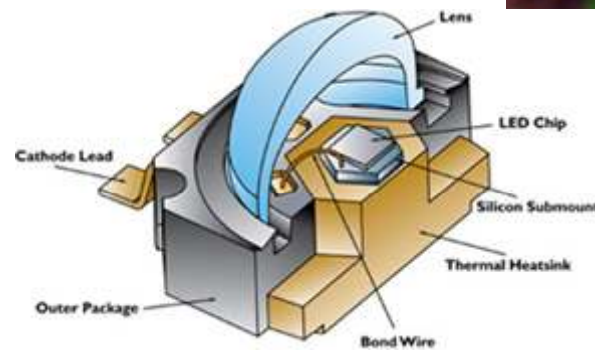


Dušan Pudiš
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Polovodičová LED, laserová dióda

Polovodiče pre optoelektroniku

III.	IV.	V.	VI.
B	C	P	O
Al	Si	N	S
Ga	Ge	As	Se
In	Sn	Sb	Te
Th	Pb	Bi	Po

GaAs, InSb, GaN
– binárne III-V

AlGaAs, GaAsP
– ternárne, III-III-V, III-V-V

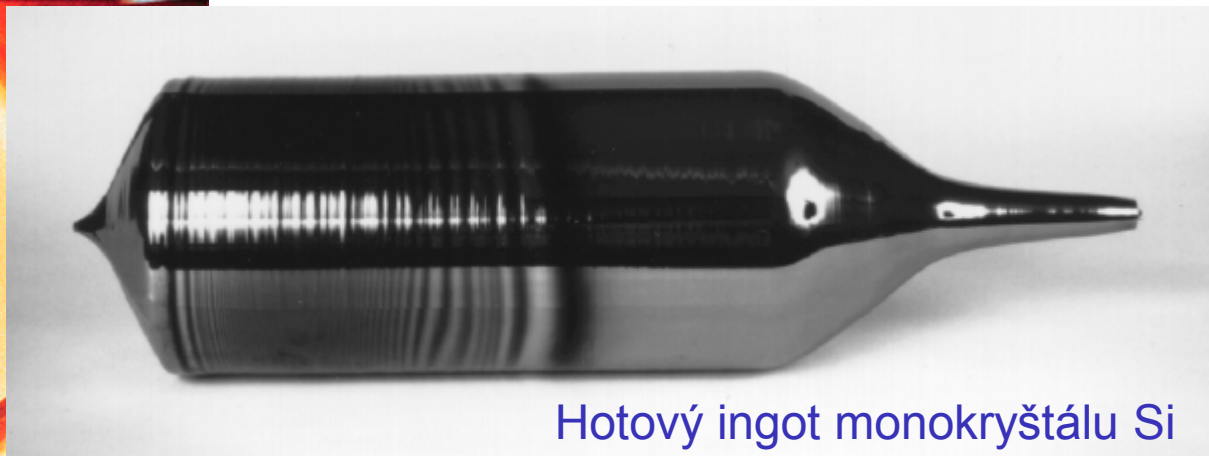
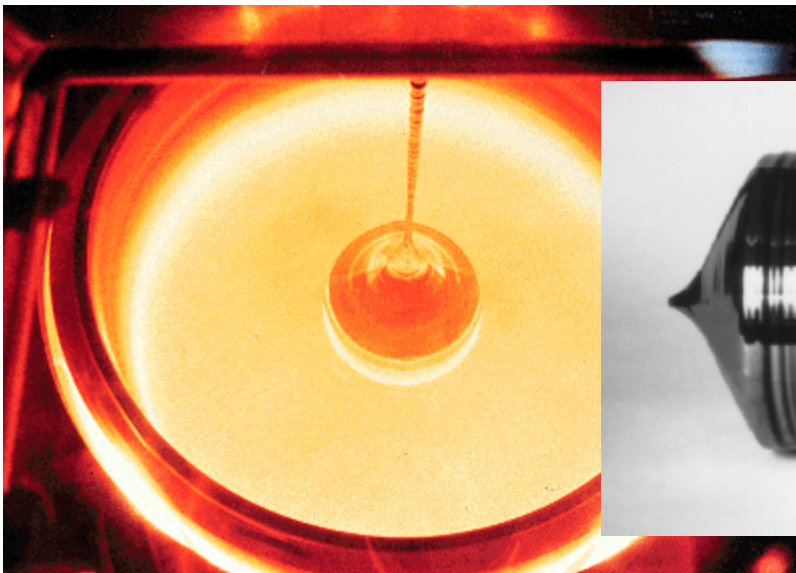


Ingoty pre polovodičový substrát

Odrezaný a vyleštený Si substrát

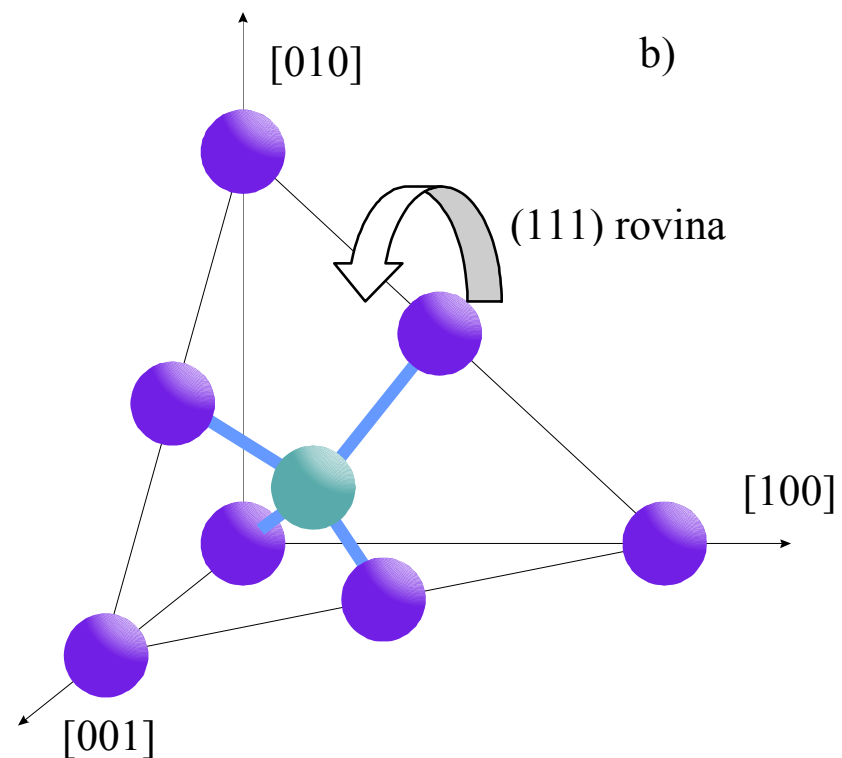
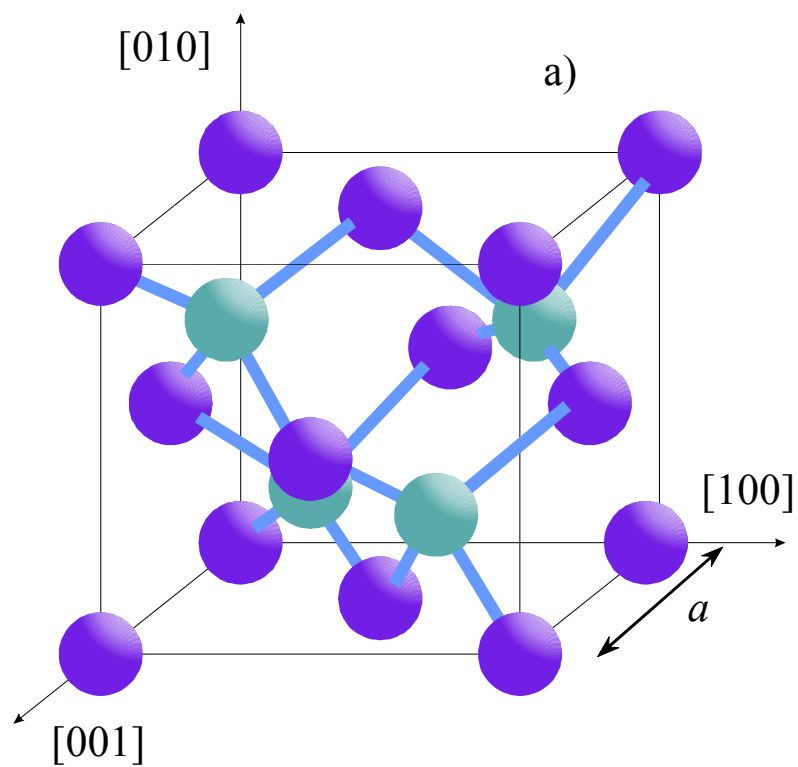


