Modeling Photonic Crystal Light Emitting Diode (PhCLED) Using APSYS

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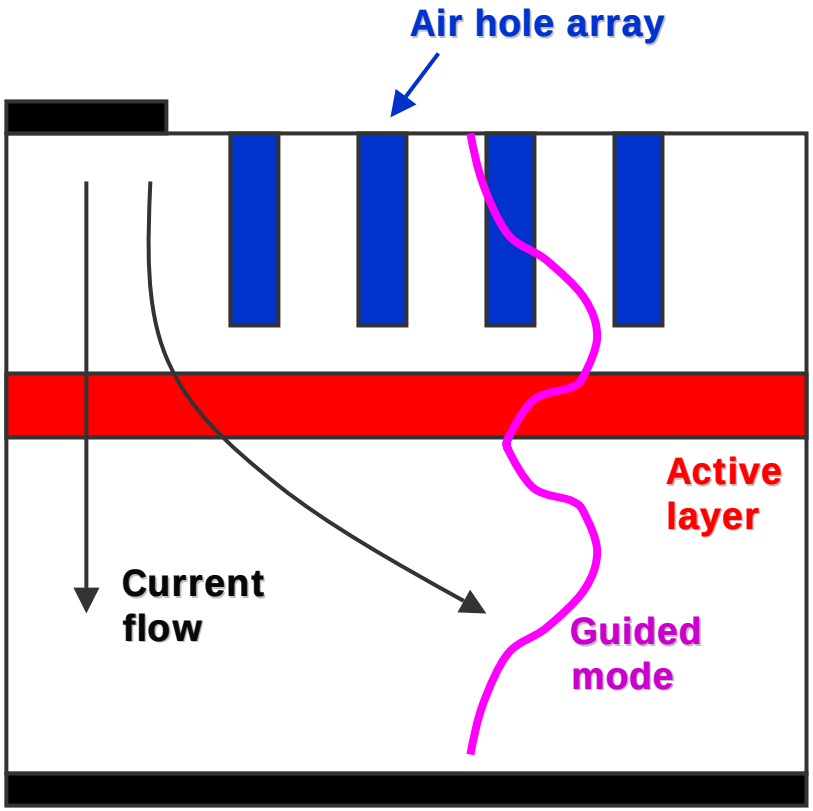
Contents

- Model
- A PhCLED with DBR
- An InGaN PhCLED with guided multimodes
- Summary

Modeling photonic crystal LED



- Current injection and spontaneous emission in MQW modeled by 2/3D drift-diffusion theory and self-consistent solution of quantum mechanical wave equations.
- Spontaneous emission coupled to guided modes by Green's function method [*].
- Guided modes coupled to photonic crystal grating by coupled mode theory [**].

[*] Green's function method is a theory to calculate field distribution produced by continuously distributed light source.

[**] Coupled-mode theory studies a series of plane waves scattered by a periodic refractive index perturbation.

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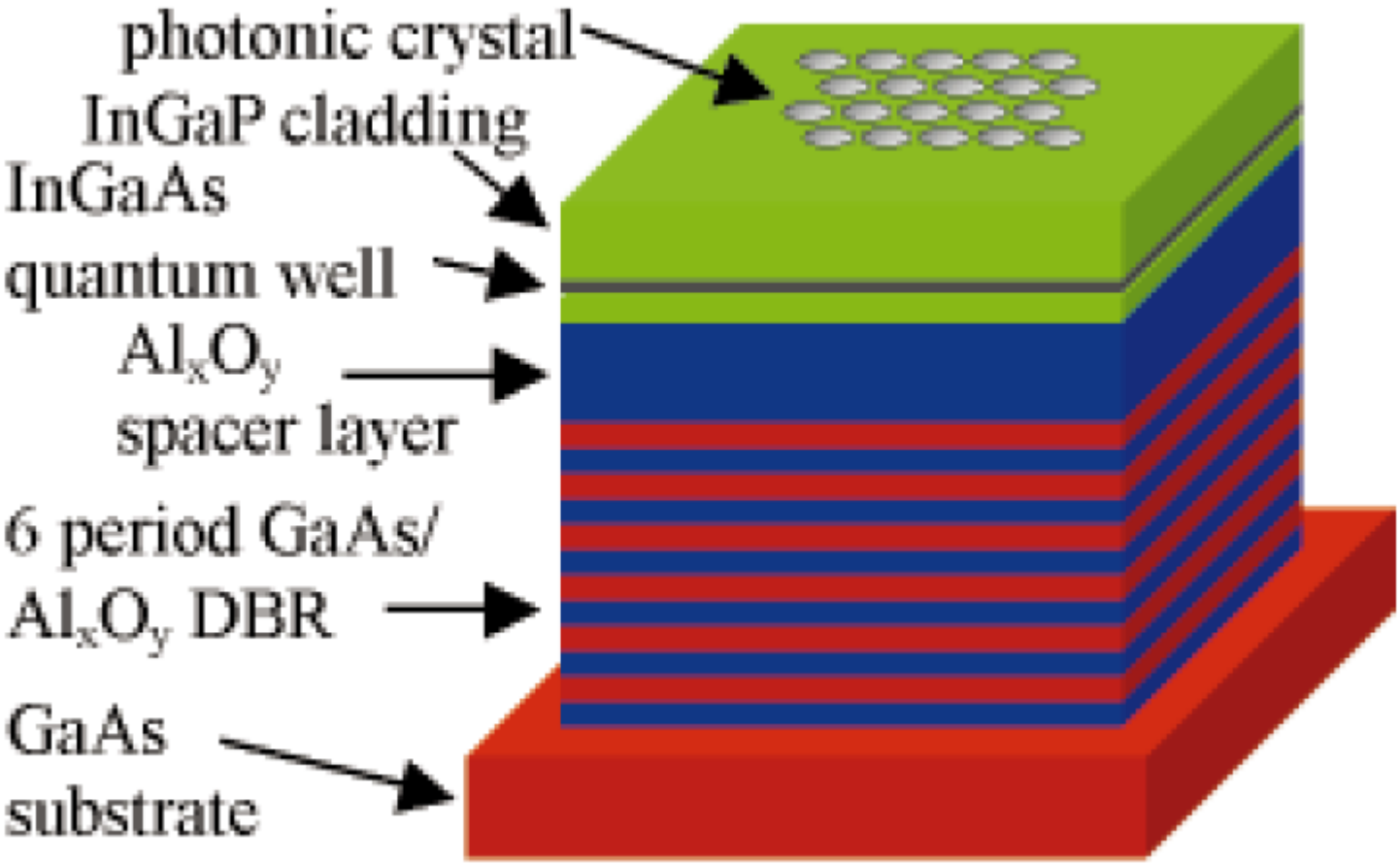
Common Ph.C. LED with DBR



