RADIATION EFFECTS ON SEMICONDUCTOR LASER DIODES.

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and

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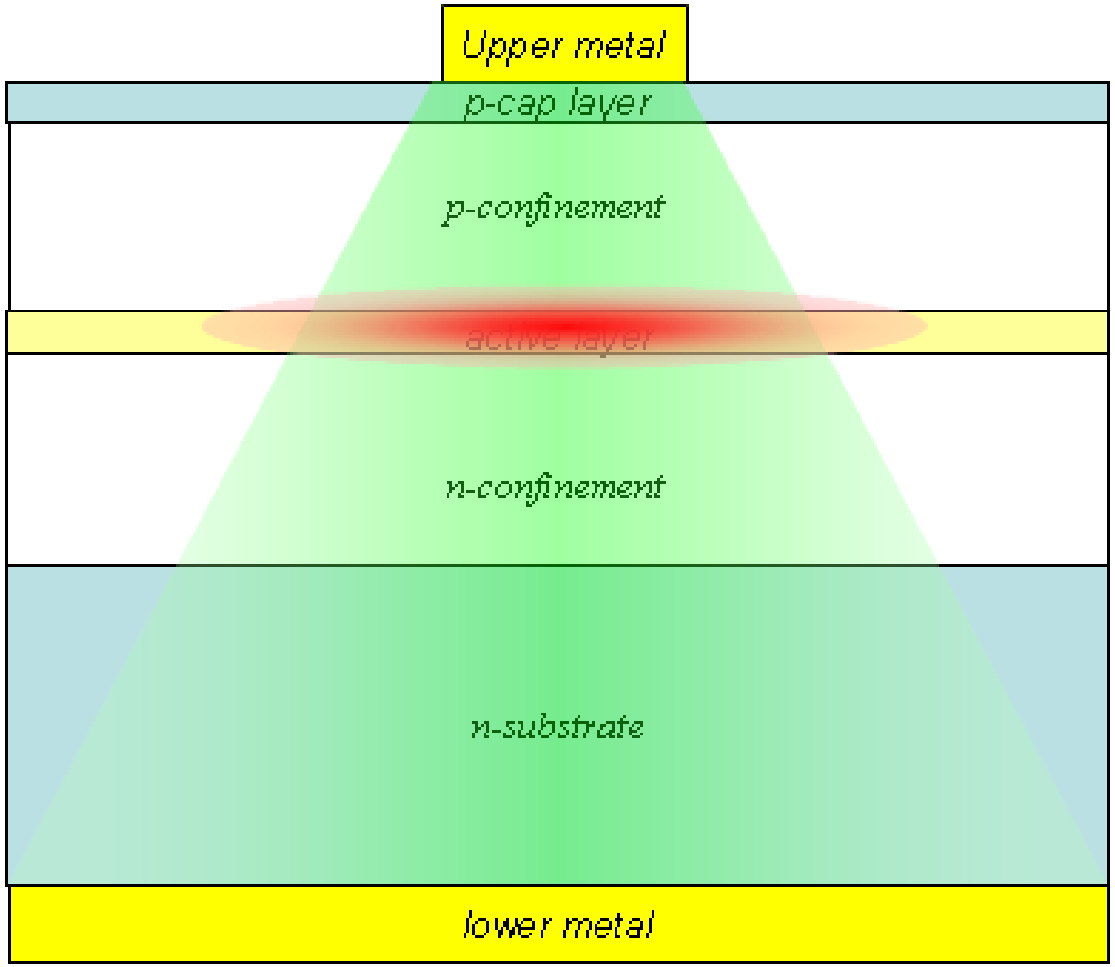
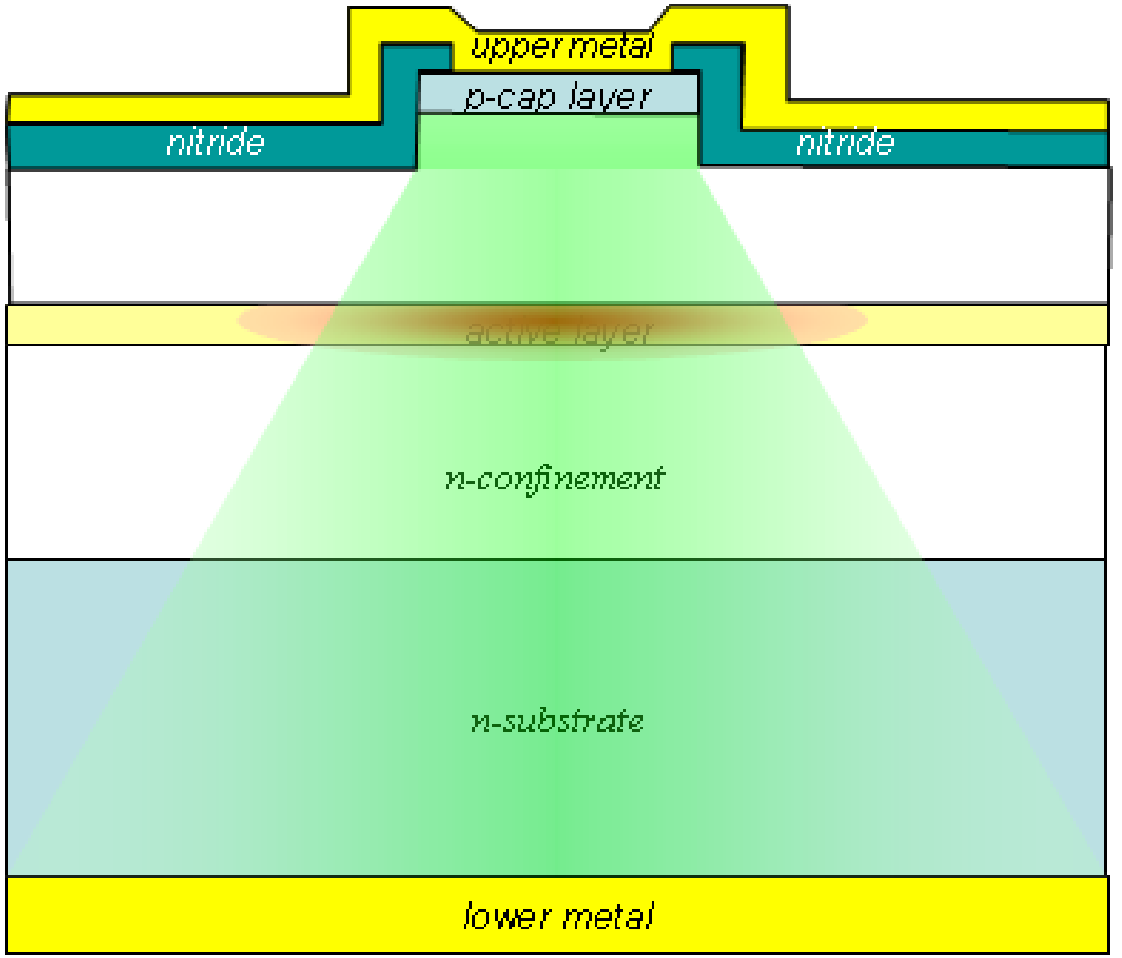
INFN Laboratori Nazionali di Legnaro
(Padova)

Outline

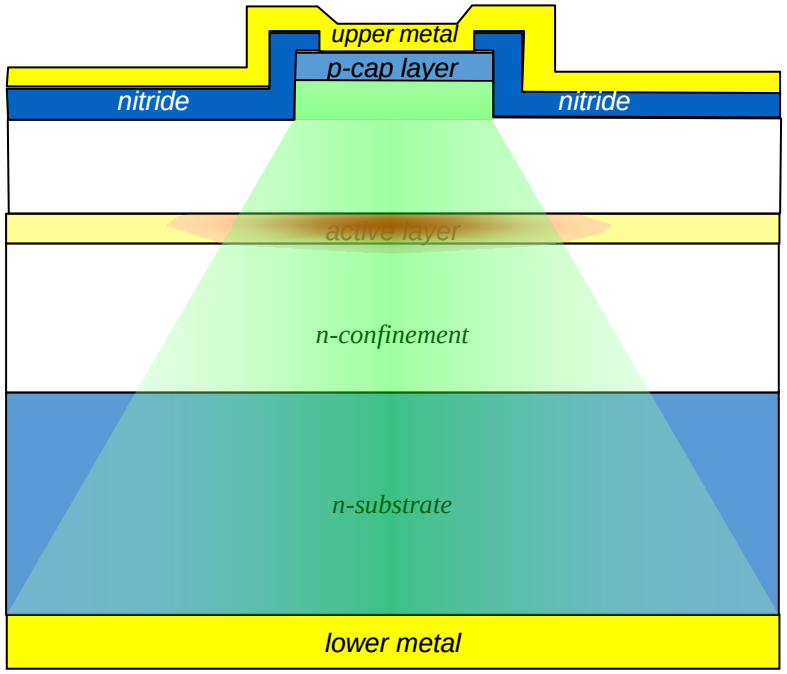
- Laser diodes: structures, models and parameters
- Proton irradiation and data analysis
- Post-irradiation kinetics: experiments and models
- Discussion and conclusions

