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Design of InGaAs/InP 1.55µm vertical cavity surface emitting lasers (VCSEL)

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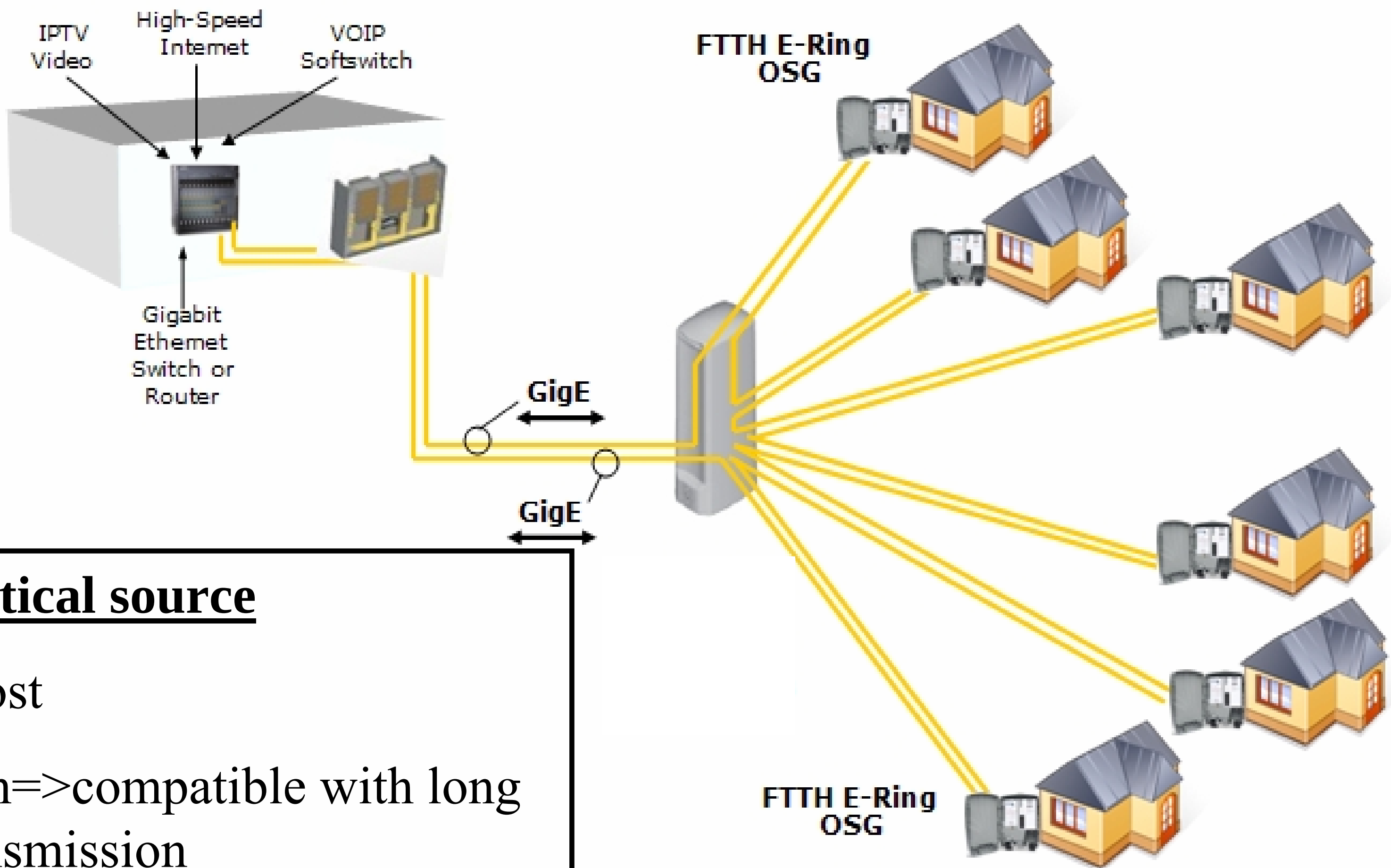
Design of InGaAs/InP 1.55µm VCSELs

