Design and Simulation of Cantilever Beam with a Bragg Grating based Optomechanical Senor for Atomic Force Microscopy in COMSOL

11/13/2023

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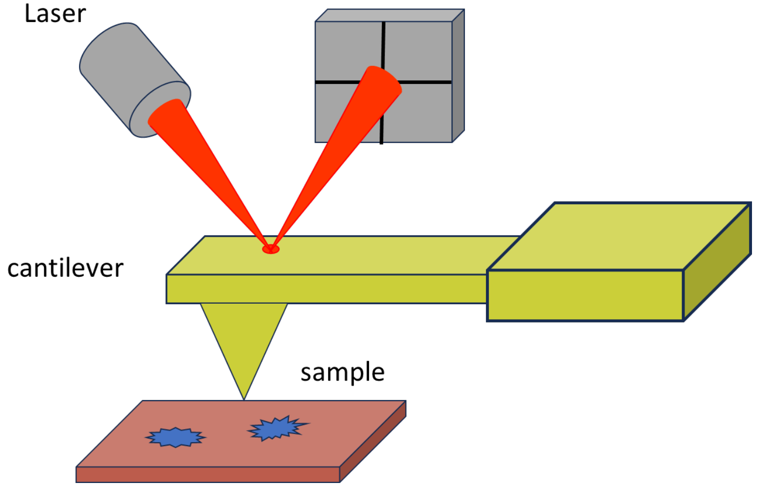
Atomic Force Microscopy



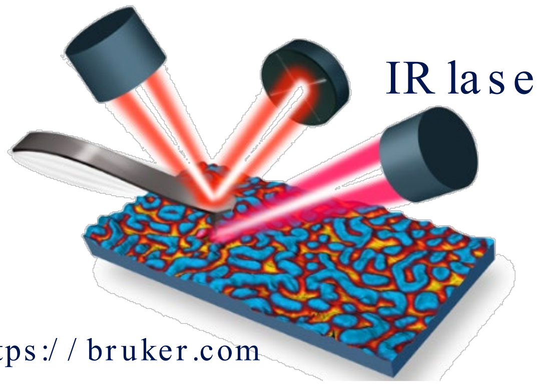
Advantages:

- High Spatial Resolution
- Non-Destructive
- Force Measurements
- Complementary Technique
- ...

Disadvantages:

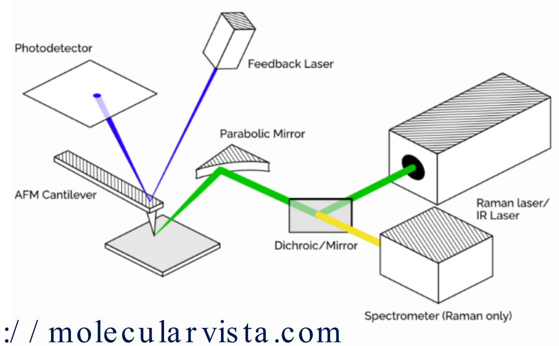
- Slow Scanning Speed
- Tip Wear and Sample Damage
- Deflection laser is an essential component noise and interference
- ...

AFM-IR



https://bruker.com

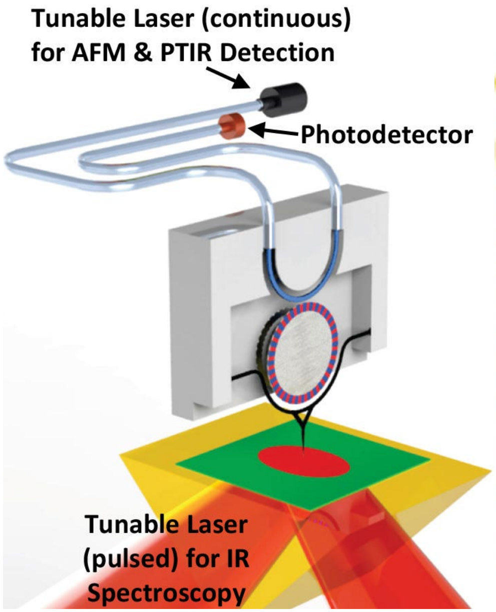
AFM-Raman spectroscopy



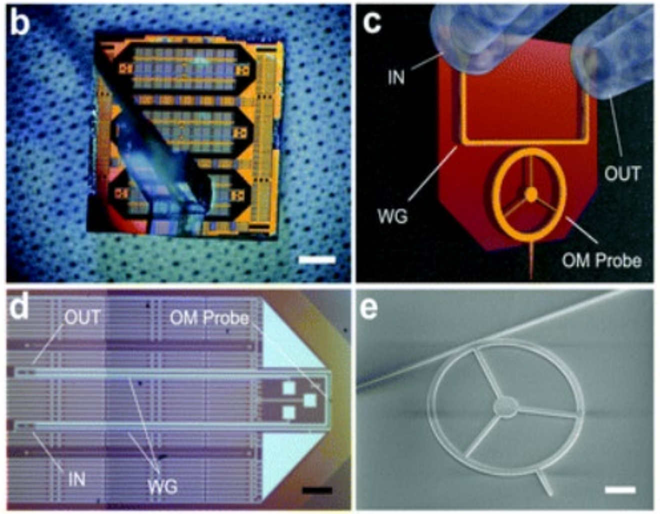
https://molecularvista.com

Solution with Silicon photonics:

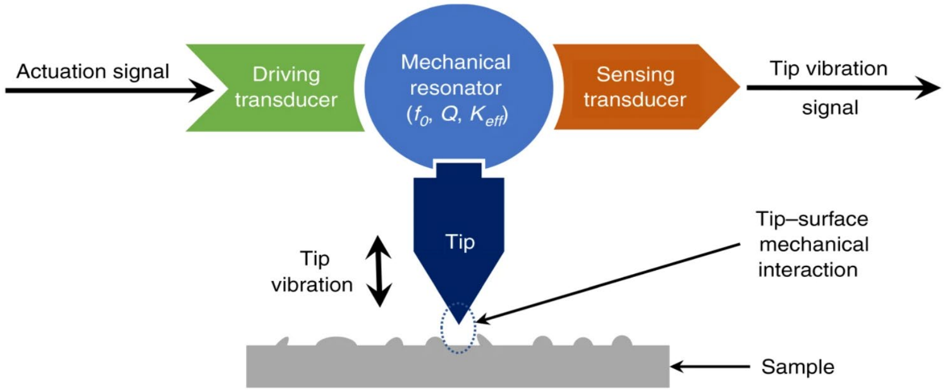
- **High scanning speed**
- **Get rid of deflection laser**
- **Low-cost**
- **Batch fabrication**
- **Compact**
- **High sensitivity**



