Modeling of PZT Slab for Generating Symmetric and Uniform Axial Strain Distribution

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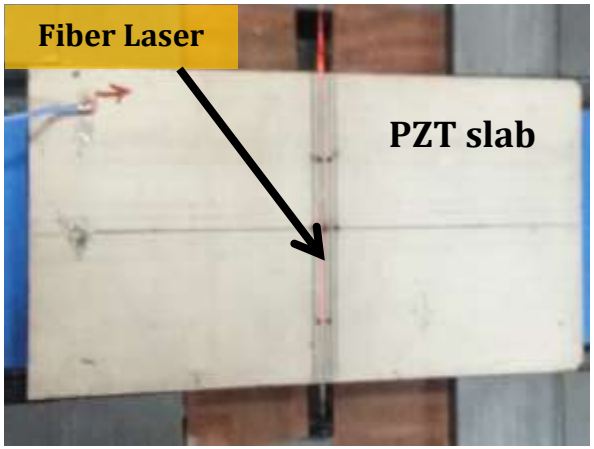
- Requirement for high frequency optical modulation
- PZT slab based fiber laser modulation
- Modelling & simulation of PZT8 & PZT 5H slabs
- Analysis of frequency response & axial strain distribution
- Investigation of constraints on Optical modulation
- Modelling & simulation results

Modulation in Fiber Laser (FL)

- Interferometric fiber optic sensing demands high frequency optical modulation
- Optical Source - Low noise & narrow line width FLs
- Generation of mechanical strain on piezoelectric slab with electric potential
- Mounting the active region of FLs on optimum & uniform strain region on PZT slab
- Optical modulation compatible with the generated axial strain on PZT slab



Fiber laser mounted on PZT slab

Modulation requirements for interferometric fiber optic sensing :-

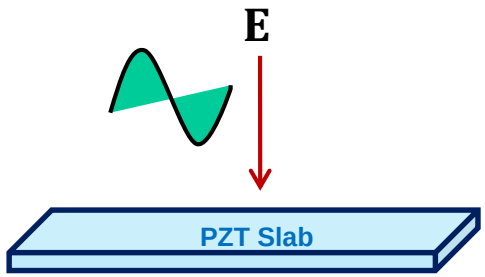
- **Optimum**
- **Symmetric**
- **Uniform**
- **High frequency**

Factors affecting Axial strain on PZT slab:-

- **Modulation Amplitude**
- **Modulation Frequency**
- **PZT material composition**
- **PZT slab dimension**
- **Region on slab for mounting the fiber laser**

Modeling & Simulation

- COMSOL Multiphysics software version 5.2 for FEM
- Modeled and simulated PZT8 & PZT5H slabs
- Modules used
  - **Structural mechanics module**
  - **AC/DC module**
- Interfaces
  - **Piezoelectric devices**
  - **Solid mechanics**
  - **Electrostatics**



Electric field to PZT slab

Basic computation Equations:-

- **For solid mechanics domain**

$$-\rho\omega^2 u = \nabla . S + F_v e^{i\phi}$$

- **For AC/DC domain**

$$\nabla . D = \rho_v$$

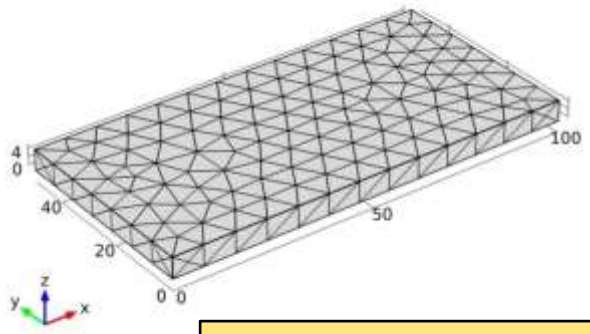
$$\mathbf{E} = -\nabla V$$

Objectives of modeling & simulation:-

- **Design the PZT slab for modulation requirements**
- **Model the PZT slab with resonance free state at required high frequency region**
- **Analyze the frequency response of PZT slabs**
- **Simulate & analyze the effect of Electric field on axial strain of PZT slabs**
- **Modulation analyze with signal of 1 V amplitude**
- **Analyze the significance of PZT material composition & dimensions for axial strain of PZT**

