Lasers
Stimulated Emission
Lasers: Trapping Photons
Terahertz Lasers
Course Overview
**P-N Junctions and LEDs**

High energy electrons (n-type) fall into low energy holes (p-type)
Energy Conservation

\[ W_{\text{stored}} = \underline{} \]

\[ W_{\text{heat}} \]

\[ W_{\text{electrical}} \]

\[ W_{\text{light}} \]
Energy Conservation

\[ W_{\text{stored}} = \text{__________} \]
Through and Across Variables

\[ W_{\text{stored}} = \text{electron energy} \]

\[ W_{\text{heat}} \]

\[ W_{\text{light}} \]

\[ W_{\text{electrical}} \]

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<tr>
<th></th>
<th>THROUGH</th>
<th>ACROSS</th>
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<tr>
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Atomic Transitions

\[ \Psi = c_{1s} \phi_{1s} e^{iE_{1s}t} + c_{2p} \phi_{2p} e^{iE_{2p}t} \]
Light Emission from Magnets

Maxwell’s Equations couple H and E fields..

\[ \int_C \vec{E} \cdot d\vec{l} = -\frac{d}{dt} \left( \int_S \vec{B} \cdot d\vec{A} \right) \]

\[ \int_C \vec{H} \cdot d\vec{l} = \int_S \vec{J} \cdot d\vec{A} + \frac{d}{dt} \int_S \epsilon \vec{E} \cdot d\vec{A} \]

Image in the Public Domain

Radiation was missing from our quasi-static approximation

http://juluribk.com/2010/01/14/radiation-from-dipole/

Courtesy of Bala Krishna Juluri and Sophocles Orfanidis. Used with permission.
Light Emission from Magnets

\[ B_0 \]

external field

\[ h\omega \]

high energy

low energy

Superposition state = oscillating magnet

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<th>Nucleus</th>
<th>Resonance Frequency (1.5 Tesla) MHz</th>
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<tr>
<td>(^1)H</td>
<td>63.86</td>
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<tr>
<td>(^2)D</td>
<td>9.81</td>
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<tr>
<td>(^{13})C</td>
<td>16.05</td>
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<tr>
<td>(^{14})N</td>
<td>4.62</td>
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<tr>
<td>(^{19})N</td>
<td>6.57</td>
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<tr>
<td>(^{23})F</td>
<td>60.07</td>
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<tr>
<td>(^{31})Na</td>
<td>16.89</td>
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<tr>
<td>(^{31})P</td>
<td>25.86</td>
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Solar Cells and Photodetectors

**Classical**:
Oscillating electric field drives charge oscillation

**Quantum**:
Electric field creates superposition of energy states
- which have an oscillating charge density
Reverse Absorption: Stimulated Emission

How do you choose the color, direction, and phase of the generated photon?

GENERATED PHOTON IS AN EXACT DUPLICATE OF THE INCOMING PHOTON
Quantum Mechanics and Stimulated Emission

Pauli Exclusion and electrons (fermions) Stimulated emission and photons (bosons)

‘Two is a crowd!’

FERMIONS GO TO DIFFERENT STATES

BOSONS PREFER TO BE IN THE SAME STATE
Quantum Mechanics and Stimulated Emission

\[ \tilde{\beta} = \frac{\tilde{n} \omega}{c} = \beta + jg \]

\[ \vec{E}(z) = \vec{E}_i e^{gz} \]

\[ I(z) = I_0 e^{+2gz} \]
The astounding phenomenon is “Stimulated Emission” - a purely quantum phenomenon!

**Lasers**

**Stimulated Emission**: If one photon is present it is more likely that an atom will emit a second identical photon! In a laser there is a cascade that causes emission of many identical photons!

Identical photons with the same frequency moving in the same direction - Result is a coherent light source with a highly directional beam!
Active Devices for DVD Players

Detector
Laser
strained QW at 655 nm
Cylindrical Lens
Polarizing Prism
Diffraction Grating
2-axis Device
¼ Wave Plate
Collimator Lens
Cylindrical Lens
Detector

Laser
strained QW at 655 nm

All images are in the public domain
Quantum Well Lasers

n-type semiconductor

p-type semiconductor

Conduction Band

Valence Band

Metal Contact

Electron

Hole

Narrow Gap Active Region
Trapping Photons: Mirrors and Waveguides

How do we keep photons around for long enough time so they have a chance to stimulate an emission?
**Longest Wavelength Semiconductor Lasers**

**INTERBAND LASER:**
- $\hbar\omega$ set by bandgap
- Bipolar: electron-hole recombination
- Opposite band dispersion

**INTERSUBBAND LASER:**
- $\hbar\omega$ chosen by design
- Unipolar: electrons make intraband transitions
- Same subband dispersion
Quantum-Cascade Lasers
(slide courtesy of Prof. Jerome Faist at Univ. Neuchâtel)

Cascade: N repetitions of a period
→ 1 electron traveling through this structure may generate N photons
Metal Mirror Waveguides

Metals are excellent reflectors at THz frequencies.
6.007 - Applied E&M - From Motors to Lasers

The course encompassed THREE THEMES with FIVE related LABS
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