Engineering the Transverse Optical Guiding in GaN-based Vertical-Cavity Surface-Emitting Lasers to Avoid Detrimental Optical Loss

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Importance of a correctly designed laser cavity

Small changes in the structure of a VCSEL cavity can have a dramatic impact on the optical loss. This is particularly important for the realization of GaN-based VCSELs, where challenges such as

- achieving high reflectivity DBRs
- obtaining precise control of the cavity length
- overcoming the low electrical conductivity of p-type GaN

have forced researchers to consider new cavity designs. However, even small modifications to the laser structure can detoriorate the laser performance, because of massively increased loss leading to increased threshold gains by several hundred percent in some cases.

"Guiding" indicates "good cavity"

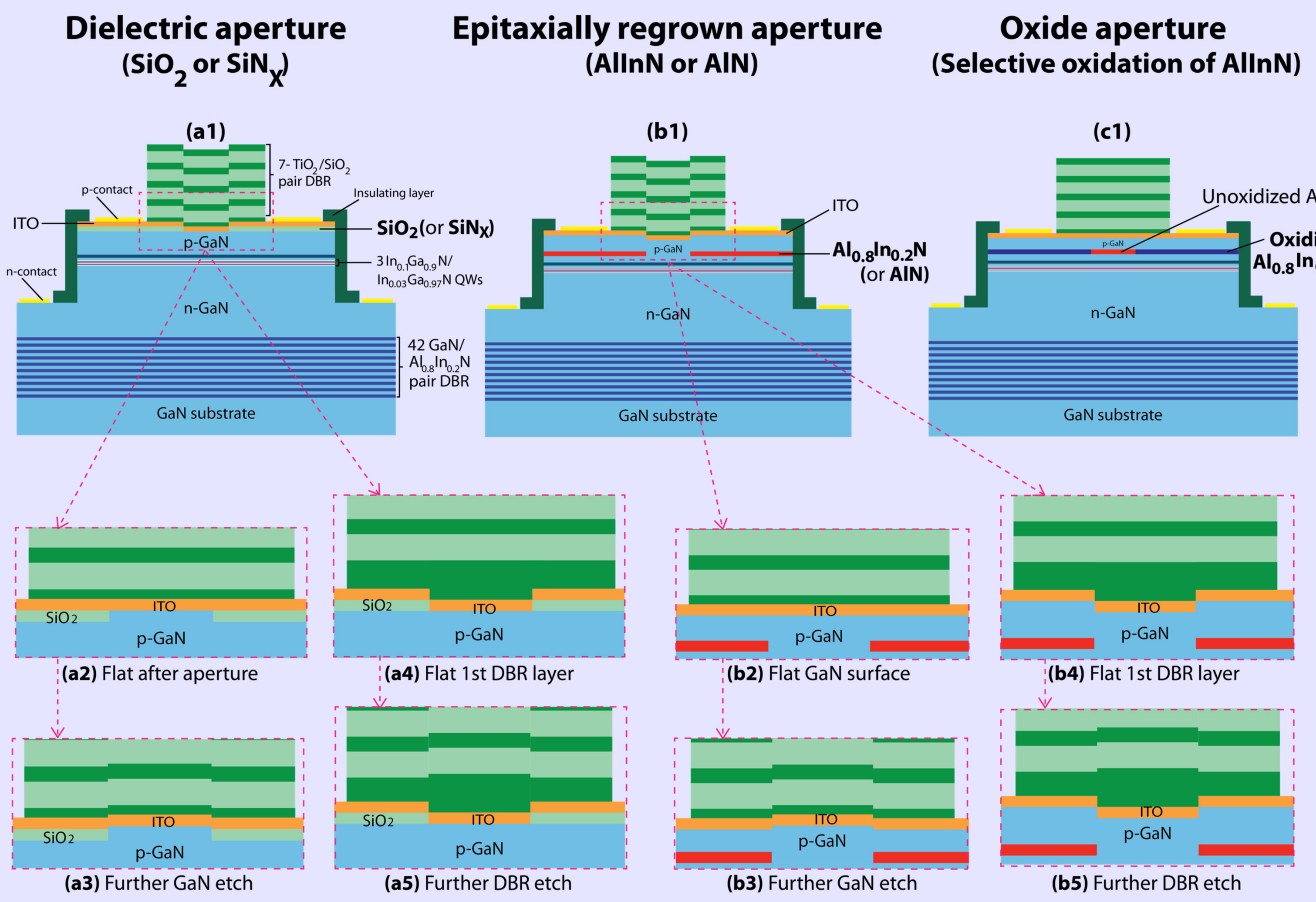
We have found that the amount of optical guiding very presicely indicates whether a cavity is close to the "best possible" structure - i.e. has the lowest possible threshold gain – or the "worst possible". Thus, it is crucial to consider the optical guiding to avoid realizing GaN structures that will inherently never lase.