Andrea Centrone . Nano Lett. 2017,19,9,5587 -5594

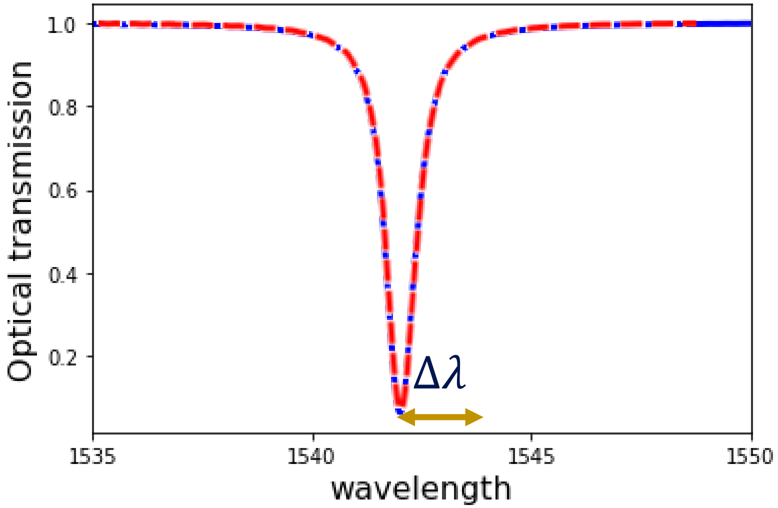


Ivan Favero & Bernard Legrand. Nanoscale, 2020,12,2939 -2945

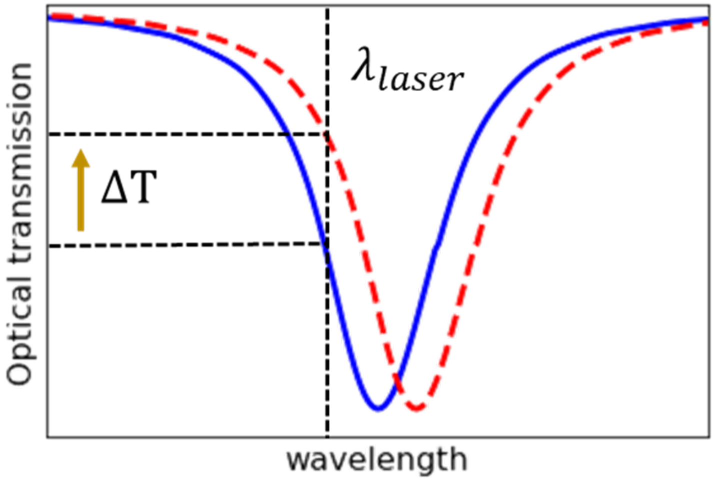


Ivan Favero & Bernard Legrand. Microsyst Nanoeng 8, 32 (2022)

Resonance shift due to cantilever motion



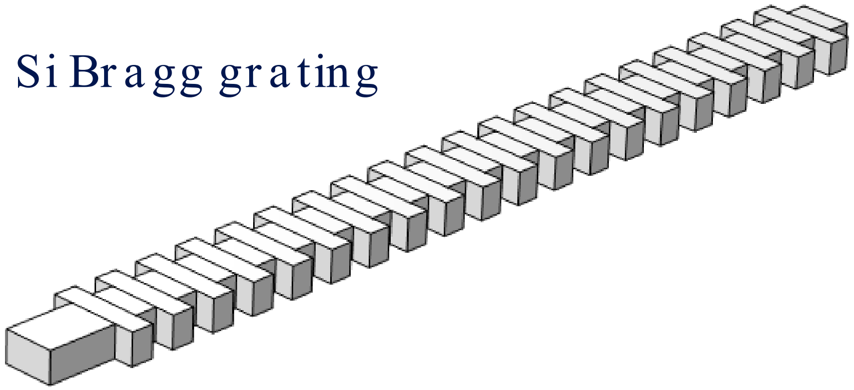
Opt. signal due to cant. motion



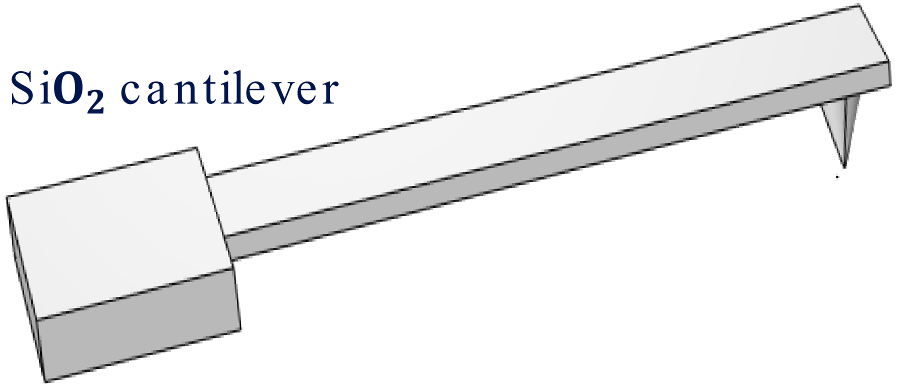
Waveguide Bragg grating (WBG):

