Electromagnetic Design of Diffractive, Micro Cavity, and Photonic Band Gap Devices

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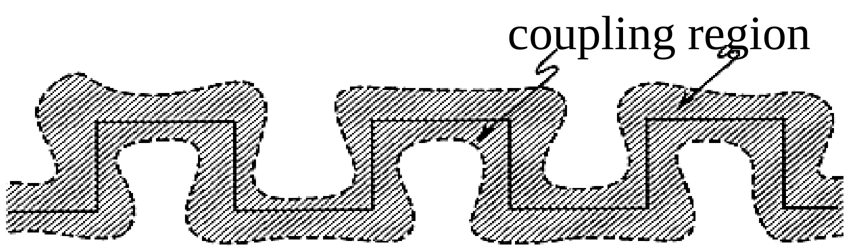
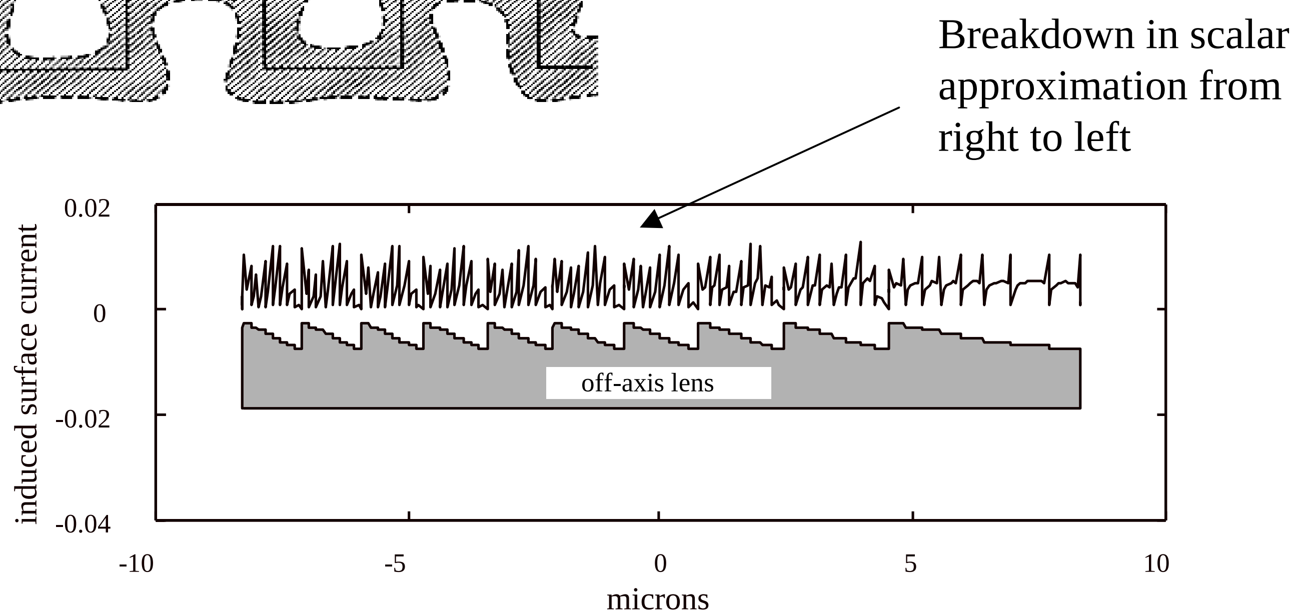
Outline

- Electromagnetic Analysis and Design of Micro-Photonic Devices
- Applications for WDM
  - Embedded spectrometer
  - Photonic band gap filtering
- Diffractive Optic Design for On-Axis Spectroscopy
  - *f*/# dependence chromatic dispersion
  - Wavelet based multiresolution optimization
  - Fabrication of meso-scopic grayscale DOEs
- Photonic Band Gap Filters
  - Band Gap Design for finite length PBGs
  - Cavity arrays for WDM
  - Active semiconductor modeling

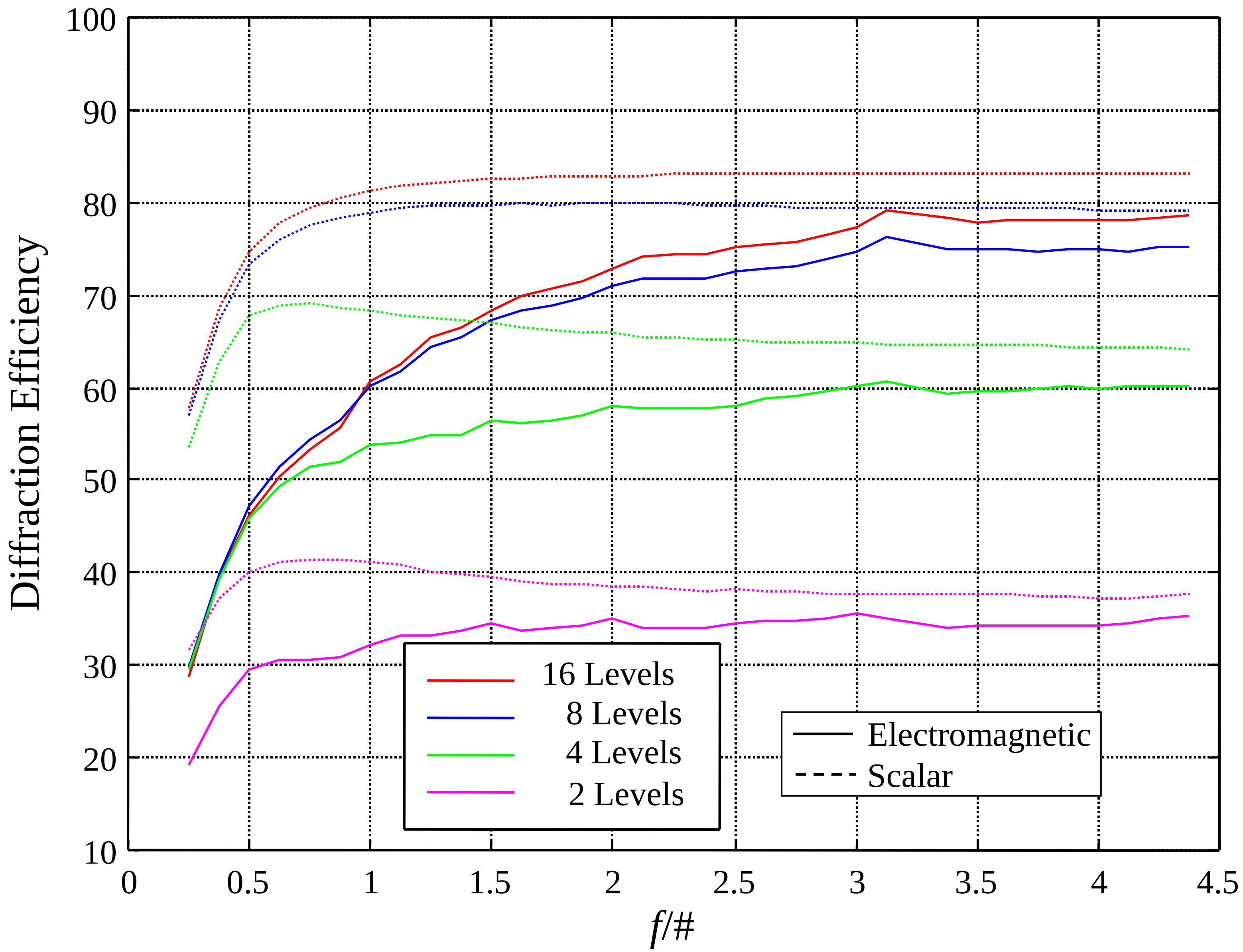
Why Electromagnetic Models Are Necessary

- As the scale of photonic devices approach the wavelength of operation boundary coupling effects significantly influence the EM fields on the boundary.
- This effect must be fully accounted for in the solution to the boundary value problem.
- This precludes the use of scalar and various other approximate methods.



