ENCAPSULATION MATERIALS RESEARCH

SPRINGBORN LABORATORIES, INC.

P. Willis

PHASE I

IDENTIFY AND DEVELOP LOW COST
MODULE ENCAPSULATION MATERIALS

- POTTANTS
- COVER FILMS
- SUBSTRATES
- ADHESIVES/PRIMERS
- ANTI-SOILING TREATMENTS

PHASE II

MATERIALS RELIABILITY

- AGING AND LIFE ASSESSMENT
- ADVANCED STABILIZERS
- CHEMICAL DIAGNOSTICS
- FLAMMABILITY
- ELECTRICAL IsOLATION

PHASE III

PROCESS SENSITIVITY

- INTERRELATIONSHIPS OF
  - FORMULATION VARIABLES
  - PROCESS VARIABLES
- MANUFACTURING YIELD ANALYSIS
  (PROCESS DEVELOPMENT SECTION)

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Module Components

- SURFACE
- OUTER COVER (OR GLASS)
- POTTANT
- BACK COVER (OR SUBSTRATE)
- GASKET/SEALANT

Current emphasis on materials and module performance characteristics:
- Determine current level of performance
- Enhance performance (e.g., reformulation)
- Service life prognosis

Performance criteria:
- Environmental degradation
- Adhesive bond durability
- Electrical integrity
- Flammability
Module Flammability

- Most modules constructions not passing UL-190O burning brand test
- Mechanism: Appears to be rupture of the back cover with the evolution of burning gases
- Modules can burn but must not serve as an ignition source to other structures
- Modules with Kapton back covers (high strength) pass test due to ability to retain combustible gases

- Kapton is very expensive
- Inexpensive high strength high temperature back cover needed
Module Flammability

GOAL:
- PREVENT SPREAD OF FLAME
- PASS UL-790

APPROACHES:
(1) HIGH STRENGTH HEAT RESISTANT BACK COVERS
   - CERAMIC PAPER
   - POLYMER FILM LAMINATES WITH GLASS SCRIM REINFORCEMENT
   - METAL FOILS
   - RESIN IMPREGNATED GLASS CLOTH

(2) REDUCTION OF COMBUSTIBLE MATERIALS
   - THINNING OF POTTANT LAYER

(3) FIRE RETARDANT ADDITIVES
   - INERT DILUENTS (TALC, CALCIUM CARBONATE)
   - RELEASE OF WATER WITH HEAT ALUMINA TRIHYDRATE (35% WATER)
   - FIRE RETARDANTS (FREE RADICAL TRAPS)
     ANTIMONY OXIDE, ZINC BORATE
     BROMINATED ORGANICS
     ORGANIC PHOSPHATES

(4) COMBINATION OF ALL THREE
EVALUATION OF CANDIDATE TECHNIQUES

CONVENTIONAL:
- UL-94 VERTICAL BURN TEST
- ASTM E-262 FLAME SPREAD INDEX
- ASTM D-2863 LIMITING OXYGEN INDEX

FOR BACK COVERS:
- CONSTRUCT SPECIAL APPARATUS

- DETERMINE BURST STRENGTH AS FUNCTION OF TEMPERATURE AND PRESSURE
- CORRELATE TO ACTUAL EFFECTIVENESS UNDER FIRE CONDITIONS
- DETERMINE ADD-ON COST FOR IMPROVEMENT IN FIRE RATING
- RECOMMEND CANDIDATES FOR UL-790 TESTING
Electrical Isolation

- POTTANTS AND COVER FILMS SERVE AS ELECTRICAL INSULATION
- NEED TO KNOW THICKNESS REQUIRED FOR VOLTAGE STANDOFF
- VARIATION WITH TEMPERATURE, ABSORBED WATER
- NEED TO KNOW VARIATION DIELECTRIC STRENGTH WITH AGING:
  - LIGHT, HEAT, HUMIDITY, FIELD STRESS

METHOD:

