Workshop Problem # 2 PH2502: Lasers

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The WLC (Worcester Laser Company) has a new division, which makes fiber lasers and fiber amplifiers. Your company has received an order from a customer for a compact, low power fiber laser source at a wavelength around 1 μm, and a student group from a local college has come up with a design. It is your responsibility to check the design to make sure that it will meet specs.

The fiber laser is required to have a threshold pump power less than 100 μW, and should yield an output power at least 150 μW when pumped at 800 nm with 425 μW of power. The student group chose a Nd:glass fiber laser, doped with 0.2 % Nd_2O_3 in phosphate glass, pumped with 800 nm light from a diode laser. At this doping level, the Nd ion concentration is 1.7 x 10^{19} cm^{-3}. From reference materials in the library the student group found that the lasing wavelength is 1054 nm, the excited state fluorescence lifetime is 300 μs, the peak stimulated emission cross section is 4 x 10^{-20} cm^2, the index of refraction of the glass is 1.54, and the effective emission linewidth is 180 cm^{-1}. In checking with optical fiber suppliers, they found that a typical fiber attenuation loss at 1054 nm is 10 dB/km.

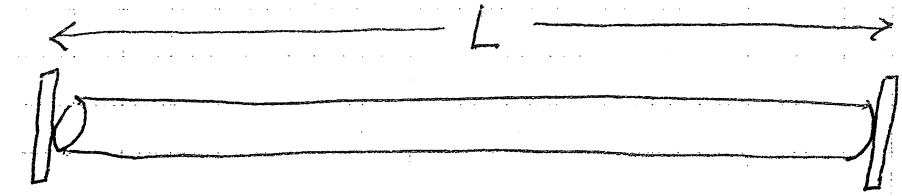
With this information at hand, the student group came up with the following design parameters:

mirror reflectivities 1.00 and 0.97
fiber length 2.5 m
fiber core radius 2.5 μm

Using the above parameters, check the students' design by determining:

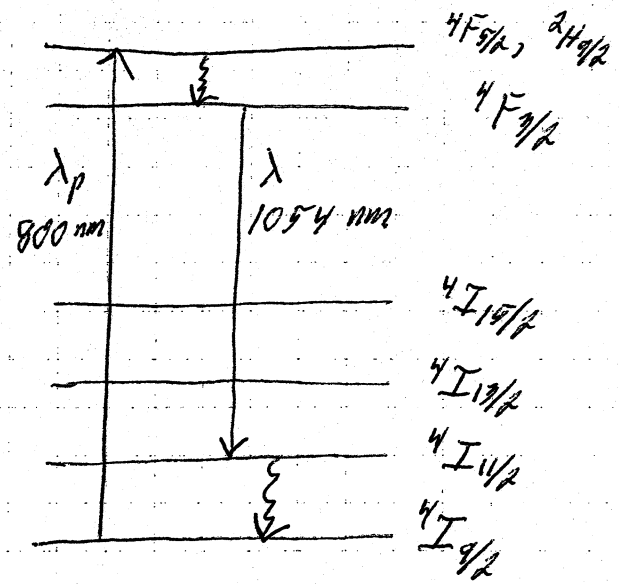
a) the threshold gain coefficient
b) the fraction of Nd ions that are excited at threshold
c) the threshold pump power
d) the slope efficiency
e) the ouput power pumping at 5 times threshold
f) the optimum mirror transmission when pumping at the pump power of part e. How does this compare with the mirror transmission specified by the students?