Ťahanie ingotov z taveniny Si pri 1400°C

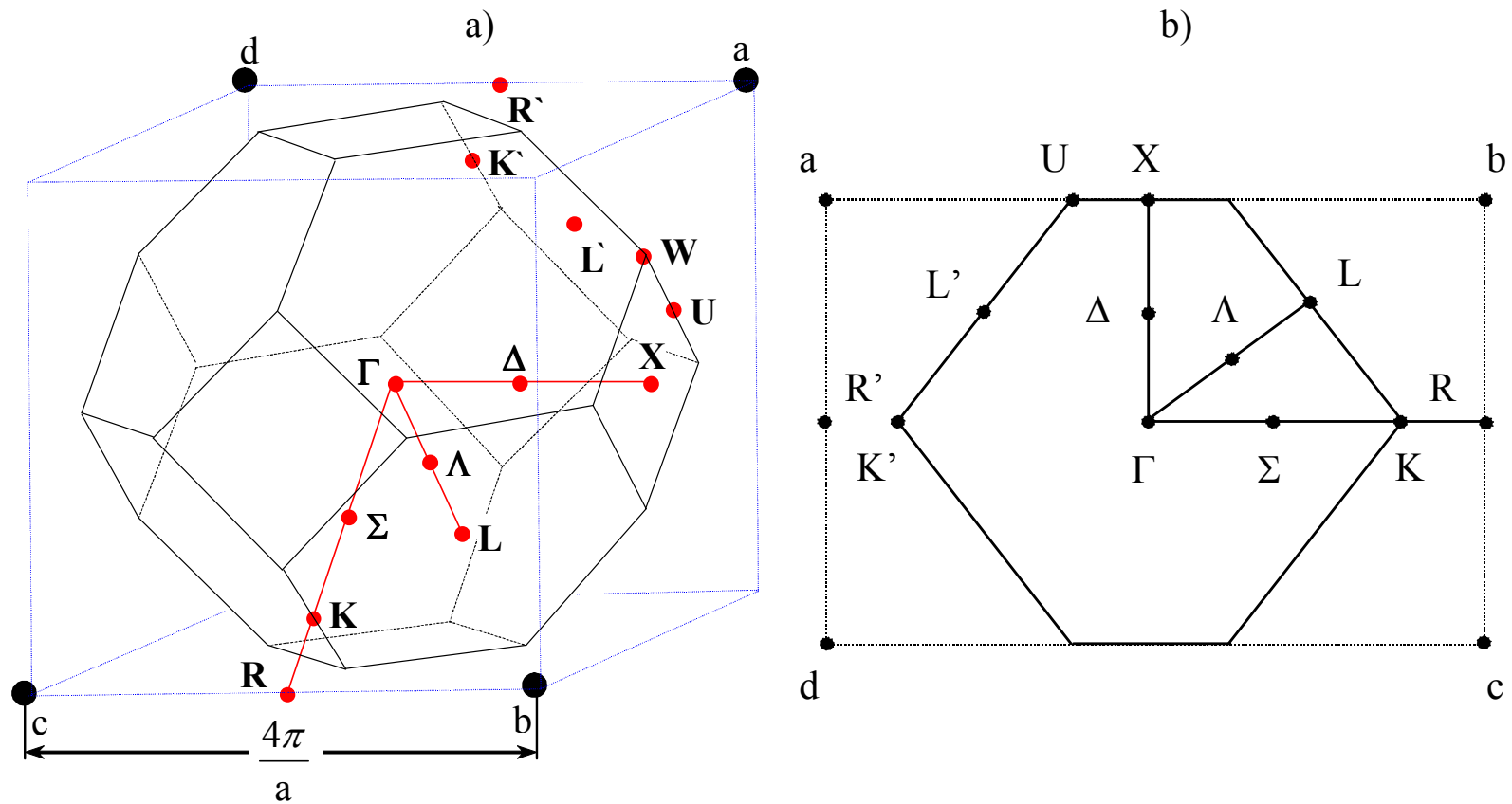


Hotový ingot monokryštálu Si

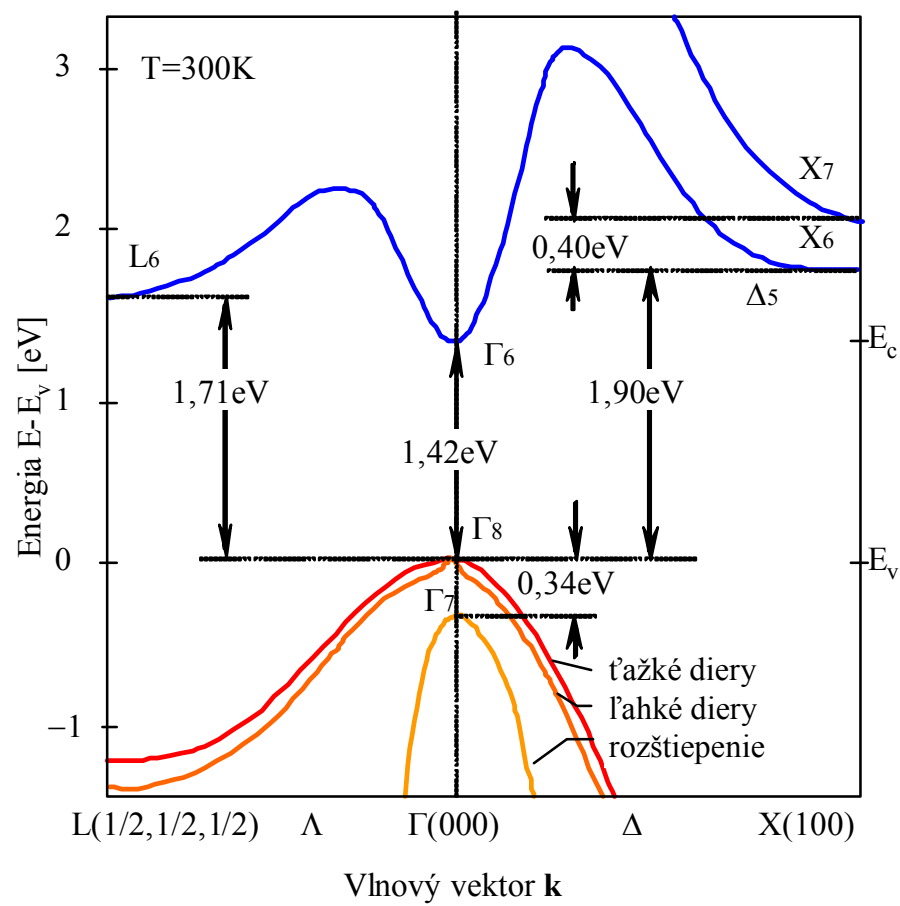
Kryštalická mriežka polovodičov



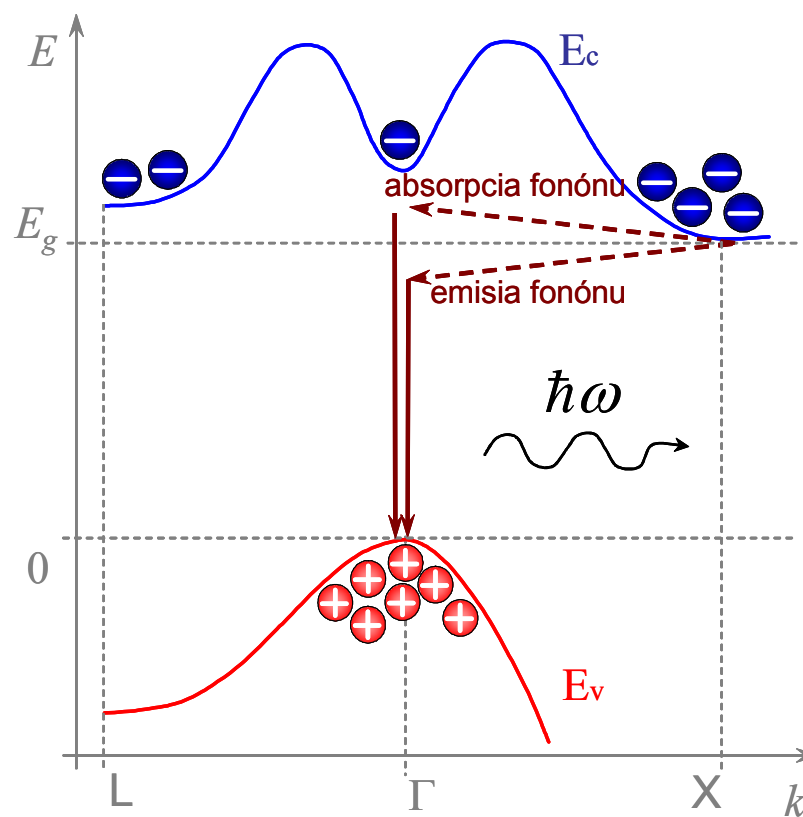
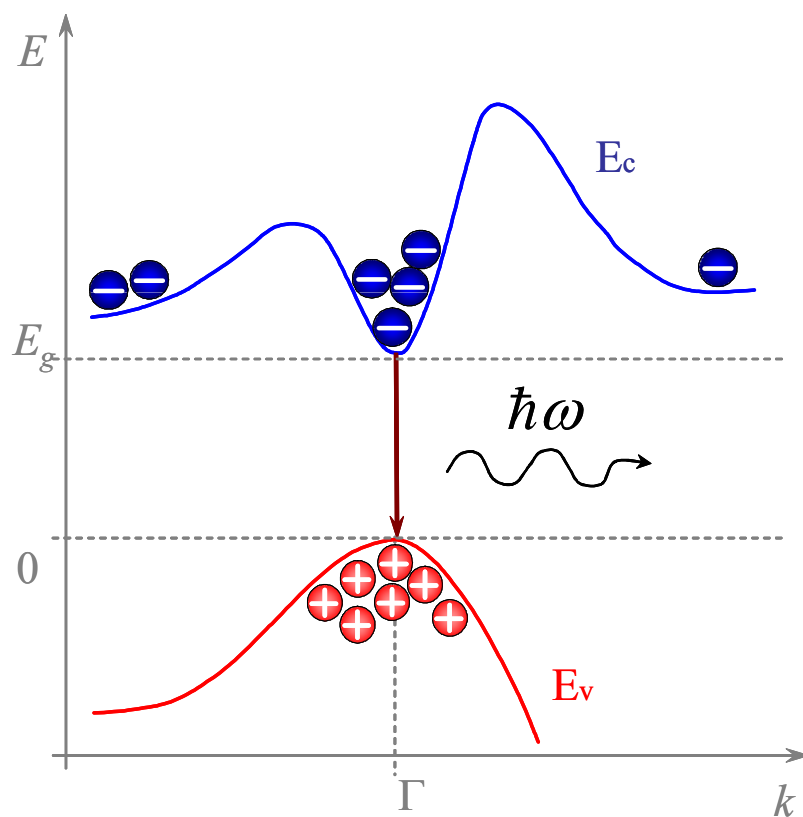
Brillouinova zóna



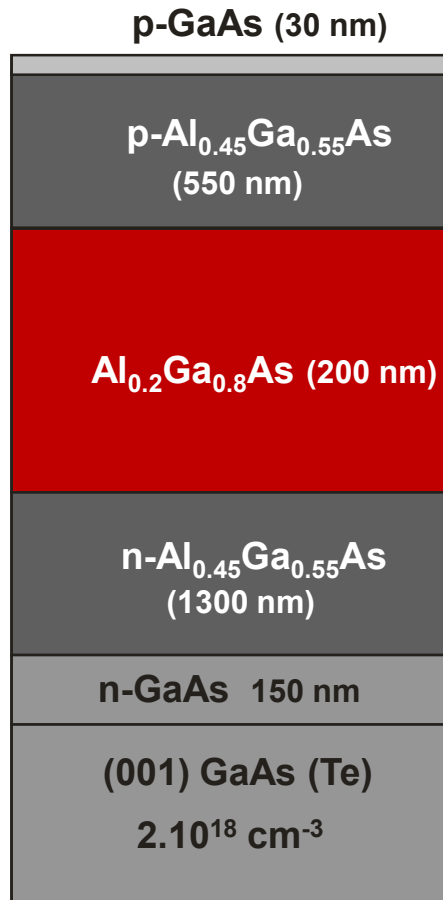
Energetický pásmový diagram polovodičov



