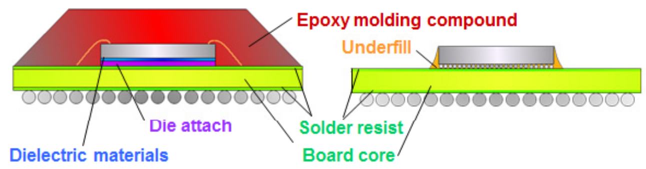
LOMSS

Simultaneous Measurements of Evolution of Effective Chemical Shrinkage and Modulus during Polymerization

Motivation

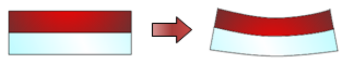
- Polymers have been used extensively in semiconductor packaging.



Availability of polymeric materials ↑ Product development cycle time ↓

- The curing properties of polymeric materials are critically required for reliability assessment and design optimization of new packaging products using predictive modeling

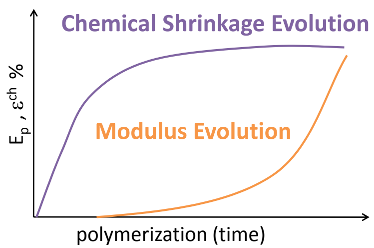
Polymer choice greatly affects the reliability of the package



- In order to accurately predict the behavior of a package containing polymers, the evolution of the curing properties should be known

Goal and Approach

- To develop and implement an integrated method using fiber Bragg gratings embedded in a polymer substrate
  - *To simultaneously measure the evolution of the effective chemical shrinkage and Young's Modulus of polymers during the polymerization process*

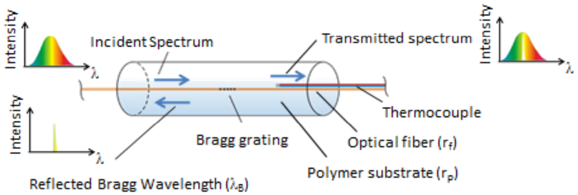


Goal and Approach

- No practical techniques can measure…
  - Both properties simultaneously *(correlation of results between different experiments can be difficult)*
  - Young's Modulus during curing *(only the shear modulus can be found)*
  - Effective chemical shrinkage *(only the total chemical shrinkage can be found)*
- Implementation of this novel technique would allow for the **rapid characterization of new polymeric materials** to help in **predictive modeling** and **design optimization**

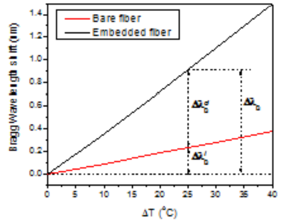
Proposed Method & Implementation

- Fiber Bragg Grating (FBG) embedded in annular polymer substrate



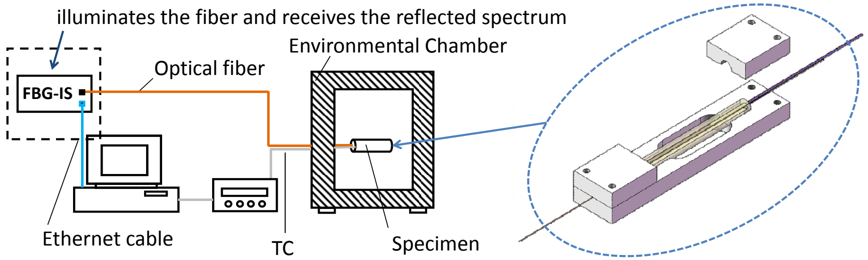
$$\lambda_B = 2 n_{eff} \Lambda \;\Rightarrow\; \frac{\Delta\lambda_B}{\lambda_B} = \frac{\Delta\Lambda}{\Lambda} + \frac{\Delta n_{eff}}{n_{eff}} = f(\varepsilon, P_{ij}, \Delta T)$$

- The **"deformation" induced Bragg wavelength (BW) shift** ($\Delta\lambda^d_B$) results from the polymer substrate and can be used to **inversely calculate the material properties** (E_p, $\Delta\varepsilon^{ch}$) based on the related analytical relationship



