Energy band structures of strained membrane quantum wires considering the redistribution of elastic strain relaxation

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Outline

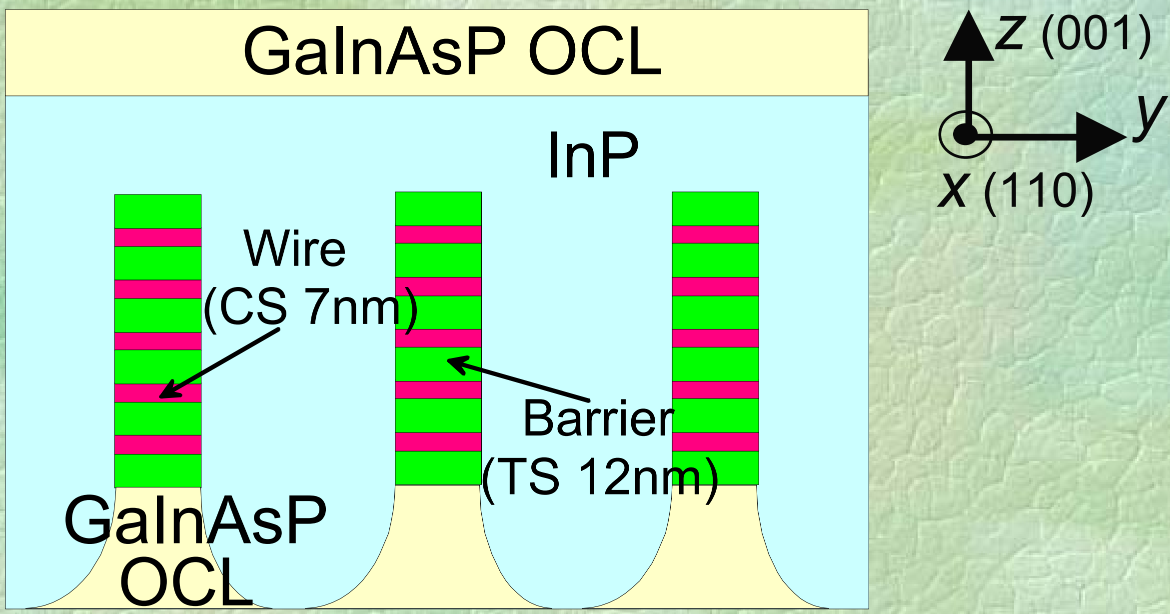
- Introduction
- Theory
- Numerical results
- Conclusions

Introduction (1)

Q-Wire lasers

● Low threshold current, ● Higher gain, ● Higher T_0

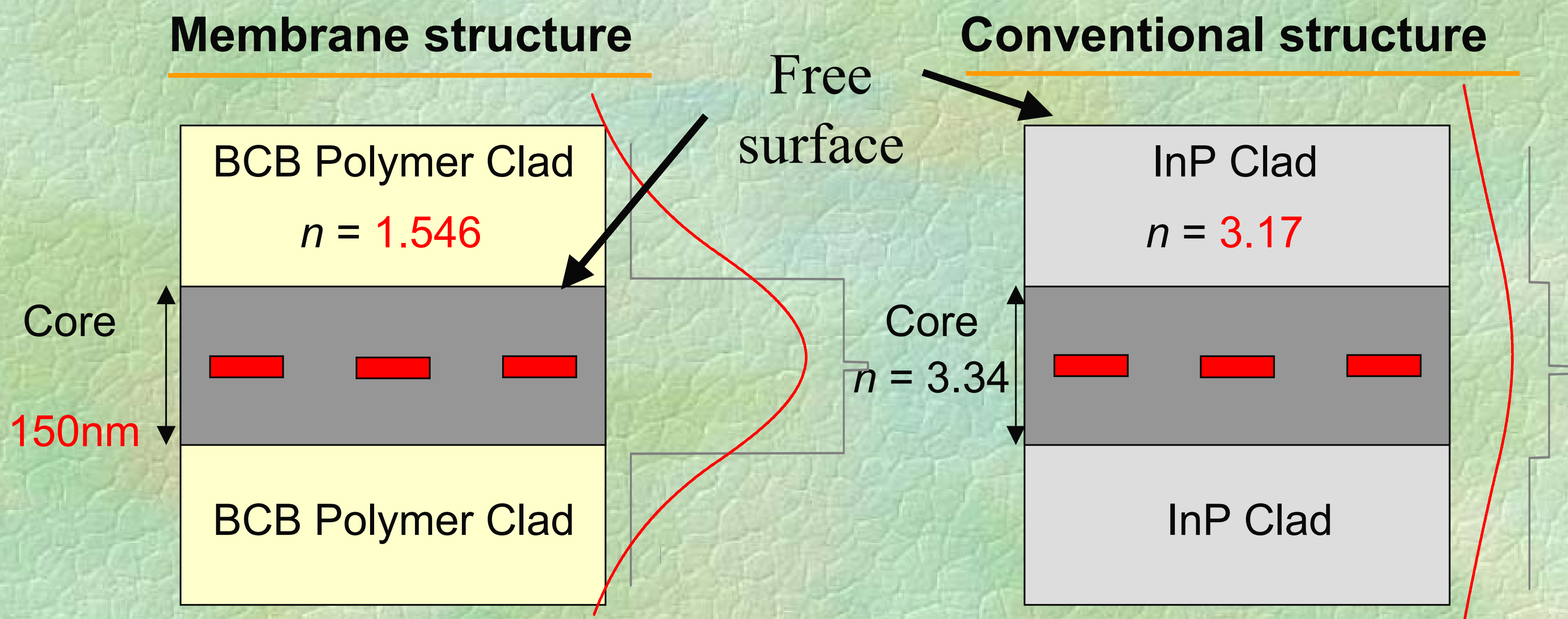
Dry-etching and OMVPE regrowth technique



