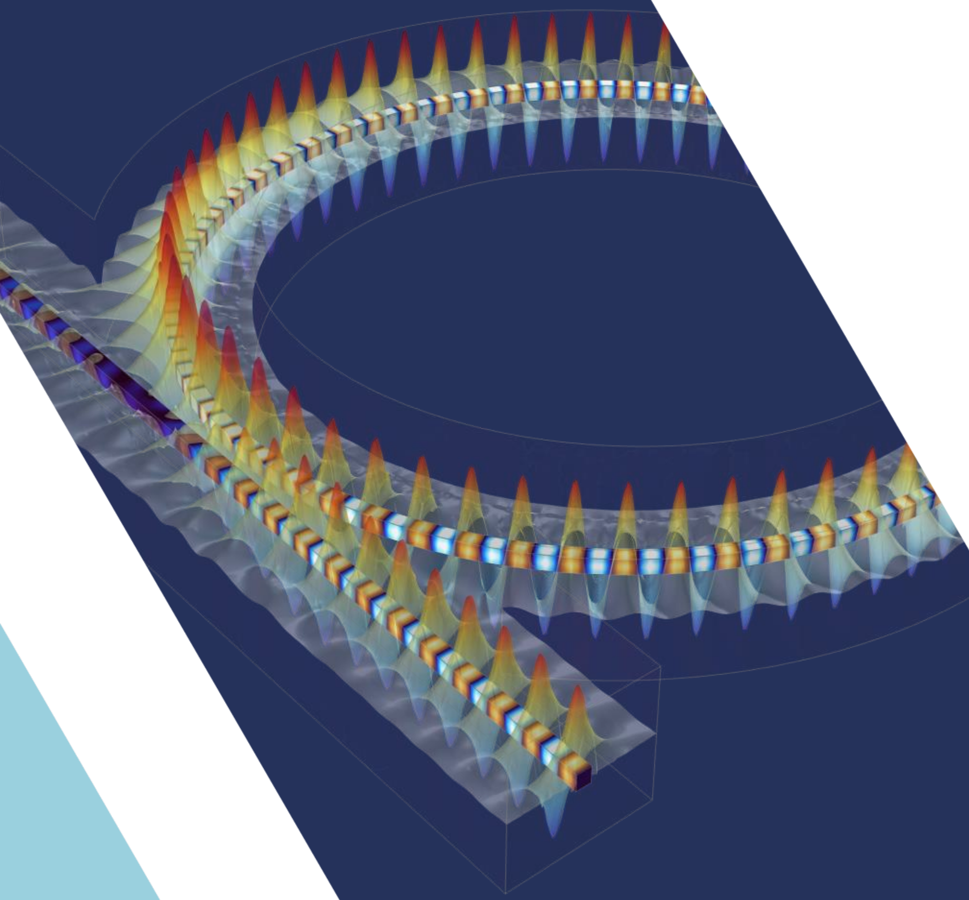

Simulation-driven development of PICs

Justus Bohn - COMSOL® Multiphysics

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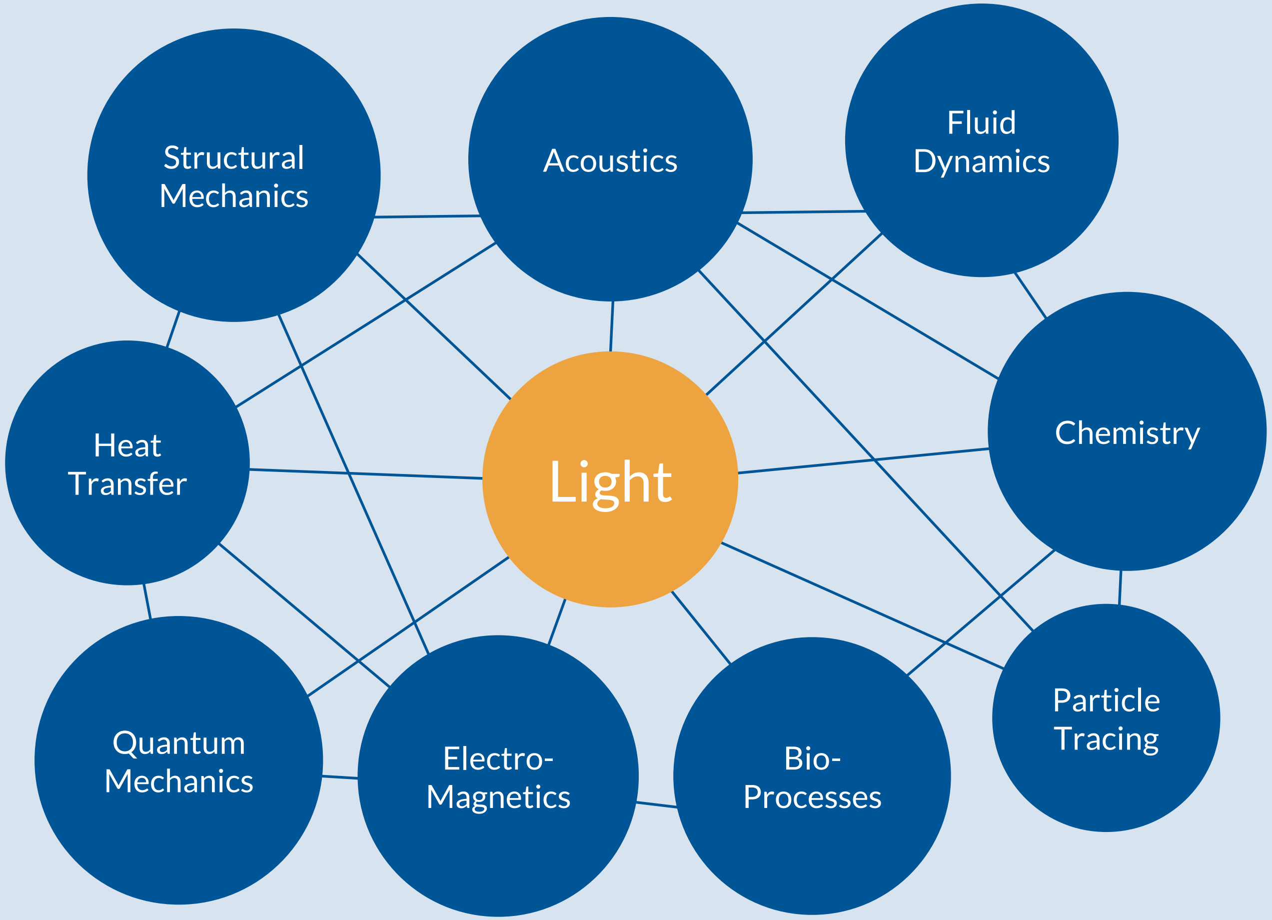
Photonic Integrated Circuits and Multiphysics

In photonic integrated circuits (PIC), optical fields interact in a desired or undesired way:

- Sensing
- Switching
- Heating
- Miniaturization



OPTOMECHANICS – ELECTROOPTICS – PHOTOCHEMISTRY - OPTOFLUIDICS - OPTOACOUSTICS - STOP ANALYSIS - QUANTUMOPTICS- OPTOELECTRONICS – OPTOMAGNETICS – THERMOOPTICS –– LASER-MATERIAL-INTERACTION – BIOPHOTONICS – MAGNETOOPTICS – BIOOPTOFLUIDICS - PHOTOPHORESIS – ETC.

