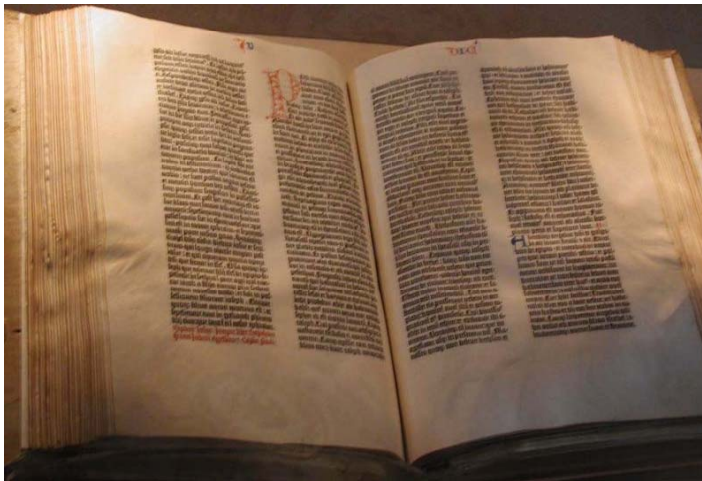


Virus is Evolving into Electronic Display Device

Yoon Sung Nam

Angela Belcher Research Group
Department of Biological Engineering
Massachusetts Institute of Technology

The Gutenberg Bible (15th Century) printed by a printing press and movable type system



Iconic status as the start of the "Age of the Printed Book"

Display Technologies

- Cathode ray tube (CRT)
- **Liquid Crystal Display (LCD)**
- Liquid crystal on silicon (LCOS)
- Digital Light Processing (DLP)
- Field emission display (FED)
- **Light-emitting diode (LED)**
- Organic light-emitting diode (OLED)
- Plasma display panel (PDP)
- Surface-conduction electron-emitter display (SED)
- Vacuum fluorescent display (VFD)

Let's think about
the principles and
major features.

What physical properties have not yet been achieved?

3



Paper-like Electronic Display

4

Have your own motivation questions



Anne M. Mulcahy
(CEO of Xerox)



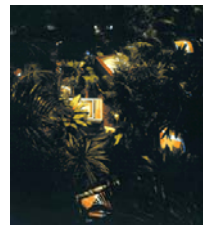
Have your own motivation questions



Nam June Paik
(the first video artist)



Charlotte Moorman performing Paik's Concerto for TV Cello and Videotapes (1971)



TV Garden, 1982 version.



Pyramid II, 1997.



TV Clock, 1989 version.

Have your own motivation questions



7

Have your own motivation questions

Heavy bags students' bane

Ludhiana, September 21

"No more heavy bags!" is a common refrain. Almost all educationists, teachers, parents, psychologists are of the opinion that heavy bags should be done away with. Many school Principals, including that of Guru Nanak Public School, BCM Arya Model School, DAV Public School, have told Ludhiana Tribune that they have done away with bags for primary classes and instead started keeping books in the schools.

These kids have to do a man's job carrying heavy bags to school. — Tribune photo by Sayeed Ahmed



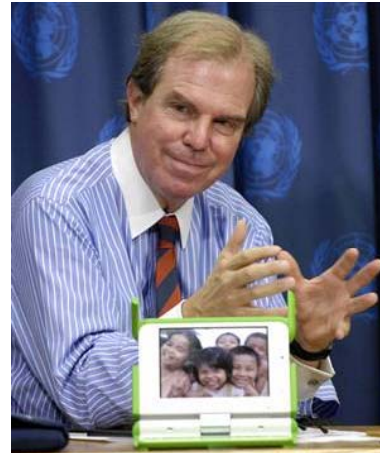
8

Have your own motivation questions



One Laptop Per Child (OLPC)

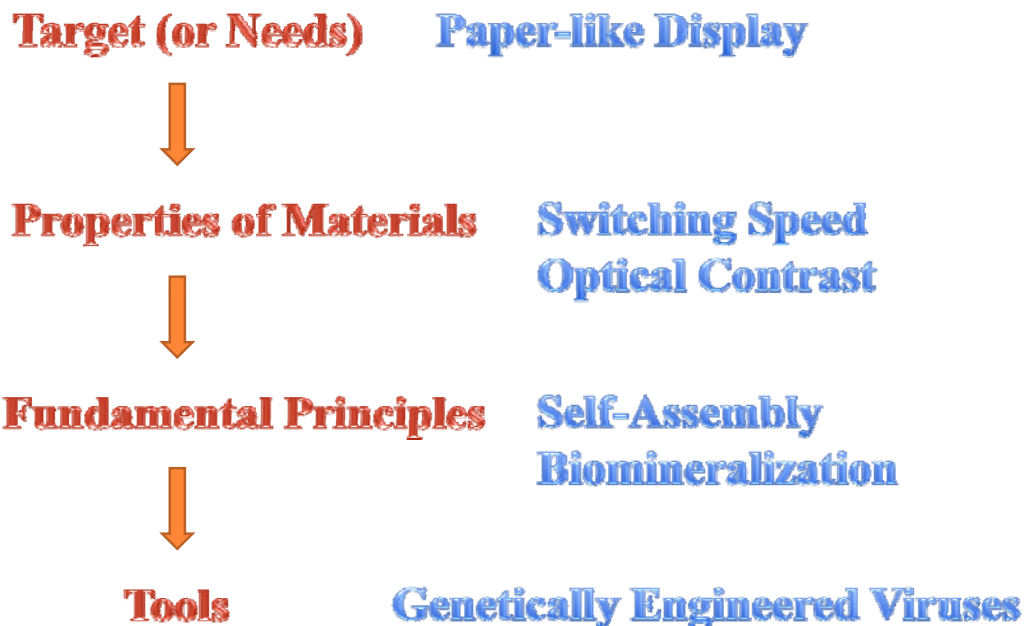
Taiwan's Quanta to manufacture MIT's \$ 100 laptop for poor children