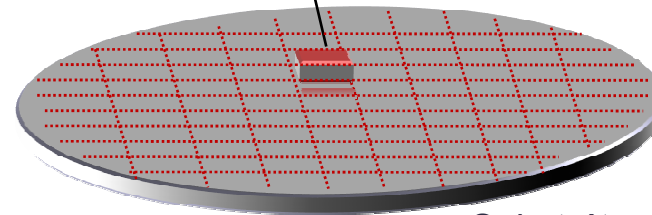
Optický prechod (priamy a nepriamy)



Ako sa robí LED? - štruktúra a čip



Čip (0,5 x 0,5 mm)



Substrátová doska
(wafer), 2-10 inch



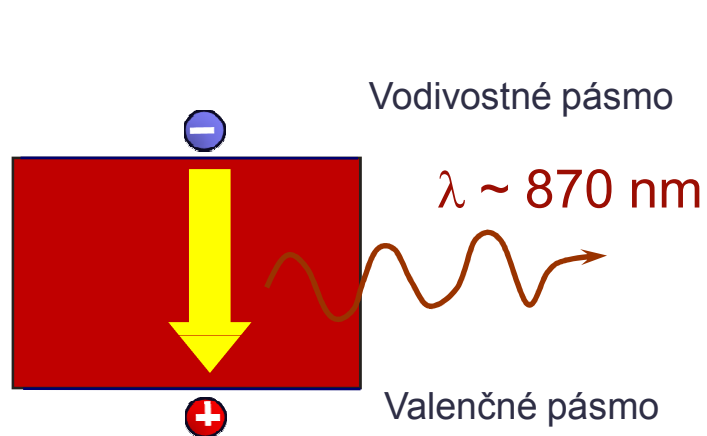
Vodivostné pásmo



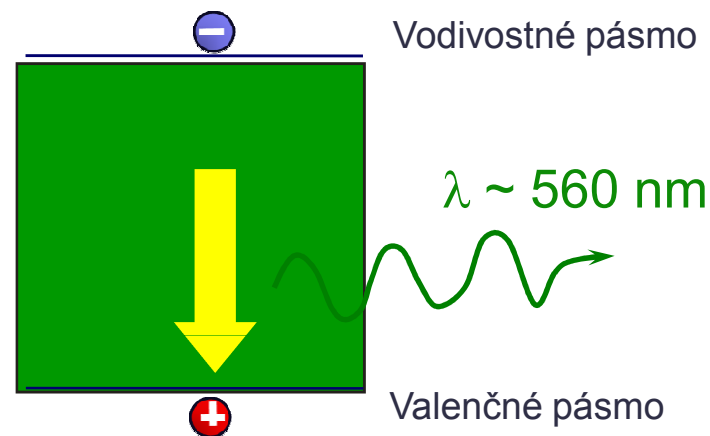
Valenčné pásmo



Ako dosiahnuť rôzne vlnové dĺžky emisie?