Simulation Results

1. PZT8 slab

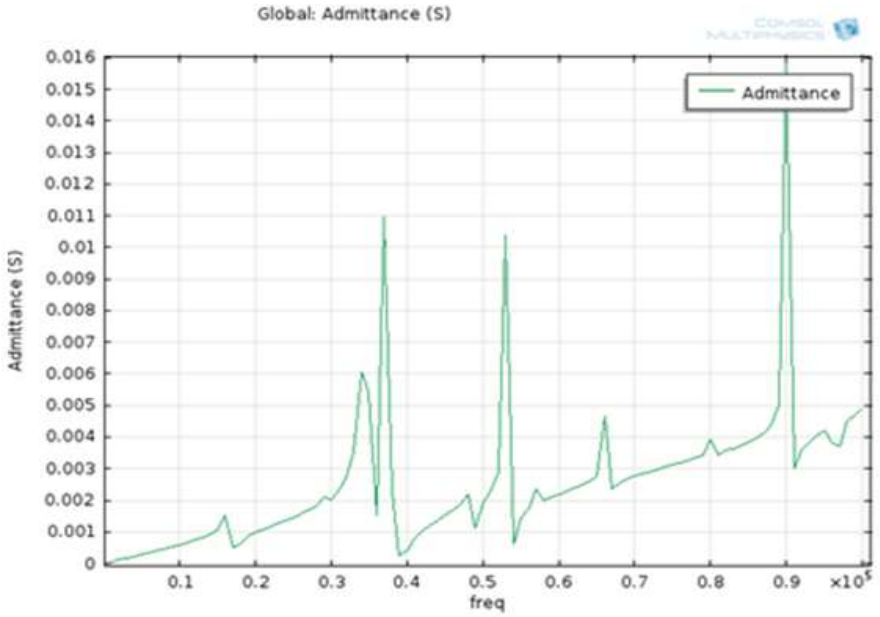


Mesh model of PZT8 slab

Dimensions of PZT8 slab (mm)		
Length	**Breadth**	**Height**
100	50	5

Material properties	Symbols	PZT 8
Relative dielectric constant	K_{33}^T	1205
Piezo electric coupling factor	k_p	.5
Charge constant	d_{33}	215
	d_{31}	-126
Strain constant	S_{33}	13.5
Density	ρ	7.45

Significant material properties for mechanical strain generation

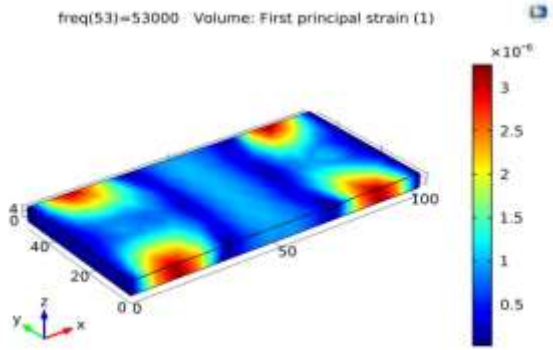


Frequency response of PZT8 slab

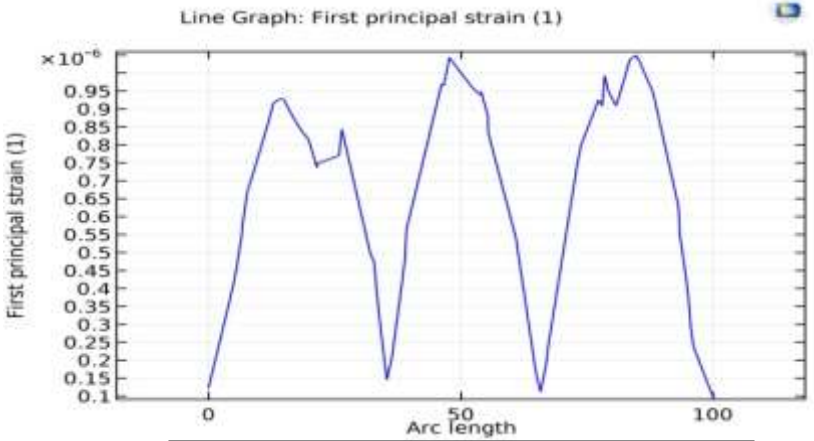
Simulation Results of PZT8 slab Contd....

