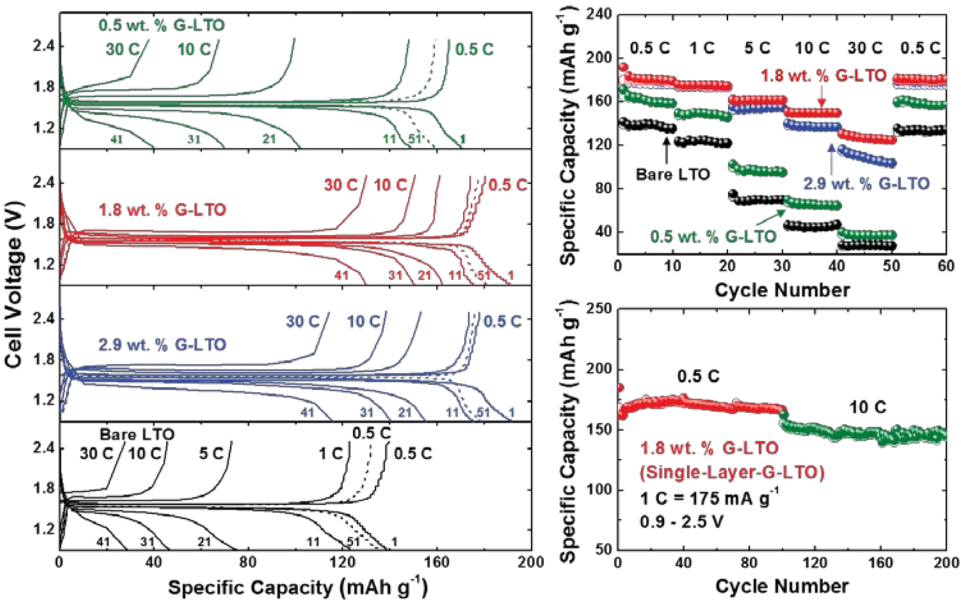
Single-Layer Graphene Wrapping on LTO

0.5 wt. % G-LTO (Half Layer) | **1.8 wt. % G-LTO (Single Layer)** | **2.9 wt. % G-LTO (Three Layers)**