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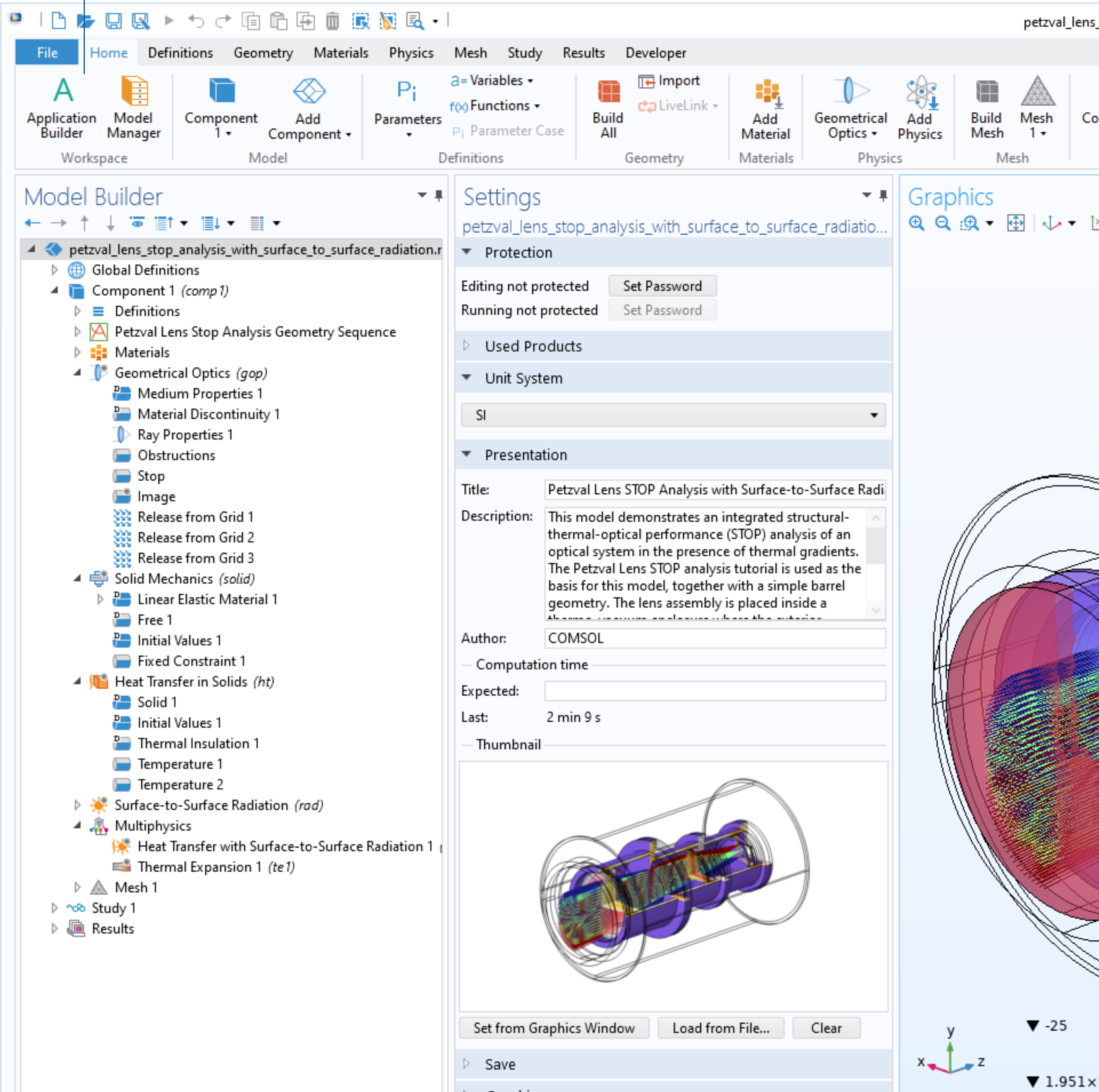
Switch to Application Builder or Model Manager mode



COMSOL DESKTOP®

An Integrated Environment for Modeling and Simulation

Model Builder

- Build physics-based models

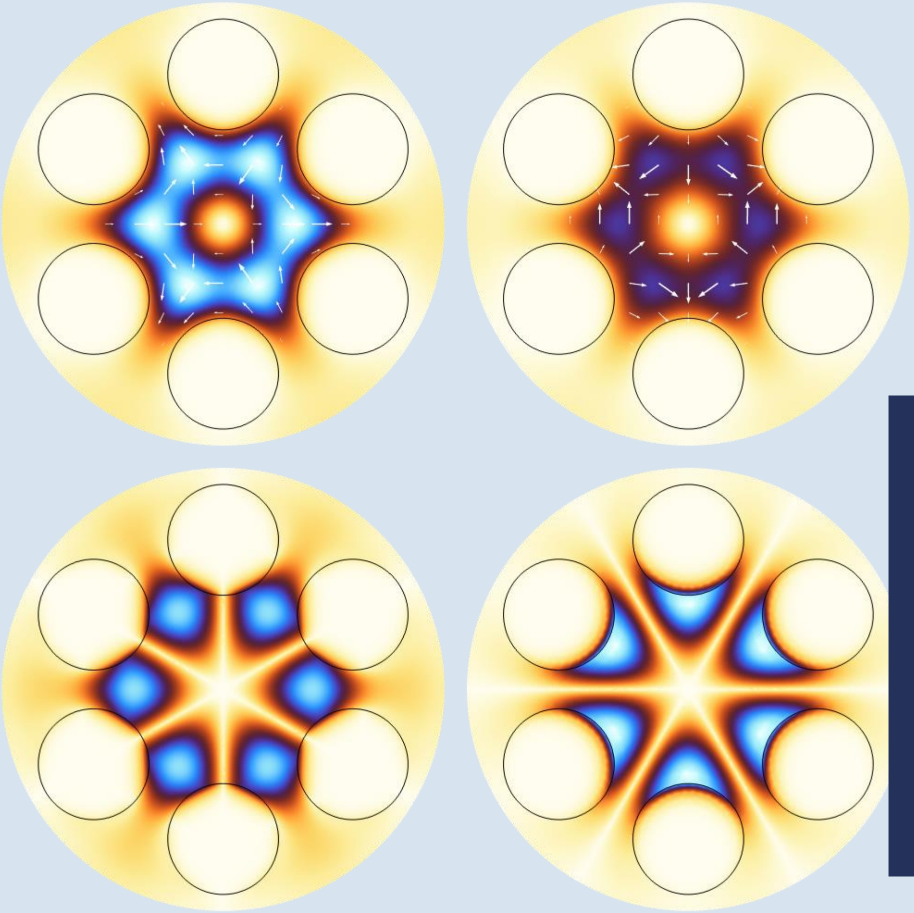
Application Builder

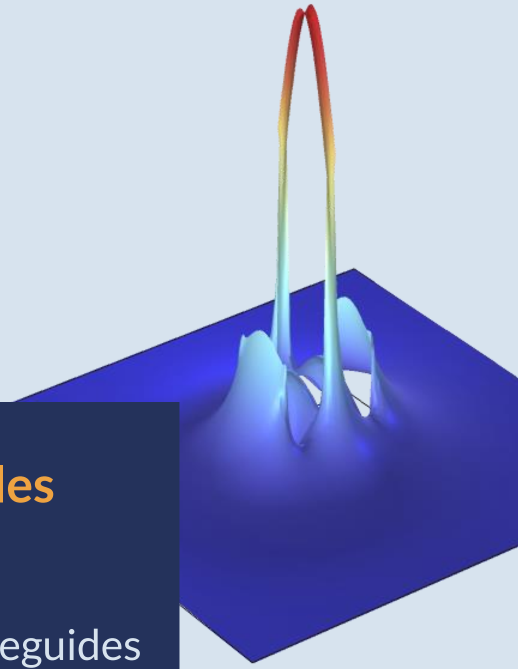
- Build apps to share

Model Manager

- Organize models and data efficiently

Mode Analysis





Problem

Analyze a waveguide cross section and deduce *mode fields* and *propagation constants*

