High Performance Barrier Films for Vacuum Insulation Panels

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Abstract

We will describe a novel high performance heat sealable barrier film that has been designed for Vacuum Insulation Panels (VIP) applications. This film combines a robust construction with multiple technical advantages to achieve its goals including a very low Moisture Vapor Transmission Rate (MVTR), due to its low defect level oxide layer, and high transparency. The film is laminated to a heat seal layer and converted into packaging based on the customers' specifications. Its neutral axis construction leads to a high degree of mechanical durability for packaging applications. The unique manufacturing technology makes this film a versatile alternative to foil and metalized film for packaging applications. Key developments will be described including a lower cost process compared to those used for ultra-low MVTR barriers films for high end electronic applications. Film performance in harsh environment for the VIP application will be also presented and benchmark against 3-ply metalized films.

Background

3M has designed a water vapor and oxygen barrier film construction for use in electronic applications such as displays, photovoltaics and organic-based electronics. However as described in this manuscript, the 3M UltraBarrier™ films can also be utilized in enclosure constructions for VIP[1]. In the following sections, we will describe these barrier films, their use in VIP products and the performances of the barrier films as well as the VIP constructed with them.

3M Barrier Film

The 3M UltraBarrier™ films[2] are comprised of polymer multi-layer (PML) constructions on flexible polymers with acrylate layers separated by inorganic oxides prepared by physical vapor deposition (PVD) methods (see Figure 1). The number of layers used in the constructions is dictated on the required barrier performance for the product. All layers are made in a roll-to-roll processing manner using various polymer-based films as substrates again dependent on the application The inorganic oxide barrier layers are characterized by a reduced number of pin hole, high transparency (>90%) and very low water (from 10^{-4}- $5x10^{-6}$ g/m^2/day, construction dependent) and oxygen (~10^{-4} cc/(m^2*day)) transmission rates. The acrylate polymer layers allow for very smooth growth surfaces. Figure 2 compares SEM photographs of the top surfaces of a bare Polyethylene terephthalate (PET) substrate with and without a polymer coating. The addition of the polymer coating leads to a reduction in the surface roughness value (Ra) from 1.36 nm to 0.52nm.

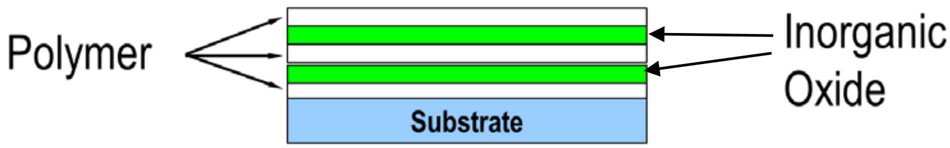

Figure 1. PML structure.