Electrochemical Properties of RGO/LTO

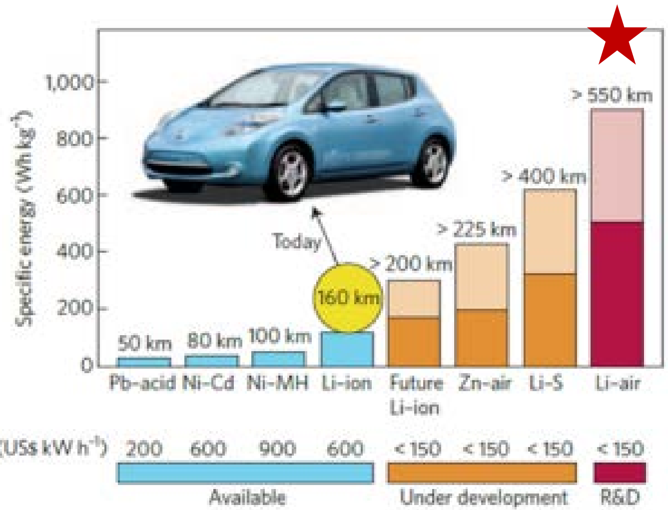


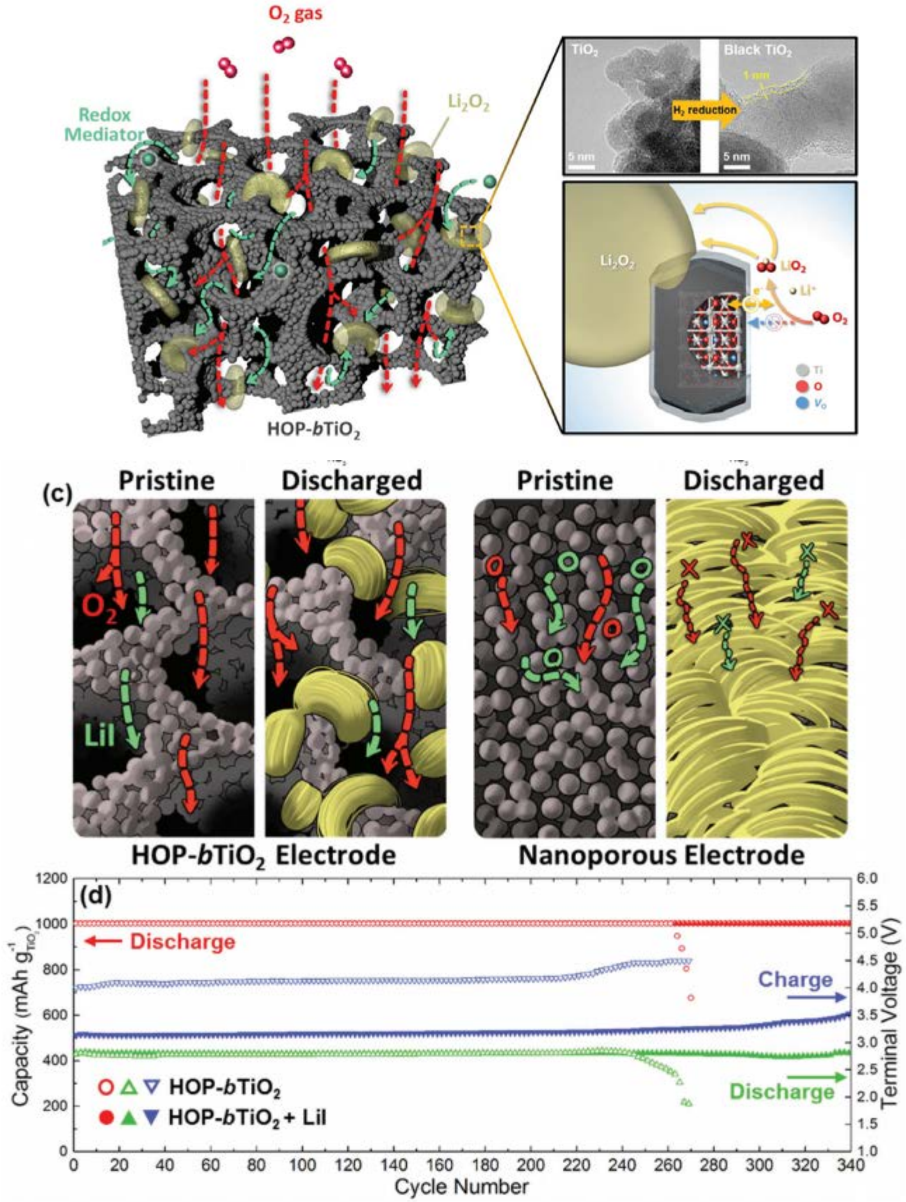
Sample	D_{Li} – CV (× 10^{-13} $cm^2\ s^{-1}$)	R_{ct} (Ω g)	Conductivity (× 10^{-3} S cm^{-1})
0.5 wt. % Graphene (Half Layer)	1.37	0.17	0.19
1.8 wt. % Graphene (Single Layer)	0.22	0.11	1.85
2.9 wt. % Graphene (Three Layers)	0.11	0.16	9.49

- J. Kim,+ K. E. Lee,+ K. H. Kim, S. Wi, S. Lee, S. Nam, C. Kim, S. O. Kim, and B. Park, *Carbon* (2017).

Lithium-Air Battery: Promise and Challenges

High theoretical energy density (≈ 3500 Wh kg^{-1})