Axial strain response at different modulation frequencies

Modulation signal @ Resonant frequency of 53 kHz

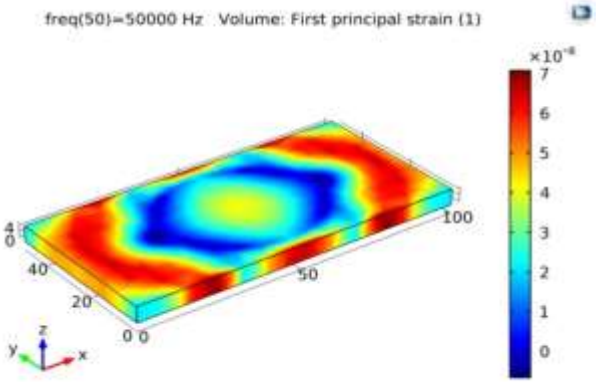


Axial strain distribution on slab

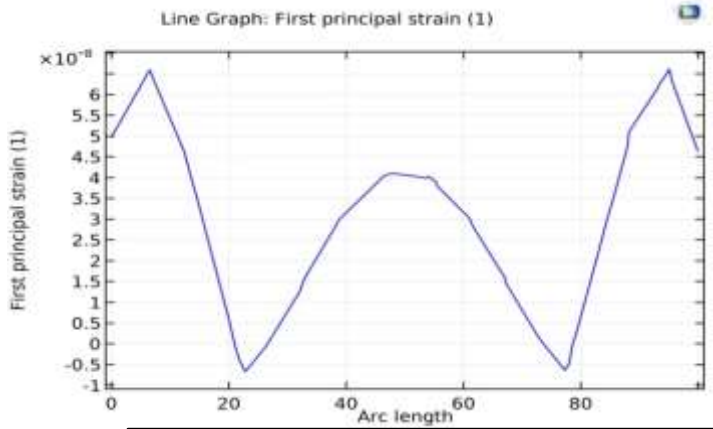


Axial strain plot along length axis

Modulation signal @ 45 kHz frequency



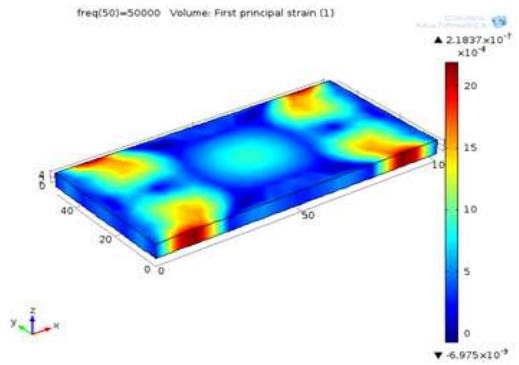
Axial strain distribution on slab



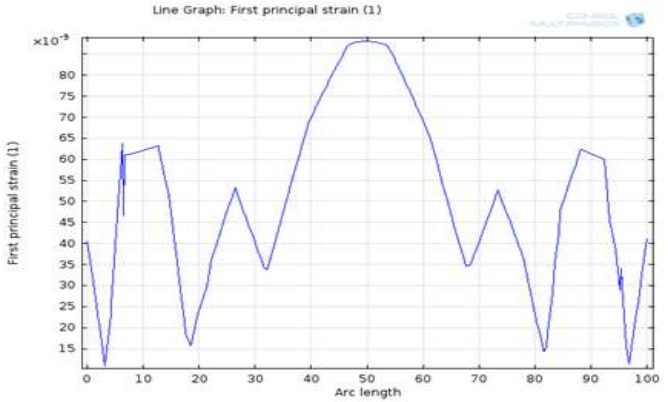
Axial strain plot along length axis

Simulation Results of PZT8 slab Contd....

