IMSS Symposium 2011
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Epochal Tsukuba

Science Cases of Energy Recovery Linac

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High Energy Accelerator Research Organization (KEK)
Institute of Materials Structure Science (IMSS)
Photon Factory

Outline

- Fundamental features of ERL
- Science cases
- Grand challenges
- Summary

ERL Science

from fundamental features to the grand challenges

ERL for realizing sustainable future

Ultrafast science	Coherent imaging, Hierarchal structure of non-periodic systems		Nano-science	
Short pulse	High rep rate	Spatial coherence	High brilliance	Nano-focusing

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Spatial features of 3GeV ERL

(natural emittance, electron beam size, and divergence)

Sources	Natural emittance (nmrad)	σ_x μm	σ_y μm	$\sigma_{x'}$ μrad	$\sigma_{y'}$ μrad
ERL (3GeV)	0.017	7.1	7.1	2.3	2.3
SPring-8 (8GeV)	3.4	298	6.1	12	1.1
Photon Factory (2.5GeV)	36	600	12	88	29

Diffraction limit @ ~7keV

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Temporal features of 3GeV ERL

(rep rate, photons, and duration)

Source	Rep rate	Photons/pulse	Photons/sec	Pulse duration
ERL	1.3GHz	10^3-10^6	10^{12}-10^{15}	100fs-1ps
SASE-XFEL	60-120Hz	~10^{12}	~10^{14}	10-100fs
Storage ring	1MHz-500MHz	10^6-10^9	10^{12}-10^{15}	~100ps

high rep rate, non-destructive (ERL)

low rep rate, single-shot, high peak power (SASE-XFEL)

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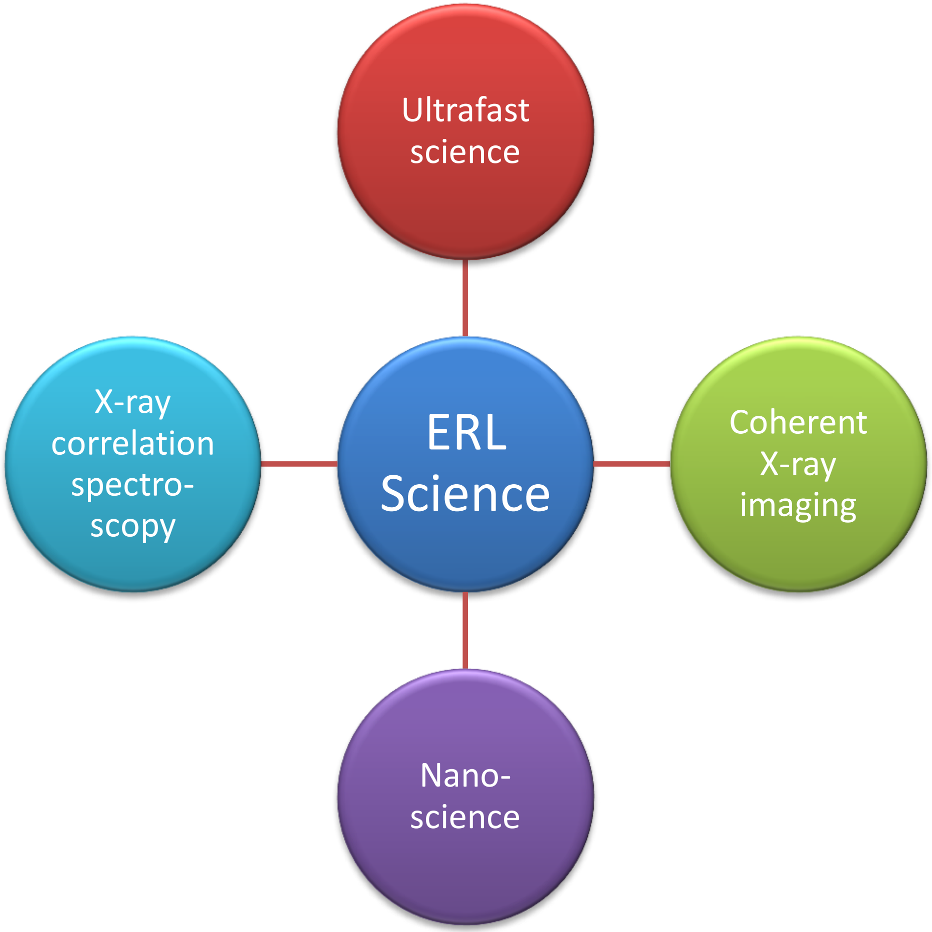
ERL Science Cases



