Diffraction Efficiency of 2D Photonic Crystal Structures on Light Emitting Diodes

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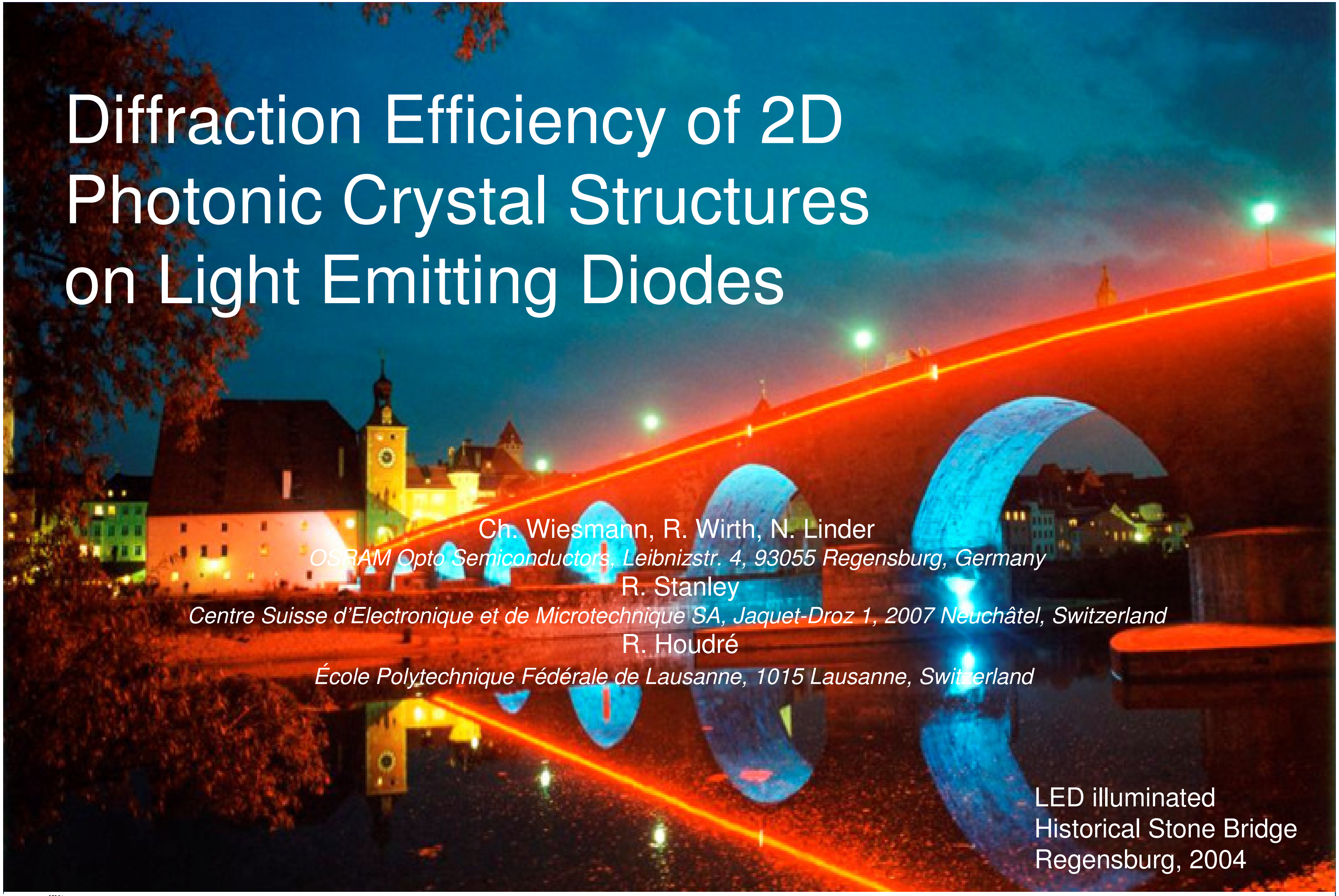


