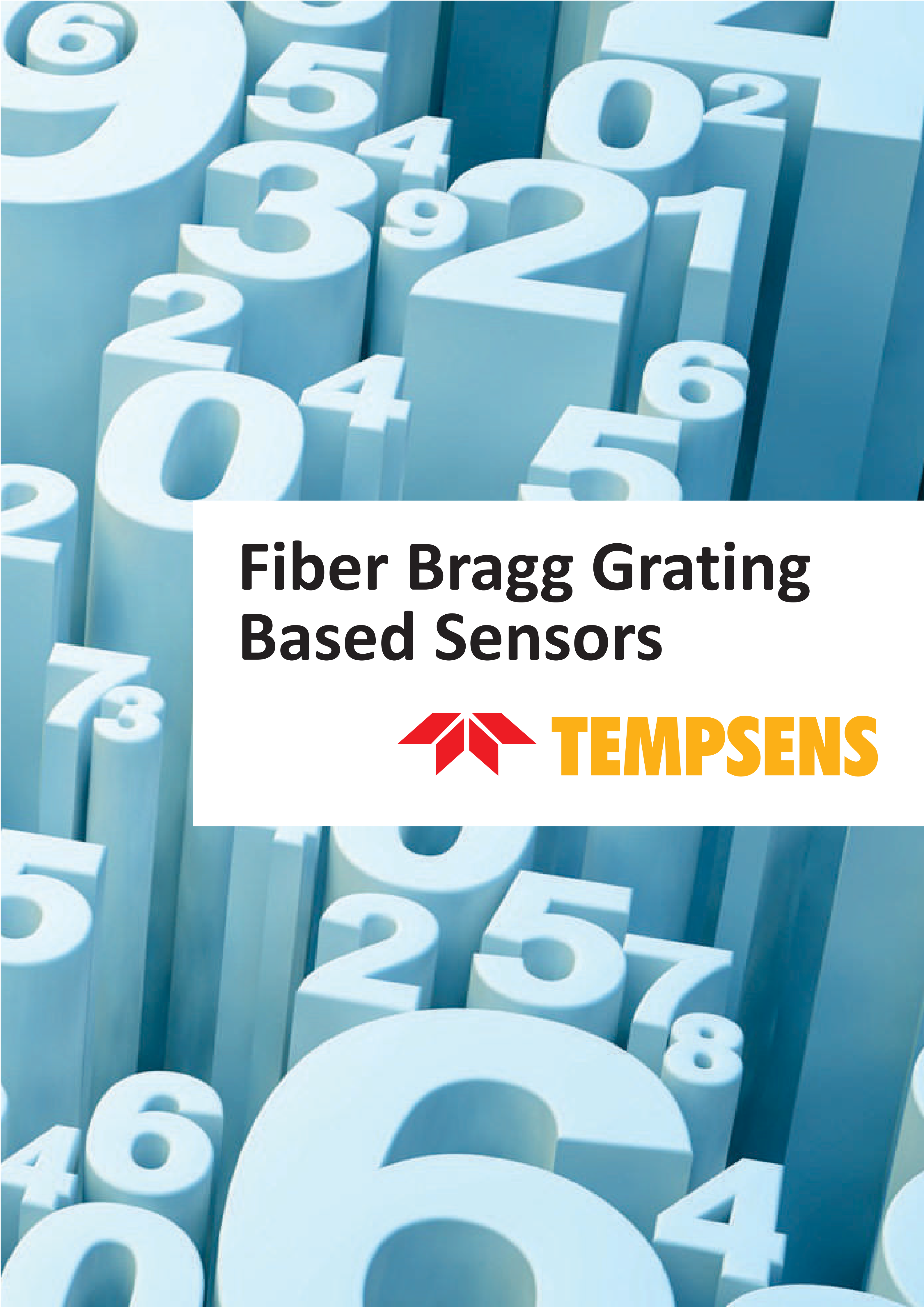

Fiber Bragg Grating Based Sensors

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Fiber Bragg Grating Based Sensors

What is Fiber Bragg Grating Based Sensors?

