16.982 Bio-Inspired Structures
Spring 2009

Chapter 14

Bioinspired and Natural Nanomaterials

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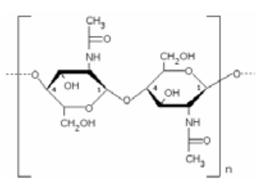
- **Velcro®** – inspired by seeds' clingy burrs
- **IMOD Display Technology** – inspired by butterfly wings
- **Low-friction ship hulls** – inspired by shark skin
- **Temperature-adapting fabric** – inspired by pinecone
- **Dirt- and water-resistant paint** – inspired by the lotus flower
- **Neuromorphic computer chips** – inspired by neural networks

1

Butterfly Wings and Interference

Chitin: hard translucent material



Chemical or Physical Color (Iridescence)

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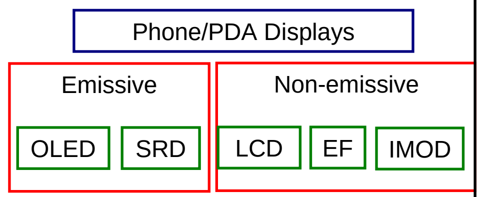
Intro to Displays

Information Displays:

- **Ink & paper ~ 5000 year ago**
- **Cathode Ray Tube (CRT) displays ~ 100 years ago**
- **Flat Panel Displays (FPD) displays ~ 40 years ago**
- **Next “big thing” - ????**



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OLED – Organic Light Emitting Diodes

LCD – Liquid Crystal Displays

EF – Electrophoretic

IMOD - Interferometric Modulator Displays

Low-power Reflective Direct View Display

- **Based on Micro-Electro-Mechanical Systems (MEMS) technology**

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- **Electro mechanical devices with optical functionality**
- **Key Benefits compared to LCD**

– 2x-3x reflectivity of reflective LCDs drives large power savings
– Near zero power for static image
– High response speed enables video

MEMS Device vs. Solid State Device

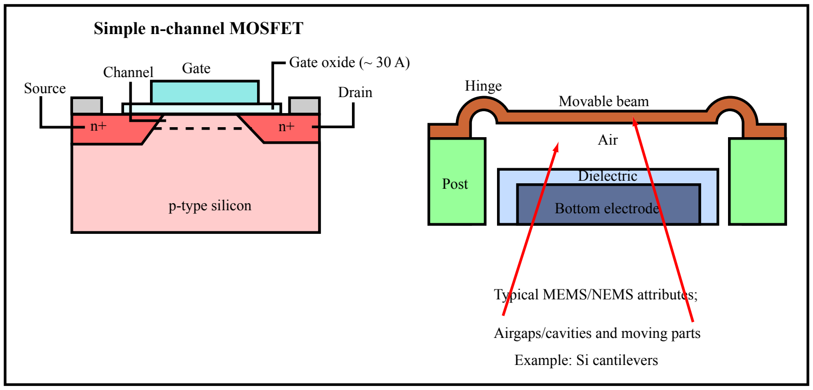


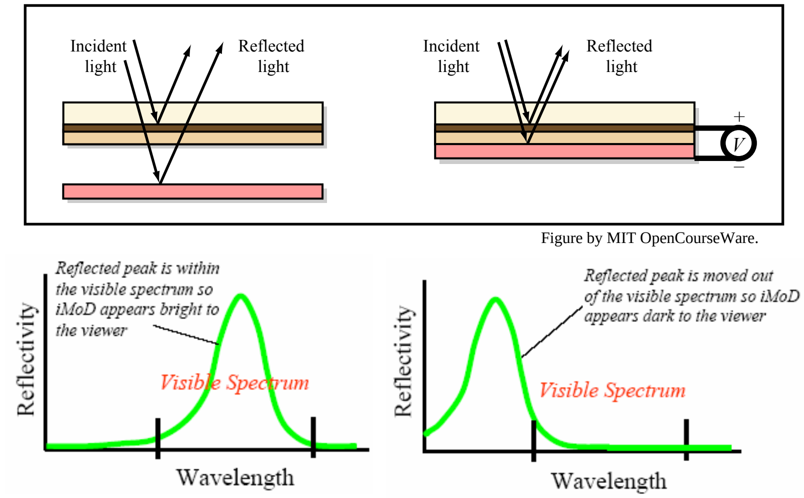
Figure by MIT OpenCourseWare.