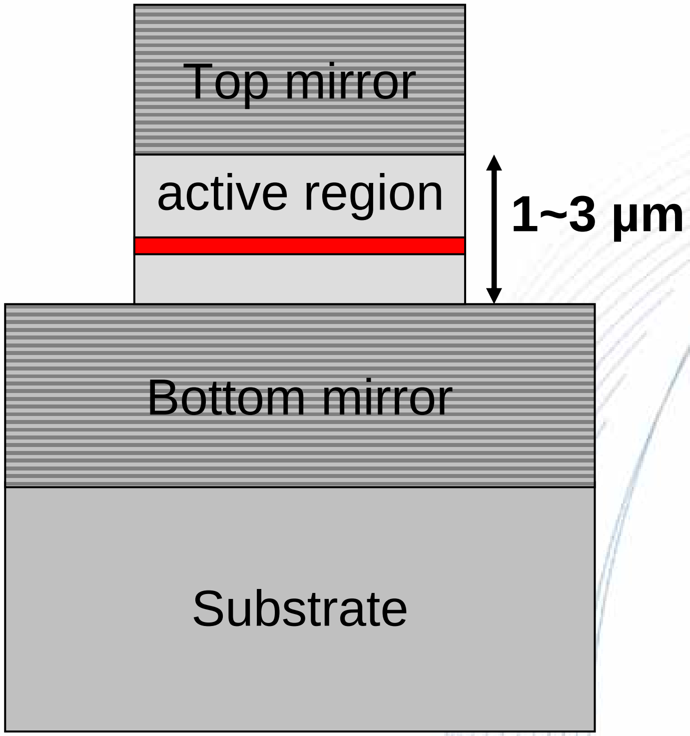
Fiber To The Home



Ideal optical source

- Low cost
- 1.55µm=>compatible with long haul transmission
- High frequency modulation
- Tunable =>WDM

VCSEL



Advantages

Surface Emitting Laser

- Device tested before packaging
- Array integration
- Output circular mode shape

Micro-cavity

- Small active region ➔ low I_{th} or P_{th}
- Short length ➔ Wide FSR

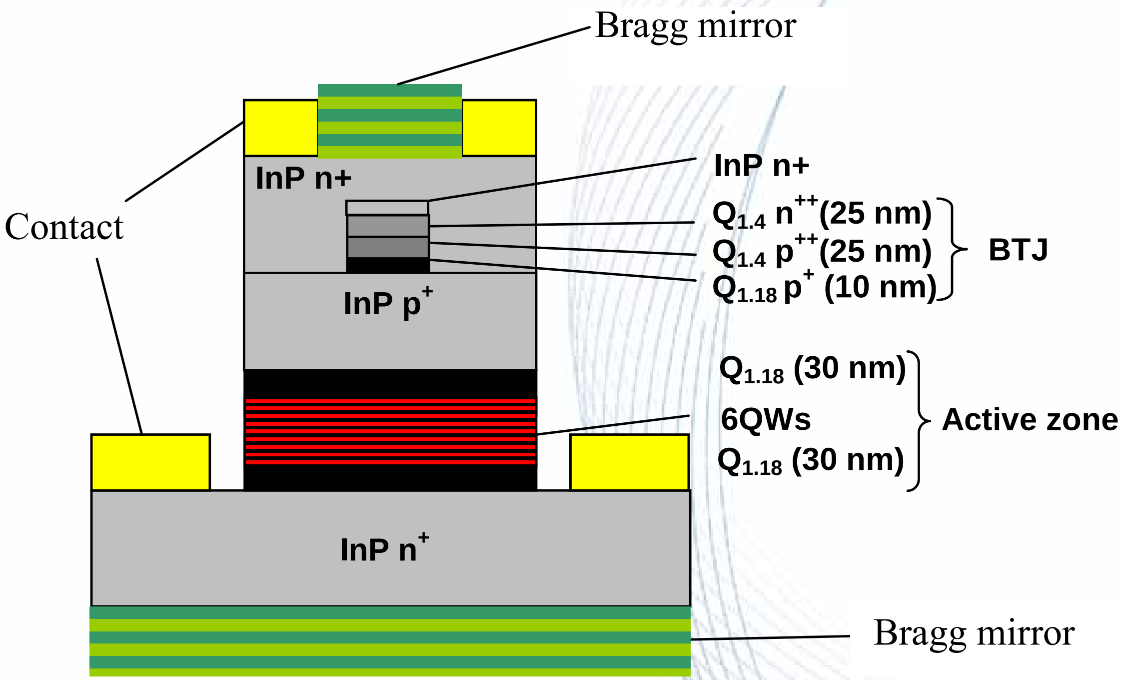
Drawbacks

Output power

Thermal dependence

Electrically pumped VCSEL

- CW 1.55 µm optically pumped VCSELs lattice-matched to InP with dielectric Bragg mirrors already demonstrated (J.M. Lamy *et al.*, IPRM'08)
- Electrically pumped VCSEL designed and fabricated at FOTON laboratory, within a collaborative ANR project named lambda-access



- *a*-Si/*a*-SiN_x DBR
- active zone grown by MBE with 6 InGaAs QW on lattice-matched alloy $In_{0.8}Ga_{0.2}As_{0.435}P_{0.565}$ ($Q_{1.18}$)
- Buried Tunnel Junction in strongly doped lattice matched alloy $Q_{1.4}$ ($N_D=N_A=5.10^{19}$ cm^{-3})

