Quick Review over the Last Lecture

Density of states (DOS) in different dimensions:

\[ D(E)_{3D} \propto E^{-\frac{1}{2}} \]
\[ D(E)_{2D} \propto \text{const.} \]
\[ D(E)_{1D} \propto E \]
Contents of Nanoelectronics

I. Introduction to Nanoelectronics (01)
   01 Micro- or nano-electronics?

II. Electromagnetism (02 & 03)
   02 Maxwell equations
   03 Schrödinger equation

III. Basics of quantum mechanics (04 ~ 06)
   04 History of quantum mechanics 1
   05 History of quantum mechanics 2
   06 Schrödinger equation

IV. Applications of quantum mechanics (07, 10, 11, 13 & 14)
   07 Quantum well
   10 Harmonic oscillator
   11 Magnetic spin
   13 Quantum statistics 1
   14 Quantum statistics 2

V. Nanodevices (08, 09, 12, 15 ~ 18)
   08 Tunnelling nanodevices
   09 Nanomeasurements
   12 Spintronic nanodevices
   15 Low-dimensional nanodevices
   16 Optical nanodevices

16 Optical Nanodevices
- Bandgap
- Light emitting diode
- Laser
- Near-field optics
Absorption fraction $A$ is defined as

Here, $j_t = Rj$, and therefore $(1 - R)j$ is injected.

Assuming $j$ at $x$ becomes $j - dj$ at $x + dx$,

$$-dj = \alpha j dx$$

($\alpha$ : absorption coefficient)

With the boundary condition: at $x = 0$, $j = (1 - R)j$

$$j = (1 - R)j \exp(-\alpha x)$$

With the boundary condition: $x = a$, $j = (1 - R)j e^{-\alpha a}$,

part of which is reflected; $R (1 - R)j e^{-\alpha a}$

and the rest is transmitted; $j_i = (1 - R - R (1 - R))j e^{-\alpha a}$

$$j_i = (1 - R)^2 j \exp(-\alpha x)$$

$$\therefore T = \frac{j_i}{j_i} = (1 - R)^2 \exp(-\alpha x)$$

Optical Absorption

*M. Sakata, Solid State Physics (Baifukan, Tokyo, 1989).*
Photo Diode

Photo voltaic effect:

\[ h\nu > \varepsilon_k \]

\[ \rightarrow \]

energy conversion


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Semiconductor Band Gap

Excited electrons will be recombined with holes with emitting photons.

**Semiconductor Band Gap in Si, Ge and GaAs**

![Graph showing the band structure of silicon, germanium, and gallium arsenide](image)

*Figure 19.8.* Essential features of band structures of silicon, germanium, and gallium arsenide. All have band gaps on the order of 1 eV. The bottom of the conduction band for silicon and germanium does not lie at Γ, so these materials have an indirect gap. Gallium arsenide, by contrast, has a direct gap. These diagrams are extracted from Figures 23.15 and 23.16, which contain information on how they were obtained.

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**Light Emitting Diode**

How does a light emitting diode works?

- In a \textit{pn} junction, electrons recombine with holes.
- Wavelength light colour depends on bandgaps.

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<table>
<thead>
<tr>
<th>Semiconductor</th>
<th>Band Gap (nm)</th>
<th>Energy (eV)</th>
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</thead>
<tbody>
<tr>
<td>InGaN</td>
<td>450</td>
<td>2.76</td>
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<tr>
<td>ZnTeSe</td>
<td>512</td>
<td>2.42</td>
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<tr>
<td>AlGaInP</td>
<td>570</td>
<td>2.18</td>
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<tr>
<td>AlGaAs</td>
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<tr>
<td>GaAs(Si)</td>
<td>980</td>
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<tr>
<td>ZnCdSe</td>
<td>489</td>
<td>2.54</td>
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<tr>
<td>GaP</td>
<td>555</td>
<td>2.23</td>
</tr>
<tr>
<td>InGaN</td>
<td>590</td>
<td>2.10</td>
</tr>
<tr>
<td>GaP(Zn)</td>
<td>700</td>
<td>1.77</td>
</tr>
<tr>
<td>InGaAsP</td>
<td>1300</td>
<td>0.95</td>
</tr>
</tbody>
</table>

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Light Emitting Diode (Cont’d)

4th generation light in human history:

- 3rd century BC (Etruria)
- 1879 (T. Edison)
- 1938
- 1962 (N. Holonyak, Jr.)

Principle of Laser

Light amplification by stimulated emission of radiation (Laser):

First demonstrated by Theodore H. Maiman in 1960.

Coherent light is generated by resonator
Quantum-Well Laser

Quantum-well (QW) laser was first fabricated by J. P. van der Ziel et al. in 1975:

Typical laser diode:

![Quantum-Well Laser Diagram](image)

* http://www.wikipedia.org/

** K. Iga (Ed.), Semiconductor Laser (Ohm-sha, Tokyo, 1994).

Quantum-Well Laser Structures

Major semiconductor quantum-well (QW) lasers:

<table>
<thead>
<tr>
<th></th>
<th>Gain-guided laser</th>
<th>Index-guided laser</th>
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<tr>
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</tr>
<tr>
<td>Beam shapes</td>
<td><img src="image" alt="Gain-guided Beam shapes" /></td>
<td><img src="image" alt="Index-guided Beam shapes" /></td>
</tr>
</tbody>
</table>

Lasers with Quantum Nano-wire / Dots

In 1982, Y. Arakawa and H. Sakaki proposed 1D / 0D lasers:

Example of a quantum-wire laser:

Example of a quantum-dot laser:

Limitation of Optical Nanofabrication

Development of photolithography:

**Near-Field Optics**

**Principles of near-field optics :**


**Scanning Near-Field Optical Microscope**

Scanning near-field optical microscope (SNOM) :


** http://www-optics.unine.ch/former/microoptics/cantilever_SNOM/cantilever_SNOM.html

* http://www-optics.unine.ch/former/microoptics/cantilever_SNOM/cantilever_SNOM.html