Vertical structure

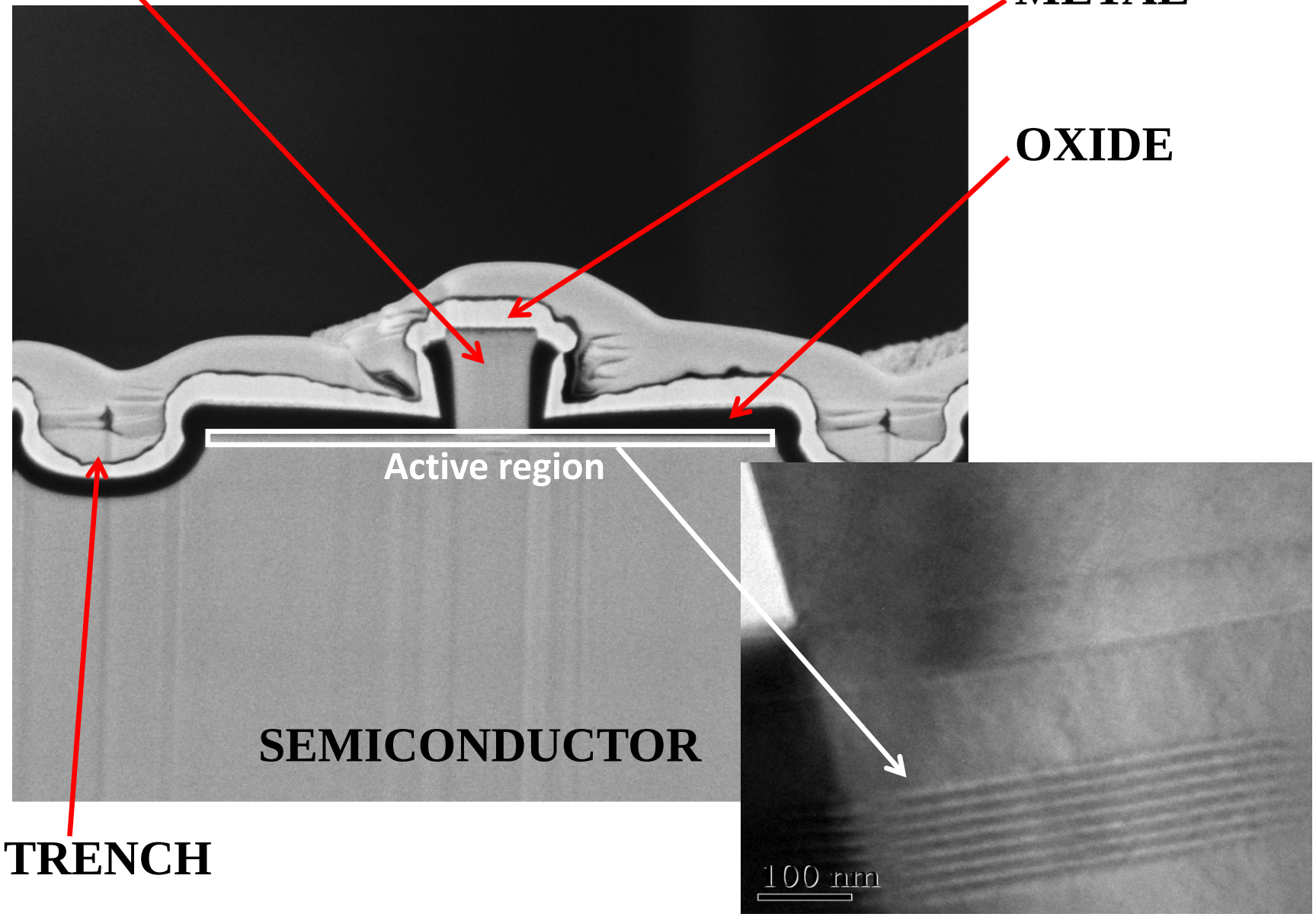




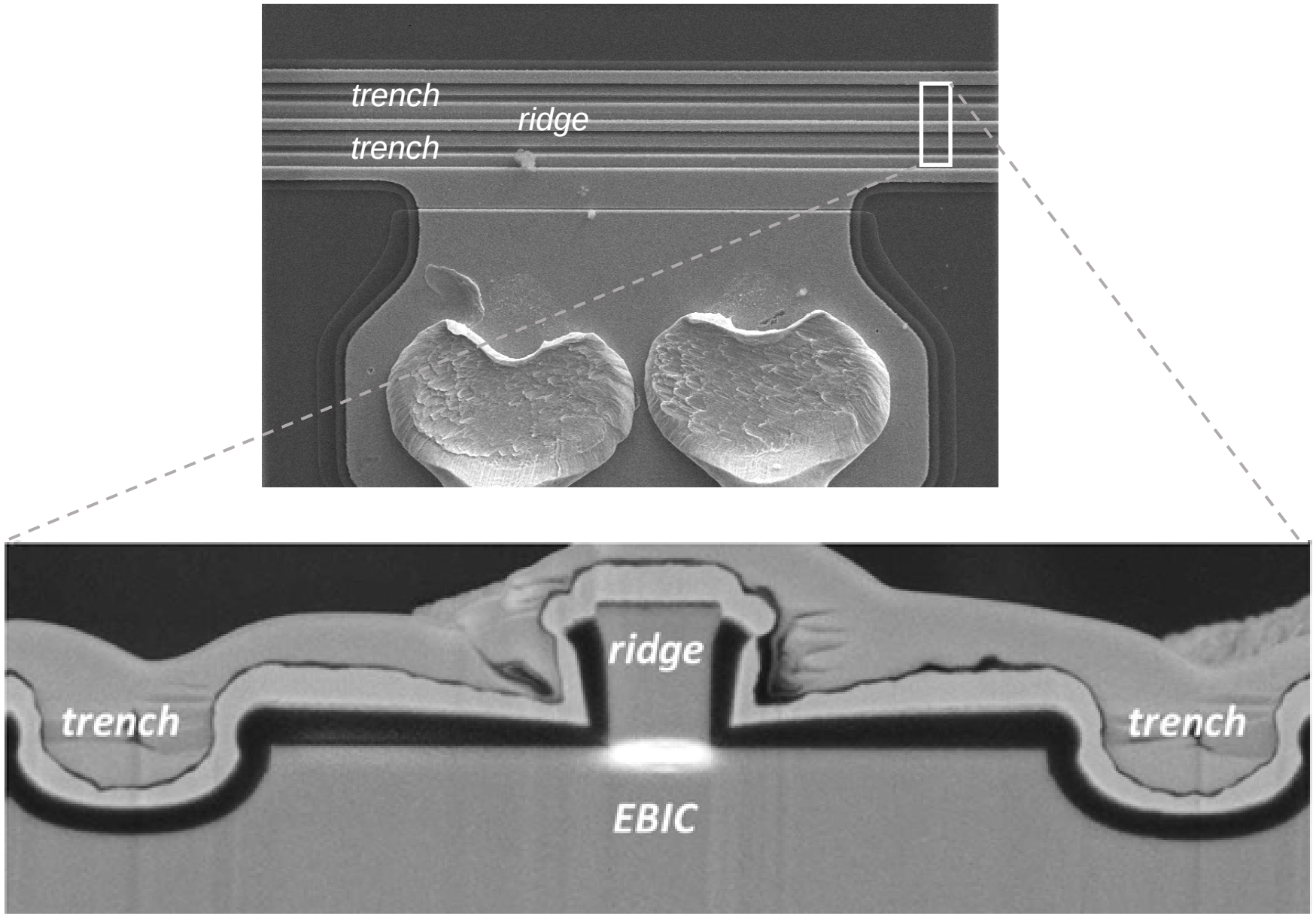
Vertical structure



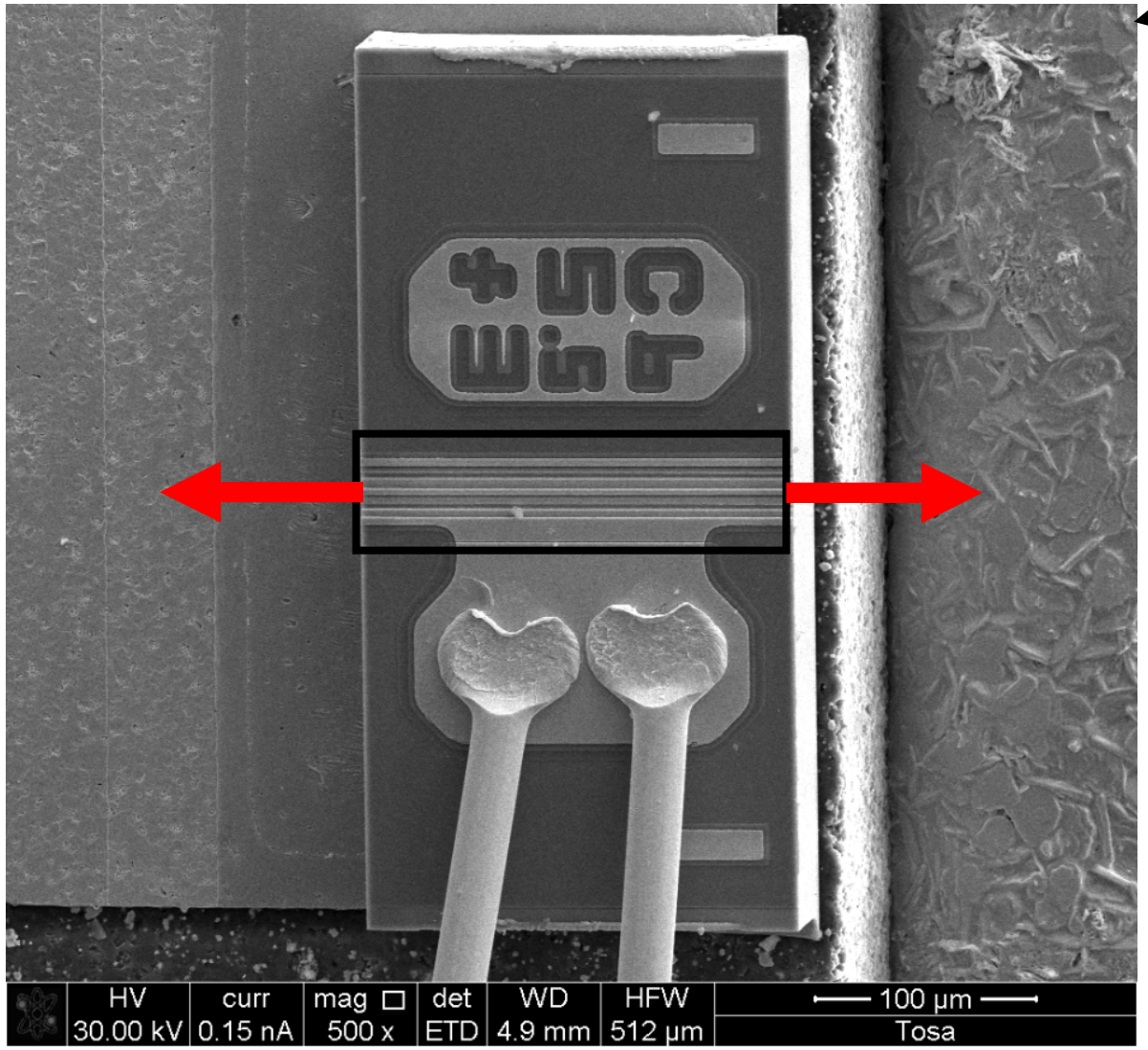
Ridge

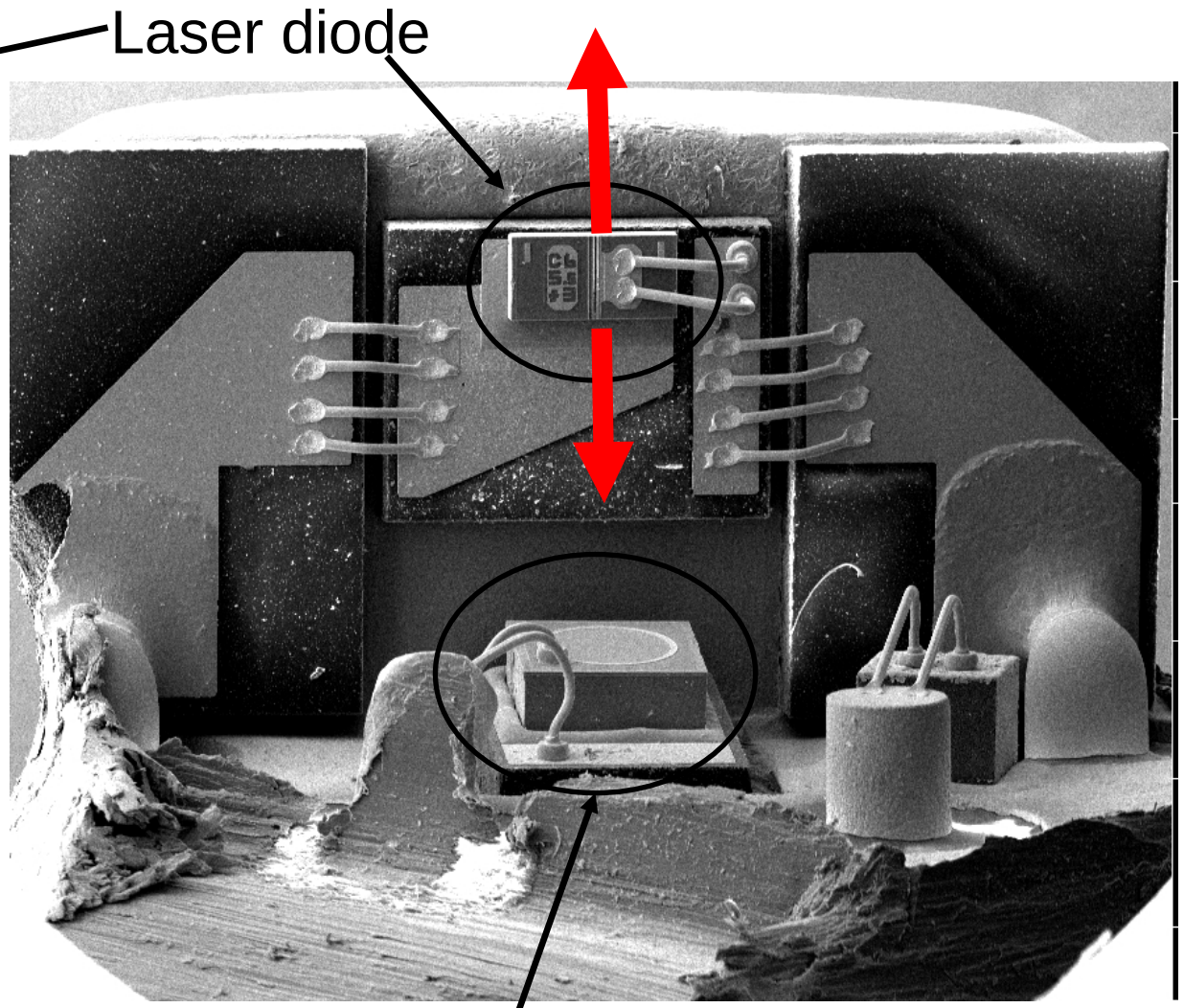


Laser assembly and vertical structure

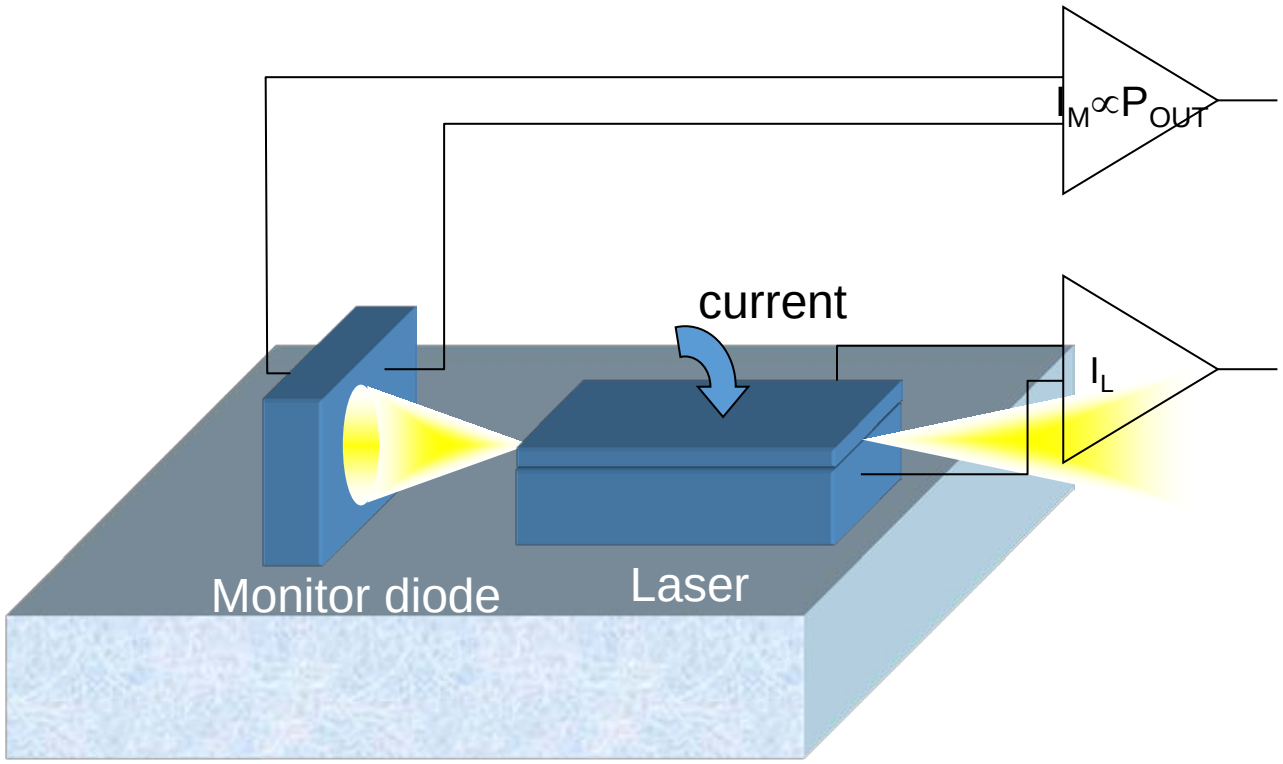


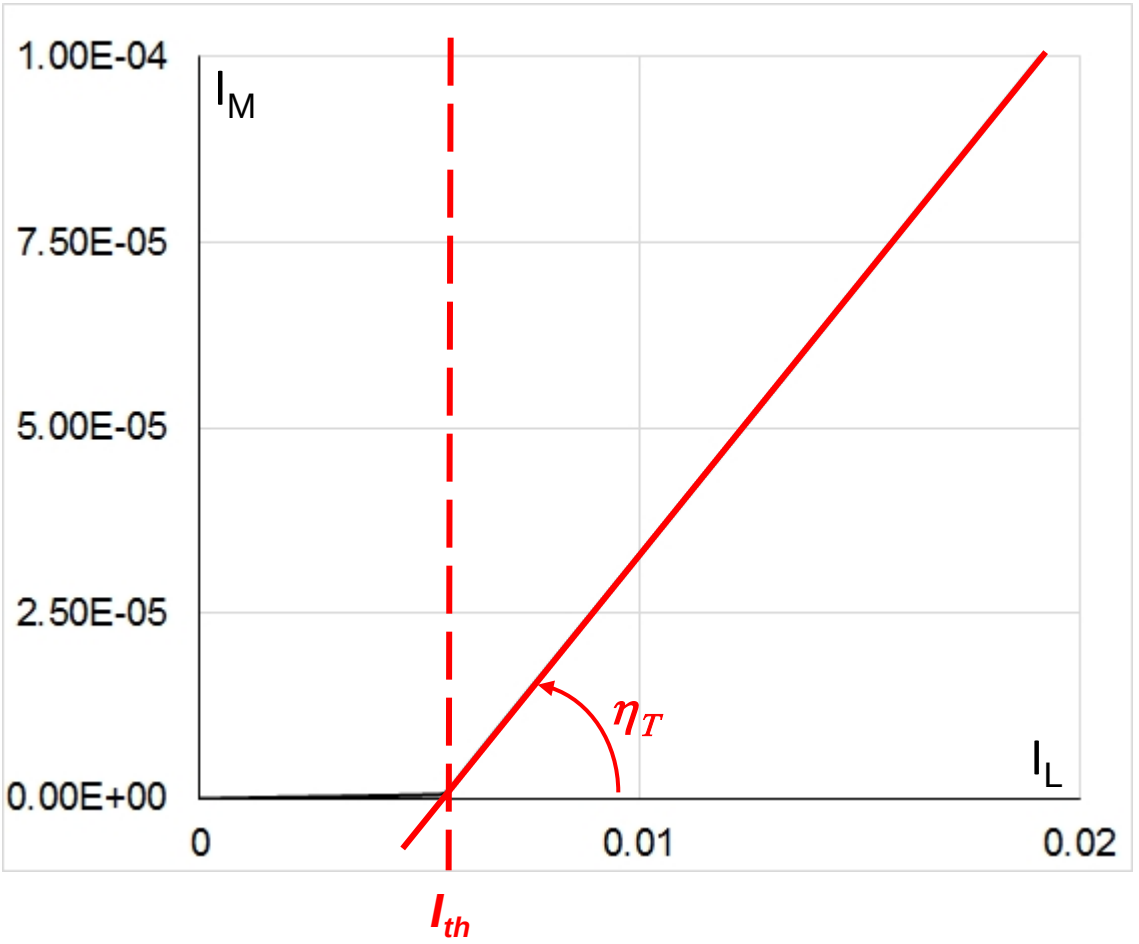
