ORGANIC LIGHT-EMITTING DIODES
LIGHTING TOWARD A SUSTAINABLE ENVIRONMENT

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Objective

Changing the parameters of a simulated OLED and analyzing the effects of these changes on OLED emission patterns.

The results of this study provide a template for a potential OLED with enhanced color-brilliance and brightness.
ORGANIC LIGHT EMITTING DIODE LIGHTING

Introduction
- What is an Organic Light-Emitting Diode?
- OLEDs Compared to Other Light Sources
- History and Applications of Organic Light-Emitting Diodes
- How Does it Work?

Method

Results and Conclusion

Why is it the Next Generation of Technology?
What is an OLED?

Organic
A compound that is carbon-based.

Light-Emitting Diode (LED)
An electronic device that emits light when an electrical current is applied to it.
What is an OLED?

An area light source that contains layers of thin, flexible sheets of organic electroluminescent material.

http://www.osadirect.com/static/img/news/img20130708lgchem01.jpg
What is an OLED?
Evolution of Light

<table>
<thead>
<tr>
<th>Lighting Technology</th>
<th>Efficiency</th>
<th>Lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incandescent lamp</td>
<td>17.5 lm/W</td>
<td>0.9 years</td>
</tr>
<tr>
<td>Compact fluorescent lamp</td>
<td>49-75 lm/W</td>
<td>7.3 years</td>
</tr>
<tr>
<td>Linear fluorescent lamp</td>
<td>67-110 lm/W</td>
<td>5.0 years</td>
</tr>
<tr>
<td>Light-Emitting Diode</td>
<td>up to 140 lm/W</td>
<td>13.7 years</td>
</tr>
<tr>
<td>Organic Light-Emitting Diode</td>
<td>120 lm/W</td>
<td>36.5 years</td>
</tr>
</tbody>
</table>

Lifespan found from GE 60W bulbs calculated for 3 hrs/day
OLEDs vs. LEDs

- **OLEDs** are area sources
- Small enough to be used as pixels in a display
- Modern displays can be less than 1mm thick and weigh less than 4.5 lbs
- Can be made flexible

- **LEDs** are point sources
- Used to backlight LCD TVs
- Modern displays can be less than 1.5 inches thick and weigh less than 35 lbs
- Encased in epoxy (plastic capsule)
History of OLEDs

- 1950’s: André Bernanose observed electroluminescence in organic materials.
- 1960: Martin Pope developed a technique to connect an electric current to organic crystals.

- 1987: Ching W. Tang and Steven Van Slyke at Eastman Kodak reported the first small-molecule OLED device.
Commercialization of OLEDs

• In 2003, Kodak began integrating OLED technology with their digital cameras.

• In 2007, Sony announced the XEL-1, the first OLED TV.

• In 2015, LG unveiled the world's thinnest OLED TV.
How does an OLED work?

• Potential difference is applied to the two electrodes.

• Electrons travel from cathode to anode.

• Holes recombine with the electrons in the emissive layer.

• Energy is released as light and directed towards the substrate.
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Why is it the Next Generation of Technology?
Refractive Index

- Property of materials
- Defined as $n = \frac{c}{v}$
- Used to determine values such as incident angle of the $m^{th}$ layer
Adding Microcavities and DBRs

Microcavity
Creates standing waves that amplify the light

DBR
Produces standing waves using phase change

*Microdisplays Based upon Organic Light-emitting Diodes.* "IBM Journal of Research and Development

https://upload.wikimedia.org/wikipedia/commons/3/30/Partial_transmittance.gif
Nine-Step Algorithm

1. User input values
2. Converting values for calculation
3. Outer loop for Incident angles (-90 degrees < q < 90 degrees)
4. Calculating Refracted angles and Layers thickness
5. Calculating the Optical admittance
6. Inner loop for Wavelength (Bragg wavelength +/- 180)
7. Calculating Phase factor and Characteristic Matrix
8. Computing the Transmittivity and Reflectivity values
9. Graphs
Validity of Code

Reflectivity vs Wavelength

Reflectivity (%) vs Wavelength (nm)

1 Stack
5 Stacks
9 Stacks
13 Stacks
**Approach**

Final Simulation

OLED with DBRs and a microcavity
Approach

- **Goals:**
  1. Maximum transmission at Bragg wavelength
  2. Maximum reflection at surrounding wavelengths

- Focus on small bandwidth
- Parametric study
  - $R + T = 1$
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Results

Changing the number of DBR stacks above and below the cavity affects transmission.

