Penn State RET in Interdisciplinary Materials
Teacher’s Preparatory Guide

How index of refraction affects OLEDs

Purpose This lab is designed to help students understand how a college prep physics concept like refraction relates to cutting edge technology development.

Objectives Students will use Snell’s law to determine the index of refraction for glass and relate that to internal reflection in n OLED.

Time required one 47 minute class period

Level High school

Next Generation Science Standards

HS-PS4-1 Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.

HS-PS4-5 Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy

Teacher Background An organic light emitting diode (OLED) can fit all the roles that LEDs currently fill if the efficiency is increased. OLEDs provide better optical qualities, are made of less expensive materials, and can be flexible. OLEDs are comprised of layers: a substrate, anode, hole transport layer (HTL), electron transport layer (ETL), and a cathode. The HTL and ETL are made of organic thin films that are semiconductors. The high index of refraction of the organics causes much of the light produced to be internally reflected.

Materials
- Glass or Acrylic blocks – 1 per lab group (2-3 students)*
- Foam board – 1 per lab group**
- Protractor – 1 per lab group
- Scientific calculator
- Straight pins – 2 per group
- Straight edge

*Available at https://www.enasco.com/product/SB28595M
**Poster sized foam board cuts nicely into 4 lab size boards with a box cutter
Advance Preparation prepare materials & make student copies of worksheet

Safety Information none

Teaching Strategies
- It is assumed that students are familiar with drawing normals (line perpendicular to the surface), and using Snell’s Law.
- To ensure engagement, lab is best done in partners. Partners would share page 1 of the student hand out, but each should have pages 2 and 3.
- It may be preferable to provide lab space that makes viewing at eye level convenient. (standing and placing foam board on top of tall file cabinet or sitting on regular height chairs with foam board on top of table height lab tables)

Resources: http://oled.com/oleds/

Directions for the activities Provide materials and Student Worksheet – it is self explanatory.

Procedure Refer to student worksheet

PART 1 -
Since many students will have trouble interpreting how to site on pins, it is good to have a model set up with one line segment drawn for students to view. For students with enduring confusion, try holding up two different colored pens and ask student to move to the position where “the red pen is blocking the blue pen”, reposition the pens a few times for students to get the idea.

Many students have the misconception that parallel lines must be right next to each other. A helpful hint is to remind students how they define parallel lines in math class. (same slope)

Many students will need a reminder on protractor usage. They usually remember to line up a side, but forget the vertex must align with the middle of the protractor. Watch for students measuring obtuse angles and try to lead them to recognize that they are using the wrong scale on the protractor.

PART 2 -
Students use Snell’s law to calculate angles and draw rays. It may be useful to review the concept of internal reflection and do a quick calculation of the critical angle between materials.
How Index of Refraction Affects OLEDs

Would you like a FLEXIBLE cell phone?

The semiconductors traditionally used in cell phones are brittle lattice structures, so they are mounted on rigid bases. Since organic light emitting diodes (OLEDs) use an organic thin film for the semiconductor, it can be mounted on a bendable surface without breaking. But there is an issue with OLEDs related to refraction. Learn more with this activity.

1. Find the index of refraction of glass

   A. Place this paper on your foam board - line up the block in the outline and place pins in “1st” and “siting pin”
   B. Looking through the block and draw a short line segment from the siting pin toward the image of 1st pin.
   C. Leave the siting pin in place and repeat the process for pin in “2nd” and “3rd”
   D. Remove the block and extend line segments to the block outline.
   E. Draw lines from 1st, 2nd, & 3rd to the top of the block parallel to the siting lines that you drew.
   F. Draw lines through the block that represent the path of the light rays.

Siting pin
QUESTIONS: Why should the top lines be parallel to the bottom lines?

Use dotted lines to draw neat normal lines each place that light rays bend. Why are there 6 lines and not 3?

Describe the process you will use to find the index of refraction for the block:

Determine the index of refraction for the block. Show all work and find the average.
2 Refraction in an OLED

OLEDs are made by depositing layers on a base, the substrate. The substrates used for OLEDs could be glass. Flexible plastics used for substrates have an index of refraction similar to glass. The organic semiconductor layers have an index fraction in the 1.7-1.9 range. An OLED only gives off the light that can pass through the substrate material.