Laser assembly and vertical structure





Laser assembly and measurable quantities





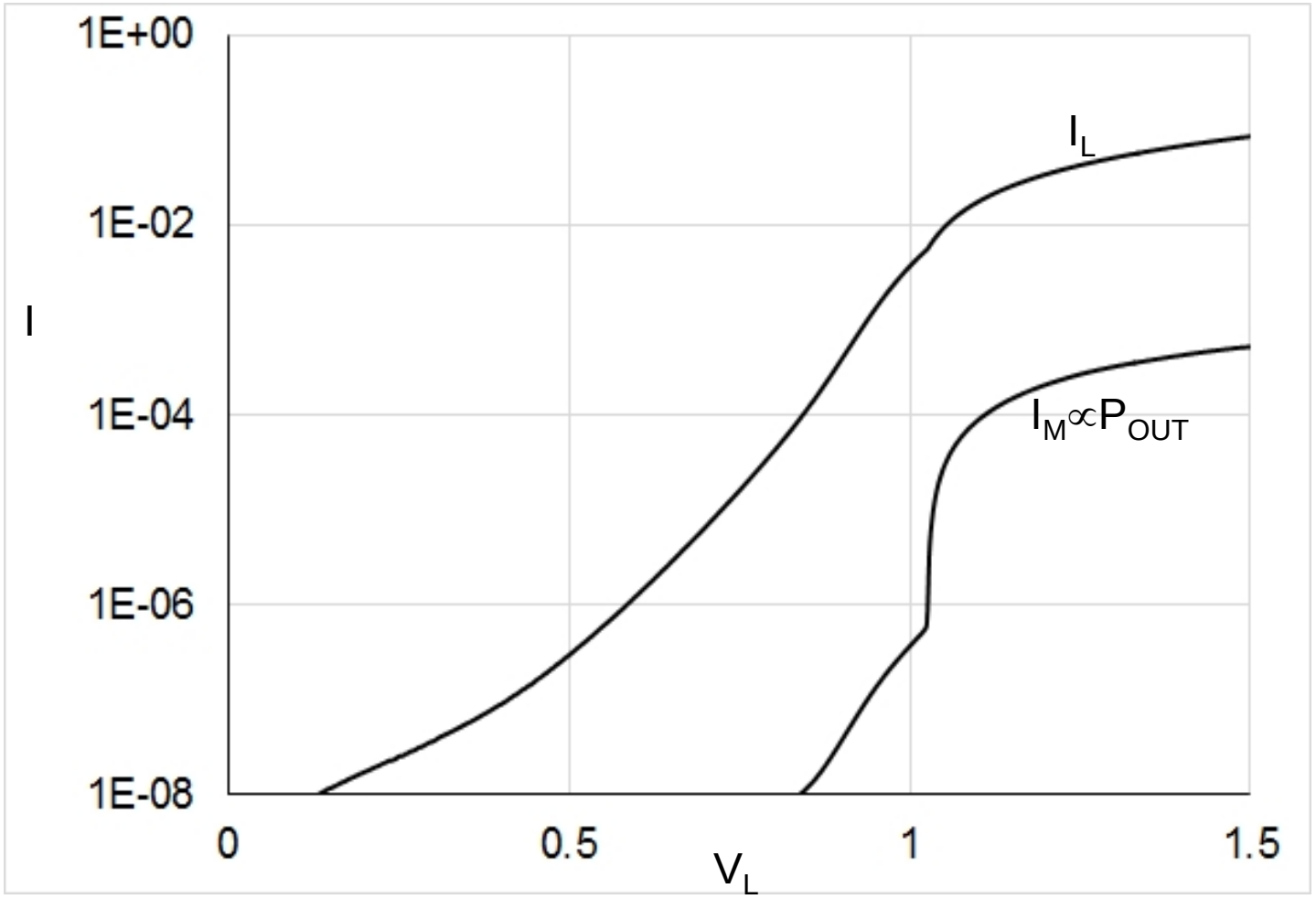
$$P_{OUT} = \eta_q \frac{h\nu_0}{q} \frac{\alpha_m}{\alpha_m + \alpha_i} (I - I_{th})$$

$$I_{th} = I_{th0} exp\left(\frac{\alpha_T}{g_0}\right)$$

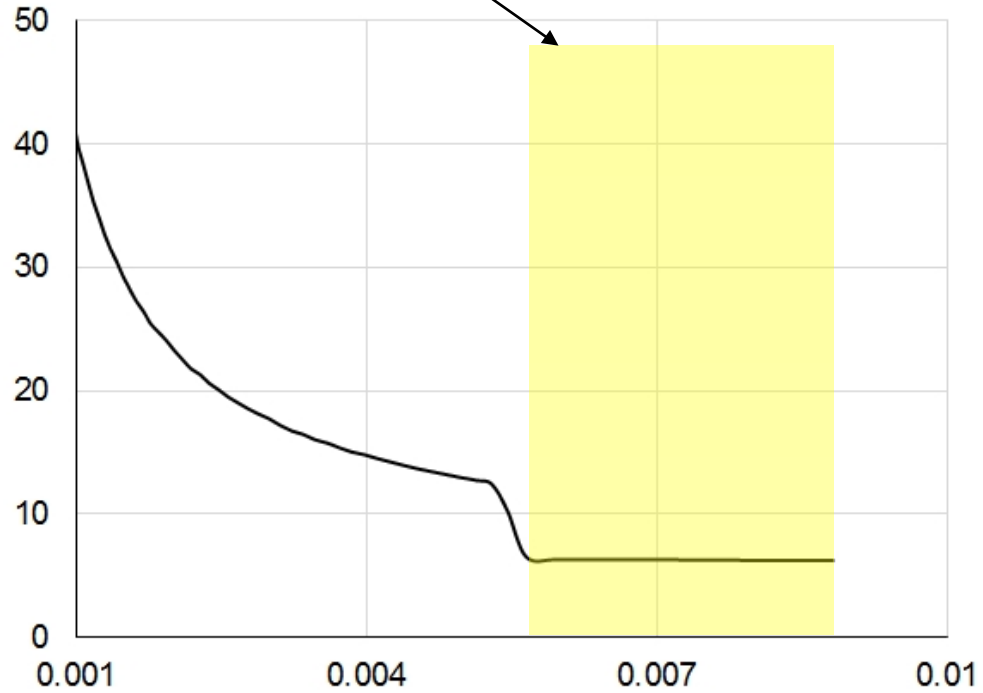
$$\eta_T = \eta_q \left(\frac{\alpha_m}{\alpha_T}\right)$$