GaAs

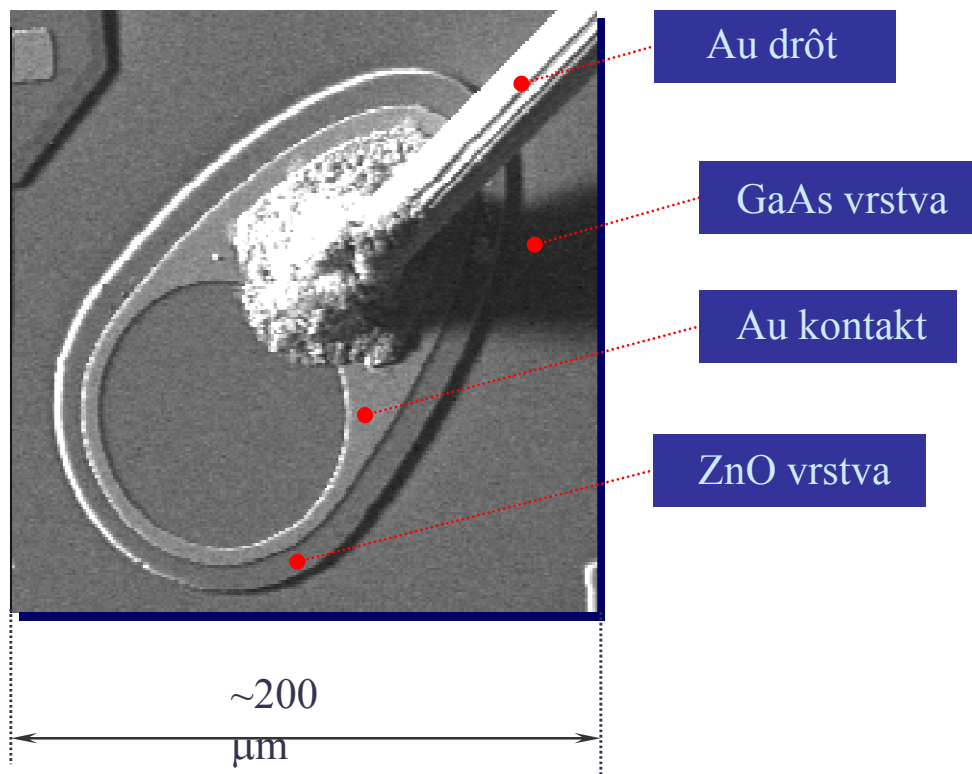


GaP

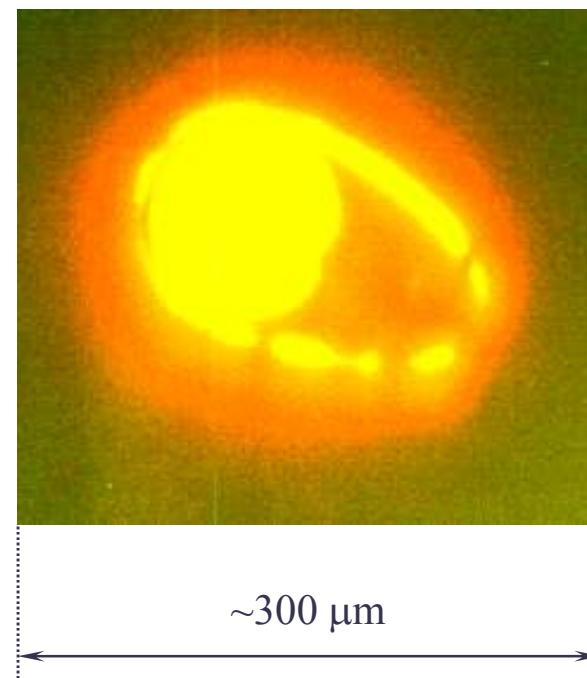
Vlnové dĺžky (farby) polovodičových laserov:

UV, blue (405), green (550), red (635, 650), IR (780, 920, 1310, 1550)

Elektroluminiscenčná dióda - LED

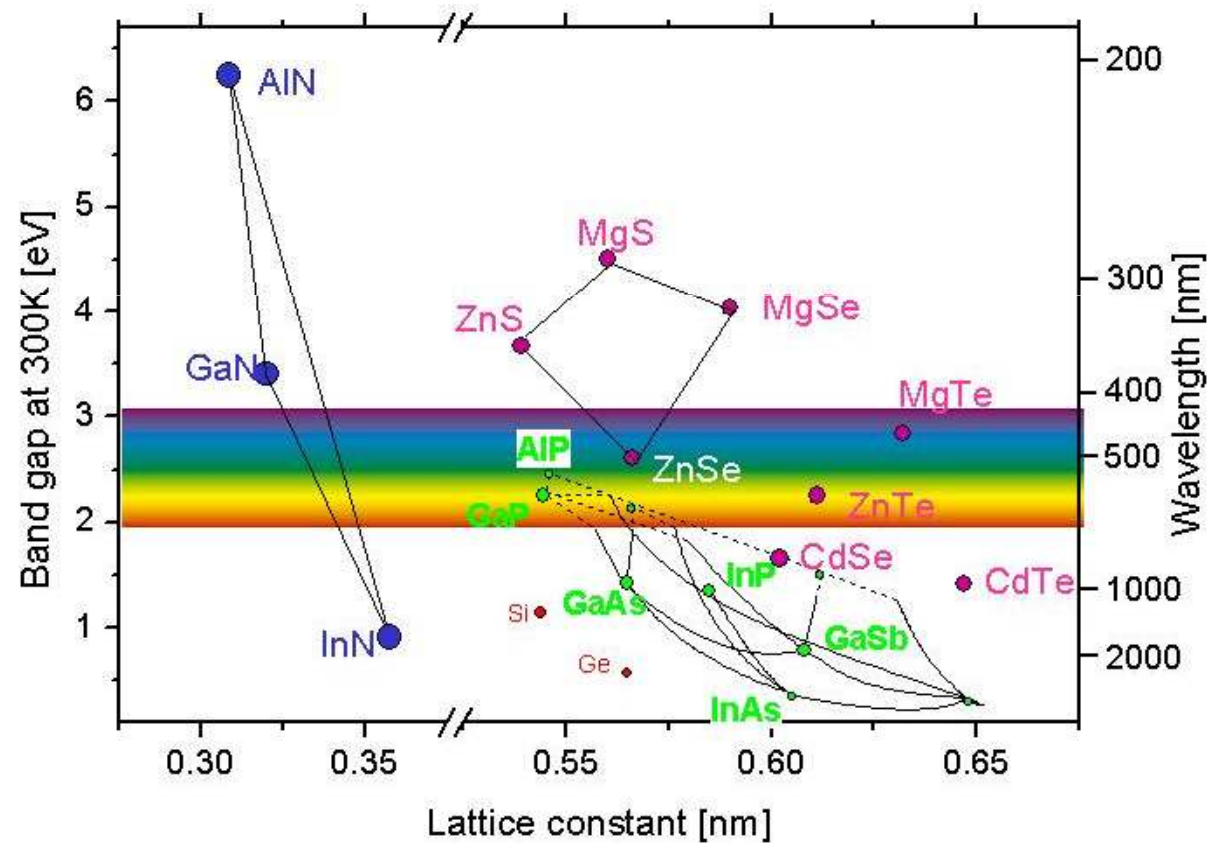


SEM obrázok LED
(pohľad zhora).