Prof. Nicholas Negroponte
(MIT Media Lab)

9

Our Approach



10

OUTLINE

1. Current *'Display Technologies'*
2. Technical Issues of Electrochromic Devices
3. *'Biological Materials'* as a technical solution

11

Liquid Crystal Display (LCD)

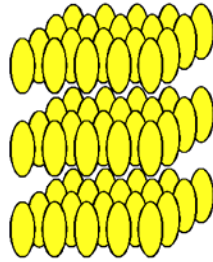


12

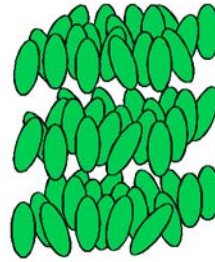
Liquid Crystal Display (LCD)

■ Liquid Crystal (LC)

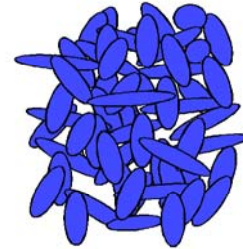
: Substances that exhibit a phase of matter that has properties between those of a conventional liquid and those of a solid crystal.



Solid crystal



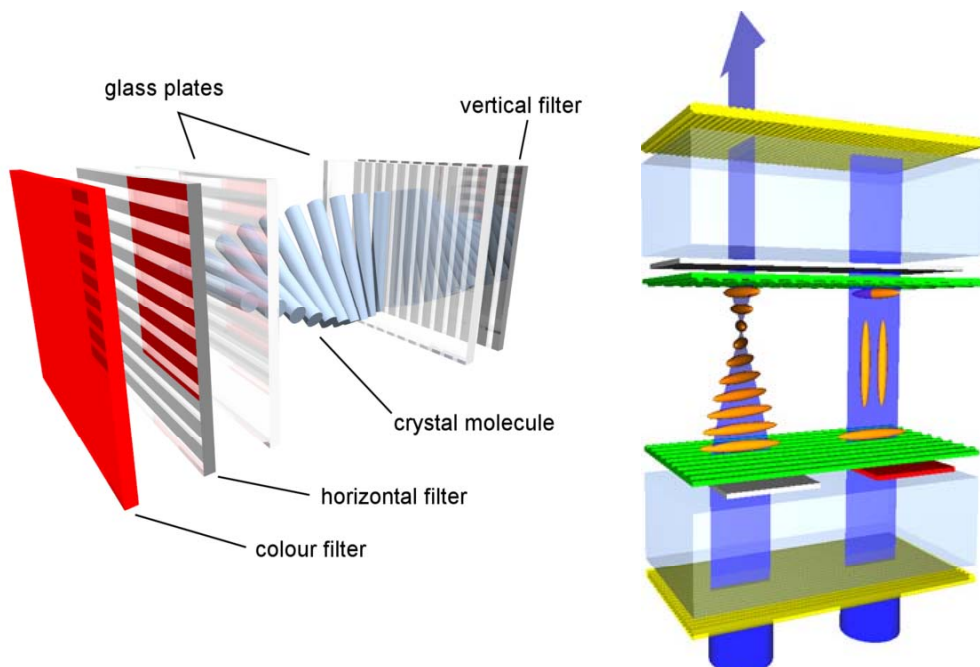
LC



Liquid

13

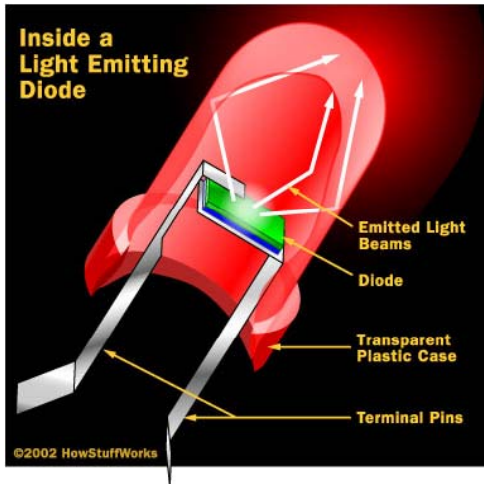
Liquid Crystal Display (LCD)



14

Light-Emitting Diode (LED)

LED is a semiconductor diode that emits narrow-spectrum light when electrically biased in the forward direction of the p-n junction.



