Introduction to lasers

Pr A. Desfarges-Berthelemot – Limoges University

Chapter 3: Laser Oscillator

Université de Limoges · Università degli Studi di Brescia · Aston University · Universidad del País Vasco / Euskal Herriko Unibertsitatea / The University of the Basque Country · Universitatea Tehnică din Cluj-Napoca

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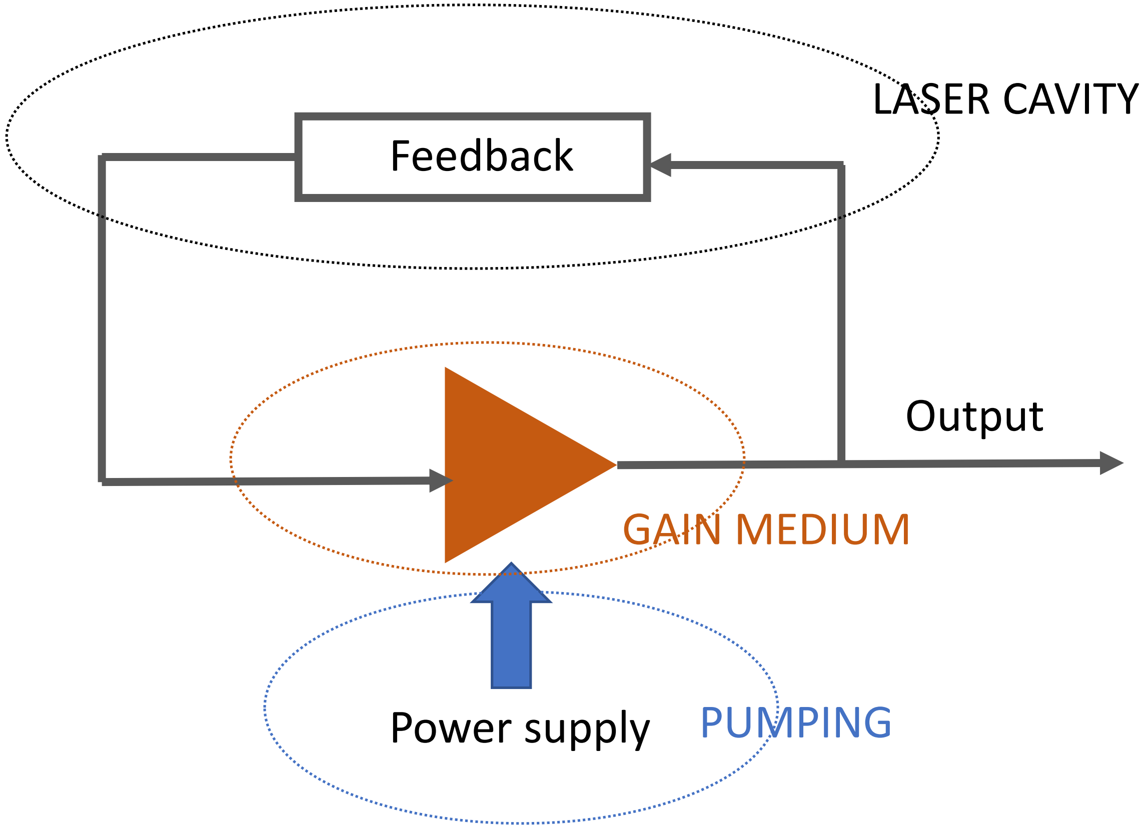