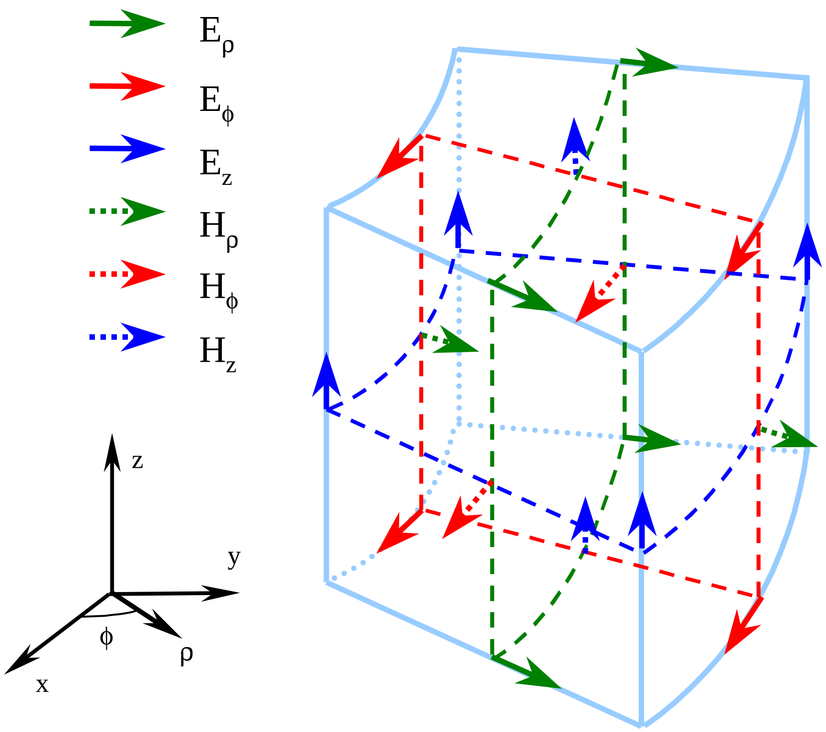


3D Diffractive Lens Analysis Results

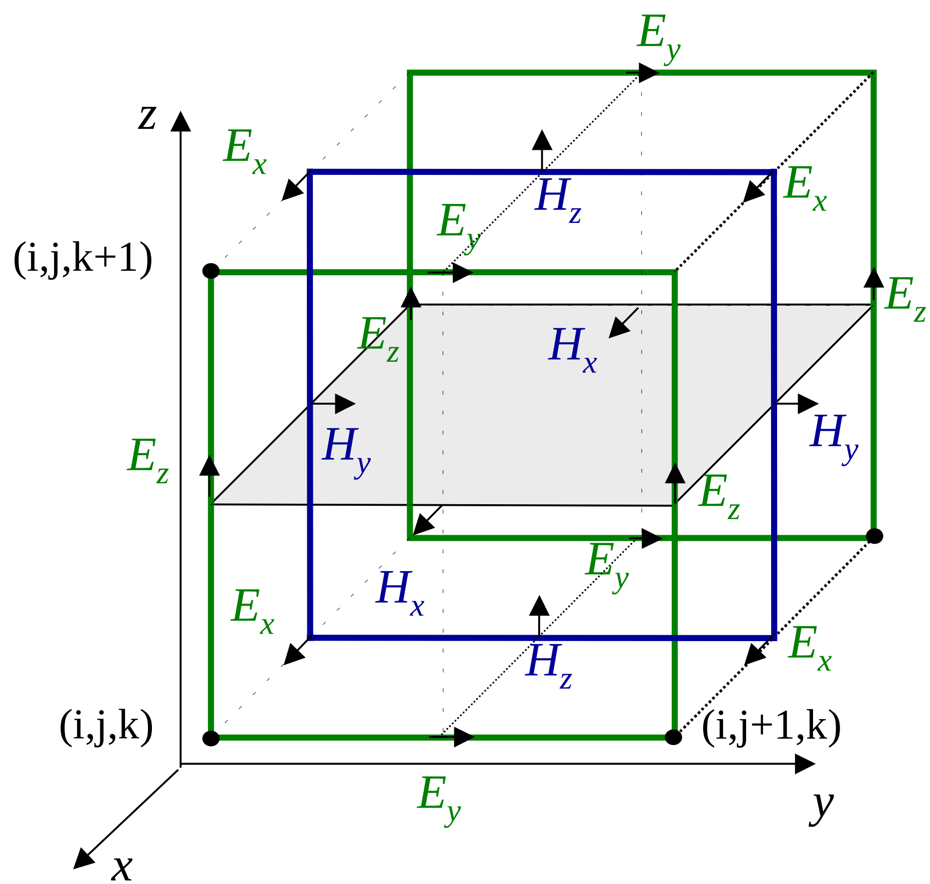


Computational Lattices In Three-Dimensions

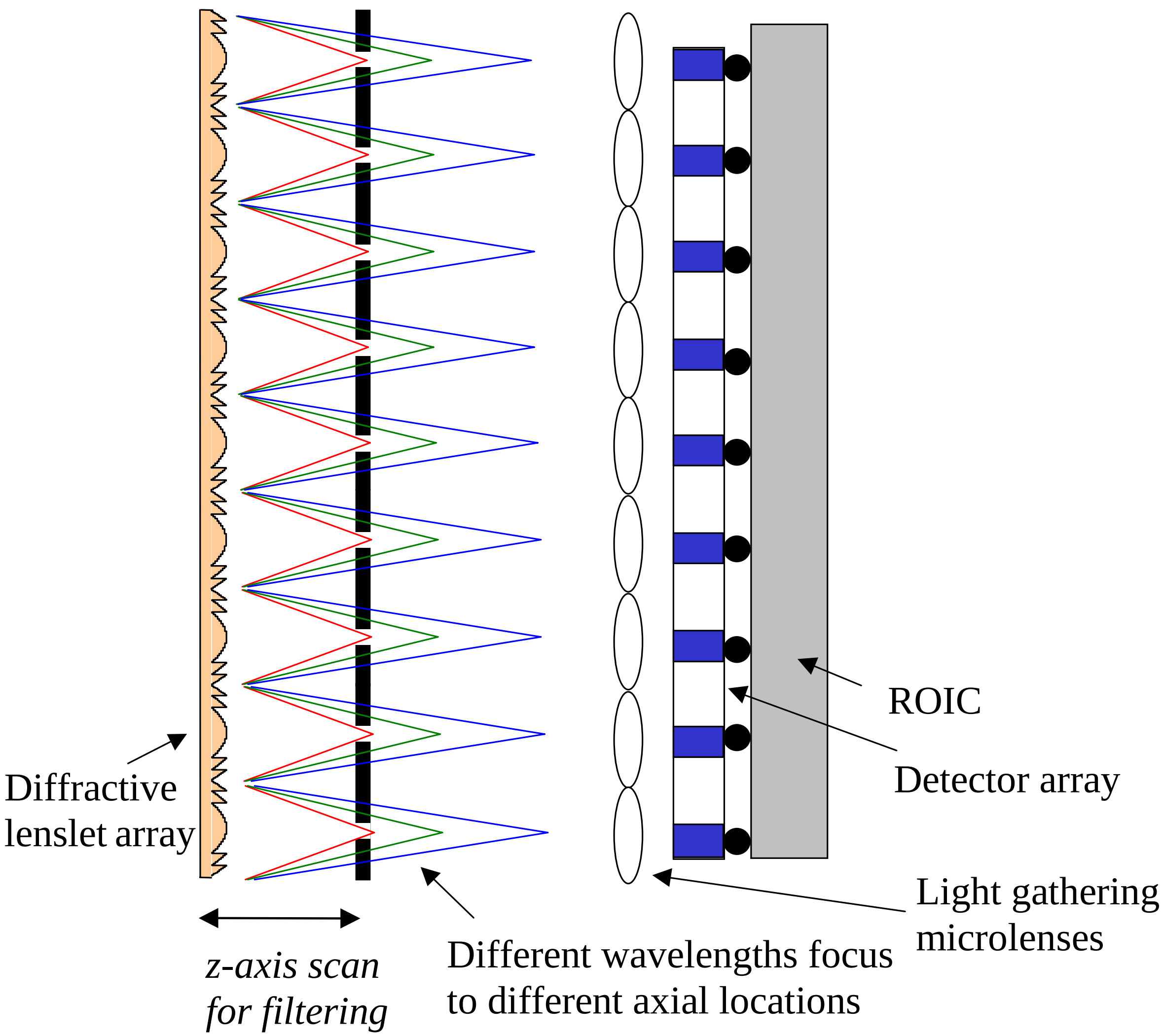
BOR FDTD Unit Cell



Full 3D FDTD

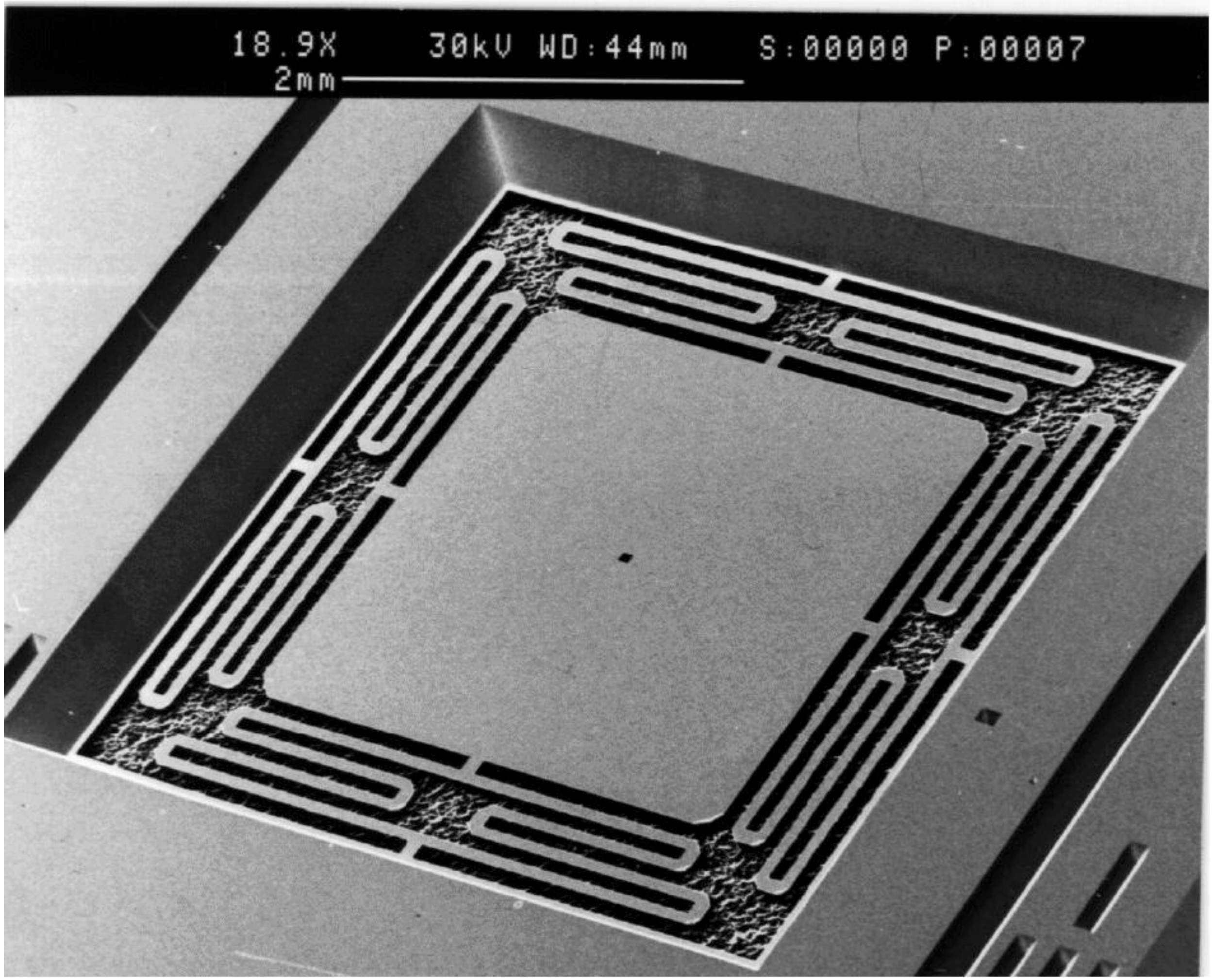