Design of InGaAs/InP 1.55µm VCSELs

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I- Introduction and context

II- Optical design of the VCSELs

Electric field calculation

Bragg mirrors

III- Thermal analysis

IV- Buried Tunnel Junction

V- Conclusion

Optical simulation

- Optical simulation algorithm : 2 parts

Optical properties thickness, index, absorption

Propagation matrices

- Electric field
- Reflectivity spectrum

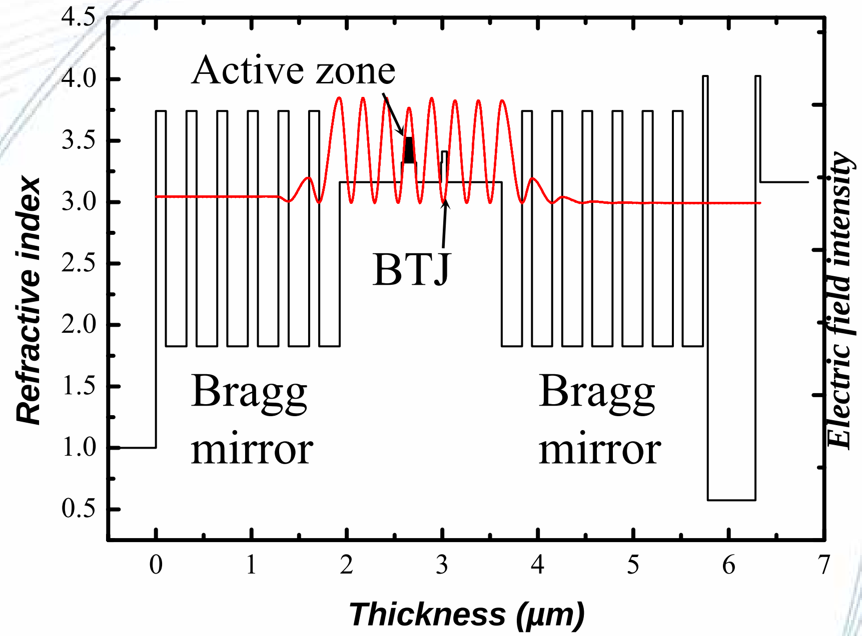
Active zone characterization

✓ QW energy levels

✓ Oscillator strength → Gain

✓ Absorption

✓ Spontaneous emission

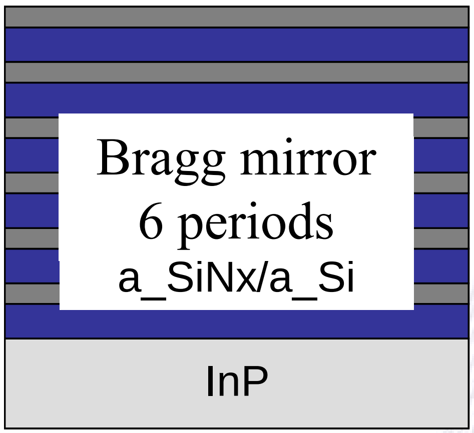


Electric field repartition in the structure

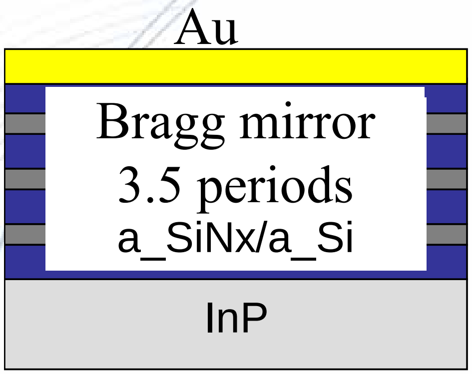
Monomode VCSEL structure around 1.55 µm

Bragg mirrors

➢2 types of Distributed Bragg Reflectors realized by magnetron sputtering :



Standard DBR



Hybrid DBR

- ➢ Simulation based on propagation matrices
- ➢ Same reflectivity (99.6 %) @ 1.55 µm in good agreement with FTIR results
- ➢Total reflectivity of the VCSEL cavity : Free Spectral Range > ***50 nm*** → *monomode VCSEL*