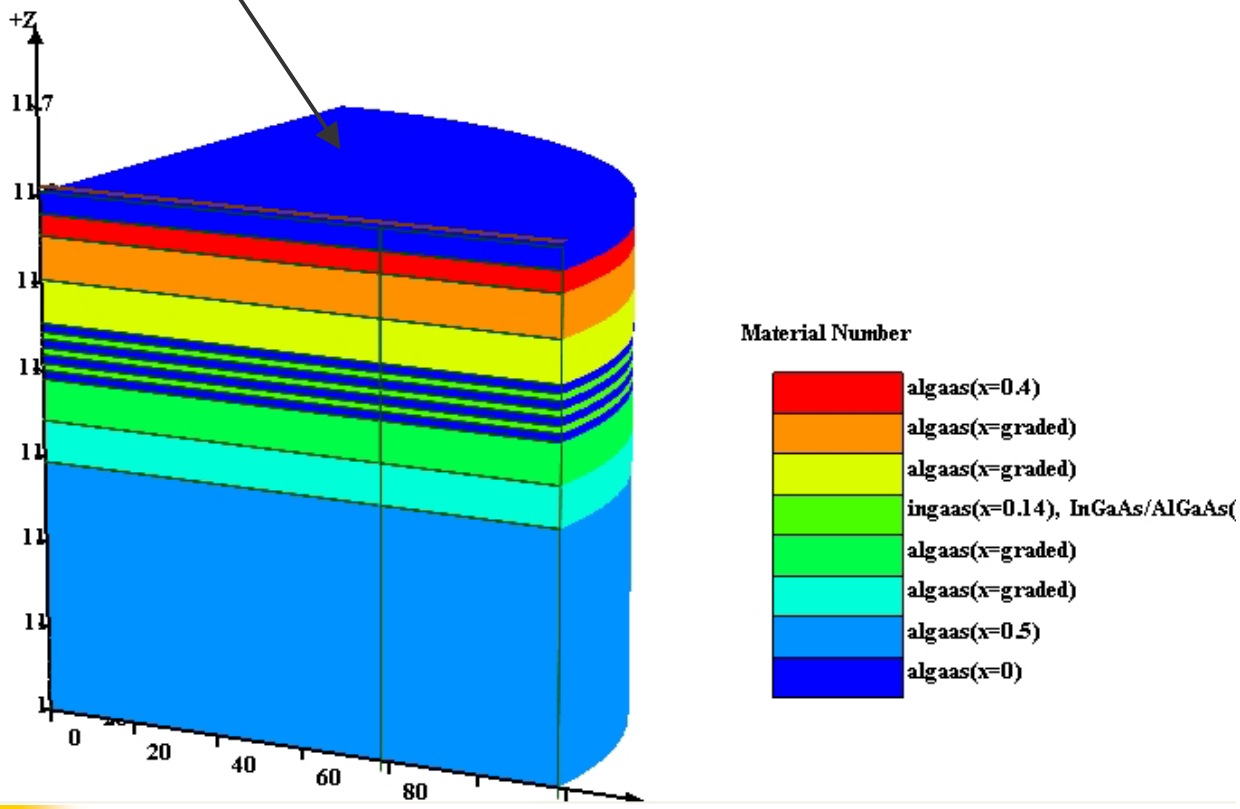
See for example: APL vol. 78, p. 563, 2001

Rem: They are similar to RCLED except for the top air holes

Simulation study

With and without air holes

Transparent top electrodes are assumed for air hole emission calculation.



Based on experimental structure from Schubert et. al., J. Lightwave Technol., vol. 14, p. 1721. Air holes were placed on top to compare its performance wih and without Ph.C. air holes.

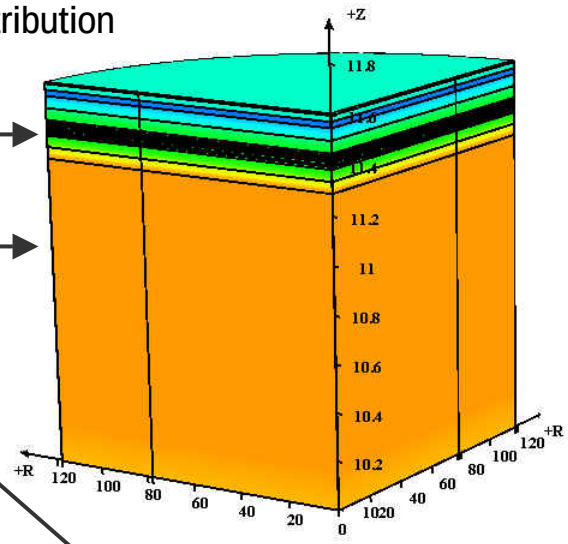
2/3D Drift-Diffusion Model

3D Potential distribution

MQW Region

DBR Region

Distribution of y-component of electronic current

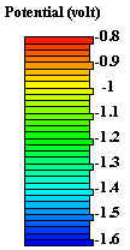


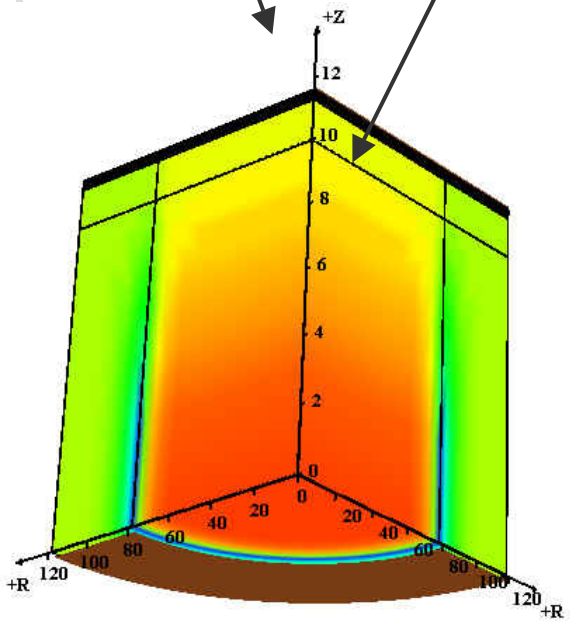
File Name : rc.std_0006
File Type : APSYS

Variable Name :
Potential (volt)

3D Cube Contour Parameters :
X Range : 0 - 118
Y Range : 10 - 11.6044
Z Range : 0 - 0

X Cut Line Num : 20
Y Cut Line Num : 20
Z Cut Line Num : 20



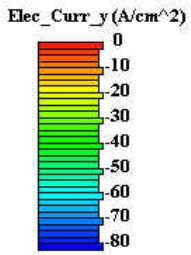


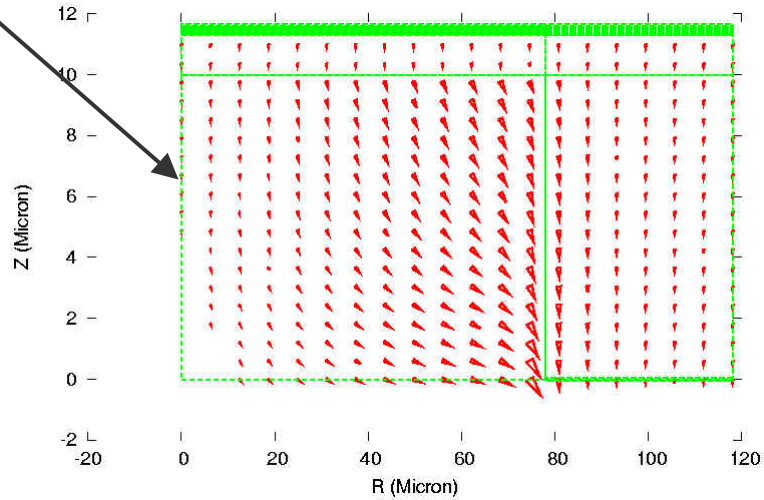
File Name : rc.std_0004
File Type : APSYS

Variable Name :
Elec_Curr_y (A/cm^2)

3D Cube Contour Parameters :
X Range : 0 - 118
Y Range : 0 - 11.6044
Z Range : 0 - 0