- USE DC DIELECTRIC TEST APPARATUS
- TIP TO TIP SYMMETRIC ELECTRODES
- SPECIFIED RATE OF RISE
- PLOT AVERAGE BREAKDOWN VOLTAGE, $V_A$ VS THICKNESS
- STRAIGHT LINE RELATIONSHIP:
  - SLOPE CONSIDERED TO BE THE INTRINSIC DIELECTRIC STRENGTH, $dv/dt$
- MEASUREMENTS TO DATE:
  - EVA $dv/dt = 3.65$ kV/MIL
- REMEASURE $dv/dt$:
  - THERMAL AGING
  - WATER ABSORPTION
  - ENVIRONMENTAL EXPOSURE
  - FIELD STRESS AGING
- RECALCULATE THE REQUIRED INSULATION THICKNESS
  FOR SERVICE LIFE OF THE MODULE
## Adhesion Experiments

**SELF-PRIMING FORMULATIONS**
*(TO SUNADEX GLASS)*

<table>
<thead>
<tr>
<th>POTENTIAL/PRIMER</th>
<th>LEVEL (PHR)</th>
<th>CONTROL</th>
<th>12 MONTHS STORAGE</th>
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<tbody>
<tr>
<td>EVA A9918</td>
<td>0.25</td>
<td>42</td>
<td>31</td>
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<tr>
<td>Z-6030</td>
<td>0.05</td>
<td>29</td>
<td>20</td>
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<tr>
<td>EVA 15295/</td>
<td>0.25</td>
<td>31</td>
<td>28</td>
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<tr>
<td>Z-6030</td>
<td>0.05</td>
<td>10.9</td>
<td>5</td>
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<tr>
<td>EMA 15257/</td>
<td>0.25</td>
<td>57.4</td>
<td>41</td>
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<tr>
<td>Z-6030</td>
<td>0.05</td>
<td>49.0</td>
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*BCNS ALSO STABLE TO WATER IMMERGSION AND BOILING WATER*

- STABLE TO STORAGE CONDITIONS (12 MO. TO DATE) AT 0.25 PHR LEVEL, .05 PHR NOT AS STABLE

- NOW COMMERCIALY AVAILABLE (SPRINGBORN)
  
  - EVA A9918-P *(LUPERSOL 101 CURE)*
  - EVA 15295-P *(TBEC CURE)*

- WORKING ON INTERNAL PRIMING FOR CELL STRING AND METALLIZATION (MORE DIFFICULT TO PRIME)
RELIABILITY PHYSICS

CONTINUED PRIMER STUDIES:

- EVALUATE THE THREE "BASIC" PRIMERS -
  DR. PLUEDDEMANN - DOW CORNING
  - POLYMER/METAL
  - POLYMER/INORGANIC
  - POLYMER/ORGANIC

- METAL PRIMER (ALUMINUM) RECOMMENDATIONS
  DR. JIM BOERIO - UNIVERSITY OF CINCINNATI

ADHESION DIAGNOSTICS:

- HOW DURABLE ARE ADHESIVE BONDS?
  UNDER WHAT CONDITIONS?

- SUCCESSFUL SPECTROSCOPIC EXAMINATION OF GLASS/
  PRIMER INTERFACE - DR. JACK KOENIG -
  CASE WESTERN RESERVE

- EVA COMPOUNDED WITH HIGH LOADINGS OF SILANE
  TREATED GLASS BEADS
  - SPECIMENS AT CASE WESTERN FOR "DRIFT"
    ANALYSIS (CHEMICAL)
  - IDENTICAL SPECIMENS AT SPRINGBORN FOR
    MECHANICAL ANALYSIS
  - HYDROLYTIC AGING
  - CORRELATE CHEMICAL OBSERVATIONS WITH
    MECHANICAL PERFORMANCE
  - DETERMINE DEGRADATION RATES
  - ASSESS SERVICE LIFE
Accelerated Aging

OUTDOOR PHOTOTHERMAL AGING DEVICES (OPT)

- Use natural sunlight, avoids spectral distribution problems with artificial light sources
- Use temperature to accelerate the photothermal reaction
- Includes dark cycle reactions
- Includes dew/raim extraction
- Intended primarily for module exposure
- Extrapolate effects to lower temperatures
RELIABILITY PHYSICS