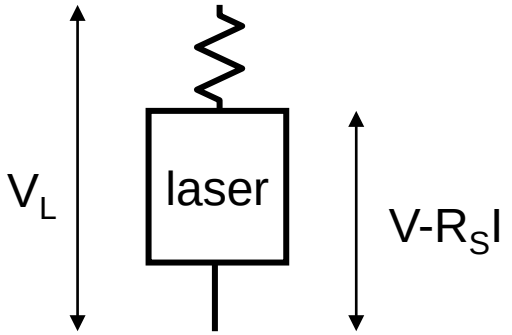
From current to voltage

Measuring $I_L(V_L)$ and $I_M(V_L)$

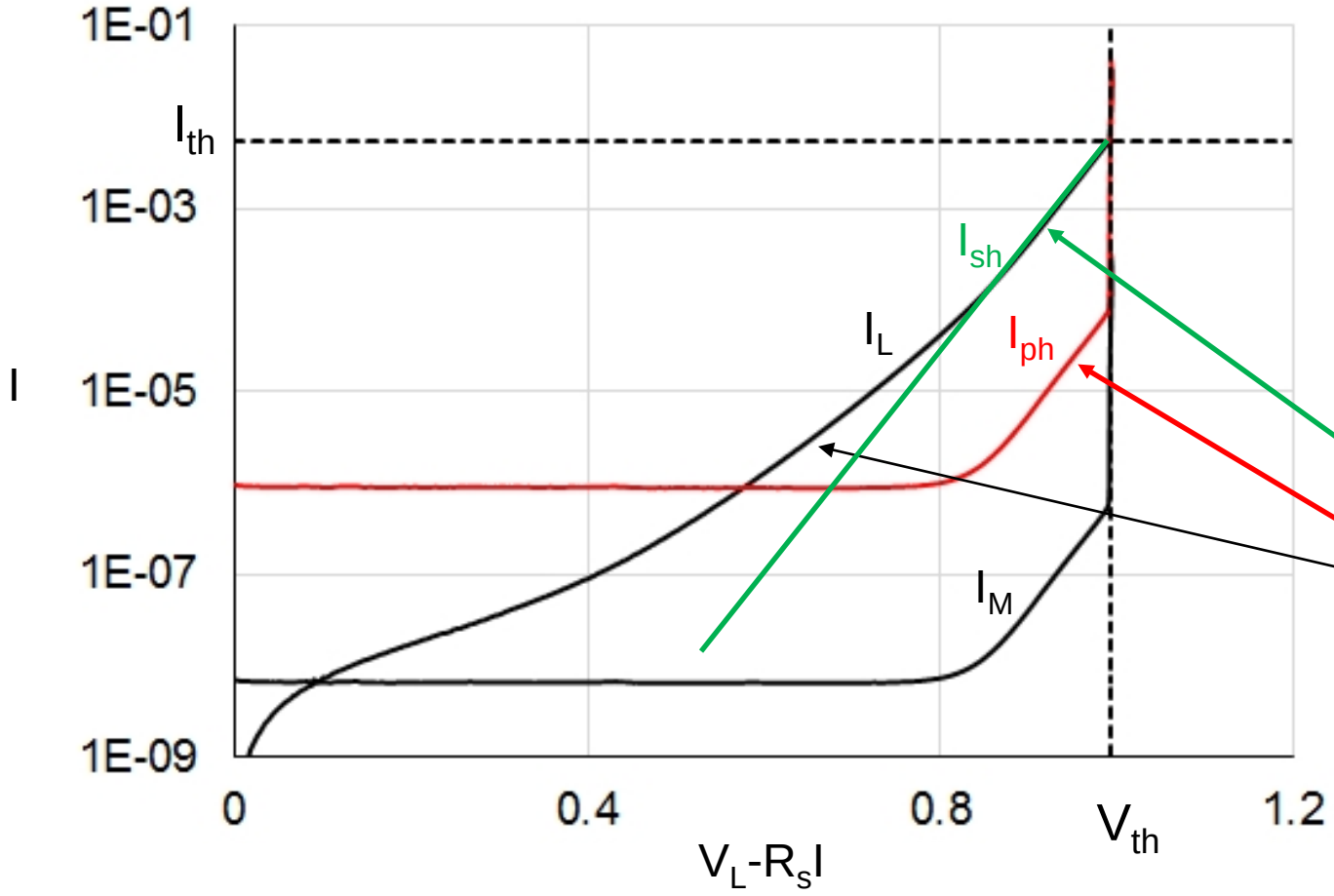


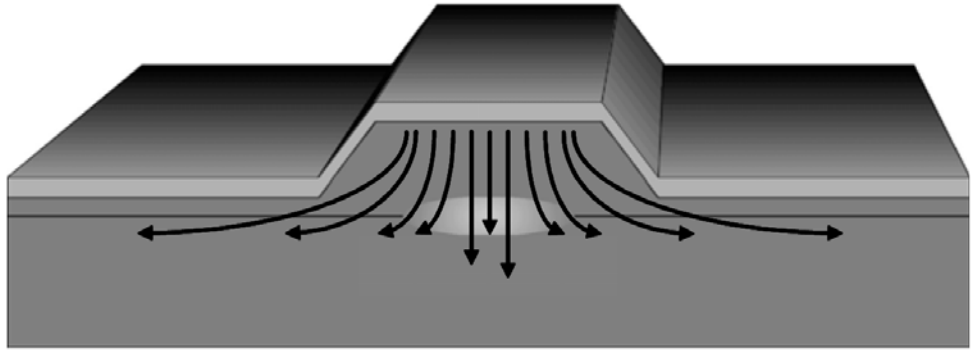
Ohmic range (differential) $\frac{dV_L}{dI_L} = R_S$





