LOMSS

Integrated Measurement Technique for Curing Process-dependent Mechanical Properties of Polymeric Materials Using Fiber Bragg Grating

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Problem Definition

- One of the most critical reasons to make modeling predictions *uncertain* is the non-linear and time-dependent mechanical behavior of the materials used in electronic packaging, especially ***polymeric materials*** *for adhesive* and underfill.
- ***More and more polymeric materials*** are introduced everyday, but ***less and less time to evaluate them***; very limited material property data are available for new polymeric materials.

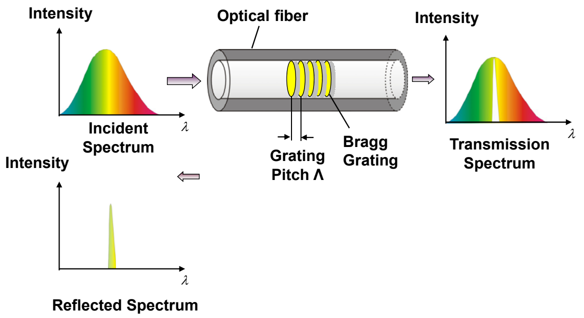
Research and Development Goals

To develop an integrated measurement technique using a Fiber Bragg grating sensor to measure the ***processing and curing conditions*** dependent polymer properties ***rapidly but accurately***.

- ***Chemical shrinkage***
- ***Glass transition temperature***
- ***Temperature-dependent coefficients of thermal expansion***
- ***Temperature and time-dependent elastic modulus (visco-elastic constitutive behavior)***

Background: Fiber Bragg Grating

- Fiber Bragg grating (FBG) is a periodic perturbation of the refractive index along the fiber length.
- A narrow band of the incident optical field within the fiber is reflected by successive coherent scattering from the index-varying bands.



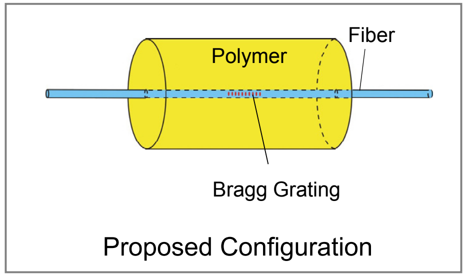
The very narrow reflected spectrum is centered on the wavelength of Bragg resonance called *Bragg wavelength,*

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

Basic Concept of Proposed Method and Experimental Setup

- A polymer of interest is cured around a glass FBG and the *BW* shift will be documented while:

(1) Polymerization progresses at the curing temperature,
(2) The temperature of the cured polymer changes.



Proposed Configuration

- Bragg wavelength (*BW*) shift

$$\Delta\lambda_B = \Delta\lambda_B^i + \Delta\lambda_B^d$$

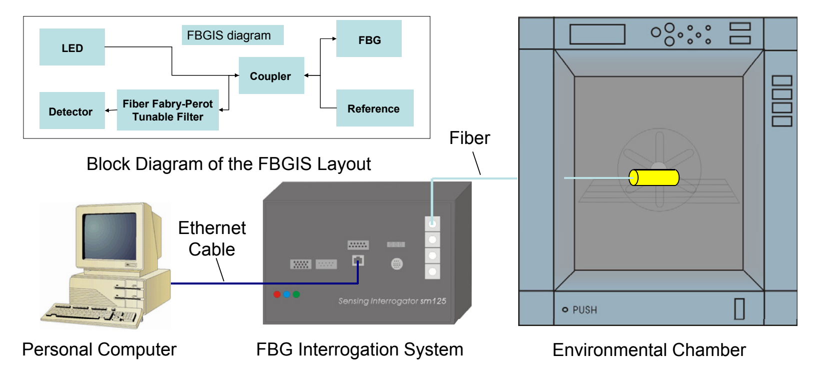
"*Intrinsic*" *BW* shift:

$$\Delta\lambda_B^i = \lambda_B\left(\alpha_f + \frac{1}{n_{eff}}\frac{dn}{dT}\right)\Delta T$$

"*Deformation*" induced *BW* shift:

$$\Delta\lambda_B^d = \lambda_B(1-P_k)\varepsilon_f^\sigma$$

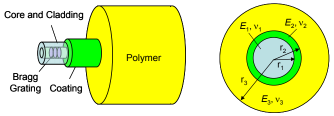
Basic Concept of Proposed Method and Experimental Setup



Experimental Setup

Specimen Configurations

- **Configuration I :** $r_3 > 200\ r_1$

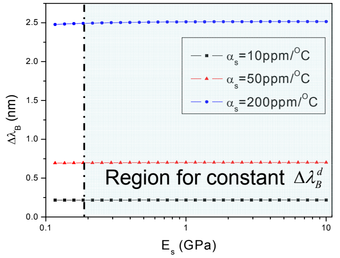


For $r_3 \approx \infty$,

$$\varepsilon_z = \varepsilon_f^\sigma = \alpha_s T_s - \alpha_f T_f$$

$$\Delta\lambda_B^d = \lambda_B(1-P_k)\varepsilon_f^\sigma$$

$E_s = 0.18\ Gpa$



For chemical shrinkage,

$$T(r) = \begin{cases} 0 \ , & 0 \le r < r_1 \\ 0 \ , & r_1 \le r < r_2 \\ T_s \ , & r_2 < r \le r_3 \end{cases} \implies \varepsilon_f^\sigma = \alpha_s T_s$$

$$\varepsilon^{ch} = \varepsilon_f^\sigma = \frac{\Delta\lambda_B^d}{\lambda_B(1-P_k)}$$

