Introduction to Optoelectronic Devices

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Outline

- What is the optoelectronics?
- Optics and electronics
- Major optoelectronic devices
- Current trend on optoelectronic devices
- Nanoscale optoelectronic devices
- My research on optoelectronics
What Did the Word “Opto-Electronics” Mean?

- **Optoelectronics** is the study and application of electronic devices that interact with light.
What is optics

- Behaviors and properties of light
- Visible, ultraviolet and infrared light
- Light is an electromagnetic wave
- Light is also treated as particle-like energy-packet, or "photons"
- Applications include visual assistance, imaging and optical communication
What is electronics

- Electronic circuits including analog circuits and digital circuits

- Electronic components, such as transistors, diodes, and integrated circuits (ICs), interconnectors

- Most electronic devices are made by semiconductor materials for electron control

- Applications include information processing, signal processing and telecommunication
Examples of Optoelectronic Devices

- **Telecommunication laser**
  - [Image: Newport.com]

- **Blue laser**
  - [Image: TDK]

- **Optical fiber**
  - [Image: Corning]

- **LED traffic lights**
  - [Image: Rsc.org]

- **Photodiodes**
  - [Image: Hamamatsu]

- **Solar cells**
  - [Image: Wikipedia]
Light-emitting diode (LED) is a semiconductor diode that emits incoherent light over relatively wide spectral range when electrically biased in the forward direction of the p-n junction.
# Semiconductor Materials vs. LED Color

## General Brightness

<table>
<thead>
<tr>
<th>Material</th>
<th>GaP</th>
<th>GaN</th>
<th>GaAs</th>
<th>GaAlAs</th>
<th>--</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>Green, Red</td>
<td>Blue</td>
<td>Red, Infrared</td>
<td>Red, Infrared</td>
<td>--</td>
</tr>
</tbody>
</table>

## Super Brightness

<table>
<thead>
<tr>
<th>Material</th>
<th>GaAlAs</th>
<th>GaAsP</th>
<th>GaN</th>
<th>InGaN</th>
<th>GaP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>Red</td>
<td>Red, Yellow</td>
<td>Blue</td>
<td>Green</td>
<td>Green</td>
</tr>
</tbody>
</table>

## Ultra Brightness

<table>
<thead>
<tr>
<th>Material</th>
<th>GaAlAs</th>
<th>InGaAlP</th>
<th>GaN</th>
<th>InGaN</th>
<th>--</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>Red</td>
<td>Red, Yellow, Orange</td>
<td>Blue</td>
<td>Green</td>
<td>--</td>
</tr>
</tbody>
</table>
Laser cavity design:
- Laser medium is similar to LEDs,
- Extra components in laser cavity are the mirrors at two facing planes (facets) for lasing mode selection.
- The laser light is monochromatic and coherent due to the mode selection in the cavity design.
Photo Diodes (PDs)

A photodiode is a semiconductor diode that functions as a photodetector. It is a p-n junction or p-i-n structure. When a photon of sufficient energy strikes the diode, it excites an electron thereby creating a mobile electron and a positively charged electron hole.
Solar Cells (Photovoltaics)

Why solar cells?

Solar Energy
- Free
- Essentially Unlimited
- Not Localized

Solar Cells
- Direct Conversion of Sunlight → Electricity
- No Pollution
- No Release of Greenhouse-effect Gases
- No Waste or Heat Disposal Problems
- No Noise Pollution — very few or no moving parts
- No transmission losses — on-Site Installation
Residential and Commercial Applications

Challenges:
- cost reduction via:  
  a) economy of scales  
  b) building integration and  
  c) high efficiency cells
Solar Energy Spectrum

Solar radiation outside the earth’s surface: 1.35 kW/m², 6500 times larger than world’s energy demand

Spectrum of the solar energy

AM0: radiation above the earth’s atmosphere
AM1.5: radiation at the earth’s surface
Blackbody radiation: ideal radiation
Trends in optoelectronic devices

- Ultra-short, high power mid-infrared light sources
- Low cost, easy fabricated materials
- Compact multi-wavelength laser sources
- Less expensive and high efficiency photovoltaic devices
- Molecular and biomedical optoelectronics
  — nanoscale optoelectronic devices
How Small Is The Nano-Scale?

Less than a nanometer
Individual atoms are up to a few angstroms, or up to a few tenths of a nanometer, in diameter.

Nanometer
Ten shoulder-to-shoulder hydrogen atoms (blue balls) span 1 nanometer. DNA molecules are about 2.5 nanometers wide.

Thousands of nanometer
Biological cells, like these red blood cells, have diameters in the range of thousands of nanometers.

A million nanometers
The pinhead sized patch of this thumb (circled in black) is a million nanometers across.

A human hair is 50,000 – 80,000 nanometers wide and grows ~10 nm every second (~600 nm every minute)
Semiconductor Nanostructures

- Quantum wells
- Quantum dots
- Nanowire
- Carbon Nanotubes (CNT)
- Buckyball
The wavelength of quantum cascades laser lies in the mid-Infrared (MIR) region (3~30 µm)

Many chemical gases have strong absorption in mid-infrared region, such as CO,NH$_3$, NO, SO$_2$, etc.
Applications of QCL

- Environmental sensing and pollution monitoring
- Automotive
  - Combustion control, catalytic converter diagnostics
  - Collision avoidance radar, cruise control
- Medical applications
  - Breath analysis; early detection of ulcers, lung cancer, etc

QCL for gas detection
Challenges in QCL design

- Identify various physics interplaying in the QCL cavity and their effects on pulse propagation
- Design Lasing medium for ultra-short, stable, high power MIR pulse generation for environmental control and biomedical sensing
Quantum-Dot Solar Cells

0.5 µm intrinsic region containing 50 layers of quantum dot layers

Au grid bar
200 nm n⁺ GaAs

30 nm n GaInP
100 nm n GaAs
Si: GaAs
Si: GaAs
Si: GaAs
Si: GaAs
100 nm p GaAs
p⁺ GaAs substrate

Au contact
Plasmonic Solar Cells

H. A. Atwater and A. Polman, Nature Materials, Vol 9, March 2010
Laser-Based Heart-Beat Detection
System Setup

- Tested with various heart beat pattern and breathing
- Implemented in Medical School at UMD
Testing Results

- Sampling rate is at 1000 Hz
- From above result we can see LBS gives more information in the low frequency
- Frequency spectrum 0-250 Hz, peak 100 Hz, 220 Hz
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