CSIR-Central Glass and Ceramic Research Institute, Kolkata

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Finite Element Analysis of a Fiber Bragg Grating Accelerometer for Performance Optimization

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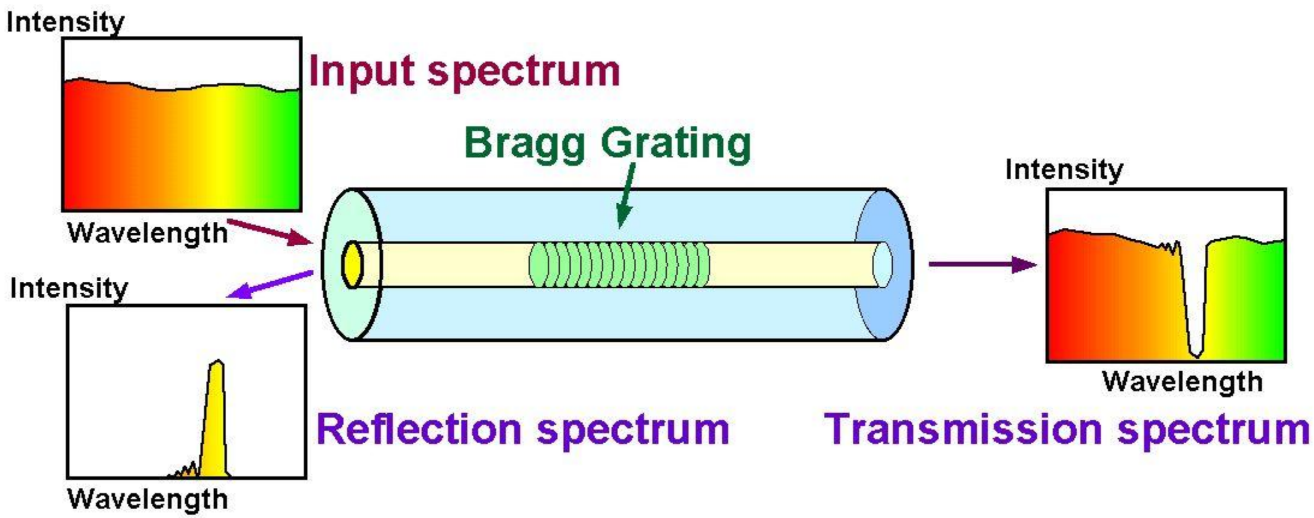
Fiber Bragg Grating (FBG)



$$\lambda_b = 2 n_{eff} \Lambda$$

$$\frac{\Delta\lambda_b}{\lambda_b} = [1 - P_e]\varepsilon_z + \left[(1 - P_e)\alpha + \frac{1}{n}\frac{dn}{dt}\right]\Delta T$$

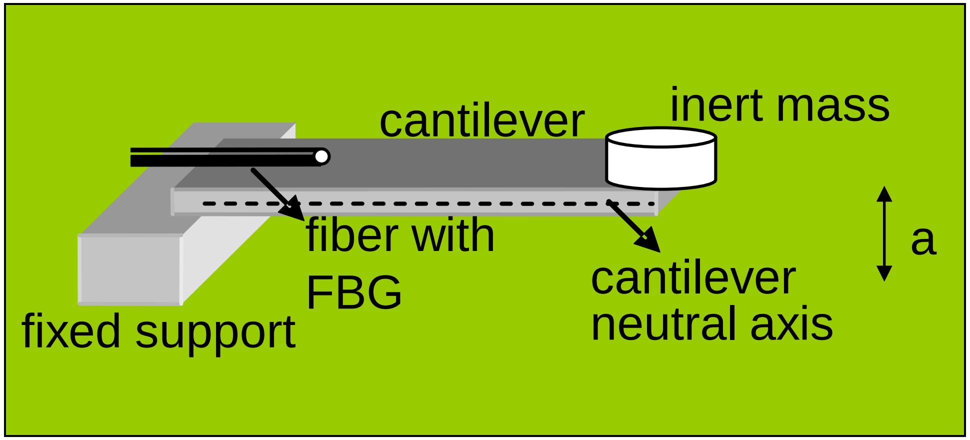
Strain related **Temperature related**

P_e - strain optic coefficient

α - coefficient of thermal expansion

$\frac{dn}{dt}$ - thermo optic coefficient

Cantilever based FBG Accelerometer



Cantilever Dimensions: L x b x d, Radius of fibre: r
Young's Modulus: E, inert mass: M