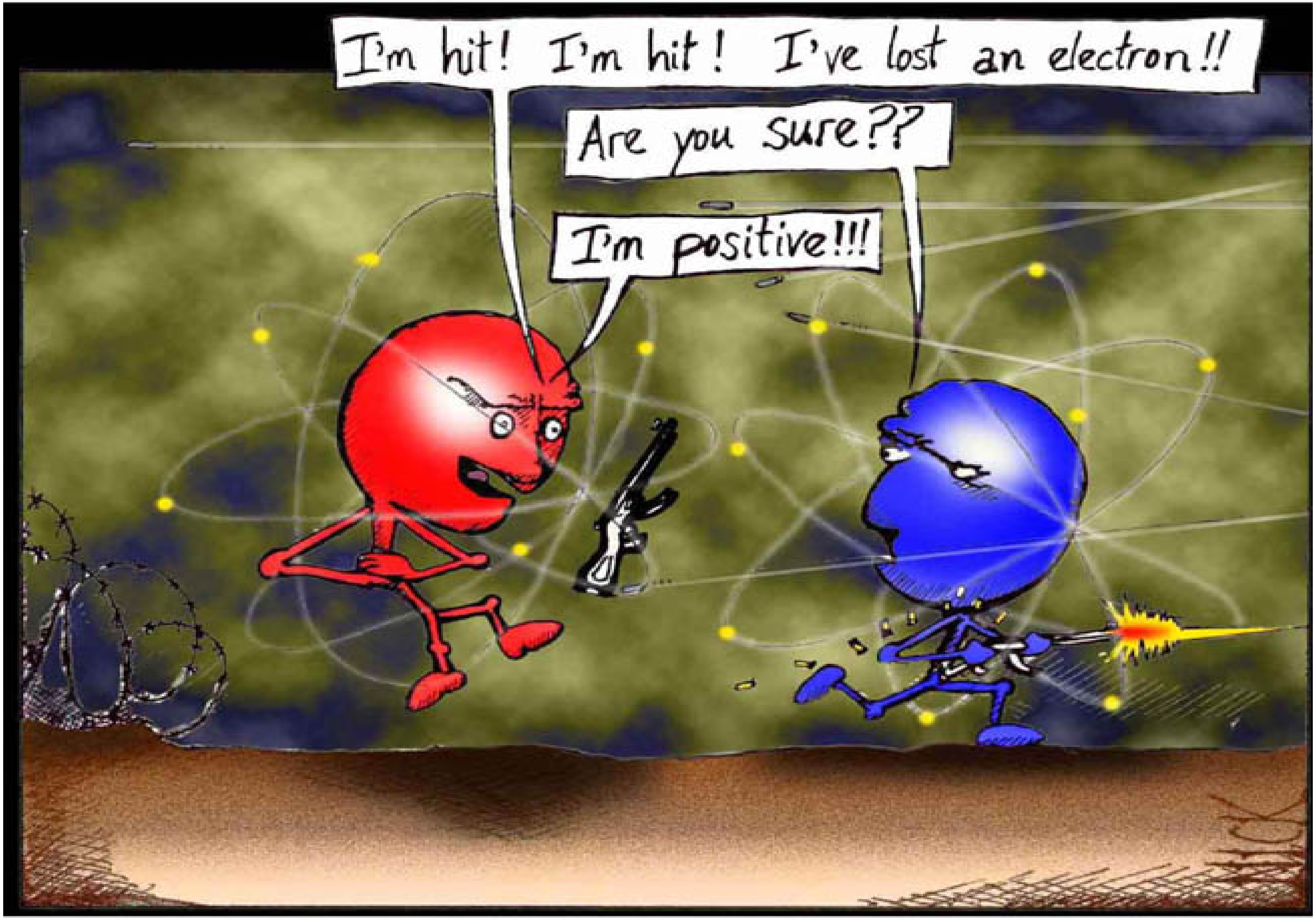


- ✓ **Hierarchically ordered porous (HOP) structure**
- ✓ **Black-TiO_2 ($b$$TiO_2$)cathode**

  → Carbon-free electrode with high conductivity

➢ J. Kang, J. Kim, S. Lee, S. Wi, C. Kim, S. Hyun, S. Nam, Y. Park, and B. Park, *Adv. Energy Mater.* (2017). **[Front Cover]**

Oxidation and Reduction



Another casualty in the War of the Atoms.

Future Nanomaterials for Energy

Nanoscale Control

- Compositions?
- Nanostructures?
- Mechanisms?

http://bp.snu.ac.kr

Solar Cell

Li Battery

Luminescence

Catalyst

Alumni

❖ Ph.D.