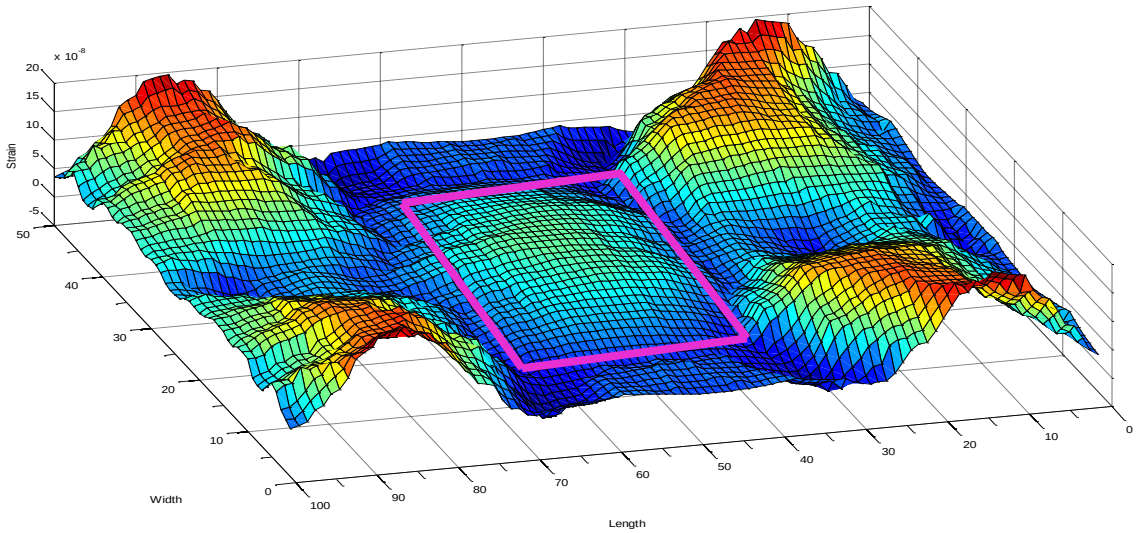
Modulation signal @ 50 kHz frequency



Axial strain distribution on slab



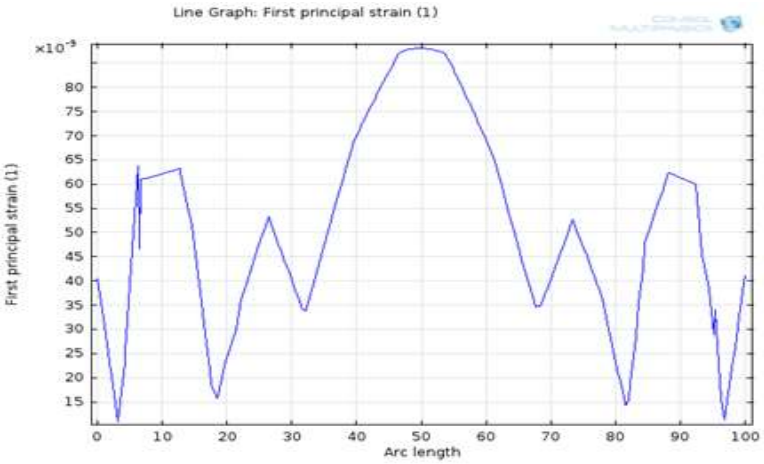
Axial strain plot along length axis



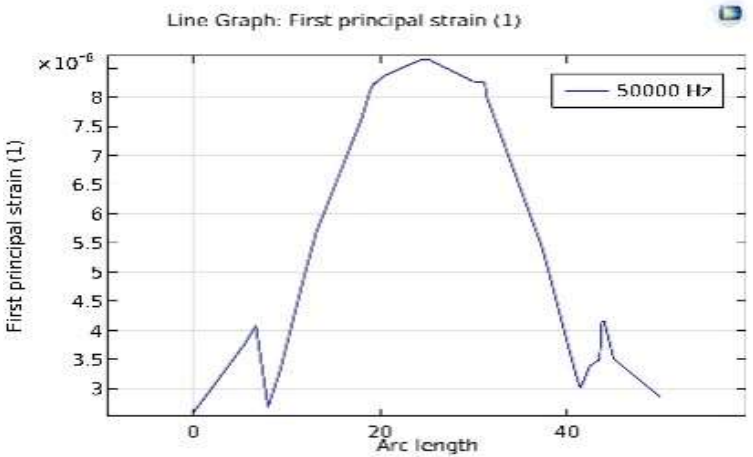
3 Dimensional Axial strain distribution @ 50 kHz modulation

Simulation Results of PZT8 slab Contd....