Oscillator: amplifier with a positif feedback

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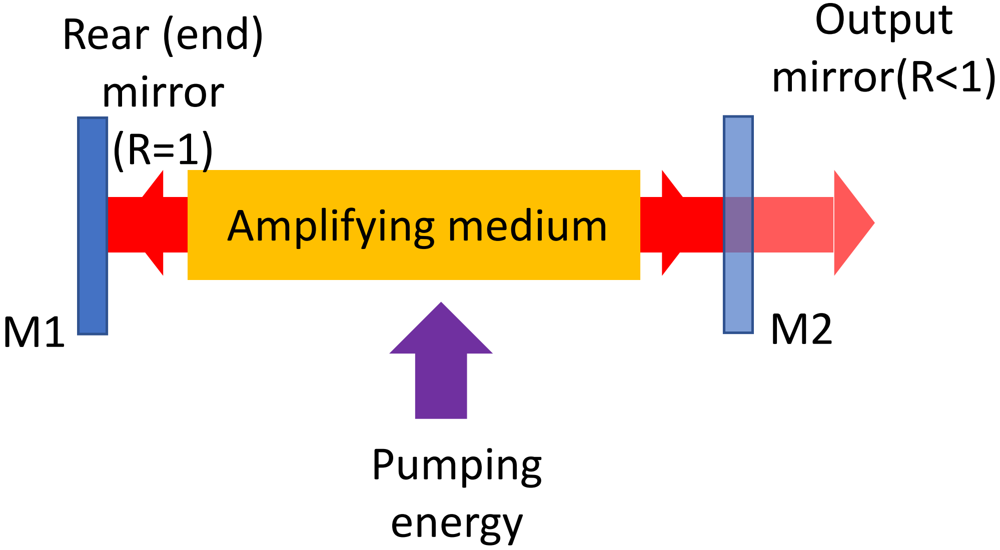
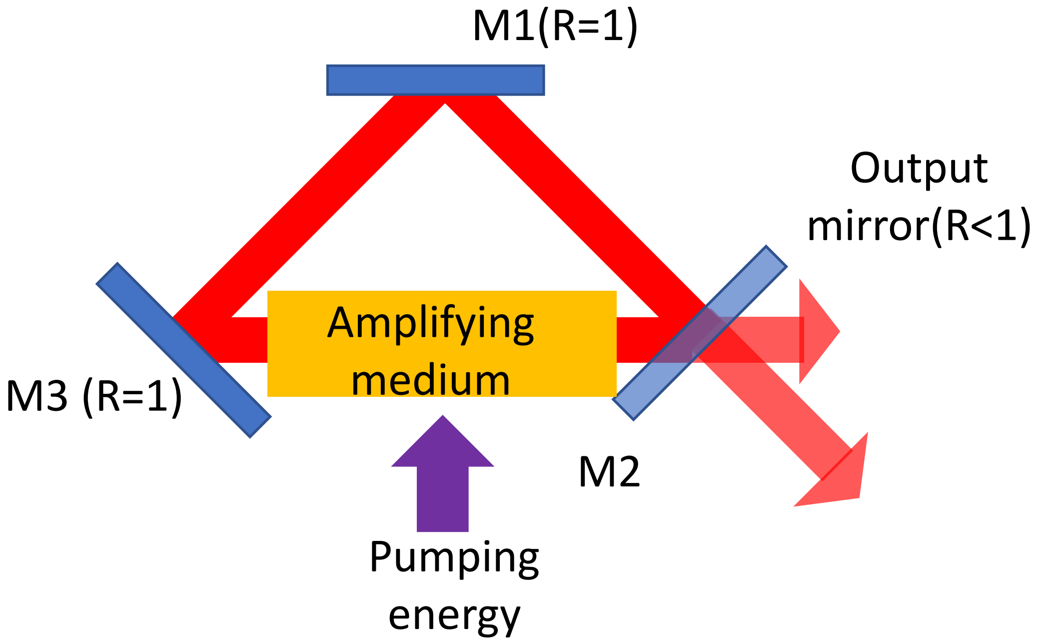
I. Types of cavities (see chapter VI for actual architectures)

Fabry-Perot cavity (schematic diagram)



Ring cavity (schematic diagram)



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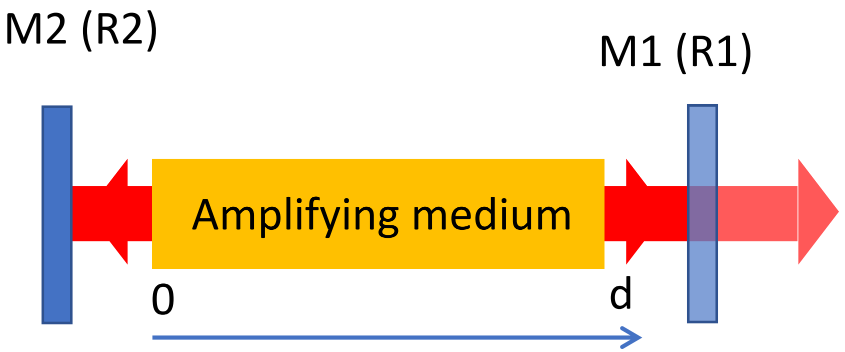
II. First condition for laser oscillation: Gain condition

1. Laser threshold for Fabry Perot cavity



$$G_0 = e^{\gamma_0 d}$$

After one round trip in the cavity, i.e. two passages through the amplifying medium, the small signal gain is : $e^{2\gamma_0 d}$

And the cavity losses (except the ones due to mirrors, i.e diffusion, spontaneous emission, finite size of cavity components) : $e^{-2\alpha d}$