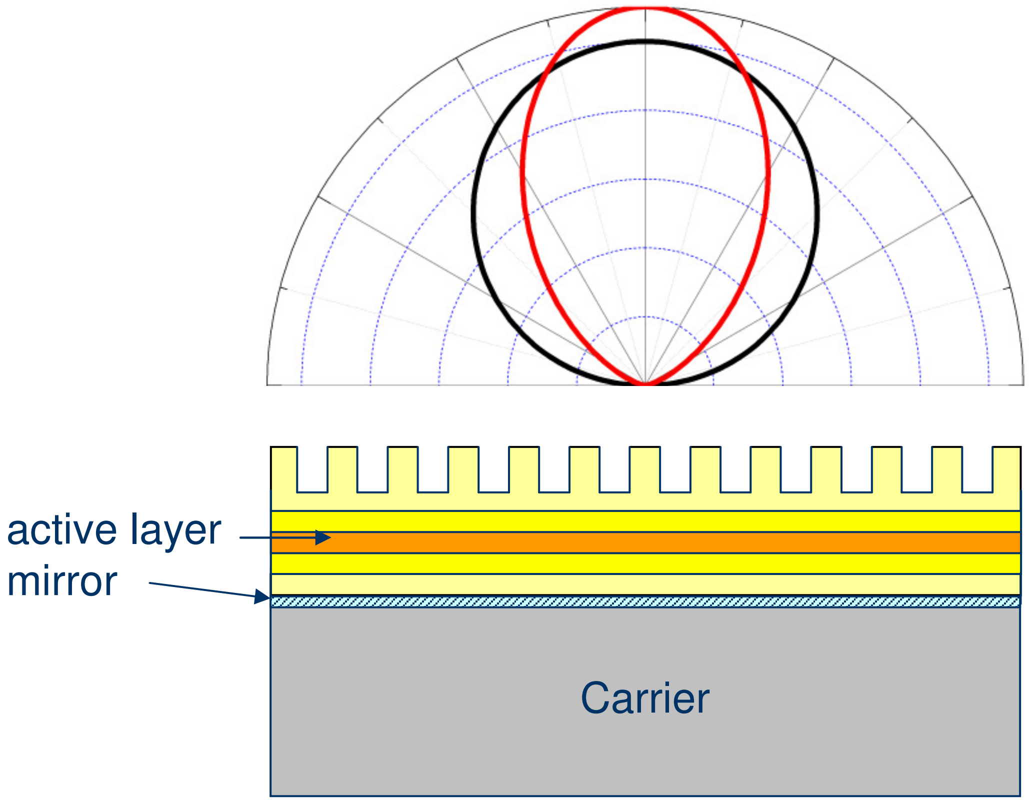
LED illuminated
Historical Stone Bridge
Regensburg, 2004

Outline

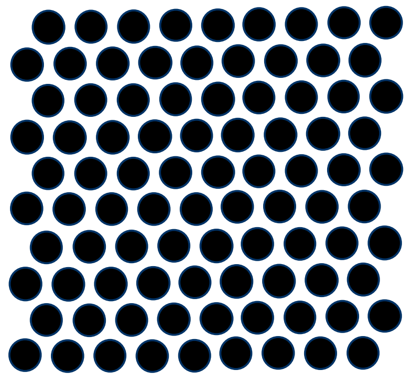
- Motivation for PC LEDs
- Description of Diffraction Model
- Simulation Results
- Summary