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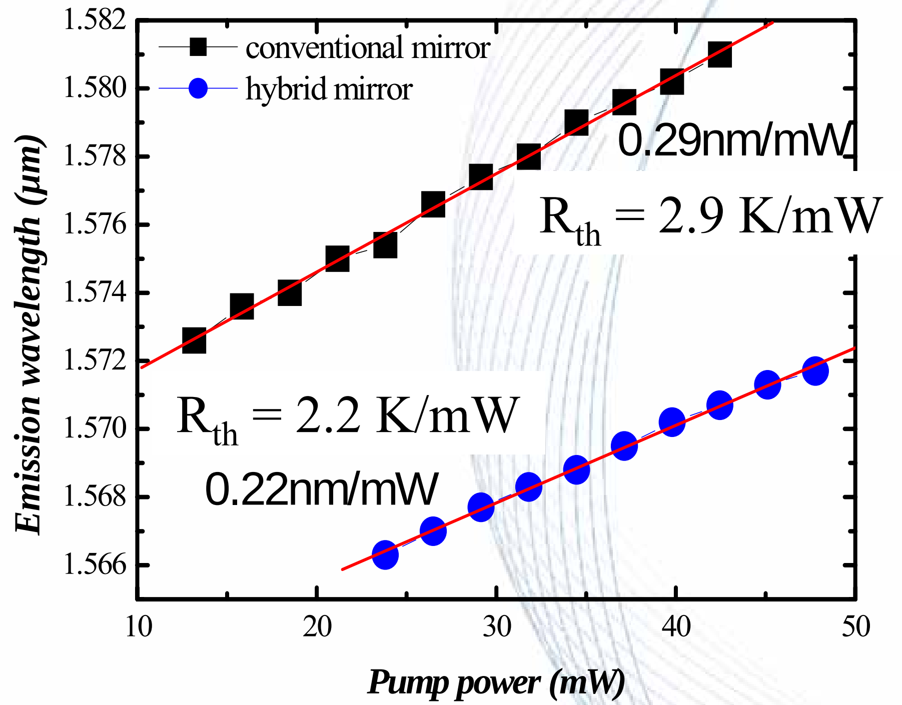
Thermal simulation

- VCSELs : Small active region → DBR → problem of heat dissipation
- optical and electrical VCSEL thermal 2D finite element simulation

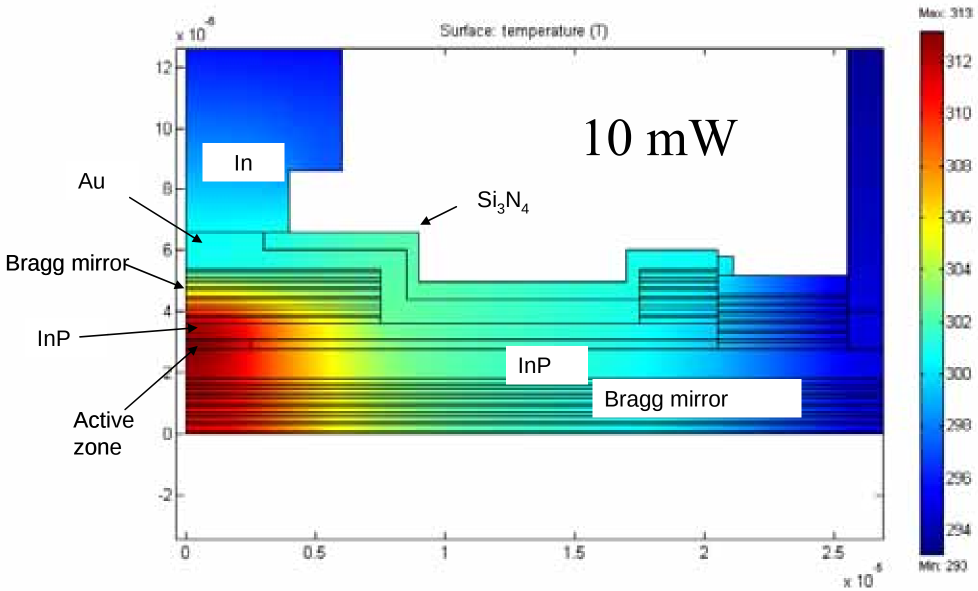
  ↳ thermal resistance evaluation compared to experiment

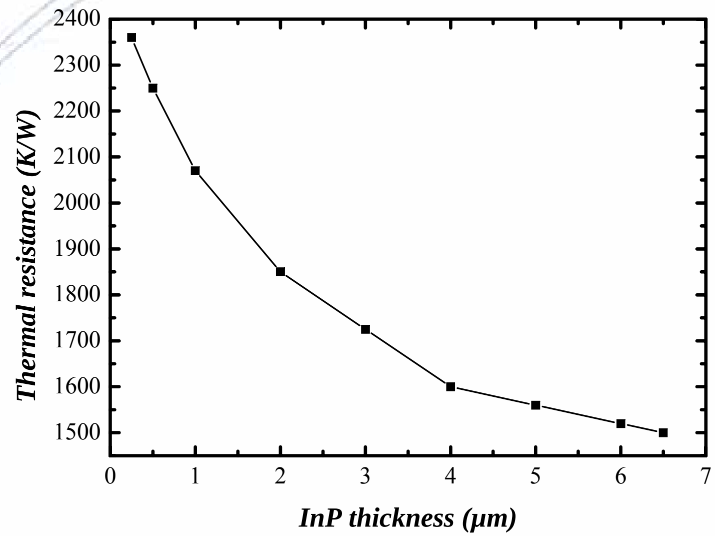


Wavelenght shift as a function of pump power for optical VCSELs with standard or hybrid DBR.

Thermal simulation

Electrically pumped VCSEL 2D thermal simulation.