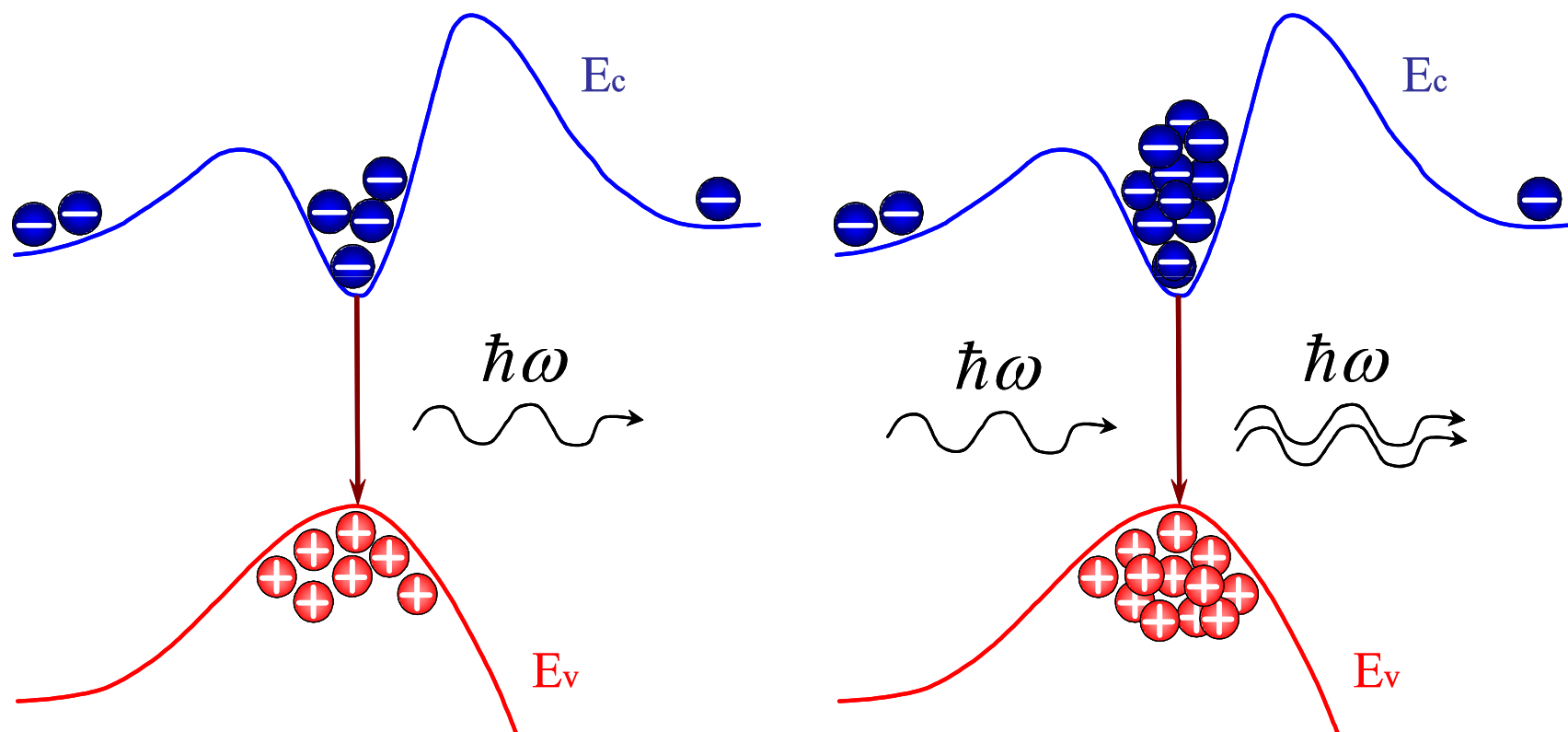
III-V a II-VI prvky pre optoelektroniku

polovica 90.-tych rokov „blue laser“

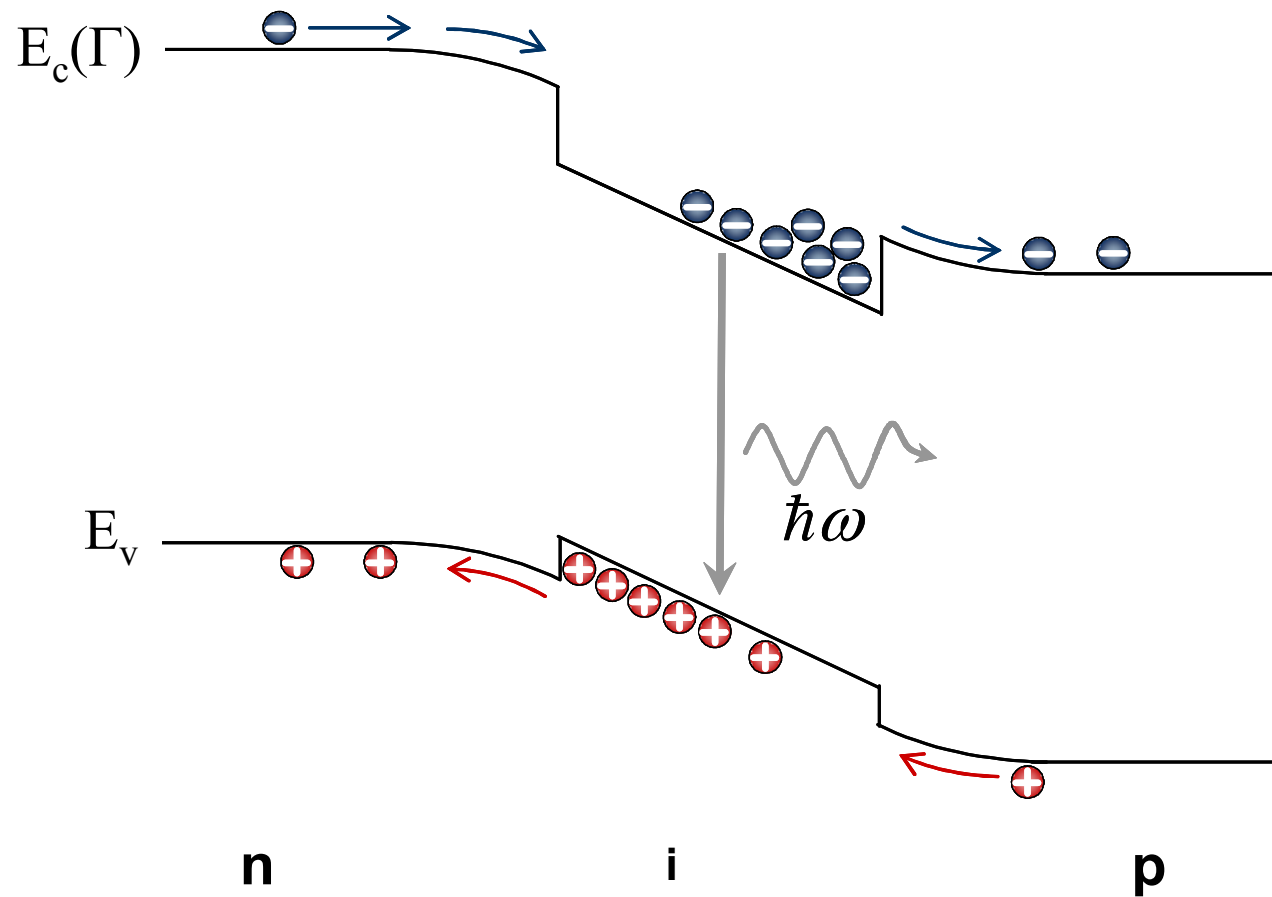


80.-te roky rozvoj red, green LEDs

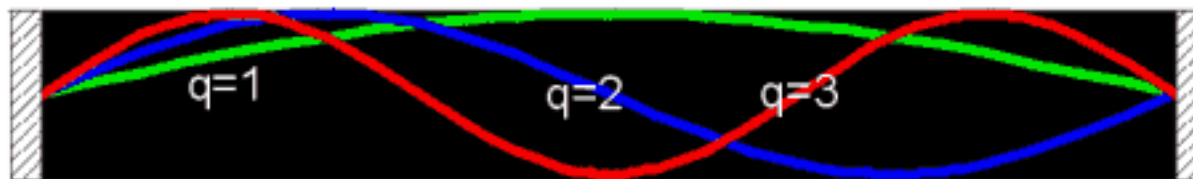
Spontánna stimulovaná emisia (inverzia)



Injekcia do aktívnej oblasti



Rezonátor v laseri, pozdĺžne módy



$$L = q \frac{\lambda_r}{2}$$

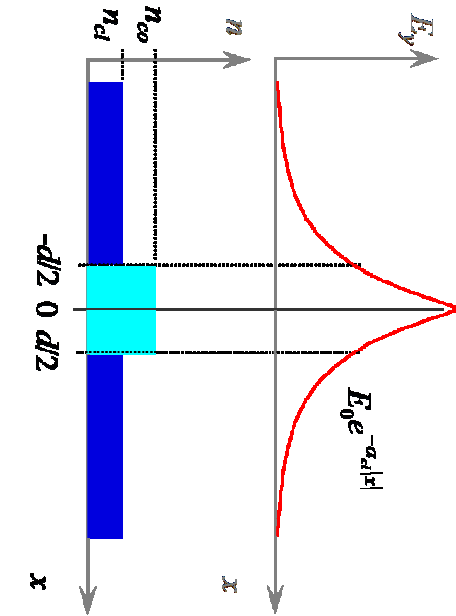
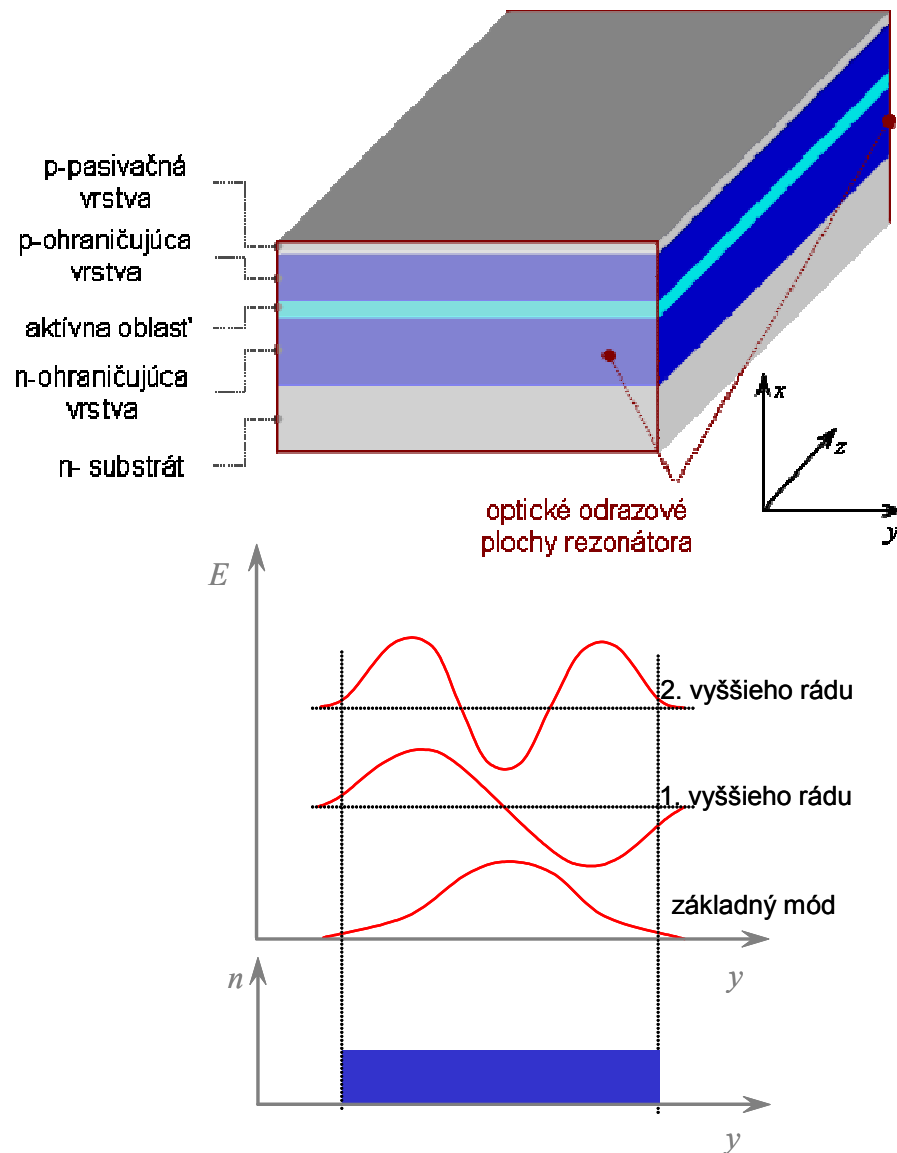
$$\lambda_r = \frac{\lambda_0}{n_r}$$