$$\boldsymbol{E}(x,y,z) = \boldsymbol{E}_m(x,y)\exp(-j\beta_m z)$$

Typical Examples

- Optical fibers
- Dielectric waveguides
- Anisotropic waveguides

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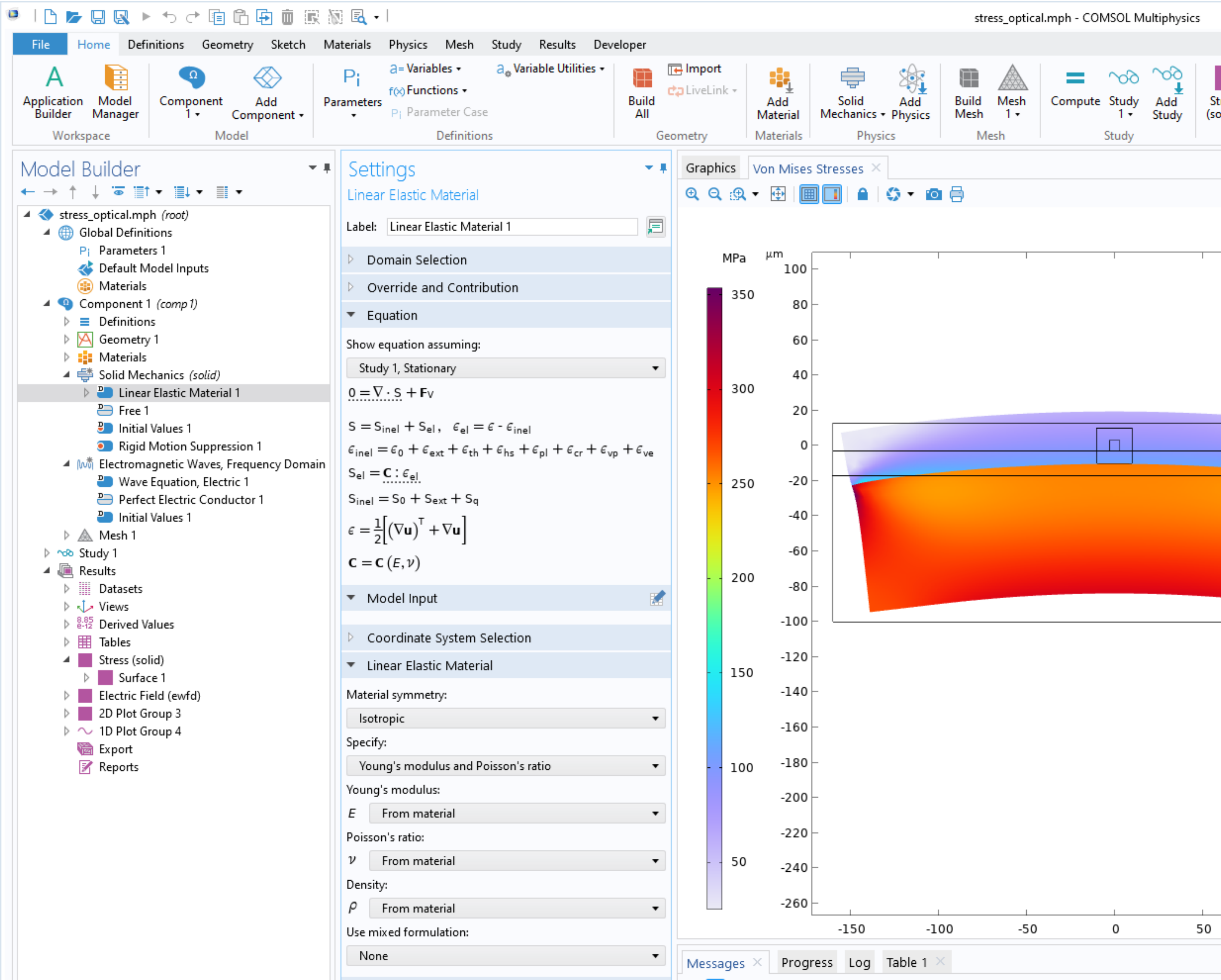
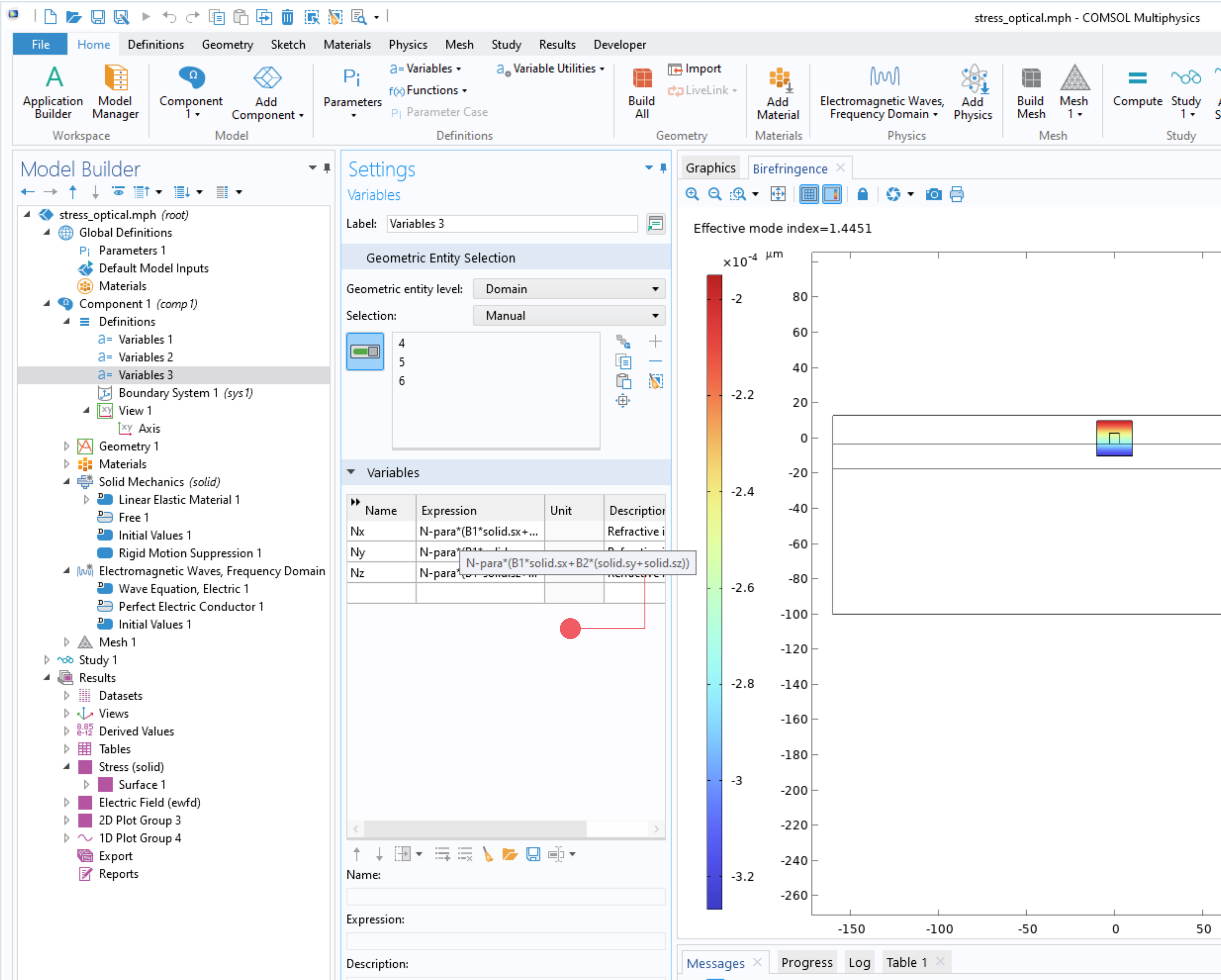
Stress-Optical Effect