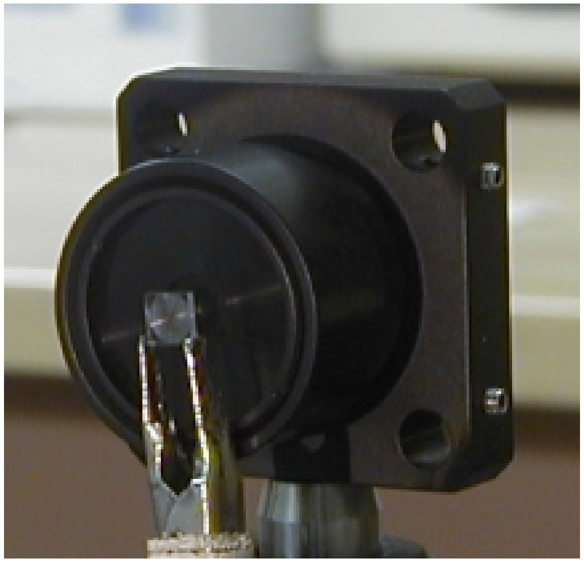
Application I: Embedded Spectrometer



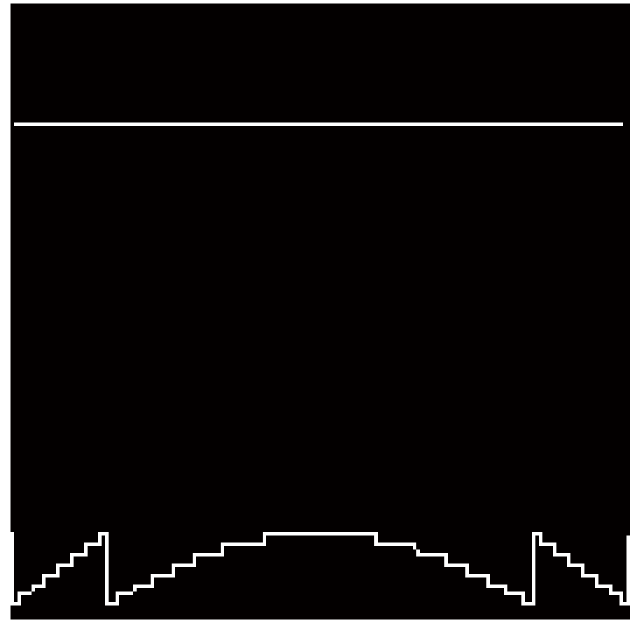
Application I: Scanner Development

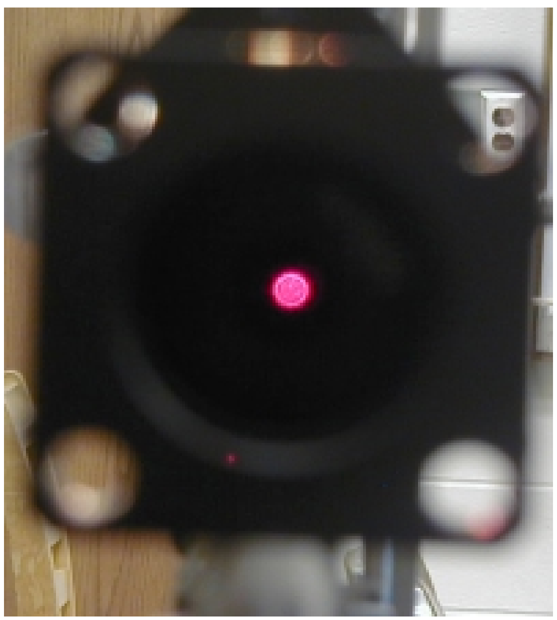
Collaboration with Chemnitz University of Technology, Germany