15

Intrinsic Properties of **LCD** and **LED**
Limit Their Applications to **Paper-like Display**

- ❖ Light emission
- ❖ Energy consumption
- ❖ Weight
- ❖ Eye fatigue
- ❖ Flexibility

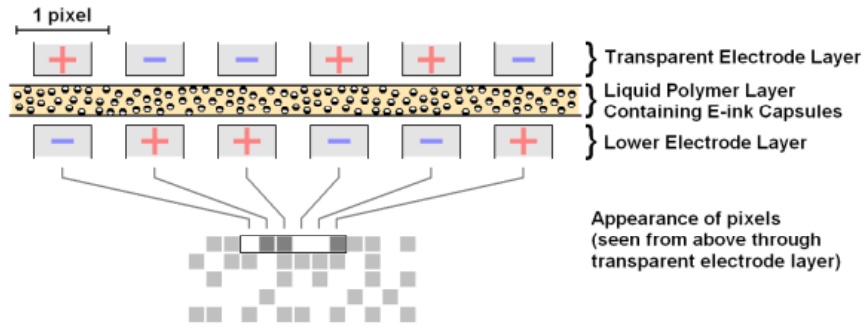
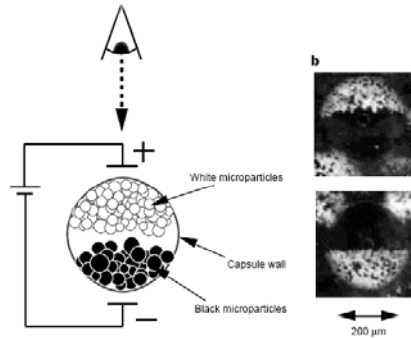
ELECTRONIC PAPER

NATURE | VOL 394 | 16 JULY 1998

An electrophoretic ink for all-printed reflective electronic displays

Barrett Comiskey, J. D. Albert, Hidekazu Yoshizawa & Joseph Jacobson

Massachusetts Institute of Technology, The Media Laboratory, 20 Ames Street, Cambridge, Massachusetts 02139-4307, USA



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ELECTRONIC PAPER



18

ELECTRONIC PAPER



SLOW RESPONSES

19

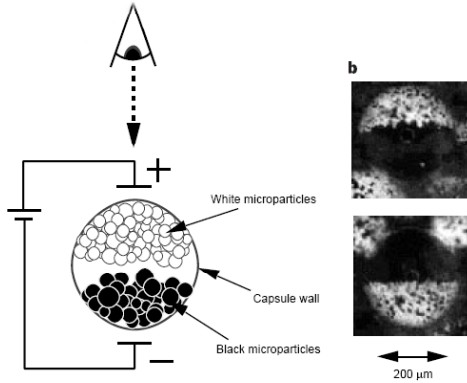
Screen Refreshing Speed

Movie film is usually displayed at a speed of **24 frames/sec**, which corresponds to display switching times of about **40 msec**.

20

Screen Refreshing Speed

Intrinsic Limitation = Particle Migration



Molar Flux Constitutive Equation

$$\underline{N}_i = -D_i \nabla c_i + \frac{z_i}{|z_i|} u_i c_i \underline{E} + c_i \underline{v}_{fl}$$

Stokes-Einstein Relation

$$D = \frac{k_B T}{6\pi \eta r}$$

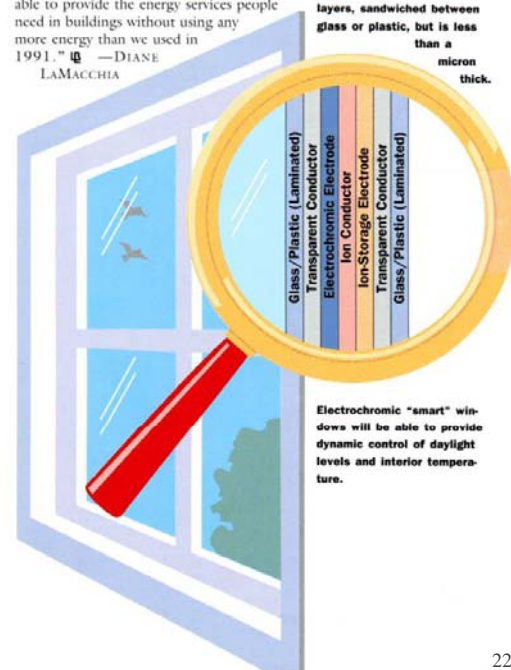
21

Electrochromism



able to provide the energy services people need in buildings without using any more energy than we used in 1991." —DIANE LAMACCHIA

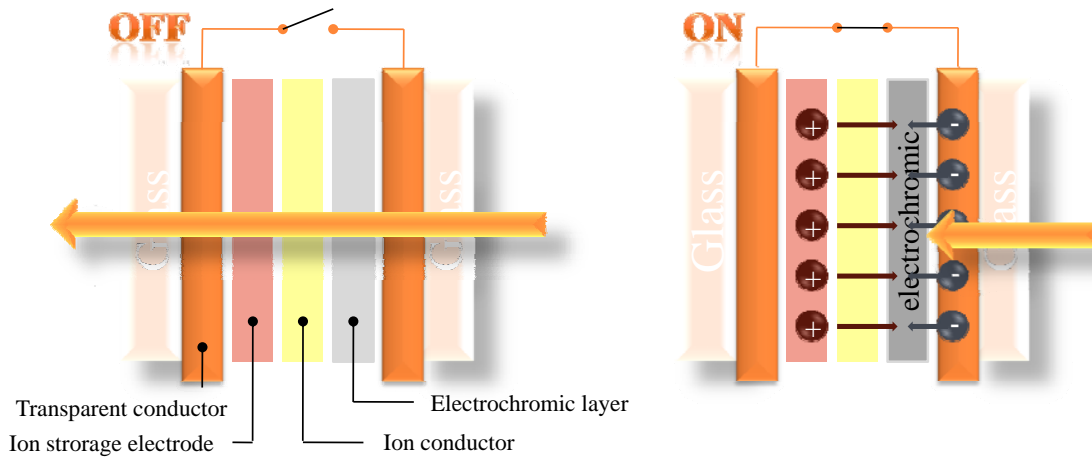
layers, sandwiched between glass or plastic, but is less than a micron thick.