- Birefringence in a silica-on-silicon waveguide
- Solid mechanics analysis of silica layer on silicon wafer
  - Deformation leads to stress
  - Stress leads to optical birefringence



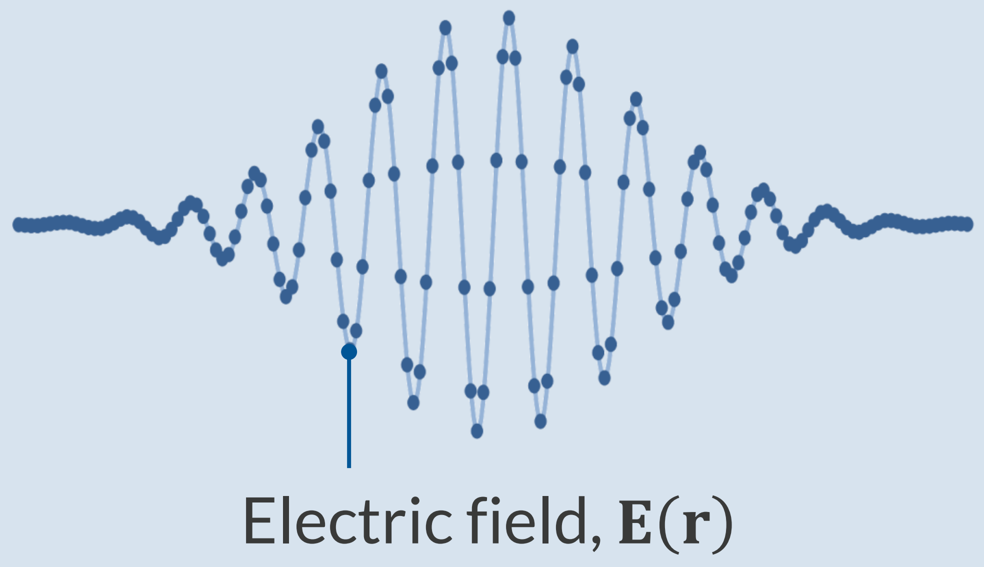
Stress-Optical Effect

- Mode analysis of optical waveguide with anisotropic (birefringent) refractive index
  - More stress leads to more birefringence
  - increasing shift of the modes' effective indices

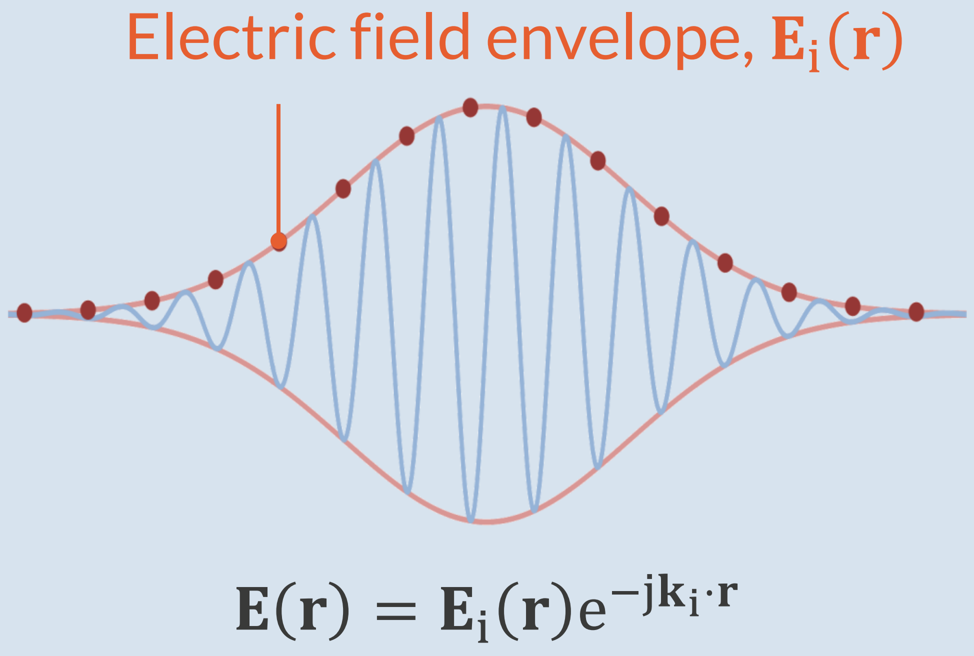


Beam Envelope Method

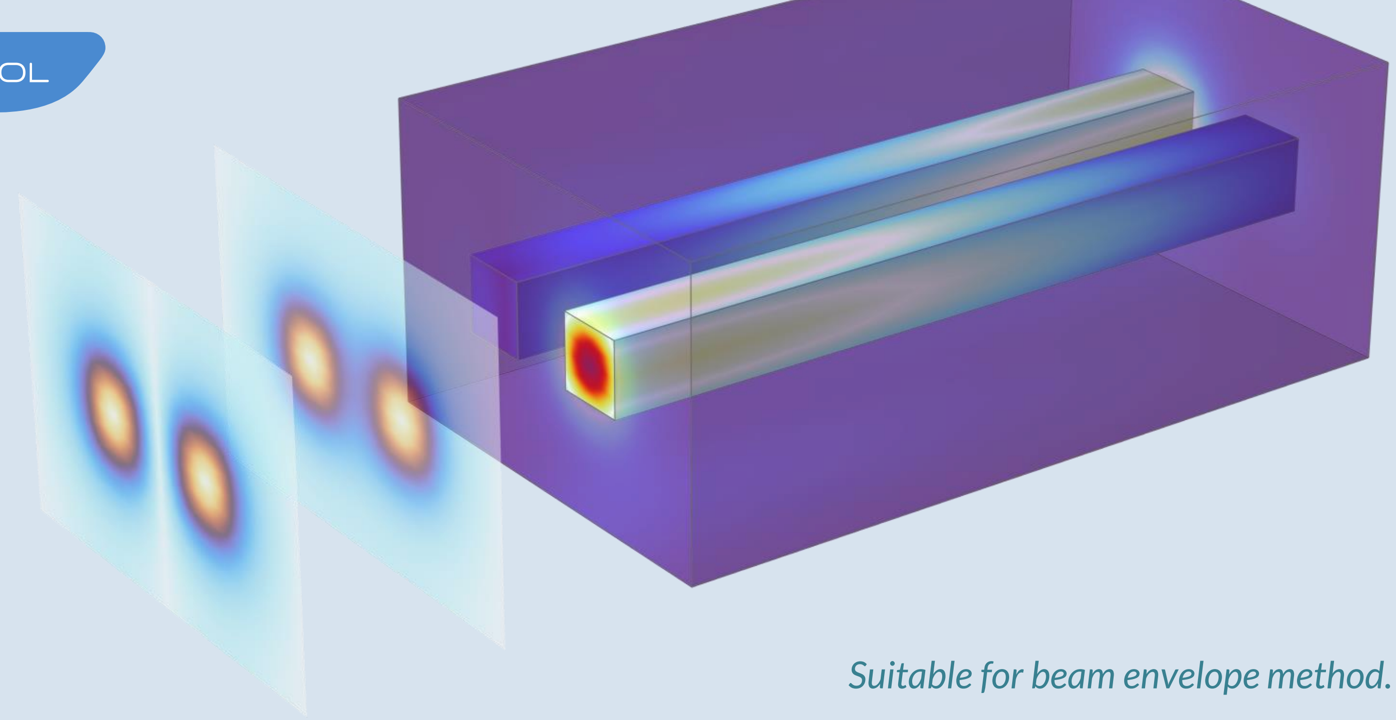
Rigorous simulations of optically large devices.