Motivation

Thinfilm-LED

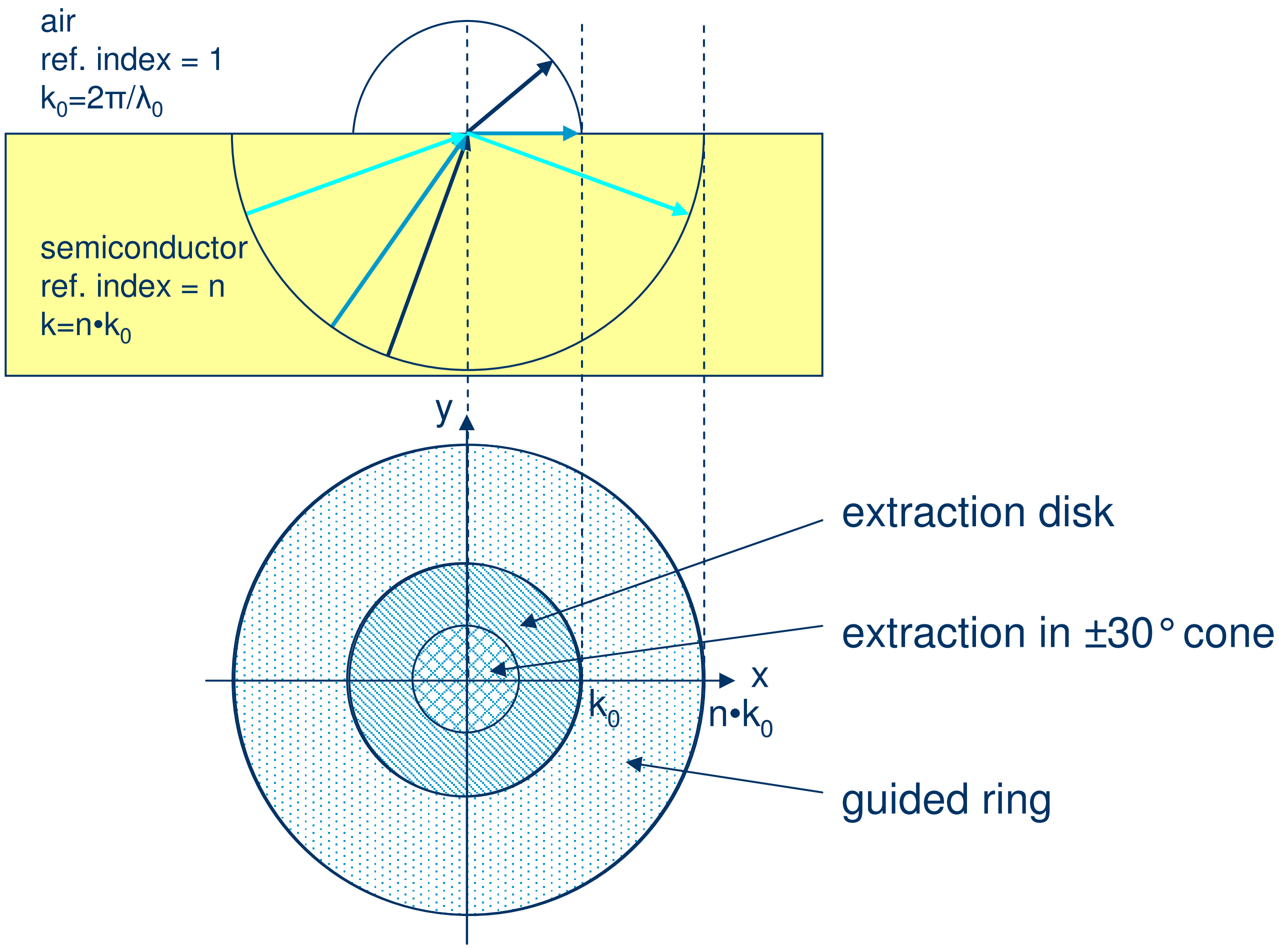


Topview

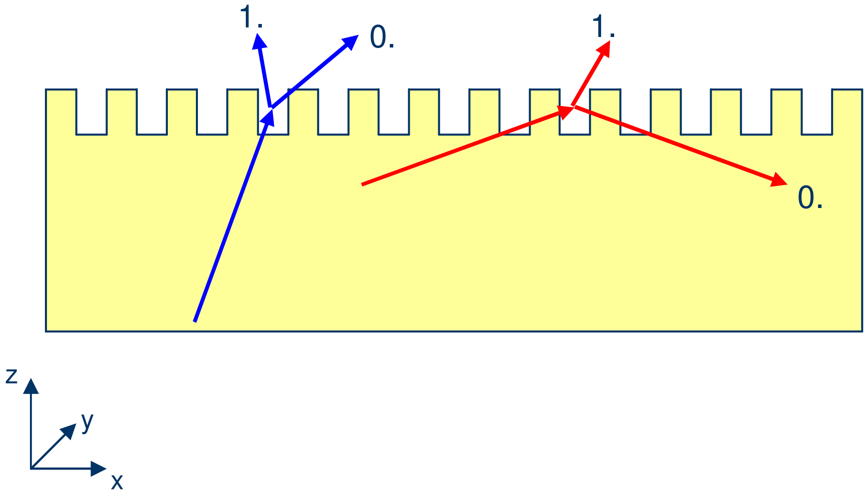


..with two dimensional photonic crystal as a surface structure.

