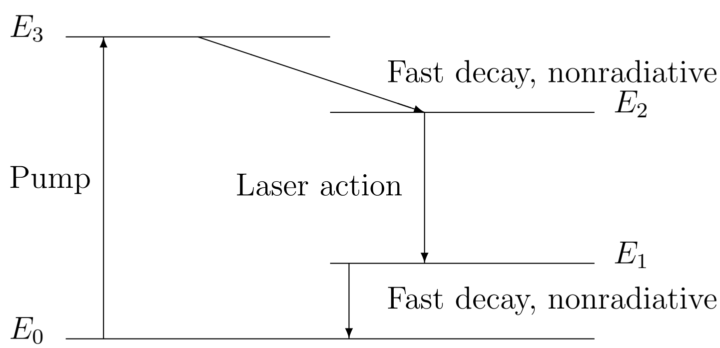
Problem 1.

Draw the energy level diagram for a 4-level laser and explain in words how it works.

Solution



An energy source excites the lasing material from the ground state, E_0 to the excited state, E_3. The material then quickly relaxes to the E_2 state. Material in the E_1 state quickly decays to the E_0 state, where it can be excited $E_0 \xrightarrow{\text{Excitation}} E_3 \xrightarrow{\text{Fast decay}} E_2$. This forms the population inversion such that $N_{E_2} > N_{E_1}$. At this point, when a photon of energy $h\nu_{32}$ passes near the lasing material in state E_2, it stimulates an emission of a second photon of the same energy ("stimulated emission"). This leaves the atom in state E_1, where it non-radiatively relaxes to E_0 and can be excited again.

Problem 2.

Calculate the (a) peak output and (b) average power for a laser that produces 12 ps pulses at a repetition rate of 1000 kHz with an energy of 100 µJ/pulse.

Solution

Part (a)

$$
\begin{aligned}
100\,\mu\mathrm{J} &= \frac{100 \times 10^{-6}\,\mathrm{J/pulse}}{12 \times 10^{-12}\,\mathrm{s/pulse}} \\
&= 8\,\mathrm{MW}
\end{aligned}
$$

Part (b)

$$
100 \times 10^{-6}\,\mathrm{J/pulse} \times 1000 \times 10^{3}\,\mathrm{s}^{-1} = 100\,\mathrm{W}
$$

Problem 3.

Briefly explain how a Q-switch works and the effect it has on the laser output.

Solution

A q-switched laser operates by first exciting the lasing medium (as with any other laser). Photons that are emitted during this process are kept out of the lasing medium, however, resulting in a low quality-factor ("q-factor"). This means that the excited atoms do not undergo stimulated emission, resulting in a larger population inversion than in continuous wave lasers. At some point, the mechanism separating the emitted photons from the lasing medium is disabled and the photons are allowed to enter the lasing medium–the q-factor is switched from low to high. This means that the larger population in the excited state can produce photons all at once, leading to a high-intensity pulse. Q-switch lasers therefore produce high-intensity pulses at comparatively low repetition rates.

Problem 4.

Explain how CW, pulsed, and Q-switched laser pulses differ from each other.

Solution

Part (a)

CW

"Continuous Wave" lasers output a near-constant intensity beam. The output beam is continuous with respect to time, and the energy output is in the mW to W range.

Part (b)

Pulsed

Pulsed lasers emit all of their energy in the amount of time required for relaxation of the laser medium. The come in single-shot or repetitive pulse mode. They have a high peak power (kW to MW) but low average power.

Part (c)

Q-switched

A q-switched laser is a pulsed laser that builds up a larger population inversion by establishing a low q-factor in the lasing medium (for example by allowing photons to leak out of the lasing medium). This allows a larger population inversion. After some time, the q-factor is switched from low to high which allows the lasing medium to de-excite, emitting a large pulse. The pulse is very energetic, but typically with a lower pulse repetition frequency than a conventional pulsed laser.

Problem 5.

Define the three χ terms which arise from the polarization in nonlinear optics and identify what frequency they oscillate at.

Solution

Nonlinear optical effects arise from especially intense electric fields. At low field intensities, the material is essentially unaffected by the beam electric field. At higher intensities/applied electric fields the material can be polarized and induce nonlinear effects:

$$P = \epsilon_0 \left(\chi^{(1)} E^{(1)} + \chi^{(2)} E^{(2)} + \chi^{(3)} E^{(3)} + ... \right)$$

Part (a)

$\chi^{(1)}$

- applies at low electric fields
- oscillates at incident frequency ω
- light is refracted normally

Part (b)

$\chi^{(2)}$

- only significant at high irradiances
- doubles frequency ($\omega \rightarrow 2\omega$)
- same direction as incident laser, still monochromatic

Part (c)

$\chi^{(3)}$

- triples frequency ($\omega \rightarrow 3\omega$)

Problem 6.

A Nd:YVO4 laser has two output wavelengths in the IR wavelength region, 1064 nm and 1342 nm. We would like to use non-linear optics to create the harmonics of the 1342 nm line. Identify the following wavelengths:

(a) Fundamental,

(b) Second harmonic, and

(c) Third harmonic.

Solution

Part (a)

Fundamental
 1342 nm

Part (b)

Second harmonic
 671 nm

Part (c)

Third harmonic
 447.3 nm

Problem 7.

Describe how a CCD works.

Solution

A voltage (10 V) is applied near the p-doped substrate of an NP junction (insulated from the p-doped silicon by a silicon dioxide layer). When a photon is incident on the N-doped substrate, an electron-hole pair is formed. The hole migrates to the n-doped substrate and the electron migrates towards the positive voltage and is collected there. It can then be migrated out and the signal collected by controlling the voltage applied to different regions of the silicon.

Problem 8.

What is the difference between random and non-random noise and is each one fundamental or non-fundamental?

Solution

Random noise can be fundamental (resulting from particle nature of light and matter) or non-fundamental (due to imperfect components and instrumentation). The sign and magnitude are unpredictable.

Non-random noise is never fundamental. The sign and magnitude of non-random noise are correlated in time.

Problem 9.

Identify the following types of noise as either fundamental (F) or non-fundamental (NF):

(a) Shot noise,

(b) Pink noise,

(c) Interference,

(d) Dark current noise,

(e) Readout noise, and

(f) Impulse noise.

Solution

Noise	**F/NF**
Shot noise	F
Pink noise	NF
Interference	NF
Dark current noise	F
Readout noise	NF
Impulse noise	NF

Problem 10.

Identify and define the 3 types of atomic spectroscopy.

Solution

Part (a)

Absorption– incident light of intensity $I_0(\lambda)$ is sent through the sample and the output light is measured at intensity of $I'(\lambda)$. The ratio $\frac{I'}{I_0}$ gives the absorbance of the sample at each wavelength examined.

Part (b)

Emission– the sample is excited by some process, e.g. heating into a plasma. This excites the electrons orbiting the atoms, which then relax, emitting light characteristic of the atom. These emissions are measured.

Part (c)

Fluorescence– the sample absorbs light of one wavelength and emits at another wavelength.