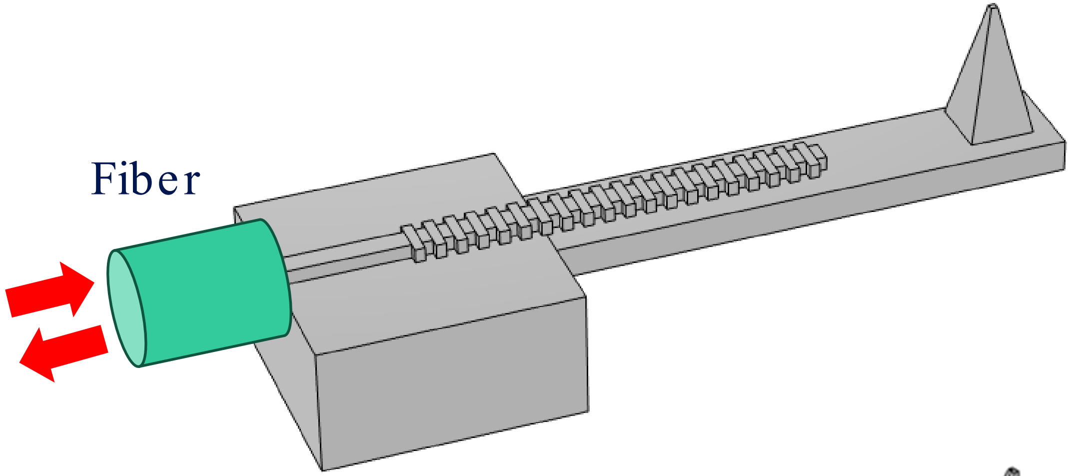
- ❑ Robust and easy to fabricate
- ❑ High-Speed Operation
- ❑ Cantilever based

Si Bragg grating

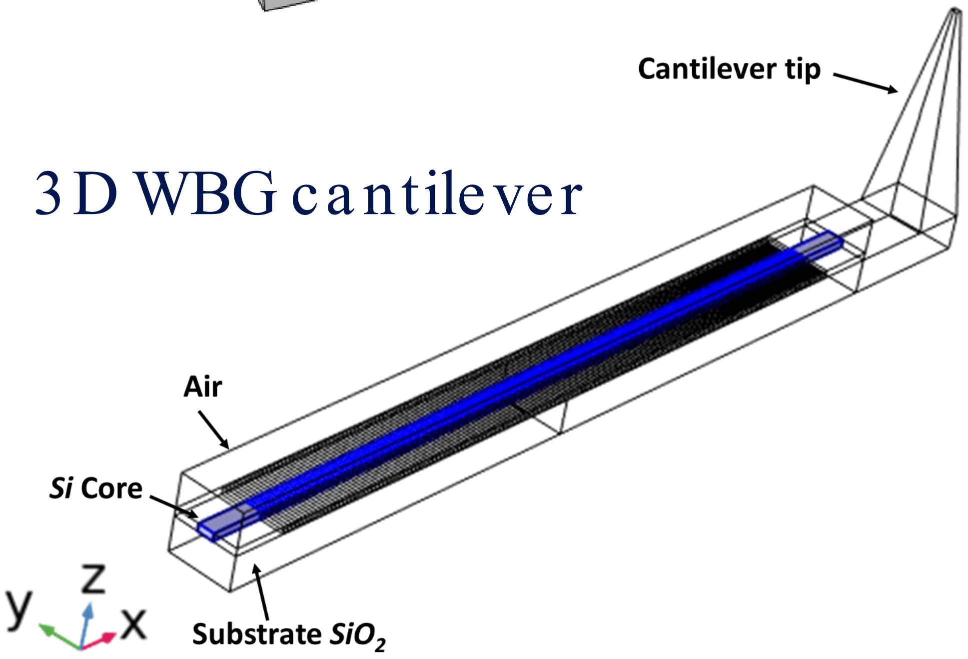


SiO_2 cantilever



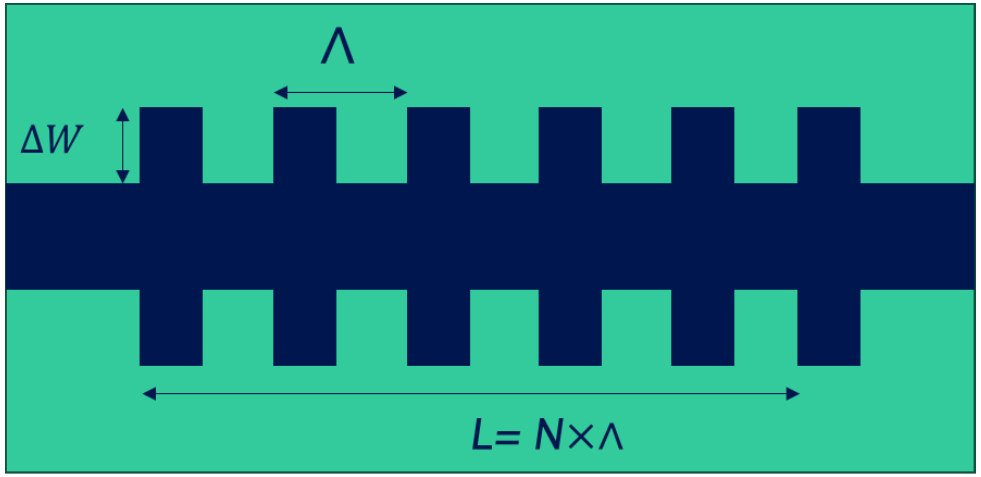


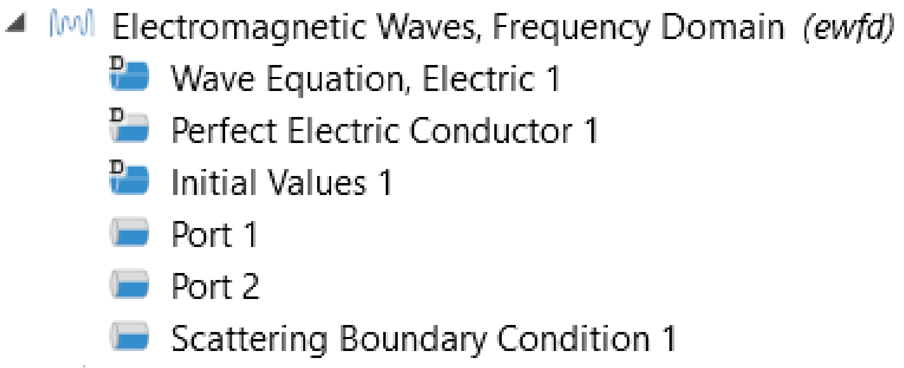
3D WBG cantilever



Waveguide Bragg grating (WBG):

