1

OEC - Assignment 3

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1. Amplifier Gain of Semiconductor Optical Amplifier.

Single Gain, or amplifier Gain, $G = \frac{P_{si\,out}}{P_{si\,in}}$ —— (1)

Single pass gain in active medium of SOA is

$$G = e^{\Gamma(g_m - \bar{\alpha})L} \equiv e^{g(z)L} \quad \text{—— (2)}$$

where Γ is optical confinement factor of cavity and g_m is material gain, $\bar{\alpha}$ is effect absorption, L is amplifier length.

An expression for G as a func of i/p power can be obtained by analysing gain parameter, g(z)

$$g(z) = \frac{g_0}{1 + \frac{P_s(z)}{P_{amp,sat}}} \quad \text{—— (3)}$$

where g_0 is unsaturated medium gain (unit length), $P_s(z)$ is internal sig power at 'z', and $P_{amp,sat}$ is amplifier sat. Power.

Incremental increase in power, $dP = g(z) \cdot P_s(z)\,dz$ —— (4)

Sub. (4) in (3),

$$g_0(z)\,dz = \left(\frac{1}{P_s(z)} + \frac{1}{P_{amp,sat}}\right) dP$$

Integrating,

$$\int_0^L g_0\,dz = \int_{P_{s,in}}^{P_{s,out}} \left(\frac{1}{P_s(z)} + \frac{1}{P_{amp,sat}}\right) dP \quad \text{—— (5)}$$

In absence of light, single pass gain, $G = e^{g_0 L}$.

$$\therefore \boxed{G = 1 + \frac{P_{amp,Sat}}{P_{s,in}} \ln\left(\frac{G_0}{G}\right)}$$

Date / /20

2. <u>External pumping mechanism of SOA.</u>

* It is the pumping method used to create population inversion in SOAs.
* Similar in operation to laser diodes.
* Sum of injection, stimulated emissions and spontaneous recombination rate gives eqn for carrier density $n(t)$.

$$\boxed{\frac{\partial(n(t))}{\partial t} = R_p(t) - R_{st}(t) - \frac{n(t)}{\tau_r}}$$

where $R_p(t) = \frac{J(t)}{qd}$,

*

and $J(t)$ is current density of external pumping into an active layer of thickness d, τ_r is time constant

* $\boxed{R_{st}(t) = \Gamma a v_g (n - n_{th}) N_{ph} = g v_g N_{ph},}$ is net stimulated emission rate.

* Since for a given optical amplifier of Power P_s with photons of energy $h\nu$ and group velocity v_g.

$$\boxed{N_{ph} = \frac{P_s}{v_g (h\nu)(wd)}}$$

*

(2)

3. $\lambda_p = 980\,nm$, $P_P = 30\,mW$, $G = 20\,dB$,
$\lambda_s' = 1550\,nm$

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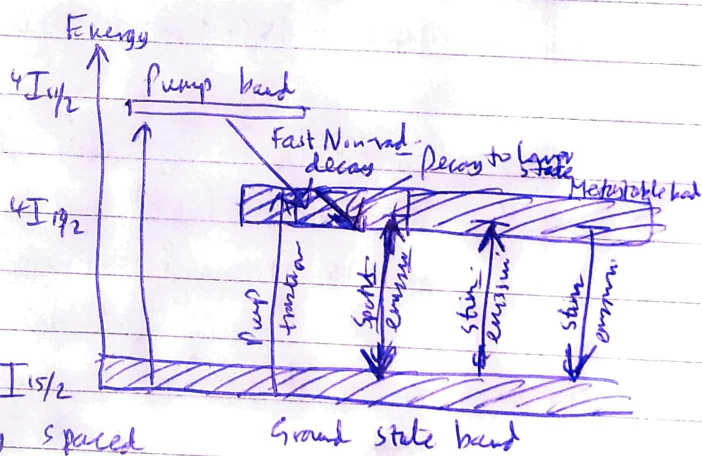
$$P_{s,in} = \frac{(\lambda_p/\lambda_s)P_{p,in}}{G-1} \le \frac{\left(\frac{980}{1550}\right)30\times10^{-3}}{20-1} = 190\,\mu W$$

$$P_{s,out} = P_{s,in} + \frac{\lambda_p}{\lambda_s}P_{p,in}$$
$$= (190 + 3610)\times10^{-6}$$
$$= 3800\,\mu W$$
$$= 3.8\,mW$$

