ELEC 5511: Optical Communication Systems

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Tutorial 2: Lasers

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1. An injection laser has a GaAs active region with a bandgap energy 2.3x 10^{-19} J. Estimate the wavelength of optical emission from the device and determine the linewidth in Hz when the measured spectral width is 0.1 nm.

$$E_g = hf = h\frac{c}{\lambda} \longrightarrow \lambda = \frac{hc}{E_g} = \frac{6.626\times10^{-34}\times3\times10^{8}}{2.3\times10^{-19}}$$ **= 0.864 *μm***

(E_g = 2.3x 10^{-19}; c = 3 x 10^{8}; h = 6.626 x 10^{-34})

$$\Delta\lambda = \lambda\frac{\Delta f}{f} = \frac{\lambda^2}{c}\Delta f \longrightarrow \Delta f = \frac{c}{\lambda^2}\Delta\lambda = \frac{3\times10^{8}\times0.1\times10^{-9}}{\left(0.864\times10^{-6}\right)^2}$$

(λ^2 = (0.864 x 10^{-6})^2; $\Delta\lambda$ = 0.1x 10^{-9}; c = 3 x 10^{8})

= 40 *GHz*

Tutorial 2: Lasers

2. A semiconductor laser can attain a maximum optical gain of g_{max} = 2000 m^{-1}. The attenuation to light propagation in the semiconductor material, without amplification, is 600 m^{-1}.

(i) If the reflection coefficients of the cavity reflectors are R1 = R2 = 0.35, what is the minimum value for the length of the cavity that must be used for the laser?

Required Gain

$$g > \alpha + \frac{1}{2L}\ln\left(\frac{1}{R_1 R_2}\right)$$

2000 m^{-1}

$$g_{max} = \alpha + \frac{1}{2L_{min}}\ln\left(\frac{1}{R_1 R_2}\right) \longrightarrow L_{min} = \frac{1}{2(g_{max} - \alpha)}\ln\left(\frac{1}{R_1 R_2}\right)$$

600 m^{-1}

0.35

= 750 µm

Tutorial 2: Lasers

(ii) If the cavity length is required to be L = 475 µm and R1 = R2 = R, what is the minimum value for the reflector value R?

2000 m^{-1}

$$g_{max} = \alpha + \frac{1}{2L}\ln\left(\frac{1}{[R_{min}]^2}\right)$$

600 m^{-1}

475µm

$$2L(g_{max} - \alpha) = \ln\left(\frac{1}{[R_{min}]^2}\right) \xrightarrow{e} e^{2L(g_{max}-\alpha)} = \frac{1}{[R_{min}]^2}$$

$$R_{min} = \sqrt{\frac{1}{e^{2L(g_{max}-\alpha)}}} = \sqrt{\frac{1}{e^{2\times 475\times 10^{-6}\times(2000-600)}}}$$

= 0.514

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3. The longitudinal modes of a semiconductor laser emitting at a wavelength of 1.1 μm are separated in wavelength by 0.8 nm. The refractive index of the semiconductor is n = 3.6.

(i) Determine the length of the optical cavity.

Wavelength Separation between adjacent modes

0.8 x 10^{-9} → $\Delta\lambda$; $(1.1 \times 10^{-6})^2$ → λ^2; 3.6 → n

$$\Delta\lambda = \frac{\lambda^2}{2 \times n \times L} \rightarrow L = \frac{\lambda^2}{2 \times n \times \Delta\lambda} = \frac{\left(1.1 \times 10^{-6}\right)^2}{2 \times 3.6 \times 0.8 \times 10^{-9}}$$

= 210 μm

Tutorial 2: Lasers

(ii) If the loss coefficient of the semiconductor is 1000 dB/m, what is the minimum gain coefficient, in dB/m, required for lasing.

Minimum gain (assume R_1=R_2=R)

$$g_{\min} = \alpha + \frac{1}{2L}\ln\left(\frac{1}{R^2}\right)$$

$$\alpha_{[m^{-1}]} = \frac{A_{[dB/m]}}{4.34} = \frac{1000}{4.34} = 230.4m^{-1}$$

$$g_{\min} = 230.4 + \frac{1}{2(210\times10^{-6})}\ln\left(\frac{1}{(0.319)^2}\right)$$

$$= 5664m^{-1}$$

$$G_{[dB/m]} = 4.34\times5664$$

= 24581.76 dB/m

Note:

