Center for Optical Technologies

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Evaluation of Encapsulation Materials for Flexible Displays

Dept. of Material Sci. & Eng./Electrical and Computer Eng.

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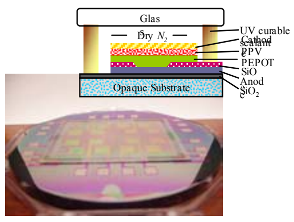
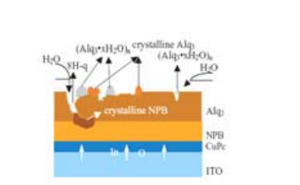
Motivation

- Flexible displays are quite promising
- moisture and oxygen reduce lifetime of OLEDs
  - Encapsulated in an inert environment
  - Searching and evaluating performance of sealant



Structure of an encapsulated PLED device

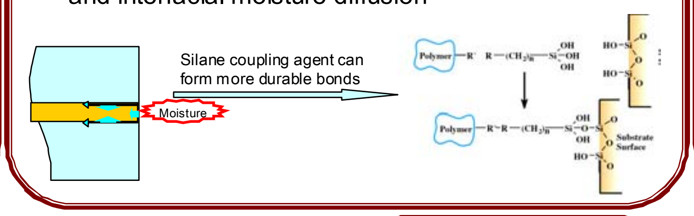


Exposure to Moisture degrades Luminescent layer

Xu, M. S. et al., J. Phys. D: Appl. Phys. 37, 2618, 2004

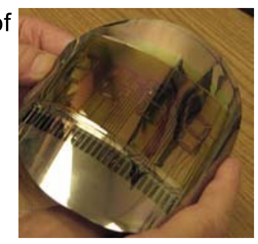
Background

- UV curable epoxy is a good candidate as a sealant for OLED/PLED
  - Shorter production times
  - Lower costs
  - Shorter startup time
  - Equipment space savings
  - Good glove box compatibility
- Epoxies are susceptible to bulk and interfacial moisture diffusion



Objectives

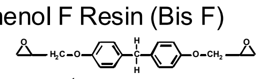
- Evaluate performance of various sealants
  - Commercial sealants
  - Model Epoxy systems
- Improve adhesion and moisture resistance of sealants
- Search for sealants and coatings for suitable flexible display encapsulation



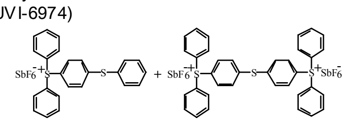
Lehigh Prototype PLED flexible steel substrate

Materials

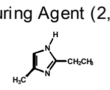
- Glass
  Borosilicate glass (BOROFLOAT)
- Epoxy
  Bisphenol F Resin (Bis F)



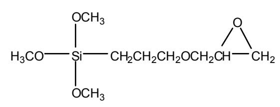
- Curing agents
  - Triarylsulfonium Hexafluoroantimonate Salt (UVI-6974)



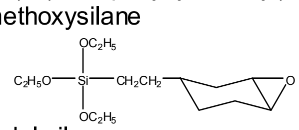
  - Imidazole Curing Agent (2,4-EMI)



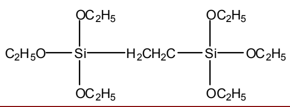
- Commercial Epoxy systems
- Adhesion promoters
  - GPS (3-Glycidoxypropyl)trimethoxysilane



  - ECH (2-(3,4-Epoxycyclohexyl) Ethyl-Trimethoxysilane



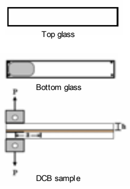
  - Dipodal silanes



Approach

- DCB Test

Sample Preparation
- IPA degreasing
- UV/O3 clean
- Au/Pt coating
- Glass Surface treatm
- Spacer for thickness
- UV curing

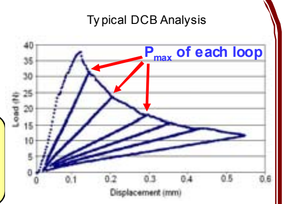


Sample Aging
- 85 °C / 85 % Relative Humidity
- Pre-Crack
- DCB Test

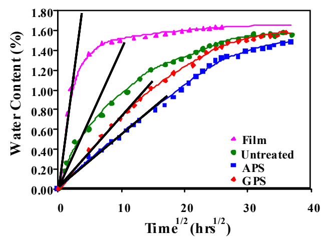
$$G_c = \frac{12P^2a^2}{w^2h^3E}$$

- P = max load
- a = crack length
- w = specimen width
- h = beam height
- E = Young's Modulus

Typical DCB Analysis



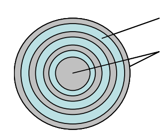
- Gravimetric Test



$$D = \pi\left(\frac{sb}{4M_\infty}\right)^2$$

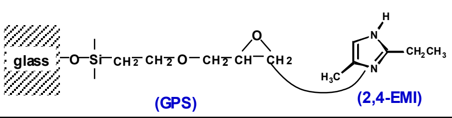
D = diffusion coefficient
s = slope
b = thickness
M_∞ = moisture content at saturation

- Calcium Test



Results

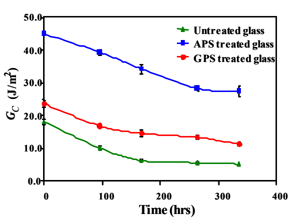
- Model Heat cure sealant



Sample	D (10^{-8} cm^2s^{-1})
Epoxy* (from literature)	1.40*
Epoxy film	1.79
Untreated DCB specimen	64.41**
GPS treated DCB specimen	13.77**
APS treated DCB specimen	8.32**