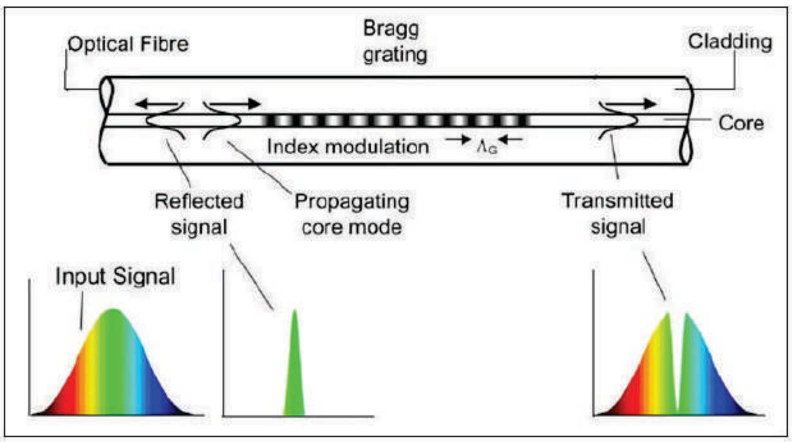
In the electrical and electronics industry, presence of high voltage and high electromagnetic interference can fail a electronic sensor. It is near impossible for conventional sensor to measure under such conditions. A good solution for this problem is the measurement of parameters by optical fiber based FBG sensor. Fiber Bragg grating (FBG) sensor is light- weight, easily installed and has multiplexing capability of sensing various parameters like temperature, strain, load, pressure etc. on different points on the same sensor cable. Conventional sensors need electrical power to operate. Optical fiber sensors are passive and can be laid few hundred kilometers on transmission lines, gas pipelines etc. without need of electric supply.

FBG works as distributed Bragg reflector build on an optical fiber with the help of periodic variation in refractive index of the single mode fiber core. When light is passed through the FBG it will reflect certain wavelength of light and transmits all other. When temperature or strain around Grating changes, shift in reflected wavelength is observed.

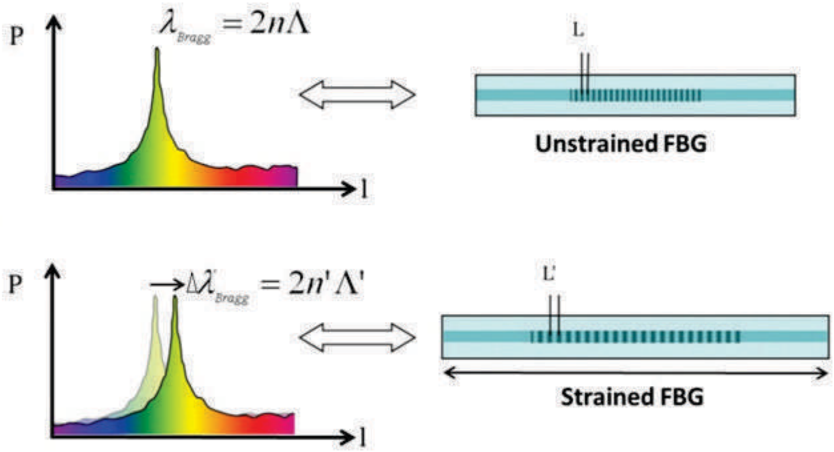
Construction and Working Principle

An FBG is an optical sensor made by laterally exposing a core of single mode fiber to periodic pattern of intense UV laser light. The exposure forms a permanent increase in the refractive index (η) of fiber's core creating fixed index modulation known as grating (Λ). The grating inside core of fiber optic shall reflect particular wavelength of input light, known as Bragg wavelength λ_{Bragg} correlating to grating period and transmits all other as shown in figure below. The Bragg wavelength is given by equation,

$$\lambda_{Bragg} = 2\,\eta\,\Lambda \qquad (1)$$



When period of grating expands or shrinks due to change in temperature/strain, change in reflected wavelength is measured as shown in below figure.