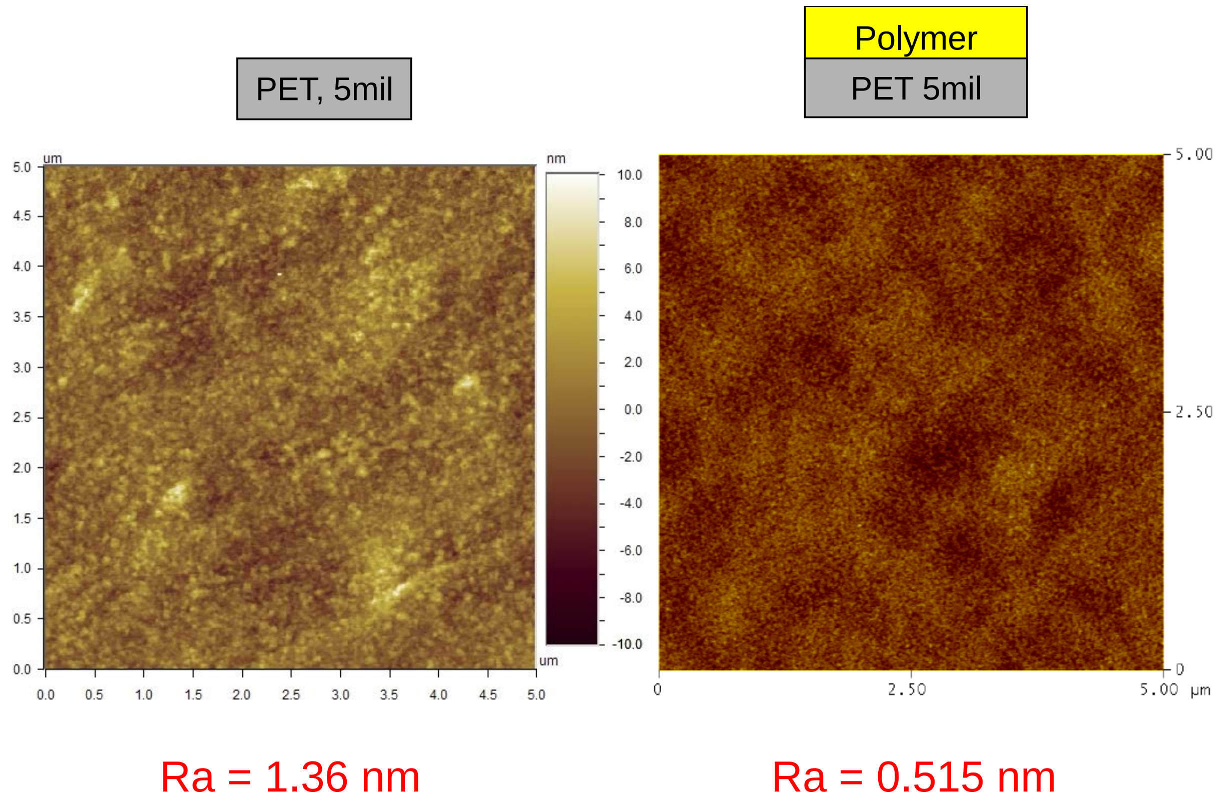

Figure 2. Scanning Electron Micrographs of PET substrate with and without polymer coating.

These barrier layer structures are ideal for flexible product applications. 3M has optimized the layer construction such that the inorganic barrier layer thicknesses are in the order of 10's of nm. In comparison, many Thin Film Encapsulation (TFE) structures have barrier layers with thicknesses in the 100's of nm to 10's of microns. The thinner inorganic layers allow for enhanced flexibility over the TFE option making them ideal for foldable and flexible electronic-based applications such as flex OLED displays.

Vacuum Insulation Panels (VIP)

Vacuum Insulation panels are thermal insulating panels that are used for construction, insulated shipping container, cold storage units, refrigerated transport and appliance applications. They consist of a low conductance porous core material surrounded by a gas tight enclosure. An example of a VIP product is shown in Figure 3 while a diagram depicting the cross section of a

VIP is shown in Figure 4. The enclosure is vacuum pumped then sealed to produce the final product. Low cost VIP typically used core materials with low thermal conductivities such as fumed silica board or powder, glass wool and polyurethane foam. By lowering the molecular material in the enclosure through pumping and sealing, both convective and conductive flow through the core material is substantially lowered diminishing the overall thermal conductivity of the panel. Thermal conductivities for the VIP can be 10 times lower than for standard glass fiber, PU foam and other standard thermal insulating materials. Specifically, the typical thermal resistance R values for VIP are 30-50/inch compared with 3-4/inch for fiberglass board and spray cellulose.

Figure 3. Example of a Vacuum Insulation Panel.

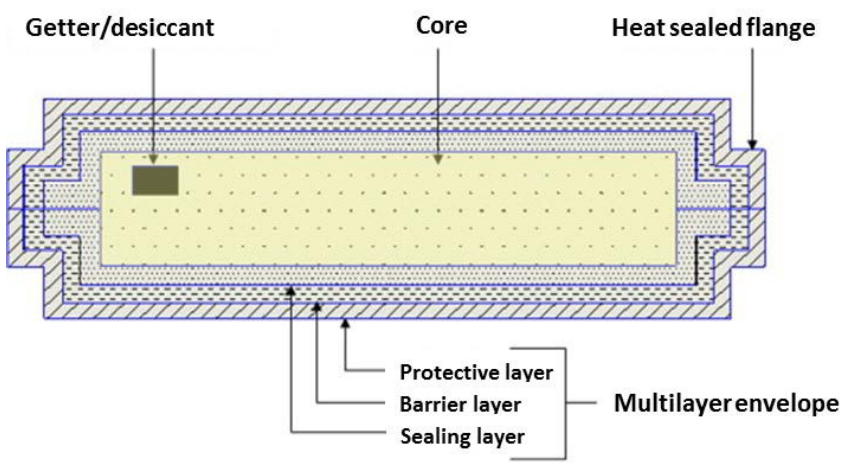

Figure 4. A depiction of a Vacuum Insulation Panel cross section.