Resonance frequency

$$\omega_0 = \sqrt{\frac{3EI_g}{ML^3}}, \quad I_g = \frac{bd^3}{12}$$

Strain on the FBG

$$\varepsilon_{FS}(x) = \frac{3(0.5d + r)(L - x)}{(\omega_0^2 - \omega^2)L^3}.a$$

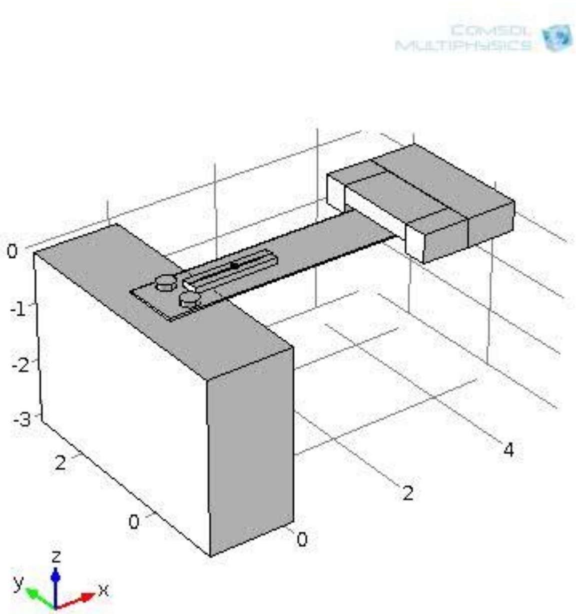
$$= \frac{(0.5d + r)}{0.5d}\varepsilon_s(x)$$

Sensitivity

$$S = \frac{\Delta\lambda}{a} = \frac{1.2 \times \varepsilon_{FS}(x)}{a} \quad pm/g$$

- **Acceleration of the structure induces dynamic strain along the fiber axis**
- **Dynamic strain results in Bragg wavelength shift**
- **Bragg wavelength shift is proportional to acceleration**

Proposed FBG Accelerometer



Strain on directly mounted FBG

$$\varepsilon_{FS}(x) = \frac{(0.5d + r)}{0.5d}\,\varepsilon_s(x)$$

Strain on FBG mounted on patch

$$\varepsilon_{FP}(x) = \frac{(0.5d + r + p)}{0.5d}\,\varepsilon_s(x)$$

Enhancement factor

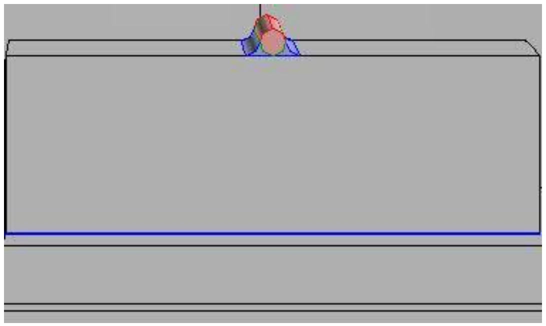
$$IF = \frac{\varepsilon_{FP}(x)}{\varepsilon_{FS}(x)} = \frac{(0.5d + r + p)}{(0.5d + r)}$$

- Sensitivity enhancement by using a backing patch to increase the distance of the FBG from the cantilever neutral axis.

