(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
17 November 2005 (17.11.2005)

PCT

(10) International Publication Number
WO 2005/108215 A2

(51) International Patent Classification[7]: B65D 1/00

(21) International Application Number: PCT/US2005/014715

(22) International Filing Date: 2 May 2005 (02.05.2005)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
10/838,701 4 May 2004 (04.05.2004) US

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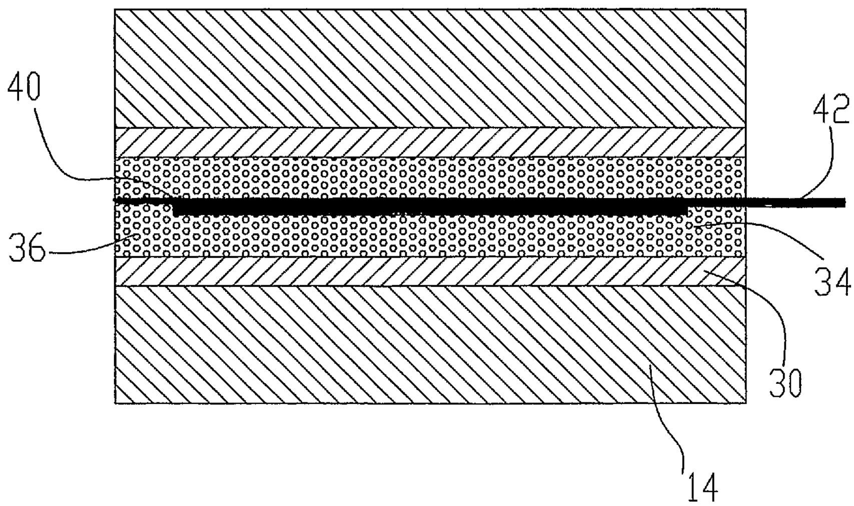
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii)) for the following designations AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA,*

[Continued on next page]

(54) **Title:** COMPOSITE MODULAR BARRIER STRUCTURES AND PACKAGES



(57) **Abstract:** A composite multi-layer barrier is produced by first vapor depositing a barrier (30,32) under vacuum over a substrate of interest (14) and then depositing an additional barrier at atmospheric pressure in a preferably thermoplastic layer (34). The resulting multi-layer barrier is then used to coat an article of interest (40) in a lamination process wherein the thermoplastic layer (34) is fused onto itself and the surface of the article. The vacuum-deposited barrier may consists of a first leveling polymer layer (46) followed by an inorganic barrier material (30) sputtered over the leveling layer and of an additional polymeric layer (32) flash evaporated, deposited, and cured under vacuum. The thermoplastic polymeric layer (34) is then deposited by extrusion, drawdown or roll coating at atmospheric pressure. The resulting multi-layer barrier may be stacked using the thermoplastic layer as bonding agent. Nano-particles (36) may be included in the thermoplastic layer to improve the barrier properties of the structure. A desiccant material may also be included or added as a separate layer (62).

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CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VC, VN, YU, ZA, ZM, ZW, ARIPO patent (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG)

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii)) for the following designations AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VC, VN, YU, ZA, ZM, ZW, ARIPO patent (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG)*

— *of inventorship (Rule 4.17(iv)) for US only*

Published:

— *without international search report and to be republished upon receipt of that report*

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COMPOSITE MODULAR BARRIER STRUCTURES AND PACKAGES

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] This invention is related in general to multi-layer transparent flexible barriers and to processes of manufacture for such barriers. In particular, the invention pertains to a composite barrier produced by vacuum as well as atmospheric deposition and a modular approach for using such a flexible barrier to produce transparent enclosures for encapsulating a flexible device with progressively higher levels of environmental protection.

Description of the Related Art

[0002] Inorganic and polymeric coatings deposited under vacuum or atmospheric conditions have been used for some time to promote desirable properties for particular applications. Multi-layer coatings of various combinations of materials have also been used to enhance the effectiveness of the coatings. Most notably, such coatings have been used successfully as barriers to moisture and oxygen permeability in packaging for foods and electronic devices.

[0003] Inorganic barrier layers consist of thin films of metals or ceramics (such as aluminum oxide, silicon oxide, indium tin oxide, etc.) deposited onto appropriate substrates by a variety of known processes, most notably by sputtering, chemical vapor deposition or physical vapor deposition. Organic polymeric barriers may be similarly produced by evaporating monomers or oligomers in vacuum, depositing the vapor to produce a film over a substrate, and curing the film to form a polymeric barrier. Inorganic and organic layers are often combined in multi-layer barriers to decrease permeability and/or add further functionalities to the barrier structure.