Advantages

☆ Position controllability
☆ Flexibility
☆ Size distribution
☆ Reliability

New structure: QWR membrane lasers



Δn(membrane)=39%

Δn(conventional)=5%

Introduction (3)

- In membrane structures, free surfaces are very close.

- Due to the closeness of free surfaces in membrane QWR, strain relaxation will be different. The strain relaxation is calculated including anisotropic and non-uniformity effects.

- Strain relaxation effects on electronic band structures in QWRs are investigated.

Theory (1)

Strain analysis

Equations of equilibrium

$$\left(C_{11}\frac{\partial^2}{\partial y^2}+\frac{1}{2}C_{44}\frac{\partial^2}{\partial z^2}\right)u+\left(C_{12}+\frac{1}{2}C_{44}\right)\frac{\partial^2 v}{\partial y\partial z}=0$$

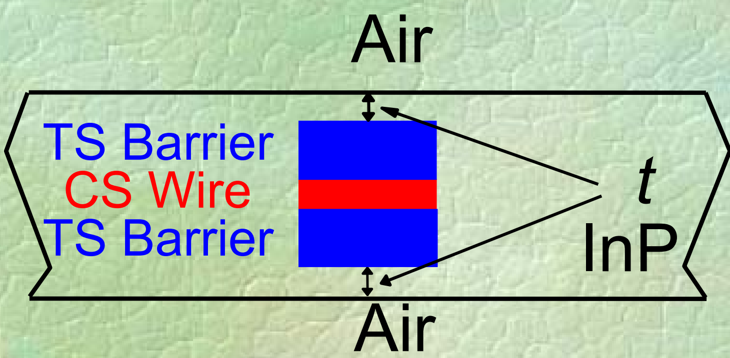
$$\left(C_{12}+\frac{1}{2}C_{44}\right)\frac{\partial^2 u}{\partial y\partial z}+\left(\frac{1}{2}C_{44}\frac{\partial^2}{\partial y^2}+C_{11}\frac{\partial^2}{\partial z^2}\right)v=0$$

Plane strain → 2D Deformation: (*u*,*v*)

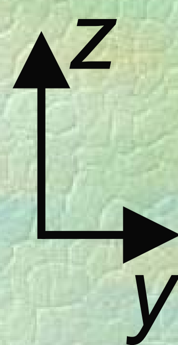
$$\varepsilon_{yy}=\frac{\partial u}{\partial y} \qquad \varepsilon_{zz}=\frac{\partial v}{\partial z} \qquad \varepsilon_{yz}=\frac{1}{2}\left(\frac{\partial u}{\partial z}+\frac{\partial v}{\partial u}\right)$$

Solve by finite element method using FEMLAB software

Membrane

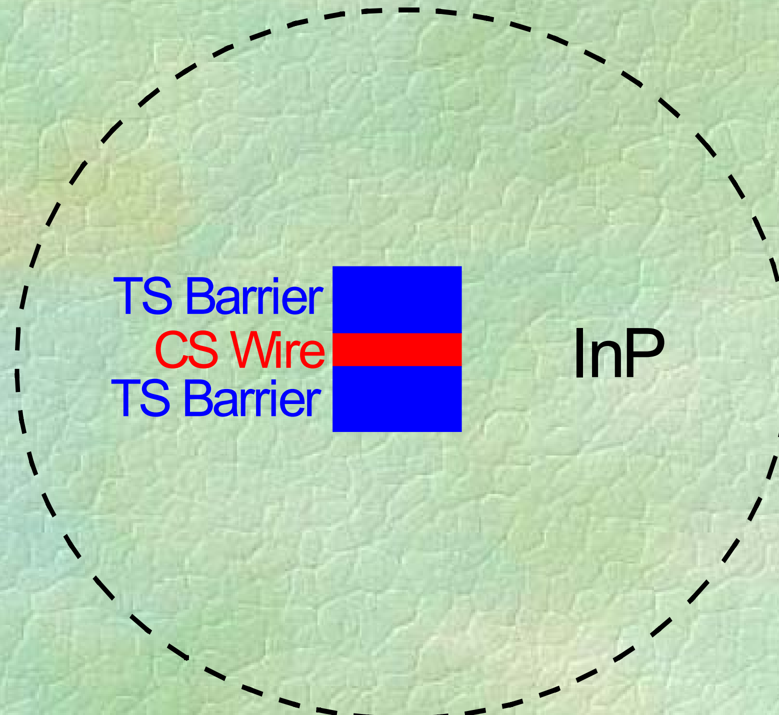


- $\sigma_{zz}=0$ @ air-InP interface
- Complicated analysis
- Numerical solution