$n_2 = 3.6$

$n_1 = n_{air} = 1$

$R = \left(\frac{n_2 - n_1}{n_2 + n_1}\right)^2 = \left(\frac{2.6}{4.6}\right)^2 = 0.319$

$G_{[dB/m]} = 4.34\, g_{[m^{-1}]}$

$A_{[dB/m]} = 4.34\, \alpha_{[m^{-1}]}$

Tutorial 2: Lasers

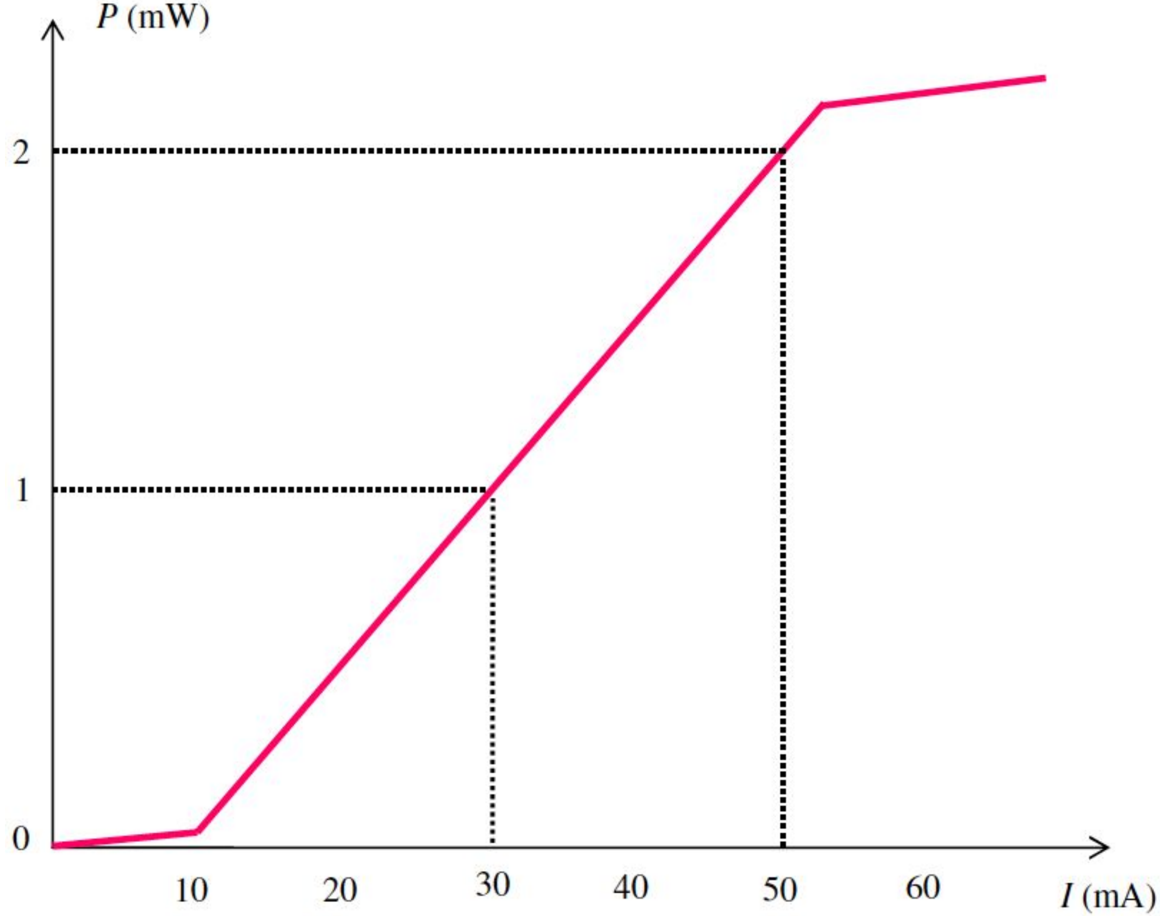
4. Semiconductor lasers and light emitted diodes are commonly found in optical communication systems. Which of these optical sources are preferred for long distance communication systems? Why?

- LEDs properties:
  - Wide spectral width → **High dispersion**
  - Low light intensity (High divergence)
  - Low Coupling efficiency → **Low output optical powers, High loss**
- Semiconductor lasers properties:
  - Narrow line widths → **Less dispersion problem than LEDs**
  - High light intensity
  - High Coupling efficiency → **Higher output optical powers, lower losses than LEDs**

Thus SC lasers are preferred for long distance communication

Tutorial 2: Lasers

5. The light-current characteristic of the semiconductor laser is shown below. Assume that the laser is biased at 25 mA and that the frequency of the modulating signal is within the laser bandwidth.