- ❑ Customized wavelength-selective
- ❑ High-Quality Factor (Q-factor)





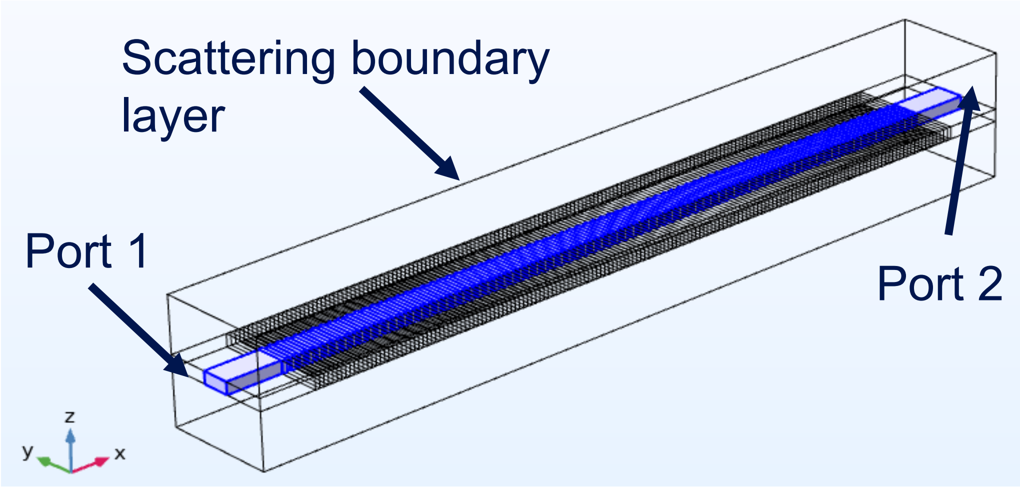
Bragg's equation

$$\lambda_B = 2 \cdot \Lambda \cdot n_{eff}$$

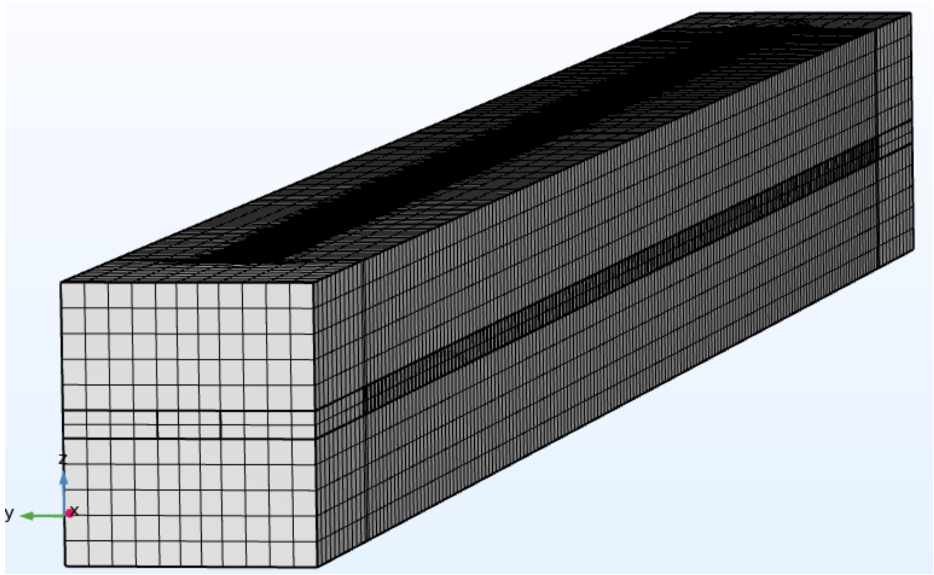
n_{eff} is the effective refractive index.

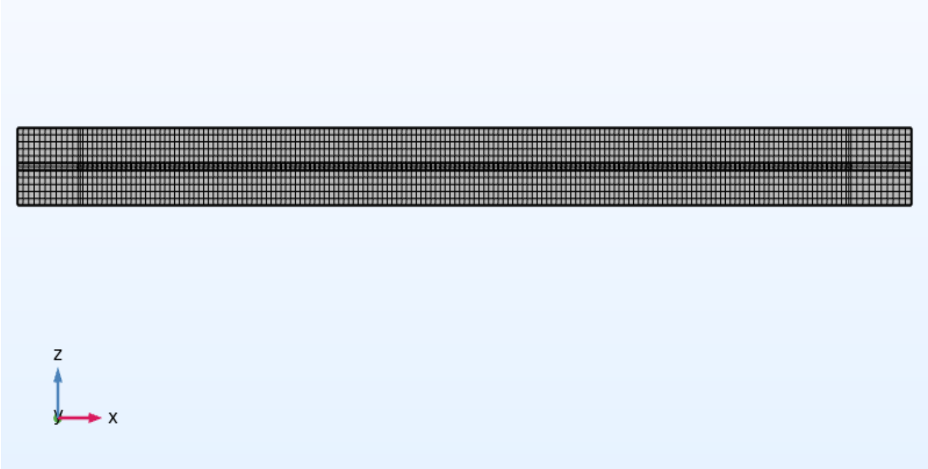
A resonance shift Δλ due to the change of refractive index Δn can be expressed by,