Axial strain response at different axes @ 50 kHz modulation



Axial strain plot along length axis

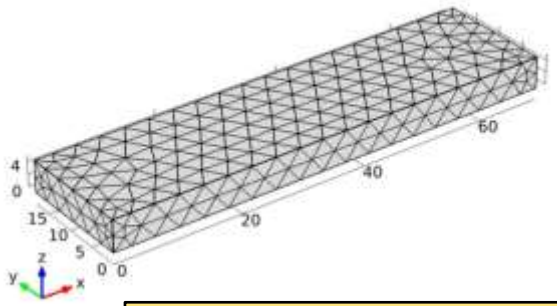


Axial strain plot along breadth axis

Generated multiple resonant states

- **50 kHz region free from resonance**
- **Generated 87 nε at center axis along the length & width of slab**
- **Obtained non-uniform higher strain at resonant state (960 nε @ 53 kHz)**
- **Generated more uniform & symmetric strain at center axis along the width of slab**

2. PZT5H slab

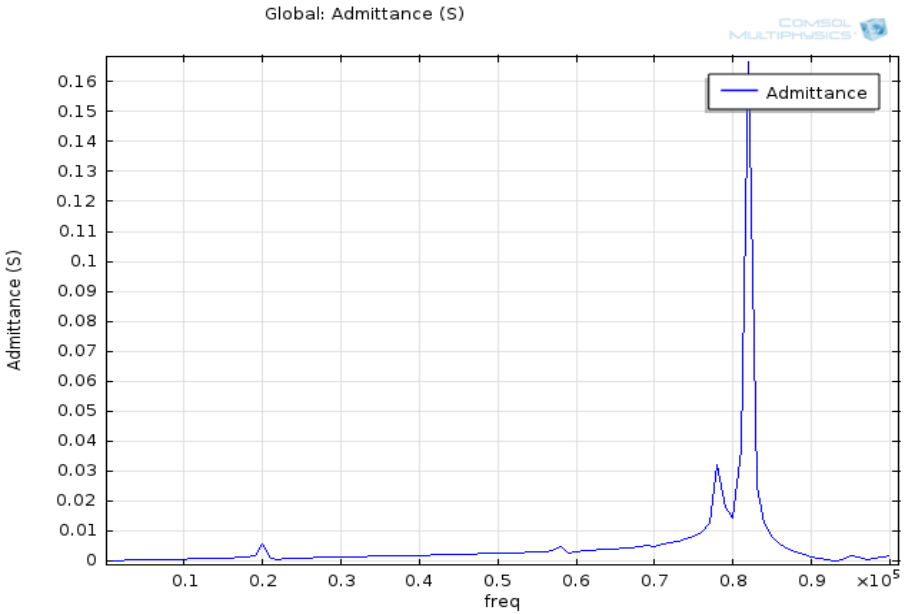


Mesh model of PZT5H slab

Dimensions of PZT5H slab (mm)		
Length	**Breadth**	**Height**
70	18	5

Material properties	Symbols	PZT5H
Relative dielectric constant	K_{33}^{T}	1725
Piezo electric coupling factor	k_p	.6
Charge constant	d_{33}	360
	d_{31}	-300
Strain constant	S_{33}	20.7
Density	ρ	7.6

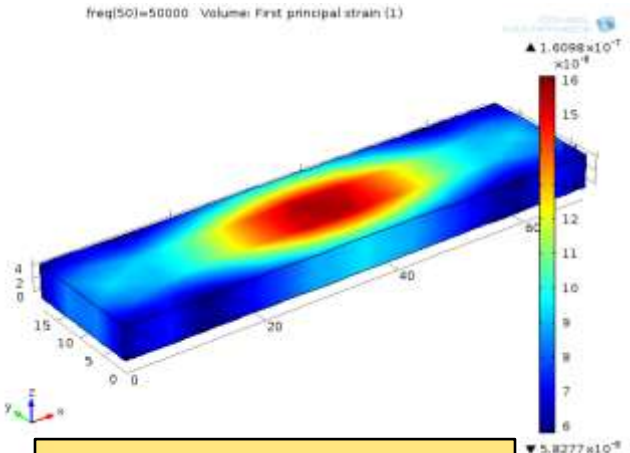
Significant material properties for mechanical strain generation