Electrical VCSEL thermal resistance as a function of InP thickness (BTJ Ø 5 μm)

R_{Th} = 2360 K/W for a 200 nm InP thickness VCSEL

R_{Th} = 2050 K/W (1 μm InP)

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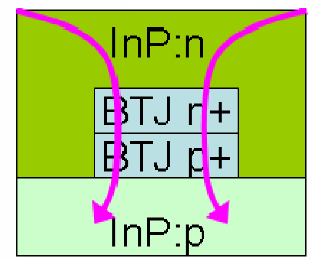
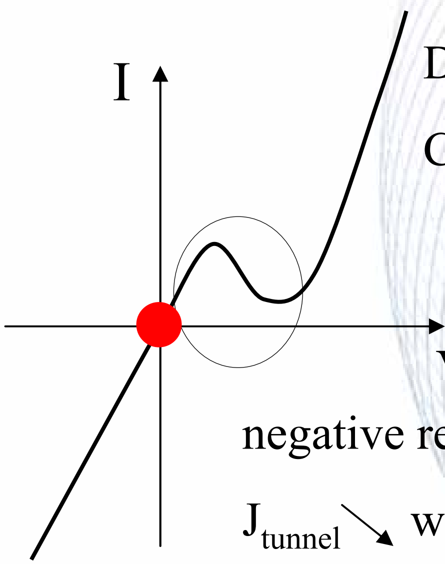
Buried tunnel junction

Objectives :

- localized current injection : electrical carrier confinement
- n-type contact, easier to realize and less resistive
- small threshold voltage and small serial resistance to limit self-heating



Theoretical operation : I(V) characteristics



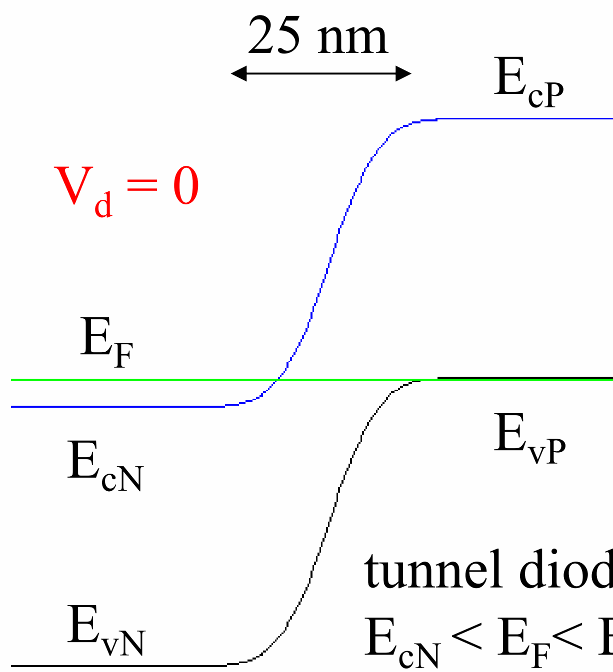
Direct : $V_d > V_{thres}$

Classical diode

Inverse : tunnel current

negative resistance :

$J_{tunnel} \searrow$ when $V_d \nearrow$



tunnel diode :

$E_{cN} < E_F < E_{vP}$

Buried tunnel junction

Objectives :

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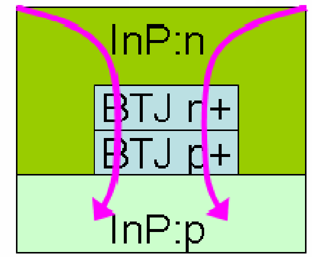
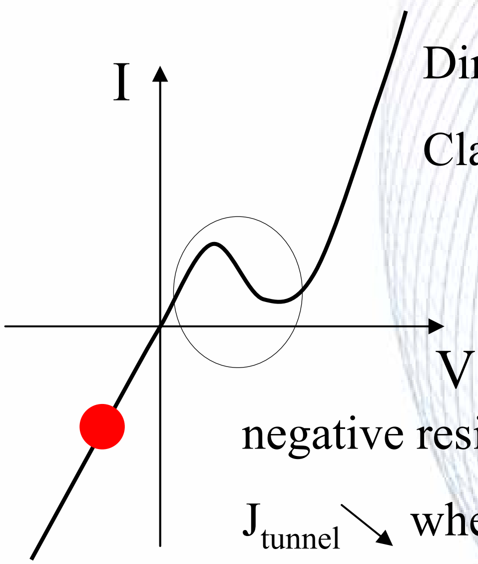


