(oxide, metal, nitride, oxynitride) layer, is barely measurable. It is believed that the improvement in barrier properties is due to two factors. First, permeation rates in the roll-to-roll coated oxide-only layers were found to be conductance limited by defects in the oxide layer that arose during deposition and when the coated substrate was wound up over system idlers/rollers. Asperities (high points) in the underlying substrate are replicated in the deposited inorganic barrier layer. These features are subject to mechanical damage during web handling/take-up, and can lead to the formation of defects in the deposited film. These defects seriously limit the ultimate barrier performance of the films. In the single pass, polymer/barrier/polymer process, the first acrylic layer planarizes the substrate and provides an ideal surface for subsequent deposition of the inorganic barrier thin film. The second polymer layer provides a robust "protective" film that minimizes damage to the barrier layer and also planarizes the structure for subsequent barrier layer (or environmentally sensitive display device) deposition. The intermediate polymer layers also decouple defects that exist in adjacent inorganic barrier layers, thus creating a tortuous path for gas diffusion.

The permeability of the barrier stacks used in the present invention is shown in Table 1. The barrier stacks of the present invention on polymeric substrates, such as PET, have measured oxygen transmission rate (OTR) and water vapor transmission rate (WVTR) values well below the detection limits of current industrial instrumentation used for permeation measurements (Mocon OxTran 2/20L and Permatran). Table 1 shows the OTR and WVTR value (measured according to ASTM F 1927–98 and ASTM F 1249–90, respectively) measured at Mocon (Minneapolis, Minn.) for several barrier stacks on 7 mil PET along with reported values for other materials.

TABLE 1

	Oxygen Permeation Rate ($cc/m^2/day$)		Water Vapor Permeation ($g/m^2/day$)+	
Sample	23° C.	38° C.	23° C.	38° C.
Native 7 mil PET	7.62	—	—	—
1-barrier stack	<0.005	<0.005*	—	0.46+
1-barrier stack with ITO	<0.005	<0.005*	—	0.011+
2-barrier stacks	<0.005	<0.005*	—	<0.005+
2-barrier stacks with ITO	<0.005	<0.005*	—	<0.005+
5-barrier stacks	<0.005	<0.005*	—	<0.005+
5-barrier stacks with ITO	<0.005	<0.005*	—	<0.005+
DuPont film[1] (PET/Si_3N_4 or PEN/Si_3N_4)	0.3	—	—	—
Polaroid film[3]	<1.0	—	—	—
PET/Al[2]	0.6	—	0.17	—
PET/silicon oxide[2]	0.7–1.5	—	0.15–0.9	—
Teijin LCD film (HA grade - TN/STN)[3]	<2	—	<5	—

*38° C., 90% RH, 100% O_2
+38° C., 100% RH
[1]P. F. Carcia, 46th International Symposium of the American Vacuum society, Oct. 1999
[2]Langowski, H. C., 39th Annual Technical Conference Proceedings, SVC, pp. 398–401 (1996)
[3]Technical Data Sheet

As the data in Table 1 shows, the barrier stacks of the present invention provide oxygen and water vapor permeation rates several orders of magnitude better than PET coated with aluminum, silicon oxide, or aluminum oxide. The barrier stacks are extremely effective in preventing oxygen and water penetration to the underlying components, substantially outperforming other barrier coatings on the market.

The preferred deposition process is compatible with a wide variety of substrates. Because the preferred process involves flash evaporation of a monomer and magnetron sputtering, deposition temperatures are well below 100° C., and stresses in the coating can be minimized. Multilayer coatings can be deposited at high deposition rates. No harsh gases or chemicals are used, and the process can be scaled up to large substrates and wide webs. The barrier properties of the coating can be tailored to the application by controlling the number of layers, the materials, and the layer design. Thus, the present invention provides a barrier stack with the exceptional barrier properties necessary for hermetic sealing of an environmentally sensitive display device. It permits the production of an encapsulated environmentally sensitive display device.

While certain representative embodiments and details have been shown for purposes of illustrating the invention, it will be apparent to those skilled in the art that various changes in the compositions and methods disclosed herein may be made without departing from the scope of the invention, which is defined in the appended claims.

What is claimed is:

1. An encapsulated display device comprising:

a substrate;

an environmentally sensitive display device adjacent to the substrate, wherein the environmentally sensitive display device is selected from liquid crystal displays, and electrophoretic inks; and

at least one first barrier stack comprising at least one first barrier layer and at least one first polymer layer, the at least one first barrier stack adjacent to the environmentally sensitive display device, wherein the at least one first barrier stack encapsulates the environmentally sensitive display device, and wherein the oxygen transmission rate through the at least one first barrier stack is less than 0.005 $cc/m^2/day$ at 23° C. and 0% relative humidity.

2. The encapsulated display device of claim **1** further comprising at least one second barrier stack located between the substrate and the environmentally sensitive display device, the at least one second barrier stack comprising at least one second barrier layer and at least one second polymer layer.

3. The encapsulated display device of claim **2** wherein the at least one second barrier layer is substantially transparent.

4. The encapsulated display device of claim **2** wherein the at least one second barrier layer is substantially opaque.

5. The encapsulated display device of claim **2** wherein at least one of the at least one second barrier layers is selected from opaque metals, opaque polymers, opaque ceramics, and opaque cermets.

6. The encapsulated display device of claim **2** wherein at least one of the at least one second polymer layers comprises an acrylate-containing polymer.

7. The encapsulated display device of claim **1** wherein the at least one first barrier layer is substantially transparent.

8. The encapsulated display device of claim **1** wherein at least one of the at least one first barrier layers comprises a material selected from metal oxides, metal nitrides, metal carbides, metal oxynitrides, metal oxyborides, and combinations thereof.

9. The encapsulated display device of claim **8** wherein the metal oxides are selected from silicon oxide, aluminum oxide, titanium oxide, indium oxide, tin oxide, indium tin oxide, tantalum oxide, zirconium oxide, niobium oxide, and combinations thereof.

10. The encapsulated display device of claim **8** wherein the metal nitrides are selected from aluminum nitride, silicon nitride, boron nitride, and combinations thereof.