Refraction in an Unstructured LED Die

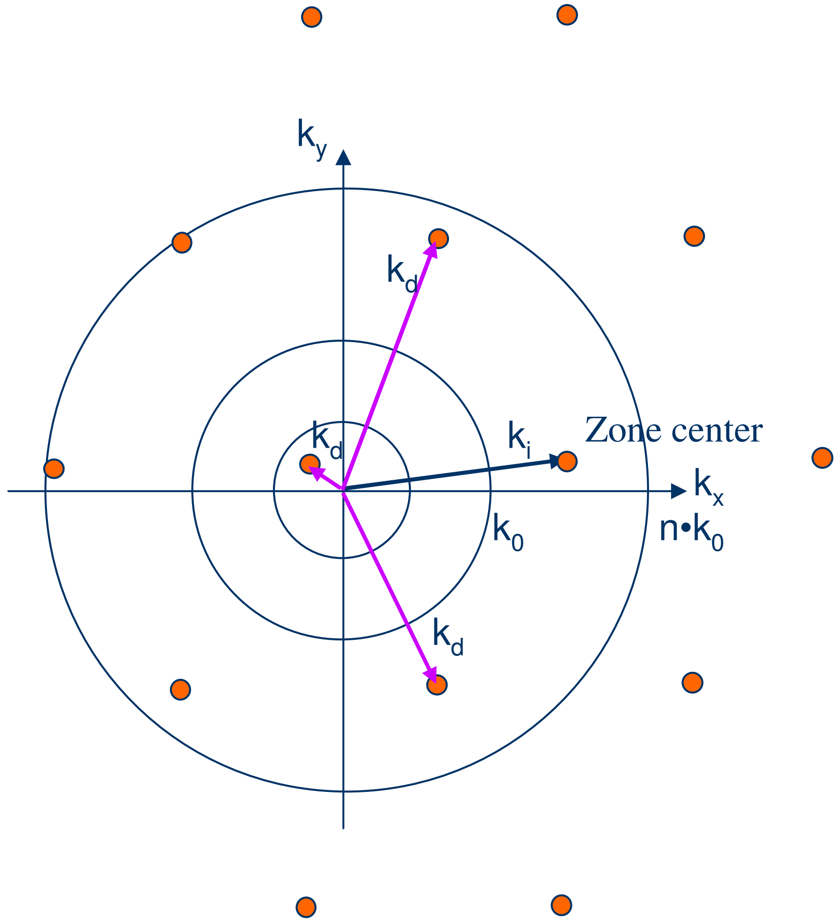


Diffraction in a LED Die with 2D PC Structuring



law of diffraction

$$\vec{k}_d = \vec{k}_i + \vec{G}$$



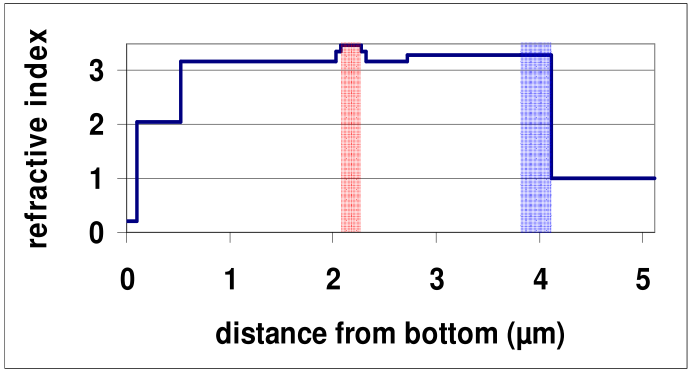
Model Description

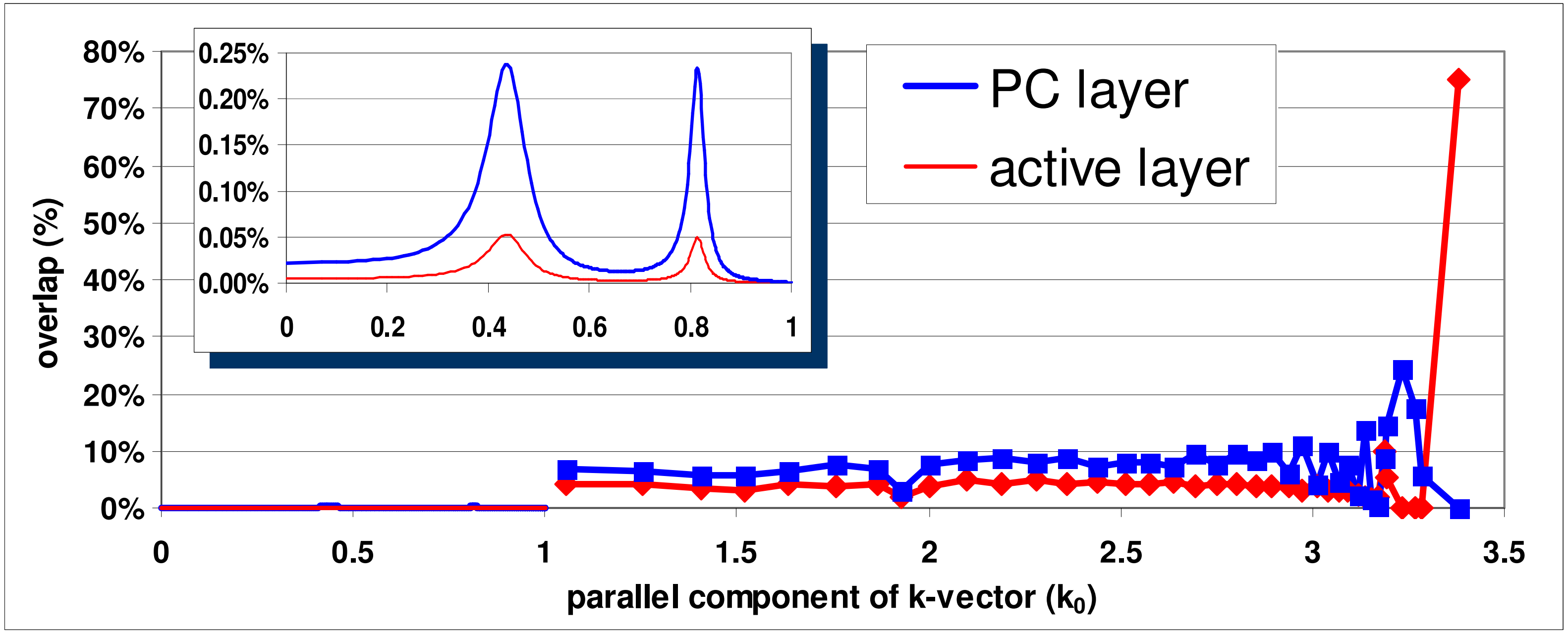
Rigorous calculation of *all* diffraction processes on *all* possible wave-vectors k

- ⇨ Consider all wave-vectors k ⇨ solving the mode structure of unstructured LED (both guided and radiating modes)
- ⇨ Fourier transform the applied 2D PC
- ⇨ Calculate the amount of diffraction between k_i and k_d

