High Performance Barrier Films for Vacuum Insulated Panels

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3M Technology to Product Commercialization Process

CRL – Corporate Research Lab
CRPL: Corporate Research Process Lab
CRML: Corporate Research Materials Lab
CRAL: Corporate Research Analytical Lab
SEMS: Software, Electronic, & Mechanical Systems Lab

Business Group: Multiple Divisions with Applied Development Engineering Teams

Industrial
From purification to aerospace – changing how industry works

Safety & Graphics
From protecting people & information to enhancing visual & design communication

Electronics & Energy
Enabling tomorrow’s lifestyle today with power, communications and electronics

Consumer
From simplifying life at home to keeping you organized at work

Health Care
From preventing infections to making smiles brighter
Outline

• Standard 3M barrier construction and performance
• Applications and WVTR specifications
• Vacuum Insulated Panels (VIP)
• Adaptions for barrier films for VIP application - Product Performance/Testing
• Summary
3M™ UltraBarrier Film (FTB3-50)

Polymer Multi-Layer (PML) constructions on flexible polymers - acrylate layers separated by inorganic oxides

- Roll-to-Roll processing
- Polymer (acrylate): Organic Vapor Deposition
- Oxides: PVD (Sputtering, Evaporation)
- Required barrier performance dictates number of layers
- Ideal for flexible products (inorganic barrier layer thicknesses of 10’s of nm)
PML Smoothing Capability

PET ST-504, 5mil

Ra = 1.36 nm
Rq = 1.75 nm
Rt = 19.84 nm

PET ST-504, 5mil

Ra = 0.515 nm
Rq = 0.646 nm
Rt = 6.673 nm
Typical WVTR values (50 °C, 100% Rh):
Mocon (Permatran 700) - <5 x 10^-3 g/(m²·day) (below detection level)
Mocon (Aquatran I) - low-mid 10^-4 g/(m²·day) (at or below detection level)

Ca Measurement Data (60 °C, 90% Rh)

Values from stoichiometric modeling, Optical Trans. Data

Blue: standard FTB3-50 barrier film
Red: two-ply laminate barrier film (OLEDS)

Pictures of samples after 136 hours at 60/90
3M barrier flexible film for electronic applications

**Displays**

**Quantum Dots (AIMCALS 2016)**
- Light Conversion
- Narrow emission lines = Expanded Gamut
- Sharp Emission Lines
- ~7nm Dot
- Blue "Pump"
- Red Output
- ~3nm Dot
- Blue "Pump"
- Green Output
- Barrier Requirements: WVTR of $10^{-2}$ to $10^{-4}$ g/(m².day)

**Organic Light Emitting Diodes (OLEDs)**
- No backlight = deep black levels
- Flexible Applications

**Lighting Applications**
- Roll-to-roll: 3M and Fraunhofer FEP

**Barrier Requirements:**
- WVTR of $10^{-6}$ g/(m².day)

Barrier Film

Polymer Matrix

Barrier Film

Quantum Dot

Barrier Film

OLED

Transparent Conductor

Barrier Film

Barrier Requirements:
UBF 512 Solar Barrier Film

Delivering Efficient And Reliable Energy “EVERYWHERE”

3M Electrical Markets Division
Renewable Solutions
Why Flexible Modules?  
– 3M UBF 512 enabling new markets for PV

- **Lightweight** (1/5 the weight of silicon modules)
- **Large Area** (not limited by glass size)
- **New Form Factors**
- **Portable Power Generation**
- No roof penetrations
- No racking needed
- Potential for roof integration
- Ability to adapt to curved roof
- Flush integration with standing seam metal roofs
- High durability and low profile
- Good for high wind zones

Barrier requirements: WVTR of $10^{-4}$ g/(m²·day)
Going beyond electronic applications for 3M barrier Vacuum Insulated Panels (VIP)

Thermal insulation consisting of a gas-tight enclosure surrounding a core material

- Building insulation
- Refrigeration

Advantages over standard insulation:
- Eliminates convection - (Vacuum)
- Lower conductance (no atom collisions)
- Higher thermal resistance per thickness
- 10 times greater efficiency than glass fiber, PU foam & other standard materials

R values: VIP ~30-50/inch depending on type of core
(typical value for fiberglass board, spray cellulose ~3-4/inch)
Vacuum Insulated Panel

- **Core Material**
  - Fumed Silica
  - Aerogels
  - Perlite
  - Glass Fiber

- **Barrier Envelope**
  - Aluminum Foil
  - Metalized PET films

- **Barriers to greater adoption**
  - Cost
  - Longer service life
  - Durability and puncture risk
  - Lack of customization

Barrier requirements: $O_2$ of $10^{-2}$ to $10^{-6}$ cc/(m²day)
Wide range for different product lifetimes
3M VIP barrier film construction

Construction Details:
1) Heat seal layer for making VIP envelope
2) Protective PET – Puncture resistance, protects barrier component
3) Optimized construction (PET and heat seal thicknesses) – neutral stress plane located at barrier film
Application of 3M barrier film to VIP

• Longer service lifetimes $\rightarrow$ excellent barrier performance:
  High end design: OTR $\sim 10^{-4}$ cc/(m$^2$*day) (23°C, 50% Rh)
  WVTR $\sim 10^{-4}$ g/(m$^2$*day) (50°C, 100% Rh)

• Durability
  Good Forming Performance – edges of panel
  Optimal bend performance
  Optimized construction – Neutral stress plane in region of barrier film
3M vs Standard VIP films

3M VIP barrier film construction

3-ply metalized competitors option

Tested Options:
1) Std.
2) Thinner heat seal layer – lower costs
3) Heat seal film with Ethylene vinyl alcohol (EVOH) layer – for O₂ gettering
After 6 months of accelerated aging exposure, 3M degradation 3X less than 3 ply metalized film.

- Thinner heat seal layer—increased degradation due to unoptimized construction—Neutral plane not at barrier film.
- Heat seal EVOH—best performance (but added cost).
Barrier Performance with bend testing

- Barrier film with transparent conductor
- Transparent conductor to monitor sheet resistance
- Good Performance up to 5 mm bend radius
- Significant (3-4x) increase in $R_{\text{sheet}}$ only at 2 mm

![Graph showing sheet resistance vs strain mode and bend radius](image)

2 hrs at 60°C/90%RH
Application of 3M barrier film to VIP

• Longer service lifetimes → excellent barrier performance:
  High end design: OTR $\sim 10^{-4}$ cc/(m$^2$*day) (Tests conditions)
  WVTR $\sim 10^{-4}$ g/(m$^2$*day) (50°C, 100% Rh)

• Durability
  Good Forming Performance – edges of panel
  Optimal bend performance
  Optimized construction – Neutral stress plain in region of barrier film

• Cost
  Barrier previously optimized for Electronic Applications: Higher price points
Cost reductions

• Why a high performance barrier film → Allows for use of glass fiber over more expensive fumed silica

• Minimizing PET thickness – Optimized for lower cost while maintaining neutral axis on barrier film

• Higher Operation Speeds – alterations to barrier film fabrication conditions

With these changes, 3M barrier films cost competitive for VIP applications
Summary

• High Performance, high transparency 3M barrier films – optimized for high opto-electronic applications

• Further optimization of the process and barrier film construction → 3M degradation is 3X less than 3 ply metalized film

• Cost effective option for Vacuum Insulating Panels:
  - Low WVTR and OTR values
  - Good durability with bending (seal formation)
  - Good durability with optimal construction- optimal placement of the neutral stress plane
  - Competitive costs
    • thinner PET
    • Lower cost core material
    • Higher web speeds