Calculate the angles and draw only each light ray that can pass through the substrate (made of the block from PART 1) into air.

<table>
<thead>
<tr>
<th>organic layer</th>
<th>44°</th>
<th>46°</th>
<th>48°</th>
<th>50°</th>
<th>52°</th>
<th>54°</th>
</tr>
</thead>
<tbody>
<tr>
<td>n = 1.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>substrate</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>n =</td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>air</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>n =</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

QUESTIONS:
Explain why all rays could not pass through the substrate.

How should the index of refraction of the organic material be altered to allow more light to pass through the substrate? (higher or lower)
How Index of Refraction Affects OLEDs

Would you like a FLEXIBLE cell phone?

The semiconductors traditionally used in cell phones are brittle lattice structures, so they are mounted on rigid bases. Since organic light emitting diodes (OLEDs) use an organic thin film for the semiconductor, it can be mounted on a bendable surface without breaking. But there is an issue with OLEDs related to refraction. Learn more with this activity.

1) Find the index of refraction of glass

A. Place this paper on your foam board - line up the block in the outline and place pins in “1st” and “siting pin”
B. Looking through the block and draw a short line segment from the sitting pin toward the image of 1st pin.
C. Leave the sitting pin in place and repeat the process for pin in “2nd” and “3rd”
D. Remove the block and extend line segments to the block outline.
E. Draw lines from 1st, 2nd, & 3rd to the top of the block parallel to the sitting lines that you drew.
F. Draw lines through the block that represent the path of the light rays.

Part B & C – looking through the block students draw lines that appear to go toward 1st, 2nd, and 3rd pin
Part D – extend lines since block is no longer in the way of the ruler
Part E
Part F
QUESTIONS: Why should the top lines be parallel to the bottom lines?

Since sides of the block are parallel, light bends back to its original direction (unlike a prism).

Use dotted lines to draw neat normal lines each place that light rays bend. Why are there 6 lines and not 3?

Each ray of light bends when it goes in (air to plastic) and when it comes out (plastic to air).

Describe the process you will use to find the index of refraction for the block:

I will use a protractor to measure each incident and refracted angle from the normal.
I will use Snell's Law to calculate \( n \)

Determine the index of refraction for the block. Show all work and find the average:

Ideally angles for the top air-block interface will be the same as the bottom, but they could be a few degrees off due to siting or measuring errors.

\[
\begin{align*}
\text{Air} & \quad \text{Block} \\
(1) \sin 30 = n_2 \sin 20 & \quad \frac{1.46}{n_2} \\
(1) \sin 40 = n_2 \sin 26 & \quad \frac{1.47}{n_2} \\
(1) \sin 50 = n_2 \sin 31 & \quad \frac{1.49}{n_2}
\end{align*}
\]

Average = 1.46
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Calculate the angles and draw only each light ray that can pass through the substrate (made of the block from PART 1) into air.

Organic to glass substrate:

\[
\begin{align*}
1.9 \sin 44^\circ &= 1.46 \sin \theta \\
65^\circ &= \theta \\
1.9 \sin 46^\circ &= 1.46 \sin \theta \\
69^\circ &= \theta \\
1.9 \sin 48^\circ &= 1.46 \sin \theta \\
75^\circ &= \theta \\
1.9 \sin 50^\circ &= 1.46 \sin \theta \\
85^\circ &= \theta \\
1.9 \sin 52^\circ &= 1.46 \sin \theta \\
\text{error} &
\end{align*}
\]

Glass substrate to air:

\[
\begin{align*}
1.46 \sin 66^\circ &= 1.0 \sin \theta \\
65^\circ &= \theta \\
\text{error} &
\end{align*}
\]

QUESTIONS:

Explain why all rays could not pass through the substrate.

Two of the rays were internally reflected and couldn’t even enter the substrate.

Those rays that did enter the substrate were at large angles that were internally reflected in the glass.

How should the index of refraction of the organic material be altered to allow more light to pass through the substrate? (higher or lower)

The n for the organic material should be lowered. Ideally it should be the same or less than n for the substrate.