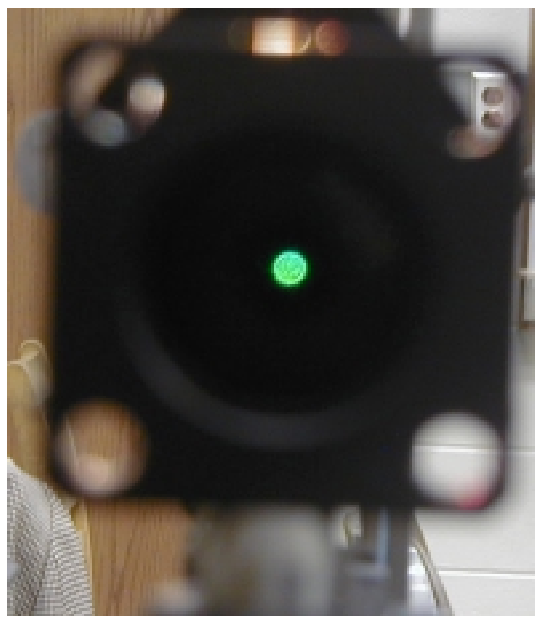


Spectrometer setup, D = 5mm, f = 5mm





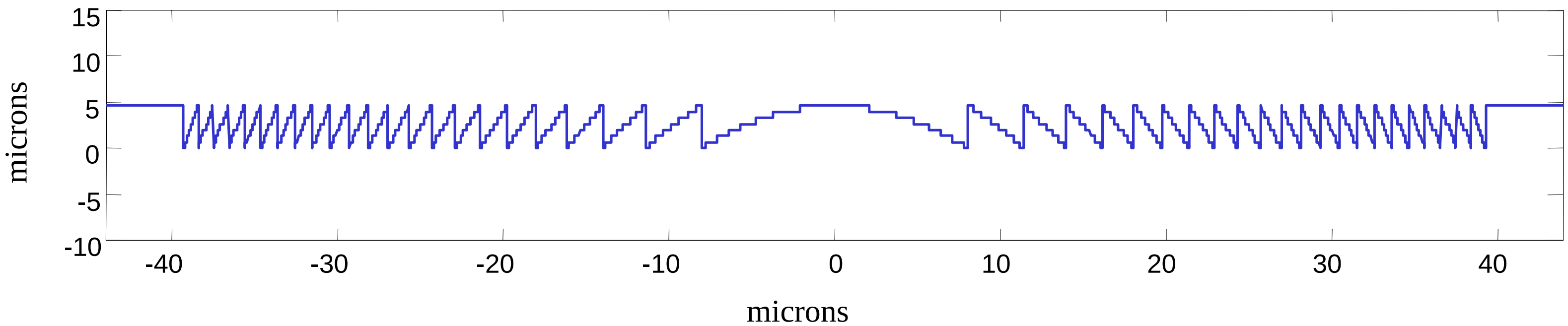
7.86mm

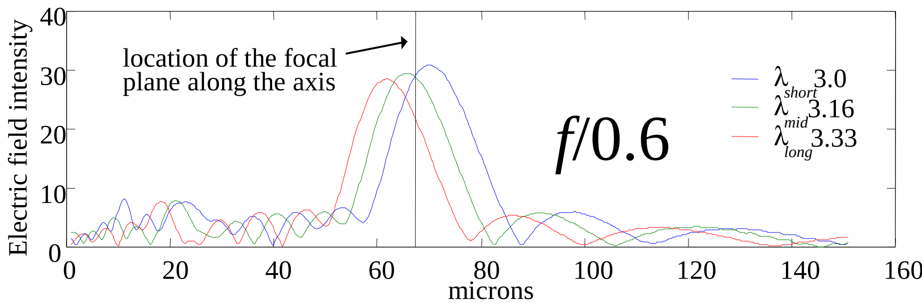


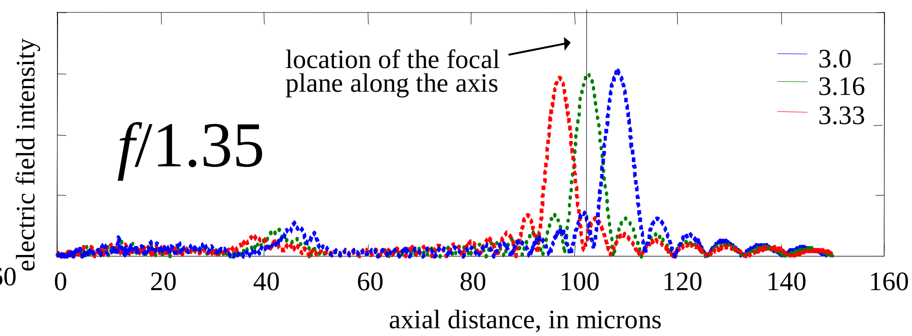
9.8mm

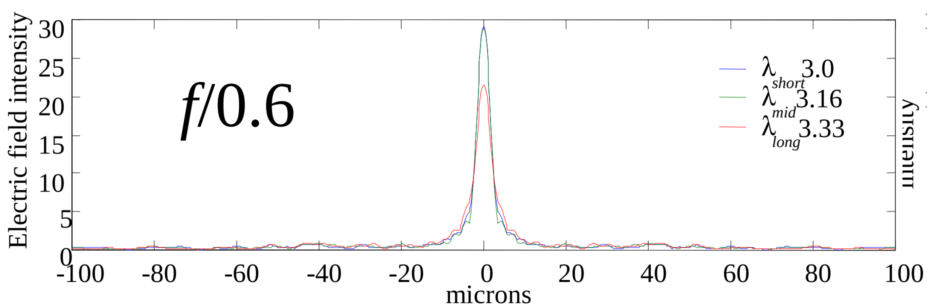
11.41mm

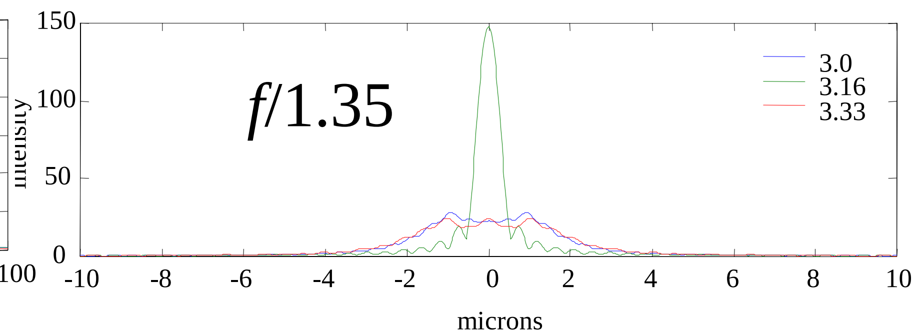
Application I: Lens Design



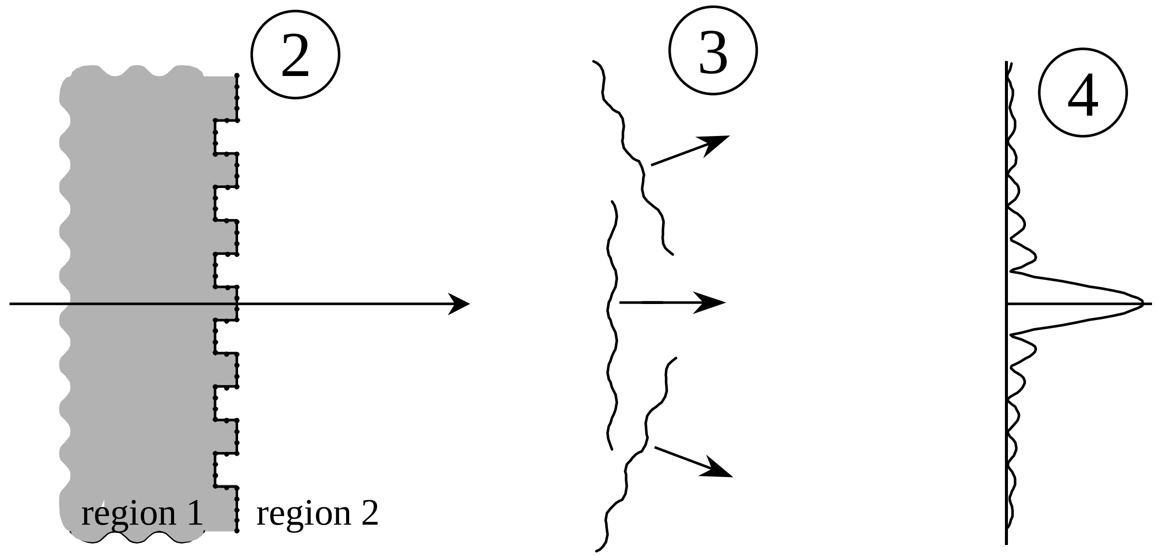








Electromagnetic-Based DOE Optimization

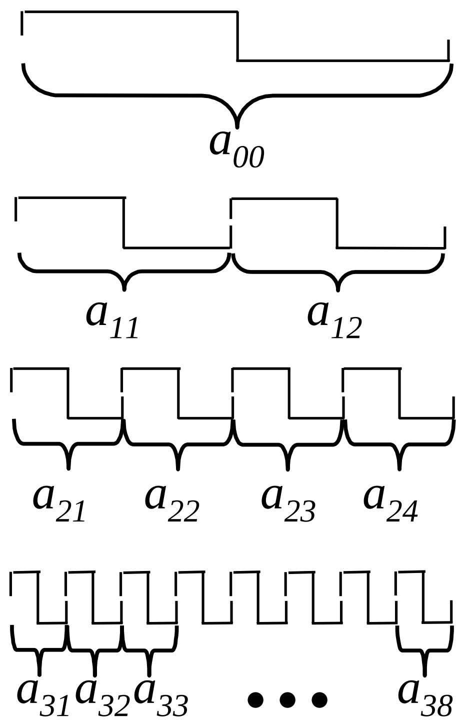


1. initial guess
2. use rigorous electromagnetic model to analyze DOE
3. evaluate performance
4. optimize performance metric

Repeat

Wavelet-Based Optimization Method

Wavelet Decomposition Process



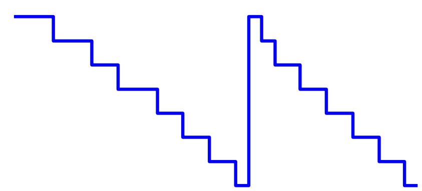
Zeroth order Haar Wavelet, $a_{00}\psi(x)$

First order Haar Wavelets, $a_{1m}\psi(2x - m)$

Second order Haar Wavelets, $a_{2m}\psi(2^2 x - m)$

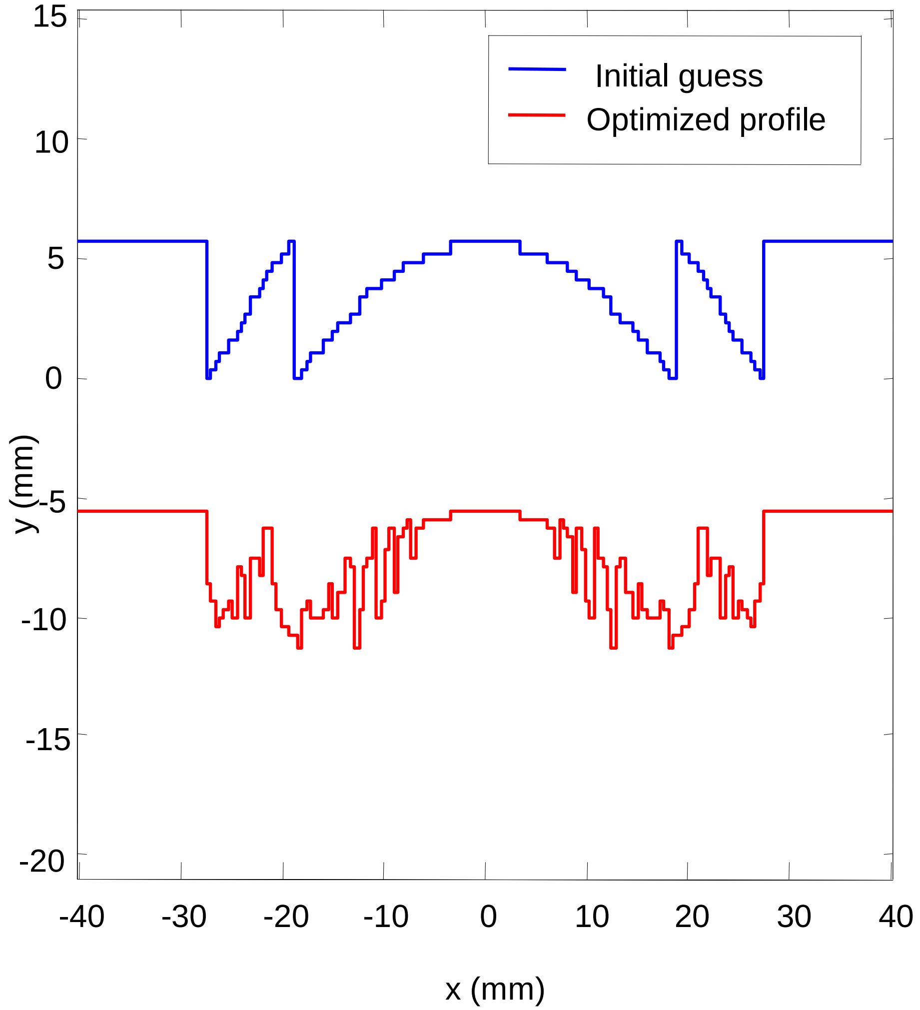
Third order Haar Wavelets, $a_{3m}\psi(2^3 x - m)$

