Láseres de colorantes en COMSOL

Passarelli Nicolás

Emilio Ruiz Reyna

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UNIVERSIDAD DE MÁLAGA | uma.es

Máster Universitario Online en Simulación Numérica en Ciencia e Ingeniería con COMSOL Multiphysics

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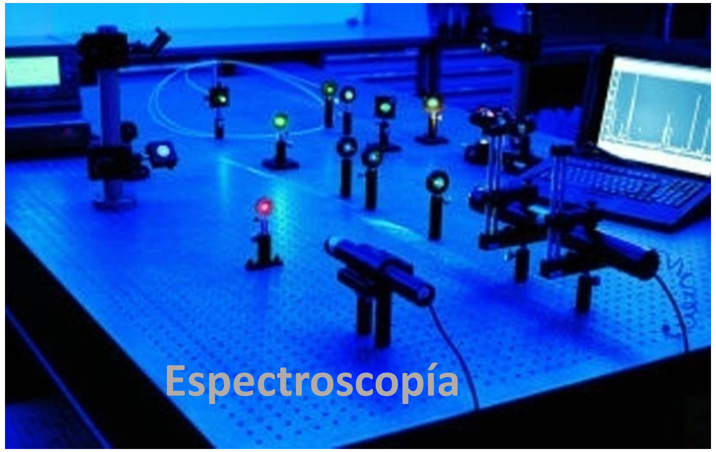
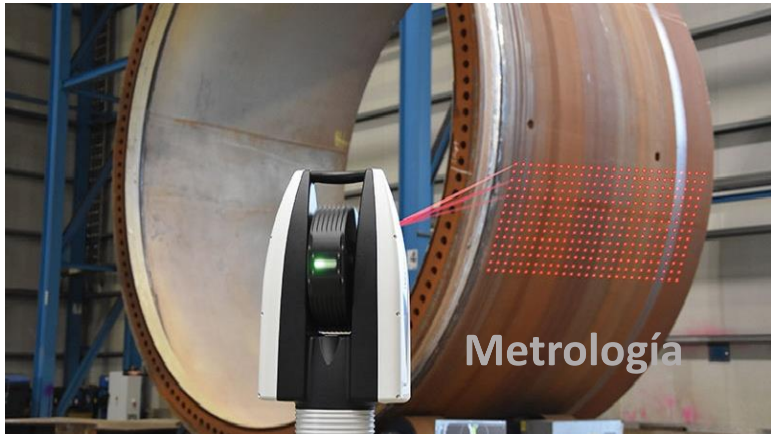
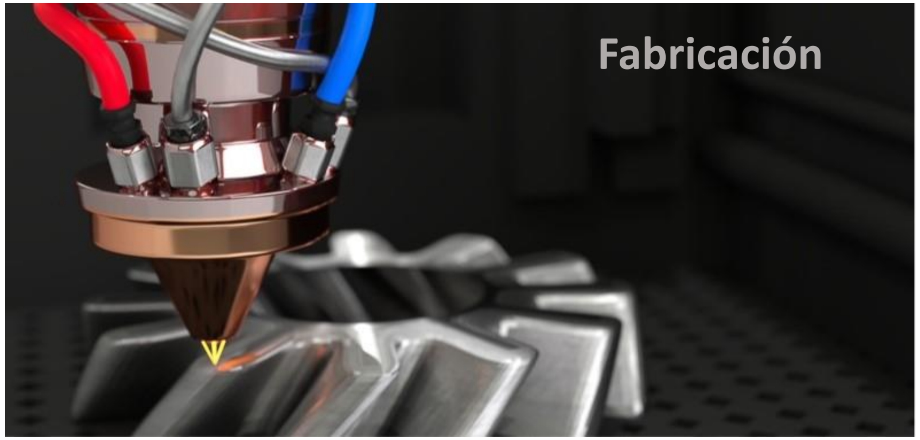
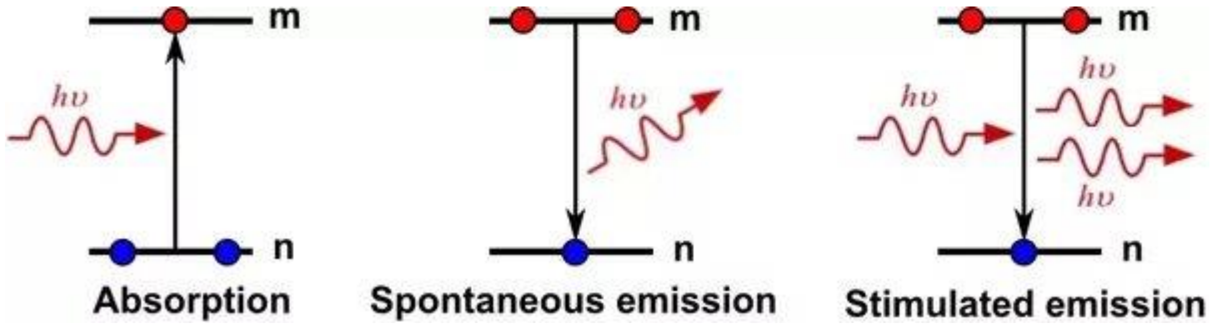
Introducción: motivación