Wire axis: x

Conventional



- Strain relaxes naturally
- Analytical solution exists

Theory (3)

Band structure calculation

8 band k.p method

$$H = \begin{bmatrix} G & \Gamma \\ -\Gamma^* & G^* \end{bmatrix}$$

$$G(k) = G_1(k) + G_2(k) + G_{so}(k) + G_{strain}(k)$$

$$\sum_{n'=1}^{8} H_{nn'}(r, \nabla) F_{n'}(r) = E F_n(r)$$

Solve by eigenfunction expansion method

$$F_n(r) = \sum_{lm}^{\infty} F_n(l, m, k_x) \phi_{lmk_x}(x, y, z)$$

Theory (4)

- E_g is also calculated using deformation theory with bulk like CB and VB.

- $E_g = E_{gu} + E_{gst}$

- $E_{gst} = a_c\, \varepsilon_{hy} - a_v\, \varepsilon_{hy} - b_v\, \varepsilon_{ax}/2$

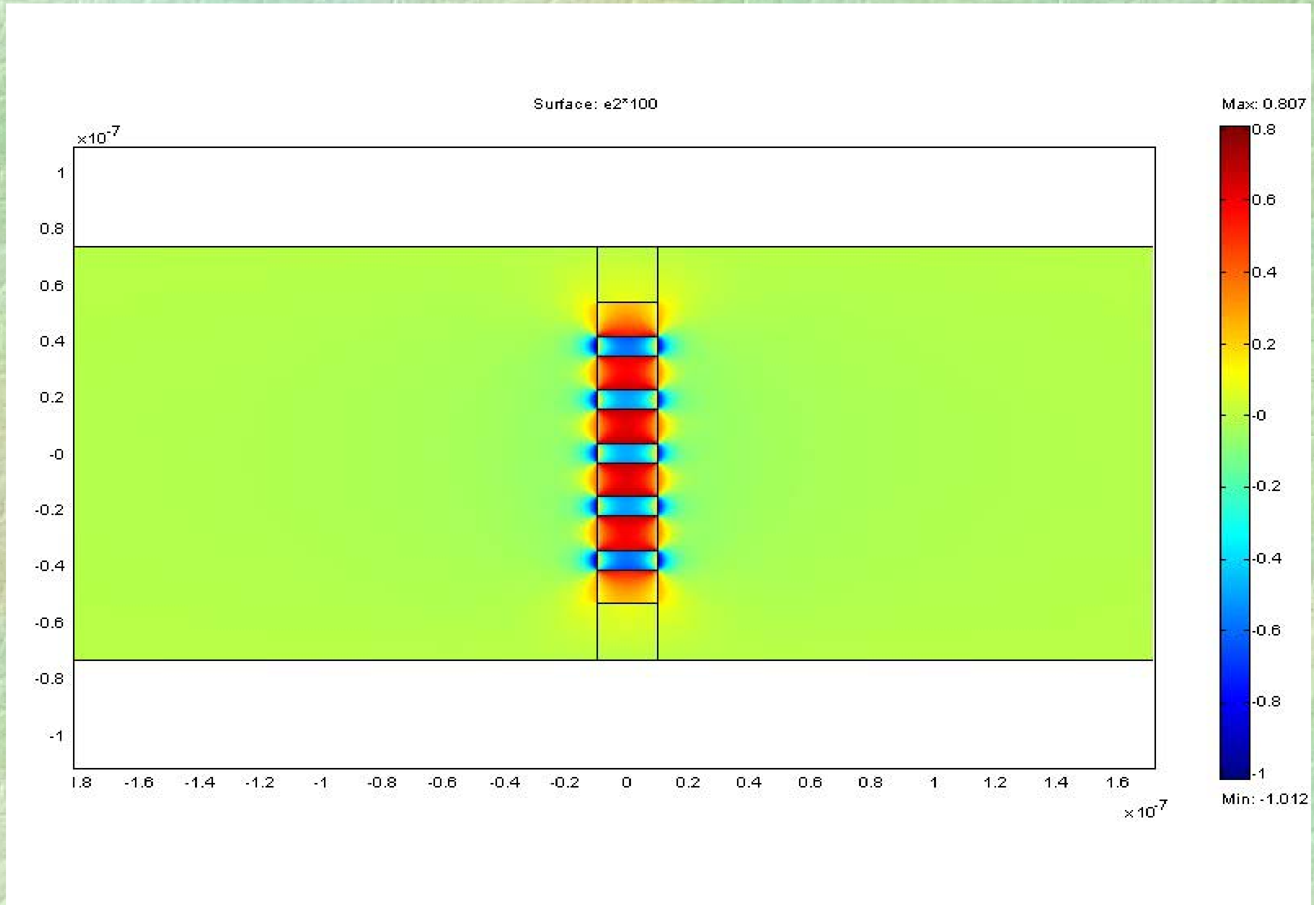
- $\Delta E_g = E_{gcon} - E_{gmem}$

Theory (5)