Electrochromic "smart" windows will be able to provide dynamic control of daylight levels and interior temperature.

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ELECTROCHROMIC DEVICES STRUCTURE

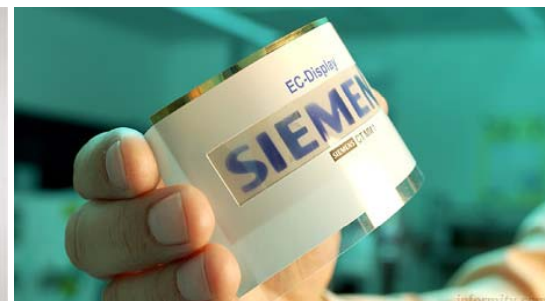


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ELECTROCHROMIC DEVICES APPLICATIONS



Nature Mater (2006) 5:89



fantasticplastic.org/2005/10/

24

NanoChromics™ Technology (Ntera Inc.)



LCD

ECD

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ELECTROCHROMIC MATERIALS

ORGANIC MATERIALS

- ❖ Small organic molecules
: viologens
- ❖ Conjugated polymers
: polypyrrole, PEDOT, PANI.

Switching speed

Optical Contrast

INORGANIC MATERIALS

- ❖ Transition metal oxides
: WO_3 , Rh_2O_3 , Ni_2O_3 , IrO_2
- ❖ Mixed-valence metal complexes
: Prussian blue.