$$\frac{\Delta\lambda}{\lambda} = \frac{\Delta n}{n}$$

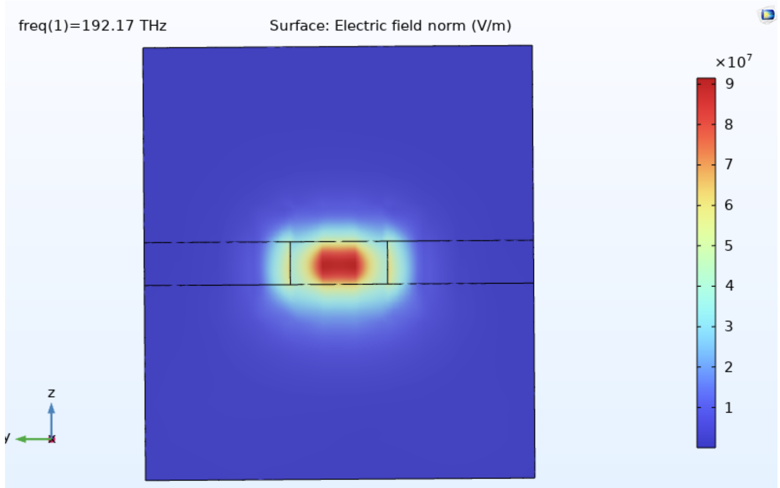


Swept mesh

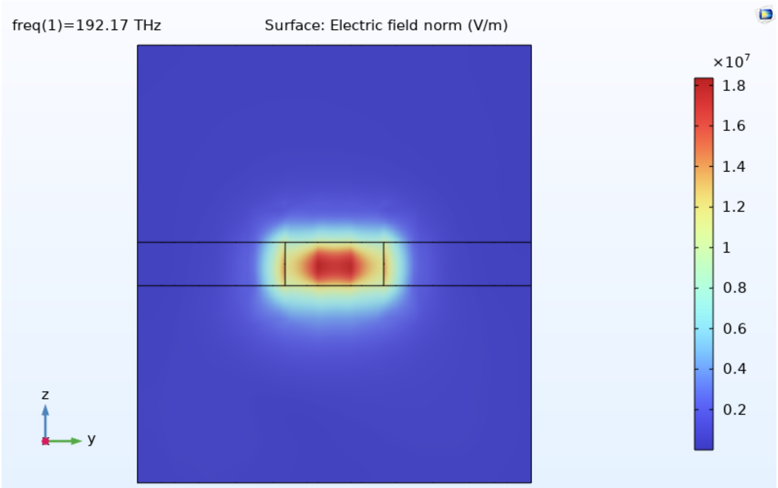


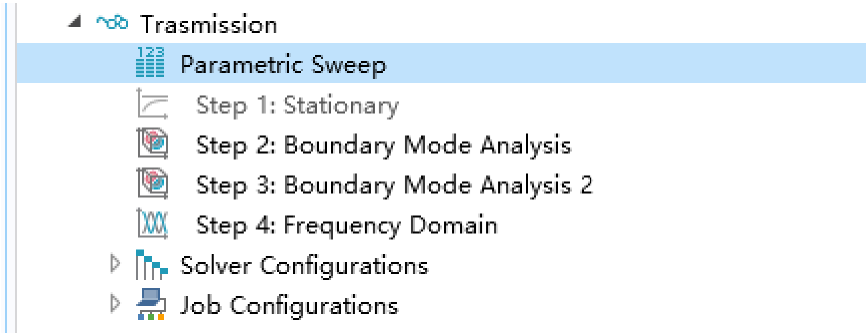


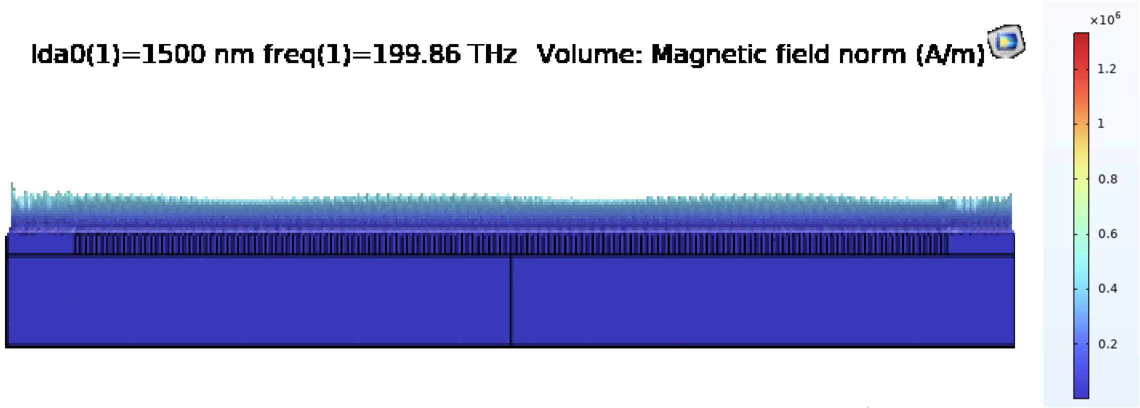