- QWR is in 1.07% CS strain and 7 nm thick along growth direction.
- Barrier is 12 nm thick along growth direction.

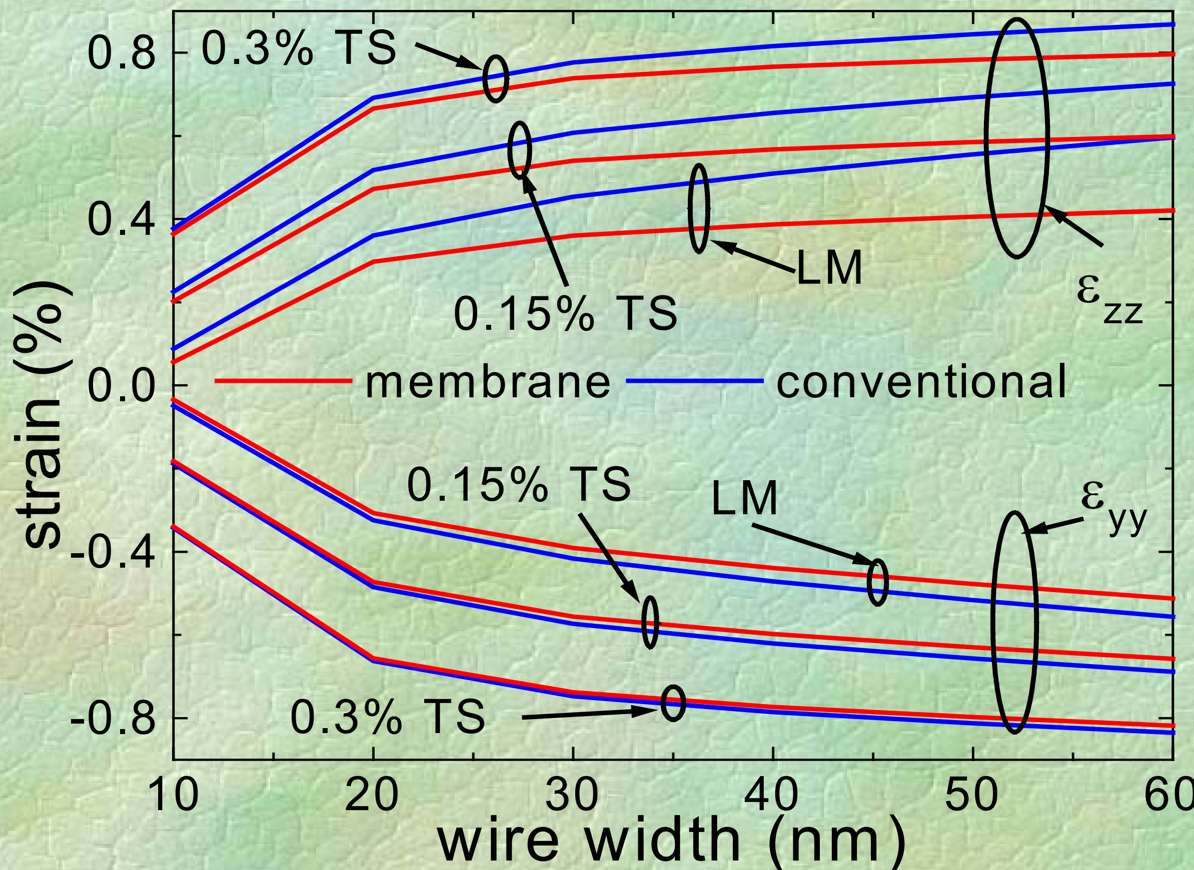
Results (1)

0.15% TS barriers



Surface plot ε_{yy} (membrane) (%)

Results (2)