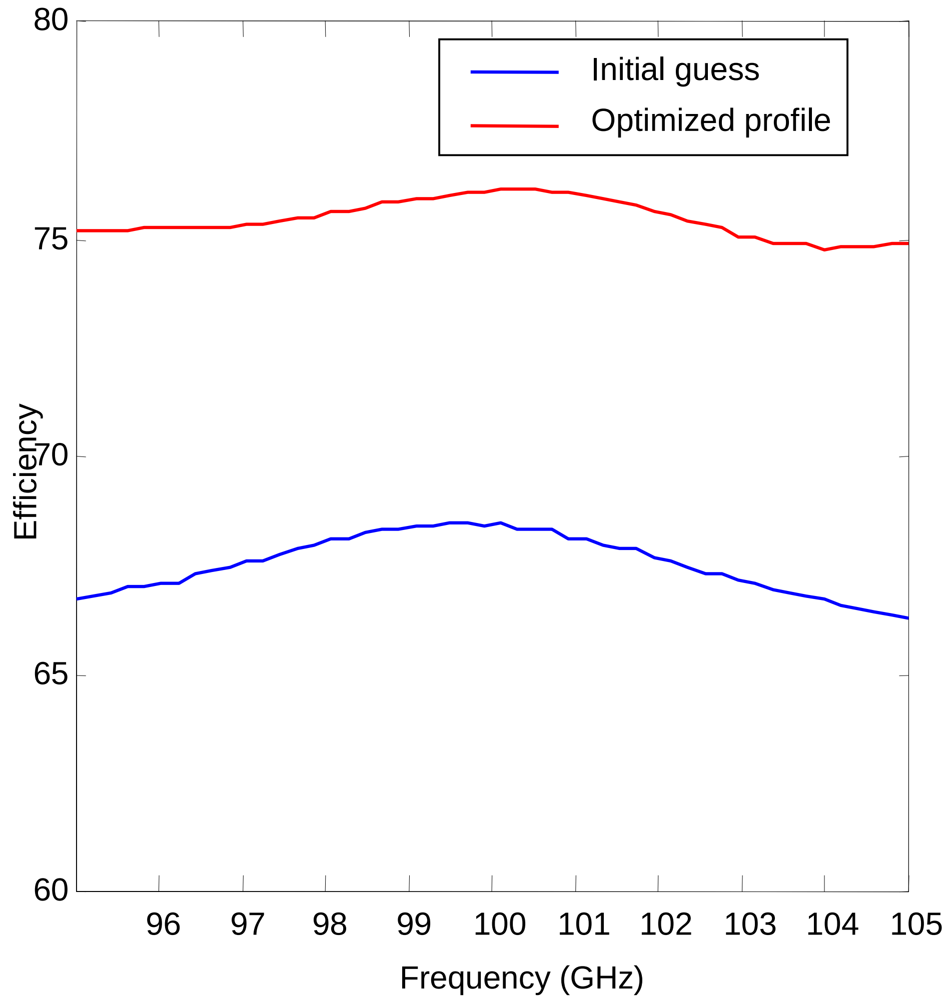
$$\sum_{n,m} a_{n,m}\psi(2^n x - m) \Longrightarrow$$



Diffractive Profile

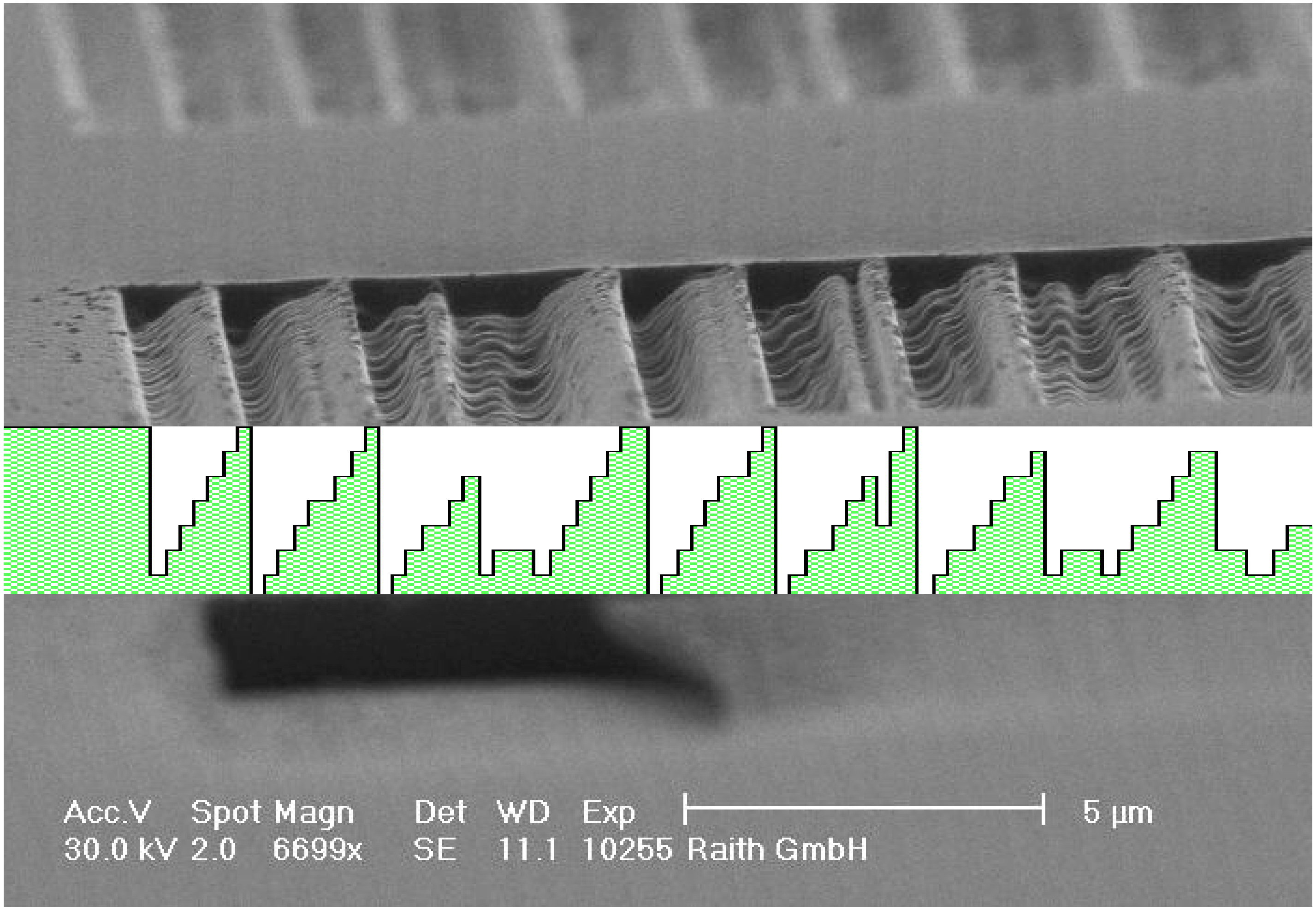
Profile and Efficiency Improvements





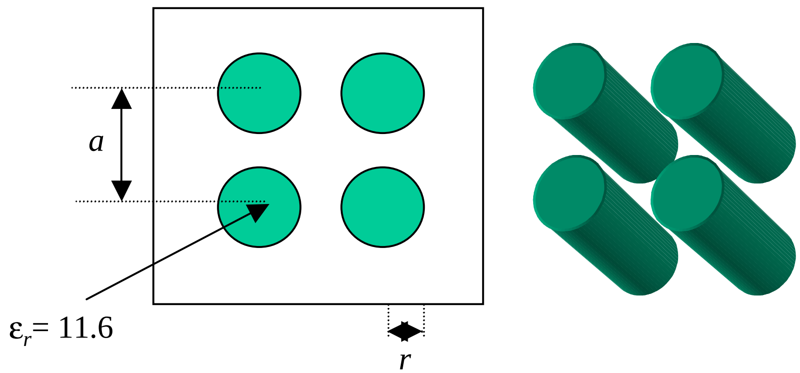
Fabrication of Grayscale Mesoscopic DOEs