To maintain low gas flow through the core material, VIP's typically have two features 1) desiccants added to the core material to getter/trap gasses and 2) barrier films as part of the envelop enclosure to limit air and moisture ingress. Aluminum foil or Metalized PET are is generally used as barrier film. A 3-ply metalized PET construction is depicted in Figure 5. Aluminum foil exhibits low moisture vapor transmission rates (MVTR) ($<10^{-3}$ g/(m2*day). However, the high thermal conductivity of Al induces a thermal bridging effect degrading the efficiency of the VIP panel.
The barrier performance of these 3-ply constructions typically have reasonable moisture vapor transmission rates (MVTR) for food packaging and other moderate MVTR applications with rates between 10^{-1} to 10^{-3} g/(m^2*day). For VIP, higher MVTR values will lead to shorter panel lifetimes.

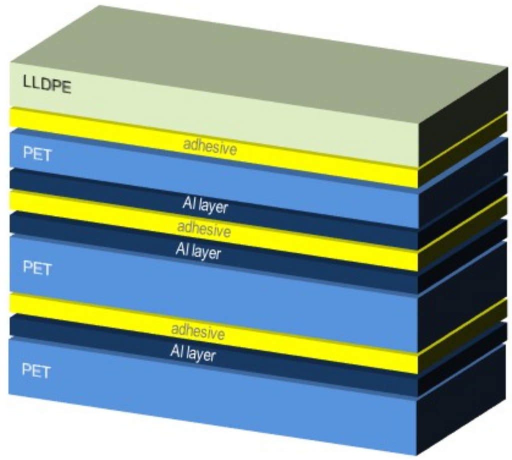

Figure 5. A depiction of a 3-ply metallized PET construction. .

3M UltraBarrier™ film performance

For the 3M UltraBarrier™ films, MVTR values are below 1 x 10^{-3} g/m^2/day, significantly below the 5 x 10^{-3} g/m^2/day detection limit of the commonly used Mocon Permatran 700 measurement system. From Ca ingress tests, calculated MVTR values in the range of 10^{-4}–10^{-5} g/m^2/day are typically observed. Figure 6 displays optical loss data from the Ca ingress tests for the standard barrier films (FTB3-50) and a two-ply laminate barrier film (red) with an increased number of barrier layers using 60 °C, 90% Rh test conditions. These lower MVTR values make the 3M UltraBarrier™ films ideal for long lifetime VIP. With the additional barrier layers, MVTR values are decreased from the 10^{-5} range to 10^{-6} range, allowing for use in applications such as flexible solar cells and Organic Light Emitting Diodes (OLEDs).

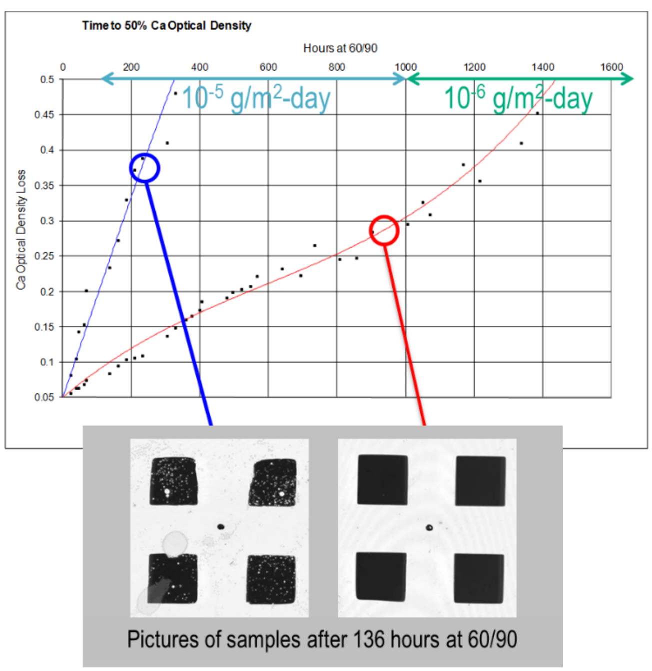

Figure 6. Optical Loss data from Ca test samples made using 3M UltraBarrier films and a two-ply version of these films.