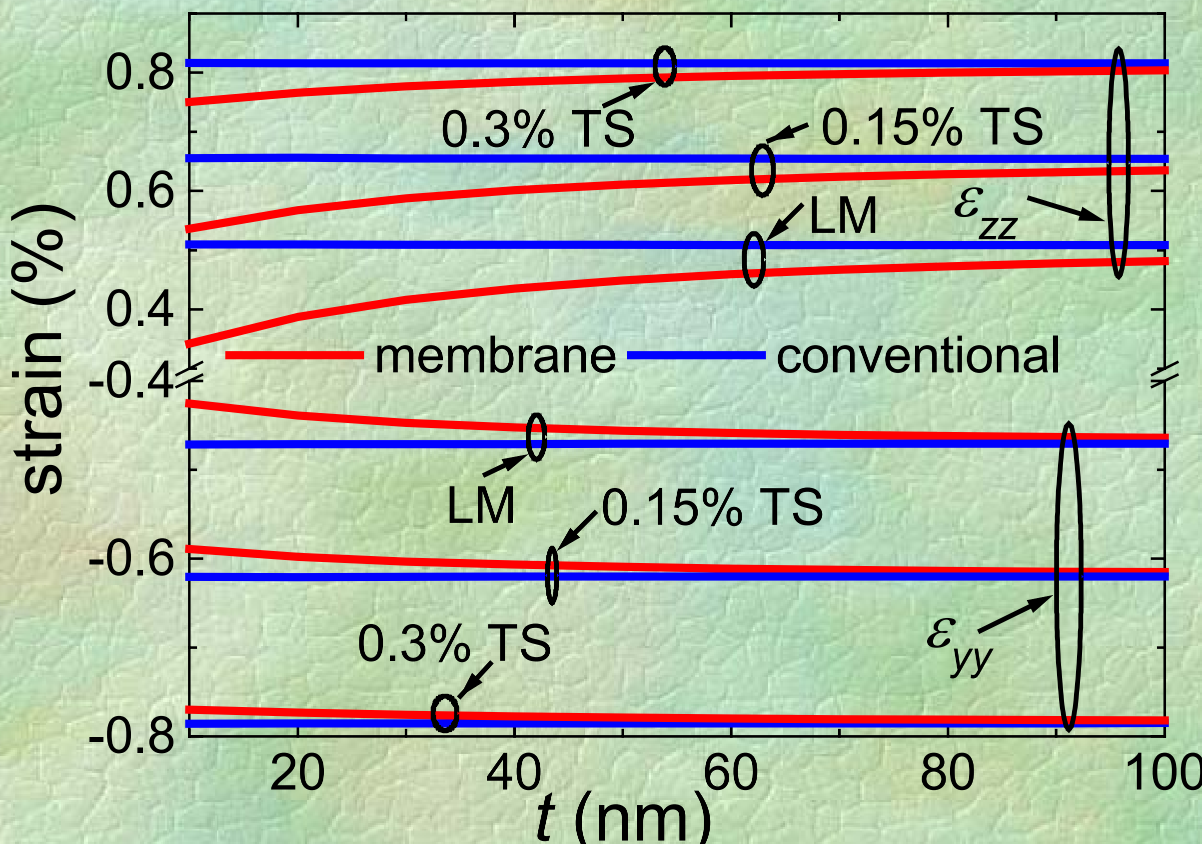


Pronounced on ε_{zz}

Depends on TS in Barriers

Results (3)

