Solutions

Task 1

a Gas. Ionized Xe, etc. Absorption in other media. 540 eV – $\lambda = \frac{ch}{eE}$

b Frequency doubled NdYAG at 946 nm, Ar ion, Cu- vapor, He-Cd.

c. $E_m = \Gamma_d l_m^2$. $\Gamma(l) = \exp(gl)\Gamma_s$.

$$l_m^2 = \frac{1}{g^2}(\ln\frac{\Gamma_s A}{h\nu})^2$$

Task 2

a.

b. (ii) Transitional metal lasers, Cr:LiSaF, Alexandrite, Ti:Sapphire, etc.

c. $\frac{A_{GaAs}}{A_{GaN}} = \frac{\tau_{GaN}}{\tau_{GaAs}} \propto \frac{n_{GaAs}E_{gGaAs}^3}{n_{GaN}E_{gGaN}^3} = 0.065$

$\tau_{GaAs} = 1.38 ns$ $\tau_{GaN} = 119 ps$

The measured ratio is in fact: 0.106, i. e. $\tau_{GaN} = 146 ps$ which is different from the estimate due to our approximation of equal dipole moment transition elements. Nevertheless the scaling gives rather good approximation.

Task 3.

a. Ro-vibrational. Mid infrared. R and P branches.

b. He Cd, HeNe, CO2 –N2, Er-Yb, Tm-Ho.

c. Saturated gain:

$$g(I) = \frac{g_0}{1 + I / I_s}$$

Wrong is the description is the implicit assumption that small signal gain $g_0 = \sigma_e \Delta N$ does not change. The saturated gain remains constant, though.

Solutions for tasks 4,5,6
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- **Task 4**

  (a) The optical length: $L_e = L + (n-1)l = 58.5$cm; mode spacing $\Delta\nu = \frac{c}{2L_e} = 2.564 \times 10^8$Hz; the number of modes $N = \frac{\Delta\nu_0}{\Delta\nu} = 468$.

  (b) Reason: a FP etalon can have very narrow transmission windows and $\Delta\nu_{\text{fsr}}$ can be comparable to the gain linewidth. A FP etalon can increase cavity length from $L \leq \frac{c}{\Delta\nu_0}$ to $L \leq 2F\frac{c}{\Delta\nu_0}$ for achieving single-longitudinal-mode operation.

  (c) Finesse: $F = \frac{\Delta\nu_{\text{fsr}}}{\Delta\nu_c} = \frac{3\times10^9}{6\times10^7} = 50$.

  Cavity length: From $\Delta\nu_{\text{fsr}} = \frac{c}{2L}$, one has $L = 5$cm.

  FWHM spectral width: from $\Delta\nu_c = \Delta\nu_{\text{fsr}}\frac{1-\sqrt{R_1R_2}}{\pi\sqrt[4]{R_1R_2}}$, one has $R^2 - 2.004R + 1 = 0$, and therefore $R = 93.91\%$.

  If mirror is lossy: Compared to the lossless case, the peak transmittance will then be $\left(\frac{1-T}{1-R}\right)^2 = \left(\frac{1-R-A}{1-R}\right)^2 = 0.5$. One then has the mirror absorption loss $A = 1.78\%$.

- **Task 5**

  (a) The stability condition: $0 < g_1g_2 < 1$,where $g_1 = 1 - \frac{L}{R_1}$; from the left side $g_1g_2 > 0$, one has $0 < L < 1.5m$; from the right side $g_1g_2 < 1$, one has $L > 0.5m$; in summary $0.5m < L < 1.5m$.

(b) Advantage: higher laser power while with reasonably good beam quality (less number of transverse modes).

(c) Pump efficiency: $\eta_p = \frac{P_m}{P_p} = 0.04$; $P_m = 2P_{\text{lamp}} \times 0.04 = 80\text{W}$.

For uniform pumping,

$$P_m = R_p h\nu_{mp} V_a, \tag{1}$$

where $\nu_{mp} = \frac{c}{0.94\times10^{-6}}\text{Hz}$, and $V_a = \pi r^2 l$ (r is beam radius).

In threshold condition, $R_{\text{cp}} = \frac{P_m}{h\nu_{mp}V_a} = 2.964 \times 10^{26}\text{m}^{-3}\text{s}^{-1}$.

(d) ...

- **Task 6**

(a) Necessary parameters: cavity single-pass logarithmic loss $\gamma = -\frac{1}{2}\ln(R_1R_2) + \gamma_i = 0.0609$; cavity photon life time $\tau_c = \frac{L_e}{\gamma c} = 5.15\text{ns}$.

Critical population inversion: $N_c = \frac{\gamma}{\sigma l} = 4.35 \times 10^{23}\text{m}^{-3}$.

Critical pump rate: $R_{\text{cp}} = \frac{\gamma}{\sigma l \tau} = 1.89 \times 10^{27}\text{m}^{-3}\text{s}^{-1}$.

Photon number inside cavity: $\phi_0 = V_a\tau_c(R_p - R_{cp}) = \pi r_b^2 l\tau_c R_{cp} = 3.44 \times 10^9$.

Output power: $P_{out} = \phi_0\frac{\gamma_2 c}{2L_e}h\nu = 31.7\text{mW}$.

(b) Modulation frqeuency is inverse of the round trip time, or the longitudinal mode frequency separation $\nu_m = \Delta\nu = \frac{c}{2L_e} = 256.4\text{MHz}$; pulse separation is the round trip time $\tau_p = \frac{2L_e}{c} = 3.9\text{ns}$; pulse duration (homogeneously broadened case) $\Delta\tau_p = \frac{0.45}{\sqrt{\Delta\nu\Delta\nu_0}} = 81.1\text{ps}$.

(c) Mode locking is achieved by the lensing effect (through nonlinear Kerr effect) incurred to the beam in the Ti:sapphire plate, together with the aperture.

Remarks:

- Calculator is needed.
- Planck constant should be given: $h = 6.626 \times 10^{-34} \mathrm{m}^2\mathrm{kgs}^{-1}$.