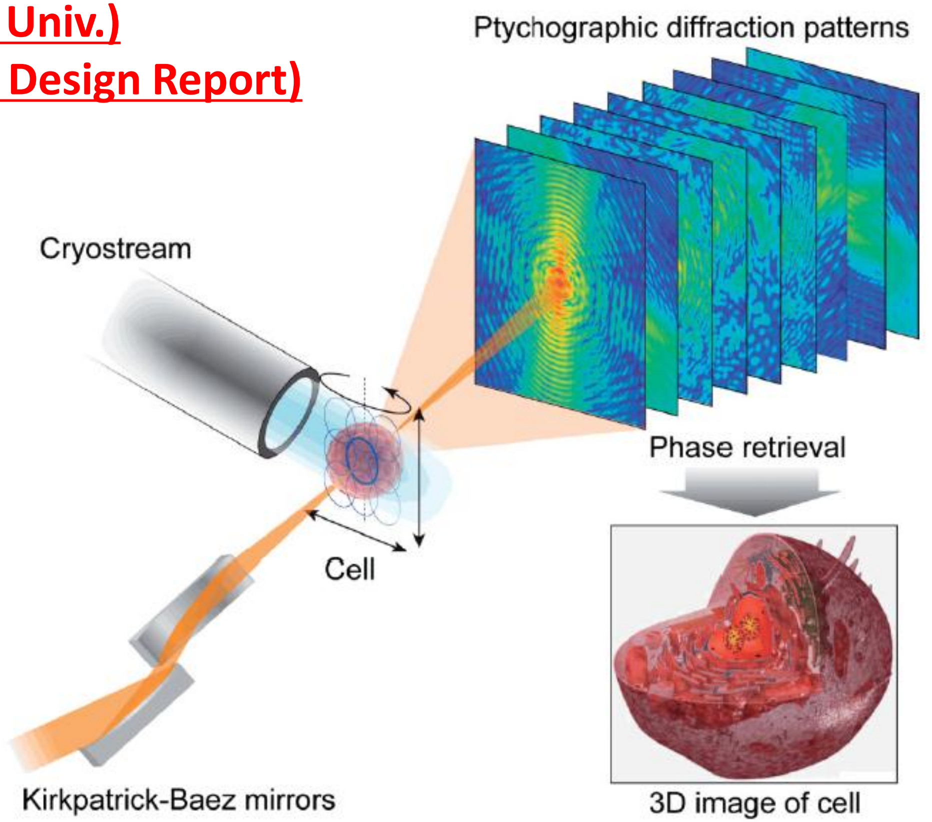
Short pulse
- Femtosecond pulse
- High rep rate

Spatial coherence
- Diffraction limit
- Non-destructive

Nanobeam
- High brilliance
- Nano-focusing

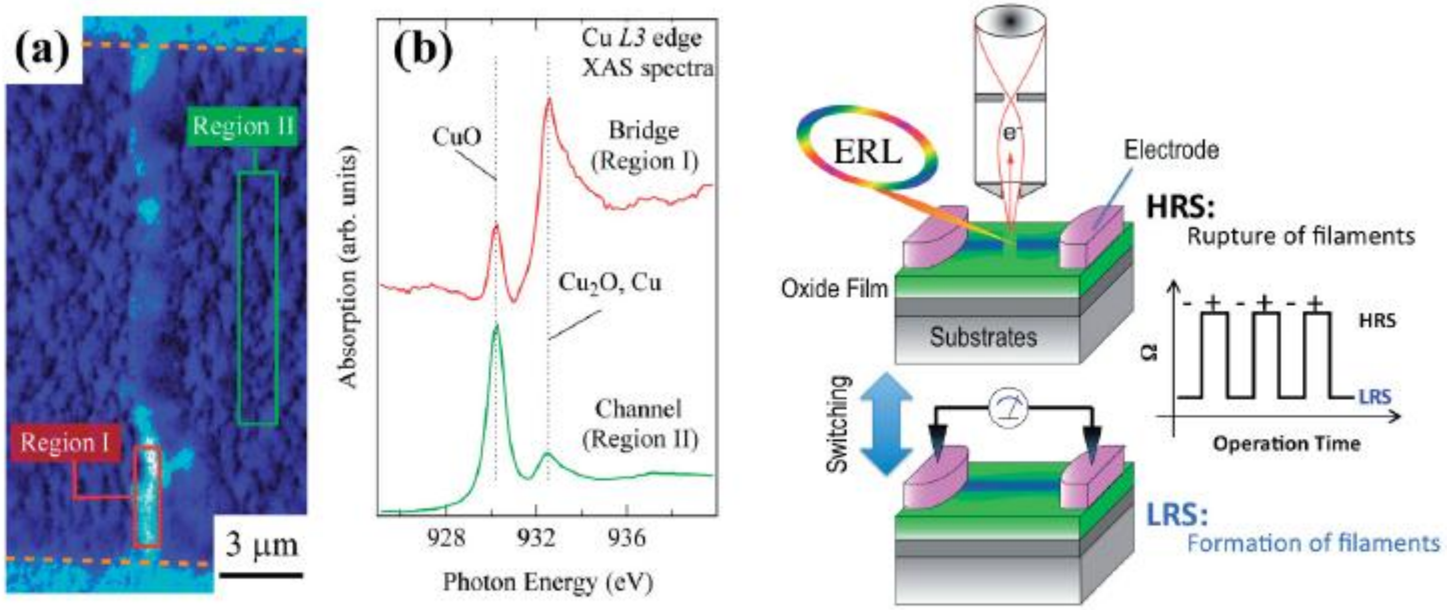
Coherent X-ray imaging in 3D

Courtesy of Prof. Yukio Takahashi (Osaka Univ.) (ERL Conceptual Design Report)



Short pulse	Spatial coherence	Nanobeam
• Femtosecond pulse • High rep rate	• **Diffraction limit** • **Non-destructive**	• High brilliance • **Nano-focusing**

Nano-science
How does ReRAM work?



