CHAPTER 13

Real Lasers and Lab Applications
### Archetypal Lasers

at which we will have a very quick look.

<table>
<thead>
<tr>
<th>Gas</th>
<th>Solid-State</th>
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</thead>
<tbody>
<tr>
<td>He:Ne</td>
<td>Ruby ($\text{Cr}^{3+}:\text{Al}_2\text{O}_3$)</td>
</tr>
<tr>
<td>CO$_2$</td>
<td>Nd lasers ($\text{Nd}^{3+}:\text{YAG}$, $\text{Nd}^{3+}:\text{glass}$)</td>
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<table>
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<tr>
<th>Excimer/Exciton</th>
<th>Liquid</th>
</tr>
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<tbody>
<tr>
<td>XeF, KrF, Ar$^+$</td>
<td>Dye Lasers</td>
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<table>
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<tr>
<th>Semiconductor</th>
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<tbody>
<tr>
<td>GaAlAs, and more recently GaN - no time for this, just mention not silicon (generally speaking, although there are examples of micro-structured Si lasers)</td>
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</tbody>
</table>
First laser of all - demonstrated by Maiman in 1960.
Still finds use today - mainly in medical applications (tattoo and hair removal!)

Used only in a pulsed mode - we will find out why on the next slide.

$\lambda \sim 694.3 \text{ nm}$

$\text{Cr}^{3+}:\text{Al}_2\text{O}_3$ with $\text{Cr}^{3+}$ being around 500ppm - otherwise introduce additional losses from dislocations

Ruby Laser

Still finds use today - mainly in medical applications (tattoo and hair removal!)
Ruby Energy Levels
Ruby Laser stuff
Absorption of Ruby

[Graph showing absorption coefficient vs. wavelength for light incident parallel and perpendicular to the c-axis of Ruby.]
Output power from Ruby Laser

Explanation??
Gain dependence on output

Intensity (W/cm$^2$)

Gain coefficient (m$^{-1}$)

$W_{41} \sim 0.2$ s$^{-1}$

$W_{41} \sim 0.1$ s$^{-1}$

$W_{41} \sim 0.4$ s$^{-1}$

Threshold
Nd:YAG, Nd:YVO$_4$, Nd:glass

$\text{YAG} = \text{Y}_3\text{Al}_5\text{O}_{12}$

$\lambda = 1064\text{nm}$ for YAG or YVO$_4$, or 1040-1080nm for various glasses

Used pulsed in industry (incl. fusion system I showed you before), and cw/pulsed in research

True 4 level system

3 orders of magnitude lower pump threshold
Nd:YAG energy structure

Energy (cm$^{-1}$)

$^4F_{3/2}$

$^4I_{11/2}$

$^4I_{9/2}$
Modern cw lasers one uses diode pumping through fibres or directly focussed into gain crystal. Pumping is extremely efficient in this case as diode laser pumping is exactly tuned to the transition (only necessary loss).
He:Ne Gas laser

First gas laser, 4 level system, first to give a cw output. Still widely used because of high quality beam, and highly monochromatic beam (much better than diode lasers). Still intrinsically fragile and relatively large so slowly being replaced by diode lasers.

He:Ne can give output at 632nm, 1.15µm and 3.39µm - less commonly in the yellow and green as well.

Typical powers from 1-30mW

RF or dc gas discharge (plasma) 1 Torr He and 0.1 Torr Ne
Typical Gas Laser Set-up

2-500 V

\[ \theta_b \]
Reflection from a bit of glass

Reflectivity vs. Incident Angle ($\theta$)
CO₂ laser (ro-vibrational)
CO₂ schematic energy levels

**Sym. Stretch**

-  (400)
-  (300)
-  (200)
-  (100)

**Assym. Stretch**

-  (004)
-  (003)
-  (002)
-  (001)
-  (000)

Very short lifetime

Very long lived
Dye Lasers
Dye Energy Level Structure

SINGLET

TRIPLET

S0 → S1 absorption

T1 → T2 absorption

k10

k13

k43

k30
LASERS IN OUR LAB
MILAN’S LAB - RB LASER COOLING
Doppler tuning

Has momentum and energy been conserved?

MILAN’S LAB - RB LASER COOLING
The Sapphire Clock

The ticking rate is determined by the size of the sapphire

4K
10 billion ticks per second

error: ±1 sec in 100 million years

The Light Clock

The ticking rate is determined by the rules of the microscopic Universe

60µK
448 trillion ticks per second

potential error: ±1 sec in 3 billion years
See DVD video
<table>
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<tr>
<th>The Sapphire Clock</th>
<th>The Light Clock</th>
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<td><img src="image1" alt="Sapphire Clock" /></td>
<td><img src="image2" alt="Light Clock" /></td>
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<td>error: ±1 sec in 100 million years</td>
<td>potential error: ±1 sec in 3 billion years</td>
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</table>
OPTICAL SYNTHESIZER
MICROSTRUCTURED FIBRE
single pulse

\[ E \]

\[ t \]

\[ \tau \]

40 fs

40 thousand-trillionths of a second
15 cm long

\[ f_n = n \times 1 \text{ GHz} \]

repetition rate = \(1/T\)
• Go to DVD
OPTICAL SYNTHESIZER
Examination

1.5 hours, 3 questions. Average assignment mark can replace worst exam question.

Past exams are a good guide

Examinable material is everything in course except:

Section 1 (Intro)

Section 4 - only need to understand how to use Gaussian-Spherical Beams, not derive them (including use of ABCD matrices to propagate). Need to understand their meaning.

Section 5.2-5.3 - need to know about the existence of higher order modes, not how to use them

Sect. 8.1 - don’t need to know, except understand what $g(#)$ is for

Section 9.2.1 and 10.1.7 are not part of the course

Section 11 and 12 are not in course except that you need to be able to use $g(#)$.

i.e. the normal approximation that $g(#) \sim 1/\Delta v$

Section 13: just broad details not intimate ones.

Neither Sect. 14 or 15 will be examined.
Semiconductor (Diode) Lasers