Design of FBG sensor system

FBG sensor system configuration for Load/Temperature/Strain Sensing

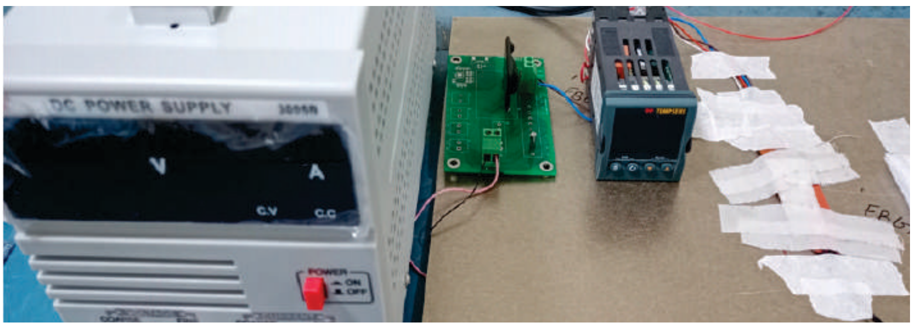
A shift in the reflected Bragg wavelength is detected with the help of interrogation unit as shown in above figure when change in physical properties occurs and is given by equation.

$$\Delta\lambda_{Bragg} = [(1 - p_e).\varepsilon + (\alpha + \zeta).\Delta T]\,\lambda_{Bragg}$$

where pe is the strain-optic coefficient, Ɛ is strain induced, α is thermal expansion coefficient, ζ is thermo-optic coefficient and ΔT is change in temperature. Above equation states that Bragg shift is a function of both temperature and strain. For silica fiber, value of pe = 0.22 and other coefficients are known.

FBG application in Temperature measurement

FBGs are widely used in temperature applications for gas pipelines, oil-gas exploration, research and development etc. From equation 2, it can be said that Bragg wavelength shift is a function of both temperature and strain. In order to measure temperature only, FBG sensor are embedded inside protective case with both ends loose to neglect the effect of strain. FBG embedment is done to protect it from external environment in temperature measurement.



Experimental set-up of temperature measurement with FBG

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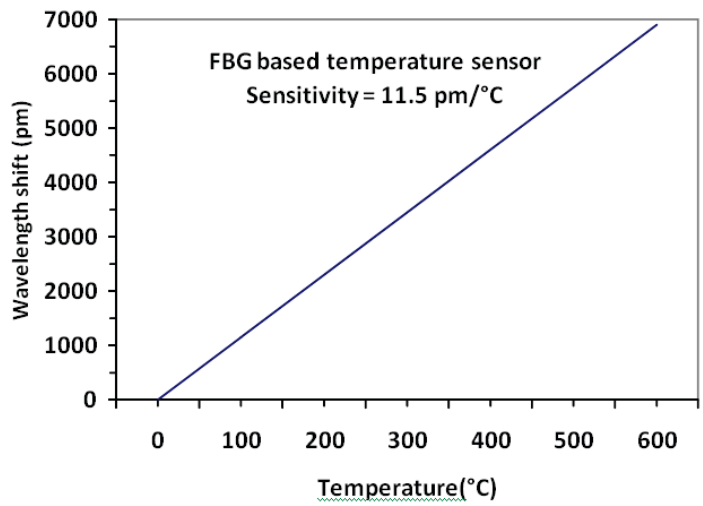
A single point bare FBG was operated at a temperature range of 600 °C on an experimental test setup. FBG remained in contact with heater and RTD as reference sensor for monitoring and regulating heat to FBG. 12 V DC supply was used. The basic of FBG temperature sensing is detecting peak shift of Bragg wavelength corresponding to that temperature.

The shift in peak of Bragg wavelength is given by equation below,

$$\Delta\lambda_{Bragg} = 2\left(\Lambda \frac{\partial \eta_{eff}}{\partial T} + \eta_{eff} \frac{\partial \Lambda}{\partial T}\right) \times \Delta T \quad \text{or} \quad \Delta\lambda_{Bragg} = \lambda_{Bragg}(\alpha + \xi) \times \Delta T \qquad (3)$$

For fused silica, $\alpha = \frac{1}{\eta_{eff}} \frac{\partial \eta_{eff}}{\partial T} = 8.8 \times 10^{-6}$ and $\xi = \frac{1}{\Lambda} \frac{\partial \Lambda}{\partial T} = 0.55 \times 10^{-6}$

$$\text{Sensitivity of Bragg wavelength with temperature} = \frac{\Delta\lambda}{\Delta T} \qquad (4)$$



The temperature sensitivity of FBG sensor comes about 11.5 pm/°C.