X Cut Line Num : 20
Y Cut Line Num : 20
Z Cut Line Num : 20





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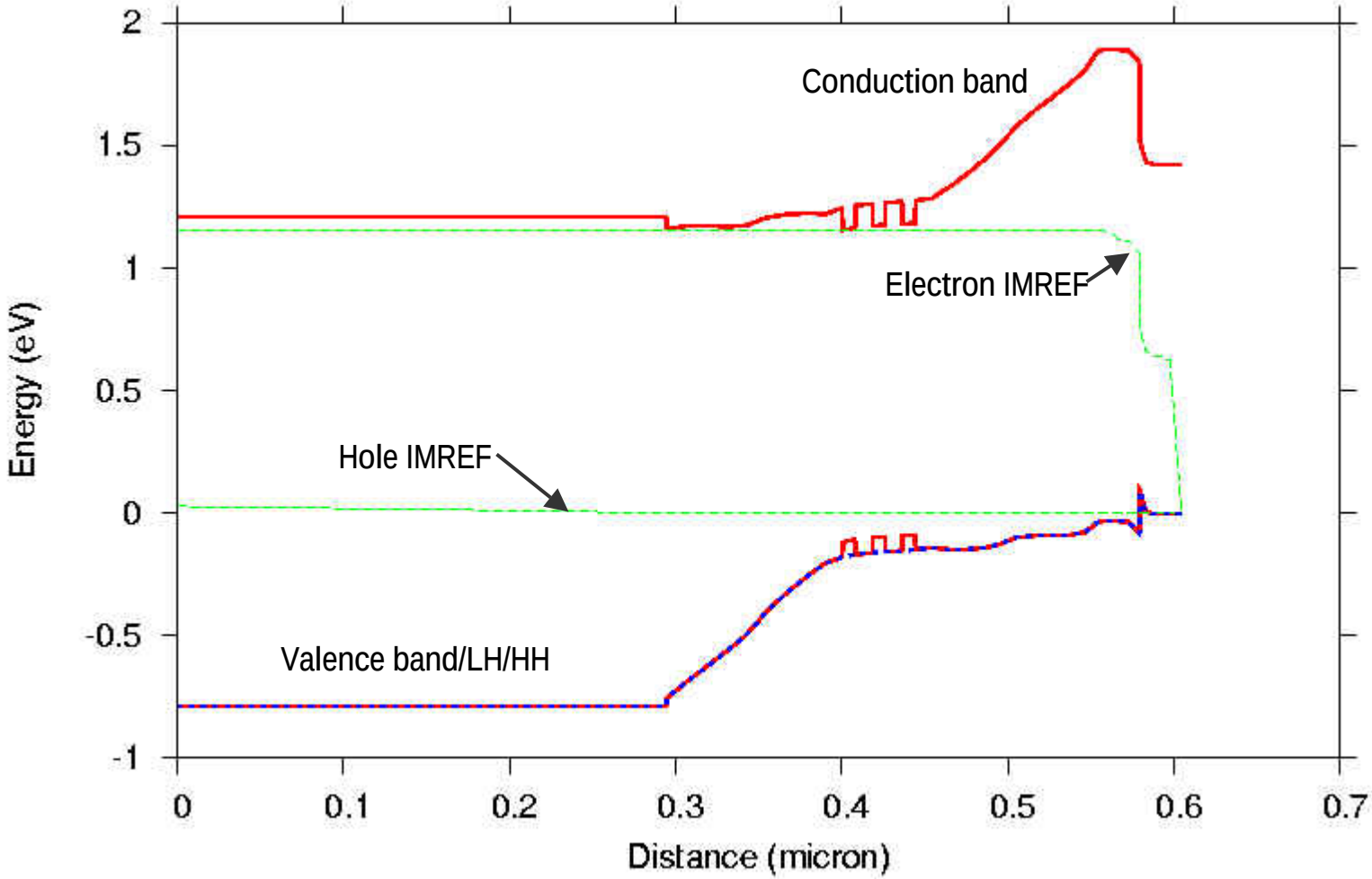
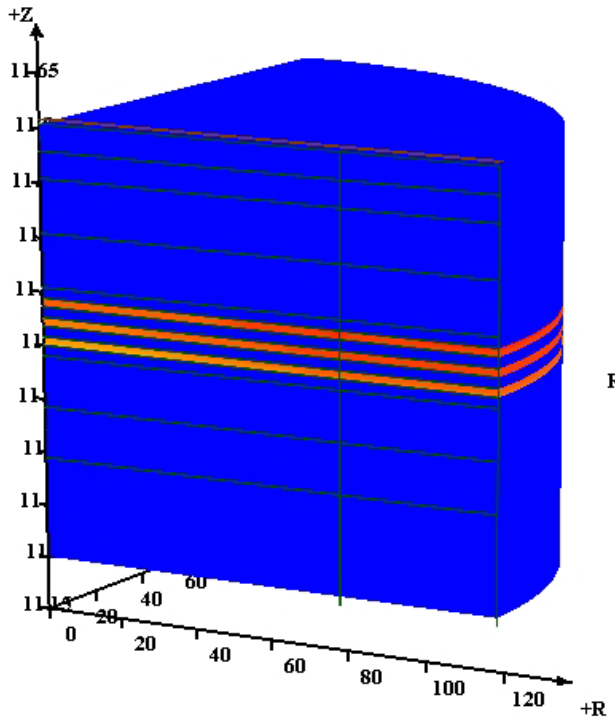
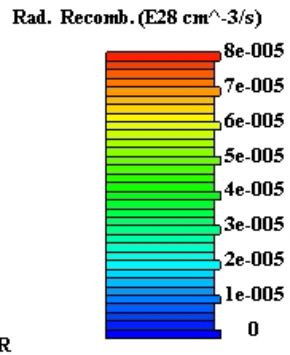
Physical Simulation

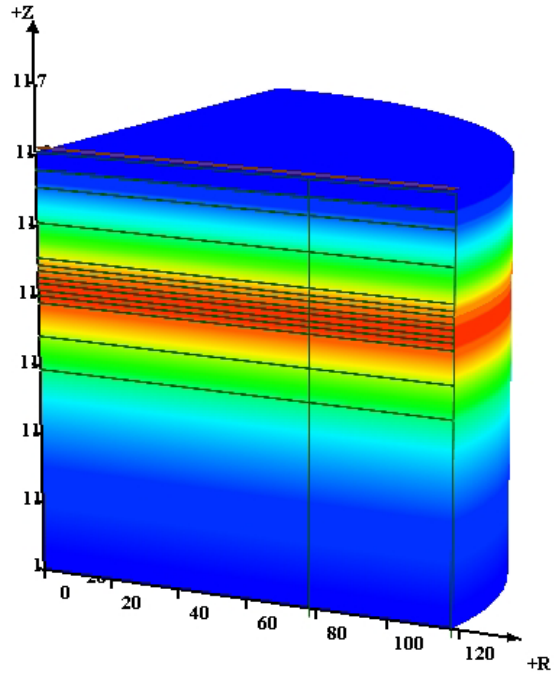


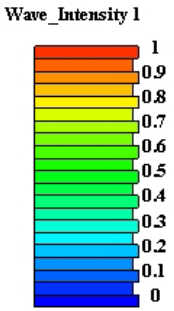
3D simulation of band structure physics including MQW strain effects. Current flow and self-heating may be included self-consistently.

Spontaneous emission & guided mode









For illustrative purpose, interaction between a single guided mode with spontaneous emission source considered.

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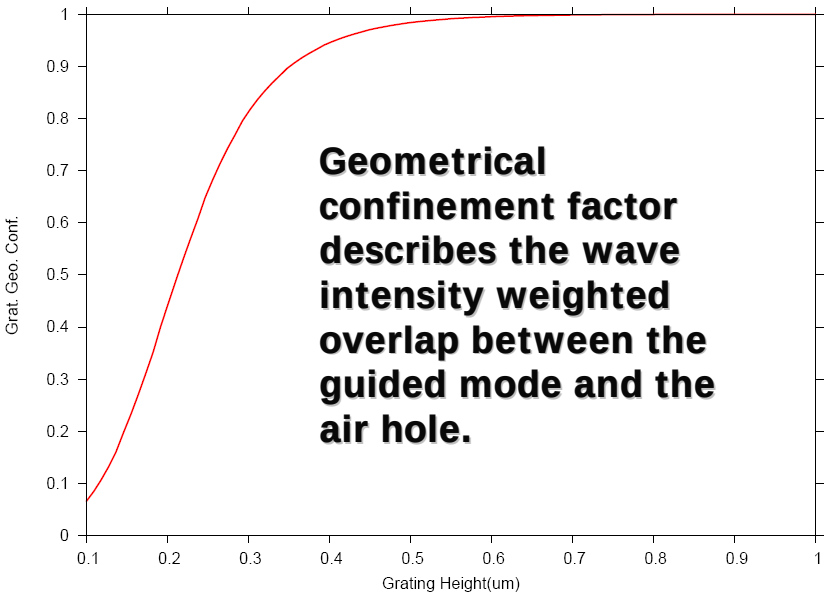
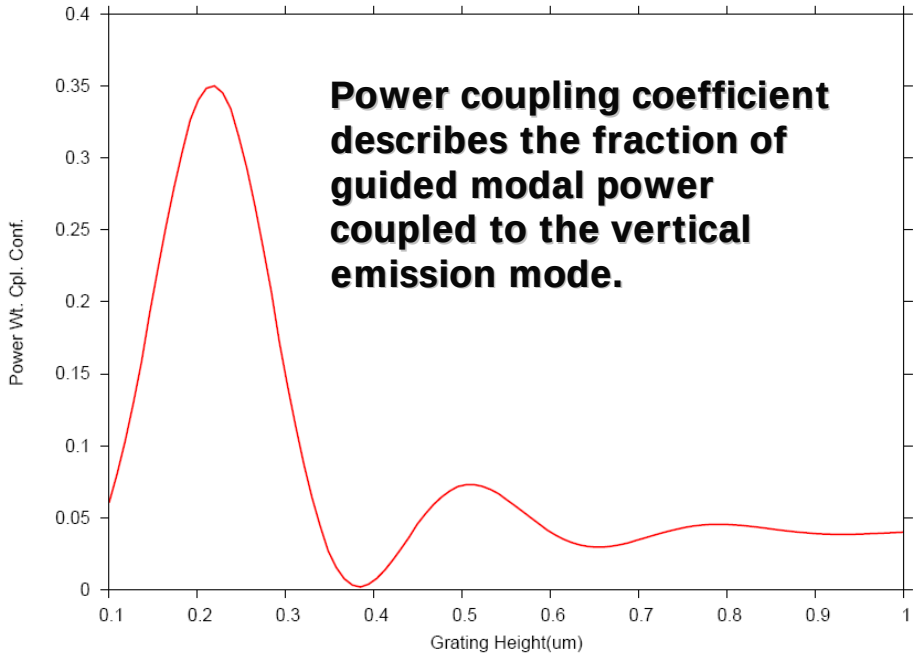
Geometric & power coupling vs. air hole depth