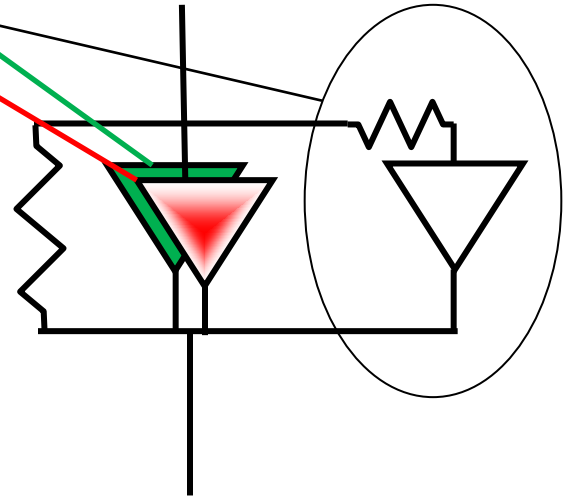
From current to voltage



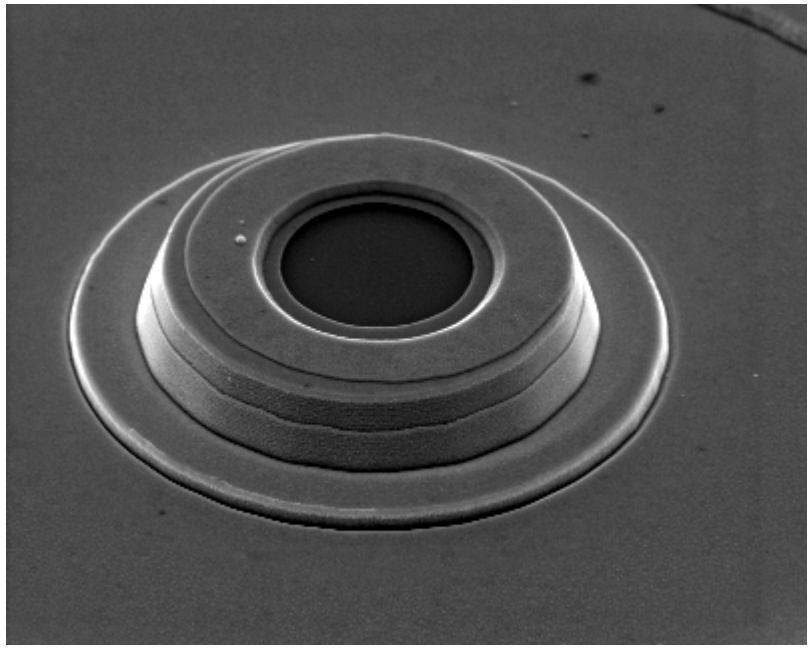


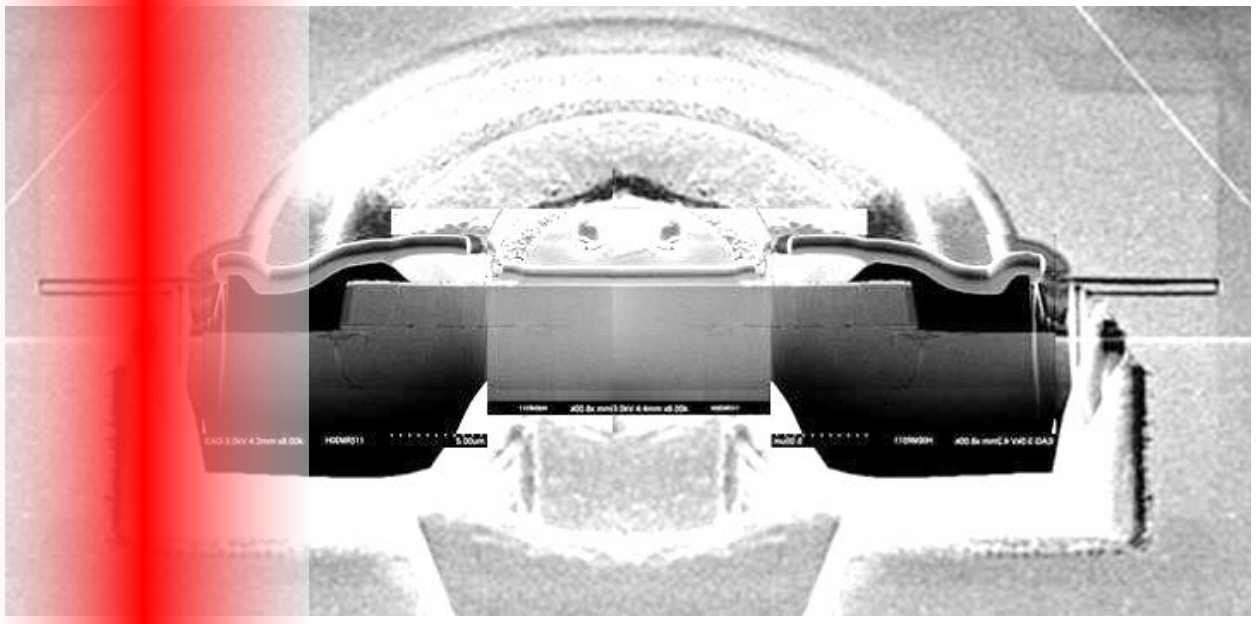
$$I_M \propto I_{ph} = KI_M$$

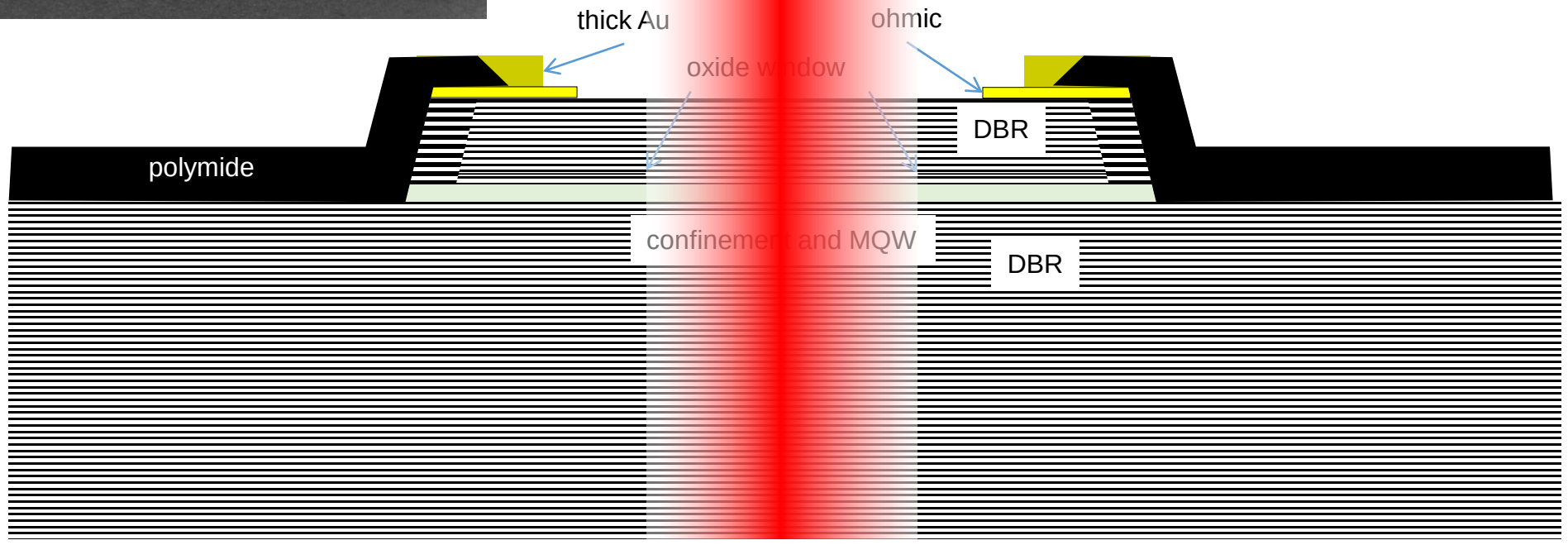
$$K = \frac{I_L - I_{th}}{I_M}$$



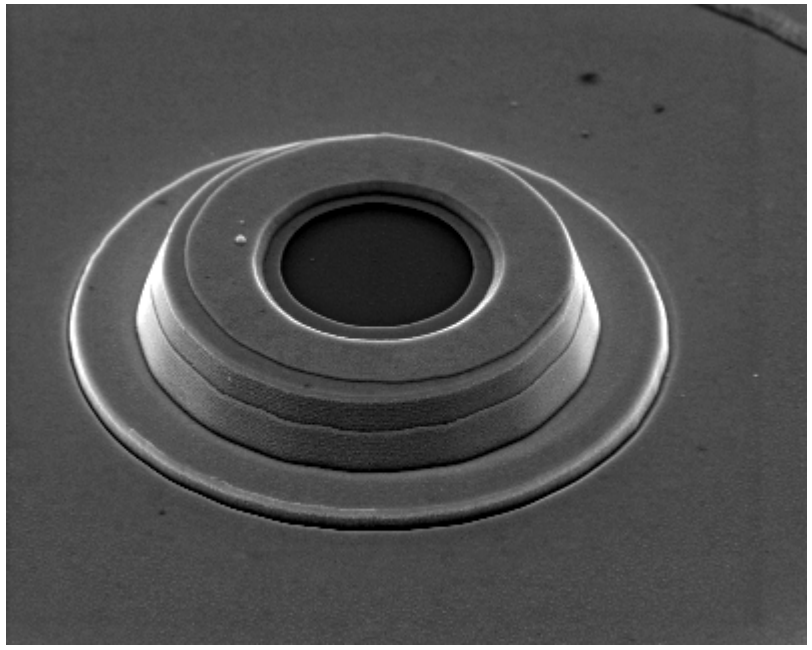
VCSEL

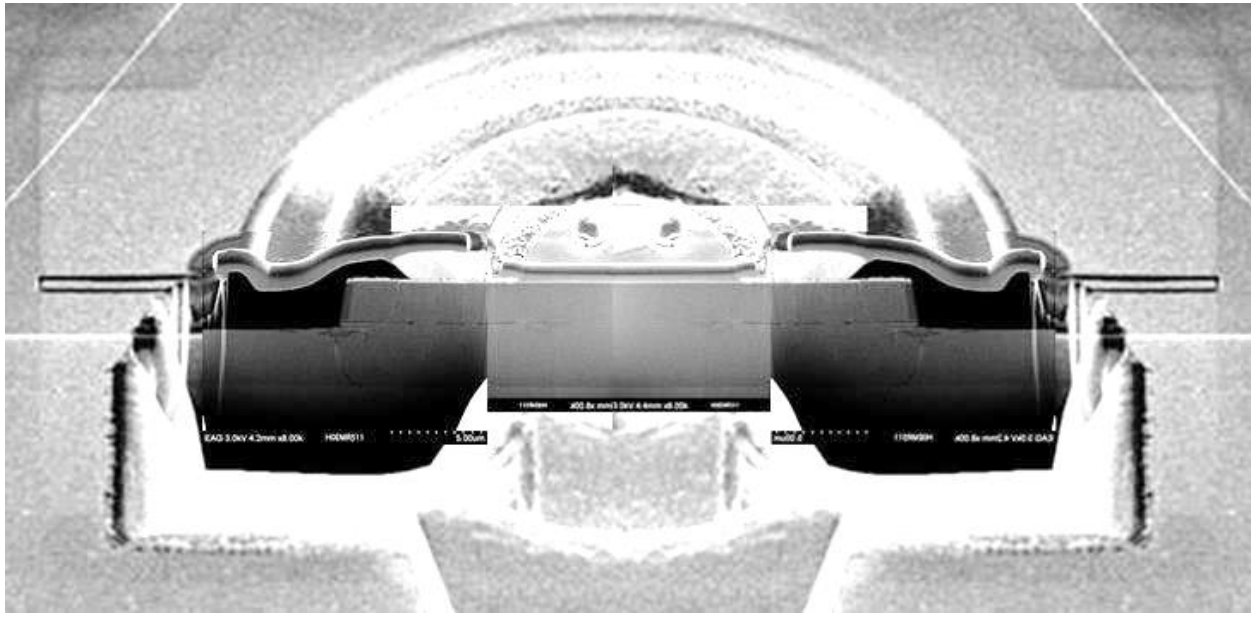


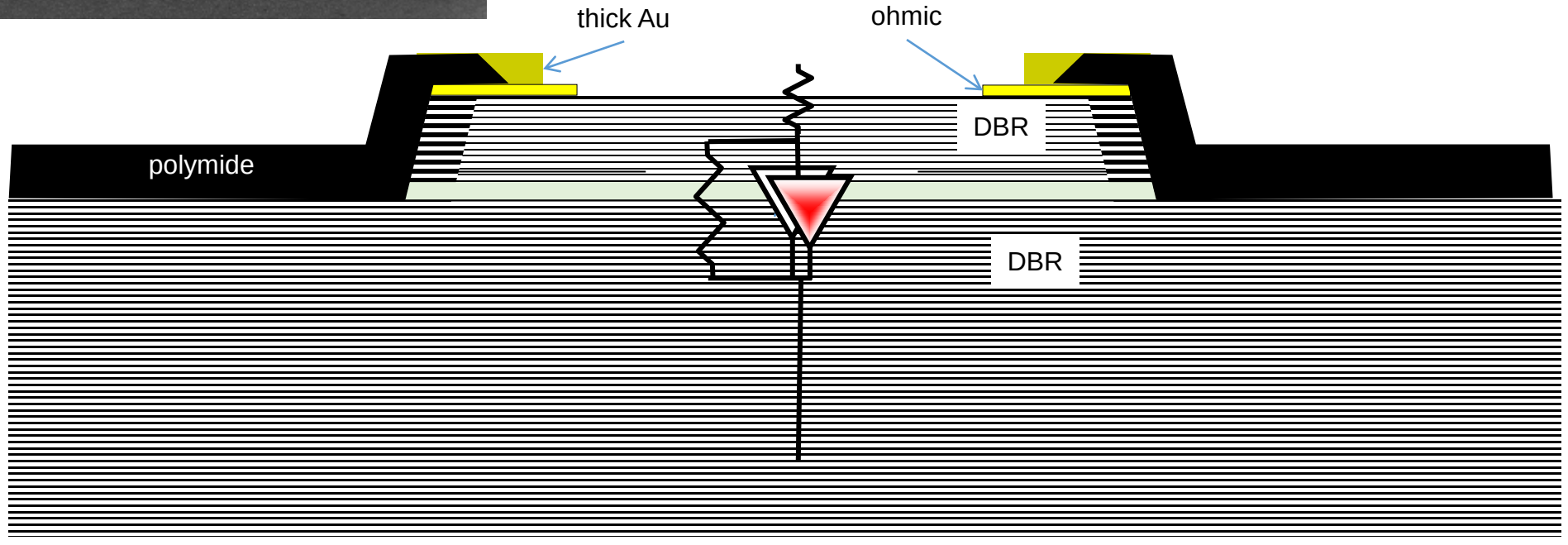



thick Au
ohmic
oxide window
DBR
polymide
confinement and MQW
DBR

VCSEL

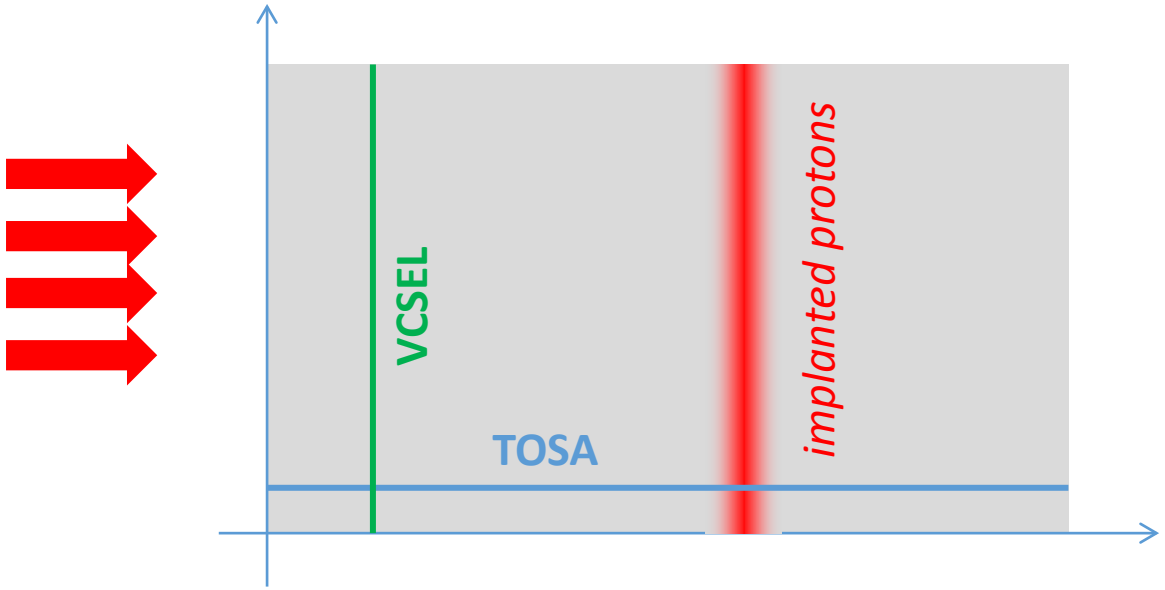






Proton Irradiation

Ion Energy 3MeV

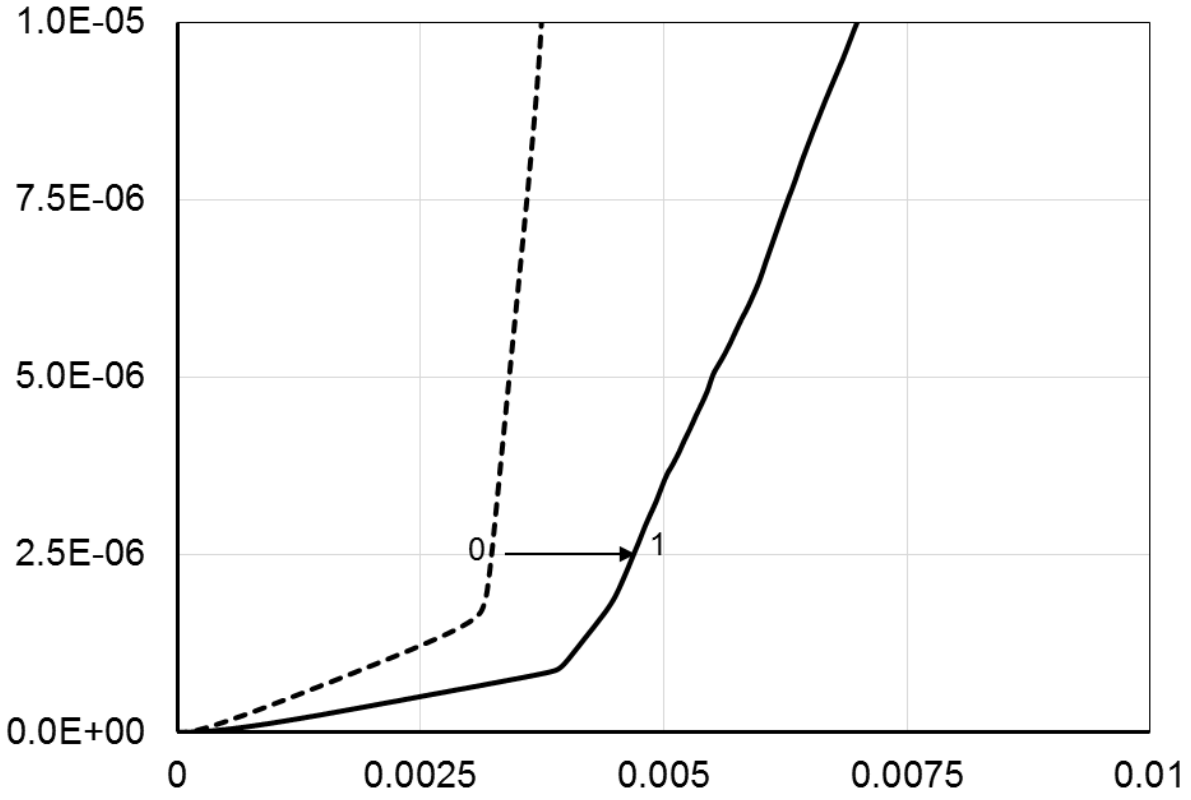


Hypothesis:

- Proton density in active region → Increase of I_{nr}
  Increase of I_{th}