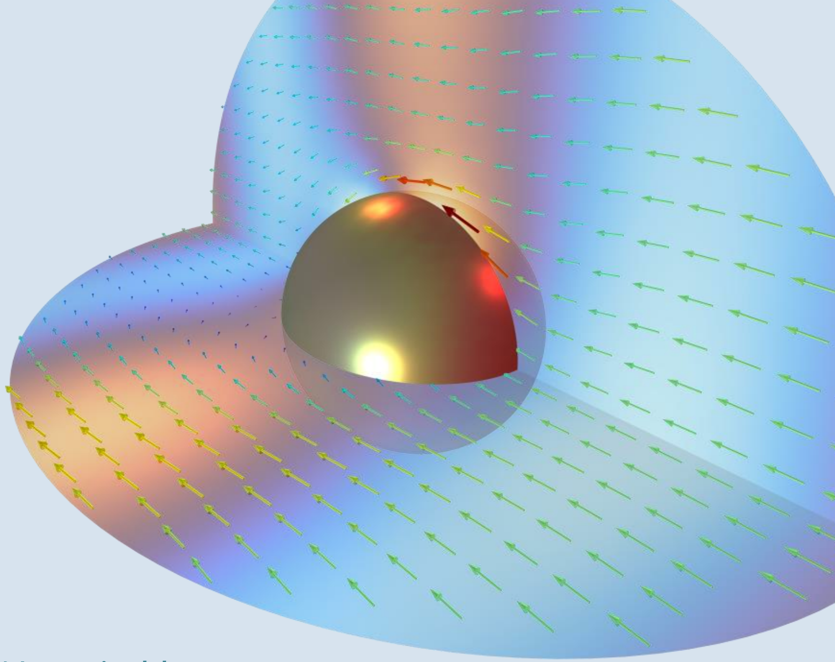
Five mesh elements per wavelength.



Mesh only needs to resolve electric field envelope.



Suitable for beam envelope method.



Not suitable.

When to Use the Beam Envelope Method

- You need to be able to guess good wave vectors (or phase functions).
  - If your problem is not characterized by one or two main wave vectors, use the *Electromagnetic Waves, Frequency Domain* interface instead.
- The beam envelope method is not suitable for scattering problems.
  - The incoming wave has a well-known wave vector, but the scattered wave propagates in many directions.

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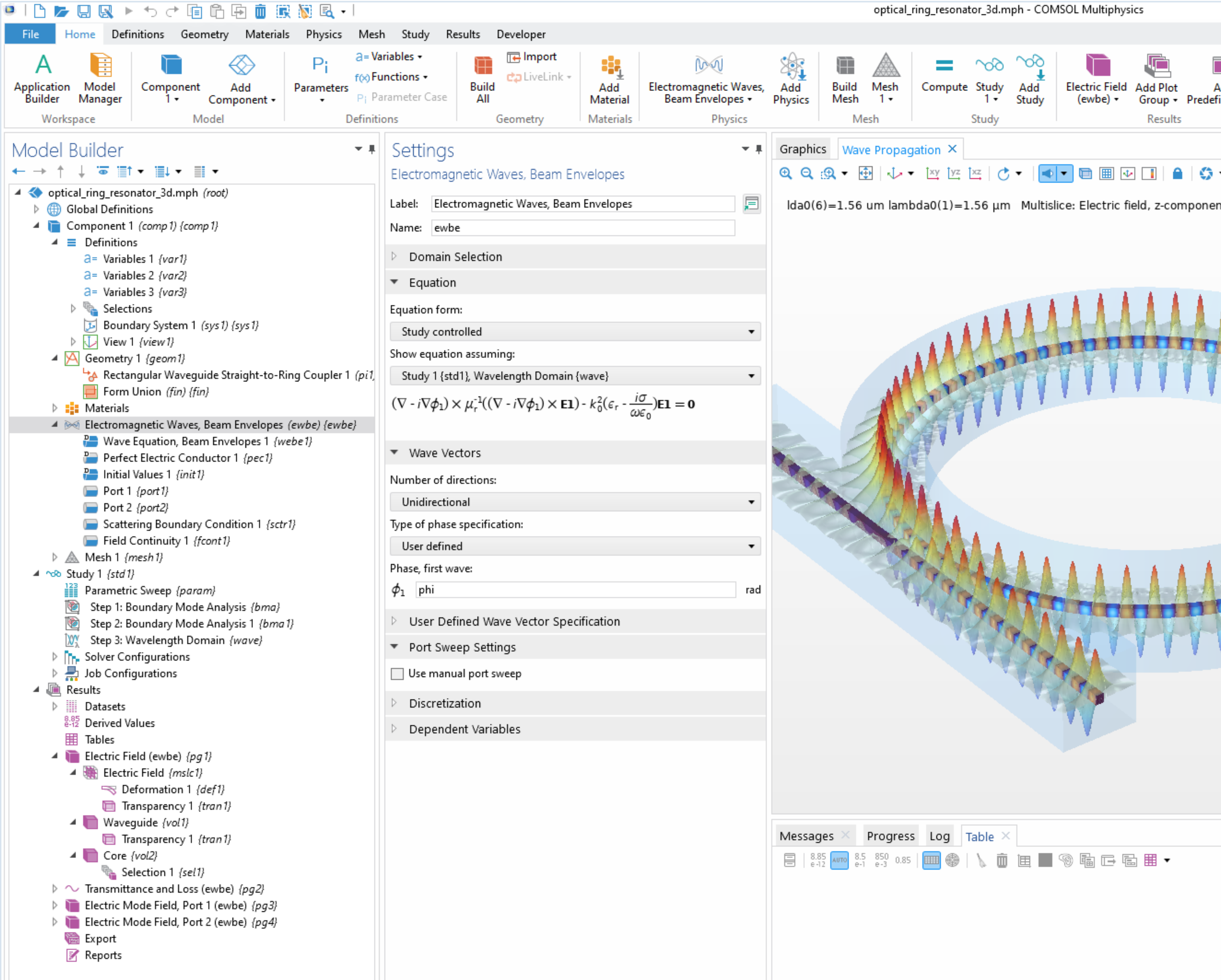
Optical Ring Resonator