Geometrical confinement factor describes the wave intensity weighted overlap between the guided mode and the air hole.

More overlap between air hole and guided mode does not guarantee higher power coupling because the air holes act as coherent emitting source driven by the guided mode in the vertical direction. Maximum power is achieved only when there is constructive interference in the vertical direction.



Power coupling coefficient describes the fraction of guided modal power coupled to the vertical emission mode.

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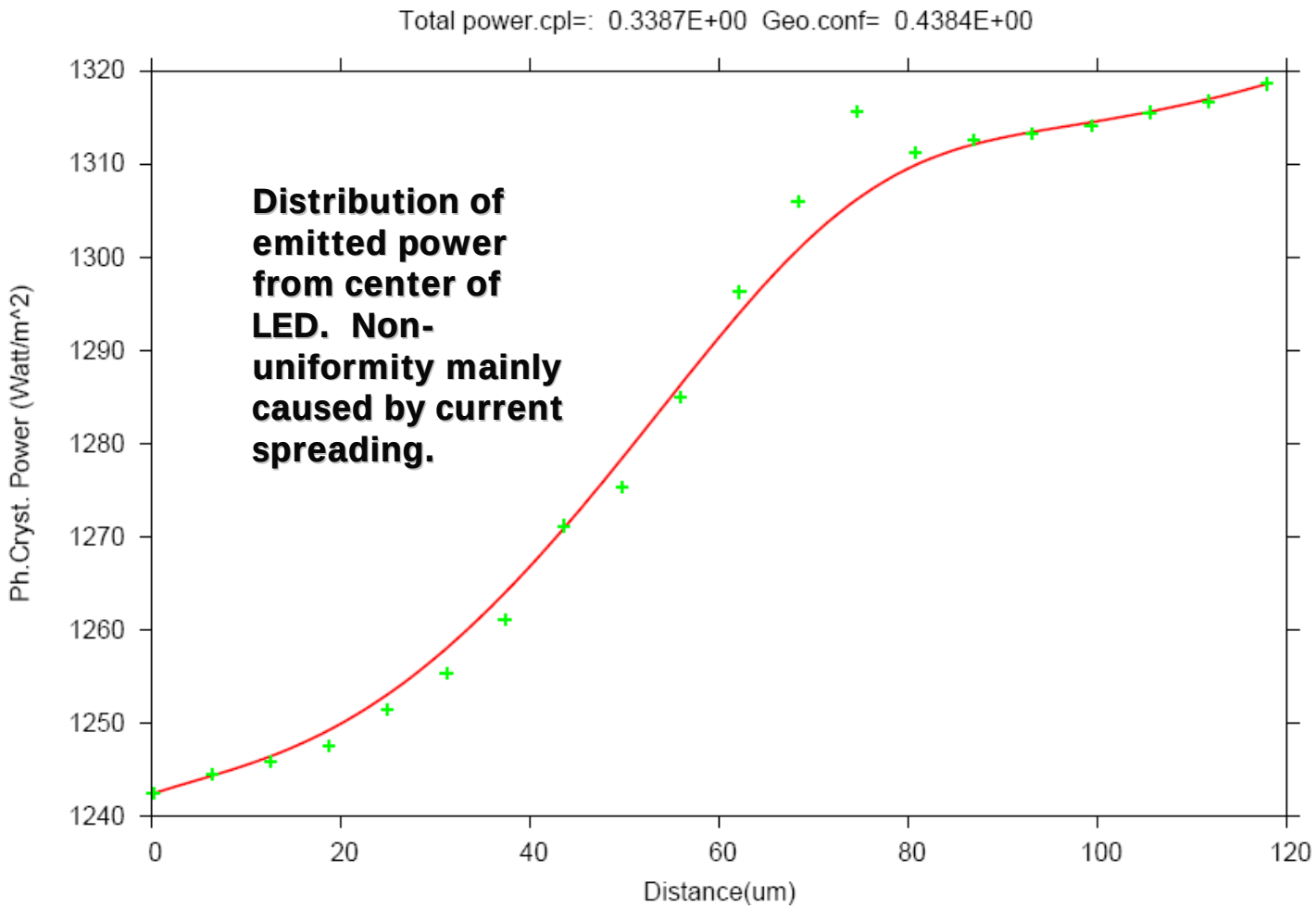
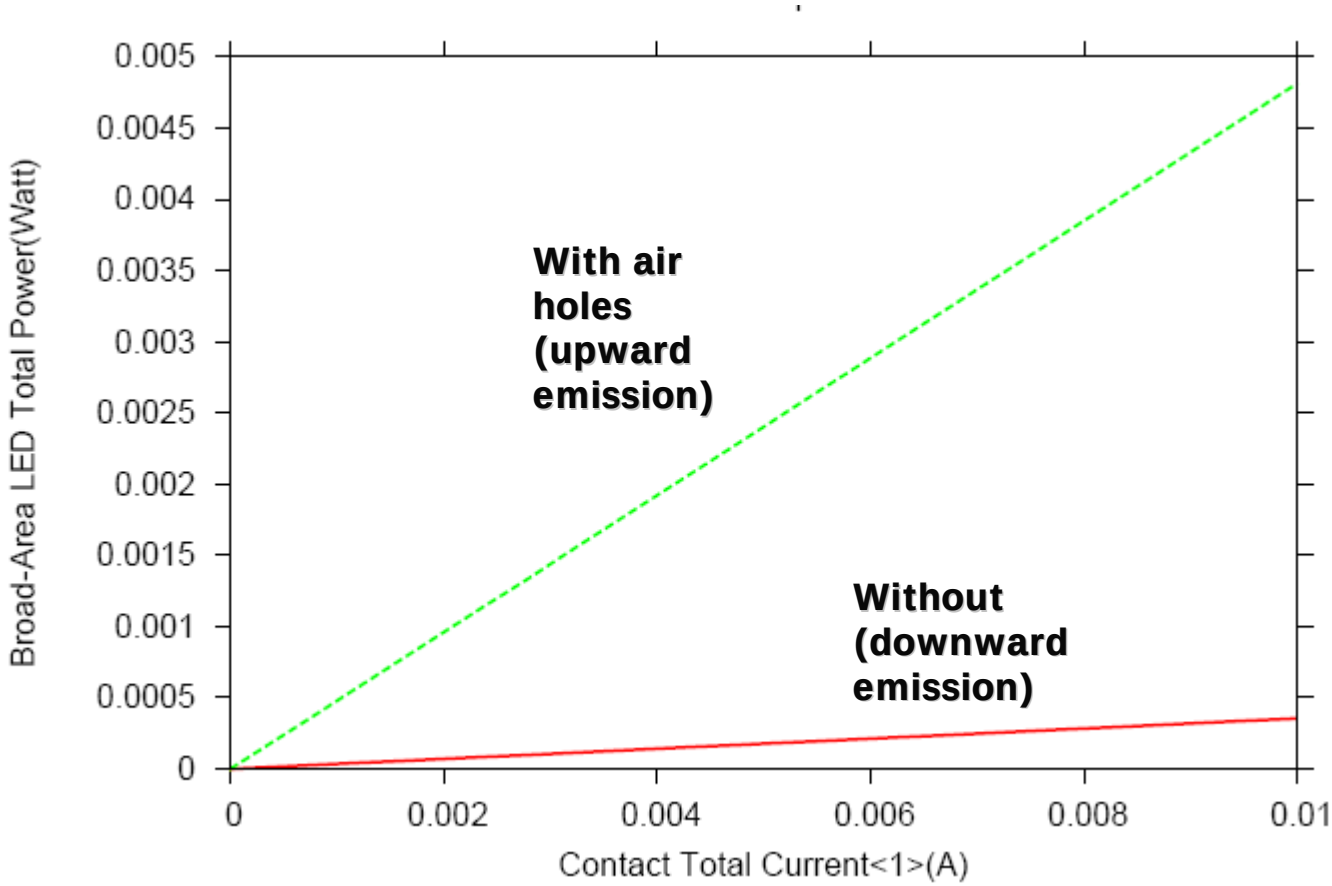
Distribution of vertical emission power density



