LASER OUTPUT POWER

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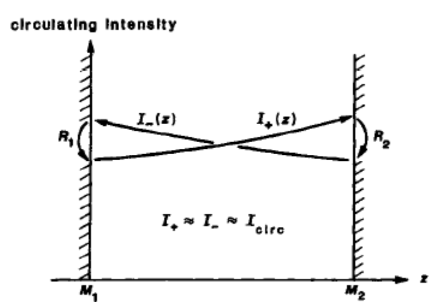
Lightly Coupled Laser Oscillator

A laser oscillator in which the reflectivities of the laser end mirrors are not too much less than unity.



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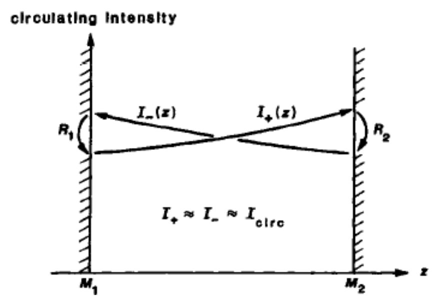
Intensity Growth

The growth of two oppositely traveling waves $I_+(z)$ and $I_-(z)$ inside the cavity:

$$\frac{dI_+(z)}{dz} = \left[2\alpha_m(z) - 2\alpha_0\right] I_+(z)$$

$$\frac{dI_-(z)}{dz} = -\left[2\alpha_m(z) - 2\alpha_0\right] I_-(z)$$



Saturated gain coefficient:

$$2\alpha_m(z) = \frac{2\alpha_{m0}}{1 + [I_+(z) + I_-(z)] / I_{\text{sat}}}$$

The interference between the right- and left-traveling waves is neglected.

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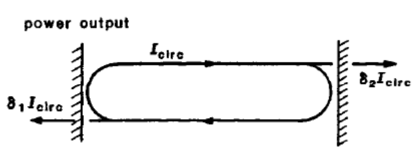
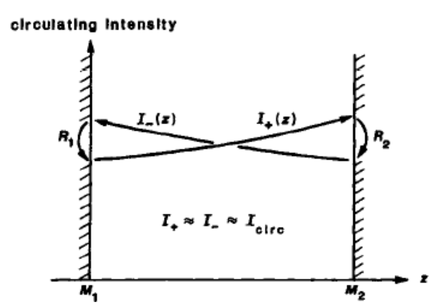
Small Output Coupling

$$R_1 = R_2 \approx 1$$

$$I_+(z) \approx I_-(z) \approx I_{\text{circ}}$$

$$2\alpha_m \approx \frac{2\alpha_{m0}}{1 + 2I_{\text{circ}} / I_{\text{sat}}}$$





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Steady-State Oscillation

Condition:

$$2\alpha_m p_m \approx \frac{2\alpha_{m0} p_m}{1+2I_{\text{circ}}/I_{\text{sat}}} = 2\alpha_0 p + \ln\left(\frac{1}{R_1 R_2}\right) = \delta_0 + \delta_1 + \delta_2$$

The circulating intensity that must build up in order to saturate the gain down to where it just equals the total cavity losses:

$$I_{\text{circ}} = \left[\frac{2\alpha_{m0} p_m}{\delta_0 + \delta_1 + \delta_2} - 1\right] \times \frac{I_{\text{sat}}}{2}$$

$$I_{\text{circ}} = \left[r - 1\right] \times \frac{I_{\text{sat}}}{2}$$

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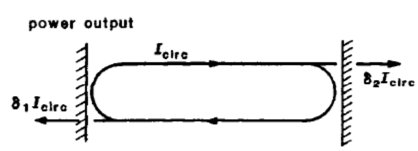
Power Output

For a lightly coupled laser cavity:

$$T_1 = 1 - R_1 \approx \delta_1,\ T_2 = 1 - R_2 \approx \delta_2$$

$$I_{\text{out}} = \left(\delta_1 + \delta_2\right) \times I_{\text{circ}} = \delta_e \times I_{\text{circ}}$$

δ_e: External cavity coupling



$$I_{\text{out}} = \delta_e \left[\frac{2\alpha_{m0} p_m}{\delta_0 + \delta_e} - 1\right] \times \frac{I_{\text{sat}}}{2}$$