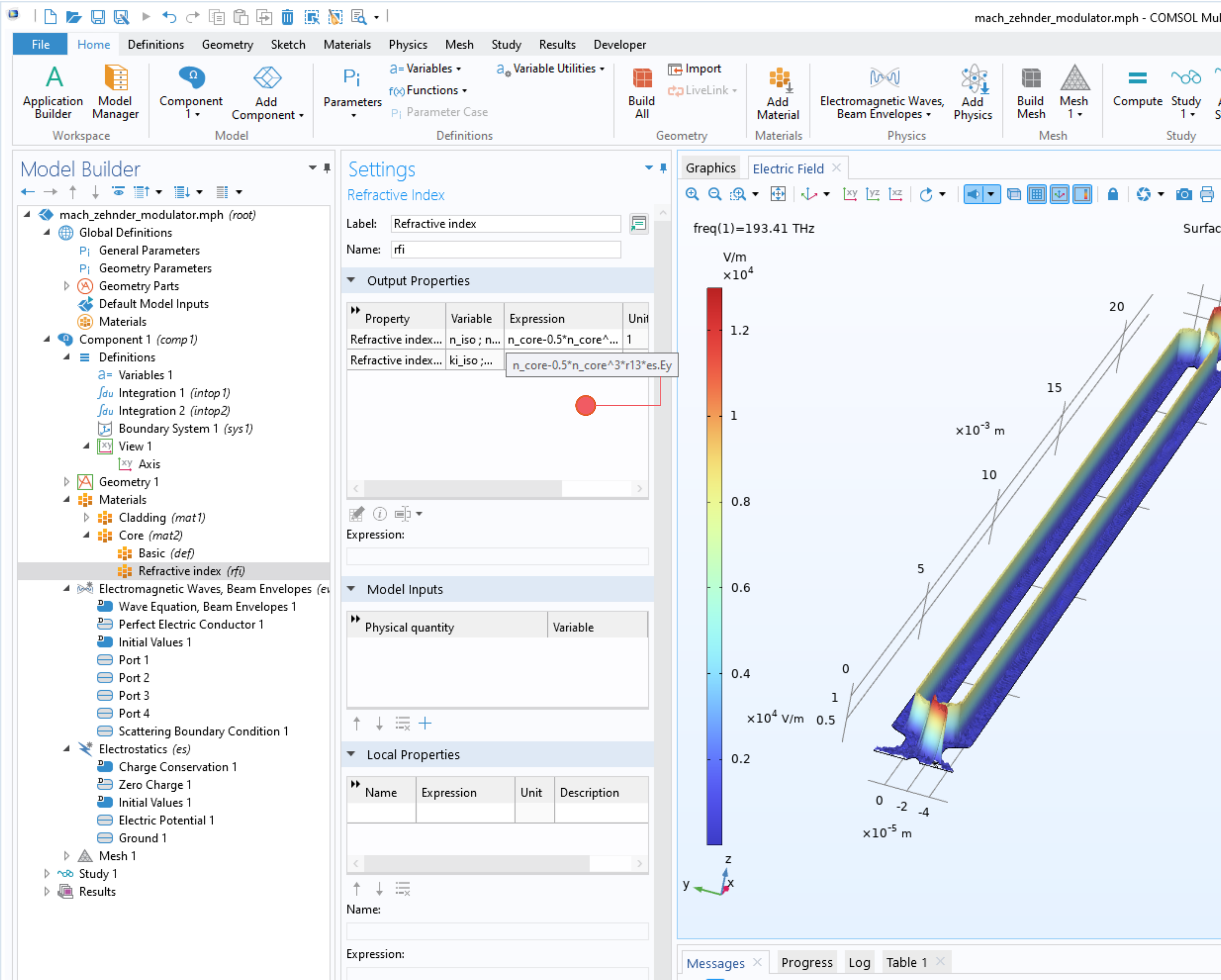
Interferes of electric fields from the ring and the straight waveguide

Phase propagation well known and even analytical.



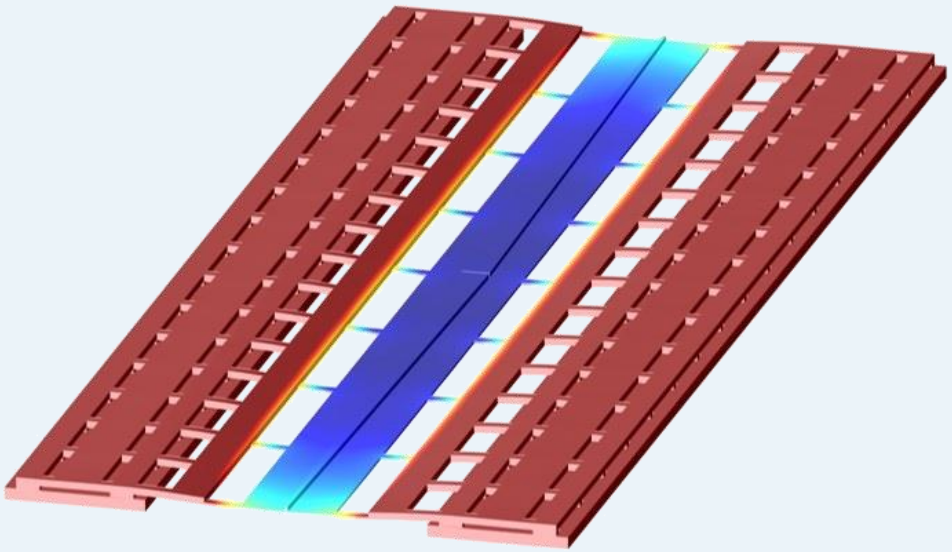
Electro-Optic Modulation

- Mach–Zehnder modulator:
  - Two-directional coupler
  - Electro-optic modulation of one interferometer path
  - Applied voltage controls power flow to output ports
- Physics interfaces:
  - *Electromagnetic Waves, Beam Envelopes* (Wave Optics Module)
  - *Electrostatics* (AC/DC Module)
- Multiphysics coupling:
  - 🔴 Refractive index (Wave Optics Module) controlled by applied voltage (AC/DC Module) through electro-optic effect



USER STORY: EPFL

Silicon Photonic MEMS Phase Shifter to Boost Optical Network Speed



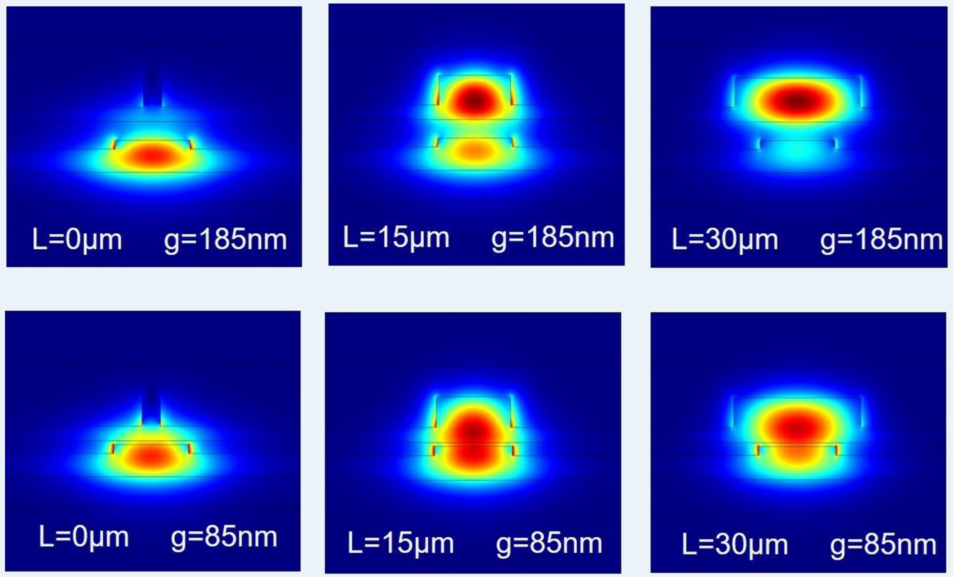
CHALLENGES

Optical fiber networks, the backbone of the internet, still rely on many electrical signal processing devices.