$$\Delta\lambda = \frac{\lambda_0^2}{2n_r L \left(1 - \frac{\lambda}{n_r} \frac{dn_r}{d\lambda} \right)}$$

$$dn_r/d\lambda = 0$$

$$\Delta\lambda = \frac{\lambda_0^2}{2n_r L}$$

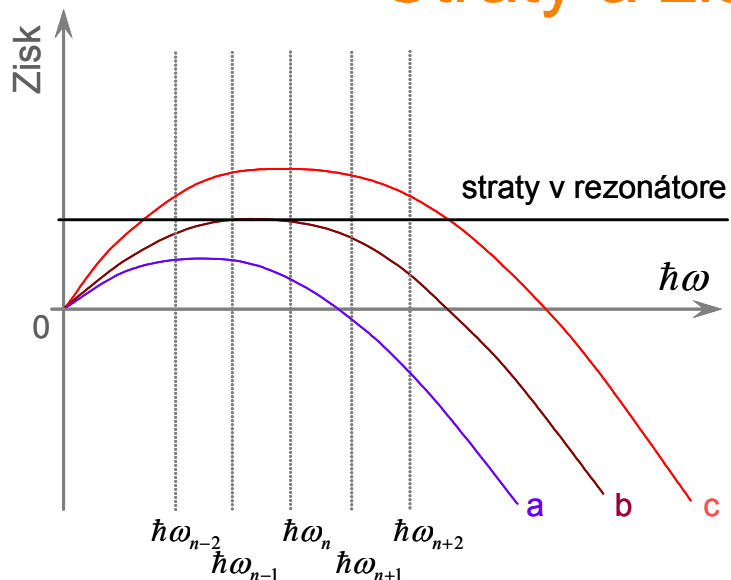
Vlnovod - ohraničenie rezonátora, priečne módy



$$\Gamma = \frac{\int_{-d/2}^{d/2} |E_y(x)|^2 dx}{\int_{-\infty}^{\infty} |E_y(x)|^2 dx}$$

$$\Gamma \approx 2\pi^2 (n_{co}^2 - n_{cl}^2) \left(\frac{d}{\lambda} \right)^2$$

Straty a zisk v rezonátore



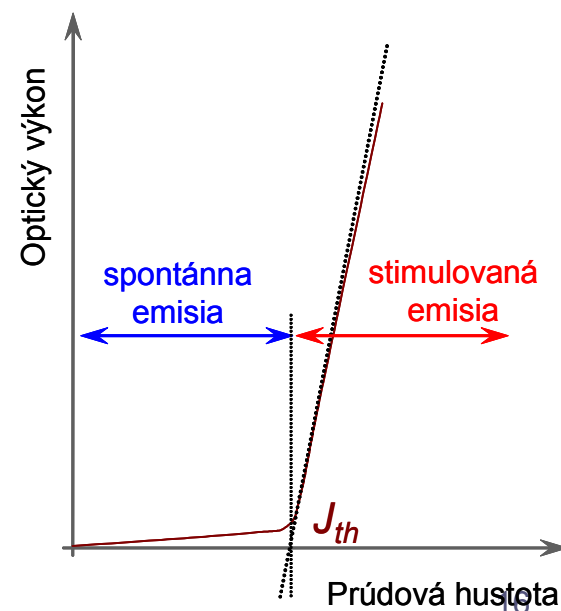
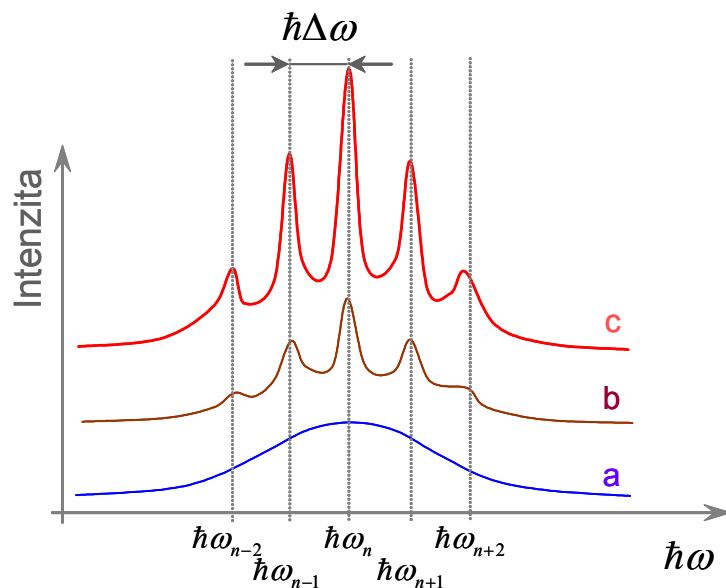
$$g_{th} = \alpha_i - \frac{1}{L} \ln(r_1 r_2)$$

$$R_r = r_1^2 = r_2^2$$

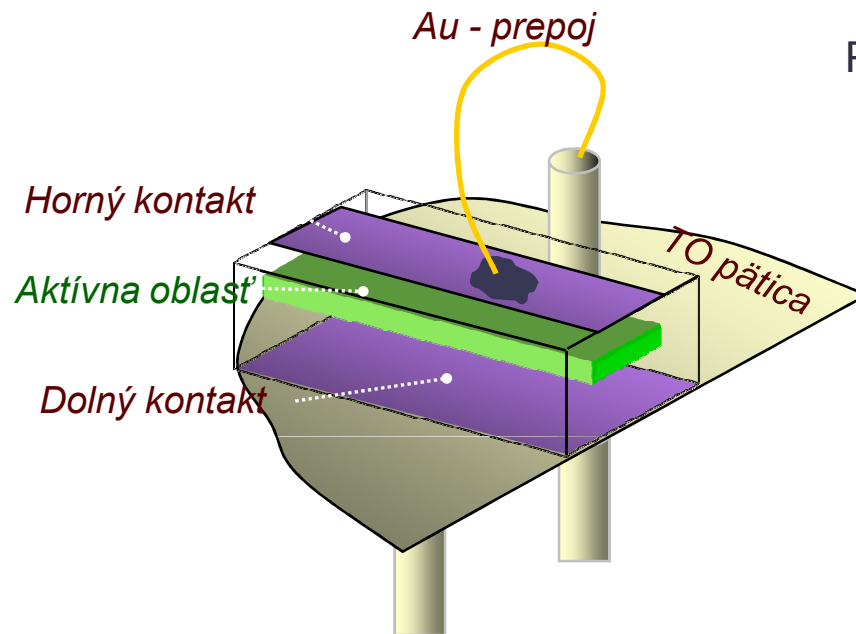
$$g_{th} = \alpha_i - \frac{1}{L} \ln R_r$$

$$R_r = \frac{(n-1)^2}{(n+1)^2}$$

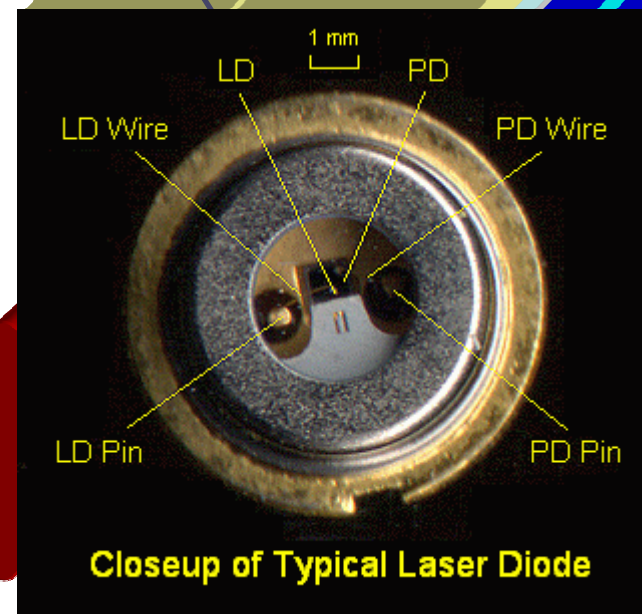
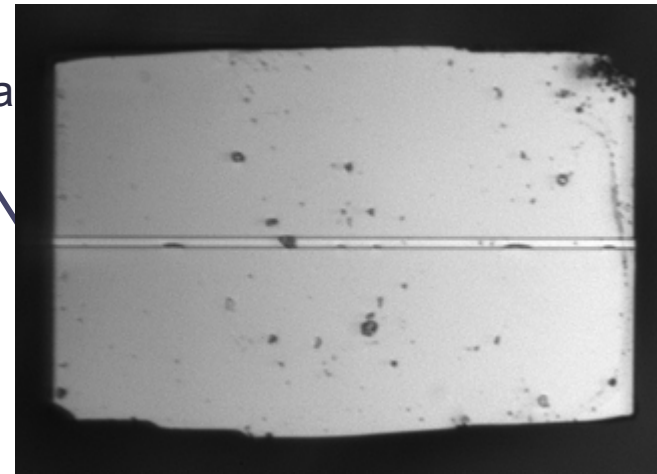
$$g_{tot} = g_{th} \Gamma$$