Open-circuit optical memory

Electrochemical stability

Mechanical stability

Optical Contrast

26

BIOMINERALIZATION

DIATOMS

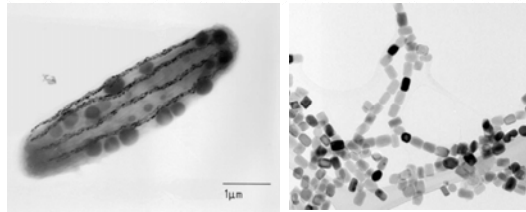


<http://www.picosearch.com>

ABALONES



MAGNETOTACTIC BACTERIA

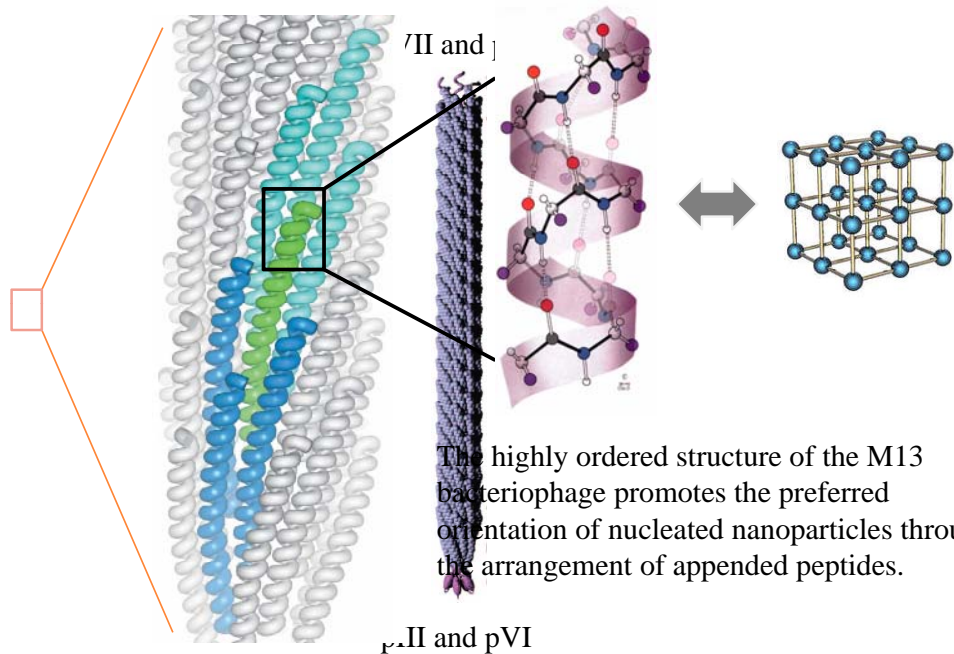


Magnetosomes extracted from MV-1 cells

<http://www.calpoly.edu/~rfrankel/mtbphoto.html>

27

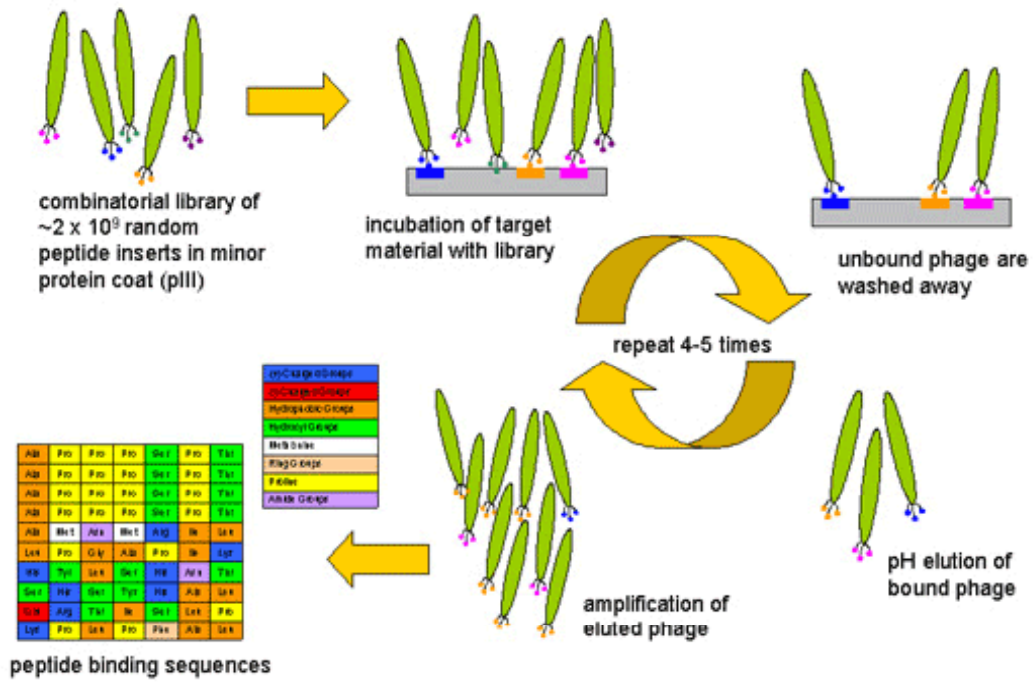
M13 BACTERIOPHAGES



J. Mol. Biol. (2004) 340, 587–597

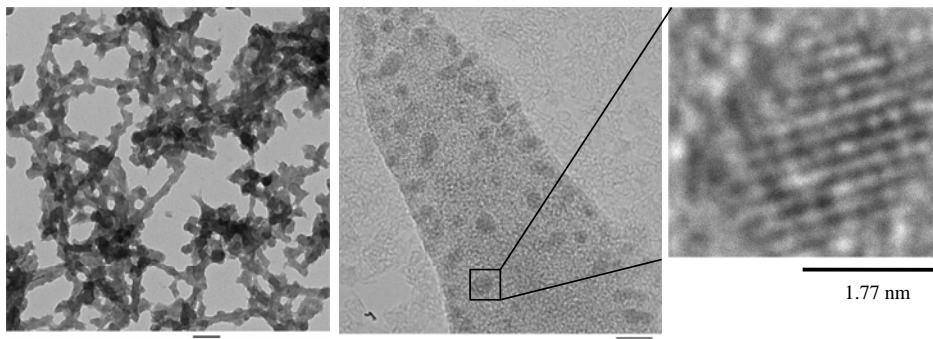
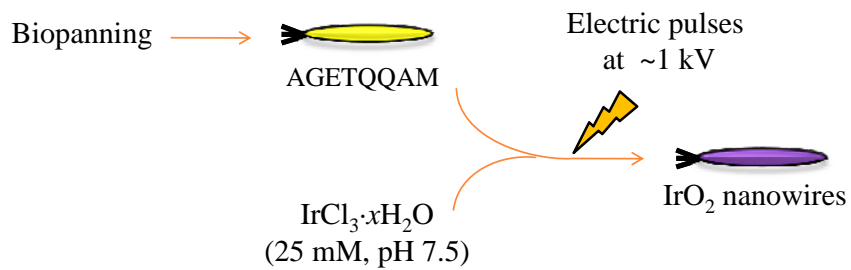
28