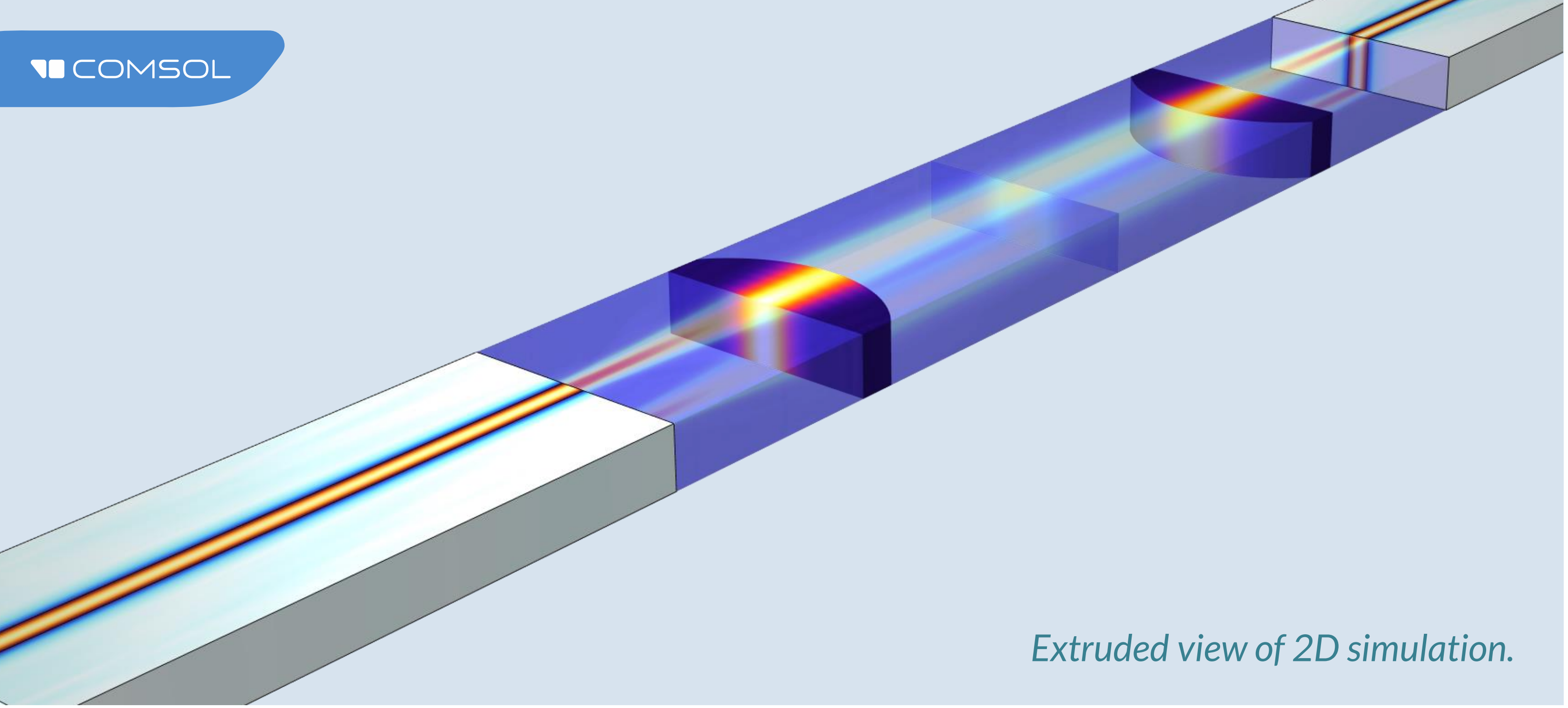
Nanoscale silicon photonic network components, such as MEMS phase shifters, can boost optical network speed, capacity, and reliability.

MODELING

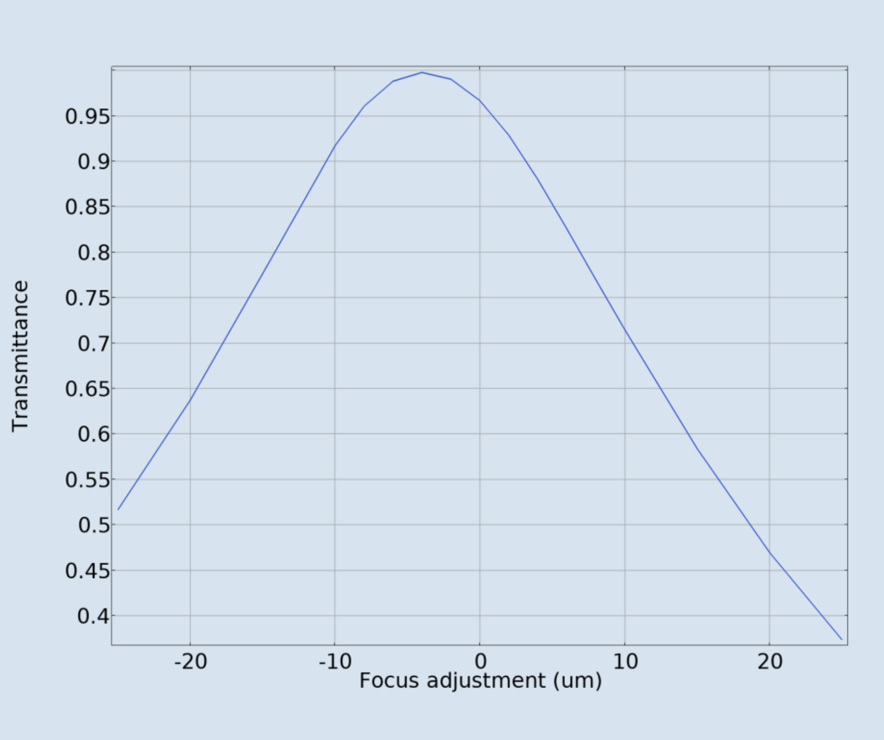
The team at EPFL analyzed how much voltage had to be applied to a MEMS supporting a waveguide to induce a wanted shift in a photonic signal.



Designing a Silicon Photonic MEMS Phase Shifter with Simulation ® COMSOL 2022. *COMSOL News 2022*. Research by Hamed Sattari, Swiss Federal Institute of Technology Lausanne (EPFL), Switzerland.



Extruded view of 2D simulation.



Fiber-to-Fiber Coupling

- Free-space coupling between two single-mode fiber ends
- Coupling efficiency depends on the lens positions
- *Transition Boundary Conditions* are used as antireflection coatings:
  - Fiber facets
  - Lens surfaces