Port 1



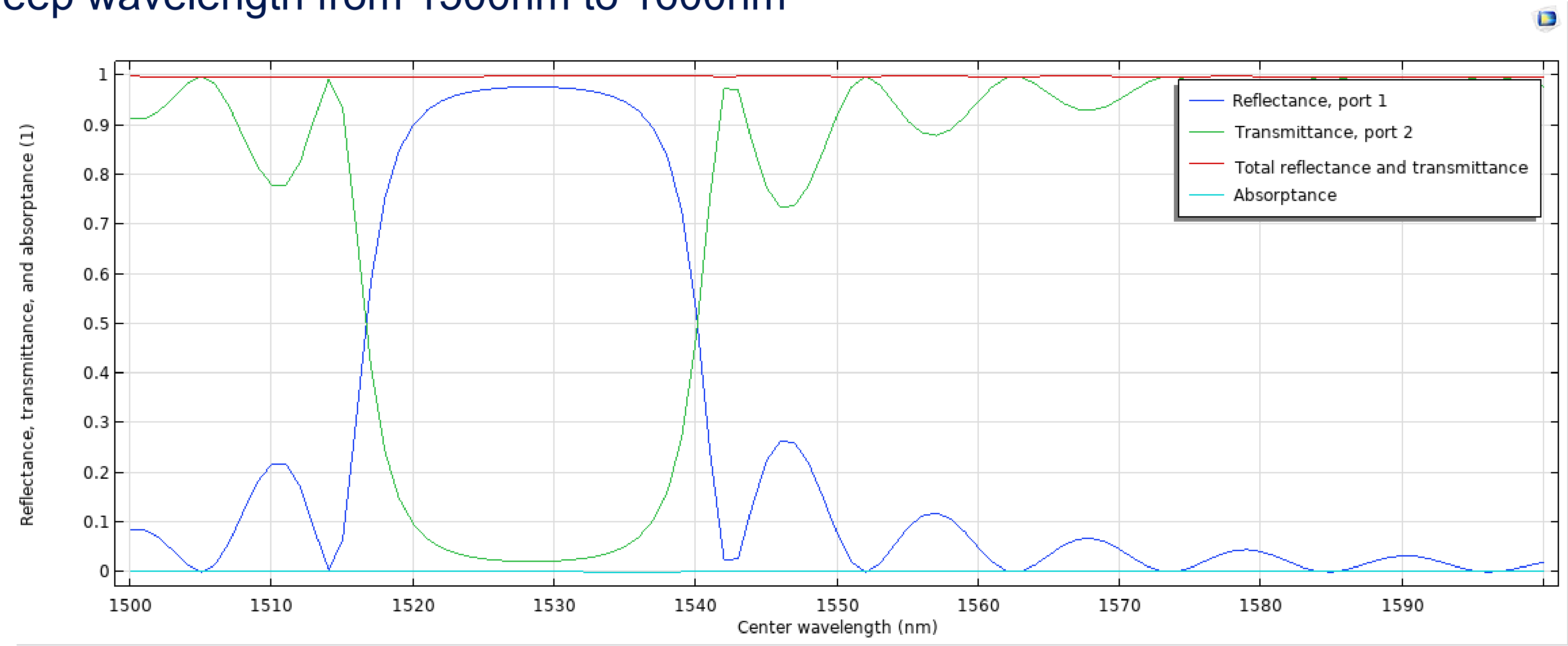
Port 2

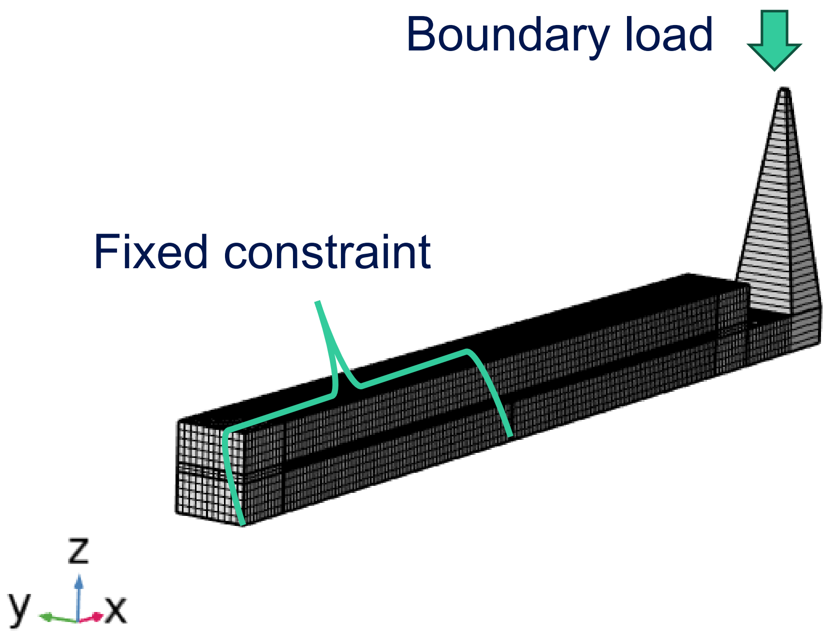




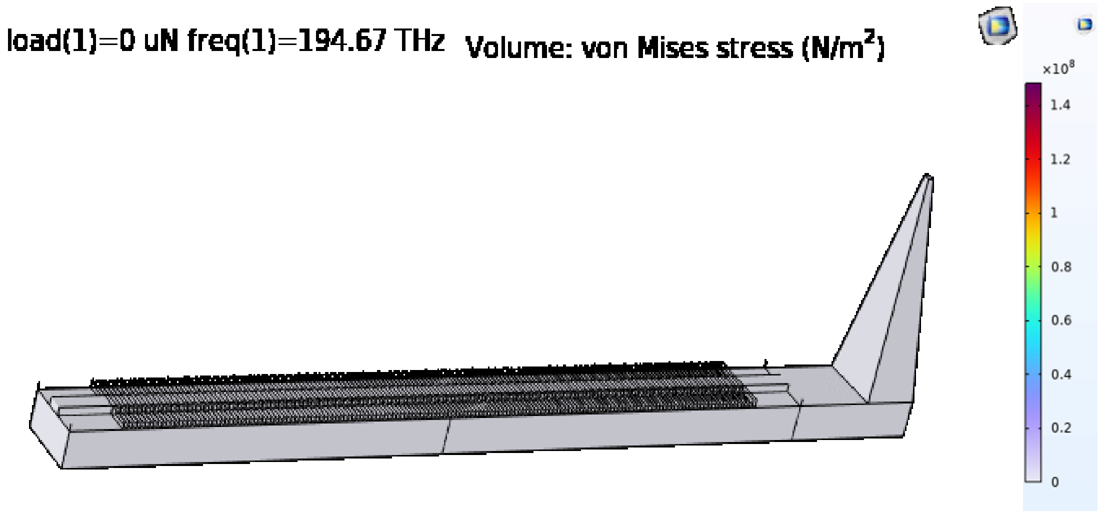


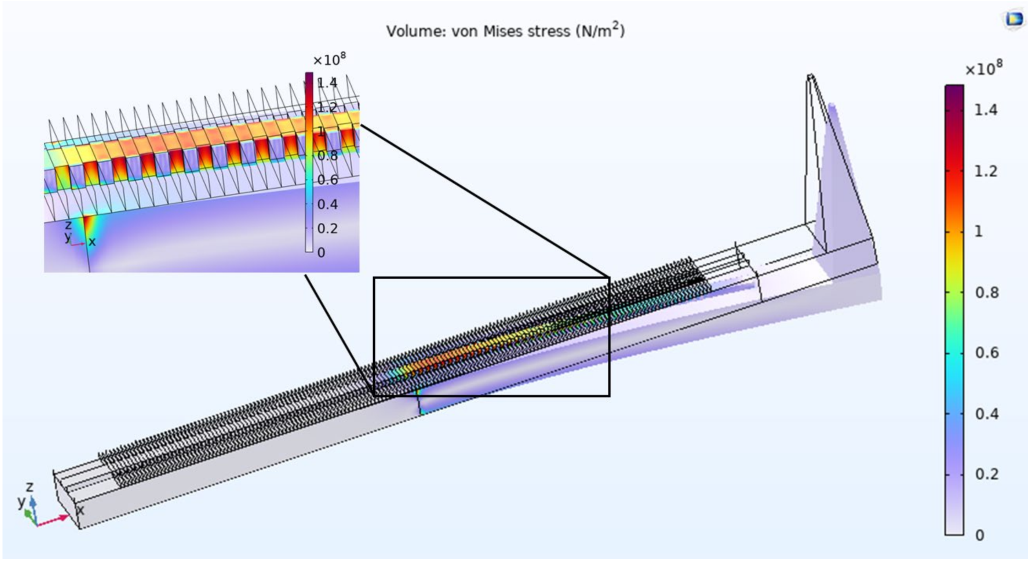
Sweep wavelength from 1500nm to 1600nm