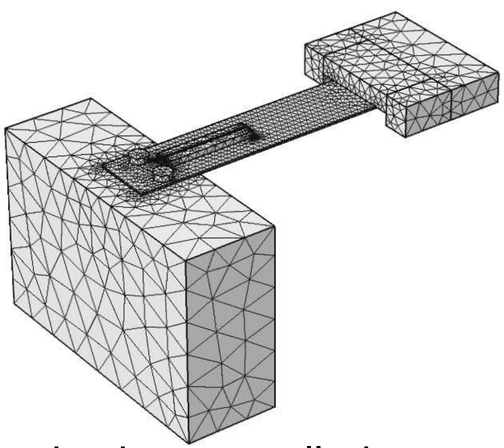
- If the surface strain happens to change due to the modification of the cantilever by adding a patch, it is required to numerically analyze the strain variation.

N. Basumallick, I. Chatterjee, P. Biswas, K. Dasgupta, S. Bandyopadhyay, Fiber Bragg Grating Accelerometer with Enhanced Sensitivity, *Sensors and Actuators A: Physical,* **Volume 173, Issue 1**, page numbers 108-115 (2012)

Model using COMSOL Multiphysics



Zoomed cross-section of the FBG-accelerometer



A physics-controlled normal mesh comprising of 20438 free-tetrahedral elements

Linear Elastic Model, Frequency Domain Study

$$\left.\begin{aligned} &-\rho\omega^2\hat{u}-\nabla.\hat{\sigma}=\hat{F}v, \quad \hat{\sigma}=\hat{s} \\ &\hat{s}-\hat{S}_0=\hat{C}:(\varepsilon-\varepsilon_0-\varepsilon_{inel}) \\ &\varepsilon=\frac{1}{2}[(\nabla\hat{u})^T+\nabla\hat{u}] \end{aligned}\right\}$$

$$\hat{u}=\begin{bmatrix} u \\ v \\ w \end{bmatrix}$$ - displacement in the three directions