Biopanning technique shown with pIII peptide insert



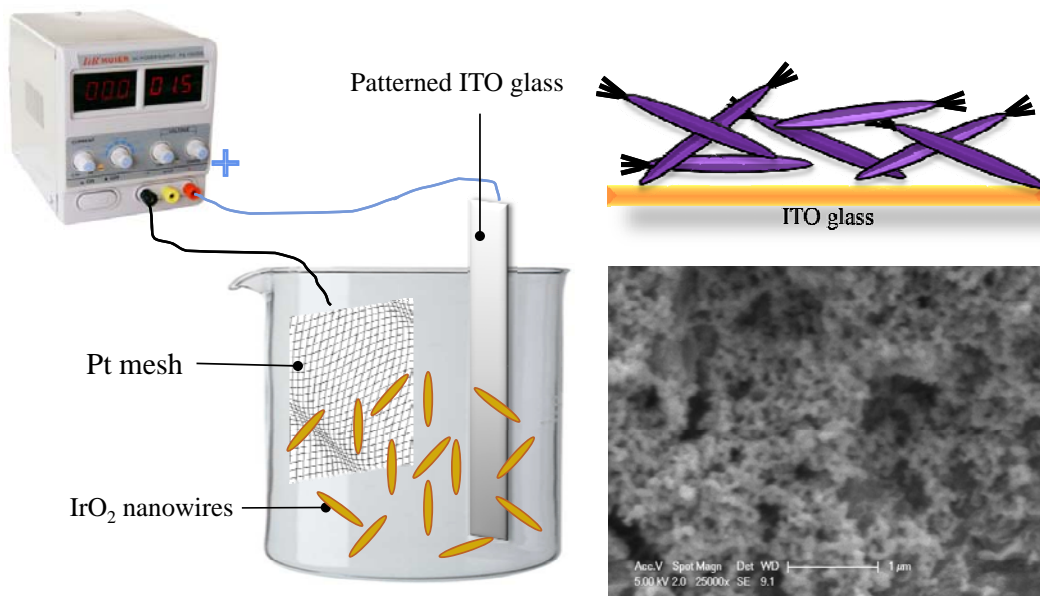
29

VIRUS-TEMPLATED IrO_2 NANOWIRES



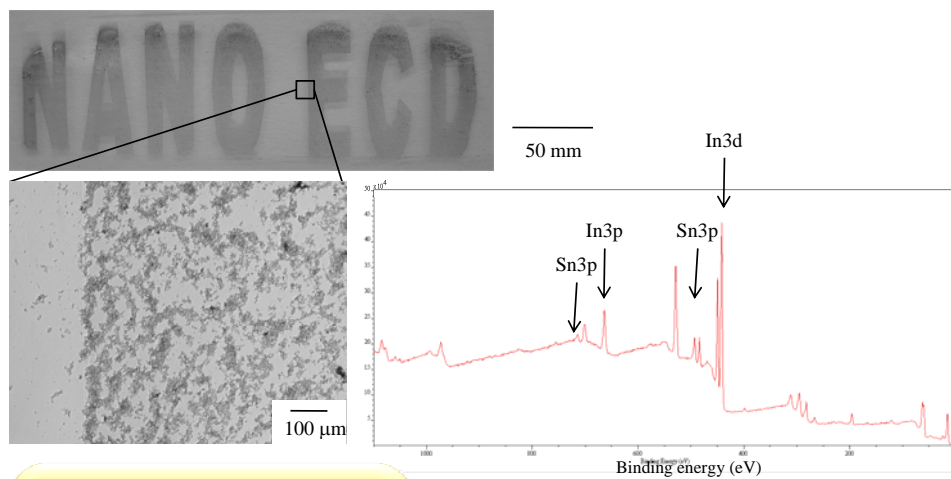
30

Electrophoretic Deposition of IrO_2 Nanowires onto ITO glasses



31

Electrophoretic Deposition of IrO_2 Nanowires onto ITO glasses

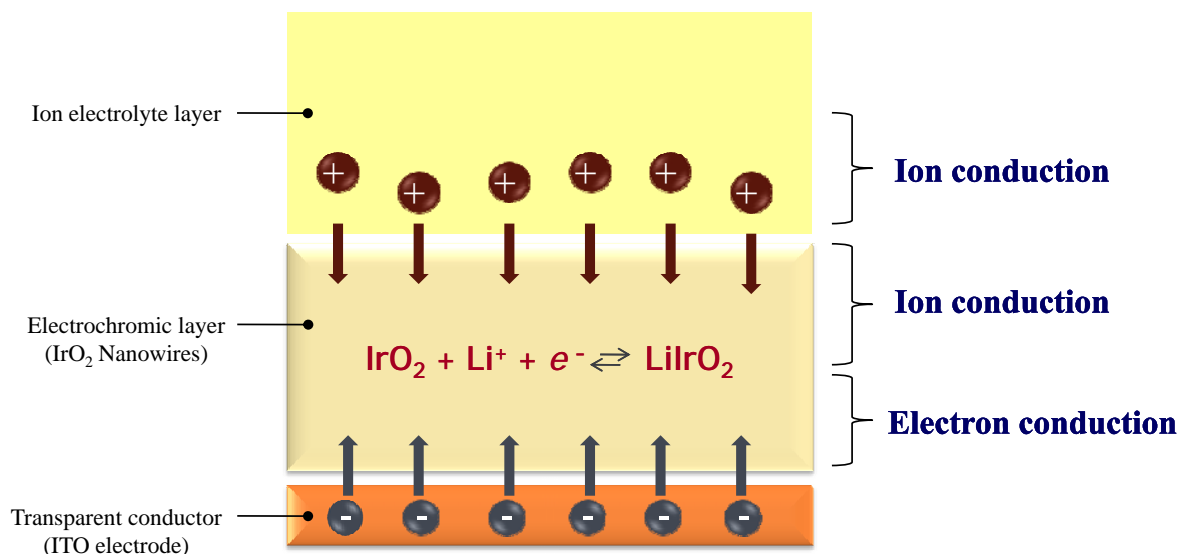


REQUIREMENTS

- ❖ Uniform thickness
- ❖ Porous structure
- ❖ Strong adhesion
- ❖ Micro-patterning

32

Which Process Determines the Overall Electrochromic Responses ?