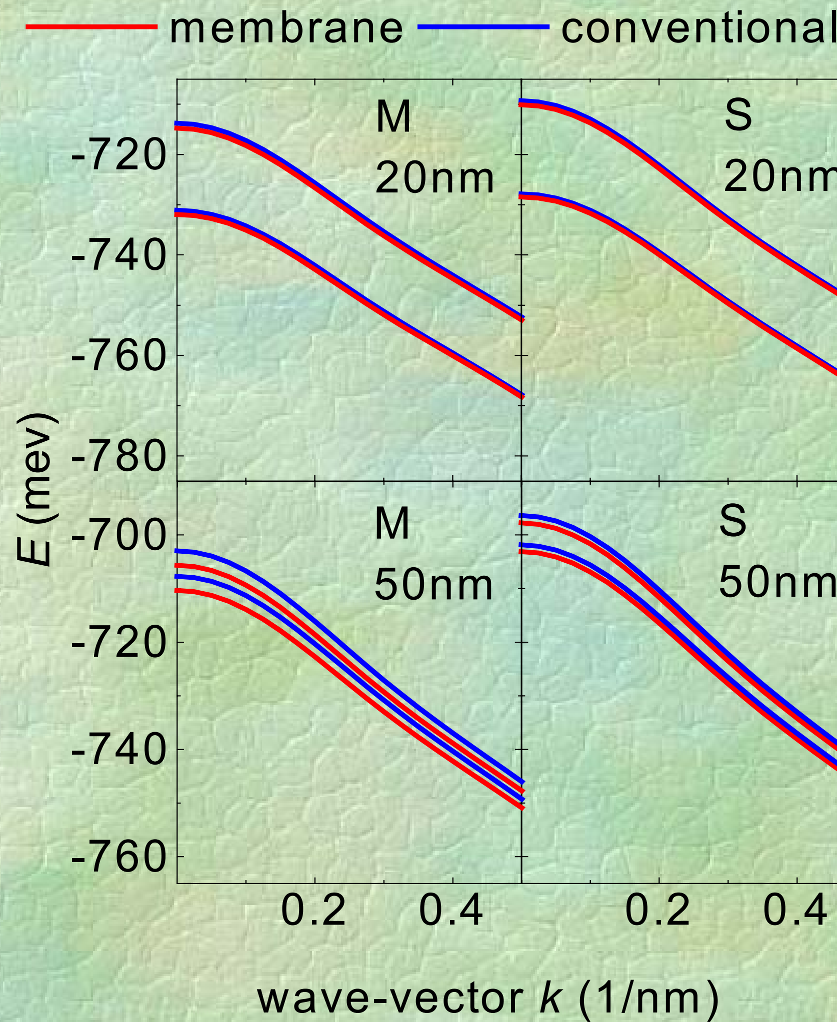
40 nm wire width



Depends on thickness of top and bottom InP layers (*t*)

Results (4)