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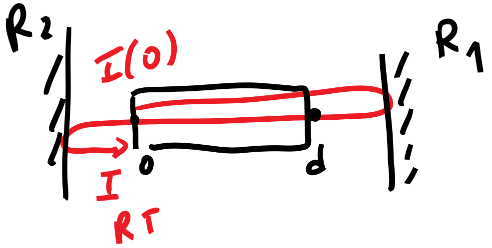
To complete

After one round-trip inside the cavity:



$$I_{AT} = I(0) \cdot R_1 \cdot \underbrace{e^{\gamma_0 d} \cdot e^{\gamma_0 d}}_{e^{2\gamma_0 d}} \cdot R_2 \cdot e^{-2\alpha d}$$

$$I_{RT} = R_1 R_2 \, e^{2(\gamma_0 - \alpha)d} \cdot I(0)$$

The initiation of the oscillations requires $I_{RT} \geq I(0)$

$$R_1 R_2 \, e^{2(\gamma_0-\alpha)d} \geq 1 \Rightarrow e^{2(\gamma_0-\alpha)d} \geq \frac{1}{R_1 R_2} \Rightarrow 2(\gamma_0-\alpha)d \geq -\ln R_1 R_2$$

$$\Rightarrow \boxed{\gamma_0 \geq \alpha - \frac{\ln R_1 R_2}{2d}}$$

GAIN CONDITION - LASER THRESHOLD

$$\alpha_t : \text{loss coefficient} = \alpha - \frac{\ln R_1 R_2}{2d}$$

$$\boxed{\gamma_0 \geq \alpha_t}$$

The small-signal gain must be greater than the loss coefficient

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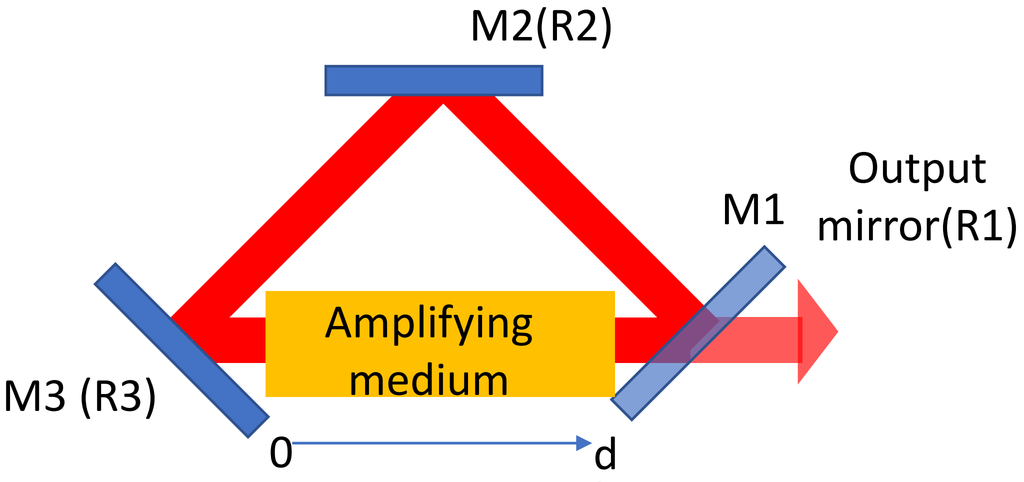
To complete

2. Laser threshold for ring cavity



$$G_0 = e^{\gamma_0 d}$$

$I(0)$

$$I_{RT} = I(0) \cdot e^{\gamma_0 d} R_1 R_2 R_3 \cdot e^{-\alpha d}$$

$I_{RT} \geq I(0)$ For oscillations

$$e^{(\gamma_0 - \alpha) d} R_1 R_2 R_3 \geq 1$$

$$(\gamma_0 - \alpha) d \geq - \ln R_1 R_2 R_3$$

$$\boxed{\gamma_0 \geq \alpha - \frac{\ln \Sigma R}{d}}$$

GAIN CONDITION

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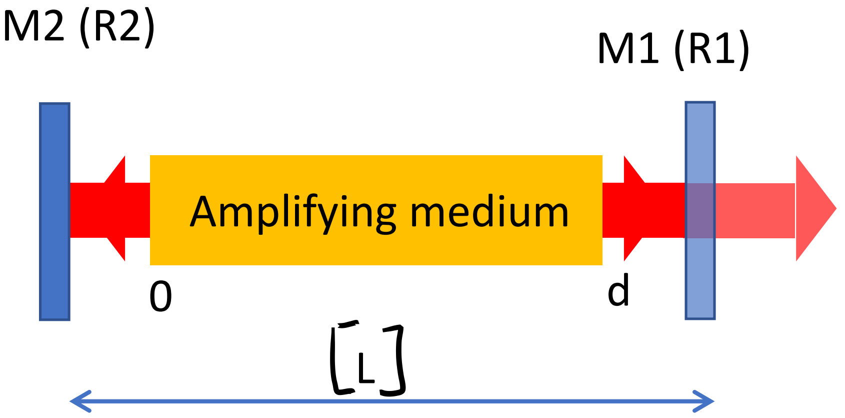
To complete