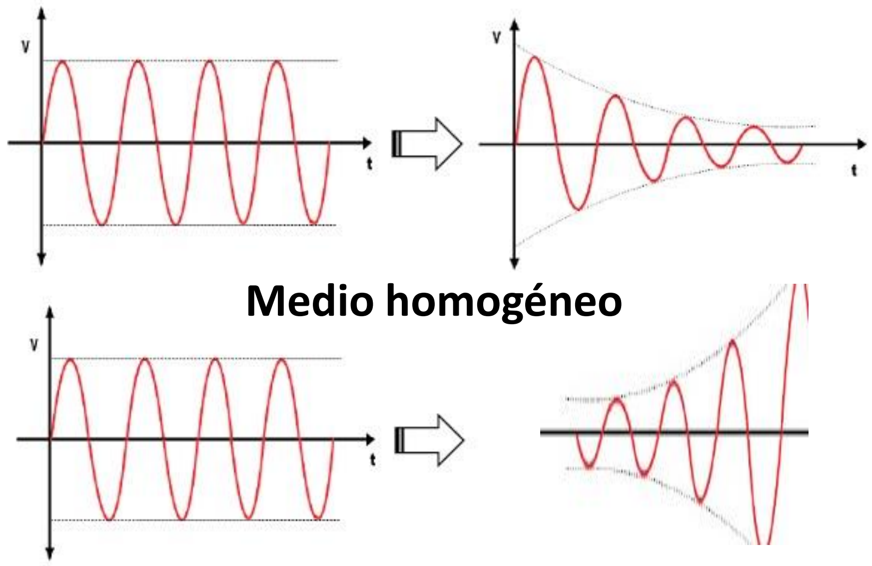


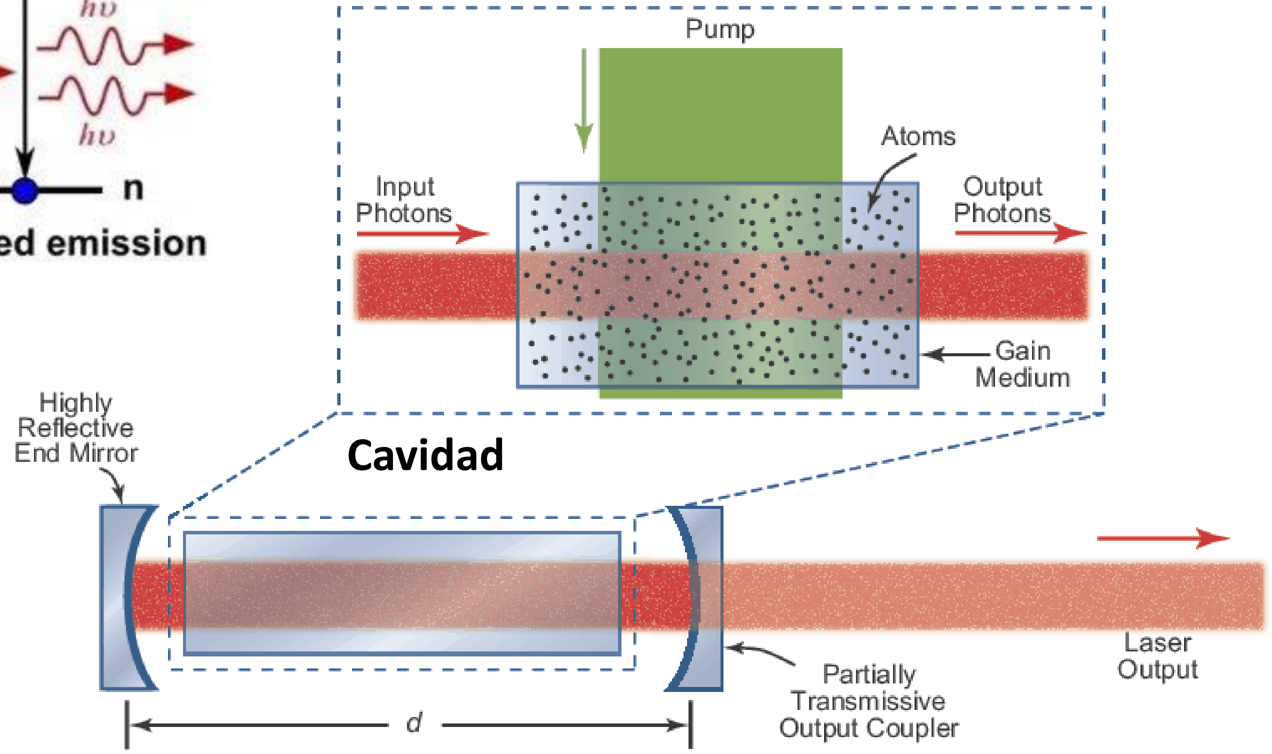




Introducción: bases



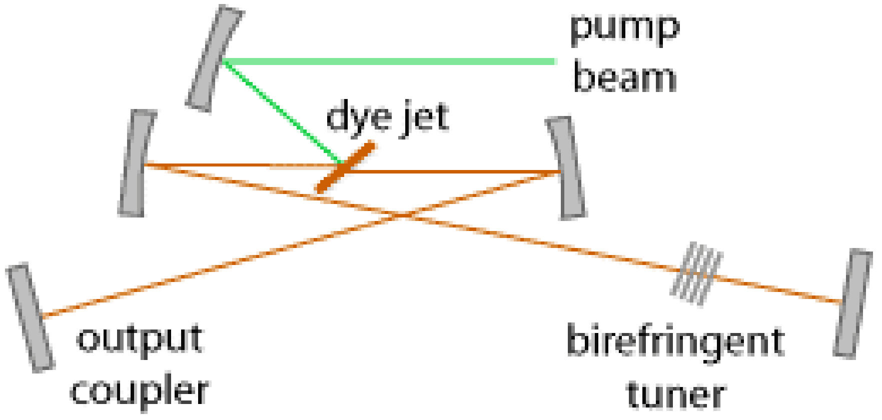


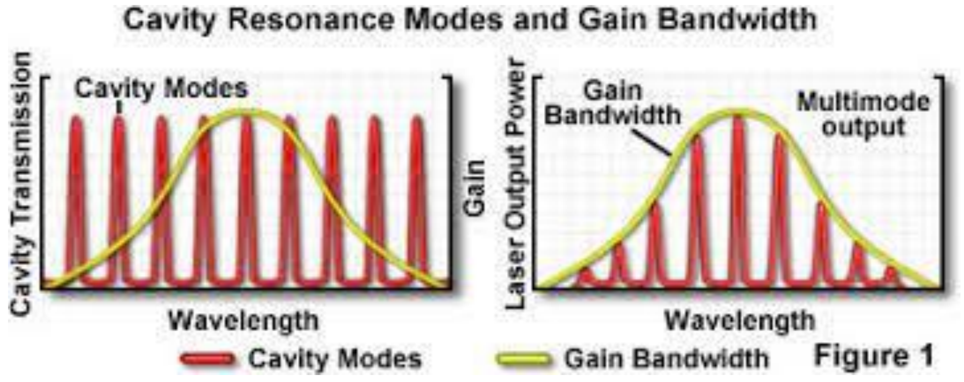


Láseres de colorante en COMSOL

Introducción: láseres de colorante

De colorantes	De estado sólido
Bombeo óptico	Bombeo eléctrico
Sintonizable	No sintonizable
Dilución	Monocristal
Degradable	No degradable
Mode loking pasivo	Modeloking asistido
Química rica	Química limitada
Riesgoso p/ salud	Inocuo