MEMS: Bulk and Surface Micromachining

- **Si is a dominant substrate/ mech structure**
- **based mainly on (deep) dry or wet etching**
- **"sculptor's" approach – structure is trimmed from a bulk (silicon) piece**

- **can be fabricated on any planar substrate**
- **based mainly on thin film depositions**
- **fabrication approach similar to solid state devices (except for sac layer removal)**

Principles of Operation



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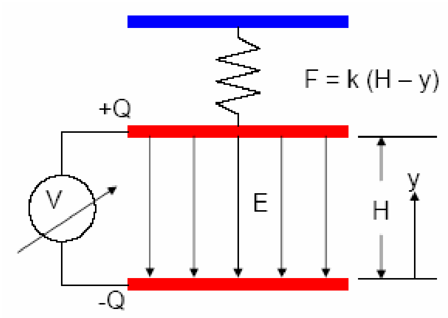
RGB Color scheme

- Color Reproduction
  – RGB sub pixels utilized in same manner as LCD
  – Color “grayscale” generated by spatial or temporal modulation

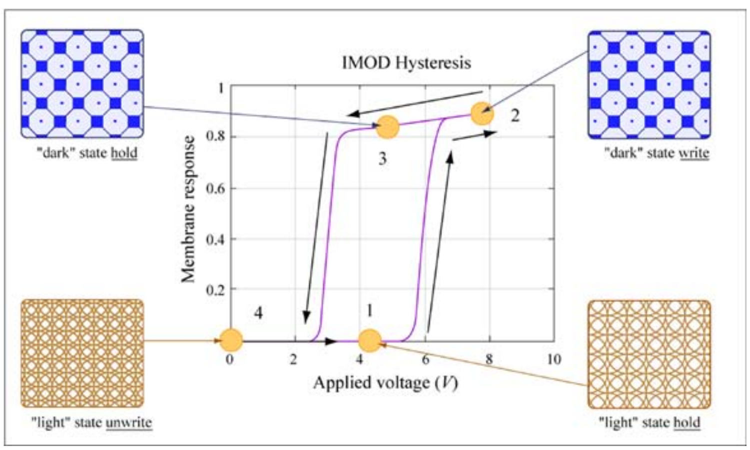
Simple electromechanical model

Competition between **electrostatic force** and **elastic** restoring force



Hysterisis

- Hysteresis loop gives the memory effect
– Allows an array to be addressed in a line-at-a-time fashion
– Image is maintained once the array is addressed



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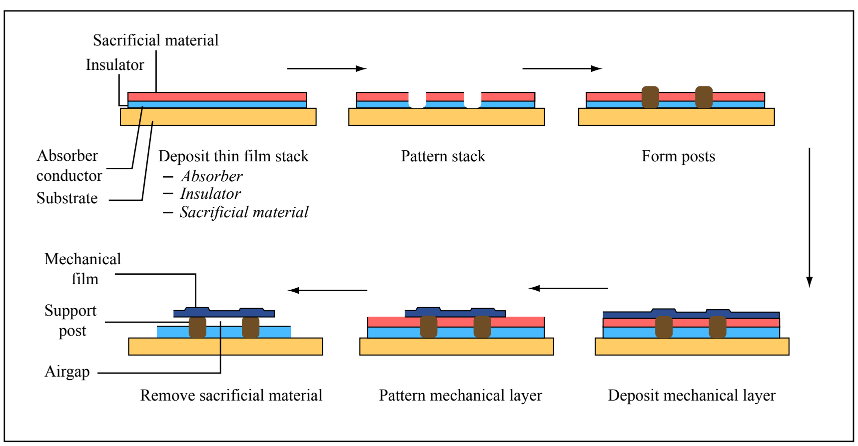
Power savings

- **Highly reflective display**
  – Viewable in most ambient lighting conditions
  – Greatly reduces the need for supplemental lighting
- **Bi-stable display technology**
  – Drastically reduces power
  – Hysteresis memory characteristic leads to near-zero standby power with full screen static image
- **Low operation voltage**

Simplified Manufacturing Scheme



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Sacrificial layer removal

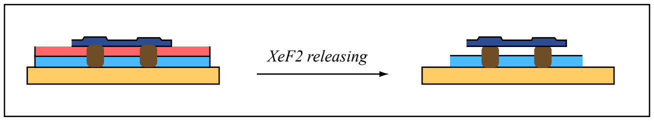

Figure by MIT OpenCourseWare.

General mechanism:

$Sac_{(s)} + 2XeF_{2\,(g)} \longrightarrow SacF_{x\,(g)} + Xe_{\,(g)}$

where $Sac_{(s)}$ = sacrificial layer material, e.g. Me, Si, etc.

Example:

$Si_{\,(s)} + 2XeF_{2\,(g)} \longrightarrow SiF_{4\,(g)} + 2Xe_{\,(g)}$ ΔH^o=-1289 kJ/mol

Superhydrophobicity

The contact angle formed between a droplet and a solid surface is a result of the equilibrium between three surface tensions: solid-vapor γ_{SV}, liquid-vapor γ_{LV}, and solid-liquid γ_{SL}

$$\cos\Theta = \frac{\gamma_{SV} - \gamma_{SL}}{\gamma_{LV}}$$

Wenzel relationship:

$$\cos\Theta_A = r\cos\Theta_T$$

r – the roughness ratio, defined as the true surface area divided by the geometric area of integration;

Θ_A – actual angle; Θ_T = theoretical (Eq. above)

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A Model Artificial Lotus Leaf

- Two scales of topography are important

Spider Silk

Spider silks are comparable in strength to the best synthetic material made by man: strength of spider silk ~ 5x strength of steel of the same weight

$$E = \frac{\sigma(stress)}{\varepsilon(strain)}$$