Theoretical operation : I(V) characteristics



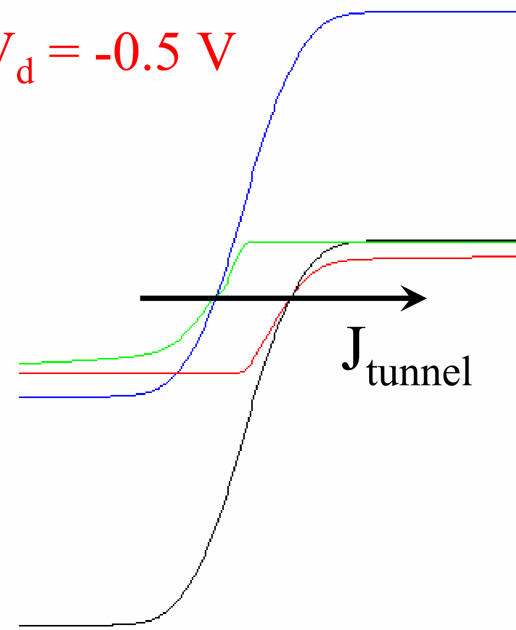
Direct : $V_d > V_{thres}$

Classical diode

Inverse : tunnel current

negative resistance :

J_{tunnel} ↘ when V_d ↗



Buried tunnel junction

<u>*Objectives :*</u>

- localized current injection : electrical carrier confinement
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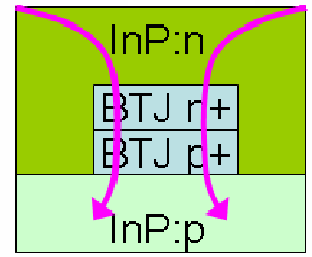
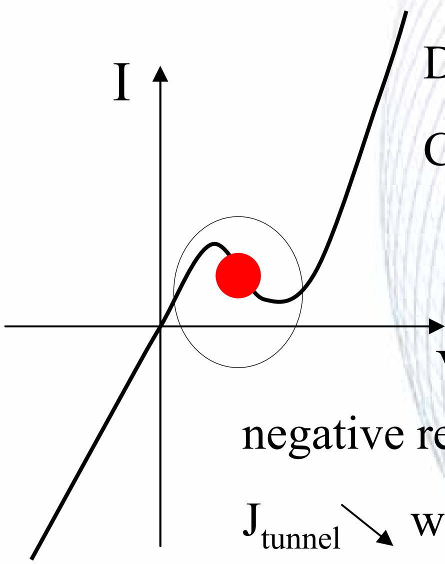


<u>*Theoretical operation*</u> : I(V) characteristics



Direct : $V_d > V_{thres}$

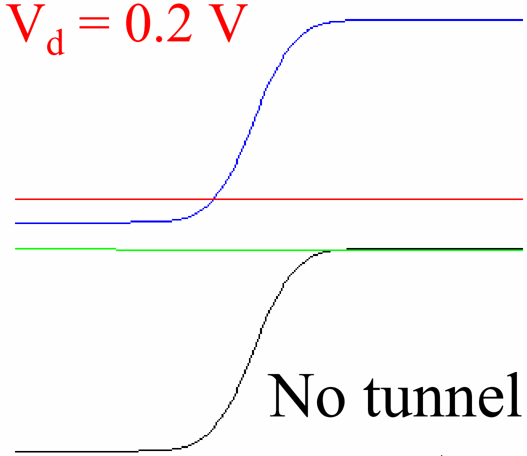
Classical diode

Inverse : tunnel current

negative resistance :