Dr. Donggi Ahn	Samsung Electronics
Dr. Hongsik Choi	Samsung Electro-Mechanics
Dr. Dae-Ryong Jung	Samsung Advanced Institute of Technology
Dr. Joonhyeon Kang	LG Chem
Dr. Byoungsoo Kim	SKC
Dr. Chohui Kim	Samsung Electronics
Prof. Chunjoong Kim	Chungnam National University
Dr. Jae Ik Kim	Samsung Display
Dr. Jongmin Kim	Samsung Fine Chemicals
Dr. Tae-Gon Kim	Samsung Advanced Institute of Technology
Dr. Tae-Joon Kim	Samsung Electronics
Dr. Yong Jeong Kim	KISTEP
Dr. Yongjo Kim	Samsung Electronics
Dr. Byungjoo Lee	JAFCO Investment Korea
Dr. Deok-Hyung (Doug) Lee	AMD/IBM Alliance
Dr. Joon-Gon Lee	Samsung Electronics
Dr. Seung-Yoon Lee	LG Electronics
Dr. Woojin Lee	Samsung Display
Dr. Changwoo Nahm	Samsung Electronics
Dr. Seunghoon Nam	Korea Institute of Machinery & Materials
Prof. Taeho Moon	Dankook University
Dr. Jeongmin Oh	Korea Technology Transfer Center
Dr. Yuhong Oh	Samsung Electro-Mechanics
Dr. Yejun Park	Samsung Electro-Mechanics
Dr. Dongyeon Son	Ministry of Trade, Industry, and Energy
Dr. Sungun Wi	Samsung Electronics

❖ M.S.

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Yoon Sang Cho	The Korea Development Bank
Myungsuk Choi	POSCO
Saeromi Hong	Seoul National University
Sun-Tae Hwang	LG Electronics
Seonghyun Jin	Samsung Electronics
Myunggoo Kang	University of Michigan
Suji Kang	Samsung Electro-Mechanics
Hoechang Kim	SK Innovation
Hyemin Kim	Y.P. Lee, Mock & Partners
Sungsoo Kim	LG Chem
Dr. Taeseok Kim	SunPower Corporation
Yumin Kim	Samsung Electronics
Doyoung Lee	LG. Philips LCD
Jin Sun Lee	Samsung Electronics
Junhee Lee	Samsung Display
Sangkeun Lee	LG. Philips LCD
Sungjun Lee	Seoul National University
Jungjin Park	Seoul National University
Sungjin Shin	LG Chem

❖ Research Assistants

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Dr. Dae-Han Choi	HRL Laboratoties
Seung-Chul Ha	SENKO
Kyounghwan Hwang	Judge
Sang Uk Hyun	University of Toronto
Prof. Kisuk Kang	Seoul National University
Prof. Sung Hoon Kang	Johns Hopkins University
Heekyung Lee	STX Institute of Technology
Prof. Hyukjae (Jay) Lee	Andong University
Sang-Min Lee	LS Mtron
Joonhee Moon	Seoul National University
Prof. Byungha Shin	KAIST
Dr. Jae Wook Shin	National Institute of Standards and Technology
Jun Wen	University of Toronto
Donghwan Yoon	Max Planck Institutes

Ten Recent Publications

***h*-index = 49**

Title	Journal	연도	SCI IF
From Nanostructural Evolution to Dynamic Interplay of Constituents: Perspectives for Perovskite Solar Cells	*Adv. Mater.*	2017	19.791
Route to Improving Photovoltaics Based on CdSe/$CdSe_xTe_{1-x}$ Type-II Heterojunction Nanorods: The Effect of Morphology and Cosensitization on Carrier Recombination and Transport	*ACS Appl. Mater. Interfaces*	2017	7.504
Insights on the Delithiation/Lithiation Reactions of $Li_xMn_{0.8}Fe_{0.2}PO_4$ Mesocrystals in Li^+ Batteries by in-situ Techniques	*Nano Energy*	2017	12.343
Breathable Carbon-Free Electrode: Black TiO_2 with Hierarchically-Ordered Porous Structure for Stable Li-O_2 Battery	*Adv. Energy Mater.*	2017	16.721
Synchrotron-Based X-Ray Absorption Spectroscopy for the Electronic Structure of $Li_xMn_{0.8}Fe_{0.2}PO_4$ Mesocrystal in Li^+ Batteries	*Nano Energy*	2017	12.343
Single-Layer Graphene-Wrapped $Li_4Ti_5O_{12}$ Anode with Superior Lithium Storage Capability	*Carbon*	2017	6.331
Evaluating the Optoelectronic Quality of Hybrid Perovskites by Conductive Atomic Force Microscopy with Noise Spectroscopy	*ACS Appl. Mater. Interfaces*	2016	7.504
Investigation of Chlorine-Mediated Microstructural Evolution of $CH_3NH_3PbI_3$ (Cl) Grains for High Optoelcectronic Responses	*Nano Energy*	2016	12.343
Wrapping Strategy for SnO_2 with Porosity-Tuned Graphene for High Rate Lithium-Anodic Performance	*Carbon*	2015	6.331
Organic-Acid Texturing of Transparent Electrodes toward Broadband Light Trapping in Thin-Film Solar Cells	*Nano Energy*	2015	12.343