Before

Unequal Stacks

After

Equal Stacks
Results

Changing the substrate index affects maximum transmission.

Before

After

High Index

Low Index
Results

Changing the cavity index affects reflection patterns.

Before

Far from Integer

After

Close to Integer
Results

Changing the length of the microcavity affects transmission at the Bragg wavelength.

Before

After

1/8 Bragg wavelength

1/2 Bragg Wavelength
Conclusion

For Maximum Transmission:

1. Equal DBR stacks above and below cavity.

2. Substrate refractive index close to 1.0 (vacuum).

3. Cavity refractive index close to integer.

4. Cavity length of $\frac{1}{2}$ or $\frac{1}{4}$ the Bragg wavelength.
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Organic Light-Emitting Diodes

ADVANTAGES

- Energy efficient
- Environmentally friendly
- Does not emit heat or UV rays
- Closest light source to natural light
- Thinner and lighter than other light sources
- Cost decrease predicted to occur in the next 5 years
- Can be produced as large sheets
- Truer blacks and better contrast on displays

DISADVANTAGES

- Efficiency is still low compared to LED efficiency
- Blue OLED lifetime is much shorter than the red and green
- The cost to manufacture is currently expensive
- Sensitive to water and UV rays
Potential OLED Applications
Sources


Acknowledgements

National Aeronautics and Space Administration (NASA)
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FAQ
ORGANIC LIGHT-EMITTING DIODES
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Circuit Basics
Semiconductors
P-N Junction
Layers of an OLED

Excitons
Microcavity
DBR
OLED Materials
Equations

Applying the Layers
Algorithm Steps
Natural Light
Black Levels/Contrast

Home
Circuit Basics

• Potential difference (voltage) creates a push

• Current flows through circuit

• Resistance restricts flow

• Direct current and alternating current

Main Menu
Semiconductors

- Conductivity increases with temperature.
- Allows for greater control of current.
- Used in transistors, diodes, microprocessors.
- Usually Silicon and Germanium

P-N Junction

**P Material**
- Semiconductor doped with an impurity that has fewer valence electrons
- The missing electron leaves a positively-charged "hole"

**N Material**
- Semiconductor doped with an impurity that has extra valence electrons
- Extra electrons can move freely and conduct electricity
P-N Junction

Diffusion
Random movement of electrons to fill an entire space (no current)

Drift
Movement of electrons due to an electric potential (current)
P-N Junction

Current can only flow in one direction.

Forward Bias
- works with drift to decrease the depletion zone
- negative current pushes electrons across
- current created

Reverse Bias
- works against drift and with diffusion
- increases the depletion zone
- negligible current

circuitstoday.com/pn-junction-diode-characteristics
Basic OLED Structure

• Invented by Kodak in 1987
• Only two layers between cathode and anode.
Cathode and Anode

• Cathode: Electrode that receives electrons when connected to a power source

• Typically a reflective metal

• Anode: Electrode that loses electrons (or “receives holes”)

• Often transparent and made of indium tin oxide (ITO)
Emissive and Conductive Layers

- Thin organic material between cathode and anode
- Combined thickness: 100-150 nanometers
- Electrons are transported to the emissive layer (ETL)
- “Holes” travel through conductive layer (HTL)
- Electrons and holes recombine in the ETL
- Energy is released in the form of light
Substrate Layer

- A protective, transparent layer
- Light passes through the clear substrate
Recombination and Excitons

- Electrons and holes recombine.
- The recombination forms exciton and releases light.
- Exciton (electron-hole pair) is electrically neutral.

