# MULTIPLEXED STRAIN MONITORING OF COMPOSITE STRUCTURES USING FIBER BRAGG GRATING SENSORS

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## ABSTRACT

In this paper, we present an improved FBG sensor system using a wavelength swept fiber laser(WSFL) for internal strain monitoring of composite laminates. The WSFL provides unique and functional output characteristics useful for sensor interrogation. In addition a real-time signal processing program was made to measure strains. Five FBG sensors in an optical fiber were used to measure internal strain of the laminated composite under 4 point bending. Experiments showed that the constructed FBG sensor system and the real-time signal processing program could successfully measure the internal strain of composite laminates.

**KEY WORDS** : Fiber Bragg grating sensor system, Strain measurement, Wavelength division multiplexing

## INTRODUCTION

In recent years, a lot of attention has been paid to the smart materials and structures. Optical fiber sensors are one of the promising sensor technologies for applications in smart materials and structures. They can be easily embedded into laminated composites and are not affected by the electro-magnetic field. Also, they have flexibility of the sensor size($\mu m \sim km$) and very highly sensitive. These advantages of a FOS make it to be the potential solution for sensor systems of smart structures[1].

FBG sensor, one of FOS's, based on the wavelength division multiplexing(WDM) technology attracts considerable research interest and appear to be ideally suitable for structural health monitoring of composite materials and infrastructures. FBG sensor is easy to be multiplexed and has many advantages of linear response, absolute measurement, simplicity in fabrication, compactness, etc.

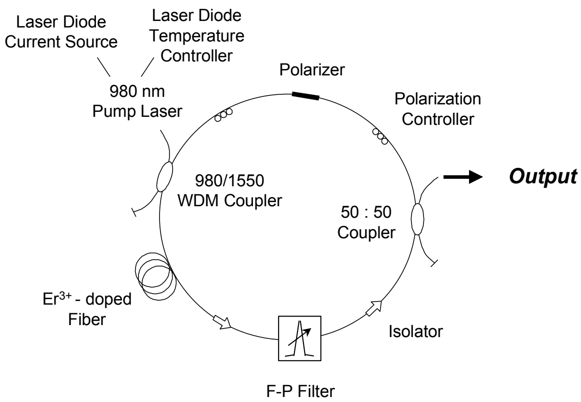
Various interrogation schemes have been reported for the detection of small Bragg wavelength shifts[2, 3]. However, these schemes have shown some drawbacks associated with low signal powers by using a narrow spectral slice from a broad source spectrum. Moreover, these results showed poor spectral resolution determined by the resolution of the tunable filter or the spectrometer itself. Recently, the interrogation technique based on the WSFL was developed[4]. This technique offers several attractive features. First, it provides for high signal powers, since the full source output is available during the measurement of a given grating's Bragg wavelength. Second, the broad source tuning range and narrow instantaneous spectral line width allow for a large number of individual elements within the array.

In this study, we constructed an FBG sensor system using a WSFL and the signal processing program for real-time strain measurement. Experiments of the composite laminates under 4-point bending were carried out to measure effectively strain real-timely by the FBG sensor array.

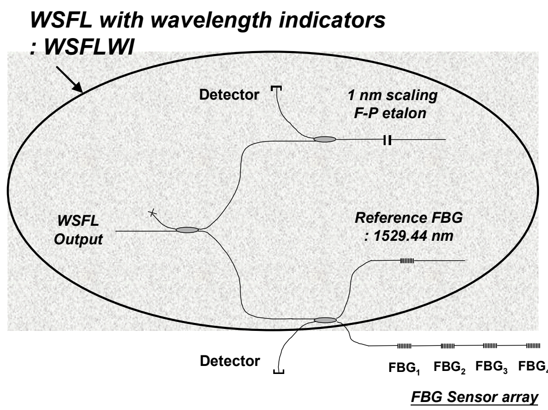
## A FIBER BRAGG GRATING SENSOR SYSTEM

A fiber Bragg grating is a periodic, refractive index perturbation that is formed in the core of an optical fiber by exposure to an intense UV interference pattern. When temperature changes or mechanical strains are applied to the FBG sensor, Bragg wavelength is changed. The accurate detection of Bragg wavelength shift is important to strain measurement. For the purpose, the WSFL is constructed and employed to the present FBG sensor system. The WSFL has a scannig tunable filter in the cavity to sweep the laser output wavelength in time continuously and repeatedly over a range of a few tens of nanometers. By measuring the reflected pulse timing characteristics and employing simple signal processing schemes based, for example, on time interval counting[4] or peak detection as in this study, one can deduce the instantaneous Bragg wavelength of the individual gratings within the array.