Substantial increase in power extraction



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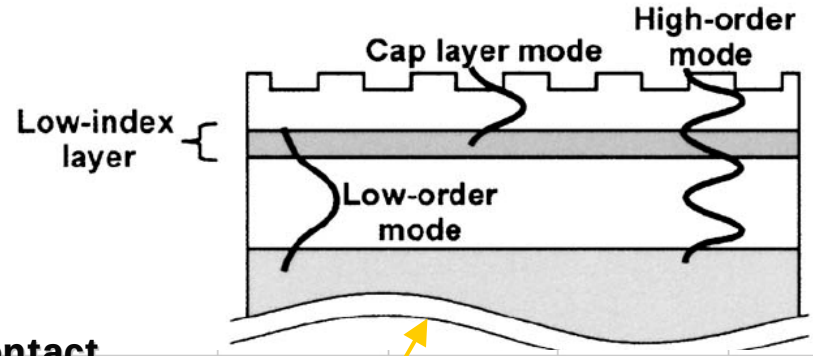
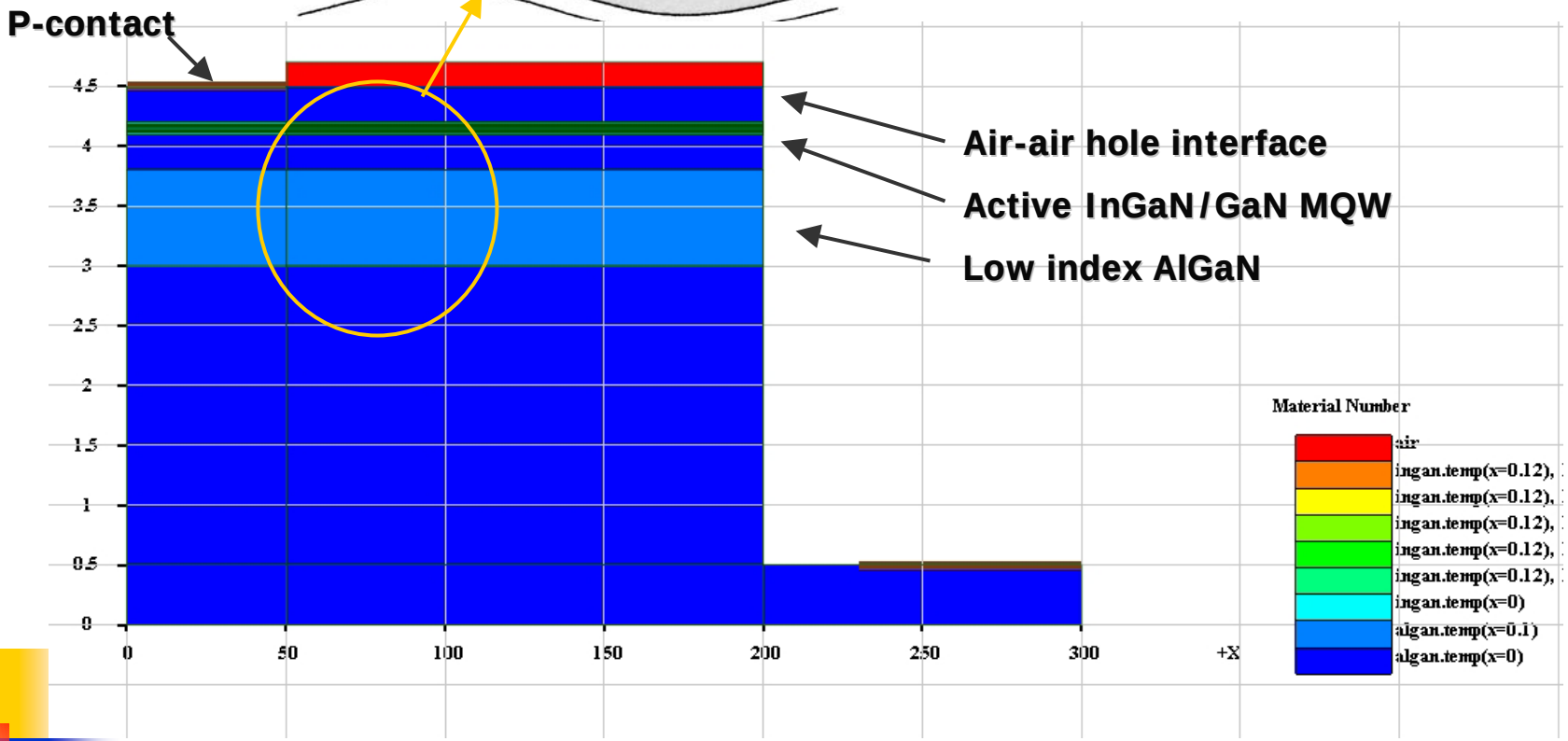
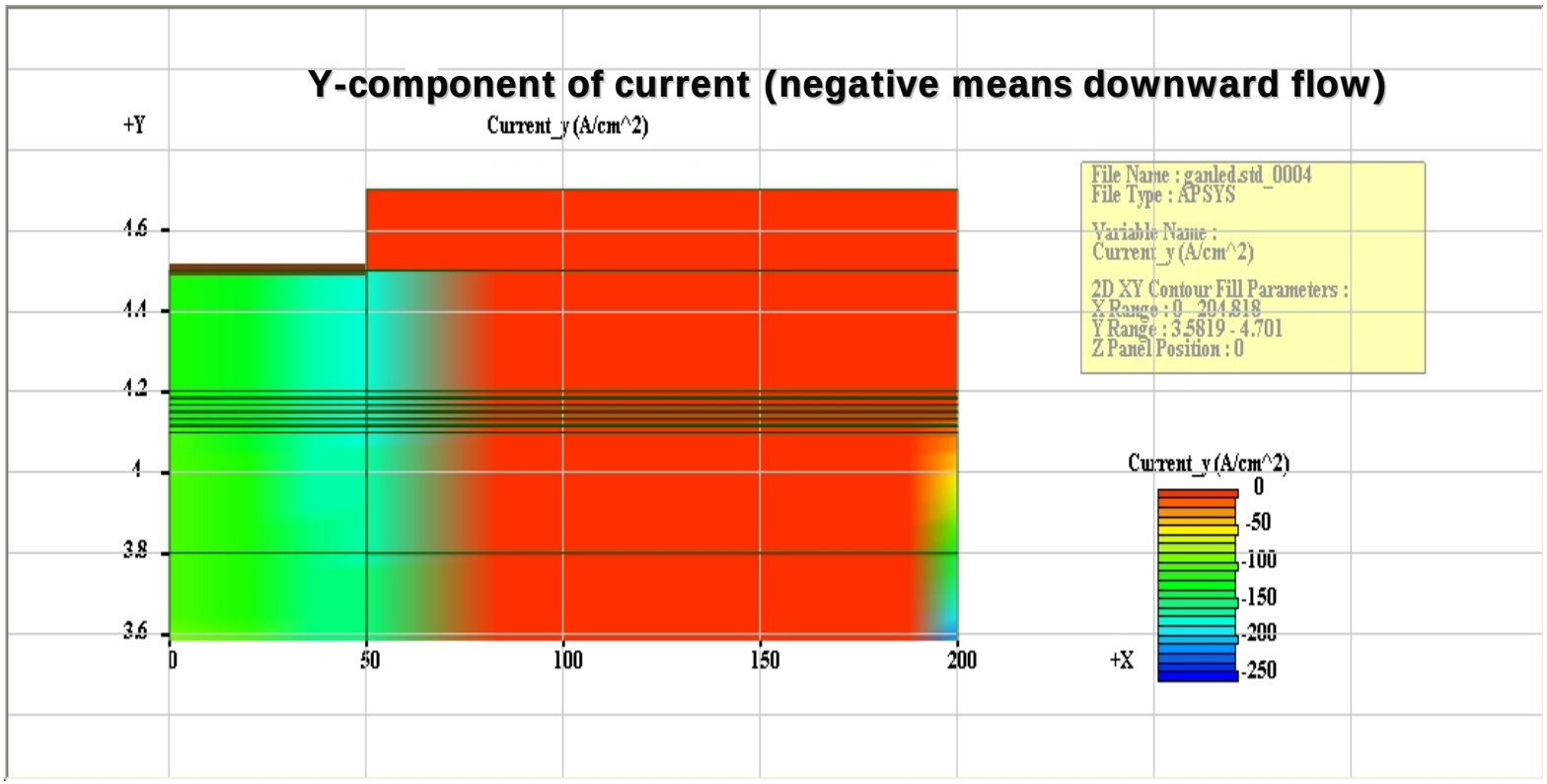
Simulated structure