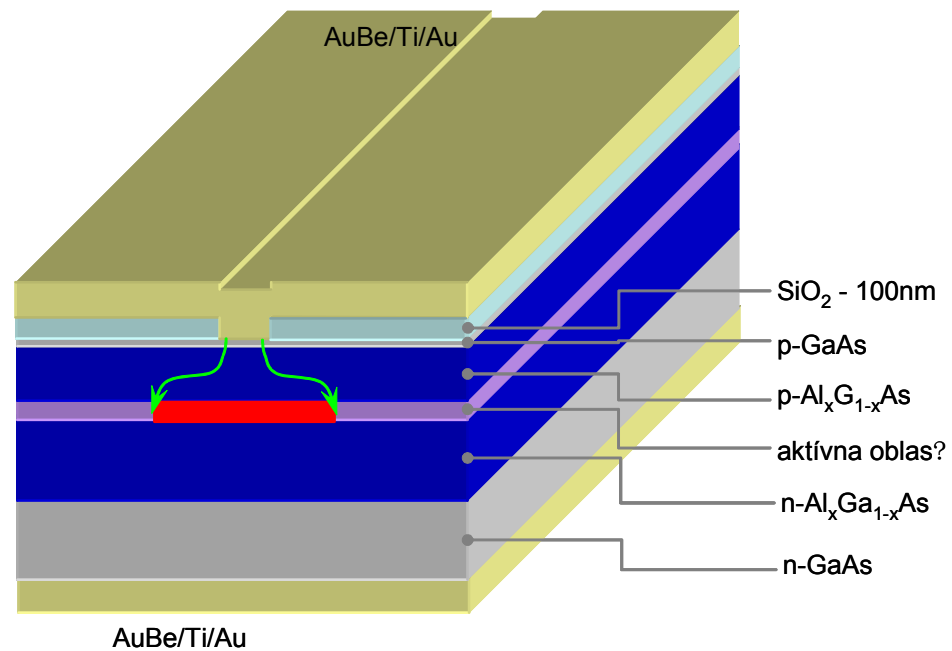
Laserová dióda = LED + rezonátor



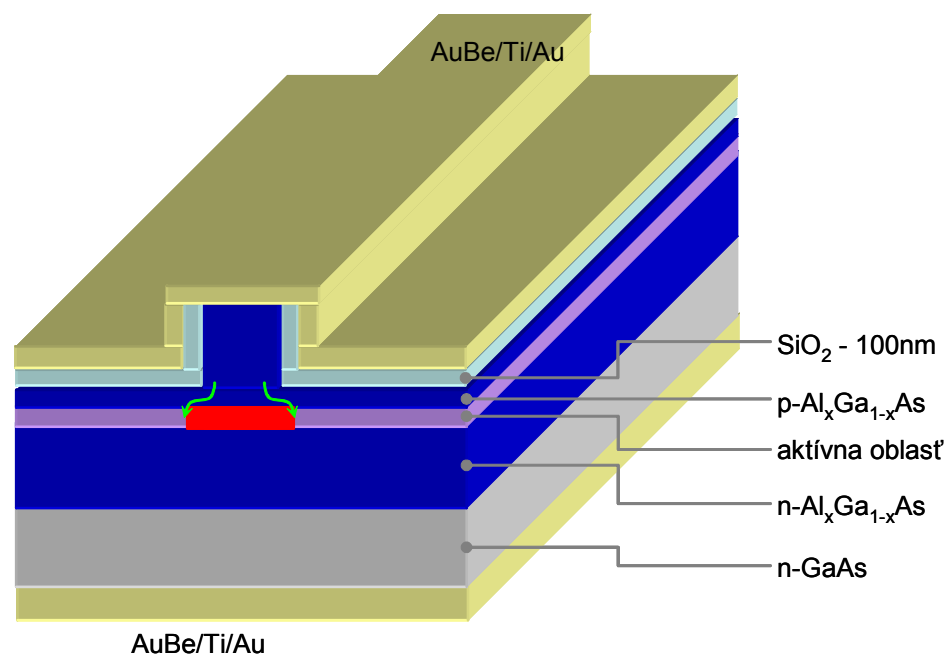
Predné a



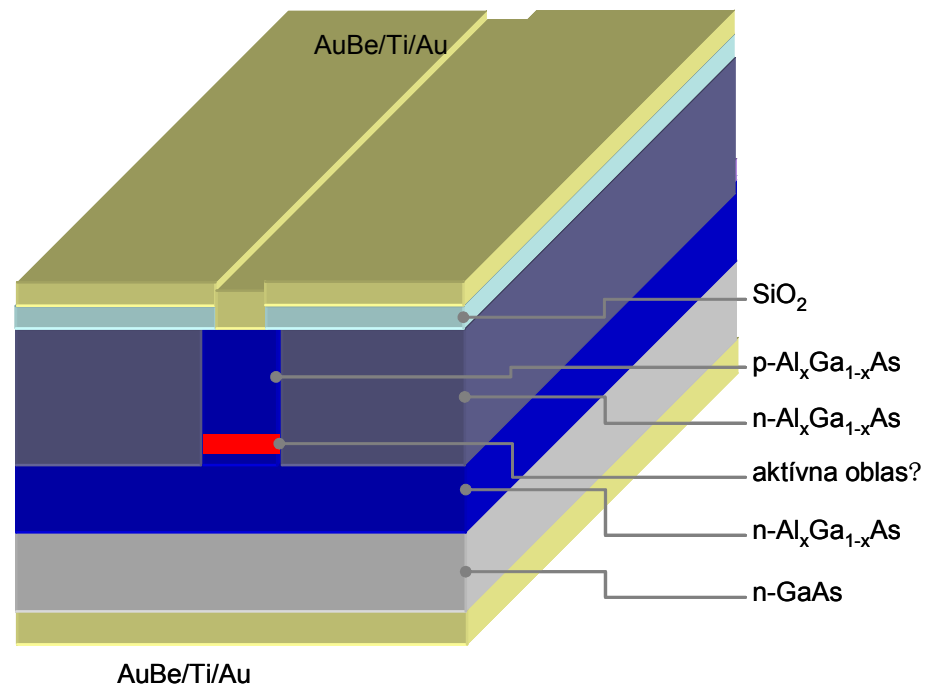
Modifikácie laserov (1) - pásikový



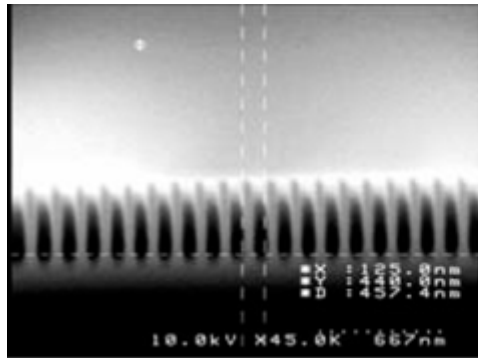
Modifikácie laserov (2) - hrebeňový



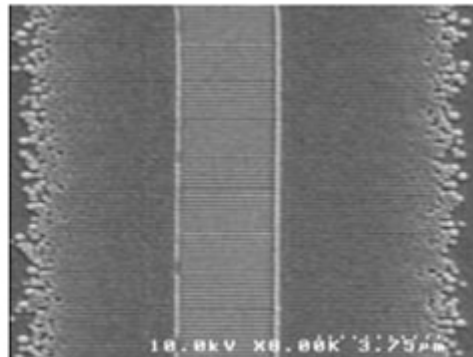
Modifikácie laserov (3) – indexom vedený