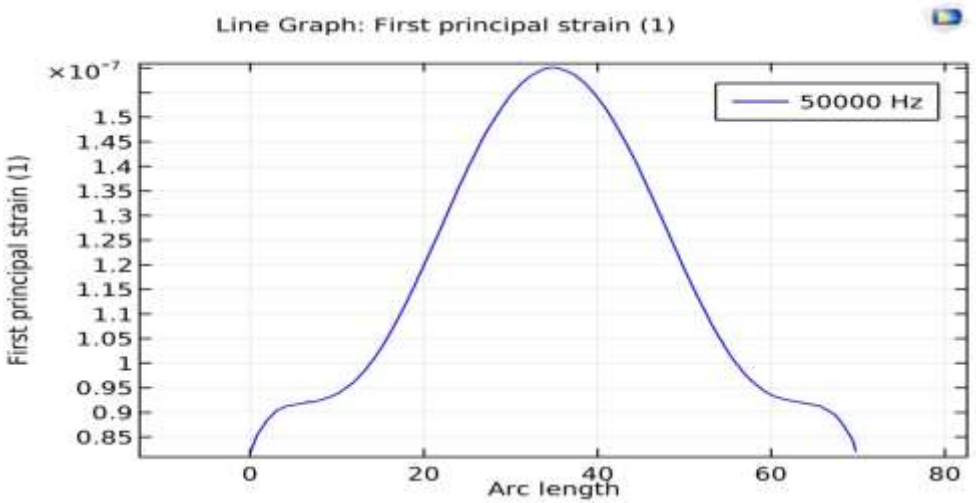
Frequency response of PZT5H slab

Simulation Results of PZT5H slab Contd....

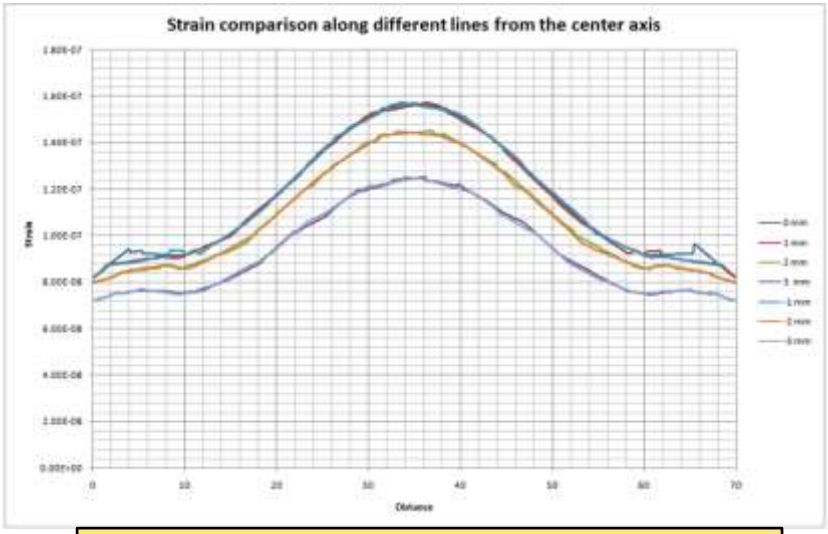
Axial strain response of PZT5H slab @ 50 kHz modulation



Axial strain distribution on slab



Axial strain plot along length axis



Axial strain @ different regions on PZT5H slab

- Reduced the multiple resonant states
- 50 kHz region free from resonance
- Axial strain improvement by changing material composition
- Obtained 156 nε at center axis along slab length
- Generated uniform & symmetric strain at center of slab

Conclusion

- Modeled and simulated PZT slabs for optimum high frequency optical modulation in FLs
- Realized a resonant free state at 50kHz region of PZT slab
- Analyzed the significance of PZT material composition & dimensions in mechanical strain generation with PZT8 & PZT5H
- Generated optical modulation in DFB-FL with PZT8 slab and verified the simulation results.
- Realized uniform & higher axial strain with a lower amplitude modulation signal- in PZT5H slab
- Simulated symmetric & uniform axial strain distribution at the center region of PZT slabs for mounting FLs for modulation

THANK YOU