III - Second condition for laser oscillation: Phase condition

→ **Laser frequencies**

→ It requires that the phase-shift impaired to the laser wave completing a round-trip within the cavity must be a multiple of 2π



Phase-shift after one round-trip:

$$\Delta\varphi = \frac{2\pi}{\lambda_k} \cdot \underbrace{2[L]}_{\text{one round-trip}} = 2k\pi \qquad k \text{ integer}$$

$$\frac{2\pi\nu_k}{c} \cdot 2[L] = 2k\pi$$

$[L]$ = optical path
= $n \cdot L$
↳ refractive index $= \frac{c}{v}$

$$\Rightarrow \boxed{\nu_k = k \frac{c}{2[L]}}$$

→ Laser frequencies

→ Free spectral range of the cavity

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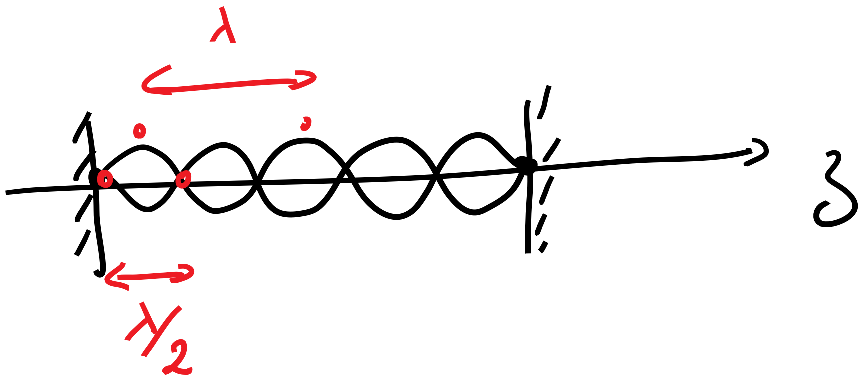

$$\Rightarrow k\,\frac{\lambda_k}{2} = [L] \Rightarrow k\,\frac{c}{2\nu_k} = [L]$$

$$\Rightarrow \boxed{\nu_k = k\,\frac{c}{2[L]}}$$

$L = 1\,m$

$$c/2[L] = \frac{3.\,10^8}{2} = 1.5\ 10^8\ Hz$$

$$\lambda = 1\,\mu m \Rightarrow \nu = \frac{3.\,10^8}{10^{-6}} = 3.\ 10^{14}\ Hz$$

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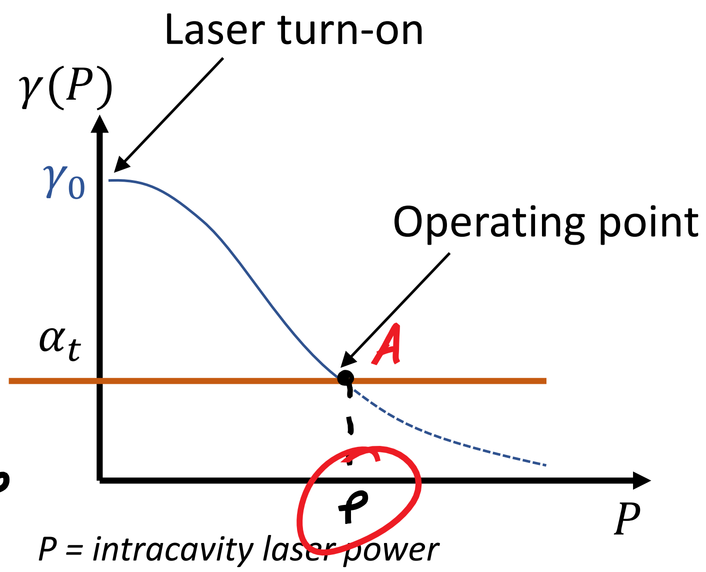
To complete

IV - Steady-state operation

→ Operating point

$$\gamma(P) = \frac{\gamma_0}{1 + P/P_{sat}} \quad (1)$$

Laser pumped above threshold ($\gamma_0 > \alpha_t$)



Transient regime

As the power inside the cavity increases, the gain coefficient decreases due to relation (1)

As long as the gain coefficient remains greater than α_t (loss level), the photon flux continues to increase.