Newspapers

뉴스
학술·연구

서울대 공대, 리튬 배터리 성능향상기술 개발

美버클리硏과 공동 ·· 그래핀 코팅 음극전극 개발성공

이우희 기자 | wooheepress@unn.net

승인 2014.02.03 14:58:28

[한국대학신문 이우희 기자] 리튬 배터리의 성능을 획기적으로 향상시키는 기술이 국내 연구진에 의해 개발됐다. 서울대 공대는 재료공학부 박병우 교수와 미국 버클리 연구소의 김천중 박사가 고체상 반응을 이용해 그래핀이 균일하게 코팅된 'Li4Ti5O12(이하 LTO) 음극전극'의 개발에 성공했다고 2일 밝혔다.

▲ 서울대학교 공과대학 재료공학부 박병우 교수(사진=서울대 제공)

LTO 음극전극은 기존의 전극과 비교해 충·방전시 효율성이 높아 기업이나 연구소에서 차세대 음극 물질로 주목해 왔지만 낮은 전기전도를 띠고 있어 상용화에 걸림돌이 있었다.

박 교수는 "전도성을 갖는 물질을 LTO 표면에 코팅해 초기 리튬이온의 빠른 반응을 유도해 LTO의 단점인 비전도성을 극복하고자 했다"며 "이번 연구로 향상된 리튬 배터리는 충전 속도도 빠르고 충전 횟수도 크게 늘어나 휴대전화, 노트북, 전기차 등에 혁신적인 발전을 가져올 것"이라고 밝혔다.

연구팀이 착안한 것은 바로 차세대 소재로 불리는 그래핀과의 접목. 티타늄 산화물을 그래핀 산화물로 미리 코팅한 후 리튬 전구체와 열처리 과정을 통해 그래핀 산화물의 환원과 고체상 반응을 동시에 진행하는 기법으로 그래핀이 코팅된 LTO 합성에 성공했다.

이를 통해 기존의 그래핀 코팅 리튬-금속 산화물과 비교해 표면이 균일하고 안정된 코팅을 형성하고, 코팅된 LTO 또한 단결정 성장을 이뤄 세계 최고 수준의 충·방전률을 기록할 수 있었다.

본 연구는 한국연구재단 기후변화 대응과제사업과 미국 에너지국 연구 과제의 일환으로 진행되었으며, 세계적 권위의 학술지 '저널 오브 머티리얼스 케미스트리 에이(Journal of Materials Chemistry A)' 최신호 표지 논문으로 선정됐다.

동아 일보 2014. 02. 03

최신기사

'숨 쉬는 전극'으로 리튬 공기전지 효율성 향상

송고시간 | 2017/08/29 10:35

서울대 박병우 교수팀 기술 개발 "배터리 수명 연장"

(서울=연합뉴스) 김기훈 기자 = 서울대 공대는 재료공학부 박병우 교수 연구팀이 티타늄 산화물을 이용해 리튬 공기전지의 효율성을 획기적으로 높이는 기술을 개발했다고 29일 밝혔다.

리튬 공기전지는 상용화된 리튬 이온전지에 비해 용량이 5~10배가량 크고 공기 중의 산소를 연료로 활용해 친환경 차세대 이차전지로 주목받고 있다. 하지만 에너지 효율이 낮고, 사용을 거듭함에 따라 용량이 급감해 수명이 짧은 점이 문제점으로 지적됐다.

이런 문제를 해결하기 위해 연구진은 탄소 대신 티타늄 산화물을 리튬 공기전지의 전극 물질로 사용했다.

블랙 티타늄 산화물을 합성해 전기 전도도를 개선하고 인간의 폐 구조에서 착안해 리튬 공기전지의 활성 물질인 산소 투과가 용이한 구조의 전극을 형성했다. 이를 통해 수백 회 충전과 방전을 거친 이후에도 전지의 수명을 유지할 수 있다고 연구진은 설명했다.

박 교수는 "이번에 개발한 블랙 티타늄 산화물 전극은 제작이 쉽고 값싼 티타늄 산화물로 제작했다는 점에서 혁신적"이라고 소개했다.

이번 연구에는 경기대 박용준 교수, 한국기계연구원 남승훈 박사가 공동 참여했다. 연구 성과는 최근 에너지 분야의 세계적 학술지 '어드밴스드 에너지 머티리얼스(Advanced Energy Materials)' 표지 논문으로 게재됐다.