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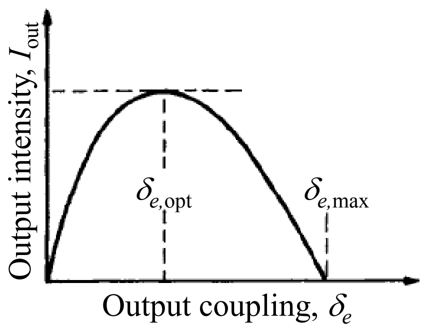
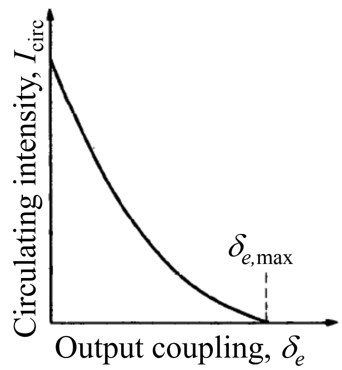
Output Coupling

$$I_{\text{out}} = \delta_e \left[\frac{2\alpha_{m0} p_m}{\delta_0 + \delta_e} - 1 \right] \times \frac{I_{\text{sat}}}{2}$$

$$I_{\text{circ}} = \left[\frac{2\alpha_{m0} p_m}{\delta_0 + \delta_e} - 1 \right] \times \frac{I_{\text{sat}}}{2}$$





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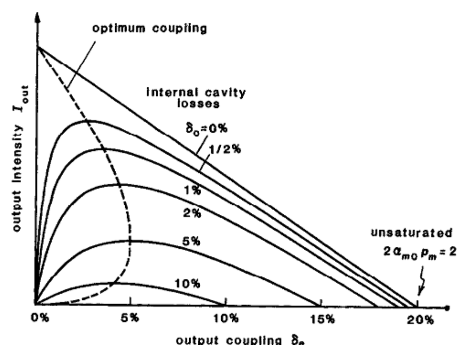
Optimum Output

$$\frac{dI_{\text{out}}}{d\delta_e} = \frac{d}{\delta_e} \left\{ \delta_e \left[\frac{2\alpha_{m0} p_m}{\delta_0 + \delta_e} - 1 \right] \times \frac{I_{\text{sat}}}{2} \right\} = 0$$

$$\delta_{e,\text{opt}} = \sqrt{2\alpha_{m0} p_m \delta_0} - \delta_0$$

$$I_{\text{out,opt}} = \left[\sqrt{2\alpha_{m0} p_m} - \sqrt{\delta_0} \right]^2 \times \frac{I_{\text{sat}}}{2}$$



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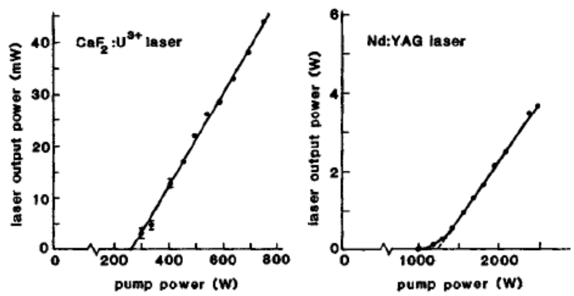
Power Output Vs. Pumping

$$r = \frac{2\alpha_{m0} p_m}{\delta_0 + \delta_e} = \frac{R_p}{R_{p,\mathrm{th}}} = \frac{\text{pumping power}}{\text{threshold pump power}}$$

$$I_{\mathrm{out}} = \frac{(r-1)\delta_e I_{\mathrm{sat}}}{2} = \left[\frac{R_p}{R_{p,\mathrm{th}}} - 1\right] \times \frac{\delta_e I_{\mathrm{sat}}}{2}$$



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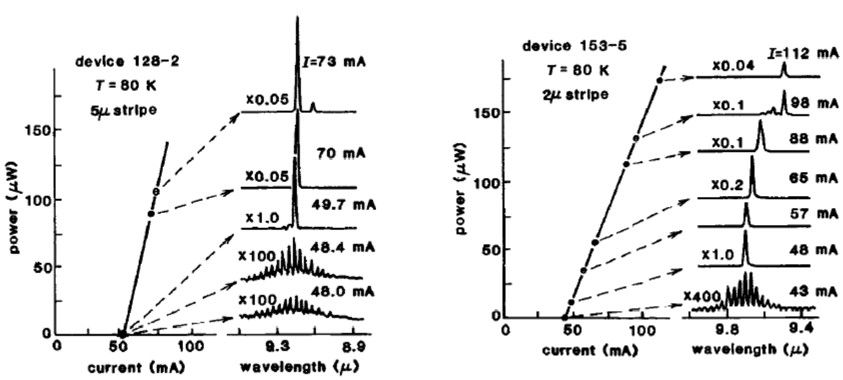
Power Output & Output Spectra



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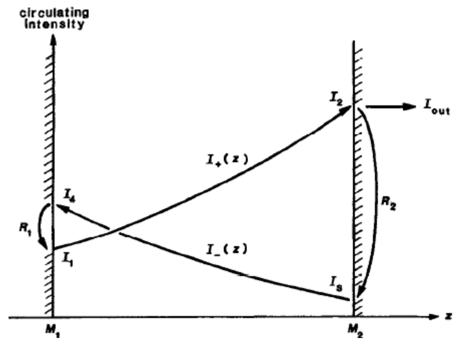
Large Output Coupling

- An analysis with arbitrarily large round-trip gain and output coupling was developed by W. W. Rigrod, and is often referred to as the “Rigrod Analysis.”
- Large output coupling.