$J_{tunnel} \searrow$ when $V_d \nearrow$

$V_d = 0.2$ V

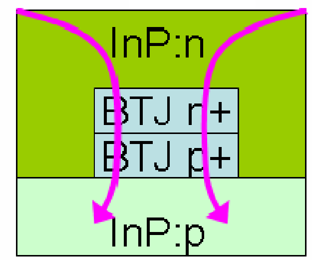


No tunnel current

$V_d < V_{thres\_diode}$

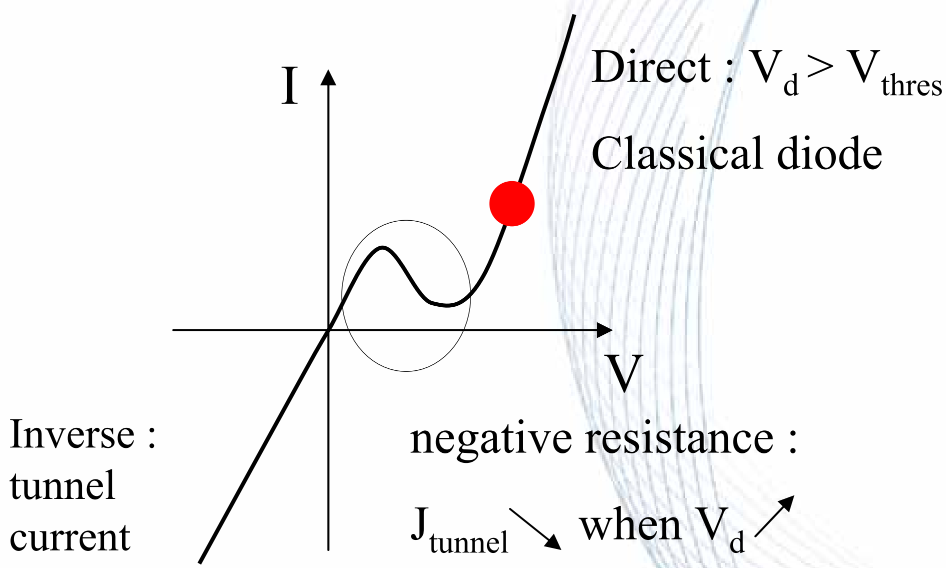
Buried tunnel junction

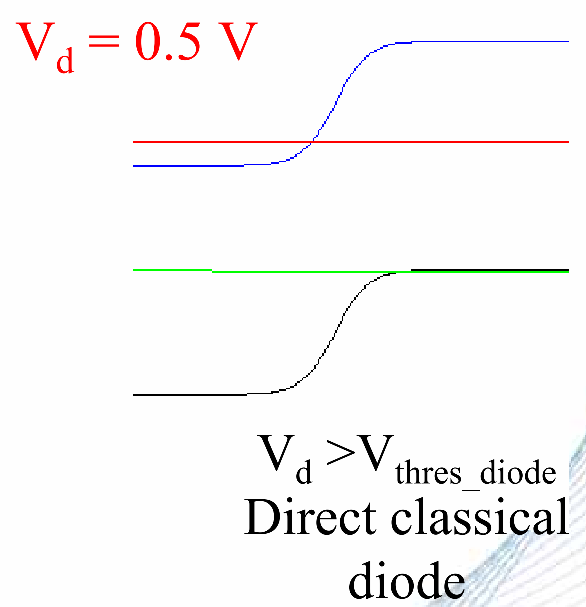
<u>*Objectives :*</u>



- ➢ localized current injection : electrical carrier confinement
- ➢ n-type contact, easier to realize and less resistive
- ➢ small threshold voltage and small serial resistance to limit self-heating