Finally, when $\boxed{\gamma(P) = \alpha_t}$, the power ceases to increase ⇒ STEADY STATE REGIME.

↳ Gain clamping at the value of losses

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GAIN SATURATION ≡ STABILIZER

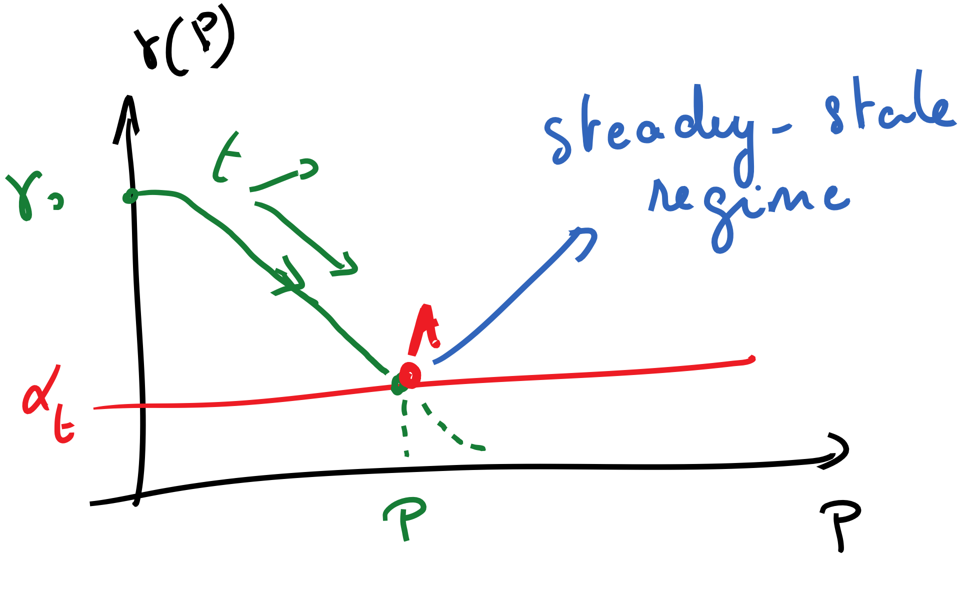
To complete

if $P \nearrow \Rightarrow \gamma(P) \searrow \Rightarrow \gamma(P) < \alpha_t \Rightarrow P \searrow$

$P \searrow \Rightarrow \gamma(P) \nearrow \Rightarrow \gamma(P) > \alpha_t \Rightarrow P \nearrow$

Stabilization on point A for which

$$\gamma(P) = \alpha_t$$



Transient regime

$$\gamma(P) = \frac{\gamma_0}{1 + P/P_{sat}} = \alpha_t$$

$$\frac{P}{P_{sat}} + 1 = \frac{\gamma_0}{\alpha_t} \Rightarrow \boxed{P = P_{sat}\left(\frac{\gamma_0}{\alpha_t} - 1\right)}$$

Power inside the cavity

Assumption: P does not depend on $z \Leftrightarrow R_1$ and R_2 close to 1.

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To complete

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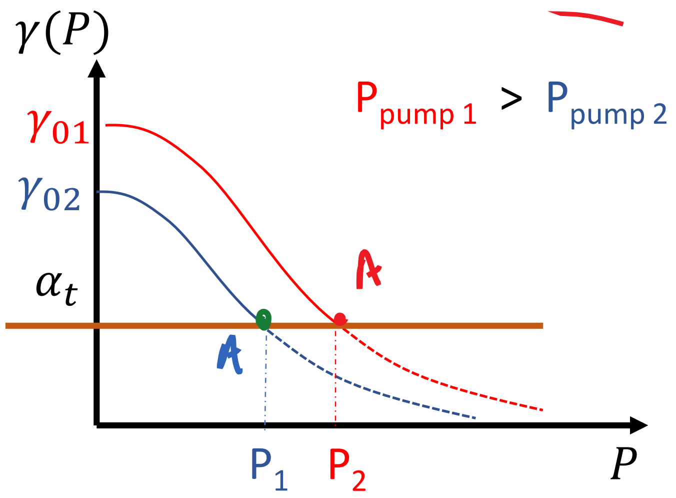

Transient regime

P = intracavity laser power

At steady-state, the intracavity power increases as the pump power increases due to the increase of $\underline{\gamma_0}$

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