Example – Solving the Mode Structure

AlInGaP ThinfilmLED
λ=630nm
PC etch depth = 300nm





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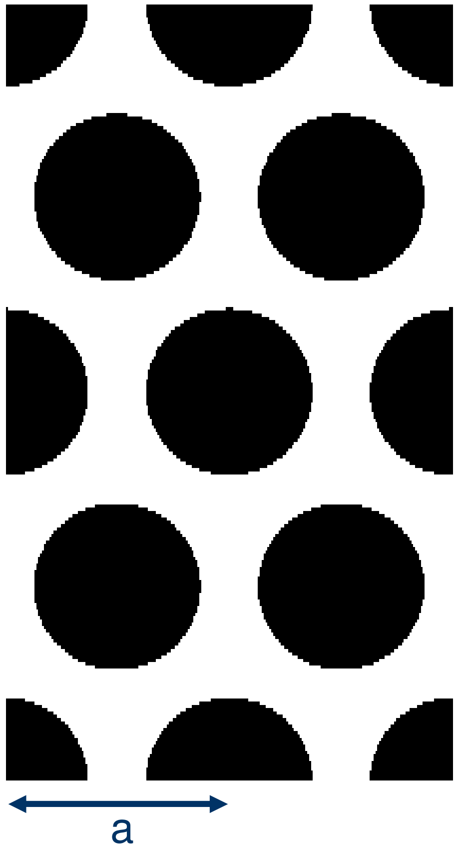
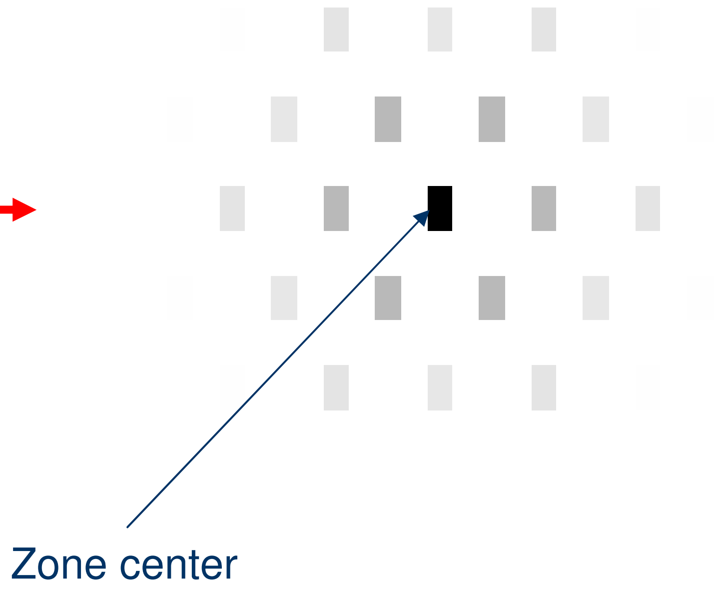
Example – Fourier Transformation of 2D PC

Triangular lattice with
pitch a and air filling factor 0.5



Fourier-

transform



Diffraction between k_i and k_d

Diffracted intensity I_s into k_d

$$I_s\left(\vec{k}_i \rightarrow \vec{k}_d\right) \propto F_i^{active} \cdot \left|\Delta\tilde{\varepsilon}\left(\vec{k}_d - \vec{k}_i\right)\right|^2 \cdot \left|\int_{PC} \vec{E}_i^*(z)\vec{E}_d(z)dz\right|^2$$

Overlap with active layer
⇔spontaneous emission
into mode i

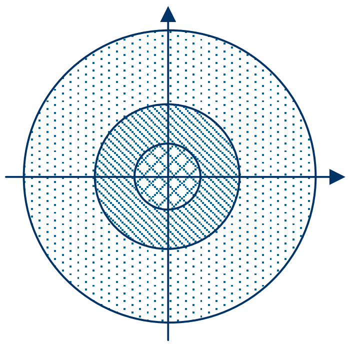
Amplitude of Fouriercomponent
corresponding to lattice vector G
with $k_d=k_i+G$