연합 뉴스 2017. 08. 29

http://bp.snu.ac.kr

MRS Organizer

2010 MRS FALL MEETING
Boston, MA • November 29–December 3

CALL FOR PAPERS

Abstract Deadline: June 22, 2010

REMINDER:
In fairness to all potential authors,
late abstracts will not be accepted.

www.mrs.org/fall2010

MRS Symposium GG: Next-Generation Fuel Cells—New Materials and Concepts

The direct conversion of chemical energy to electricity via fuel cells has attracted significant attention for many decades. However, the mass marketing of fuel cells is often limited by high component costs and inadequate durability in service. Breakthroughs in materials and concepts are necessary for the development of viable fuel cells for stationary, transportation, and portable applications. This symposium will focus on new materials (novel electrocatalysts, electrolytes, and membrane-electrode assemblies) and new fuel cell concepts (alternative cell designs or approaches) for next-generation fuel cells. Symposium topics will range from fundamental research to proof of concept, with featured speakers from industry, academia, and government laboratories, to capture a broad perspective of the next-generation fuel cells.

Symposium Organizers

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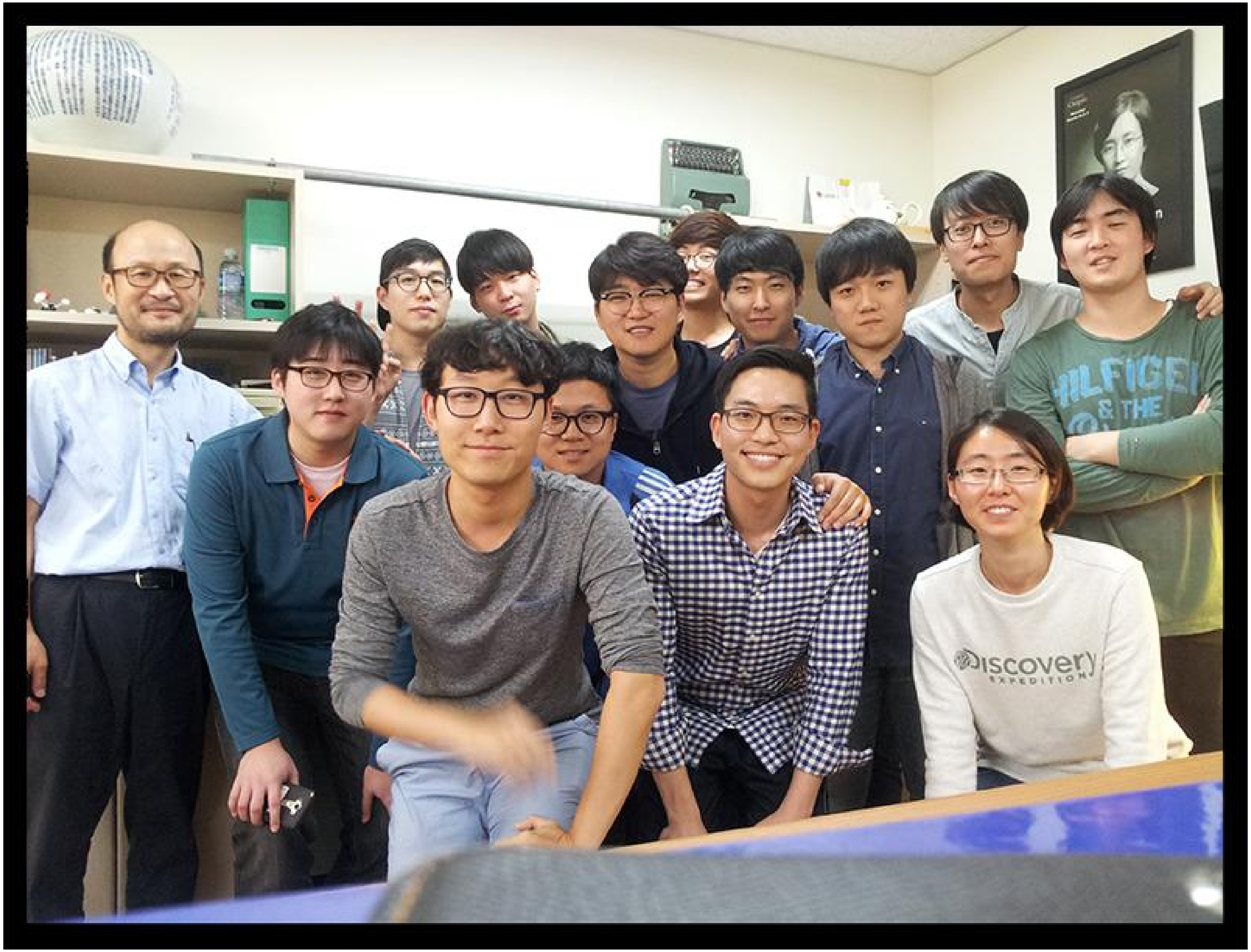
International Meetings (MRS)