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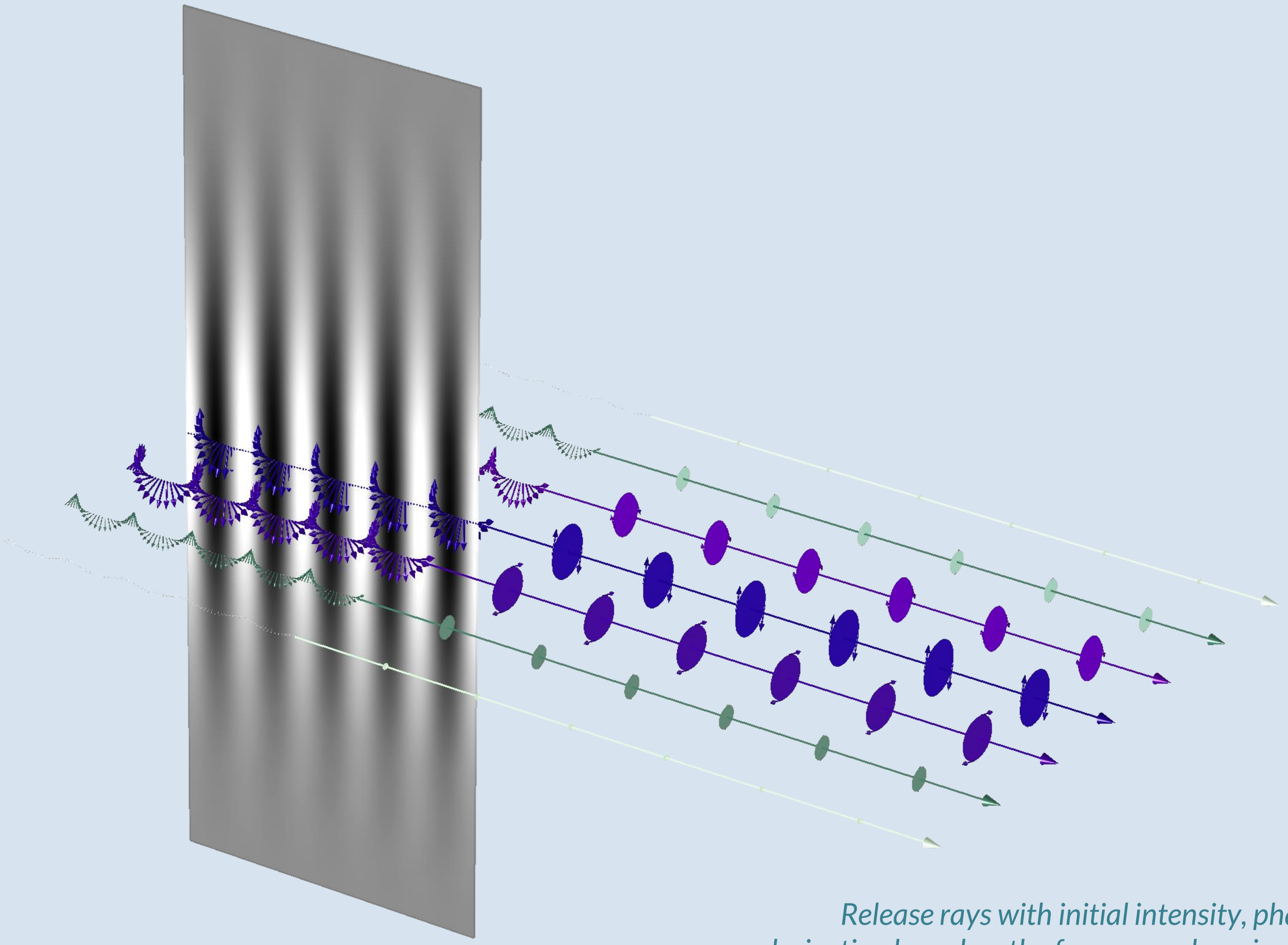
RAY OPTICS AND EM FIELDS

Multiscale Electromagnetics Modeling

Solve for the electric field over several wavelengths using FEM: Electromagnetic Waves, Frequency Domain or Electromagnetic Waves, Beam Envelopes



Release rays with initial intensity, phase, and polarization based on the frequency domain solution.

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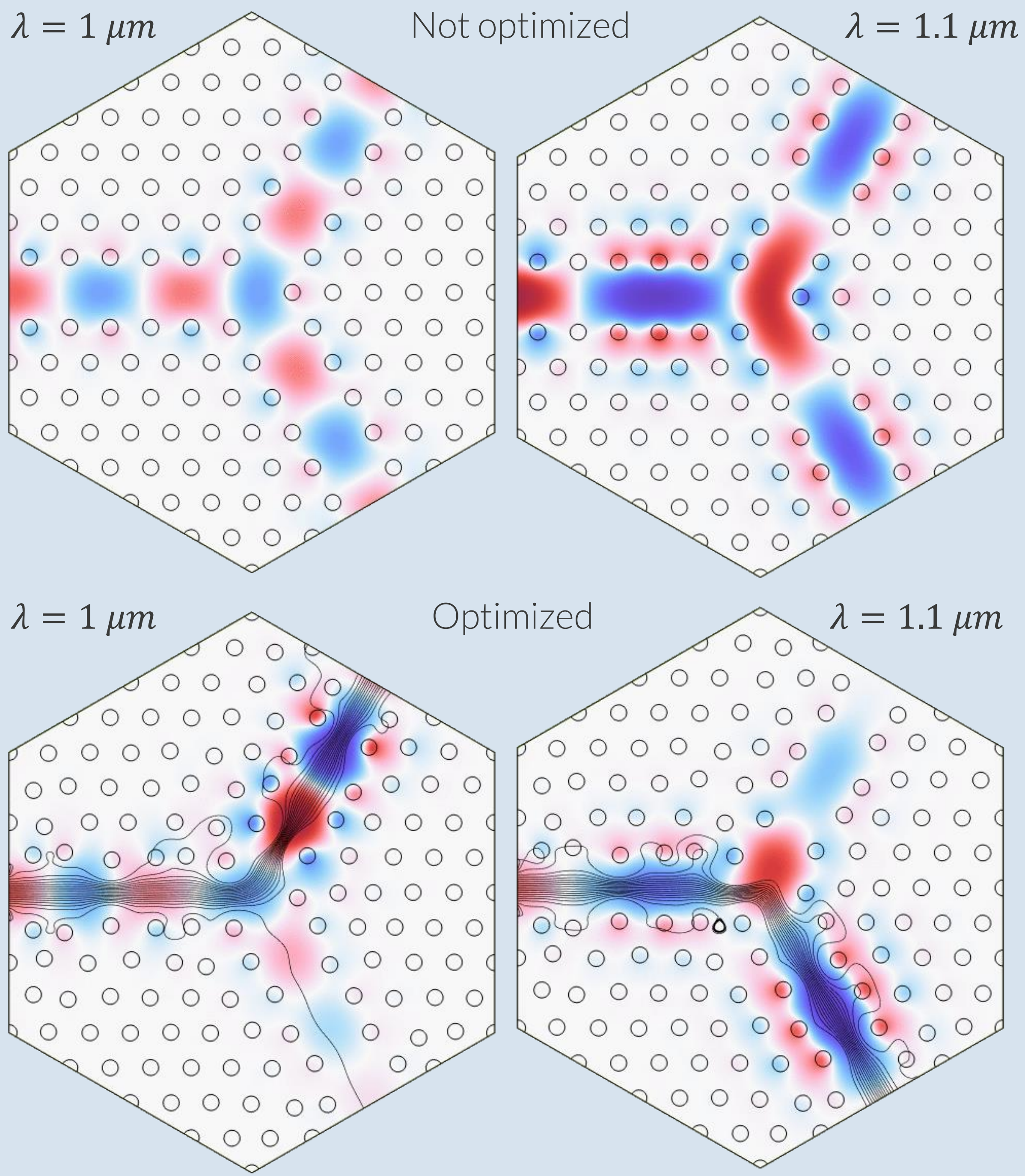
Optimization

- Gradient-free optimization
  - Geometric parameters optimization
  - Remeshing of the geometry
  - Optimize geometry for a CAD model created in COMSOL® or via the LiveLink™ products
- Gradient-based optimization
  - Differentiable objective function via moving mesh
  - Can handle many more design variables and solve much faster
  - Adjoint method is used to compute exact sensitivities



COMSOL Day
Sensor Technology

June 25, 2024
10–15 CEST

12:00 KEYNOTE TALK
Quantum-Enhanced Sensing with Photonic Integrated Circuits
Phoebe Tengdin, Miraex SA

See what is possible with modeling in the development of sensors

Join us for this COMSOL Day to see how multiphysics modeling facilitates the design and optimization of sensing devices across many research areas and industries.

» comsol.com/comsol-days/sensor-technology

Topics Include

- Electromechanical sensors
- Chemical sensors
- Modeling of hall sensing and inductive sensing
- Parameter estimation
- Uncertainty quantification
- Speeding up sensor calculations