$\hat{s}$ - stress tensor,

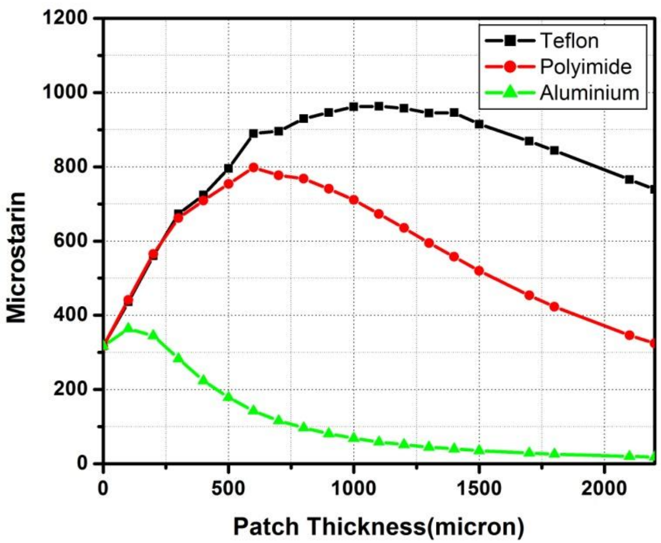
ε - total strain tensor,

$\hat{F}$ - force,

ω - angular frequency

ρ - density

Simulation Results

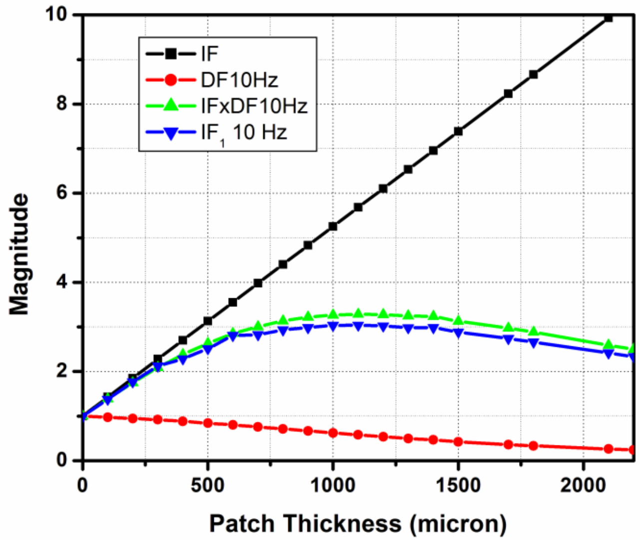


Simulated strain experienced by FBG on teflon, polyimide and aluminum patch for 10Hz excitation frequency and 1g (0-p) amplitude.

Material	Optimum patch thickness (micron)	Maximum Strain at 10 Hz (microstrain)
Teflon	1100	963
Polyimide	600	798
Aluminium	100	364

Strain on directly mounted FBG at 10 Hz = 317 microstrain

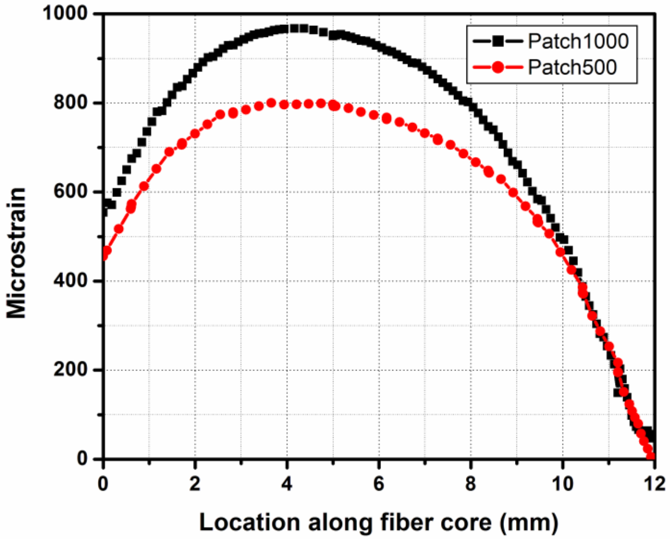
Simulation Results



Simulated plot of enhancement factor without the effect of surface strain IF, decrement factor DF, IF x DF and enhancement factor with the effect of surface strain IF1 at 10Hz for teflon patch.

- The two factors IF and DF contribute to practical IF1 i.e. their product has a maxima at a particular patch thickness and the effective strain on the patch beyond a certain thickness decreases.
- This effect is not predominant up to ~250 micron patch thickness. As a result the plots for IF1 and IF are close to each other up to this thickness and is almost linear.

Simulation Results



Simulated Strain along the fiber core for a teflon patch of 500 micron and 1000 micron for 1g (0-p) excitation amplitude at 10Hz.

- Parabolic strain distribution along the fiber core.
- Strain is almost uniform over a few millimeter.
- Care must be taken to localize the FBG close to the maximum strain location.
- Deviation may cause a decrease in sensitivity.
- A significant chirp may be generated along a long length FBG due to the non-uniform strain distribution along the FBG.
- Use of a small length FBG would alleviate the problem.
- The variation of strain as found in the present case along the FBG is equivalent to a chirp of ~.01nm which is insignificant.

Conclusions

- The influence of patch material (Young's modulus) and patch thicknesses on the strain transfer to the FBG sensor was thoroughly explored using COMSOL Multiphysics.

- In agreement with the numerical analysis, sensitivity ~1062 pm/g has been experimentally achieved with a particular accelerometer configuration with 1000 micron teflon patch. This value is about 3 times as compared to a similar FBG-accelerometer without patch.

Future Scope

- The effect of the patch material and the patch thickness on the resonance frequency and neutral axis position of the FBG accelerometer also requires a thorough investigation and is our future target.

- Further experiments with different patch thicknesses and at different excitation frequencies will be carried out to corroborate the simulation results.

Thank You