Courtesy of Prof. Hiroshi Kumigashira (KEK PF)
(ERL Conceptual Design Report)

Short pulse	Spatial coherence	Nanobeam
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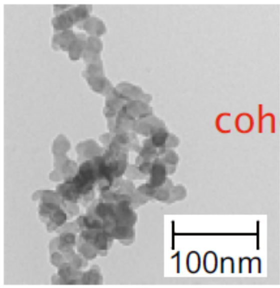
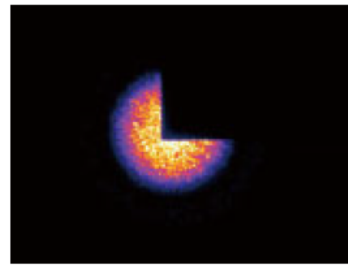
X-ray photon correlation spectroscopy

hierarchal structures in space and time (e.g. rubber)

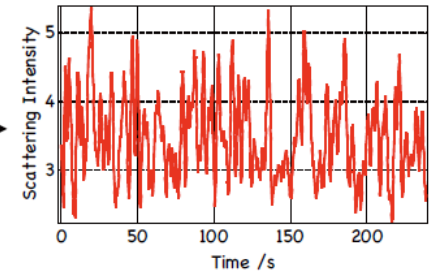


nano-particles in rubber

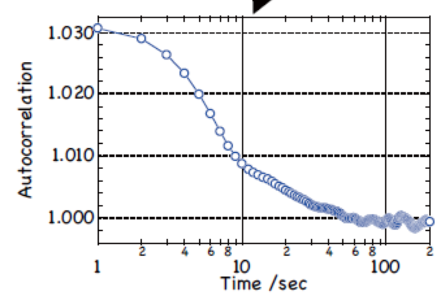
coherent x-ray



speckle pattern



fluctuation of scattering intensity

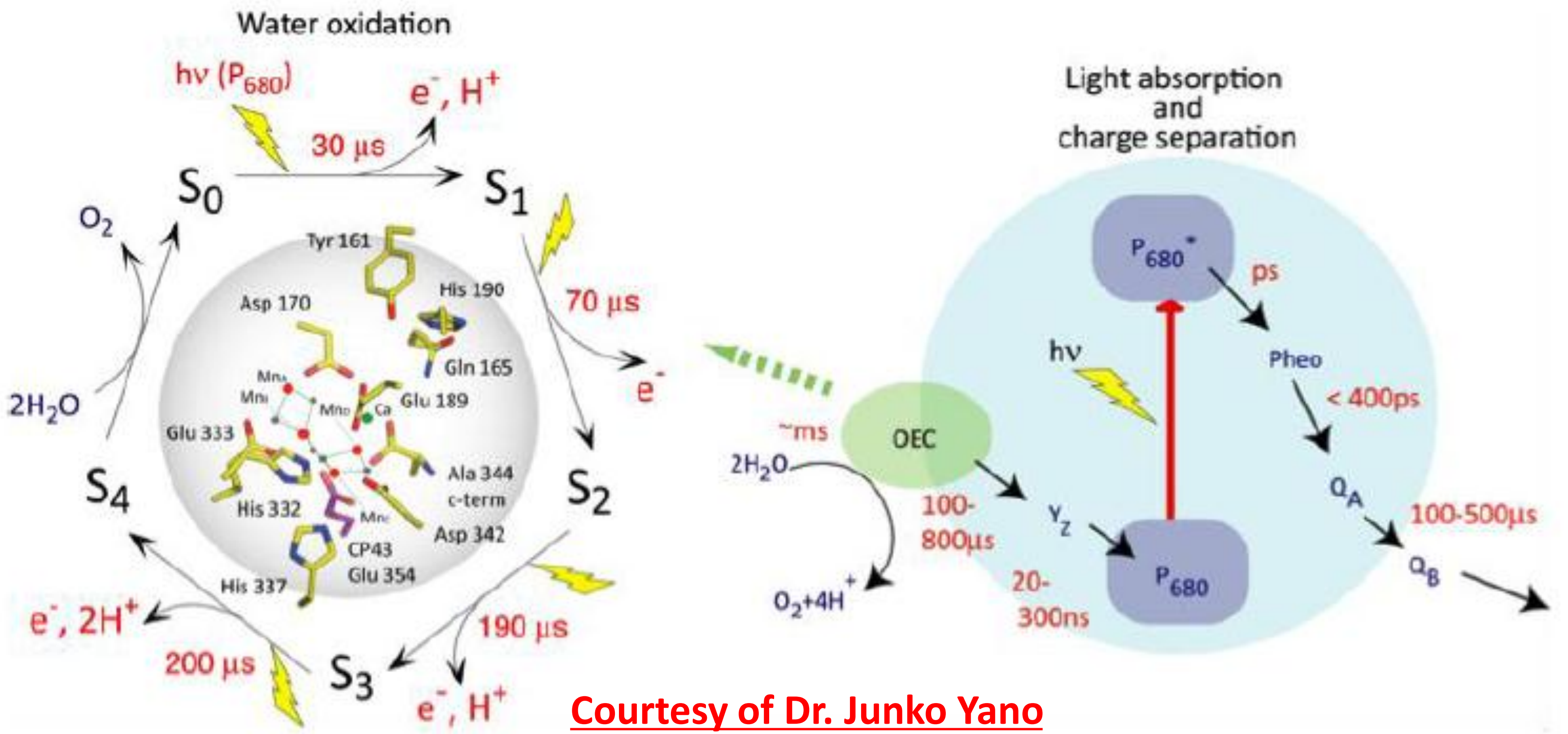


Dynamics of Filler in Rubber

Courtesy of Prof. Yuya Shinohara
(The Univ. of Tokyo)
(ERL Workshop I)