Fig. 1(a) shows a schematic of the configuration of the WSFL and (b) the grating array with a reference FBG and a Fabry-Perot(F-P) etalon. The WSFL was in a unidirectional ring configuration with isolators, a 3-*dB* output coupler, and an $Er^{3+}$ - doped fiber pumped by a laser diode at 980 *nm*. A F-P tunable filter was used as the intracavity scanning filter and had a 3 *dB* bandwidth of 0.27 *nm* and a free spectral range of 58 *nm*. We modulate the F-P filter with a triangular waveform to produce a wavelength sweep over 40 *nm* from 1525 to 1565 *nm* at a 130 *Hz* repetition rate. The laser output was directed into an array of sensing gratings and a reference grating($\lambda_0$ =1529.4 *nm*) for temperature compensation and a F-P etalon used for a grid line that has a same spacing of 1 *nm* via a 50 % coupler.




(a)




(b)

Fig. 1 : Configuration of (a) the wavelength-swept fiber laser and (b) the grating sensor array.

### THE STRAIN MEASUREMENTS OF LAMINATED COMPOSITE

The experiments of internal strain measurement of laminated composite beam under 4 - point bending were carried out using a FBG sensor system. The composite beam was fabricated using graphite/epoxy prepreg, and its material properties are $E_1$ = 130 *GPa*, $E_2$ = $E_3$

= 10 $GPa$, $G_{12} = G_{13}$= 4.85 $GPa$, $G_{23}$ = 3.62 $GPa$, $\nu_{12} = \nu_{13}$ = 0.31, $\nu_{23}$ = 0.52, $X_T$ = 1933 $MPa$, $X_C$ = 1051 $MPa$, $Y_T$ = 51 $MPa$, $Y_C$ = 141 $MPa$ and $S$ = 61 $MPa$. The geometry and dimensions of the composite beam and a schematic of 4-point bending test are shown in Fig. 2. Load was displacement-controlled, 6 *mm/min*. Five FBG sensors were embedded in the composite beam. The Bragg wavelengths are FBG1 = 1544.68 *nm*, FBG2 = 1552.43 *nm*, FBG3 = 1547.92 *nm*, FBG4 = 1554.87 *nm* and FBG5 = 1533.88 *nm*. In order to measure surface strains of the beam, electrical strain gages(ESG), ESG1 and ESG2 were bonded to lower and upper surface of the beam.

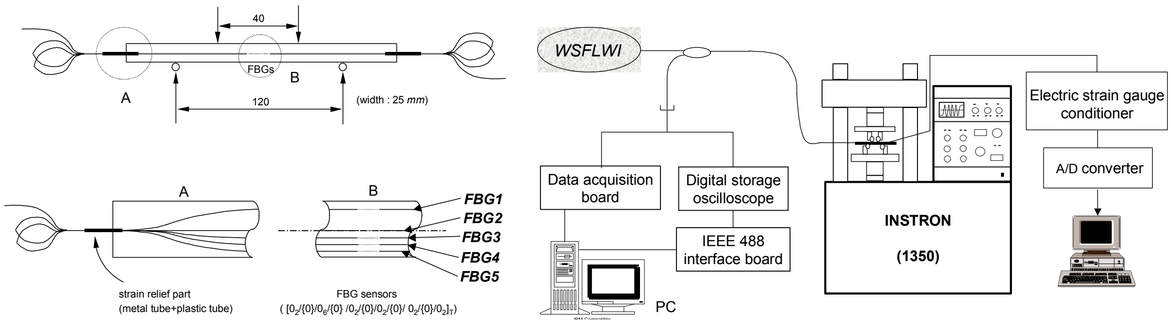



Fig. 2 : Configuration of the specimen and a schematic of 4-point bending test.