  Decrease of η_T

Data analysis

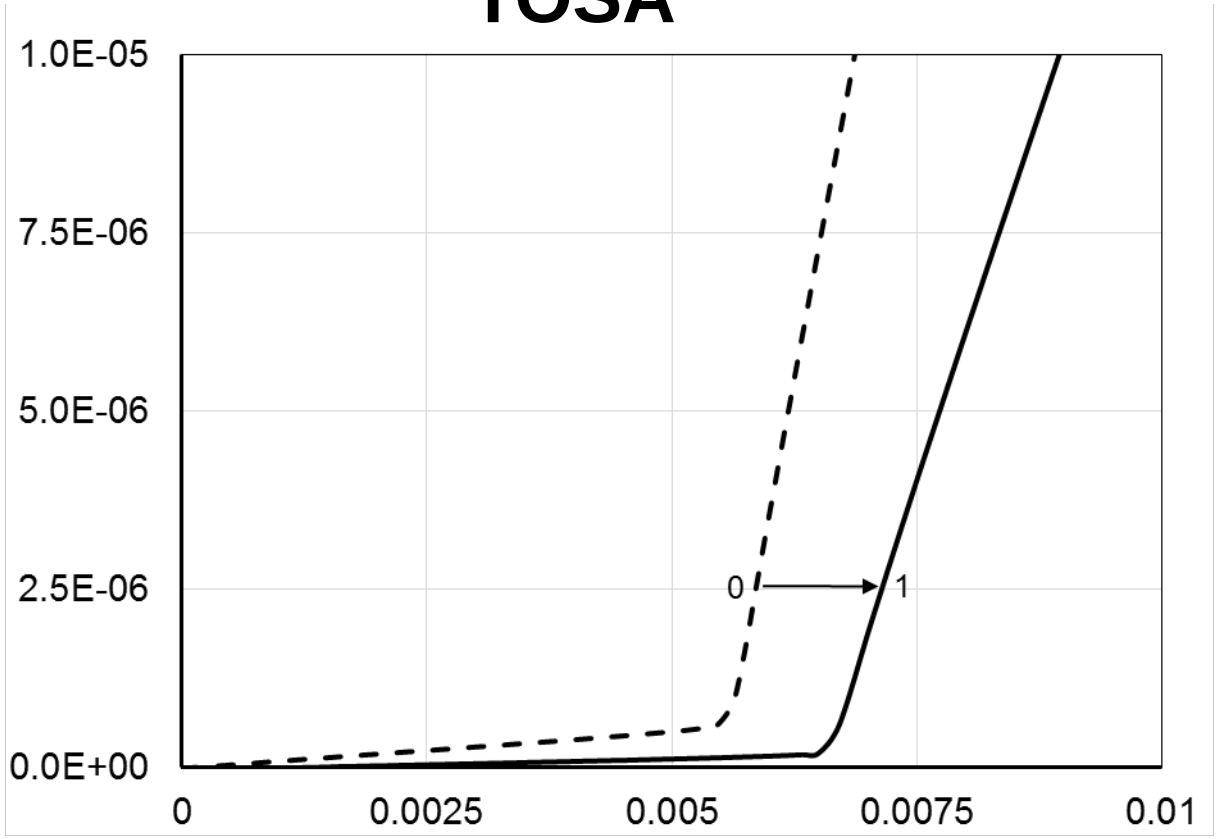
VCSEL



I_{th}=3.26mA ⟶ I_{th1}=4.10mA

$I_{th} \propto I_{nr} \longrightarrow N_t$

TOSA



I_{th}=5.51mA ⟶ I_{th1}=6.5mA

$$\eta_q = \frac{I_{ph}}{I_{ph} + I_{nr}}$$

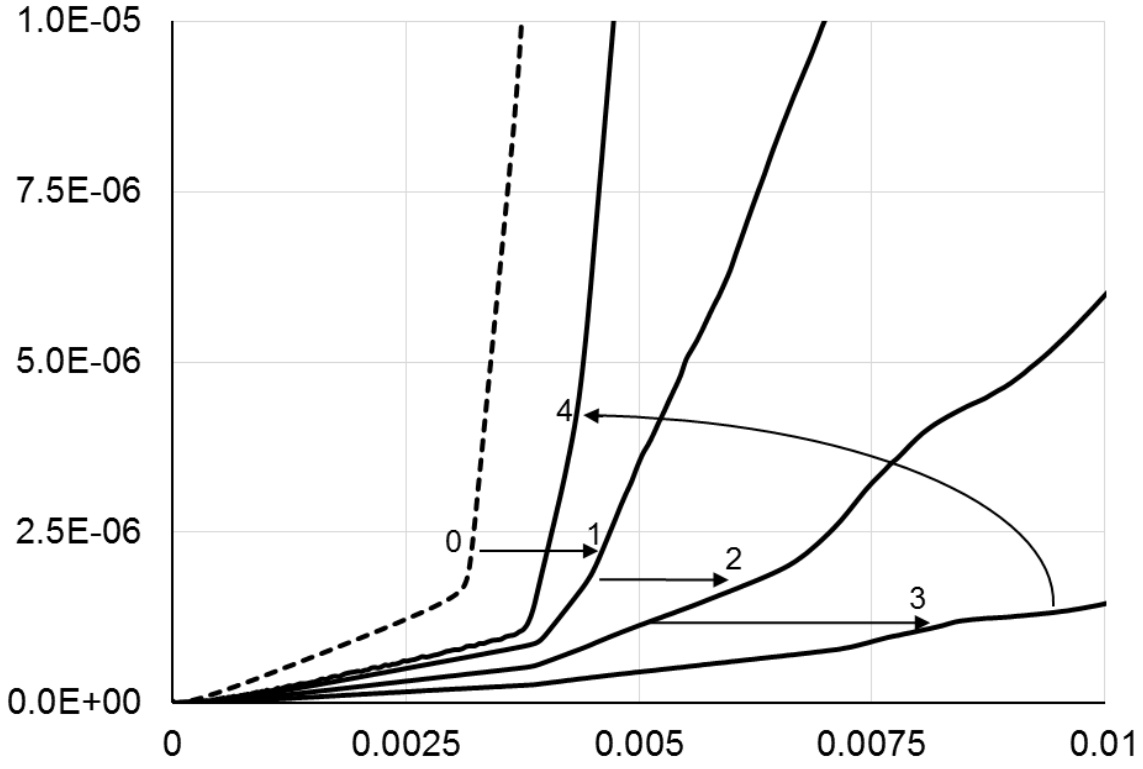
$$\eta_T = \eta_q \left(\frac{\alpha_m}{\alpha_T} \right)$$

The proton irradiation induced both an increase of the threshold current I_{th} *and* a corresponding decrease of the total optical efficiency η_T.

Time evolution

Data analysis

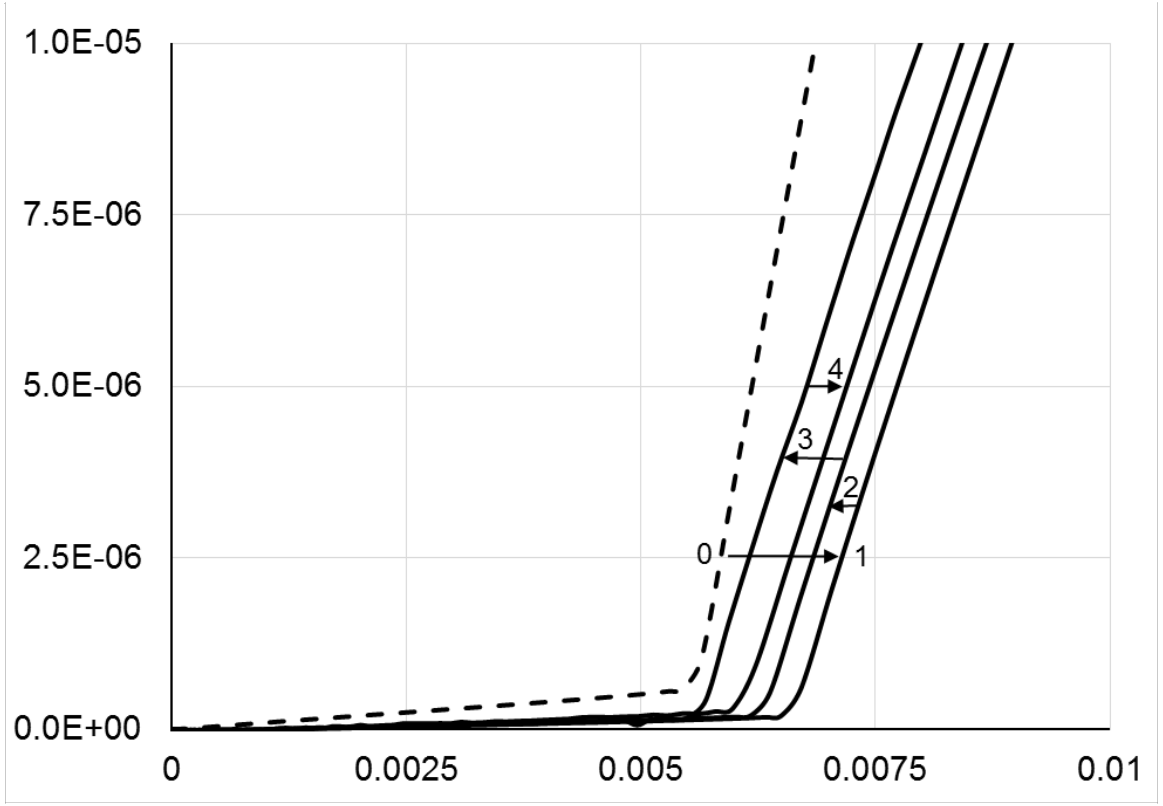
VCSEL



From state 0 to 3:
- increase of the threshold current I_{th}
- decrease of the total optical efficiency η_T