Short pulse	Spatial coherence	Nanobeam
• Femtosecond pulse • **High rep rate**	• **Diffraction limit** • **Non-destructive**	• **High brilliance** • **Nano-focusing**

Ultrafast dynamics in photosynthesis



Courtesy of Dr. Junko Yano
(Laurence Berkley National Lab.)
(ERL Conceptual Design Report)

Short pulse	Spatial coherence	Nanobeam
• **Femtosecond pulse** • **High rep rate**	• Diffraction limit • **Non-destructive**	• High brilliance • Nano-focusing

Future challenges with ERL for sustainable society

Exhaustion of Fossil fuels

Global warming

Renewable energy source

Safety of nuclear power

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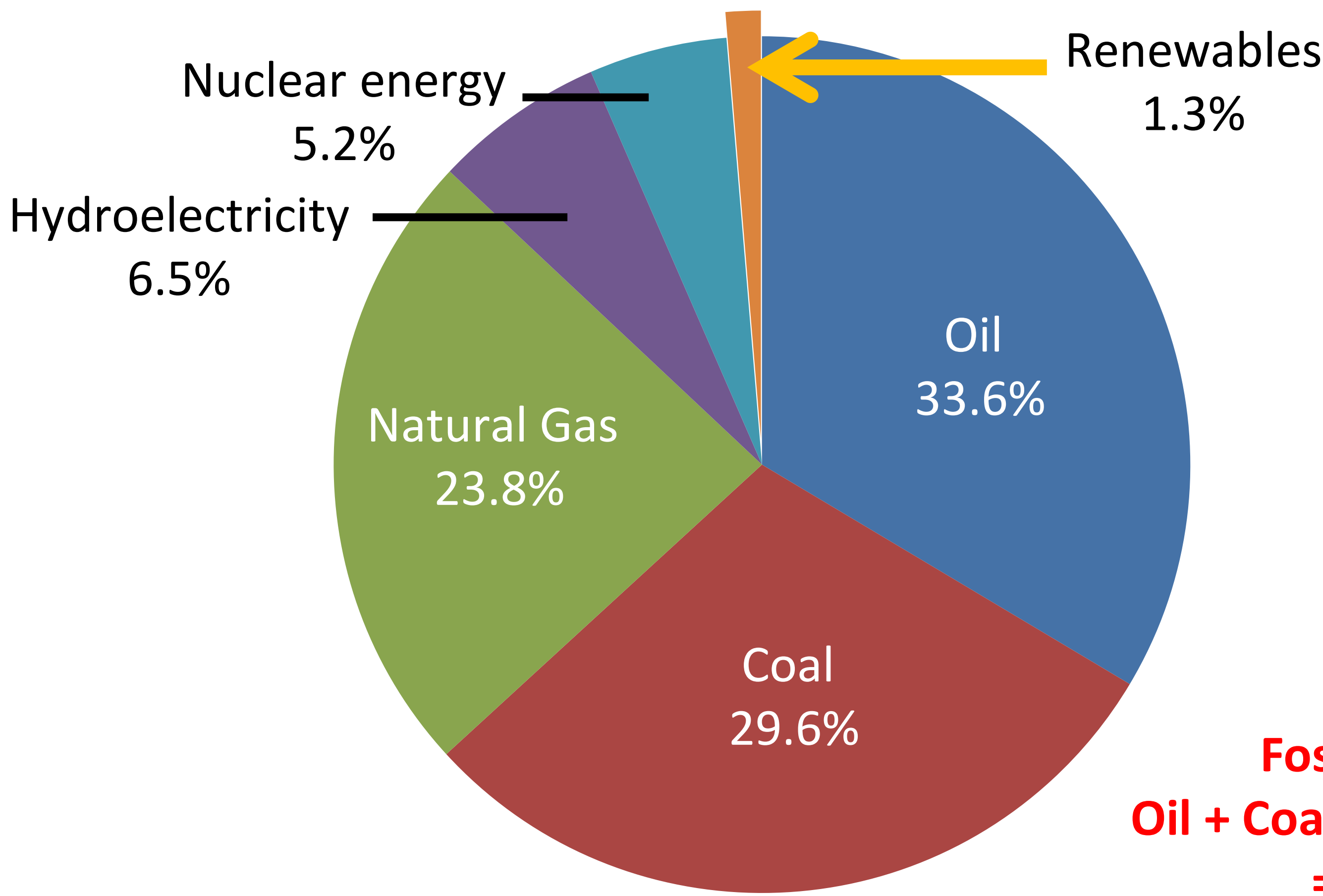
World energy consumption by fuel type in 2010