Graduation of Members

Homecoming Party

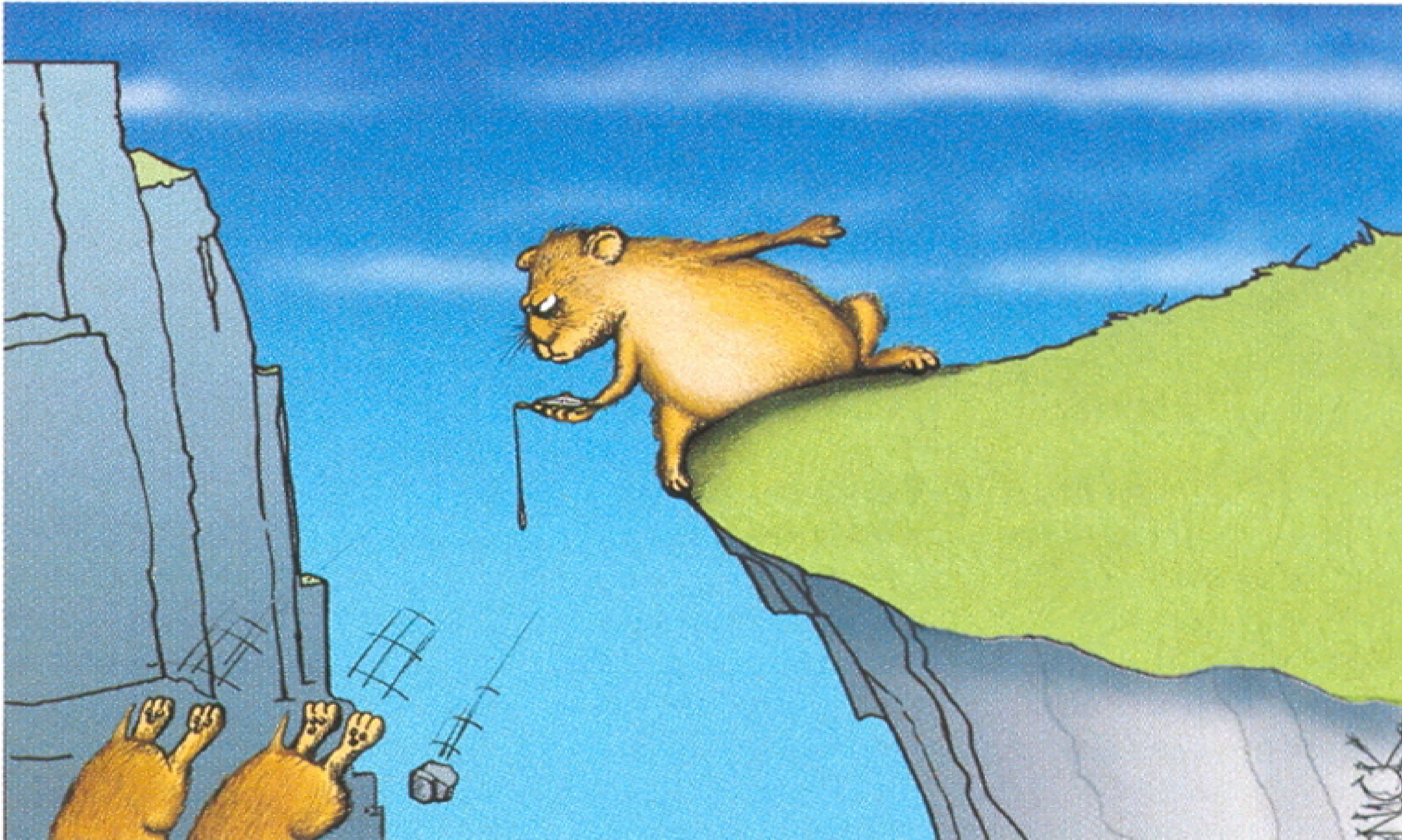
Teacher's Day



House Party

Once in a While

What is My Goal?