- MODULE EXPOSURE: OPT 105°C, 7,000 HRS
- ALL SHOW SEVERE COPPER REACTION
- BEST PERFORMANCE: EVA-ADVANCED STABILIZER
  TBE, UV-2098, TINUVIN 770
  VIRTUALLY NO DEGRADATION APPARENT
- CONSPICUOUS DEGRADATION IN OTHERS
- GLASS FRACTURE - THERMAL SHOCK
- MODULE EXPOSURE: OPT 70°C, 7000 HRS.
- SOME COPPER REACTION W/EVA 9918
- NO OTHER EFFECTS NOTICEABLE
- USEFUL FOR EVALUATING CANDIDATE FORMULATIONS - COMPARISON
- EVALUATES WHOLE MODULES
- DETERMINE UPPER LEVEL SERVICE TEMPERATURES
- MODELLING:
  - ARRHENIUS : LOG P VS. 1/K⁰
  - PREDICT SERVICE LIFE BY EXTRAPOLATION TO LOWER TEMPERATURES
  - TIME TO ONSET OF DEGRADATION (INDUCTION PERIOD)
  - PROBABILITY DISTRIBUTION-FAILURE
- EXAMPLE: POLYPROPYLENE - INDUCTION TIME

TIME, HOURS

<table>
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<tr>
<th>VT (°C), SHOWN AS DEGREES CENTIGRADE</th>
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<tr>
<td>60</td>
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<tr>
<td>80</td>
</tr>
<tr>
<td>100</td>
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<td>120</td>
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<td>140</td>
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Advanced Stabilizers

**GENERAL DEGRADATION MECHANISM**

- **LIGHT (UV)**
  - **ABSORPTION**
  - **EXCITED SPECIES** (ACTIVATED KETONES)
  - **RADICALS**
    - **P*, H**
    - **RO**

**STABILIZATION ADDITIVE**

- **SCREENERS**
- **QUENCHERS**
- **FREE RADICAL SCAVENGERS**
- **HYDROPEROXIDE DECOMPOSERS**

**AUTOCATALYTIC DEGRADATION**

- **QUENCHERS STRONGLY COLORED - NOT USED**
- **LONG TERM STABILIZERS:**
  - **OXIDATIVELY STABLE**
  - **NON-FUGITIVE**
- **UV-2098 (AMERICAN CYANAMIDE) BEST SCREENER FOUND TO DATE (CO-REACTIVE BENZOPHENEONE)**
- **HINDERED AMINE LIGHT STABILIZERS (HALS)**
  - FREE RADICAL TRAPS AND HYDROPEROXIDE DECOMPOSITION
- **COMBINATION OF SCREENER AND HALS BEST STABILIZER PACKAGE**
RELIABILITY PHYSICS

CANDIDATE HINDFRED AMINES (HALS)

- HIGH EFFICIENCY FROM REGENERATIVE CHEMISTRY:
  ACTIVE SPECIES RECYCLES - NON SACRIFICIAL

- EVALUATION OF CANDIDATES:
  - EVA, TBEC CURE, 0.1% HALS
  - % ELONGATION VERSUS TIME
  - OPT DEVICE, 90 °C

![Graph showing percent elongation versus exposure hours for different candidates]

- FAILURE: LOSS OR CONSUMPTION OF CHEMISTRY?
  NEED FOR ANALYTICAL METHOD

- CYASORB UV-336 (CYANAMIDE) CLEARLY BETTER

- SYSTEM EVALUATION: EVA/TBEC/UV-2098/UV-3346
  MODULES, ADHESION, FLAMMABILITY, ETC.
Antisoiling Treatments

SURFACE CHEMISTRY:
- HARD
- SMOOTH
- HYDROPHOBIC
- OLEOPHOBIC
- ION FREE
- LOW SURFACE ENERGY

SURFACE INVESTIGATED:
- SUNADEX GLASS
- TEDLAR (100 BG 30 UT)
- ACRYLAR (ACRYLIC FILM)

TREATMENTS REMAINING:
- L-1668 FLUOROSILANE (3M)
- E-3820 PERFLUORODECANOIC ACID/SILANE (DOW CORNING)
- STILL EFFECTIVE AT 38 MONTHS OUTDOOR EXPOSURE
- RESULTS IN IMPROVED POWER OUTPUT
- FLUOROALKYL SILANE CHEMISTRY APPEARS TO BE MOST EFFECTIVE
Soiling Experiments

THIRTY-TWO MONTHS EXPOSURE
ENFIELD, CONNECTICUT

% LOSS IN $I_{sc}$ WITH STANDARD CELL TREATED
TEDLAR 100BG300UT
(SUPPORT ON GLASS)