Fossil Fuels
Oil + Coal + Natural gas
= 87 %

BP statistical review of world energy, June 2011
http://www.bp.com/sectionbodycopy.do?categoryId=7500&contentId=7068481

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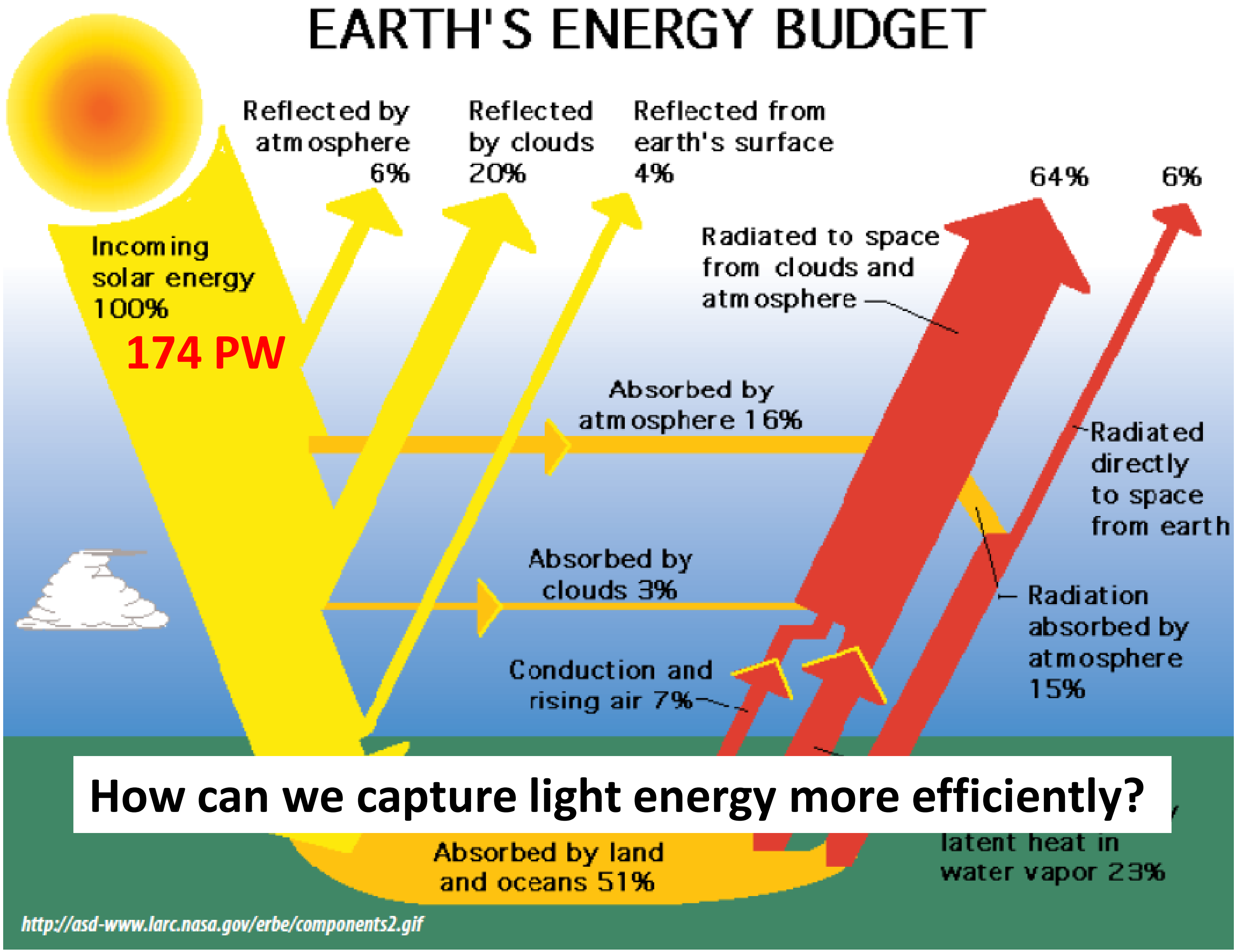
Energy consumption and supply on the earth

- Incoming solar energy: 5.5×10^{24} (J/year)
- Global energy consumption: 3×10^{20} (J/year)
  - 0.005% (~1 hour) of incoming solar energy
- Global production of photosynthesis: 3×10^{21} (J/year)
  - 0.05% (~10 hours) of incoming solar energy



How can we capture light energy more efficiently?