Fig. 3 shows Bragg wavelength shift of FBG sensors and real-time strain measurement window. Since FBG sensors(FBG3, 4, 5) embedded below neutral axis in laminated composite beam undergo tension strain, wavelength of the FBG sensors move to long wavelength region. The strain from FBG2 embedded in neutral axis of the beam was almost 0 assumed by a classical lamination theory(CLT). By processing the wavelength shift data to graphical strain, internal strain state of laminated composite beam could be monitored real-timely. The comparison of strains measured by ESGs and FBG sensors with a CLT under the loading state of 326 *kgf* is shown in Fig. 4. Under pure bending, strain distribution through the thickness can be assumed as a linear distribution when the thickness is thin and deformation is small. A linear distribution of internal strain is well represented in Fig. 4. Since FBG sensors could move from the initial embedding location because of resin-flow, pressure and vacuum during the curing process, a little error occurred. Accordingly, when we measure the internal strain of composites using a fiber optic sensor, especially under the out-of-plane load, the movement of the embedded fiber optic sensor induced by the curing of composites should be considered.

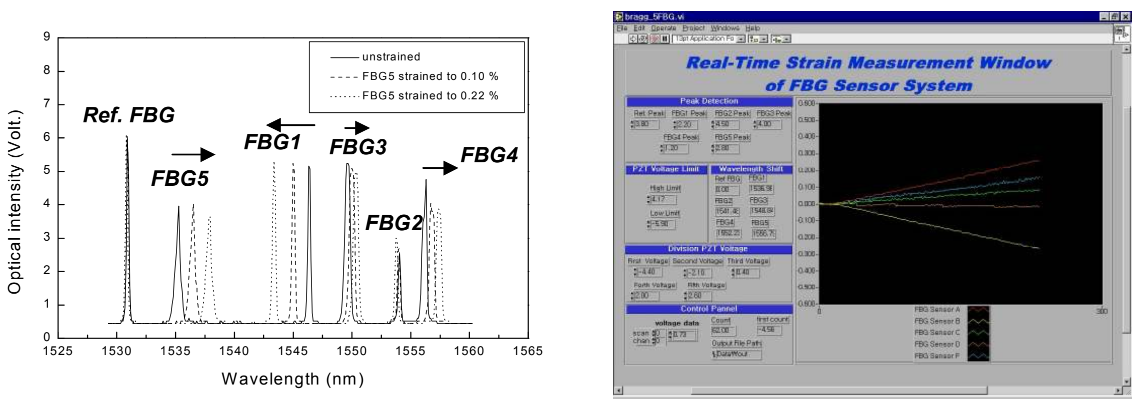


Fig. 3 : Bragg wavelength shift of FBG sensors and real-time strain measurement window.

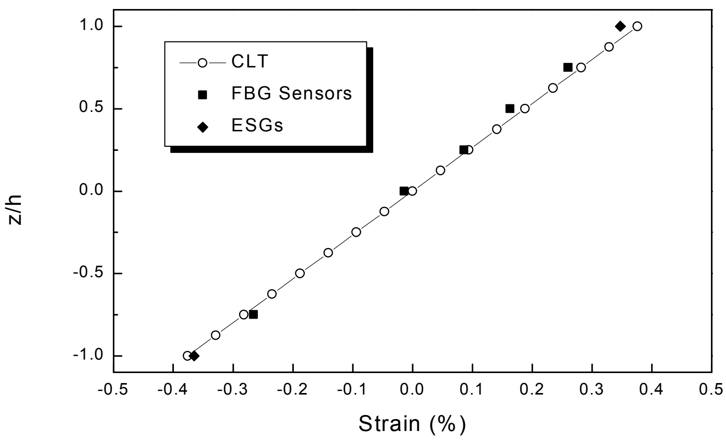



Fig. 4 : The comparison of strains measured by ESGs and FBG sensors with classical lamination theory under the loading state of 326 *kgf*.

## CONCLUSIONS

We constructed an improved FBG sensor system by using a WSFL. Five FBG sensors in an optical fiber were used to measure internal strains of the laminated composite beam under 4-point bending with multiplexing technique. Experiments showed that the constructed FBG sensor system and the real-time signal processing program could successfully measure the internal strain of composite laminates.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