Organic Electronic Devices

Week 5: Organic Light-Emitting Devices and Emerging Technologies
Lecture 5.1: Introduction to Organic Light-Emitting Devices

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Lecture Overview and Learning Objectives

• Concepts to be Covered in this Lecture Segment

  • Introduction to the Current and Future Applications of Organic Light-emitting Devices (OLEDs)
  • General Device Structure, Operating Mechanism, and Device Optimization of OLEDs
  • Determination of Device Efficiencies and Color Response of the Human Eye

• Learning Objectives
  By the Conclusion of this Presentation, You Should be Able to:

  1. **Describe** the operating mechanism of OLEDs and compare and contrast this operation to OPV devices.
  2. **Calculate** the external quantum, current, and luminous efficiencies of OLEDs given input parameters.
  3. **Explain** why OLEDs should be designed with the response to the human eye in mind.
Organic Light-emitting Devices (OLEDs) Are Marketable

Televisions and Displays (LG)

Solid-State White Lighting (Siemens)

Smartphones (Samsung)

Emerging Applications (Samsung)
An OLED Has a Similar Device Structure to an OPV

**General OLED Structure**

- Al Cathode
- Organic Emissive Layer
- Transparent ITO Anode

**J-V Response and Emission Curves**

- In OPV Devices, Light Was Input to Generate a Voltage
- In OLED Devices, a Voltage Bias is Applied to Generate the Emission of Light
- Holes are Injected from the Anode
- Electrons are Injected from the Cathode
- Recombination and Photoemission Occurs in the Organic Active Layer

Quantum Efficiencies in OLEDs

The Quantum Efficiency of the Device Includes the Internal and External Quantum Efficiencies

- **External Quantum Efficiency** ($\eta_{ext}$): The Number of Emitted Photons per Number of Injected Charges

  $$\eta_{ext} = \eta_r \phi_f \chi \eta_{out} = \eta_{int} \eta_{out}$$

  - $\eta_r$: Probability of Holes and Electrons Recombining (Can Approach 1)
  - $\phi_f$: Fluorescent Quantum Efficiency (Can Approach 1)
  - $\chi$: Probability for Radiative Decay to Occur (Generally Confined to 25%)
  - $\eta_{out}$: Fraction of Photons that Escape the Device (Usually ~20%)

- **In classical OLED systems, the external quantum efficiency is ~4-5%**

**Further Reading:** Geffroy, B.; le Roy, P.; Prat, C. Polym. Int. 2006, 55, 572.
Electrons have spin states of +1/2 and −1/2. Therefore, there are four possible combinations: 1) Up, Up; 2) Down, Down; 3) Up, Down; and 4) Down, Up.

For Triplet States, the Angular Momentum Sums to 1
For Singlet States, the Angular Momentum Sums to 0
Changing Device Design Improves Device Efficiency

Macroscopic Efficiency Calculations

Luminance: The amount of light emitted from a given area of a device

Candela (Cd): SI base unit of luminous intensity

Then we can define the Current Efficiency \((\eta_L)\)

\[
\eta_L = \frac{L}{J} \left[ \frac{Cd}{m^2} \right] \frac{m^2}{A} = \frac{Cd}{A}
\]

Luminous Efficiency: The ratio of the optical flux to the electrical input

Lumen (lm): SI unit of luminous flux, which is a measure of the total amount of visible light emitted by a source

Then we can define the Luminous Efficiency \((\eta_p)\)

\[
\eta_p = \frac{L \pi}{J V} = \eta_L \frac{\pi}{V} \frac{Cd}{A} \frac{rad}{V} \frac{lm}{W} = \frac{Cd}{W}
\]

Need High Luminance at Low Voltage!

The Human Eye Matters in OLEDs

\[ \eta_L = \frac{L}{J} \left[ \frac{Cd}{A} \right] m^2 \left[ \frac{Cd}{A} \right] \]

\[ \eta_p = \frac{L \pi}{J \frac{rad}{V}} = \eta_L \frac{\pi}{V} \left[ \frac{Cd}{A} \right] \frac{rad}{V} \left[ \frac{lm}{W} \right] \]

There is One Key Difference Between OPV Devices and OLEDs – We cannot control the solar emission spectrum.

However, we do have colors to which the human eye is more sensitive. Therefore, we need to consider human response when designing the emission of the devices.

For instance, the human eye responds much better to green light than red or blue light.

Therefore, the current and luminous efficiencies must be tuned to specific wavelengths of light in order to adjust for how the human eye perceives the emitted color.
The Color of Emission for OLEDs Matters Greatly

Commission Internationale d’Eclairage (CIE) Chromaticity Diagram
Examples of Artistic Solid State Lighting Through WOLEDs
Organic light-emitting devices (OLEDs) are in the early stages of commercialization, and the future is very bright for emerging applications. The operating mechanism of OLEDs is somewhat the opposite of the operating mechanism of OPV devices. The clear commercialization advantage that OLEDs have over OPV devices is the relative cost of personal electronics versus power conversion devices.

When designing OLED systems, it is important to consider the device geometry in order to maximize the overall output efficiency of the OLED. Critically, the emission of the OLED device must be tuned to the photo-response of the human eye. Furthermore, the appropriate mixture of emitted colors must be utilized in order to produce different hues of white light from OLED devices.

Next Time: Design Considerations for OLEDs