Investigating the Climate System, NASA, June 2003
http://www.nasa.gov/pdf/62319main_ICS_Energy.pdf

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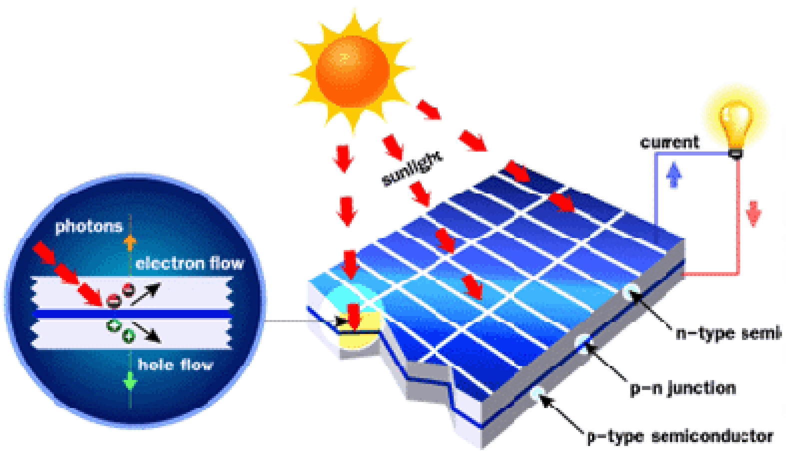
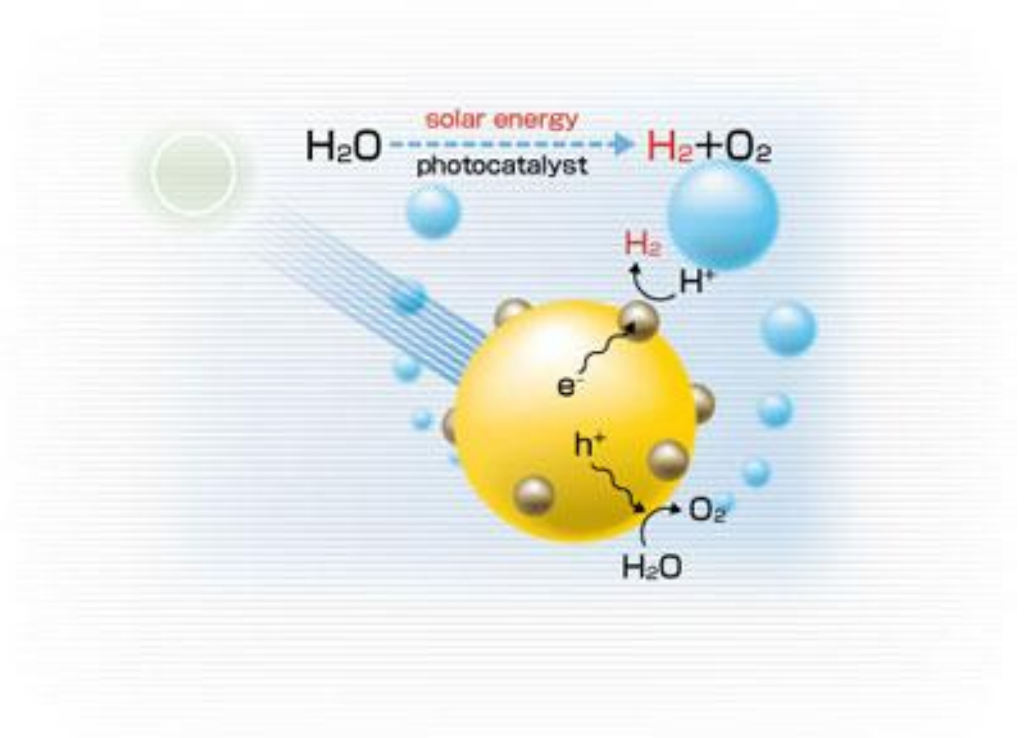
Key players
Solar Cell and Photocatalyst

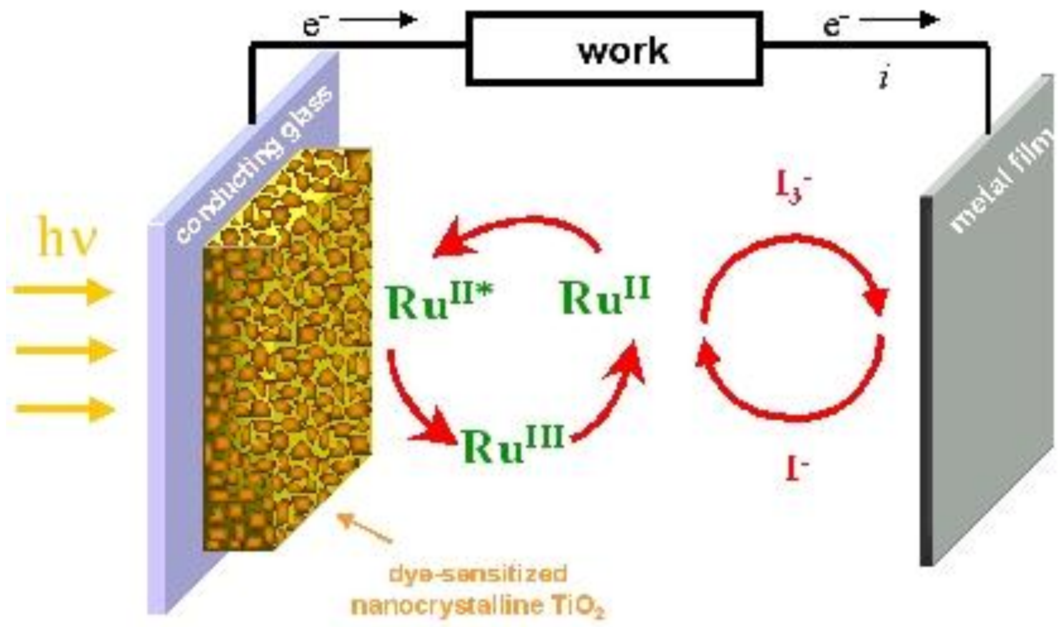




- Converts light energy to electricity
- Large-scale battery is needed for storage
- Quantum efficiency : ~20%

- Converts light energy to chemical energy
- Stored as hydrogen or hydrocarbons
- Quantum efficiency: ~5%

Toward developing highly efficient dye-sensitized solar cell



Ultrafast dynamics of the dye molecule is the key process.