Outer zones of an 8-level EM optimized DOE

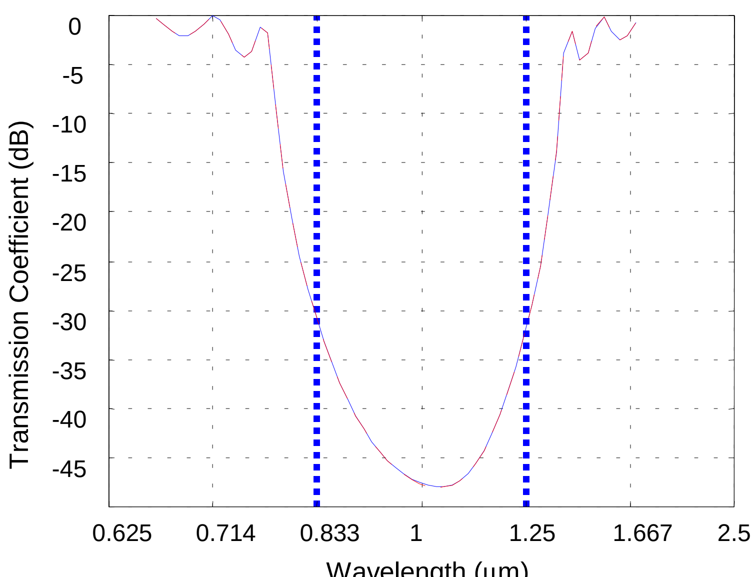


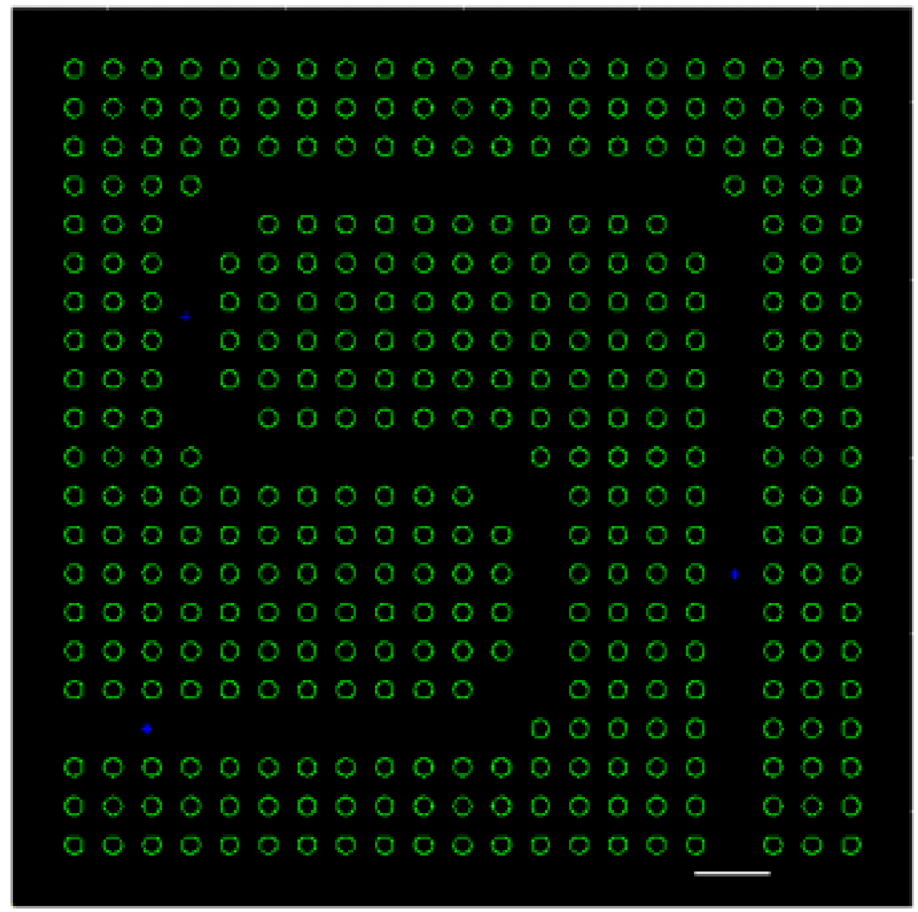
Application II: Photonic Band Gap Devices

- PBG's guide light based on the scattering properties created by tailoring the surface profile.
- They have a strong spectral dependence, which can be exploited in design.

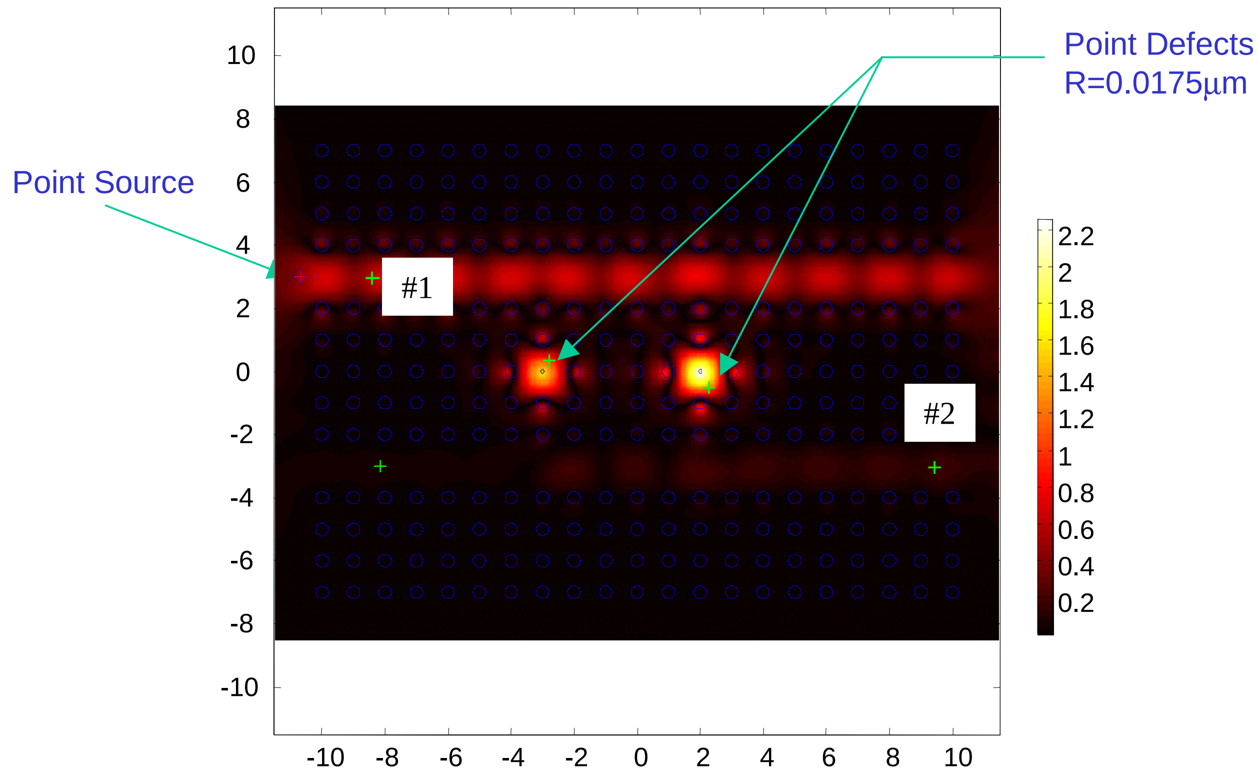


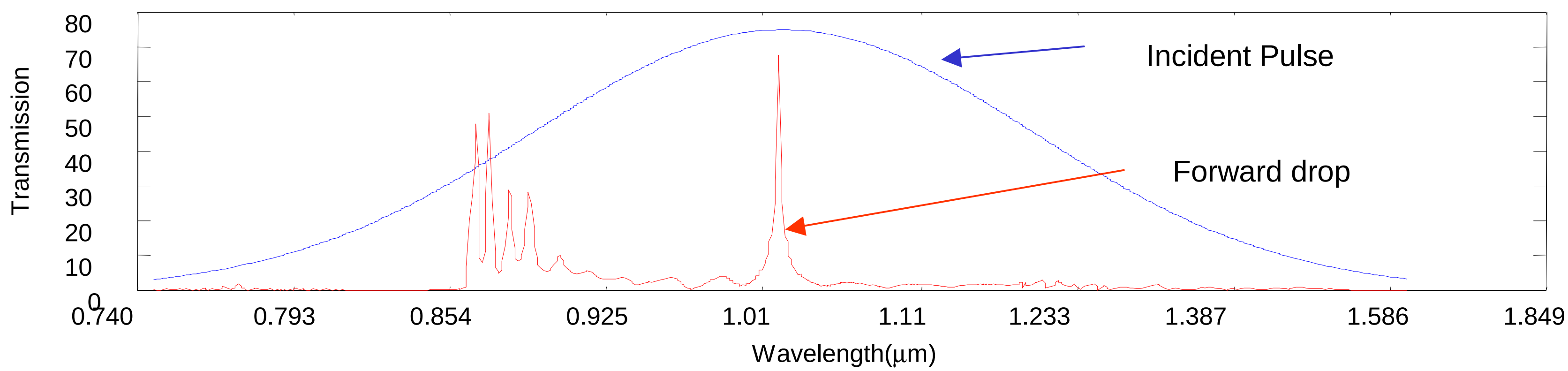
Rectangular Lattice: a = 0.35 µm, r = 0.07 µm