Based on experimental structure of David et al. Appl. Phys. Lett. 88, 061124 2006

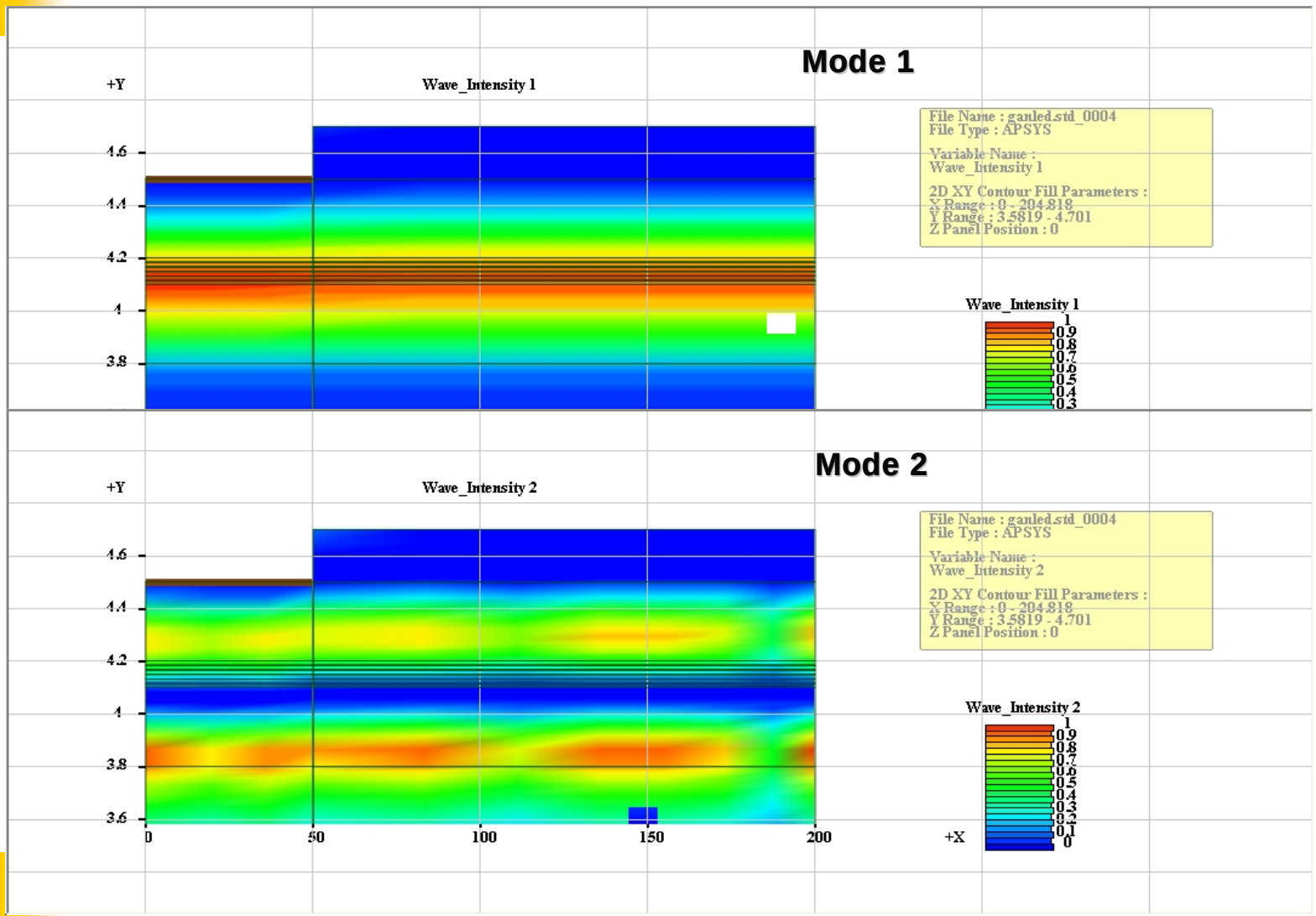


Simulated current crowding

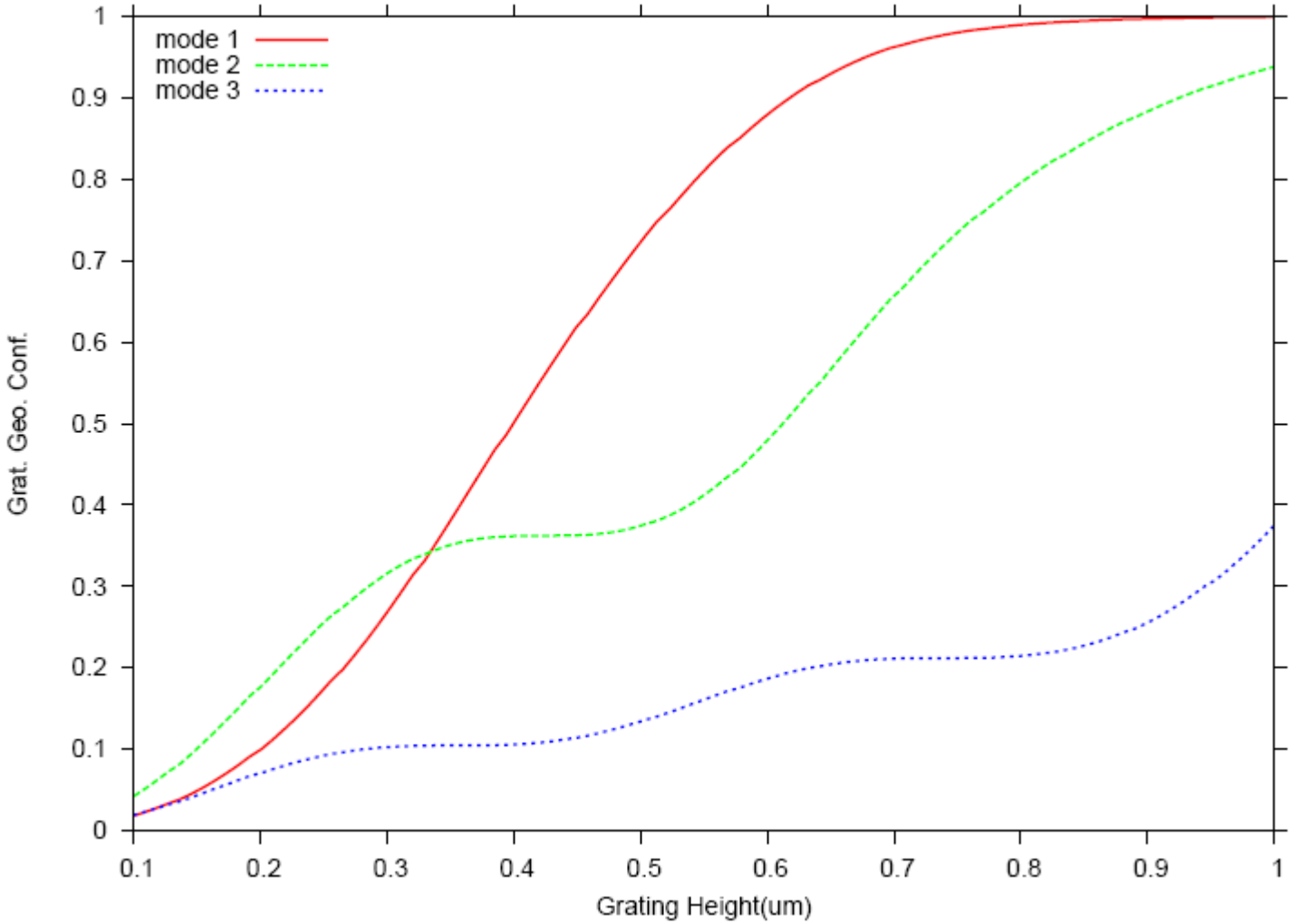


Strong current crowding is present in this structure.