Proposed Method & Implementation

- Specimen sizes chosen to **maximize measurement sensitivity** and to **minimize heat generation effects** during curing
- Mold of silicon rubber tubing and Teflon used to negate any constraints to polymer while curing, align FBG and thermocouple



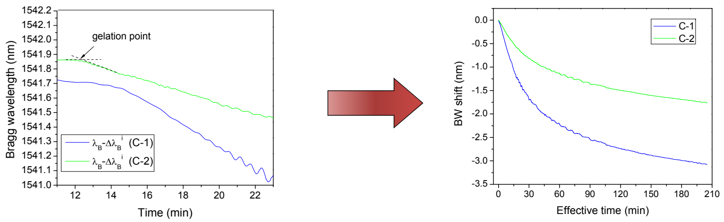
Experiment Results

- FBG cured around an underfill material in two different configurations

C-2: $r_p = 19\ r_f$

C-1: $r_p = 38\ r_f$

- Throughout curing, at the **gelation point** the BW begins to decrease from deformation induced stresses



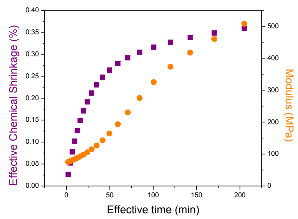
Experiment Results

- BW shifts of **C-1** and **C-2** after the **gelation point** used to calculate the evolution of the **modulus** and **effective chemical shrinkage** throughout the curing process

$$\begin{cases} \Delta\lambda_{B1,j} = F\left(E_{pj}, r_{p1}\right)\cdot\Delta\varepsilon_{pj}^{ch} \\ \Delta\lambda_{B2,j} = F\left(E_{pj}, r_{p2}\right)\cdot\Delta\varepsilon_{pj}^{ch} \end{cases} \rightarrow E_{pj}\ \&\ \Delta\varepsilon_{pj}^{ch}$$

$$E_p(t_j) = E_{pj} \qquad \varepsilon_p(t_j) = \sum_{i=1}^{j}\Delta\varepsilon_{pj}^{ch}$$

$\rightarrow$ $E_p(t)$ & $\Delta\varepsilon^{ch}(t)$



Validity of Method

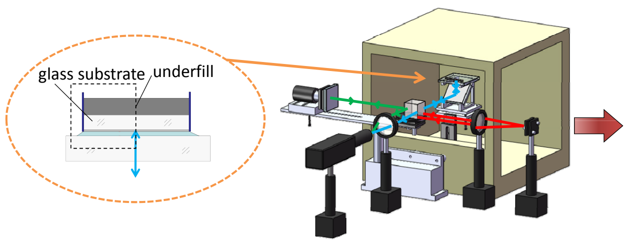
- The evolutions of the effective chemical shrinkage and Young's Modulus were used to predict the **time dependent warpage** of a bi-material strip during the curing process

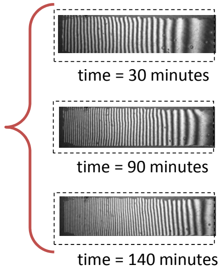
$E_p(t)$ & $\Delta\varepsilon^{ch}(t)$ → **Warpage w(t) during curing** →

$$w(t)=\int f\left(t_p,t_g,E_g,E_p(t),\frac{d\varepsilon^{ch}(t)}{dt}\right)dt$$

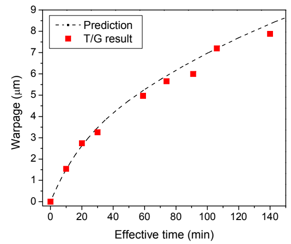
Validity of Method

- The prediction was verified using **Twyman-Green Interferometry**





Twyman-Green warpage data agrees well with prediction calculated from evolutions



Warpage can be directly calculated from the interference pattern

$$w=\frac{N}{2n}\lambda$$

Conclusion

- A FBG-based technique was proposed and successfully implemented to ***simultaneously*** measure the ***evolution of the effective chemical shrinkage and modulus*** of an underfill material during the curing process
- The proposed technique was validated via an independent experiment using a bi-material strip.
- The chemical shrinkage and modulus evolutions can be used *to* ***predict the behavior of package assemblies*** to ***further optimize the manufacturing process***