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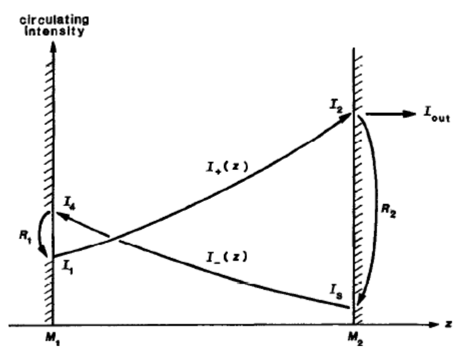
Intensity Growth

Assume no distributed loss, i.e., $2\alpha_0 p = 0$.

$$\frac{dI_+(z)}{dz} = +2\alpha_m(z)I_+(z)$$
$$\frac{dI_-(z)}{dz} = -2\alpha_m(z)I_-(z)$$

Let us assume that $I_+(z)$ and $I_-(z)$ are normalized to the saturation intensity I_{sat}.

$$\alpha_m(z) = \frac{\alpha_{m0}}{1 + I_+(z) + I_-(z)}$$



The interference between the right- and left-traveling waves is neglected.

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Intensity Growth

$$I_-(z)\frac{dI_+(z)}{dz} = +2\alpha_m(z)I_+(z)I_-(z)$$

$$I_+(z)\frac{dI_-(z)}{dz} = -2\alpha_m(z)I_-(z)I_+(z)$$

$$\frac{d}{dz}\left[I_+(z)I_-(z)\right] = -2\alpha_m I_+ I_- + 2\alpha_m I_+ I_- = 0$$

$$I_+(z)I_-(z) = \text{constant} = C$$

$$\frac{dI_+(z)}{dz} = \frac{2\alpha_{m0}I_+(z)}{1+I_+(z)+C/I_+(z)}$$

Integrating: $\int_{I_1}^{I_2}\left(1+\frac{1}{I_+}+\frac{C}{I_+^2}\right)dI_+ = 2\alpha_{m0}\int_0^L dz$

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Intensity Growth

For $I_+(z)$: $2\alpha_{m0}L = \ln\left(\frac{I_2}{I_1}\right) + I_2 - I_1 - C\left(\frac{1}{I_2}-\frac{1}{I_1}\right)$

For $I_-(z)$: $2\alpha_{m0}L = \ln\left(\frac{I_4}{I_2}\right) + I_4 - I_3 - C\left(\frac{1}{I_4}-\frac{1}{I_3}\right)$

Mirror power reflectivities:

$$I_1 = R_1 I_4, \qquad I_3 = R_2 I_2$$

$$I_2 = \frac{1}{(1+r_2/r_1)(1-r_1r_2)}\left[2\alpha_{m0}L - \ln\left(\frac{1}{r_1r_2}\right)\right]$$

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Power Output

$$I_2 = \frac{1}{(1+r_2/r_1)(1-r_1r_2)}\left[2\alpha_{m0}L - \ln\left(\frac{1}{r_1r_2}\right)\right]$$

$$I_{out} = T_2 I_2 = \frac{T_2 I_{sat}}{(1+r_2/r_1)(1-r_1r_2)}\left[\ln G_0 - \ln\left(\frac{1}{r_1r_2}\right)\right]$$

Maximum intensity that can be extracted:

$$I_{avail} = 2\alpha_{m0}L_m I_{sat} = (\ln G_0) I_{sat}$$

Power extraction efficiency:

$$\eta = \frac{I_{out}}{I_{avail}} = \frac{T_2}{(1+r_2/r_1)(1-r_1r_2)}\left[1 + \frac{\ln r_1r_2}{\ln G_0}\right]$$

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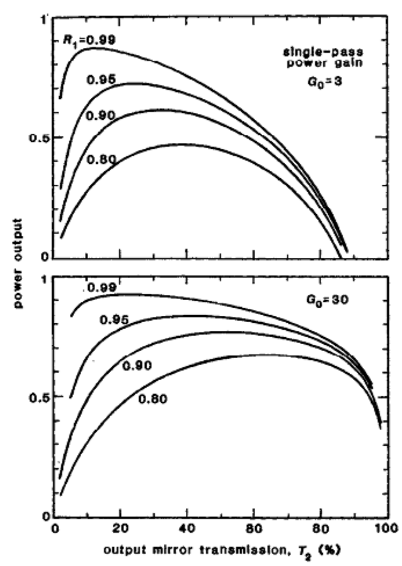
Power Output

- η is not much less than 1 for large G_0 and R_1.
- Output coupling level in a high-gain laser is not a critical factor.
- $R_1 \rightarrow 100\%$ and $T_2 \leq 50\%$ for high output power.



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