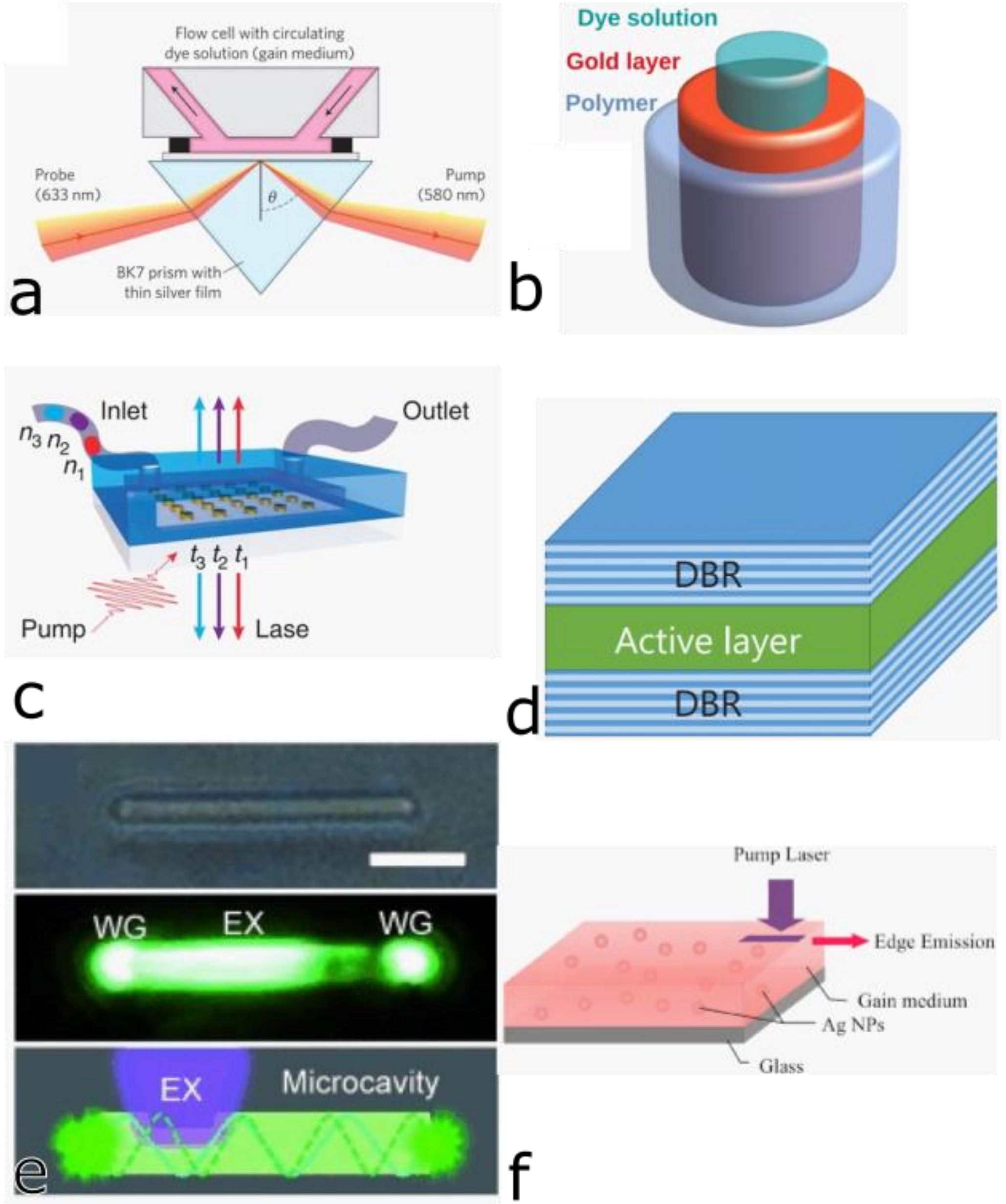




Láseres de colorante en COMSOL

Introducción: nanoláseres de colorantes

a) SPASER
b) Nanotube Laser
c) Photonic crystal
d) VCSEL
e) Nanowire laser
f) Nanoparticle SPASER



Teoría: electromagnetismo

Ecuaciones de Maxwell:

$$\varepsilon\nabla\cdot\mathbf{E} = 0$$

$$\nabla\cdot\mathbf{B} = 0$$

$$\nabla\times\mathbf{E} = -\frac{\partial B}{\partial t}$$

$$\frac{1}{\mu}\nabla\times\mathbf{B} = J_f + \varepsilon\frac{\partial E}{\partial t}$$

Condiciones de contorno:

$$\hat{n}_{12}\times(\boldsymbol{E}_2 - \boldsymbol{E}_1) = 0$$

$$\hat{n}_{12}\cdot(\varepsilon_2\boldsymbol{E}_2 - \varepsilon_1\boldsymbol{E}_1) = 0$$

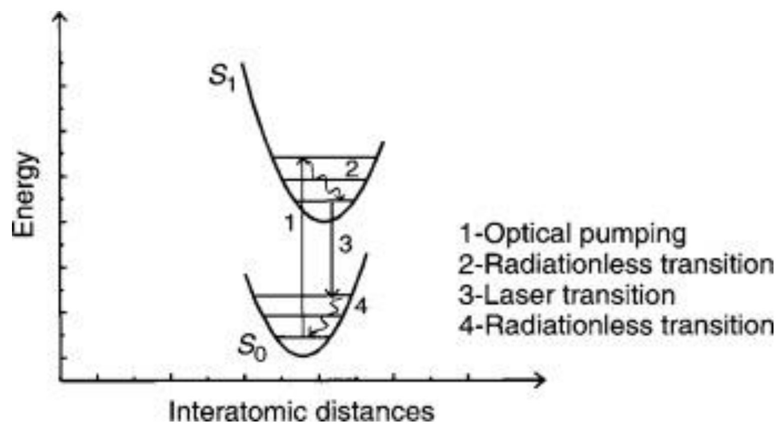
$$\hat{n}_{12}\times\left(\frac{\mathbf{1}}{\boldsymbol{\mu_2}}\boldsymbol{B}_2 - \frac{\mathbf{1}}{\boldsymbol{\mu_1}}\boldsymbol{B}_1\right) = 0$$

$$\hat{n}_{12}\cdot(\boldsymbol{B}_2 - \boldsymbol{B}_1) = 0$$