From state 3 to 4:
- Reinstatement of I_{th} and η_T

TOSA



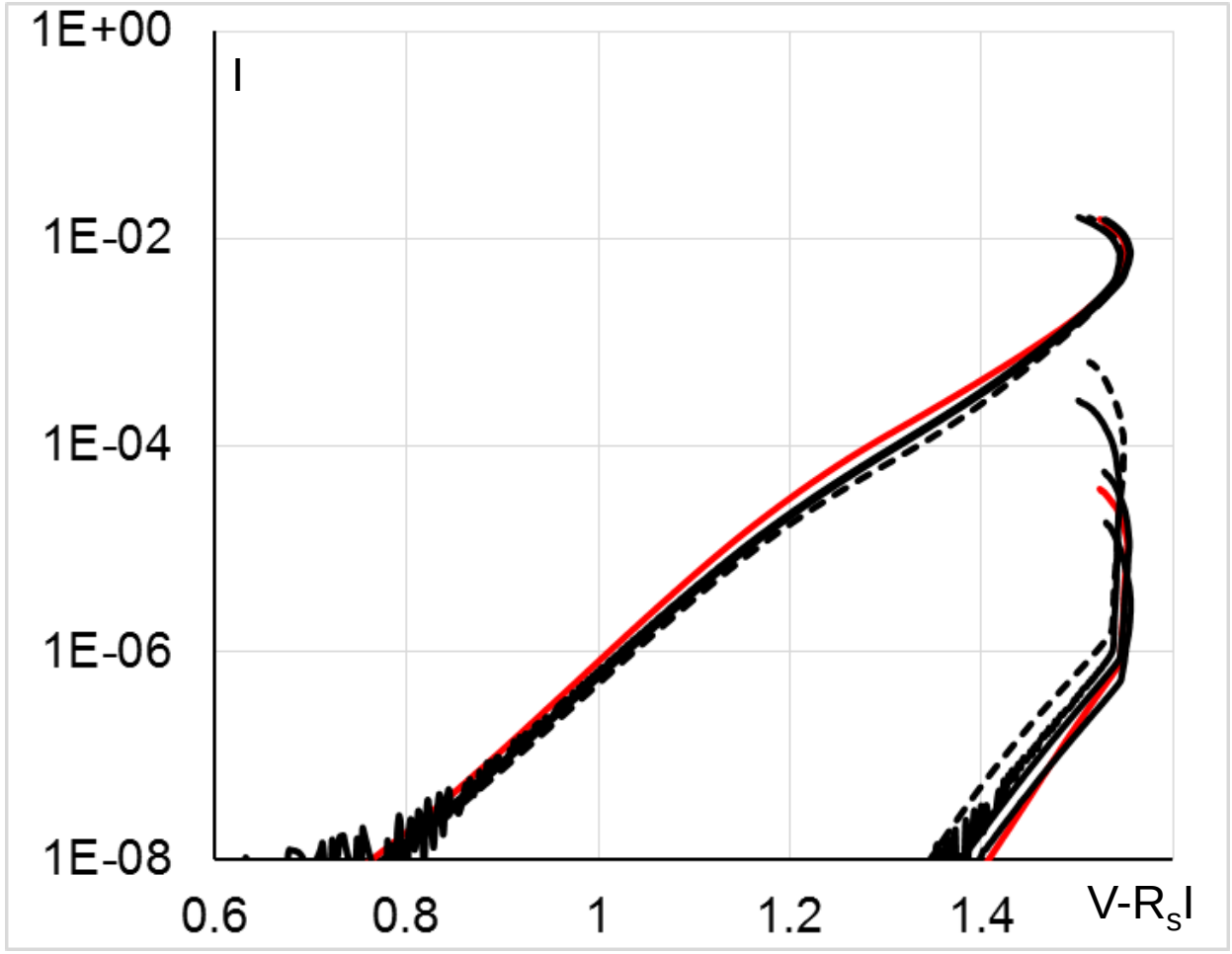
From state 0 to 1:
- increase of the threshold current I_{th}
- decrease of the total optical efficiency η_T

From state 1 to 3:
- Reinstatement of I_{th} but not η_T

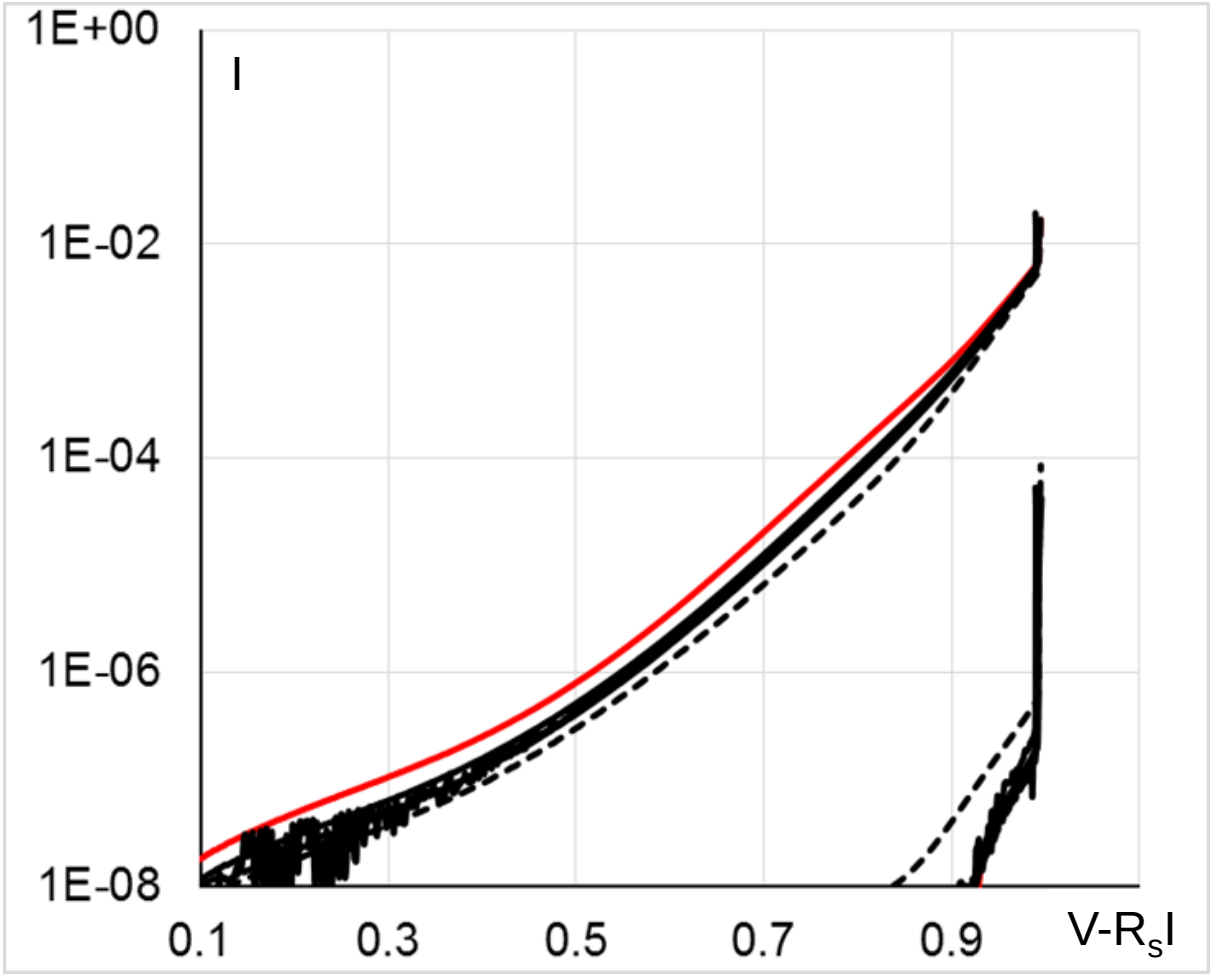
From state 3 to 4:
- increase of the threshold current I_{th}

Data analysis

VCSEL

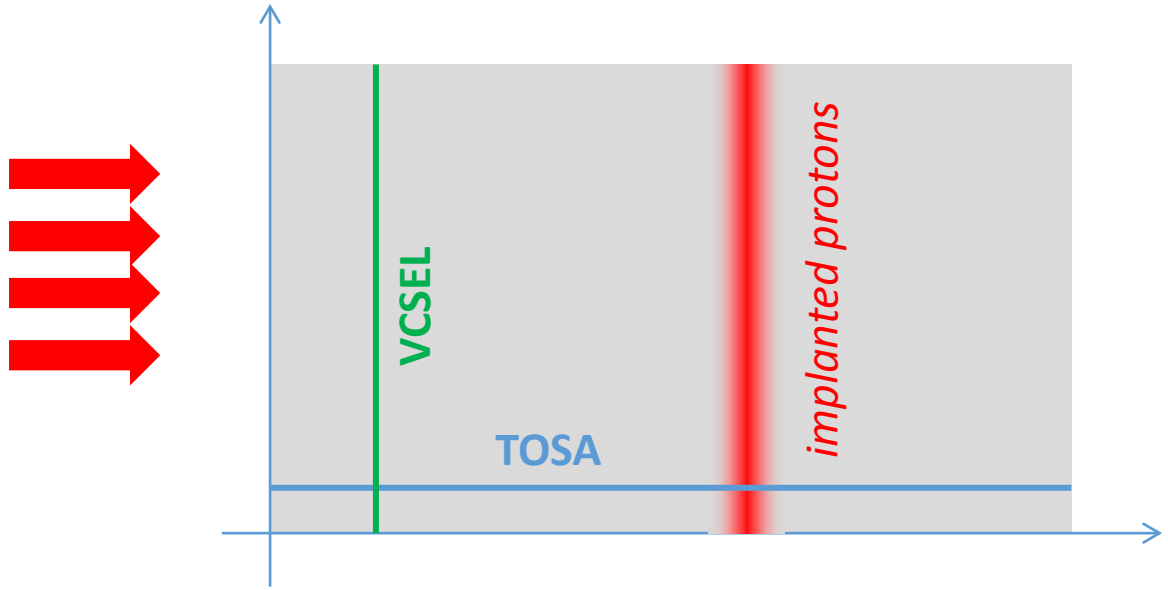


TOSA



Proton Irradiation

Ion Energy 3MeV



Hypothesis:

- Nuclear activation → Negligible
- Proton diffusion → Dominant
- Proton "recombination" → Negligible
- Proton density in active region

Proton diffusion

Diffusion Equation → $\frac{\partial C}{\partial t} = \nabla^2 C$

Théorie de la chaleur
Fourier (1822)
Heat equation

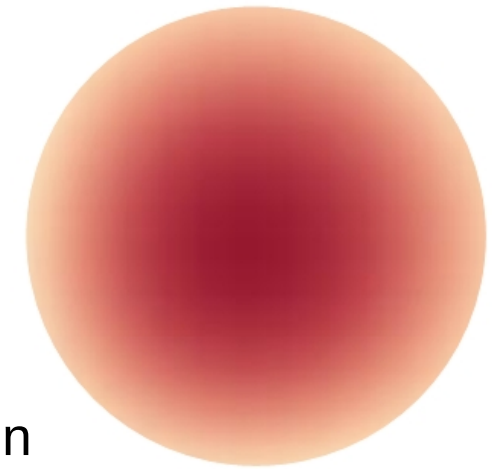
$$C = C_0 * G$$

Green function

$$G(x,y,z) = \frac{\exp\left[-\frac{\left(x^2+y^2+z^2\right)}{4Dt}\right]}{[4\pi Dt]^{3/2}}$$