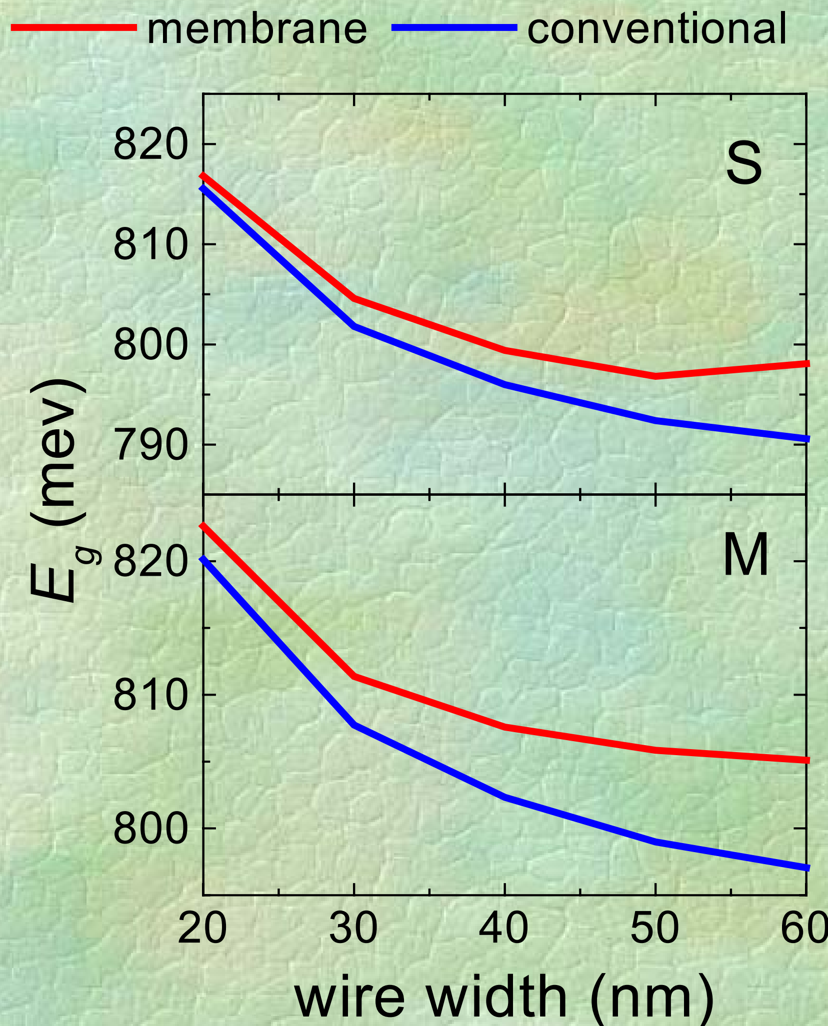
0.15% TS



E_g in membrane structure increases : ΔE_g negative

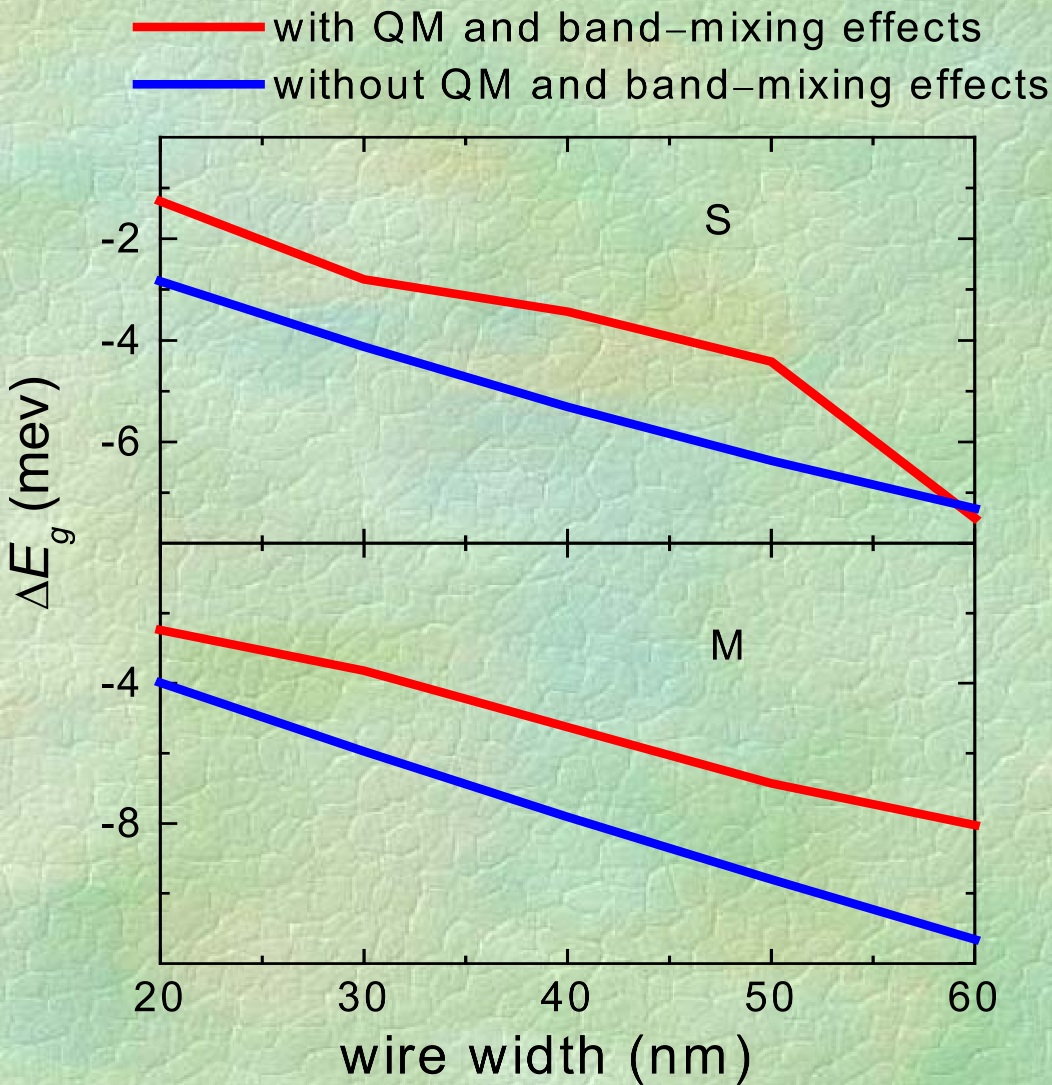
Membrane: Blue shift

Results (5)



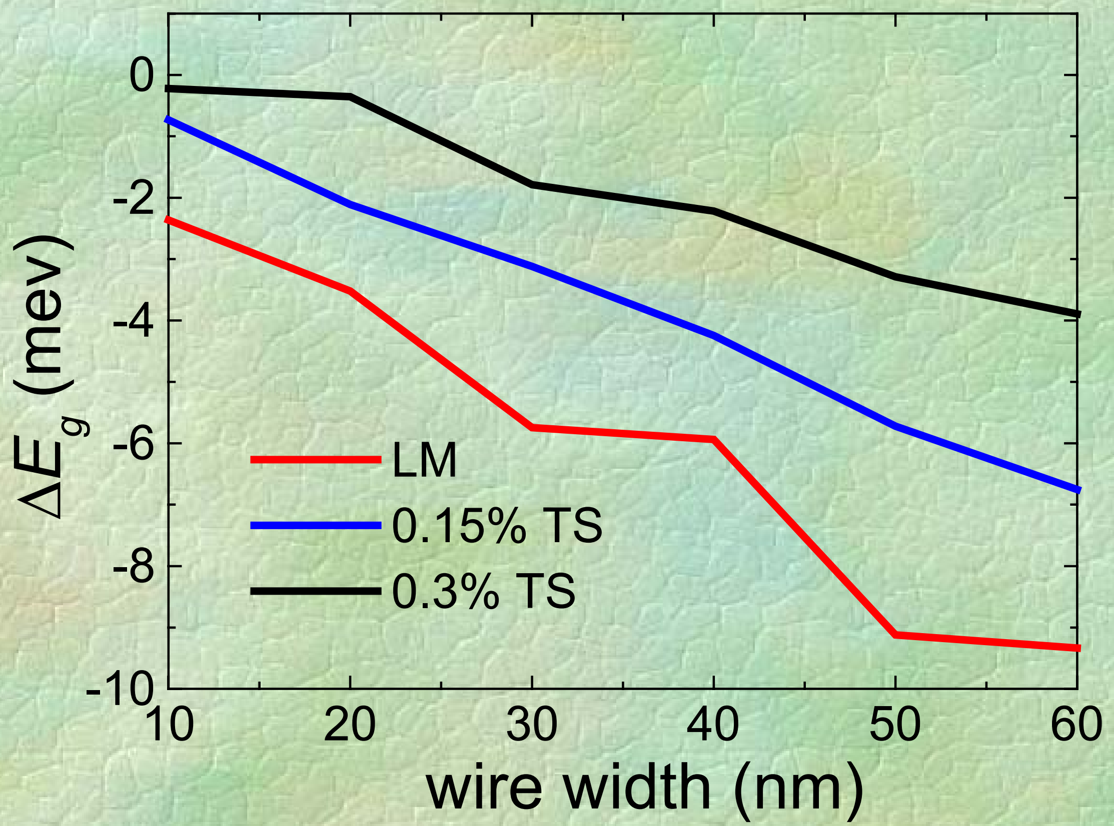
0.15% TS t = 13 nm

Results (6)