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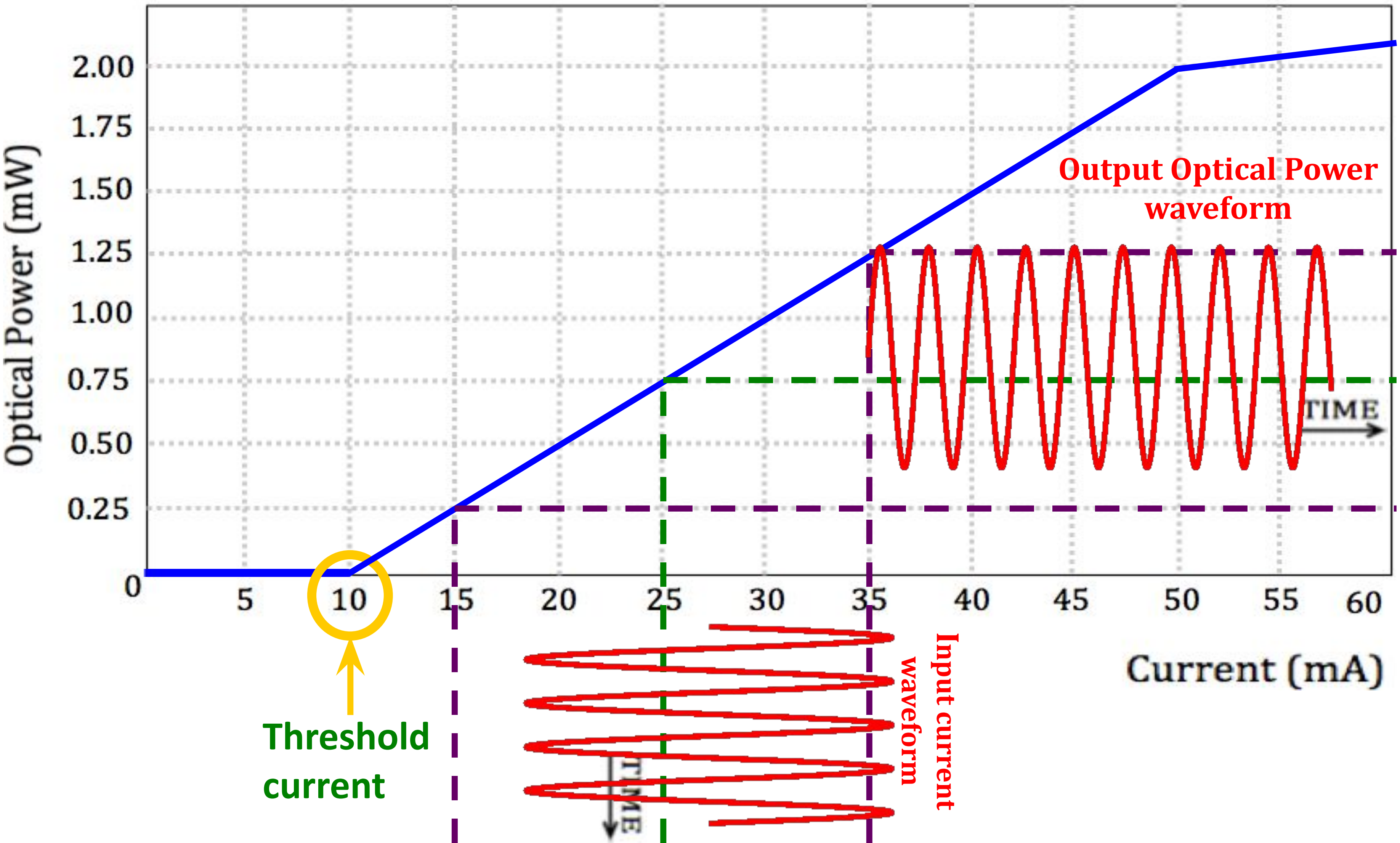
(i) Fore peak value current of 10 mA (a) Plot the input current and output power as a function of time



Tutorial 2: Lasers

b) Does the laser behave as a linear device for this modulating current? Why?

- The laser behaves as a linear device for this modulating current because the modulating current's amplitude range fall entirely in the linear region.