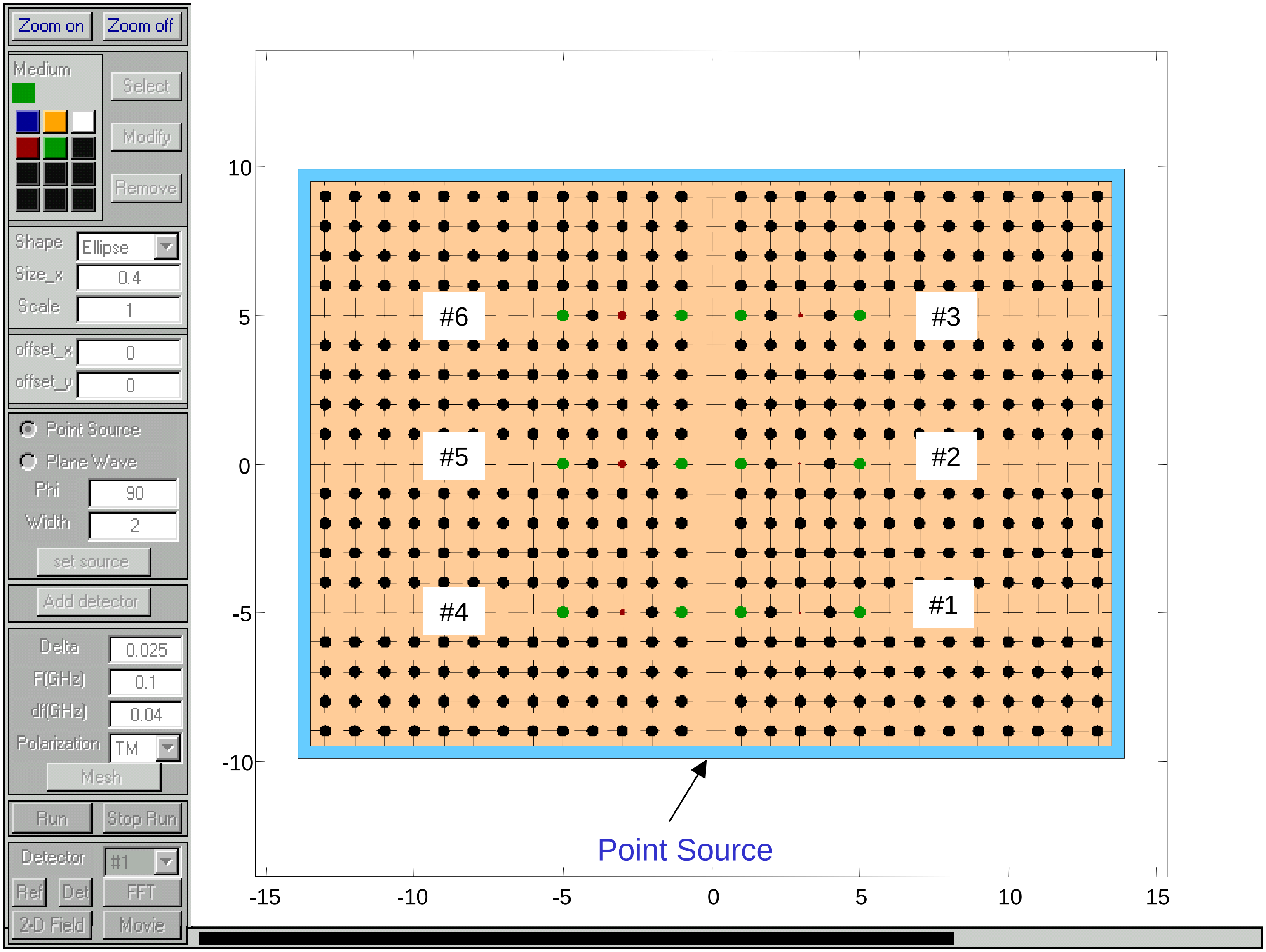


WDM Filtering using Two Cavities

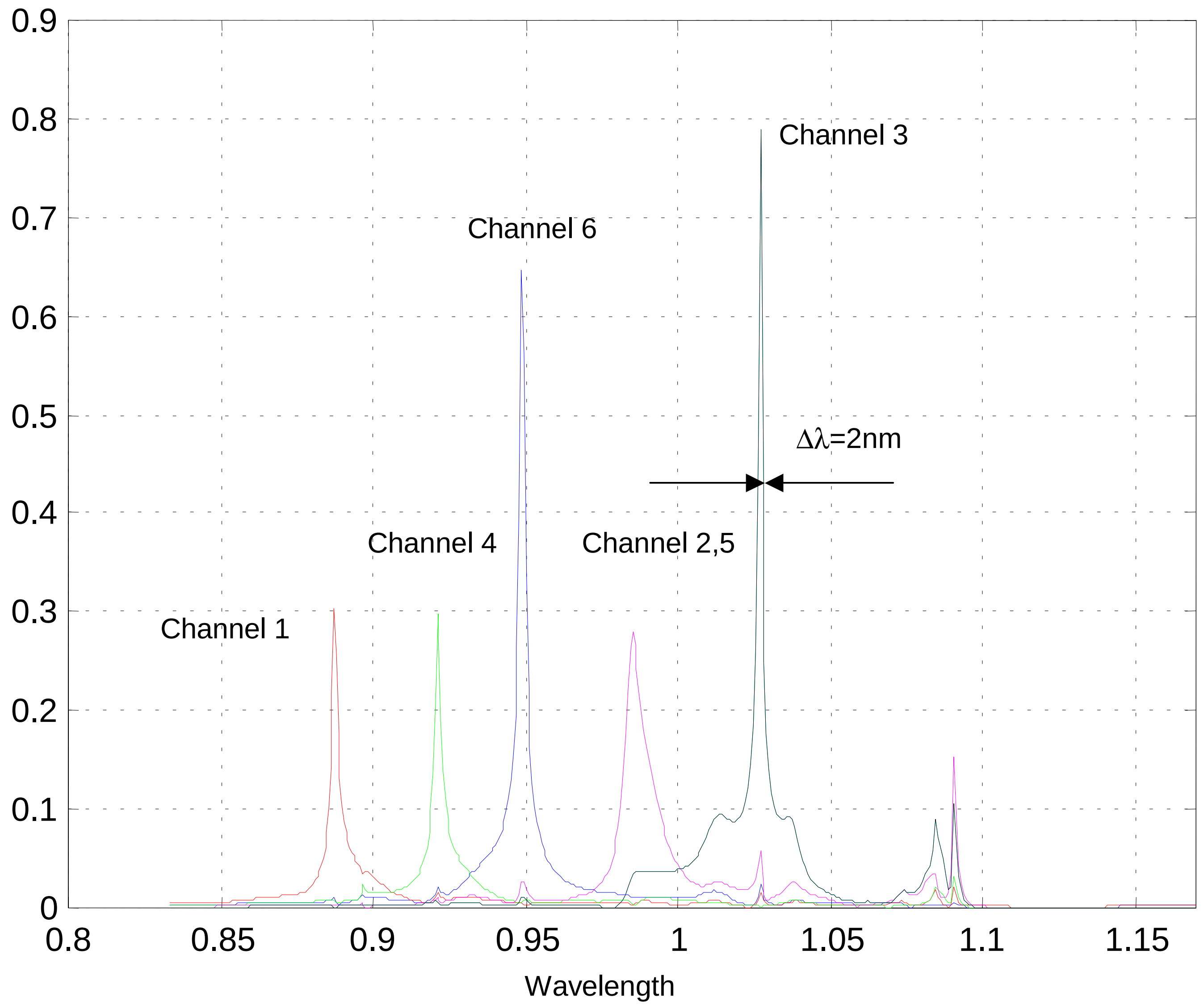




6 Channel WDM Filtering using Single Cavity Filters



6 Channel WDM Filtering using Single Cavity Filters



Parameterization Method for Semiconductor Amplifier

Input

material :
- effective mass
- dipole moment

Structure:
- well width
- barrier height
- energy bands

Susceptibility

$\chi(t)$ in time domain
$\chi(\omega)$ in frequency domain

Polarization

$P(\omega) = \varepsilon\, \chi(\omega) E(\omega)$
$P(t) = \varepsilon\, \chi(t) * E(t)$