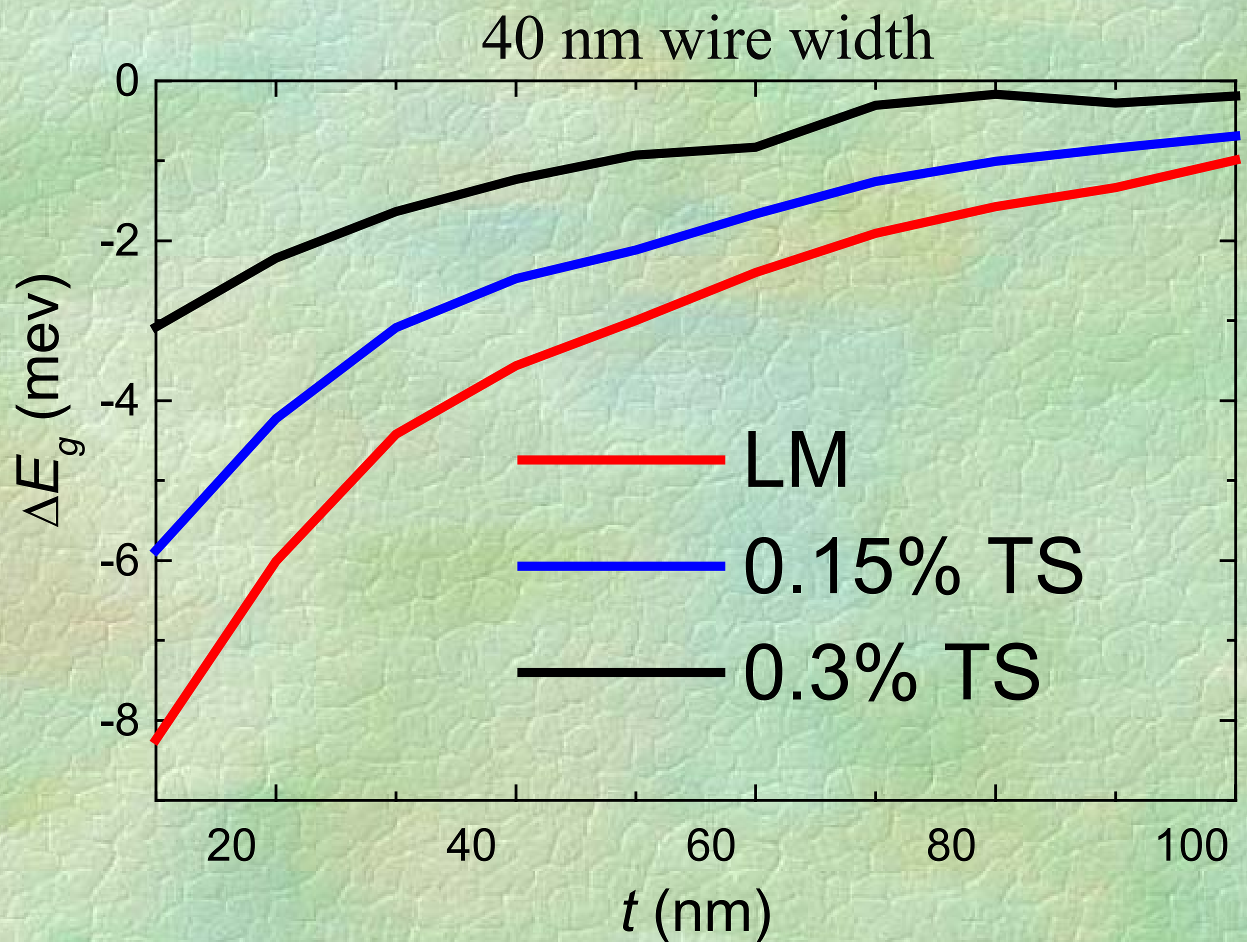
0.15% TS t = 13 nm

Results (7)



t = 20 nm

Results (8)



40 nm wire width
0
-2
-4
-6
-8
ΔE_g (mev)
20
40
60
80
100
t (nm)
LM
0.15% TS
0.3% TS

Conclusions

- Strain relaxation different in membrane QWR structures.
- Depends on *wire width*, *number of stacked layers*, *core thickness* etc.
- Strain relaxations strongly modify energy band structures.
- Blue shift due to etching.

Thank you.