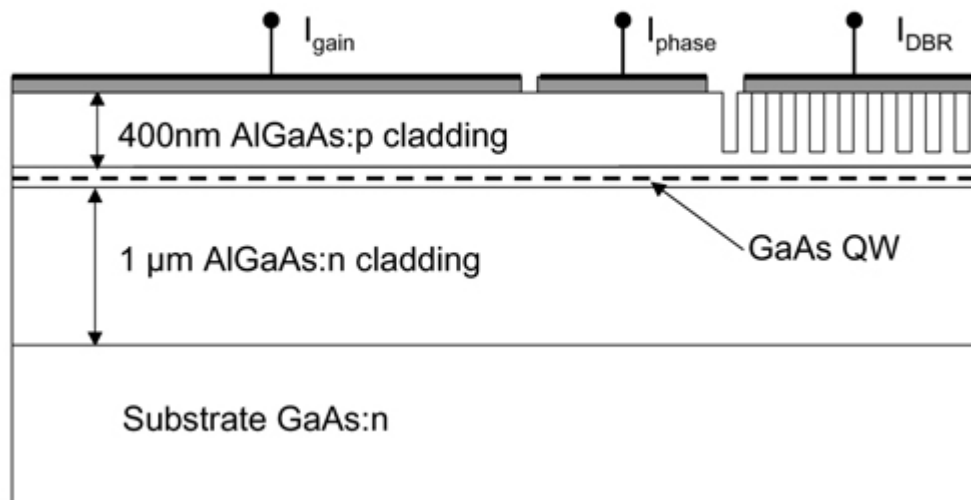
DBR laser



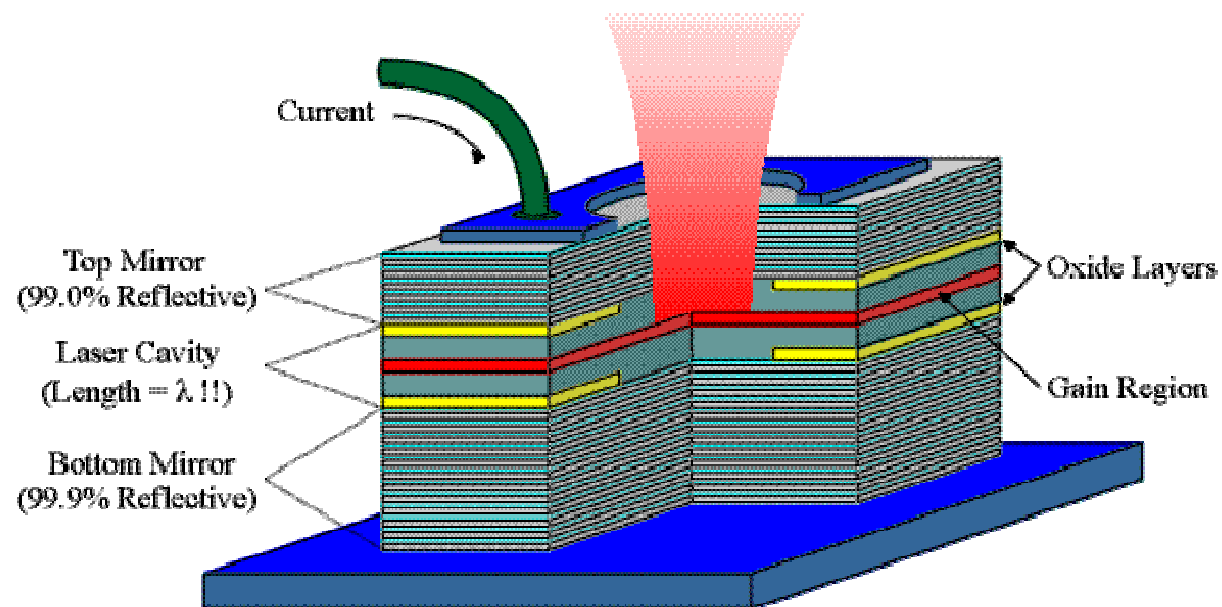
(a)



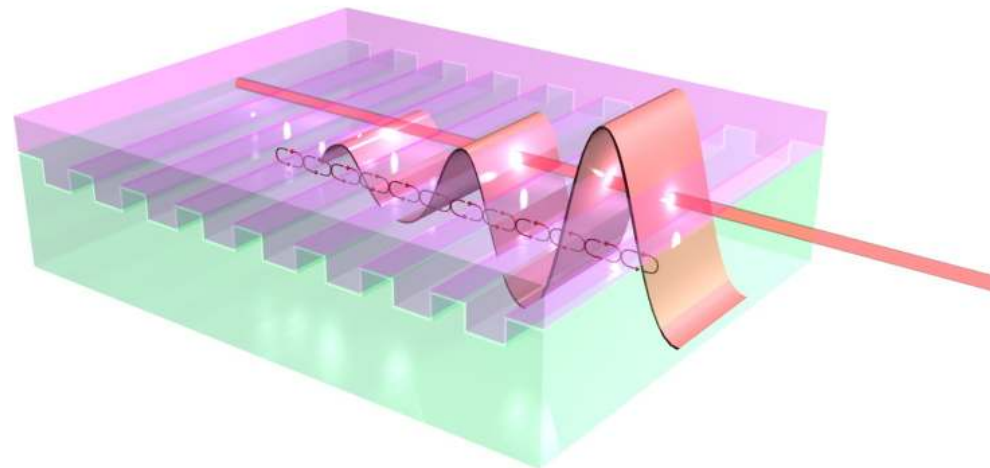
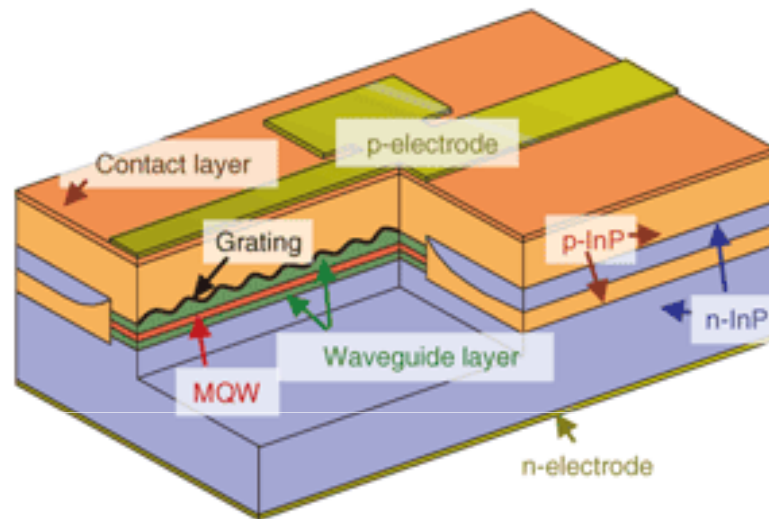
(b)



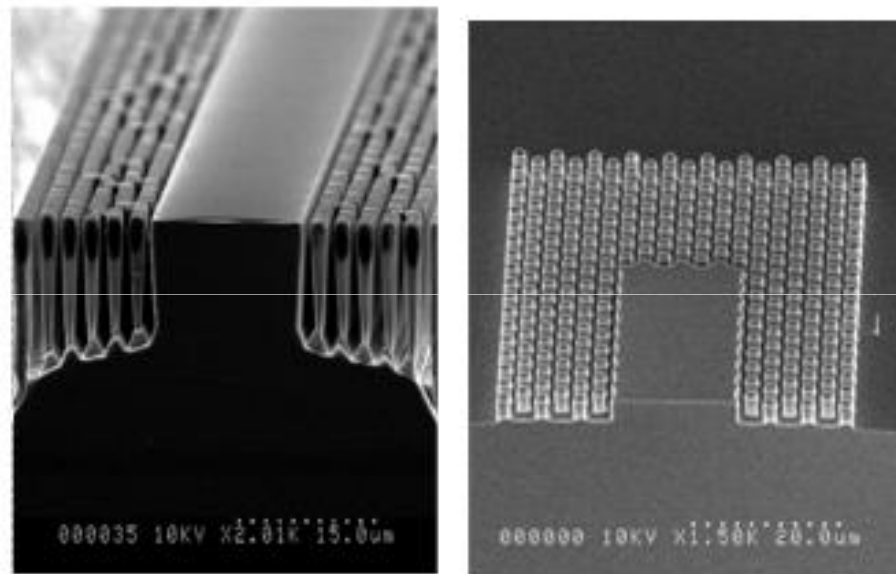
Modifikácie laserov (4) – VCSEL



DFB laser



Lasery s fotonickou strukturou



SEM pictures of a QCLs including photonic bandgaps for improved mode confinement