With an MVTR value in the 10^{-4} g/m^2/day range, the standard 3M UltraBarrier films product outperforms that standard barriers used in the VIP industry which have values in the 10^{-2} - 10^{-3} g/m^2/day range. This added barrier protection allows for the use of less expensive porous core materials for the VIP that are more susceptible to air or water vapor exposure including open glass fiber cores.

In terms of transparency through the barrier films, values greater than 90% are needed for these display applications. Figure 7 shows a transmittance spectrum for 3M Ultrabarrier Film demonstrating the high transmission (>90%) across the visible wavelengths, even though high transparency is not a need for the VIP application.

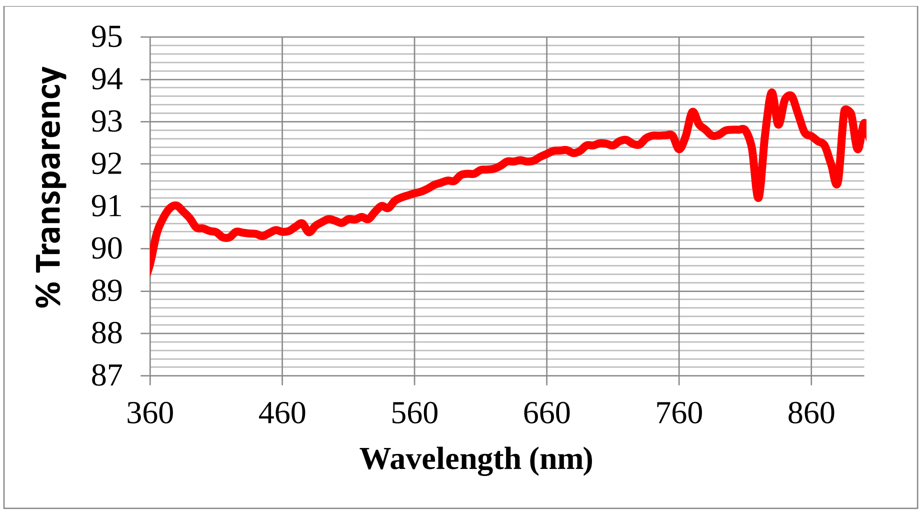

Figure 7. Transparency spectrum for 3M™ Ultrabarrier.

3M barrier films for VIP

The encapsulating film construction using 3M barrier films for VIP is shown in Figure 8. The barrier film itself is comprised of the 3M barrier thin film construction (green) and is PET substrate (blue). It is attached to a heat seal layer used for the encapsulating process and a second PET film (bottom of the stack) using an application specific adhesive. The bottom PET acts to protect the 3M barrier film from scratches during the encapsulating process.

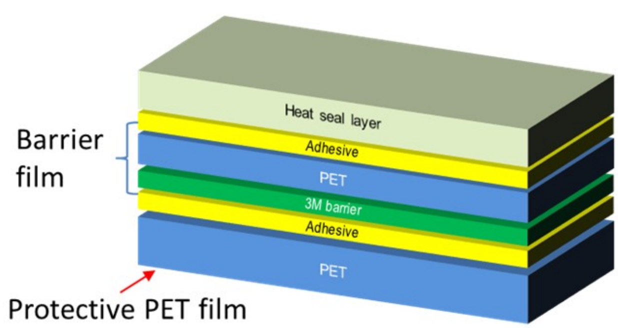

Figure 8. VIP encapsulating film with 3M barrier construction.

To form the VIP, this film construction is heat sealed and encapsulated around the core material while air and other gases are pumped out of the material. During this encapsulation process, the construction is subjected to stresses and strains in addition to those typically locked into the thin film construction during film growth. In order to protect the barrier thin films from crack formation and barrier breach during encapsulation, the neutral stress plane, where internal stress remains 0 with flexing, is engineered to be at the 3M barrier film layer location. The construction is optimized by controlling the ratio of the thicknesses of the protective PET film and PET substrate + heat seal film combination in function of their mechanical properties.

To test the performance of this VIP encapsulating film construction, side-by-side accelerated aging tests were completed on polyurethane cores VIP using to compare the performance of3M VIP encapsulating films with standard 3-ply metalized PET construction (see Figure 5.) In this study, three different versions of the 3M encapsulating film construction were tested; 1) a standard product, 2) a version with a thinner heat seal layer and 3) a version with an Ethylene Vinyl alcOHol (EVOH) layer added to the heat seal to getter oxygen. Each of these types of these constructions were placed in a 50°C, 70% RH environment for 8 months with all of the samples removed each month for thermal conductivity measurements.