38 MONTHS EXPOSURE

CONTROL, NO COATING
E-3920 COATING (BEST)

ESTIMATED AVERAGE POWER IMPROVEMENT, 3.8%
THIRTY-TWO MONTHS EXPOSURE
ENFIELD, CONNECTICUT

% LOSS IN I_{SC} WITH STANDARD CELL TREATED ACRYLAR
(SUPPORTED ON GLASS)

38 MONTHS EXPOSURE

CONTROL, NO TREATMENT

OZONE WITH E-3820 (BEST)

ESTIMATED AVERAGE POWER IMPROVEMENT, 3.9%
RELIABILITY PHYSICS

THIRTY-TWO MONTHS EXPOSURE
ENFIELD, CONNECTICUT

% LOSS IN $I_{sc}$ WITH STANDARD CELL TREATED
SUNDEX GLASS

38 MONTHS EXPOSURE

CONTROL, NO TREATMENT
E-3820 (BEST)
RAINFALL, INCHES

ESTIMATED AVERAGE POWER IMPROVEMENT, 1%
Antisoiling Coatings

- Still effective after three years outdoor exposure
- Permanence appears to be good
- Possibility for improved performance by increasing soil repellancy

New candidate(s):
- Lowest surface energy ever reported: polymer of perfluoro-octyl methacrylate
  \[ \gamma_c = 10.6 \text{ dyne cm}^{-1} \]
- React with trimethoxy hydrogen silane to form adduct with glass-reactive group
- Evaluate in soiling tests

\[
\begin{align*}
\text{O} & \quad \text{C} \quad \text{O} \\
\text{C}_2\text{H}_4 & \quad \text{Si} \quad \text{O} \\
\text{O} & \quad \text{Si} \quad \text{O} \\
\text{F}_2 & \quad \text{F}_2 \quad \text{F}_2 \quad \text{F}_2 \quad \text{F}_2 \\
\end{align*}
\]
RELIABILITY PHYSICS

Outer Covers (Substrate Design)

- Low cost UV screening films commercially available
- Problems: shrinkage, stabilizer extraction adhesion, weather stability
- Pottants appear to have good stability
- Non-screening candidate films clear, weatherable, bondable?

<table>
<thead>
<tr>
<th>FILM</th>
<th>REF. INDEX</th>
<th>% T</th>
<th>COST $/FT²/MIL</th>
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<tbody>
<tr>
<td>TEFZEL</td>
<td>1.403</td>
<td>85.6</td>
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<tr>
<td>KAYMAR</td>
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<td>HALAR</td>
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<td>85.3</td>
<td>0.096</td>
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<tr>
<td>FFA</td>
<td>1.300</td>
<td>88.4</td>
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<tr>
<td>FEP</td>
<td>1.340</td>
<td>93.6</td>
<td>0.109</td>
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</table>

- FEP may be good choice:
  - High transparency
  - Outstanding weatherability
  - May improve optical throughput by 2% due to optical coupling
  - Requires primer technology
  - Will be evaluated in module fabrication and outdoor exposure experiments
Conclusions

- Outdoor photothermal aging devices (OPT)
- Best accelerated aging method discovered yet
- Simulates worst case field conditions
- Evaluate formulations
- Evaluate module performance
- Possibility for life assessment

Avoid metallic copper exposure

- Self priming formulations have good storage stability at 0.25 phr

Stabilizers - enhanced performance
- UV-2098 UV screener
- UV-3346 hindered amine (HALS)

Soil resistance treatments still effective
RELIABILITY PHYSICS

Future Work

- FLAMMABILITY: FIRE RETARDANTS AND FLAME RESISTANT WORK COVERS
- ELECTRICAL INTEGRITY: DIELECTRIC STRENGTH VERSUS AGING OF ENCAPSULATION MATERIALS
- ADHESION DIAGNOSTICS AND SERVICE LIFE ASSESSMENT
- MODULE EVALUATION: EVA POTTANT WITH ADVANCED STABILIZER PACKAGE
- NEW ANTI-SOILING CONCEPTS
- MODULE SERVICE LIFE ASSESSMENT
  (PHASE III)
- PROCESS AND MANUFACTURING VARIABLES