Laser & Optoelectronics Techniques Engineering

Al-Farahidi University

Laser Principles

First year

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Lecture 8

- **Thresholds for Lasing**

The laser threshold, in essence, is the lowest excitation level at which a laser begins to operate in its standard, steady-state mode. Below this level, lasing action does not occur, while above it, a well-defined beam of light is emitted and the laser is said to be lasing.

The lasing threshold is reached when the optical gain of the laser medium is exactly balanced by the sum of all the losses experienced by light in one round trip of the laser's optical cavity. This can be expressed, assuming steady-state operation, as:

$$R_1 R_2 \exp(2 g_{\text{threshold}}\, l) \exp(-2\alpha l) = 1. \qquad (1)$$

Here R_1 and R_2 are the mirror (power) reflectivities, l is the length of the gain medium, $exp(2g_{threshold}\ l)$ is the round-trip threshold power gain, and $exp(-2\alpha l)$ is the round trip power loss. Note that $\alpha > 0$. This equation separates the losses in a laser into localised losses due to the mirrors, over which the experimenter has control, and distributed losses such as absorption and scattering.

The optical loss is nearly constant for any particular laser ($\alpha = \alpha_o$), especially close to threshold. Under this assumption the threshold condition can be rearranged as:

$$g_{threshold} = \alpha + \frac{1}{2l} ln \frac{1}{R_1 R_2} \qquad (2)$$

Since $R_1R_2<1$, both terms on the right side are positive, hence both terms increase the required threshold gain parameter. This means that minimizing the gain parameter $g_{threshold}$ requires low distributed losses and high reflectivity mirrors.

- **Calculating Threshold Gain**

As mentioned previously, when the laser is operating at steady-state conditions (i.e., constant optical power output), the net gain in the laser must be 1. If the net gain were greater than 1, the output power would increase. Net gains below 1 cause the output power to drop until the laser ceases to operate. So consider, then, a round trip by a stream of photons in the tube (Figure (1)). The power after the round trip must equal the power before the round trip. Sure, the photon stream gains energy (through laser gain), but just as much power as is gained is lost through absorption in the medium, in addition to the portion extracted as the output beam.

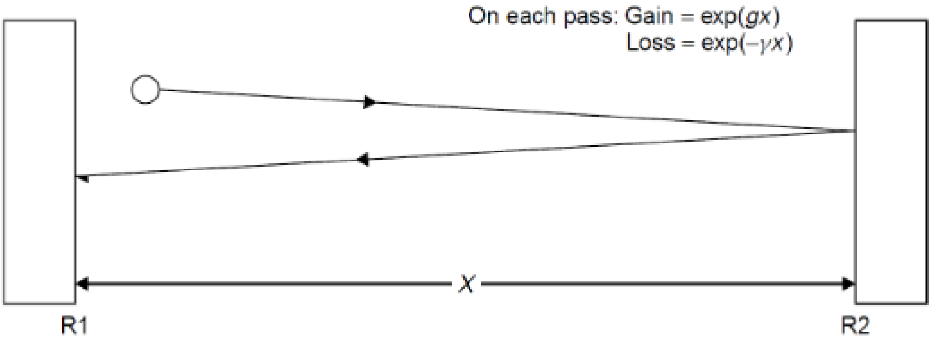

Figure (1). Gain and loss in a round trip through a laser

The power gained during the round trip is exp(g . 2x), where 2x is the total path length of the laser (x is the length of the gain medium through which the stream of photons passes twice). The power lost during the same trip is exp(-γ . 2x), where γ is a new term describing all losses in the cavity due to the lasing mechanisms, with the exception of the mirrors themselves. The losses from the mirrors themselves will be seen as the reflectivities of the two mirrors (R_1 and R_2). A perfect mirror, with 100% reflection, has an R value of 1.

Equating these parameters for a round trip through the tube yields:

net gain = laser gain × loss × loss at mirror 1 × loss at mirror 2 = exp(2gx) exp(-γ . 2x)R_1R_2 (3)

Knowing R_1 and R_2 as well as γ, we can solve for gain, which must equal 1 for an operating laser. This gain will be the threshold gain, the gain required to allow the laser to operate in this steady-state condition:

$$g_{\text{threshold}} = \gamma + \frac{1}{2x} \ln\left(\frac{1}{R_1 R_2}\right) \qquad (4)$$

where x is the length of the gain medium. In many lasers the gain of the laser medium is proportional to the pump energy. A minimum pump energy will hence be required to generate a gain of at least the threshold value in order for lasing to begin.

Ex. 1

Gain and Loss in a He Ne Laser as an application of the threshold gain formula, consider a helium–neon laser in which the loss is known to be 0.05 m^{-1}. The laser has an actual plasma tube length (where gain occurs, not the entire length of the tube between mirrors) of 20 cm. One mirror is 99.9% reflecting, and the output coupler is 95% reflecting. Calculate the threshold gain for the tube.

Sol.

$$g_{\text{threshold}} = \gamma + \frac{1}{2x} \ln\left(\frac{1}{R_1 R_2}\right)$$

$$\begin{aligned} g_{\text{threshold}} &= \gamma + \frac{1}{2x} \ln\left(\frac{1}{R_1 R_2}\right) \\ &= 0.05 + \frac{1}{0.4} \ln\left(\frac{1}{0.999 \times 0.95}\right) \\ &= 0.181 \text{ m}^{-1} \end{aligned}$$