Potencial vector magnético:

$$\nabla\times\mu_r^{-1}(\nabla\times\boldsymbol{A}) - \mu_0\boldsymbol{J}_f + \mu_0\frac{\partial}{\partial t}\left(\varepsilon_0\varepsilon_r\frac{\partial\boldsymbol{A}}{\partial t}\right) = 0$$

Teoría: Modelo para colorantes



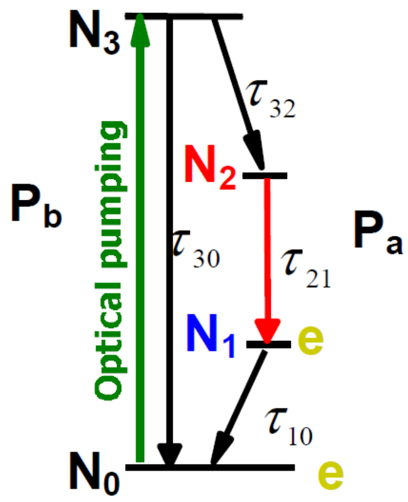


Fig. 1. four-level two-electron model

$$\frac{d^2P_a}{dt^2} + \gamma_a \frac{dP_a}{dt} + \omega_a^2 P_a = \zeta_a (N_2 - N_1) E$$

$$\frac{d^2P_b}{dt^2} + \gamma_b \frac{dP_b}{dt} + \omega_b^2 P_b = \zeta_b (N_3 - N_0) E$$

$$\zeta_a = \frac{6\pi\varepsilon_0 c^3}{\omega_{21}\tau_{21}} \qquad \zeta_b = \frac{6\pi\varepsilon_0 c^3}{\omega_{30}\tau_{30}}$$

Referencia clave:

Shih-Hui Chang and Allen Taflove, "Finite-difference time-domain model of lasing action in a four-level two-electron atomic system", Optics Express, Vol. 12 Issue 16, pp.3827-3833 (2004).