Equivalent Susceptibility Using Prony method

$\chi(t) = \sum G_i e^{(\alpha_i + \omega_i)\, t}$

$\chi(\omega) = \sum G_i / [j(\omega - \omega_i) - \alpha_i]$

Superposition of finite modes N

Propagation with FDTD

Based on Maxwell's Equations

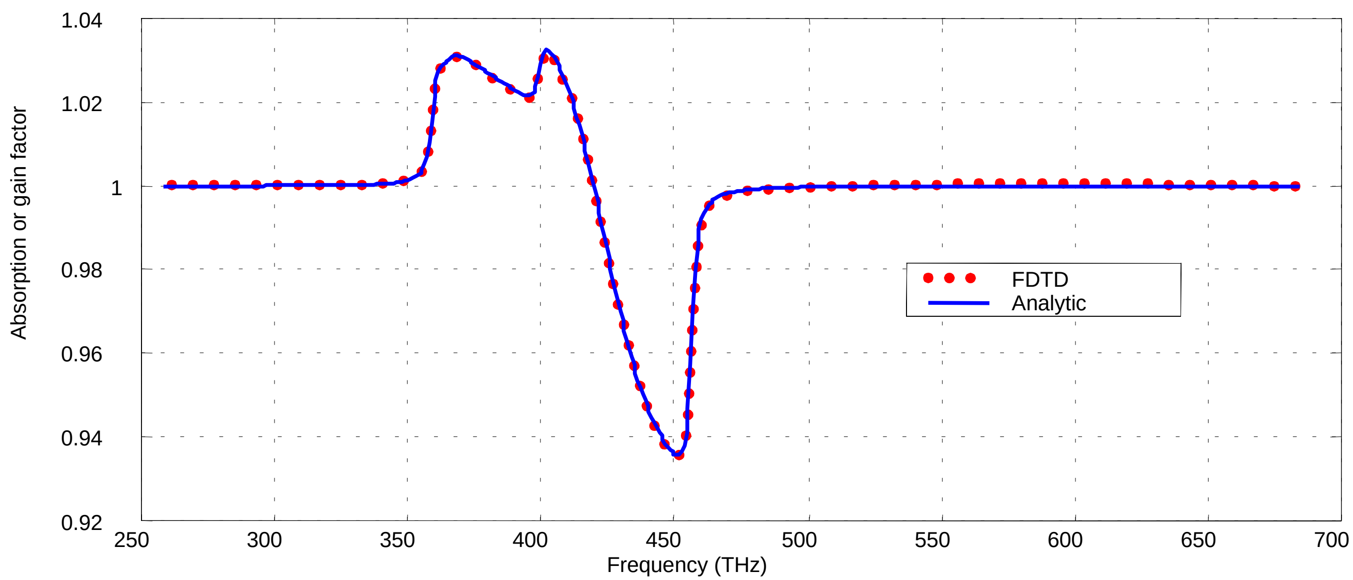
Gain and phase shift

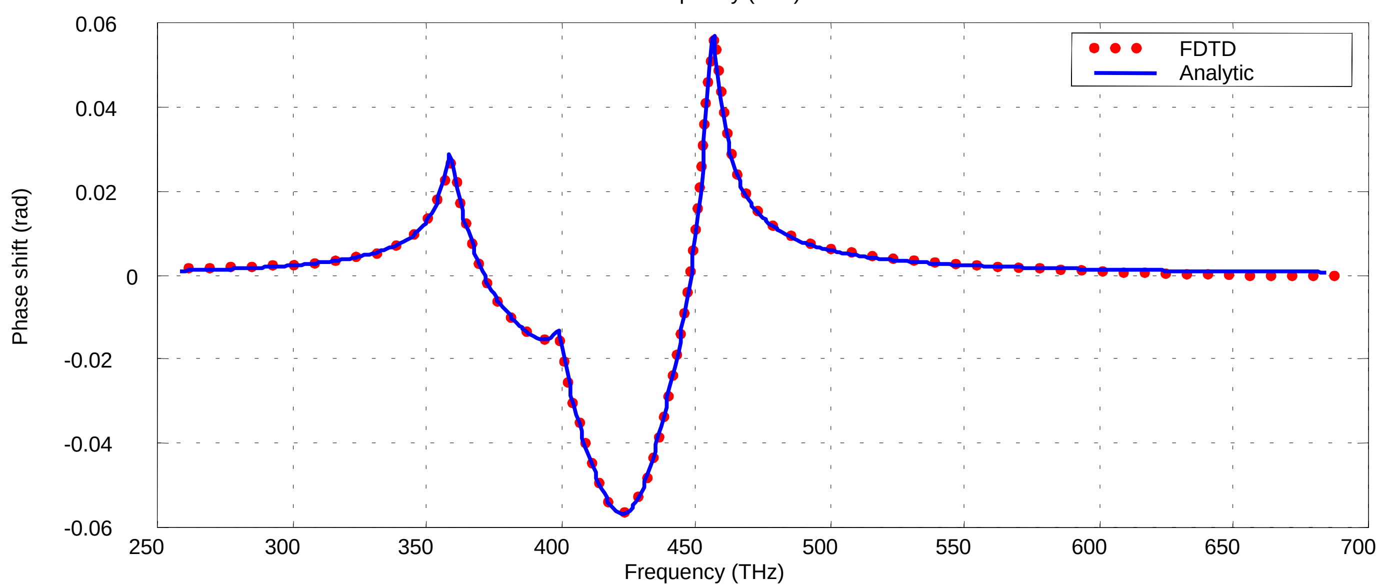
Perform FFT on Data obtained from FDTD computation

Applications

- Laser Amplifiers
- Laser cavities
  VCSELS, QWs

FDTD Results: N = 12e18/cm^{-1}





Semiconductor Gain Modeling in FDTD

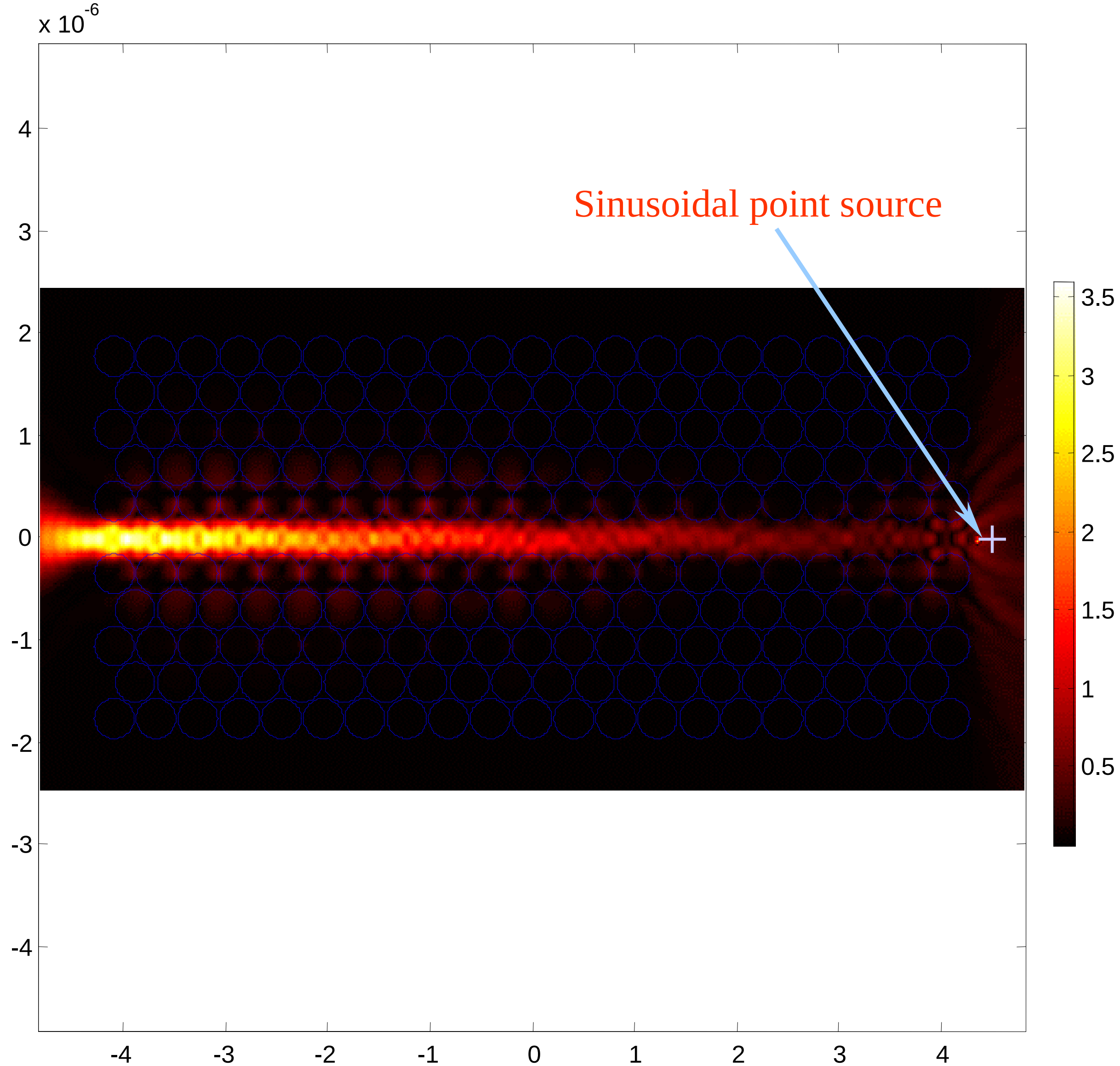
GaAs :

Injected carrier: $N=9e24/m^{-3}$
Dephasing time: $T_2=0.1ps$
Central frequency: $f=3.52\ 10^{14}Hz$

A = -2.0896e+029
B = -3.6279e+043
ω_0 =2.4125e+015
ω_t = 1.7361e+014

Equivalent conductivity

$\sigma = (j\ \omega\ A+B)/(\omega^2_o - 2j\omega_o\omega - \omega^2)$



Summary

- Discussed the electromagnetic analysis and design of diffractive lenses and photonic band gap devices.
- Presented two applications for WDM
  - Embedded spectrometer
  - Photonic band gap filtering
- Introduced Wavelet based multiresolution optimization of diffractive lenses.
- Showed *f*/# dependence chromatic dispersion and its effect on spectral filtering.
- Channel drop filters based on an array of single cavity photonic band gap channels.