Bioinspired and Natural Nanomaterials

- **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

Butterfly Wings and Interference

Chitin: hard translucent material

Chemical or Physical Color (Iridescence)
**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” - ????

**Phone/PDA Displays**

<table>
<thead>
<tr>
<th>Emissive</th>
<th>Non-emissive</th>
</tr>
</thead>
<tbody>
<tr>
<td>OLED</td>
<td>SRD</td>
</tr>
<tr>
<td>LCD</td>
<td>EF</td>
</tr>
<tr>
<td>IMOD</td>
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</tr>
</tbody>
</table>

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

- 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

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

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 \textit{electrostatic force} and \textit{elastic} restoring force

\[ F = k (\text{H} - \text{y}) \]

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
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

Figure by MIT OpenCourseWare.
Sacrificial layer removal

General mechanism:

\[ \text{Sac}_{(s)} + 2\text{XeF}_2 \rightarrow \text{SacF}_x + \text{Xe} \]

Where \( \text{Sac}_{(s)} \) = sacrificial layer material, e.g. Me, Si, etc.

Example:

\[ \text{Si}_{(s)} + 2\text{XeF}_2 \rightarrow \text{SiF}_x + 2\text{Xe} \quad \Delta H^\circ = -1289 \text{ kJ/mol} \]

Superhydrophobicity

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

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

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;
- \( \Theta_A \) – actual angle; \( \Theta_T \) = theoretical (Eq. above)
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 \( \sim 5 \times \) strength of steel of the same weight

\[
\varepsilon = \frac{\sigma_{\text{stress}}}{\varepsilon_{\text{strain}}}
\]