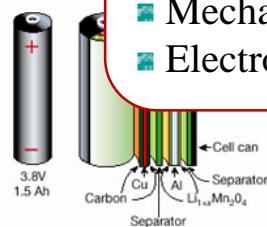
33

Lithium Ion Conducting Polymer Electrolytes

MICROPOROUS MEMBRANE

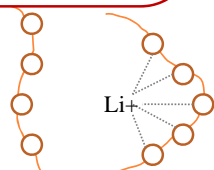
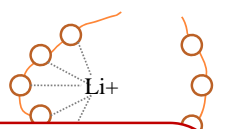


Celgard 2400 (S)



Nature **414**, 359 (2001)

SOLID POLYMER ELECTROLYTES



ORGANOSEL ELECTROLYTES

PMMA/PC gel



Oil absorbent



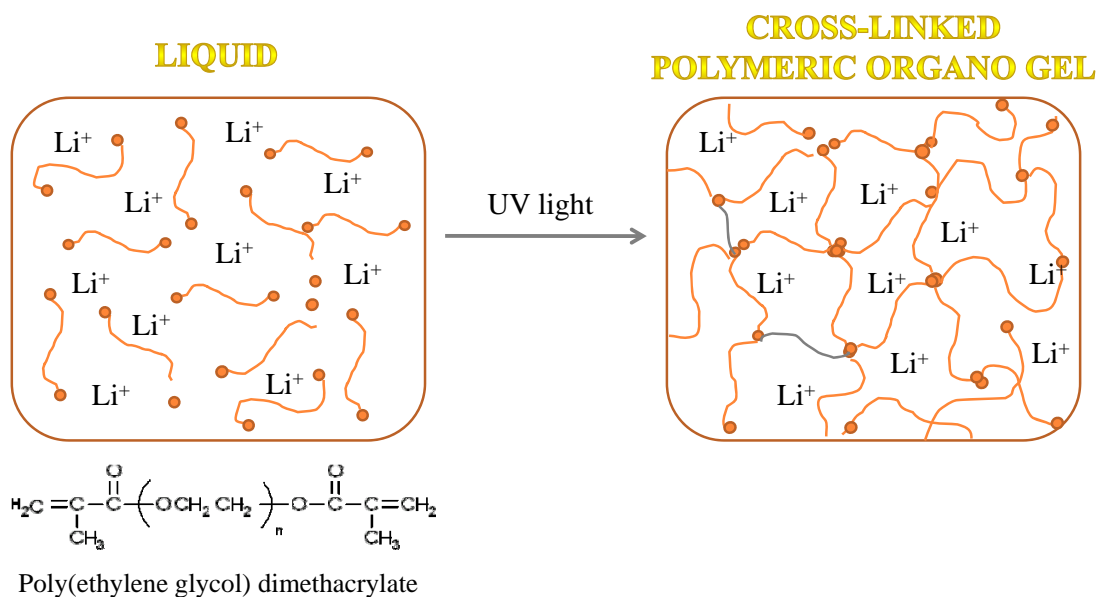
Nature Mater **6**, 429 (2007)

REQUIREMENTS

- High ion conductivity
- Transparency
- Mechanical stability
- Electrochemical stability

34

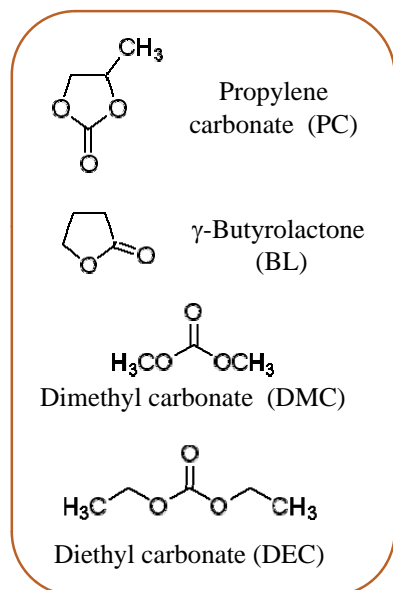
Cross-linked Gel Electrolytes Prepared via **Photo-initiated** Polymerization



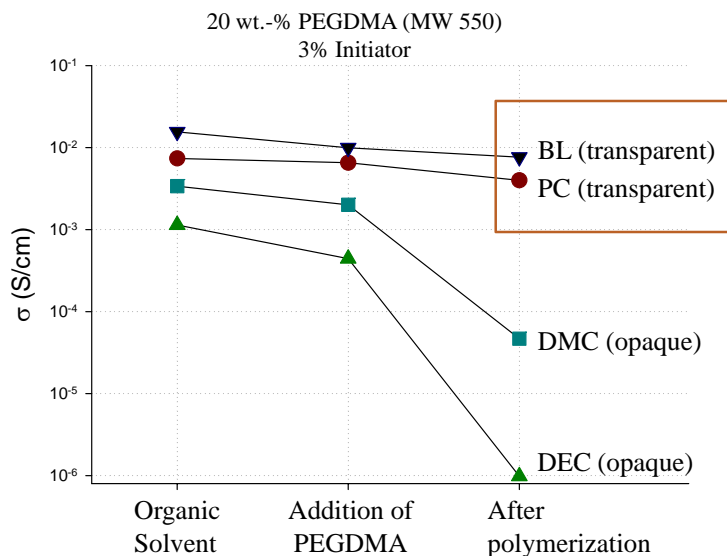
35

Ion Conductivities of 1.0 M LiClO₄ **Polymer-Organic Solvents Compatibility**

Organic Solvents for Dissolution of Lithium Salts



Ion Conductivities Before and After Polymerization

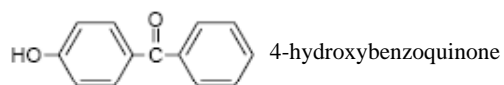
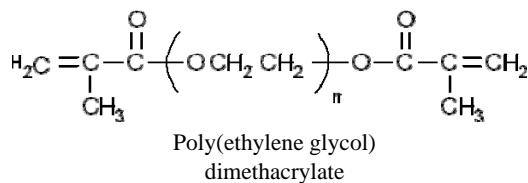
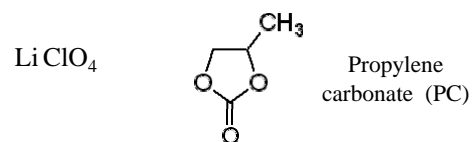