For CTE,

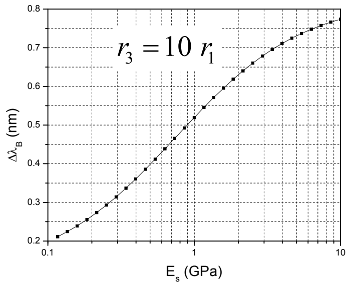
$$T(r) = \Delta T,\ 0 \le r < r_3$$

$$\implies \varepsilon_f^\sigma = \left(\alpha_s - \alpha_f\right)\Delta T$$

$$\alpha_s = \frac{\varepsilon_f^\sigma}{\Delta T} + \alpha_f = \frac{\Delta\lambda_B^d}{\lambda_B(1-P_k)\Delta T} + \alpha_f$$

Specimen Configurations

- **Configuration II :** $r_3 = 10 \text{ to } 20\ r_1$



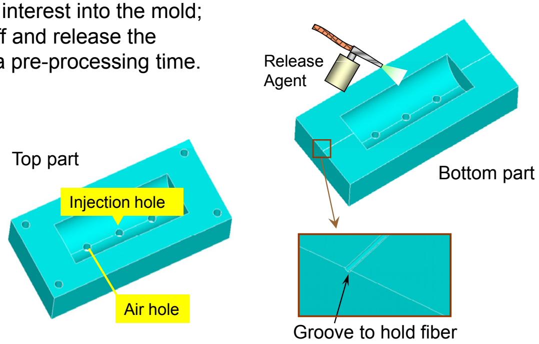
$$\Delta\lambda_B^d = \lambda_B(1-P_k)\varepsilon_f^\sigma \qquad \varepsilon_f^\sigma = \frac{1}{E_f}\left(\sigma_z - \nu\sigma_r - \nu\sigma_\theta\right)$$

$\Delta\lambda_B^d$ is extremely sensitive to E_s. And the unknown E_s can be determined from $\Delta\lambda_B^d$ by solving the analytical solution numerically.

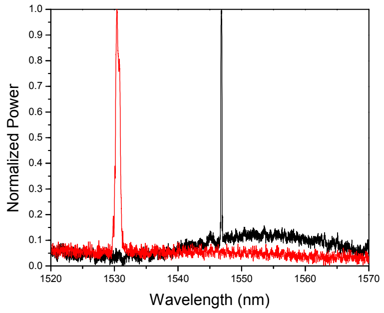
Implementation of the Proposed Method and Experimental Results

Specimen Preparation Procedure

1. Apply a release agent;
2. Place a FBG along the groove of the bottom part;
3. Assemble the mold;
4. Inject a polymer of interest into the mold;
5. Pry the top mold off and release the bottom mold after a pre-processing time.



Measurement of Chemical Shrinkage



- Configuration I (b = 200a)

$$\varepsilon^{ch} = \frac{\Delta\lambda_B}{\lambda_B(1-P_k)}$$

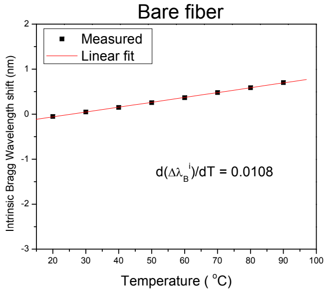
$$= \frac{1546.829 \text{ - } 1530.440}{1546.829*(1\text{-}0.1831)} = 1.30\%$$

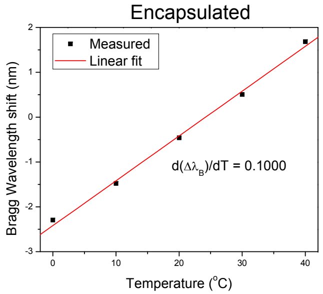
The *effective chemical shrinkage* is smaller than typical total chemical shrinkage values reported in the literature (2% to 10%).

Measurement of CTE

- Configuration I (b = 200a)

Material: West System epoxy resin 105 and hardener 205



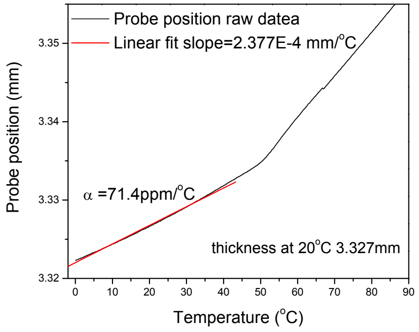


CTE (before T_g) by the proposed method:

$$\alpha_s = \frac{\Delta\lambda_B^d}{\lambda_B(1-P_k)\Delta T} + \alpha_f = \frac{0.1000-0.0108}{1546.829\cdot(1-0.18)} + 0.55\cdot10^{-6} = 70.9\cdot10^{-6}\ /^o\ C$$

Measurement of CTE

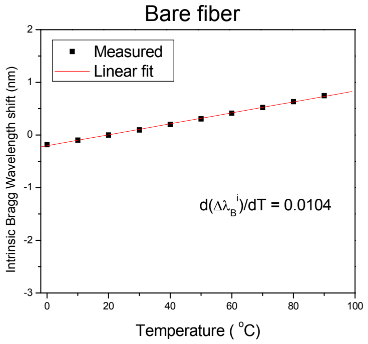
- CTE by TMA:

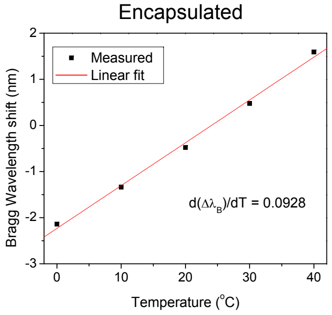


The values are matching very well within the typical measurement uncertainty of TMA.

Measurement of Young's Modulus

- Configuration II (b = 20a)





By solving non-linear equation, the modulus is determined to be:

$$E_s = 2.5GPa$$