4. * Erbium atoms are actually in Er^{3+} state in silica.
* Two principle states are metastable ($^4I_{13/2}$) and pump level ($^4I_{11/2}$).
* Metastable, pump and ground state are actually closely spaced energy levels that form manifold due to "stark splitting".



* Metastable ($^4I_{13/2}$) is seperated from ground ($^4I_{13/2}$) by energy gap ranging from 0.814 eV at bottom of metastable band, to 0.841 eV at top of band.
* Energy band for pump level exists at 1.27 eV seperation.
* Pump band is narrow, so must be accurate to within a few nanometres.
* Gap between top of $^4I_{15/2}$ and bottom of metastable state is around 0.775 eV (1600 nm)
* In normal operation, a pump laser with 980 nm photons

Date / /20

is used to excite ions from ground state to pump level.

* When electrons ~~the~~ decay, they fall to metastable state, where they tend to occupy lower end of the band.
* Some ions ~~can~~ decay back to ground state, emitting energy in the process in a process called spontaneous emmissions.
* Two more types of transition occur when a flux of signal photons have energy corresponding to levels, namely stimulated absorption leading to jump from ground to metastable state, and stimulated emmissions from metastable back to ground.
* The widths of metastable and ground state levels allow high levels of stimulated emmission in 1530 – 1560nm range.

5. Semiconductor Optical Amplifiers

* Two main types are the resonant Fabry-Perot Amp (FPA) and non-resonant traveling-wave Amp. (TWA).
* FPA is easy to fabricate, but optical signal gain is sensitive to amp. temp. and i/p opt. freq..
* Structure of FPA consists of two cleaved facets of a semiconductor crystal acting as partially reflective mirrors that form Fabry-Perot Cavity.
* A signal which enters is reflected back and forth till it is emitted at higher intensity.
* Structure of TWA is similar to FPA, but coated with antireflective coating so no internal reflection takes place; thus light amplified only once.
* TWA have 3dB greater BW, hence are preferred.
* TWA used as amp in 1300nm window, wavelength converters in 1550nm window.
* In general, SOA ~~are~~ usually refers to a TWA.

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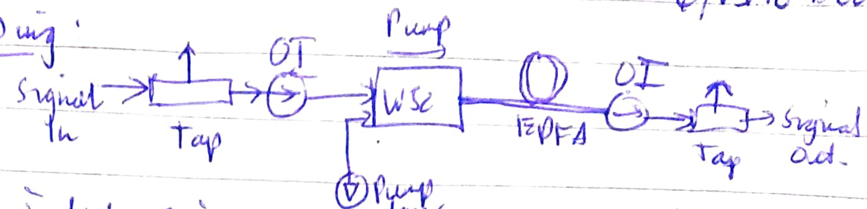
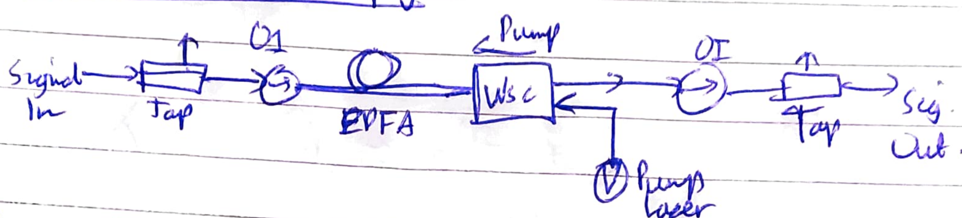
6. Configurations of EDFA.

i) Codirectional Pumping:



* Pump light injected in same direction as flow
* Higher gains.