Coupling between k_i
and k_d in the PC layer

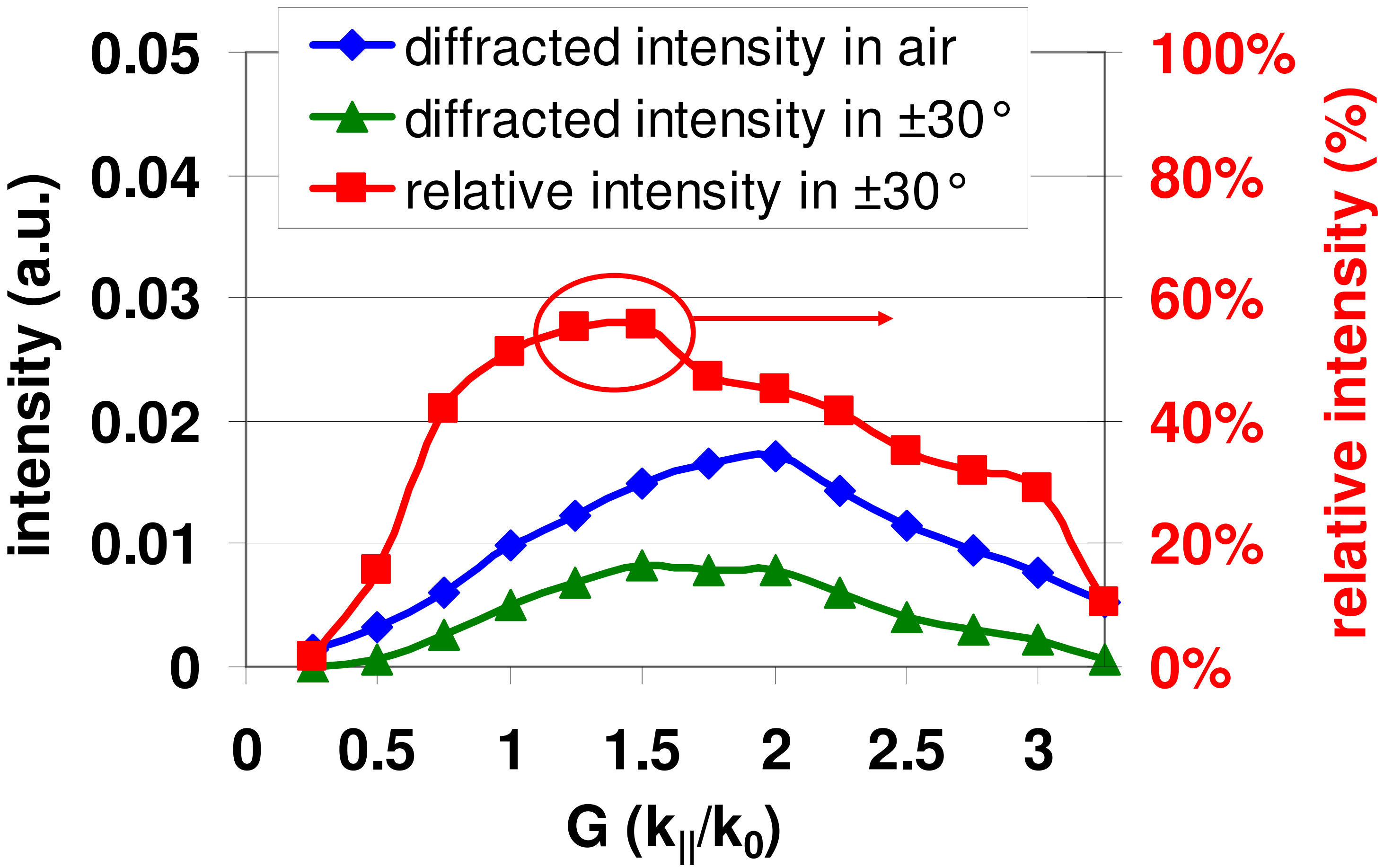
$$I_s(\vec{k}_d) = \sum_i I_s(\vec{k}_i \rightarrow \vec{k}_d)$$

$$\text{diffracted intensity in air} = \frac{\sum_{k \le k_0} I_s(\vec{k})}{\sum_k I_s(\vec{k})}$$

$$\text{relative intensity in} \pm 30° = \frac{\sum_{k \le 0.5k_0} I_s(\vec{k})}{\sum_{k \le k_0} I_s(\vec{k})}$$