Distributed Bragg Reflectors

Quarter-wave stack

CONSTRUCTIVE INTERFERENCE

Similar phases

Added

DESTRUCTIVE INTERFERENCE

Different phases

Canceled

http://www.batop.de/information/pictures/quarter-wave_stack.jpg

http://www.webexhibits.org/causesofcolor/images/content/11z.jpg
OLED Materials

Cathode
- Aluminium
- Silver
- Magnesium
- Indium
- Lithium-fluoride

Electron Transport Layer (ETL)
- Tris-(8-hydroxyquinoline) Aluminum

Emissive Layer
- Tris-(8-hydroxyquinoline) Aluminum
- Coumarin
- Dichloromethane

Hole Transport Layer (HTL)
- Copper phthalocyanine
- Naptha phenyl benzidene

Anode
- Indium-tin oxide
- Zinc oxide

Main Menu
Mathematical Concepts

Characteristic Matrix

• Necessary in order to calculate reflection and transmission.

• There is a characteristic matrix for:
  
  Upper DBR, $M_{\text{DBR}1}$
  
  Microcavity, $M_{\text{Cavity}}$
  
  Lower DBR, $M_{\text{DBR}2}$

• The total characteristic matrix can be found using:

$$M_{\text{Total}} = M_{\text{DBR}1} \times M_{\text{Cavity}} \times M_{\text{DBR}2}$$

Main Menu
Mathematical Concepts
Reflection and Transmission Equations

• $M_{Total}$, a 2x2 matrix, contains real and imaginary parts.

• The top and bottom two elements of the matrix form two complex numbers, denoted as $B$ and $C$, respectively.

It is possible to calculate the reflection and transmission, given by:

$$R = \frac{(y_0 B - C)(y_0 B - C)}{(y_0 B + C)}$$
$$T = 4y_0 \frac{Re(y_{sub})}{(y_0 B + C)}$$
Applying the Organic Layers

- Vacuum Thermal Evaporation (VTE):
  - Organic molecules are evaporated and condensed.
  - Kodak’s original process.
  - Expensive and inefficient.

- Organic Vapor Phase Deposition (OVPD)
  - Carrier gas transports evaporated organic molecules
  - More efficient and less expensive.

- Inkjet Printing
  - Materials sprayed directly to substrate.
  - Most efficient and least expensive application technique.
Defining Parameters

Steps 1-2

• User enters properties of the layers:
  - Number of layers
  - Angle of incidence
  - Index of refraction
  - Wavelength

• Convert from degrees to radians

http://www.schoolphysics.co.uk/age16-19/Optics/Refraction/text/Refraction_/images/1.png

Main Menu
Calculating Material Properties

Steps 3-5

• Test all possible initial incident angles (-90° to 90°)

• Find values:
  Incident angle of $m^{th}$ layer, $\theta_m$
  Thickness of each layer, $t$
  Optical admittance, $y$

Showing how the light behaves in the DBR structure
Changing Wavelengths
Steps 6-7

• Test visible spectrum with each initial incidence angle

• Determines values for:
  
  Phase change, $\delta m$

  Characteristic matrix, $M_{\downarrow m}$

  Total characteristic matrix, $M_{\downarrow T}$

![Diagram showing reflection vs. thickness with peaks at $\lambda/4$, $\lambda/2$, and $3\lambda/4$ and minimum at $\lambda$.]

Showing the maximum and minimum reflection in the DBR layers.
Results
Steps 8-9

- Receive output when all possibilities have been checked. Includes:
  - Reflectance, $R$
  - Transmittance, $T$
  - Phase angle, $\Psi$, between $R$ and $T$

- Produce graphs from results
Spectral Power Distribution

http://www.lgoledlight.com/

Main Menu
Black Levels and Contrast

Black displayed on an OLED TV (left) and LCD TV (right).

Main Menu