So what is "guiding"?

The guiding is determined by the guiding parameter Δn_{eff}, which is a function of the refractive index variation in the cavity. In essence, Δn_{eff} is the difference between the refractive index near the optical axis and that in the periphery, where here the refractive index is an effective index experienced by the optical mode.

Cavity structures tested for guiding and threshold gain

The effects on optical guiding and threshold gain by the following transverse current confining schemes have been studied.

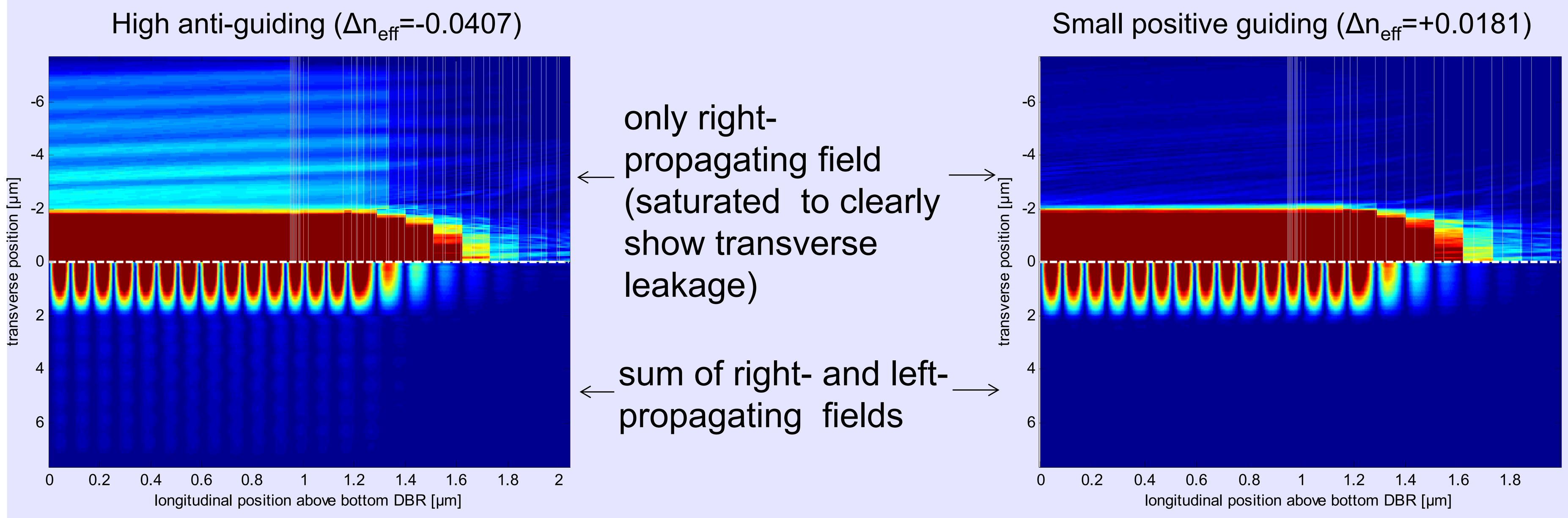


Numerical methods

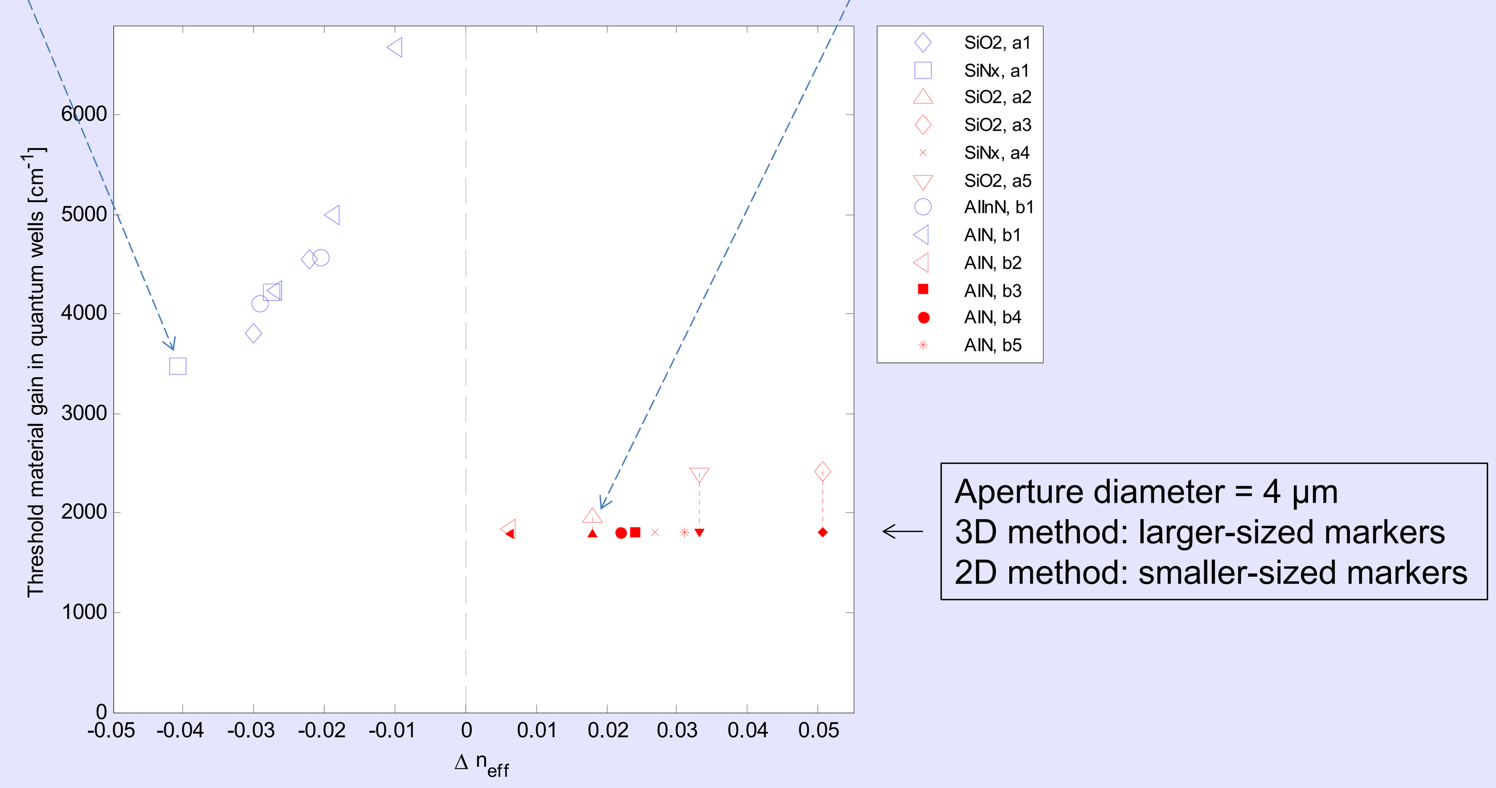
- 2D effective index method
  → Δn_{eff}
  → threshold material gain for the fundamental mode (accurate for weakly positive index-guided structures)
- 3D coupled-cavity beam propagation method
  → threshold material gain for the fundamental mode

Threshold material gain versus Δn_{eff}

Intracavity field above the bottom DBR in a cross-section of the VCSEL. The vertical lines indicate the interfaces between the subcavities in the 3D simulation.



Calculated threshold material gain for the fundamental mode for VCSEL structures with different built-in index-guiding.



Conclusions

- Lateral leakage and diffraction losses, and thus threshold material gain, strongly depend on design of transverse current confinement scheme.
- A "negative" physical step translated into the top DBR (which exists in many GaN-based VCSEL designs) ⇒ optical anti-guiding and high threshold gain.
- Close to zero index guiding ⇒ dramatic changes in threshold material gain (from 6000 cm^{-1} to 2000 cm^{-1})
- By small modification, an index-guided structure with low threshold gain can be achieved, with similar index guiding as a standard oxide-confined 850-nm GaAs-based VCSEL.

Acknowledgement

This work was supported by the Swedish Research Council (VR).

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