<u>*Theoretical operation*</u> : I(V) characteristics

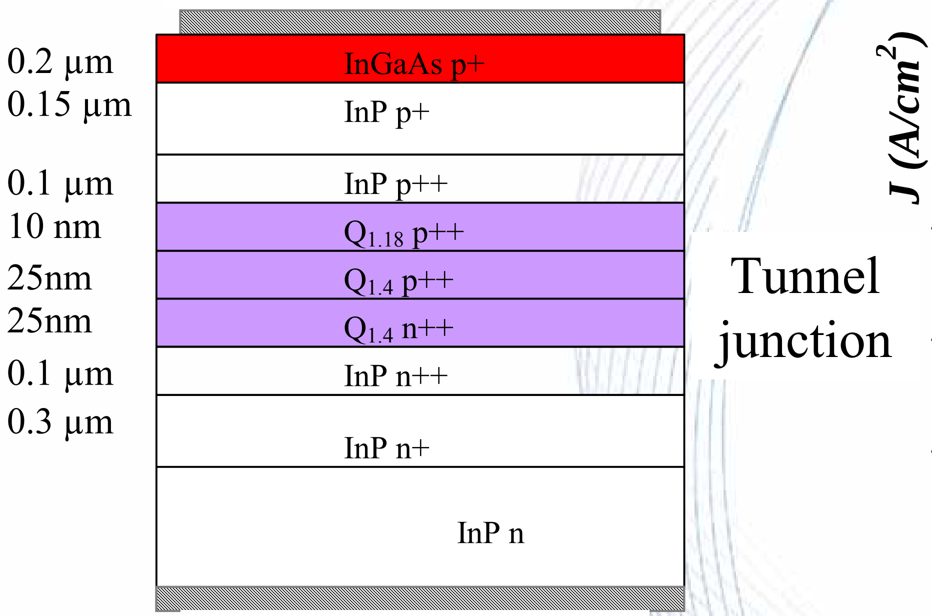




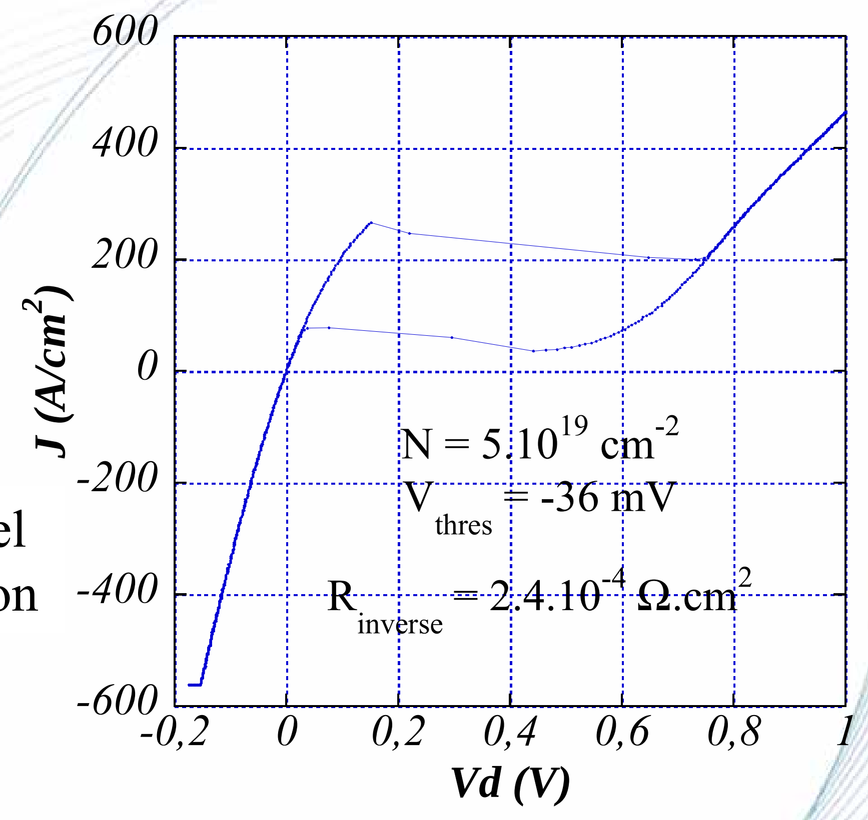
Buried tunnel junction

Experimental study of the BTJ :

P-type contact



n-type contact

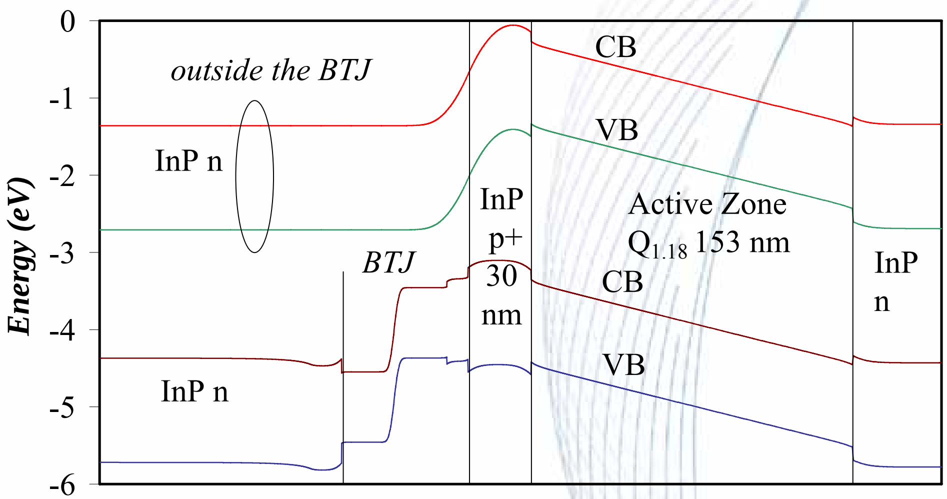


I(V) characteristics

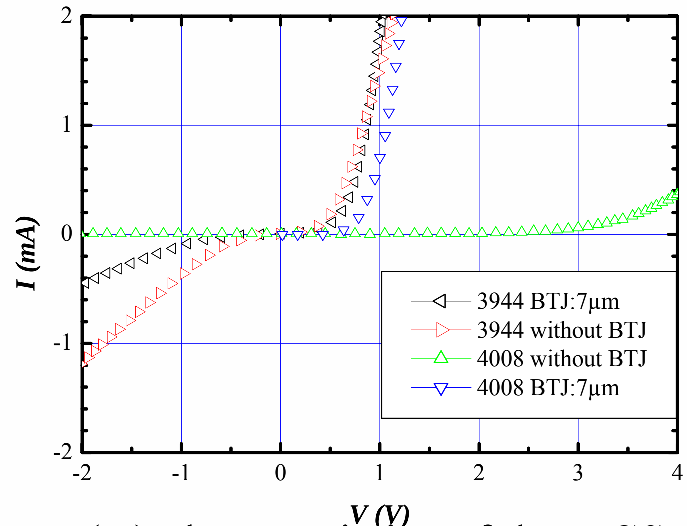
Buried tunnel junction

1D Schrödinger-Poisson simulation useful to :

- verify the tunnel effect in the reverse BTJ
- avoid current leakage in the reverse InP junction outside the BTJ



Simulation of the band diagram of the VCSEL in vertical direction, inside and outside the BTJ



I(V) characteristics of the VCSEL cavities (without DBR)

3944 : 15 nm InP p+ → leakage current

4008 : InP p+ = 240 nm …OK

Conclusion

3 steps of simulation to design electrically pumped VCSELs :

- Optical simulation → epilayer structure and DBR reflectivity
- Thermal analysis → thermal resistance and contact design
- Schrödinger Poisson 1D → avoid leakage current around the BTJ

… towards an integrated model ?

First electrical VCSEL sample from FOTON laboratory

measurement in progress…