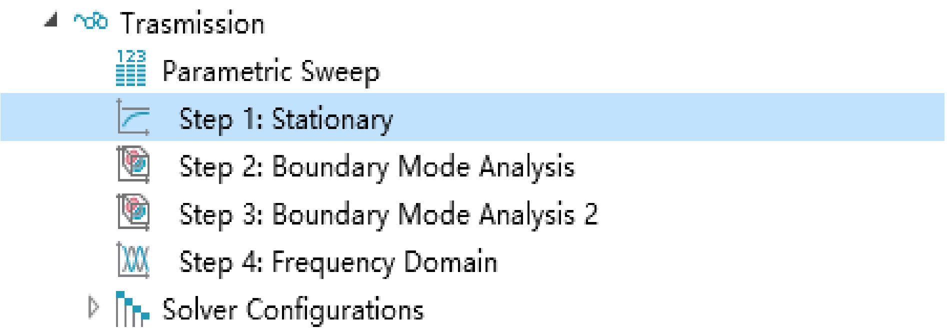


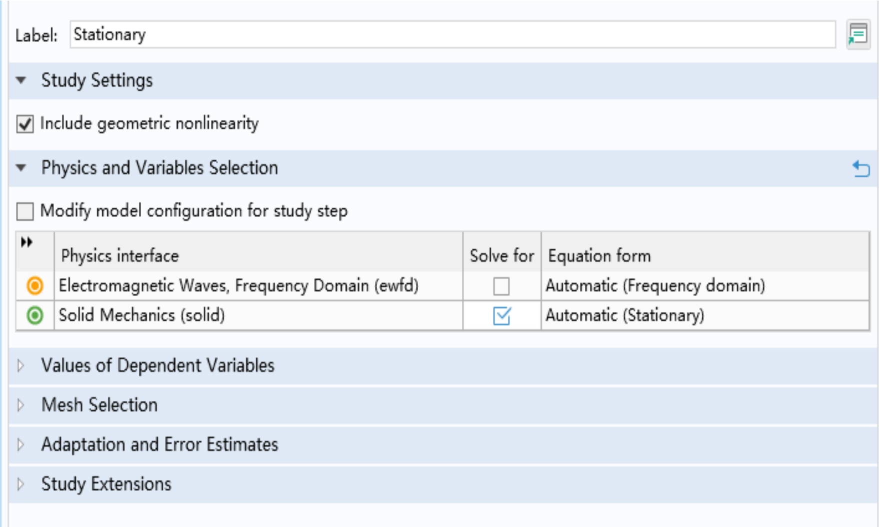


- Solid Mechanics *(solid)*
  - Linear Elastic Material 1
  - Free 1
  - Initial Values 1
  - Fixed Constraint 1
  - Boundary Load 1
- Mesh 1
  - Size
  - Swept 1