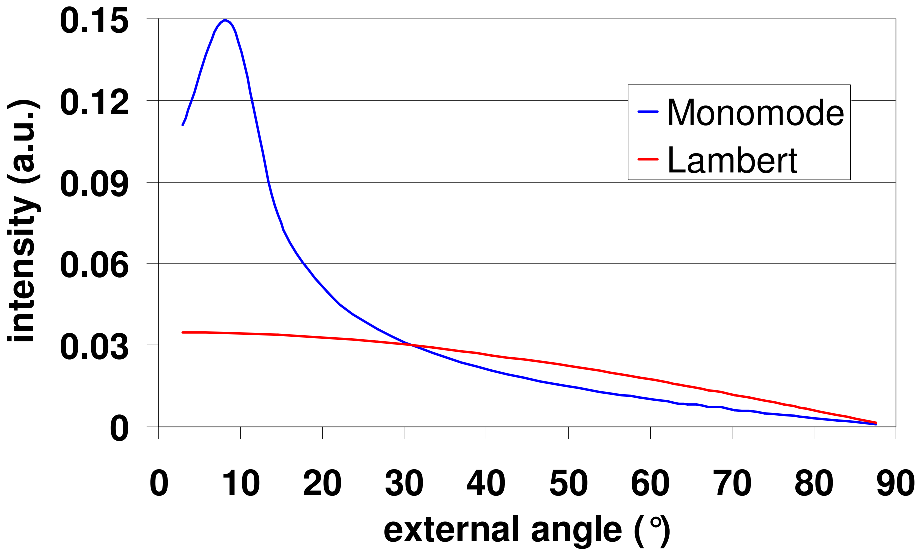
Variation of Reciprocal Lattice Vector

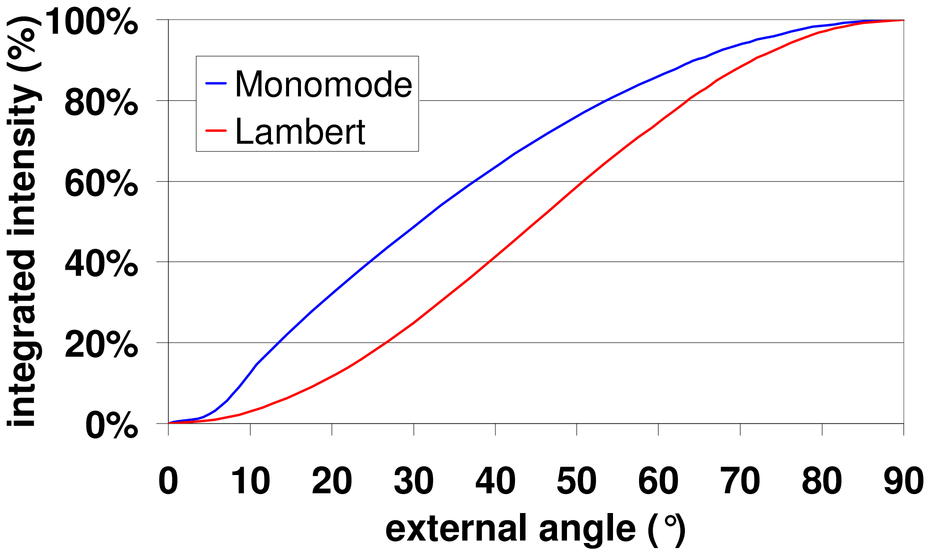


G=1.5•k_0 ⇔ a=485nm and d=360nm (air filling factor=0.5)

The „Ideal-Diffraction-LED“

Assumptions:
virtual LED with only one guided mode ($k_{||}=3.3 \cdot k_0$)
emitting wavelength $\lambda=(630 \pm 10)$nm
2D PC with perfect ring-like fourier transform (optimized $G=3.2 \cdot k_0$)





⇨highest „directionality“ achievable: 50% (2x Lambertian)

Summary

- Introduction of a model to calculate diffraction efficiency of 2D PC structures on LEDs
- Model is capable of optimizing
  - lattice pitch/lattice type
  - etch depth
  - air filling factor/shape of holes
  - internal mode structure
- Highest relative intensity in ±30° achievable with 2D PC is about 50%.

Thank you
for your attention.