* Diglycidyl ether of bisphenol A/dicyandiamide under 70°C/100% RH. condition [Int. J. Adhesion & Adhesive, 1995, 15, 137-142]

** Apparent diffusion coefficients (higher because of capillary diffusion mechanism)



Organosilane improves both initial and wet adhesive strength

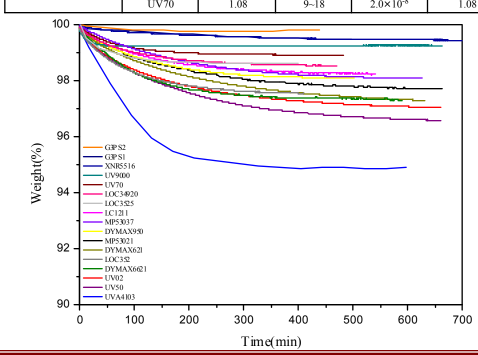
G_c drops with aging time under hygrothermal aging → Loss of interfacial forces

Physical interaction (H-bond) b/w epoxy and untreated glass → Easily disrupted by water

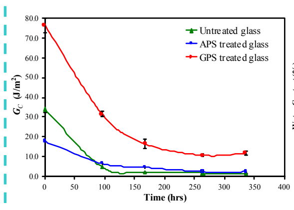
Chemical bond formed at interfaces can resist hygrothermal conditions

- Commercial sealants

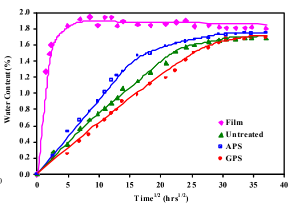
Company	Product code	Density (g/cm³)	Viscosity (poise)	D (cm²/s)	Absorption%
NAGASE	XNR5516	1.41	1260	3.8×10^{-8}	0.50
National Starch & Chemicals	G3PS1	1.74	442	2.6×10^{-8}	0.53
	G3PS2	1.51	307	3.6×10^{-8}	0.25
Emerson Cumming	Eccobond UV-9000	1.03	300	10.3×10^{-8}	0.77
Henkel Loctite	LOC3525	1.11	~95	2.0×10^{-8}	1.68
	LOC352	1.11	140	3.1×10^{-8}	2.60
	LOC3492	1.03	5	1.8×10^{-8}	1.50
3M	LC1211	1.14	~155	3.4×10^{-8}	1.75
Star Technology	UVA4103	1.13	~10	4.8×10^{-8}	5.12
DYMAX	621	1.06	~7.5	2.4×10^{-8}	2.19
	6-621	1.07	~7.5	3.6×10^{-8}	2.67
	950	1.07	~5.0	1.5×10^{-8}	1.50
Heigl Technology	MP53021	1.00	7.5	2.8×10^{-8}	2.30
	MP53037	1.10	25	3.4×10^{-8}	1.92
Chemence	UV02	1.09	26~38	1.2×10^{-8}	2.96
	UV50	1.09	55~75	1.2×10^{-8}	3.40
	UV70	1.08	9~18	2.0×10^{-8}	1.08



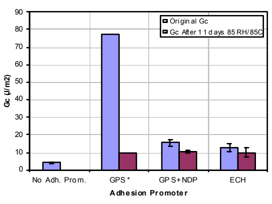
- Model UV cure sealant



Decrease of Gc by DCB Testing after Hygrothermal Aging

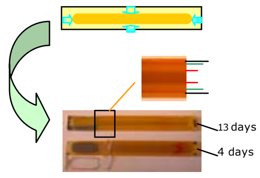


Moisture Pickup of DCB Samples under 85RH/85°C



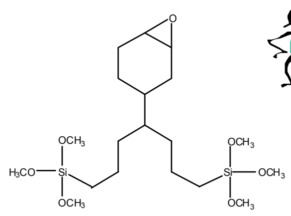
Comparison of Gc for Adhesion Promoter Treated and untreated DCB samples

- Critical Strain Energy Release Test



- $G_{c\text{-}comp}^{1/2} = xG_{c\text{-}dry}^{1/2} + (1-x)G_{c\text{-}wet}^{1/2}$
- Measure of $G_{c\text{-}dry}$ and $G_{c\text{-}wet}$
- x vs. time → interfacial diffusion coefficient

- Desired Adhesion Promoters



Summary

- Moisture diffuses much faster through interface than bulk for epoxy/glass interfaces (Apparent values)
- Silane coupling agents can improve critical strain energy release rate for both wet and dry interfaces
- GPS, ECH and mixture of GPS with dipodal silane can improve moisture resistance of the interface between model UV curable epoxy sealant and glass

Future Work

- Augment bulk diffusion data with quantitative interfacial diffusion data
- Develop a process utilizing a differential pressure encapsulator allowing
  a) removal of traces of moisture and oxygen from the PLED surface coupled with
  b) Selection of transparent coating and layered material and to provide a gap free surface coating able to shield the surface from moisture degradation for around 10000 hours

Prototype Differential Pressure Encapsulator

Acknowledgements

- Financial Support from ARL
- National Starch & Chemicals Co. and other commercial sources for donations of sealants
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