Teoría: Modelo para colorantes

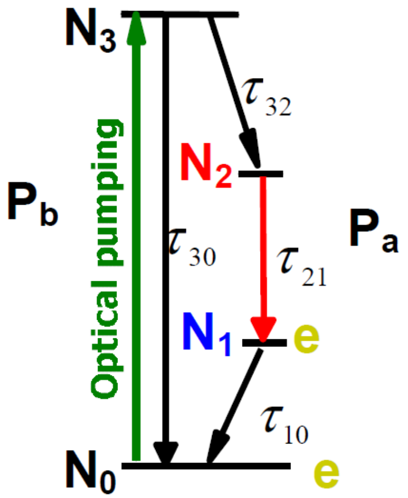


Fig. 1. four-level two-electron model

$$\frac{dN_3}{dt} = -\frac{N_3(1-N_2)}{\tau_{32}} - \frac{N_3(1-N_0)}{\tau_{30}} + \frac{1}{\hbar\omega_b}\boldsymbol{E}\cdot\frac{d\boldsymbol{P}_b}{dt}$$

$$\frac{dN_2}{dt} = \frac{N_3(1-N_2)}{\tau_{32}} - \frac{N_2(1-N_1)}{\tau_{21}} + \frac{1}{\hbar\omega_a}\boldsymbol{E}\cdot\frac{d\boldsymbol{P}_a}{dt}$$

$$\frac{dN_1}{dt} = \frac{N_2(1-N_1)}{\tau_{21}} - \frac{N_1(1-N_0)}{\tau_{10}} - \frac{1}{\hbar\omega_a}\boldsymbol{E}\cdot\frac{d\boldsymbol{P}_a}{dt}$$

$$\frac{dN_0}{dt} = \frac{N_3(1-N_0)}{\tau_{30}} + \frac{N_1(1-N_0)}{\tau_{10}} - \frac{1}{\hbar\omega_b}\boldsymbol{E}\cdot\frac{d\boldsymbol{P}_b}{dt}$$

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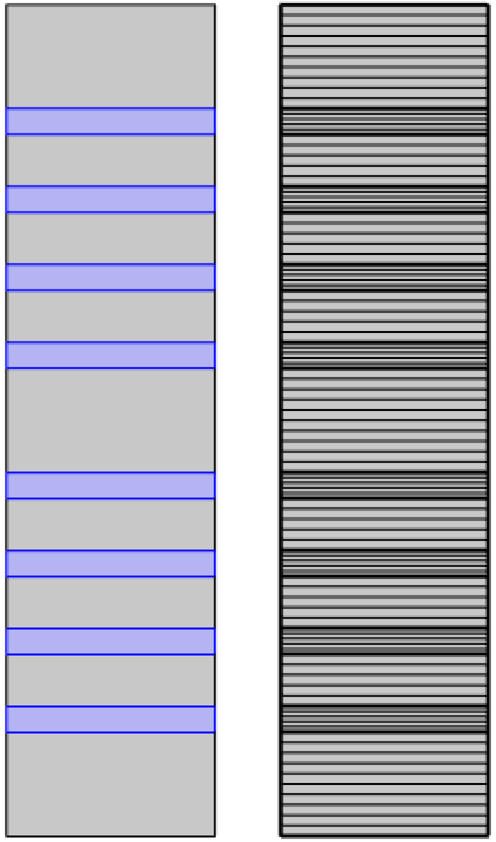
Teoría: acoplamiento multifísico

$$\frac{d\boldsymbol{E}}{dt} = \frac{1}{\varepsilon}\nabla \times \boldsymbol{H} - \frac{1}{\varepsilon} N_{density}\left(\frac{d\boldsymbol{P}_a}{dt} + \frac{d\boldsymbol{P}_b}{dt}\right)$$

$$\nabla \times \mu_r^{-1}(\nabla \times \boldsymbol{A}) + \mu_0\left(\sigma\frac{\partial \boldsymbol{A}}{\partial t} + N_{dye}\frac{d\boldsymbol{P_a}}{dt} + N_{dye}\frac{d\boldsymbol{P_b}}{dt}\right) + \mu_0\frac{\partial}{\partial t}\left(\varepsilon_0\varepsilon_r\frac{\partial \boldsymbol{A}}{\partial t}\right) = 0$$