FBG application in strain measurement

Strain is a measure of change in length by original length L of sensor on applying stress. Over an applied stress on the fiber corresponding strain will be ΔL/L. Temperature compensation is required due to the fact that temperature affects the physical dimensions due to thermal expansion. Using FBG sensor, measurement of strain alone requires elimination of the effect of temperature on determining wavelength shift. This can be done by installing a FBG temperature sensor along it to compensate local temperature effect on FBG. Hence we have subtracted eq. (3) from eq. (2) to get eq. (5) below to measure strain.

The wavelength shift corresponding to applied strain is given by equation,

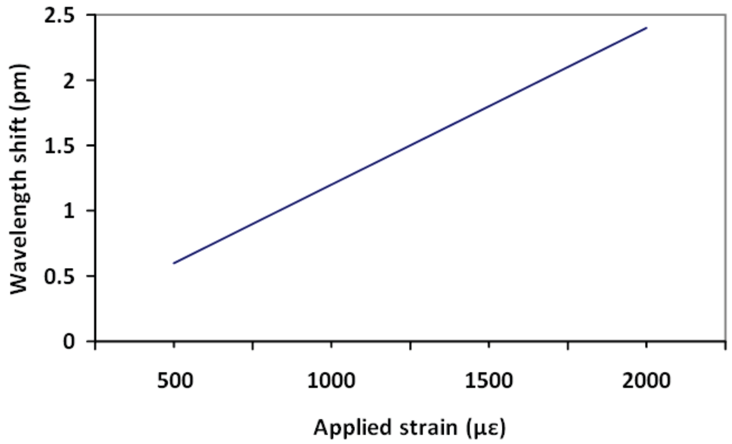
$$\Delta\lambda_{Bragg} = 2\left(\Lambda \frac{\partial \eta_{eff}}{\partial L} + \eta_{eff} \frac{\partial \Lambda}{\partial L}\right) \times \Delta L \quad \text{or} \quad \Delta\lambda_{Bragg} = \lambda_{Bragg}(1 - p_e) \times \varepsilon_z \qquad (5)$$

where ε is the applied axial strain and p_e is the effective strain-optic constant which is given by,

$$p_e = \frac{\eta^2_{eff}}{2}\left[p_{12} - v(p_{11} + p_{12})\right] \qquad (6)$$

where p11 and p12 are components of strain-optic tensor and v is Poisson's ratio. For a germanosilicate optical fiber p11 = 0.113, p12 = 0.252, v = 0.16 and ηeff = 1.482. This gives a value of 0.22 for pe.

$$\text{Sensitivity of Bragg wavelength with strain} = \frac{\Delta\lambda}{\Delta\varepsilon} \quad (7)$$

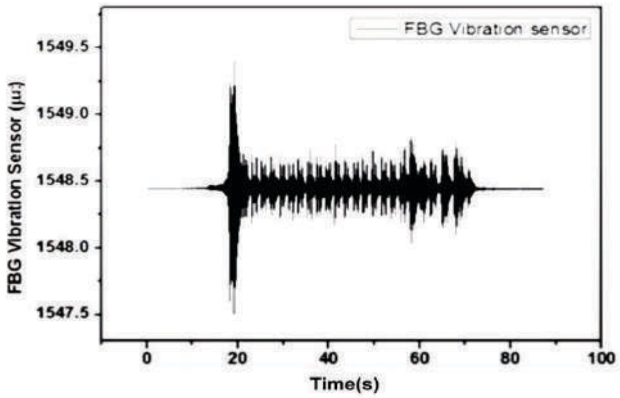


The strain sensitivity of the FBG sensor comes out about 1.02 pm / με.

Other Applications of FBG sensors

1. FBG sensors can be used as optical accelerometers in the vibration measurement of structures, heavy machineries, bridges and railway infrastructure.

   In the figure below vibrating pattern of an FBG occurring due to dynamic strain on the cantilever beam are shown,



2. Multiple parameters can be measured at same time such as temperature, load, strain, pressure, vibration, tilt etc.

3. Single and multi-point sensing applications where user defined location's parameters are to be measured.

4. It has high sensitivity and long-term reliability than conventional sensors. For applications requiring high sensitivity, FBG is a good solution.