Guided multimodes

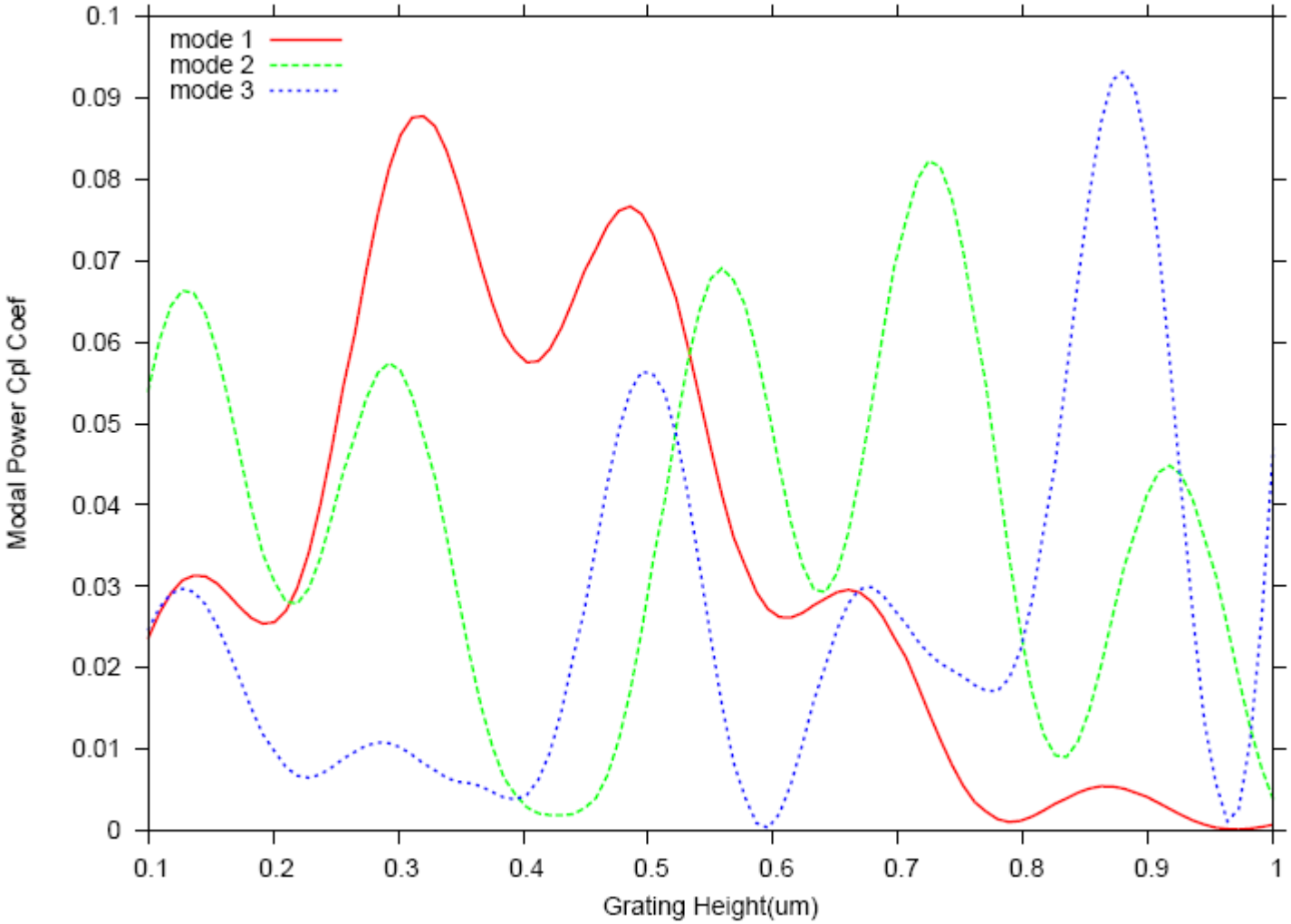


Geometric confinement factor



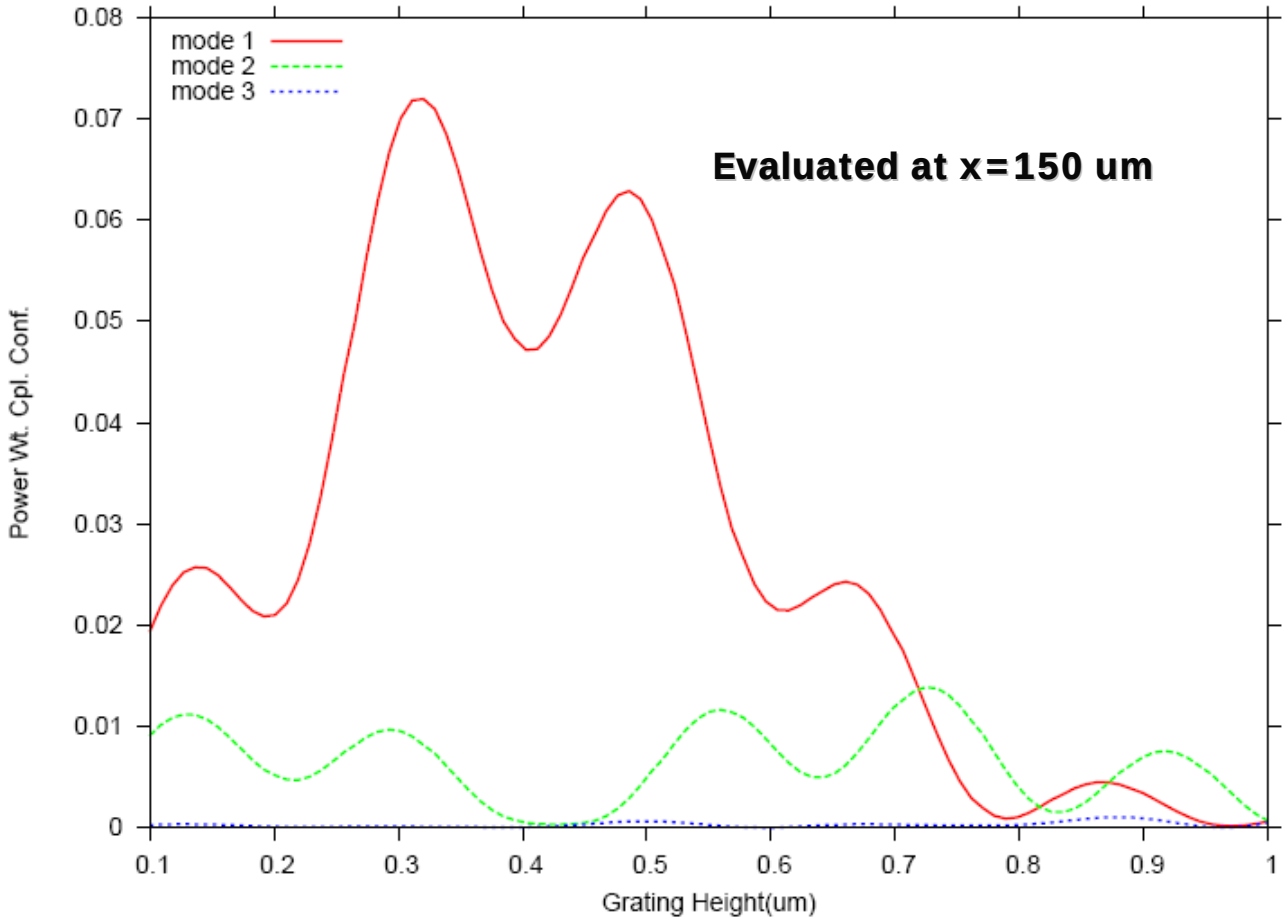
Remark: For shallow air holes, higher order modes may have higher geometric coupling coefficient.