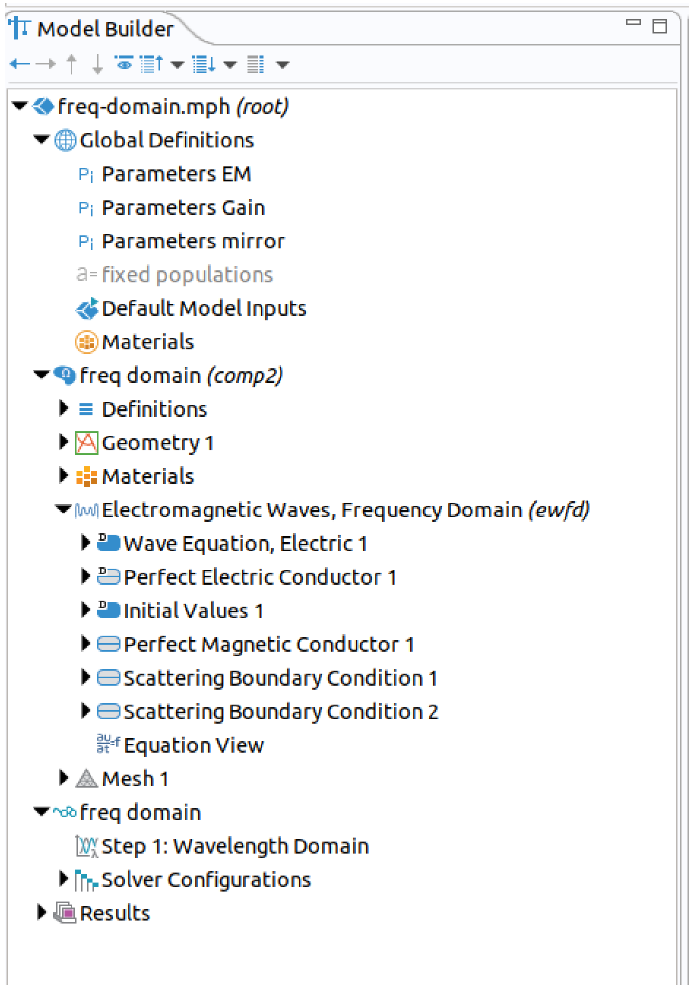
Métodos: VCSEL

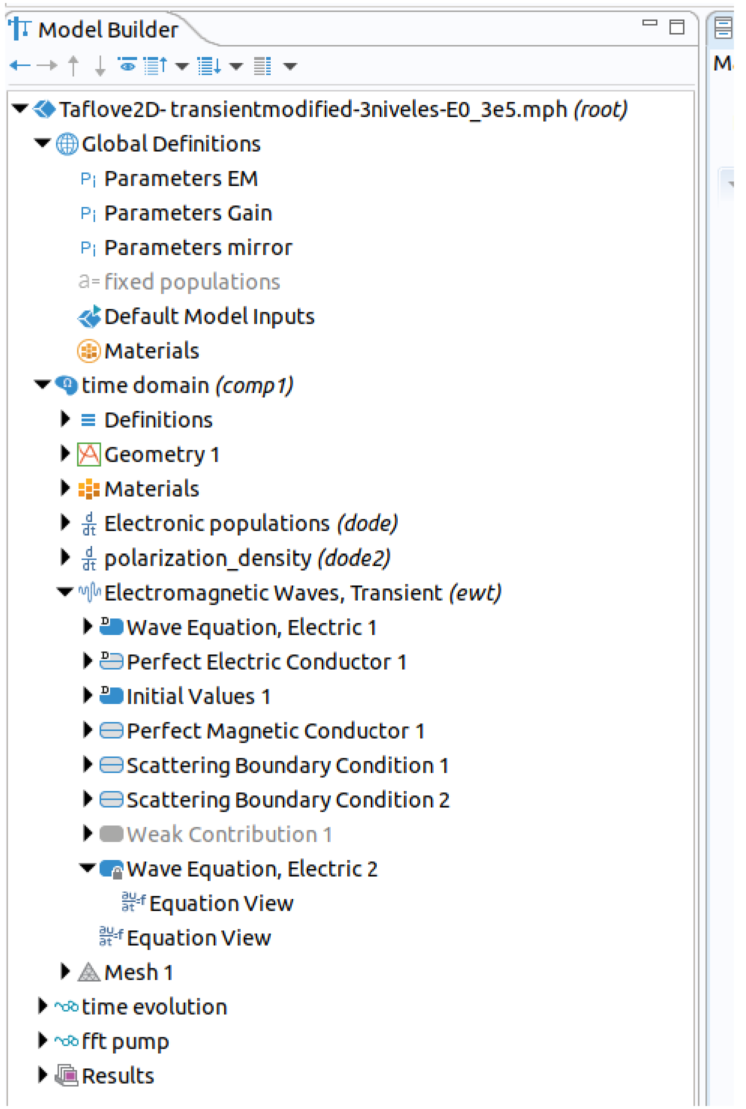


dL=350nm
dH=175nm
dDefect=350nm
nL=1
nH=2
nDefect=1