Nd: glass Fiber Laser



data: 0.2 % Nd_2O_3 in phosphate glass

$N_0 = 1.7 \cdot 10^{19}\ cm^{-3}$
$\lambda = 1.054\ \mu m$ (lasing)
$\lambda_p = 800\ nm$ (pump)
$\tau_2 = 300\ \mu s$
$\sigma = 4 \cdot 10^{-20}\ cm^2$ (emission cross section)
$n = 1.54$
$\Delta\nu = 180\ cm^{-1}$ (linewidth)
$a = 2.5\ \mu m$ (core radius)
$\alpha = 10\ dB/km = 2.3 \cdot 10^{-3}\ m^{-1}$
$L = 2.5\ m$



Nd^{3+}

a) $\gamma_{th} = \alpha + \frac{1}{2L}\ln\left(\frac{1}{R_1 R_2}\right) = 2.3\cdot10^{-3}\,m^{-1} + \frac{1}{2(2.5)}\ln\left(\frac{1}{0.97}\right)$

$\gamma_{th} = \boxed{8.39\cdot10^{-3}\ m^{-1}}$

b) $N_{th} = \frac{\gamma_{th}}{\sigma} = \frac{8.39\cdot10^{-3}\,m^{-1}}{4\cdot10^{-24}\,m^2} = 2.1\cdot10^{21}\,m^{-3}$

$N_{th} = 2.1\cdot10^{15}\,cm^{-3}$

Fraction excited $= \frac{2.1\cdot10^{15}}{1.7\cdot10^{19}} = \boxed{1.24\cdot10^{-4}}$

c) $R_{th} = \frac{N_{th}}{\tau_2} = \frac{2.1\cdot10^{15}\,cm^{-3}}{300\cdot10^{-6}\,s} = 7.0\cdot10^{18}\,\frac{1}{cm^3\cdot s}$

$h\nu_p = \frac{hc}{\lambda_p} = \frac{(6.63\cdot10^{-34})(3\cdot10^8)}{800\cdot10^{-9}} = 2.48\cdot10^{-19}\,J$

$P_{th} = R_{th}\,V\,h\nu_p$

$P_{th} = \left(7\cdot10^{18}\,\frac{1}{cm^3\cdot s}\right)(250\,cm)\,\pi\left(2.5\cdot10^{-4}\,cm\right)^2\left(2.48\cdot10^{-19}\,J\right)$

$P_{th} = 8.54\cdot10^{-5}\,W = \boxed{85.4\ \mu W}$

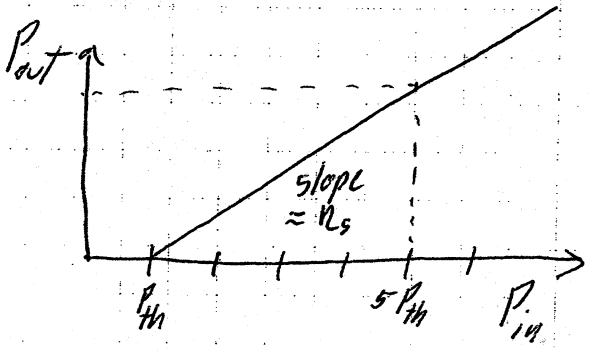
d) $\eta_s = \frac{T}{\delta+T}\,\frac{h\nu}{h\nu_p} = \frac{T}{2\alpha L+T}\left(\frac{\lambda_p}{\lambda}\right)$

$\eta_s = \frac{0.03}{2(.0023)(2.5)+0.03}\left(\frac{800}{1054}\right) = \boxed{0.549}$

e) $P_{out} = \eta_s(P_{in} - P_{th})$

$= (.549)(5-1)(85.4\,\mu W)$

$P_{out} = \boxed{187\ \mu W}$



f) $\gamma_0 2L = 5(\delta + T)$ unsaturated gain is 5 times threshold

$$T_{opt} = \sqrt{5(\delta+T)\delta} - \delta$$

$$\delta = \alpha(2L) = (2.3\cdot10^{-3}\,m^{-1})(5\,m) = 0.0115$$

$$T \approx 1 - R_2 = 0.030$$

$$\therefore\quad T_{opt} = \sqrt{5(.0415)(.0115)} - .0115$$

$$T_{opt} = \boxed{0.0373}$$