Thermal conductivities as a function of time are shown in Figure 9. With increased aging, the degradation of the 3M films is clearly less than what is observed for the 3-ply metalized film with the thermal conductances being between 6 and 9 mWmK compared to 12 for the 3-ply metalized film at the end of the 8 month study. The construction of the samples with the thinner heat seal film were not optimized in order to have the neutral stress plane in the barrier thin film stack. This is likely the cause of the poorer performance (higher thermal conductivities with aging) for the samples with the thinner heat seals as compared with that for the standard construction. The addition of the EVOH to the heat seal film did lead to less degradation with an increase in thermal conductivity of around 2.5 mW/mK compared with over 3 mW/mK for the standard construction.

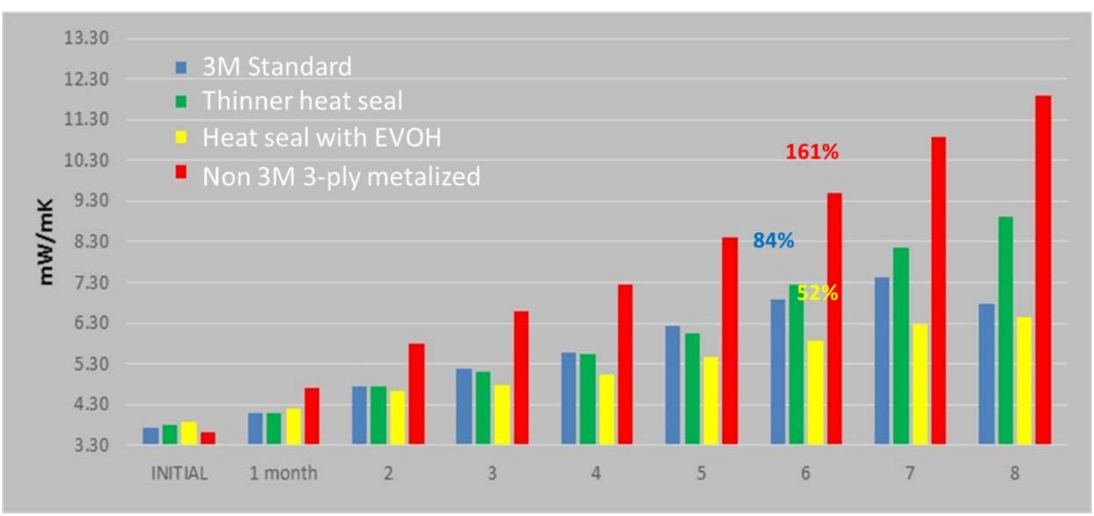

Figure 9. Thermal conductivities of the 3M VIP encapsulating structures and a 3-ply metalized construction as a function of accelerated aging time.

After the commonly used six months of accelerated testing, the thermal conductivity of the 3M construction with the EVOH added heat seal has increased by 52% from its initial value compared with a 161% increase for the 3-ply metalized construction demonstrating a superior performance with the 3M film. This added protection can lead to significantly longer VIP lifetimes.

As compared with electronic applications, VIP products typically require lower price points. The 3M barrier construction (Figure 8) and the accompanying VIP panel has been optimized for these lowered costs. The use of this high performance (low MVTR) barrier allows for the use of lower cost core materials such as glass fibers which are more susceptible to air/oxygen ingress. Long panel lifetimes are still observed even with the very porous core structures. In addition, the thicknesses of the PET films in the barrier construction have been optimized for the smallest values while still maintaining the neutral plane at the barrier thin film construction for good barrier durability. These optimization steps have led to a cost competitive VIP product.

Summary

With a number of desirable traits, the 3M barrier films are ideal for encapsulating films for vacuum insulating panels. The low MVTR values in the 10^{-4} g/m^2/day range allow for long panel lifetimes and or use of low cost core materials. A VIP encapsulating film design in which the neutral stress plane is engineered to be at the 3M barrier thin film stack leads to a very durable final product. Side-by side aging tests of VIP samples made with polyurethane cores demonstrated a factor of 3 less in thermal conductance degradation for the samples with the 3M film as compared with samples made with a standard 3-ply metalized film demonstrating the superior performance.

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