Virus is Evolving into Electronic Display Device

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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?

Paper-like Electronic Display
Have your own motivation questions

Anne M. Mulcahy (CEO of Xerox)

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

Nam June Paik (the first video artist)

TV Garden, 1982 version.


TV Clock, 1989 version.

Nam June Paik (the first video artist)
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, NAVE Public School, have told Ludhiana Tribune that they have done away with bags for primary classes and instead started keeping books in the school bags.

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

Our Approach

Target (or Needs)  Paper-like Display

Properties of Materials  Switching Speed
Optical Contrast

Fundamental Principles  Self-Assembly
Biomineralization

Tools  Genetically Engineered Viruses
1. Current *Display Technologies*

2. Technical Issues of Electrochromic Devices

3. ‘*Biological Materials*’ as a technical solution

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**Liquid Crystal Display (LCD)**
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.
**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.

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

- Light emission
- Energy consumption
- Weight
- Eye fatigue
- Flexibility
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, USA

1 pixel

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Appearance of pixels (seen from above through transparent electrode layer)

Transparent Electrode Layer
Liquid Polymer Layer
Containing e-ink capsules
Lower Electrode Layer
Movie film is usually displayed at a speed of 24 frames/sec, which corresponds to display switching times of about 40 msec.
Screen Refreshing Speed

Intrinsic Limitation = Particle Migration

Molar Flux Constitutive Equation

\[ \dot{N_i} = -D_i \nabla c_i + \frac{z_i}{|z_i|} u_i c_i \bar{E} + c_i \nabla \bar{f} \]

Stokes-Einstein Relation

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

Electrochromism
ELECTROCHROMIC DEVICES
STRUCTURE

OFF

ON

Electrochromic layer
Ion conductor
Transparent conductor
Ion storage electrode
Glass
Electrochromic

ELECTROCHROMIC DEVICES
APPLICATIONS

fantasticplastic.org/2005/10/
NanoChromics™ Technology
(Ntera Inc.)

ELECTROCHROMIC MATERIALS

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

INORGANIC MATERIALS
- Transition metal oxides: WO₃, Rh₂O₃, Ni₂O₃, IrO₂
- Mixed-valence metal complexes: Prussian blue.

Switching speed
Optical Contrast

Open-circuit optical memory
Electrochemical stability
Mechanical stability
Optical Contrast
The highly ordered structure of the M13 bacteriophage promotes the preferred orientation of nucleated nanoparticles through the arrangement of appended peptides.
**Biopanning technique shown with pIII peptide insert**

- Combinatorial library of ~2 x 10⁶ random peptide inserts in minor protein coat (pIII)
- Incubation of target material with library
- Unbound phage are washed away
- Repeat 4-5 times
- Amplification of eluted phage
- pH elution of bound phage

**Peptide binding sequences**

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**VIRUS-TEMPLATED IrO₂ NANOWIRES**

- Biopanning
- AGETQQAM
- Electric pulses at ~1 kV
- IrCl₃·xH₂O (25 mM, pH 7.5)
- IrO₂ nanowires

**1.77 nm**
Electrophoretic Deposition of IrO₂ Nanowires onto ITO glasses

Patterned ITO glass

Pt mesh

IrO₂ nanowires

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

Binding energy (eV)

50 mm

100 μm

Sn3p

In3d

Sn3p

In3p
Which Process Determines the Overall Electrochromic Responses?

Ion electrolyte layer

Electrochromic layer (IrO₂ Nanowires)

Transparent conductor (ITO electrode)

IrO₂ + Li⁺ + e⁻ ⇌ LiIrO₂

Ion conduction

Ion conduction

Electron conduction

Lithium Ion Conducting Polymer Electrolytes

MICROPOROUS MEMBRANE

SOLID POLYMER ELECTROLYTES

ORGANOCEL ELECTROLYTES

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

Celgard 2400 (SEM 20kX)

PMMA/PC gel

Oil absorbent

Nature 414, 359 (2001)

Cross-linked Gel Electrolytes
Prepared via Photo-initiated Polymerization

LIQUID

\( \text{H}_2\text{C} = \text{C} = \text{C} = \text{O} \bigg( \text{O} \bigg( \text{CH}_2 \text{CH}_2 \bigg)_n \bigg) = \text{C} = \text{C} = \text{CH}_2 \)

Poly(ethylene glycol) dimethacrylate

CROSS-LINKED POLYMERIC ORGANO GEL

UV light

Ion Conductivities of 1.0 M LiClO₄
Polymer-Organic Solvents Compatibility

Organic Solvents for Dissolution of Lithium Salts

- Propylene carbonate (PC)
- γ-Butyrolactone (BL)
- Dimethyl carbonate (DMC)
- Diethyl carbonate (DEC)

Ion Conductivities Before and After Polymerization

- BL (transparent)
- PC (transparent)
- DMC (opaque)
- DEC (opaque)
Lithium Ion Polymer Electrolytes

Major Ingredients

- LiClO$_4$
- Propylene carbonate (PC)
- Poly(ethylene glycol) dimethacrylate
- 4-hydroxybenzoquinone

Lithium Ion Polymer Electrolytes
ELECTROCHROMIC DEVICES
STRUCTURE

Lithium Ion Electrochromic Devices

Oxidized (+3V)          Reduced (-3V)
Engineered Biomolecules
M13 phages
Specific interactions between peptides on phages and inorganic crystals

Inorganic Nanomaterials
IrO$_2$ nanowires

Device Applications
Electrochromic Devices

Functional Thin Film
Phage assembly
ITO electrode