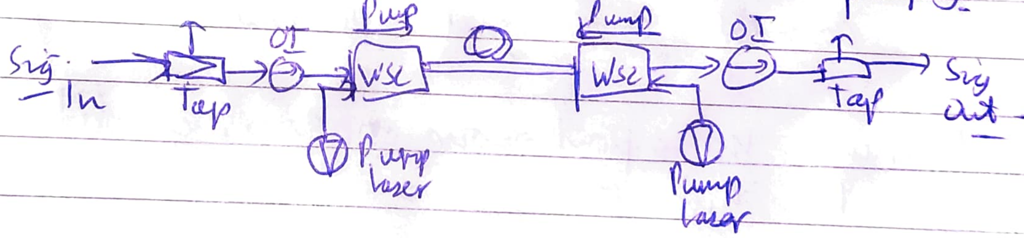
ii) Counterdirectional Pumping:



* Pump light injected opposite to flow direction.
* Better Noise performance.

iii) Dual pumping:

* Provides +35 dB gain, as opposed to +17 dB with single pump.
* Benefits of both co- and counter pumping.



7. Applications of Optical Amps:

i) Power Amplifiers: Used to boost output at transmission end

ii) In-Line Amps: Used to restore power levels that decrease due to cable attenuation during long distance transmissions.

iii) Pre-amplifiers: Used to improve detector sensitivity.

iv) Multi-Channel Ops: Allows multichannel ops if BW of multi-channel signal is lower than amplifier B/w.

v) <u>In-line Amp. Gain Control</u>: Used to keep power levels constant and minimise fluctuations.

8. Power Conversion Efficiency (PCE) and Gain of EDFA.

* Power Conversion Efficiency is defined as,

$$\boxed{PCE = \frac{P_{s,out} - P_{s,in}}{P_{p,in}} \approx \frac{P_{s,out}}{P_{p,in}} \leq \frac{\lambda_p}{\lambda_s} \leq 1}$$

* Max theoretical value of PCE is λ_p/λ_s.
* In terms of Quantum conversion efficiency, QCE

$$PCE = QCE \cdot \frac{\lambda_p}{\lambda_s}$$

The max value of QCE is 1, when all pump photons are converted to signal photons.

* Assuming no spontaneous emissions, amplifier gain can be given as,

$$\boxed{G = \frac{P_{s,out}}{P_{s,in}} \leq 1 + \frac{\lambda_p P_{p,in}}{\lambda_s P_{s,in}}}$$

* To acheive specific max gain 'G', input signal power cannot exceed value given by

$$P_{s,in} \leq \frac{(\lambda_p/\lambda_s) P_{p,in}}{G-1}$$

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9. $w = 3\mu m,\ d = 0.3\mu m,\ L = 500\,\mu m.$

$\Gamma = 0.3,\ \tau_r = 1ns,\ a = 2\times10^{-20} m^2$

$n_{th} = 1\times10^{24} m^{-3}$

$I_i = 100 mA.$

$g_0 = ?,$

ii) $\cancel{g_0 = \Gamma a \tau_r \left(\frac{J}{qd} - \frac{n_{th}}{\tau_r}\right)}$

$\cancel{= 0.3\times(2\times10^{-20}\times1\times10^{-9}\times(1.39}$

i) Pumping rate,

$$R_p = \frac{J}{qd} = \frac{I}{qdwL}$$

$$= \frac{0.1}{(1.6\times10^{-19})\times0.3\times10^{-6}\times3\times10^{-6}\times500\times10^{-6}}$$

$$\simeq 1.39\times10^{33} \text{ electrons}/m^3/s$$

ii) Zero signal gain, $g_0 = \Gamma.a.\tau_r\left(\frac{J}{qd} - \frac{n_{th}}{\tau_r}\right)$

$$= 0.3\times2\times10^{-20}\times1\times10^{-9}\times\left(1.39\times10^{33} - \frac{1.0\times10^{24}}{1\times10^{-9}}\right)$$

$$= 2340\ m^{-1}$$

$$= 23.4\ cm^{-1}$$