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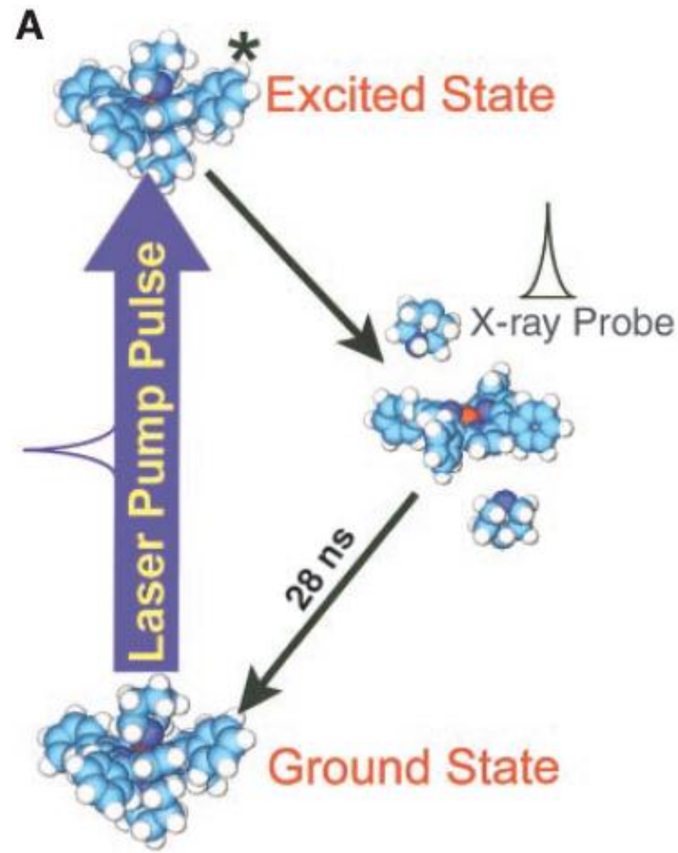
Toward better dye-sensitized solar cell

Ultrafast dynamics of metal complexes revealed by time-resolved X-ray spectroscopy

SCIENCE VOL 292 13 APRIL 2001

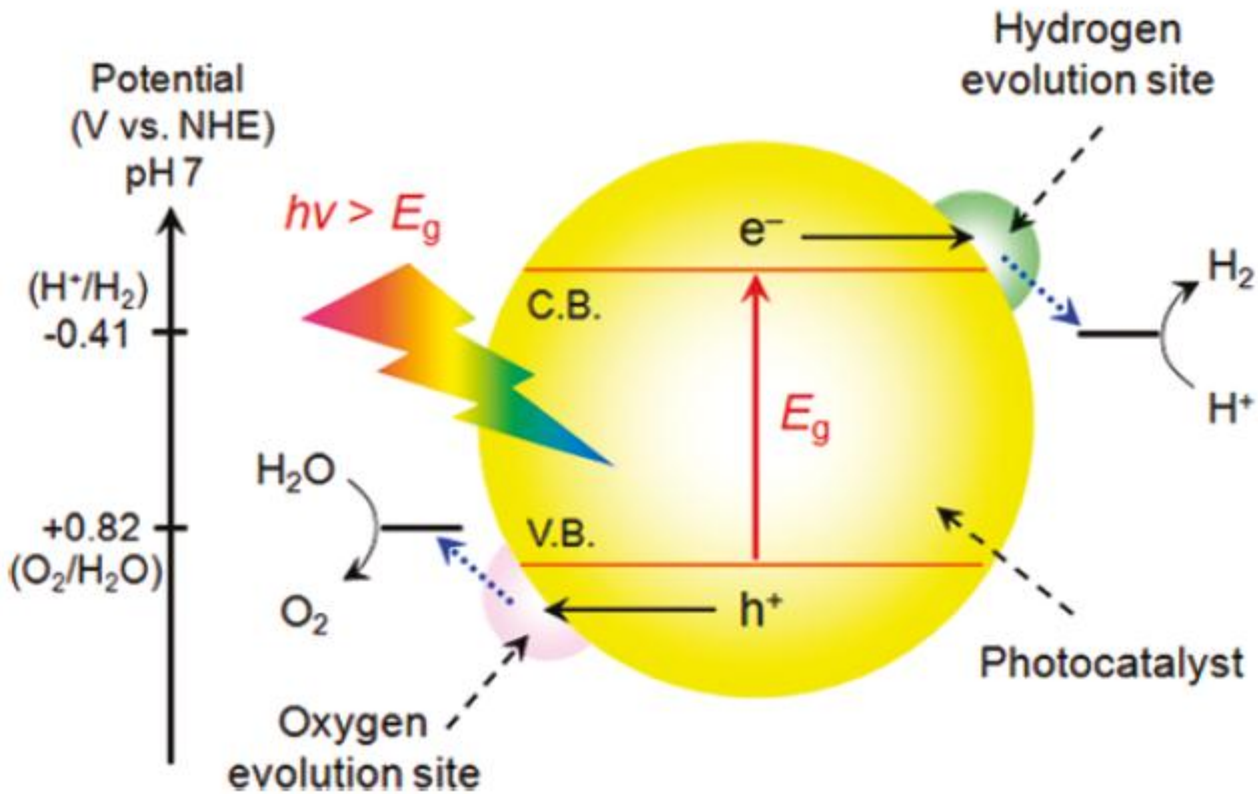
Capturing a Photoexcited Molecular Structure Through Time-Domain X-ray Absorption Fine Structure