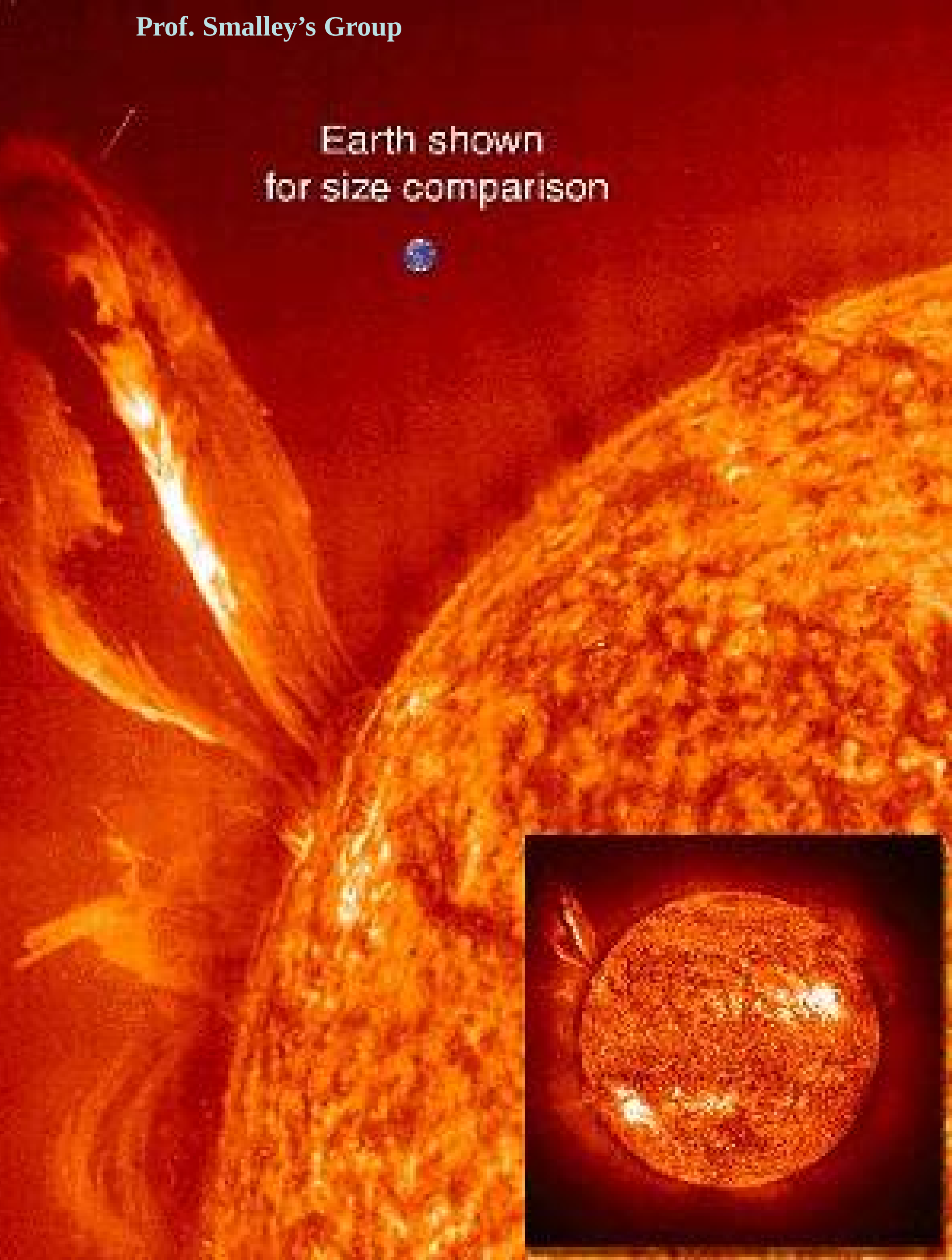


Fluffy, the “Galileo of the Lemmings,” with his stopwatch.

Physics Today (October 2008)


EXIT
86 9

Prof. Smalley's Group



Google Earth