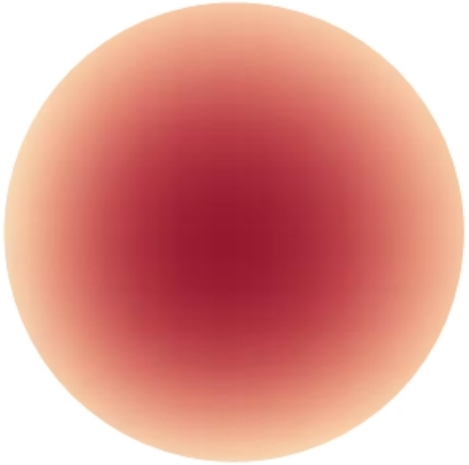
Gaussian profile of implantation

$$C_0(x_0,y_0,z_0) = C_0(x_0) = \frac{S}{\sqrt{2\pi}\Delta R_p}\exp\left[-\frac{(x_0-R_p)^2}{2\Delta R_p^2}\right] \xrightarrow[\Delta R_p \to 0]{} S\delta(x_0-R_p)$$

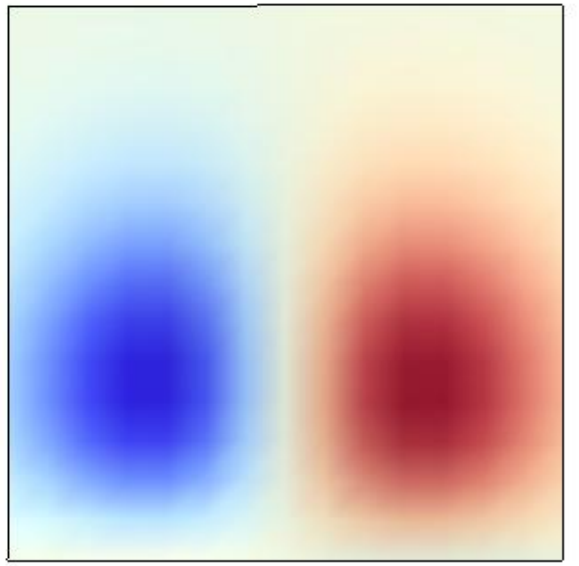


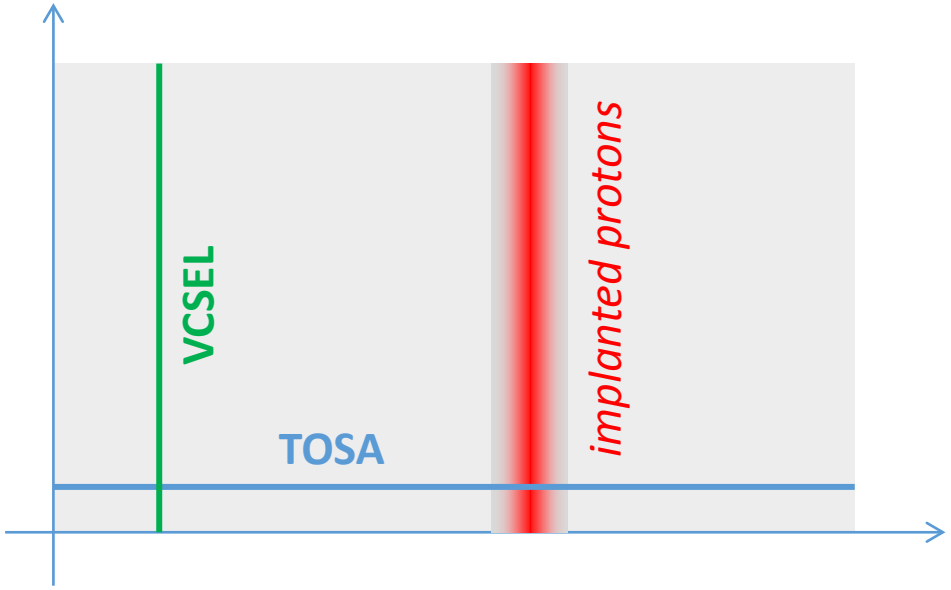
Infinite three-dimensional domain

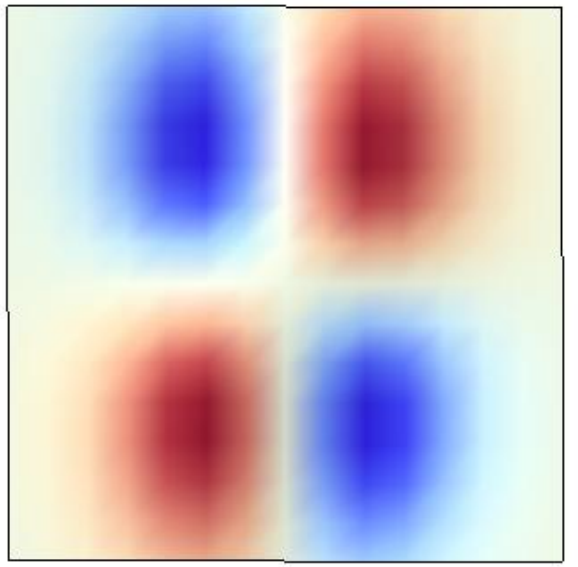
Proton diffusion



Not infinite three-dimensional domain → Image method from electrostatics

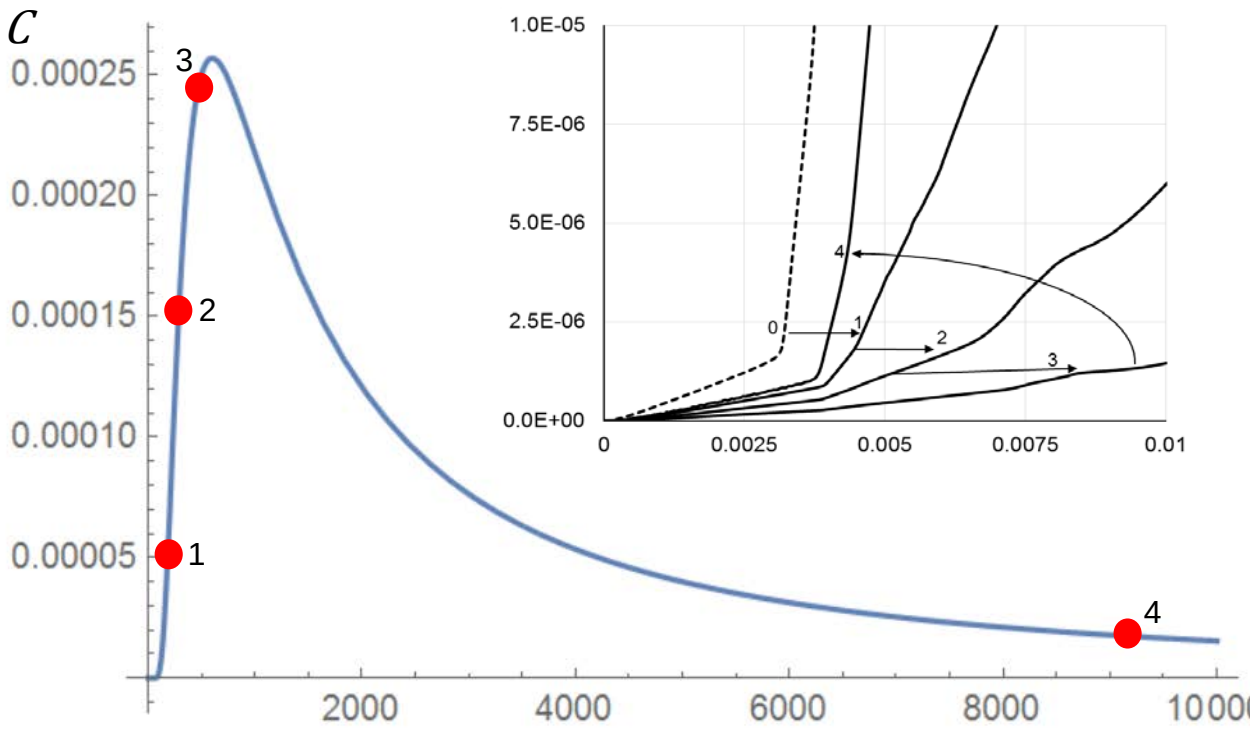




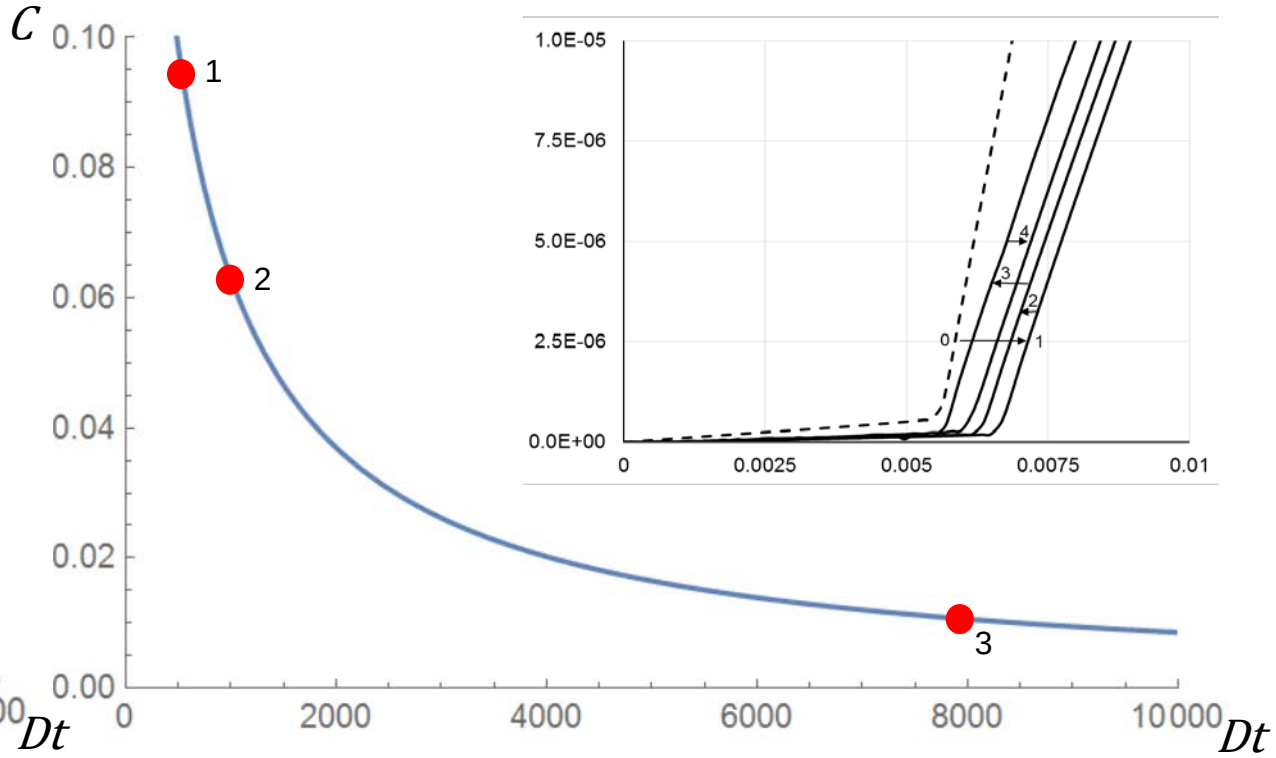


Proton diffusion

VCSEL



TOSA



Discussion and conclusions:

- Open points:
  - 1. The fourth measurament of the TOSA
  - 2. The fast recovery of VCSEL («recombination»?)
  - 3. The finite value of ΔR_p
- Further investigations:
  - Kinetics at different temperatures
  - Kinetics under operational life
  - Kinetics under combined stresses (T,I)