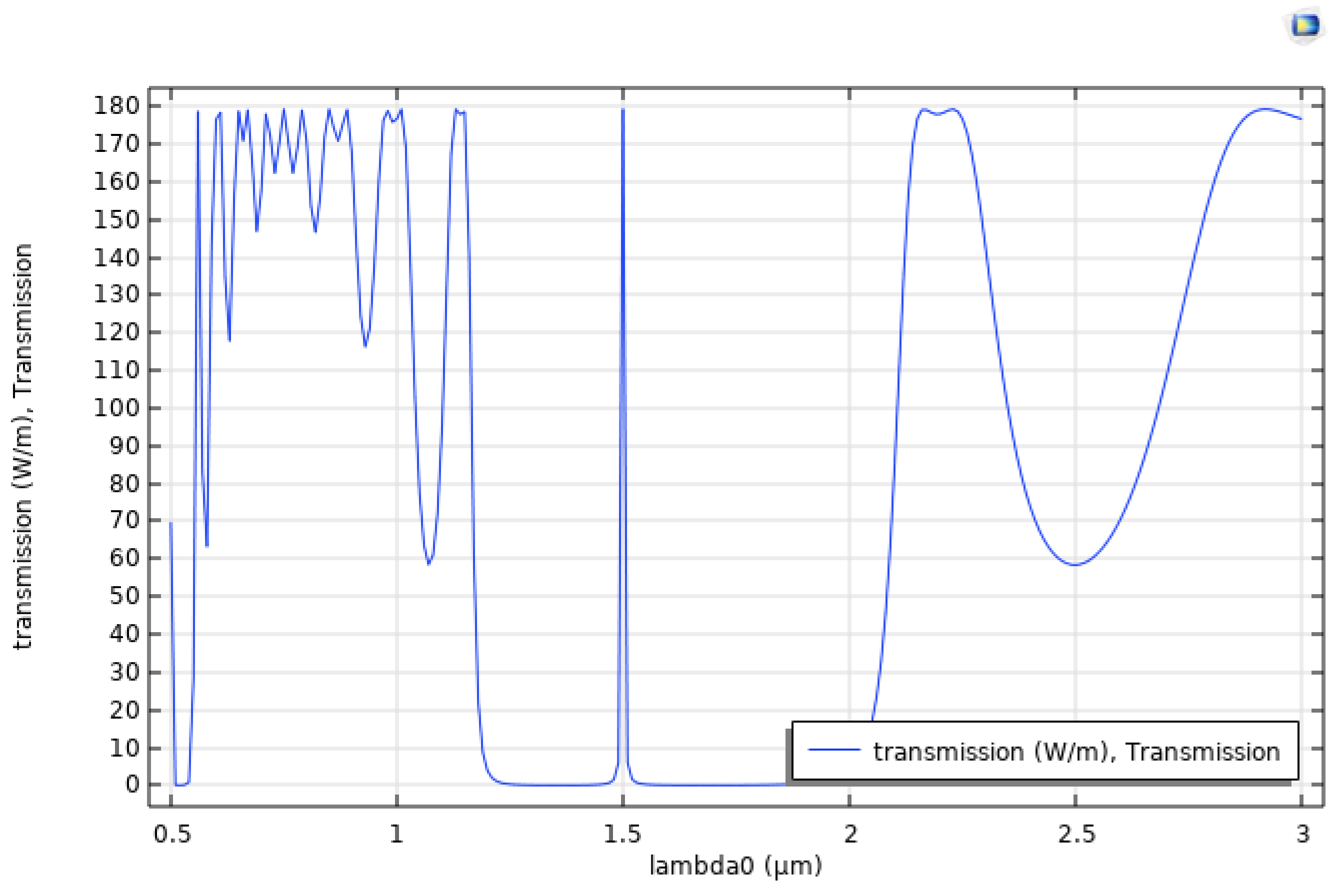
λ=1.5μm

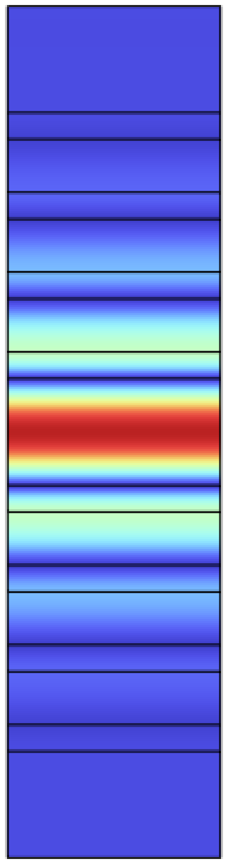
Métodos: Dominio de la Frecuencia vs Transiente