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Lithium Ion Polymer Electrolytes

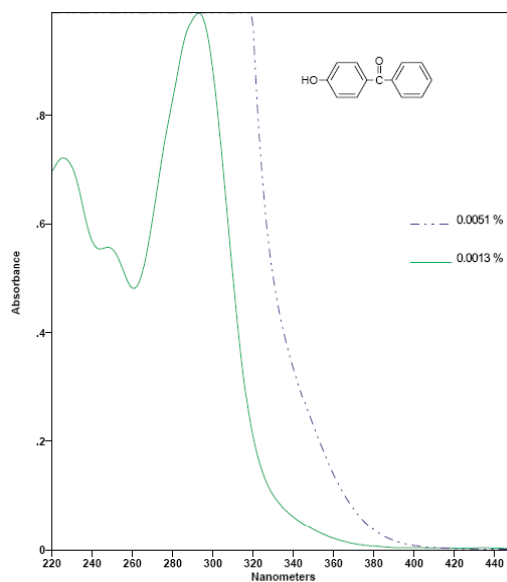


Major Ingredients



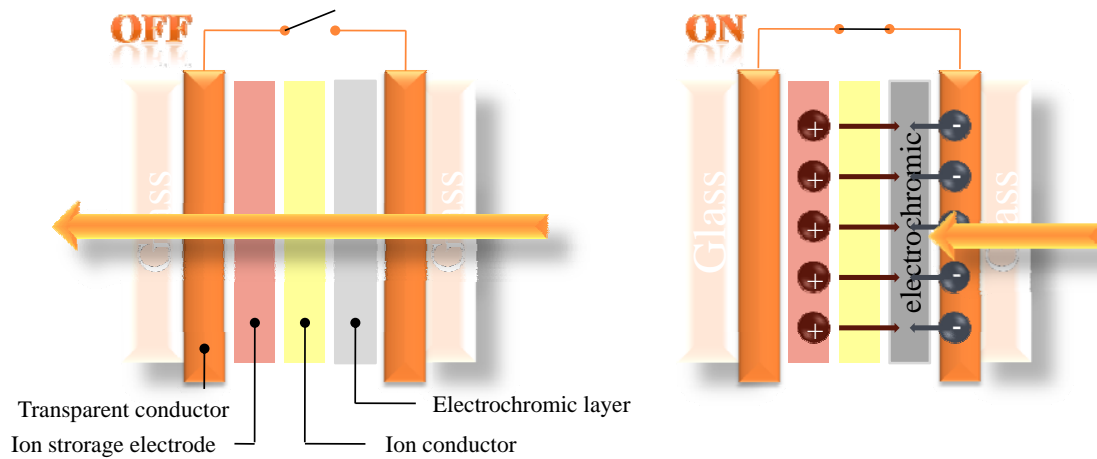
37

Lithium Ion Polymer Electrolytes



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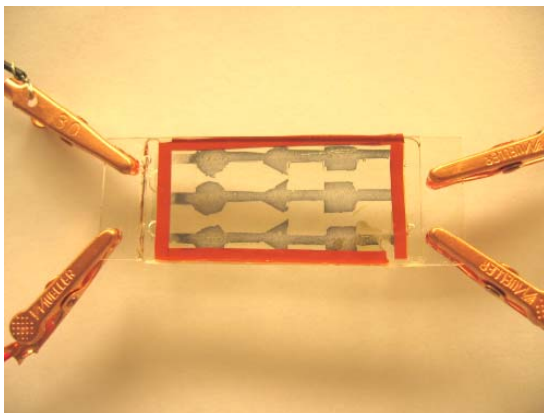
ELECTROCHROMIC DEVICES STRUCTURE



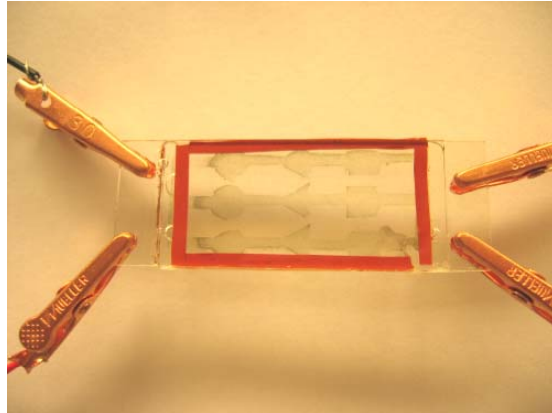
39

Lithium Ion Electrochromic Devices

Oxidized (+3V)



Reduced (-3V)



40

Closing Remarks

Engineered Biomolecules

M13 phages

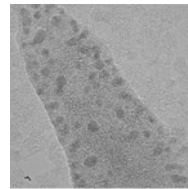


Specific interactions between peptides on phages and inorganic crystals



Inorganic Nanomaterials

IrO₂ nanowires



Functional Thin Film

Phage assembly



ITO electrode



Device Applications

Electrochromic Devices