Lin X. Chen,[1]* Wighard J. H. Jäger,[1] Guy Jennings,[2] David J. Gosztola,[1] Anneli Munkholm,[1]† Jan P. Hessler[1]



Toward artificial photosynthesis

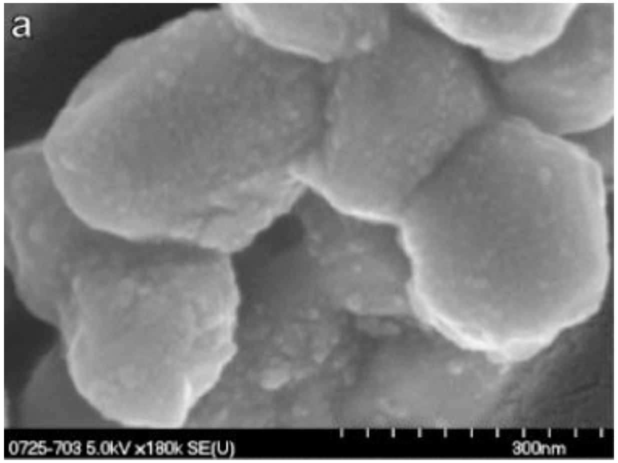
Ultrafast dynamics of photocatalyst

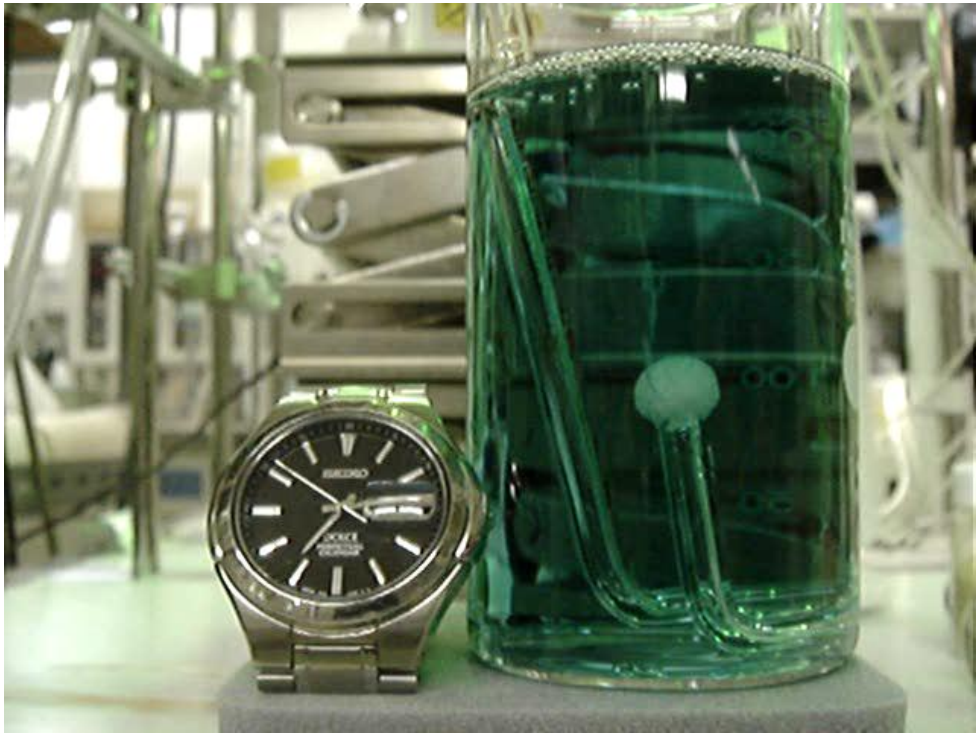


Maeda, K. and Domen K. (2010) *J. Phys. Chem. Lett*. **1**, 2655.

Toward artificial photosynthesis

Hydrogen generation from water by photocatalyst $(Ga_{1-x}Zn_x)(N_{1-x}O_x)$





Courtesy of Prof. Kazunari Domen
(The Univ. of Tokyo)

Maeda K. et al. (2006) *Nature* **440**, 295

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Summary #2

(by Chi-Chang Kao @ XDL2011, Cornell, June 2011)

- **In order to realize future light source,**
  - Identify problems that can capture the imagination of many
  - Organize the community to develop the scientific case, the necessary tools
  - Work with accelerator community to support the R&D effort

Thank you!