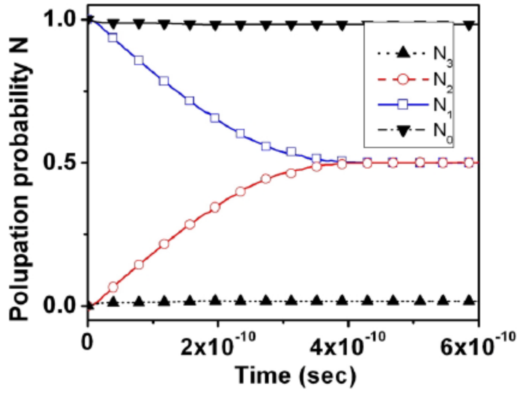
Resultados: dominio de la frecuencia

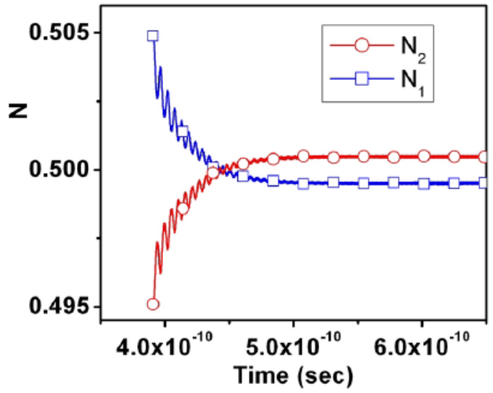


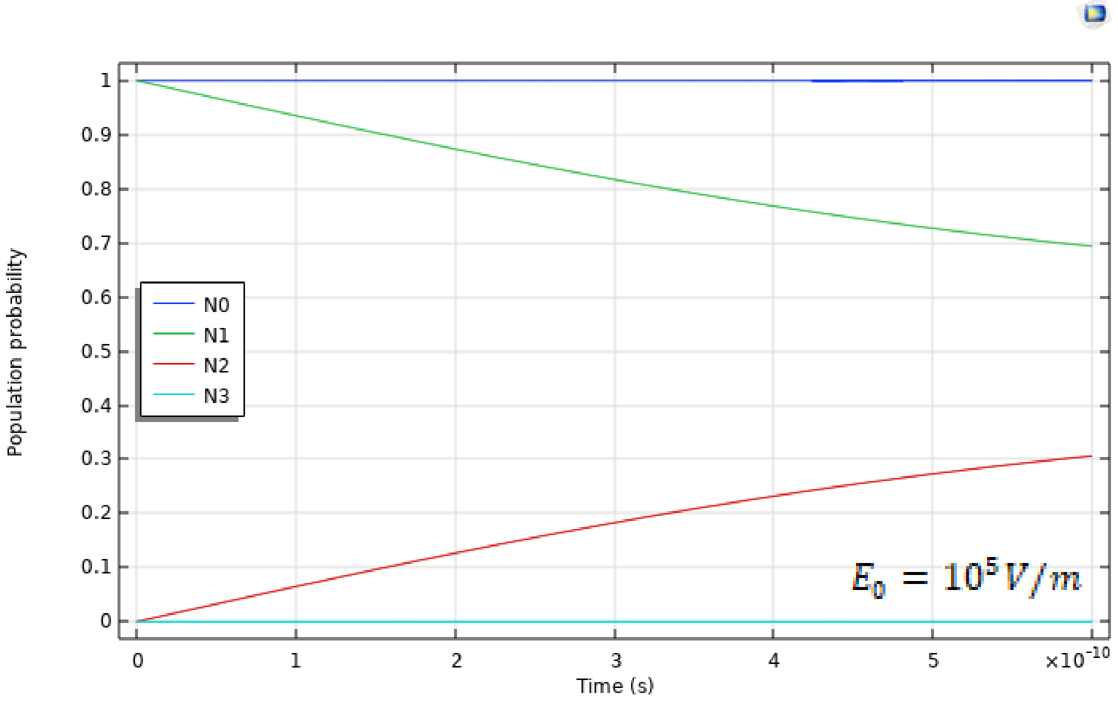


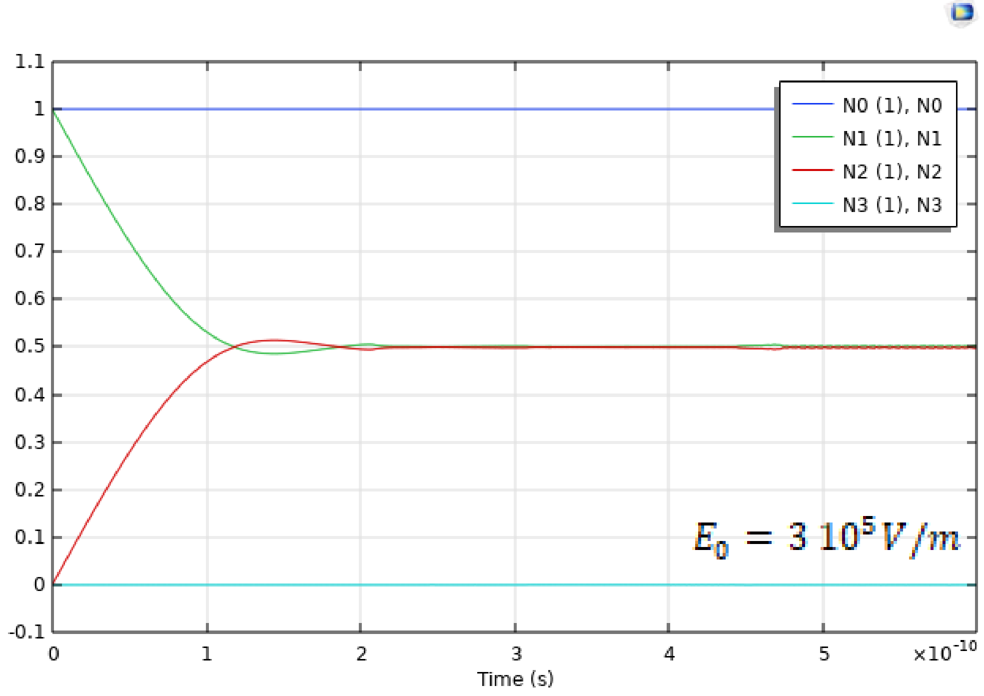
Modo a 1.5 µm

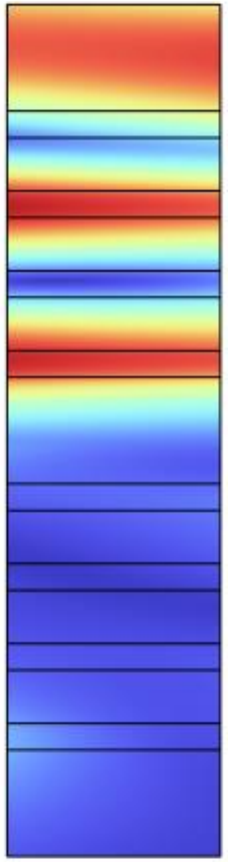
Resultados: Transiente











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Conclusiones

- Se logró la implementación del modelo de 4 niveles 2 electrones en COMSOL
- Se logró reproducir los resultados de la referencia original,
  sorteando erratas en las ecuaciones y falta de información
- Se ha puesto a punto el modelo para utilizarlo en otros sistemas

Perspectivas

- Generalizar la física : 2 y 3 niveles, strong coupling.
- Buscar un diseño de nanolaser que permita explotar mas multifísica en COMSOL:
  - -micro fluídica
  - -degradación del colorante
  - -calentamiento
  - -deformaciones estructurales

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