Define refractive index variables for Si, SiO_2 and air

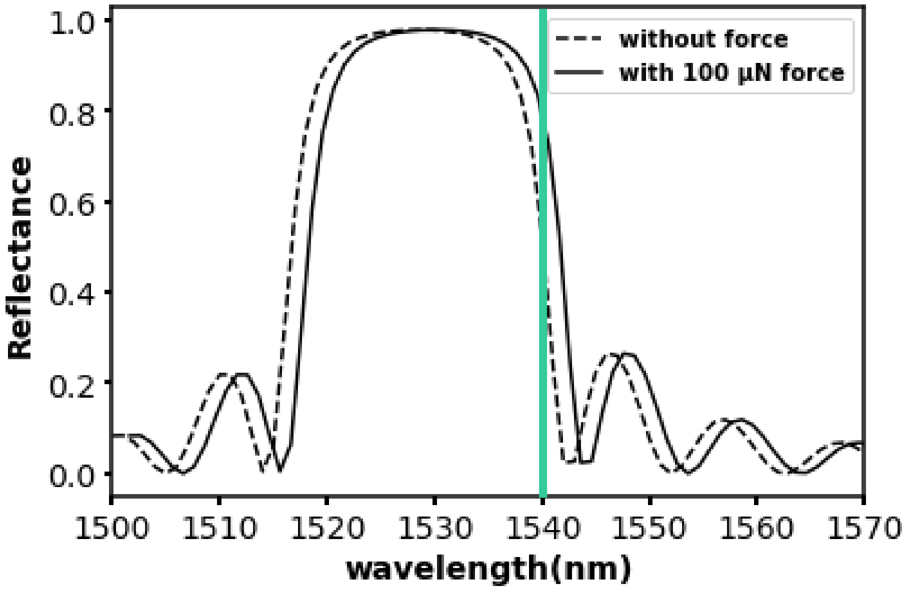
▾ Variables

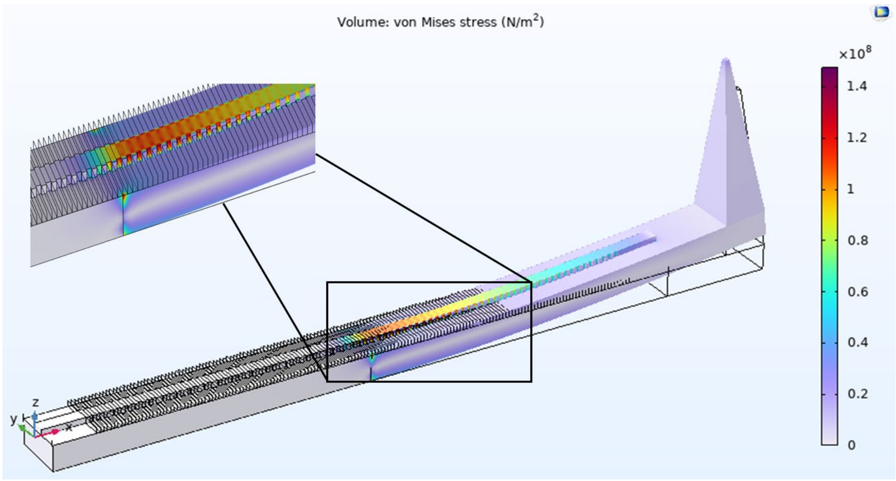
Name	Expression	Unit	Description
Nx	N-para*(B1*solid.sx+B2*(solid.sy+solid.sz))		Refractive index, x co...
Ny	N-para*(B1*solid.sy+B2*(solid.sx+solid.sz))		Refractive index, y co...
Nz	N-para*(B1*solid.sz+B2*(solid.sx+solid.sy))		Refractive index, z co...

Para: 1: stress-optical coupling,
0: no coupling

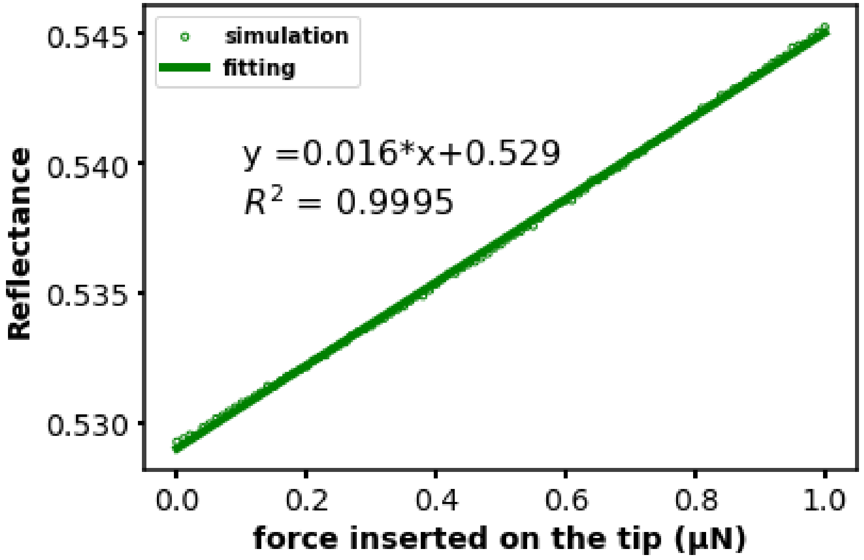
B1: First stress optical coefficient

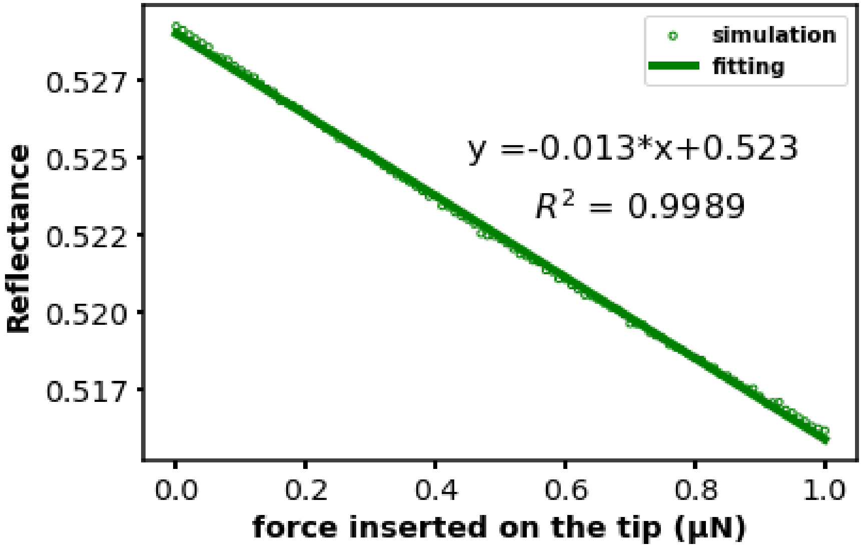
B2: Second stress optical coefficient





At wavelength 1540nm





Conclusion

- A 3D Bragg grating-based optomechanical sensor has been designed and simulated in COMSOL.
- Cantilever stiffness is about 0.06 N/m.
- The direction of the applied force by monitoring the increase or decrease in reflected power at the specified wavelength.
- We present the comprehensive 3D coupled finite element analysis aimed at understanding the mechanical stress-induced effects on electromagnetic wave simulations.

Thank you!

Supervisors:

Dr. Georg Ramer

Dr. William Whelan Curtin

Funding:

European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 860808