Modal power coupling coefficient



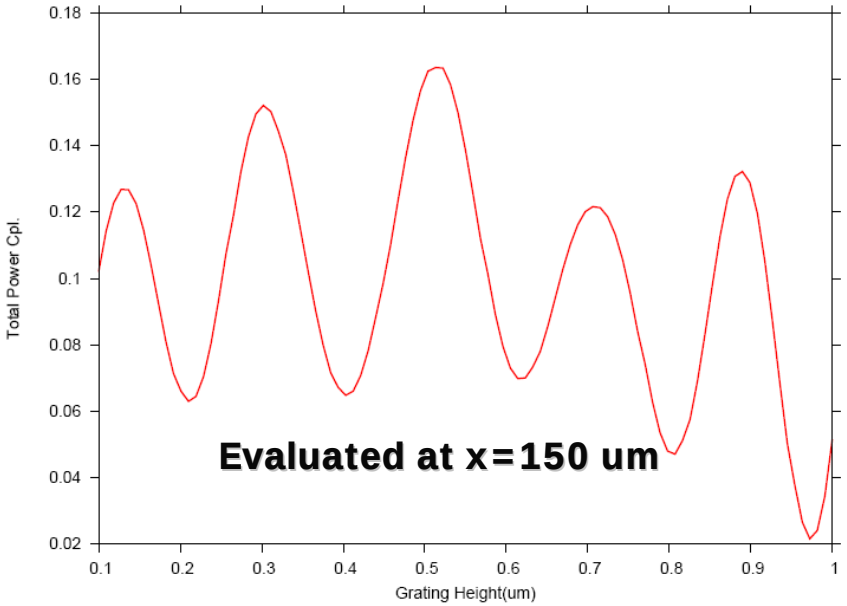
Remark: For shallow air holes, higher order modes may have higher modal coupling coefficient.

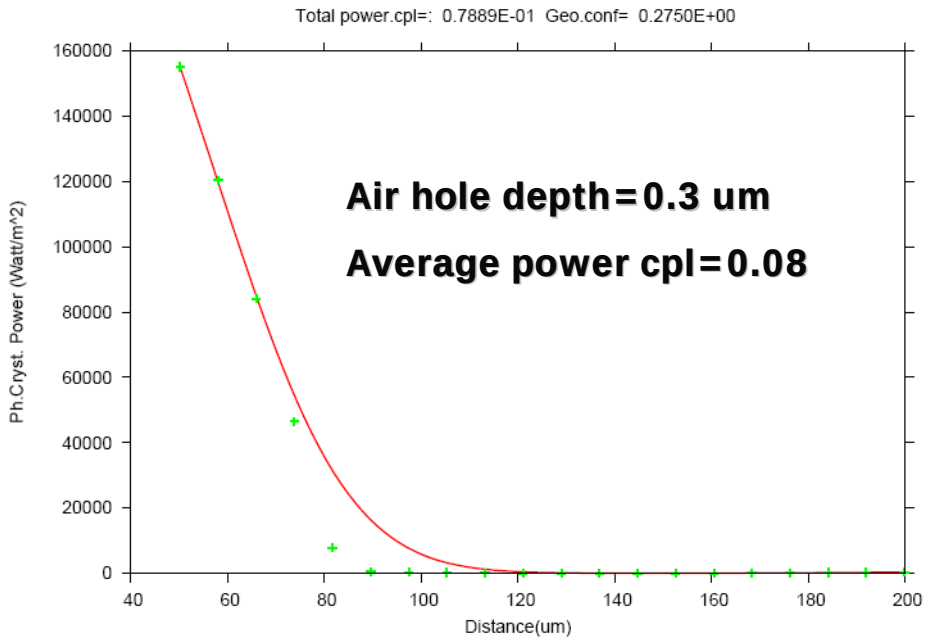
Power weighted coupling coefficient



Remark: For this structure, the fundamental mode carries most of the power and still dominates power coupling, assuming only three multimodes in the calculation.

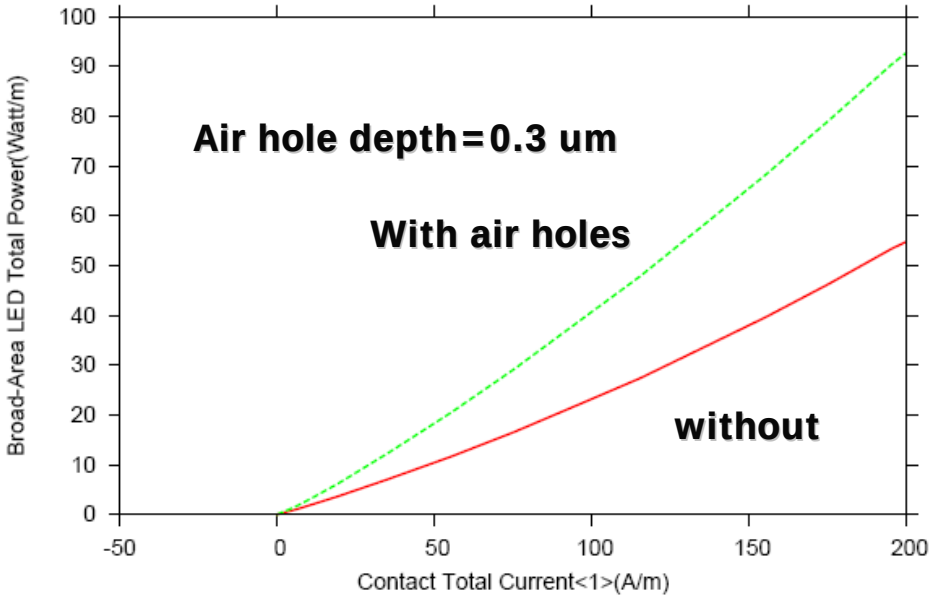
Total power coupling





Remark: due to current crowding, substantial variation is seen in spatial distribution of extracted power.

Total power extraction enhancement



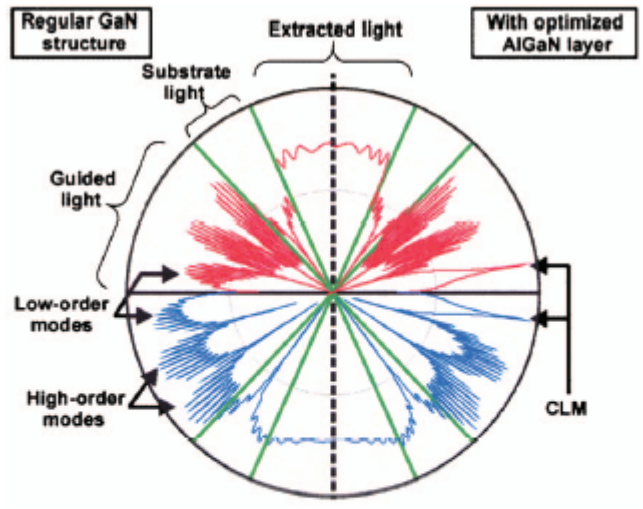


FIG. 3. (Color) Emission of a dipole plane in a GaN structure as a function of the polar angle of emission (log scale, TE polarization, red=upwards, blue=downwards). The lightlines of air and sapphire are depicted by green lines. Left half: typical GaN structure, 30% of light is emitted in low-order modes and not coupled to the PhC. Right half: same structure with an AlGaN layer, the low-order modes are replaced by a CLM carrying 30% of the total light.

APPLIED PHYSICS LETTERS **88**, 061124 2006

Using an air hole depth of 0.3 um (nearly touching the MQW) extracted power is nearly doubled. This result is consistent with experimental data.

Modeling results are reasonable considering only three modes are included.

Summary

- The APSYS-PhCLED option is an useful tool for optimization of air hole-spontaneous emission power coupling.
- Simulation results are consistent with published theories and experiments.