- i.e. not below the threshold current or in the saturation region

0 - 10mA → non-linear region
Spontaneous emission

10 - 50mA → linear region

50 - 60mA → Saturation region
(Non-linear)

- **The output optical power is pure sinusoid of the same frequency**

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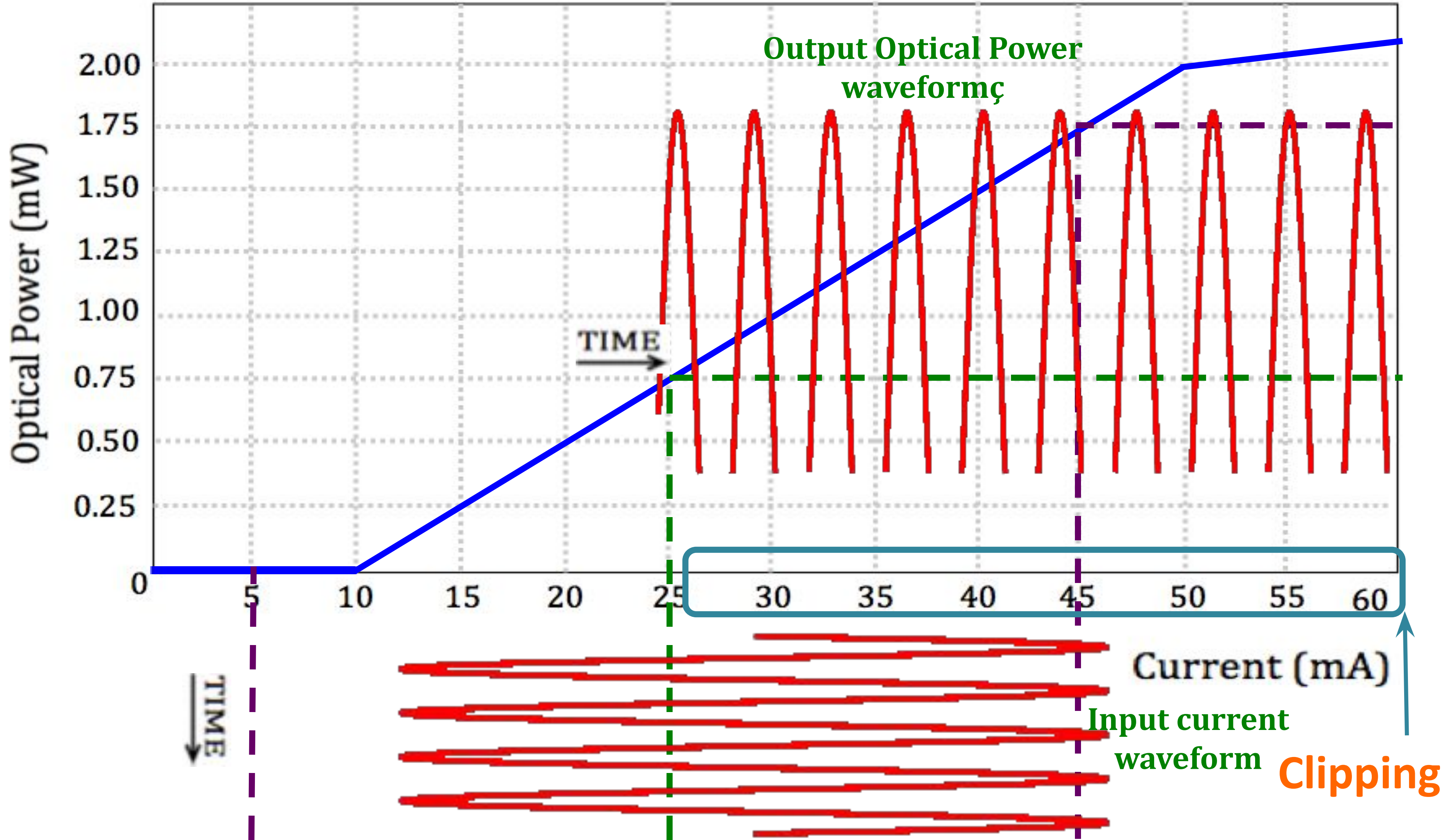
(ii) Fore peak value current of 20 mA (a) Plot the input current and output power as a function of time



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b) Does the laser behave as a linear device for this modulating current? Why?

 The laser is not linear for this input current

 The output power is clipped when $I < I_{th}$

 not a replica of the input sinusoid current