[0004] Flexible barriers may be transparent or opaque. Transparent barriers are used in applications where the product needs to be visible or where light must enter or exit the enclosed package. Such applications include, for example, food, medical and chemical packages, information displays, lights, and photovoltaic devices. Flexible transparent barriers utilize a combination of polymer layers with thin inorganic coatings that are transparent. Opaque barriers are used in packages where light transmission is not necessary. Opaque barriers are commonly produced using metal foils, such as aluminum, laminated with polymer layers.

[0005] Barriers have also been produced by mixing inorganic materials, such as metals, oxides and other ceramics, in a liquid monomer/oligomer and curing it to form a polymeric composite that is then used as a barrier material. In the case of a thermoplastic polymer, the material may be applied as a coating by a variety of application processes, such as extrusion, drawdown or roll coating, over the article of interest. Thermoset polymers, on the other hand, are first deposited as a layer over the article and then crosslinked to form the desired barrier.

[0006] As barrier coatings have increasingly become a normal part of manufacturing processes, the specifications for low permeability to oxygen and moisture have also become more and more stringent. That is particularly true in the evolving field of flexible displays, photovoltaic devices and flexible solid-state lights that utilize organic light emitting diodes and corrosion sensitive electrode systems where enclosures with very high barrier levels are required. Current flexible barrier designs focus on the use of specific single or multi-layer barrier structures that are deposited or laminated onto a device that is fabricated on a similar barrier sheet. However, device fabrication on a barrier layer imposes additional limitations to the barrier sheet properties, such as temperature and thermo-mechanical stability. Therefore, there is a continuing need for improved barrier structures that can be used to meet different performance specifications as needed in a commercial environment and for improved methods of producing device enclosures that are independent of or can withstand device manufacturing conditions.

BRIEF SUMMARY OF THE INVENTION

[0007] In view of the foregoing, the present invention consists of a flexible enclosure that is at least partially transparent and is designed to encapsulate a flexible electrical device that requires light transmission through at least part of the barrier walls of the enclosure. According to one aspect of the invention, a flexible device with electrical leads is encapsulated using two multi-layer barrier sheets that incorporate a thermoplastic layer or glue material. Each barrier sheet has a surface area larger than the device and is laminated onto the device and the other sheet on the back side of the device, thereby forming a protective enclosure that is transparent on at least one side of the device. The enclosure may also contain additional barrier reinforcement at the edges and a form of desiccant material to prolong the life of the enclosed device. In this manner, the barrier used to produce the packaging enclosure and the device are produced independent of each other. The device's electrical leads, which may be in the form of metalized or printed conductors on a flexible substrate, are allowed to exit on one or more sides of the enclosure.

[0008] Each composite barrier sheet may consist of one of several barrier structures that result in different levels of barrier performance. Such multi-layer structures may also be laminated onto themselves to produce different barrier sheets with much higher barrier properties than achievable with the single multi-layer structure.

[0009] In one such barrier structure, an inorganic transparent barrier layer is vacuum-deposited over a polymeric film substrate. A layer of thermoplastic polymer is then deposited by extrusion, drawdown or roll coating at atmospheric pressure over the vacuum-deposited layer to yield a multi-layer barrier according to the invention. This composite layer preferably also incorporates inorganic nano-particles particles or nano-flakes to further reduce its permeability without blocking light transmission in and out of the enclosure. The barrier also preferably incorporates a desiccant material either in the form of nano-particles, which may be included in the thermoplastic layer or may be in the form of a film attached to another layer, or as regular desiccant or water-retaining material otherwise encased in the package in a way that does not affect its transparency where required for the functionality of the enclosed device.

[0010] According to another aspect of the invention, the resulting composite barrier is stacked to form a thicker and progressively less permeable barrier either by repeating the deposition process in multiple passes or by fusing the single barrier structure into a stack using the thermoplastic nature of its last layer. This attribute of the composite barrier makes it possible to use the same product for multiple commercial applications having differing permeability specifications. Therefore, the composite barrier provides a flexibility of application heretofore unknown in the art.

[0011] In another embodiment of this barrier structure, an inorganic barrier layer is first deposited onto a polymeric substrate by vacuum deposition. A protective radiation-cured polymer layer is then deposited onto the inorganic barrier layer in vacuum and inline with the inorganic layer. A layer of thermoplastic polymer is then deposited over the thermoset polymer by extrusion, drawdown or roll coating at atmospheric pressure, preferably also incorporating inorganic nano-particles or nano-flakes to further reduce its permeability and/or absorb moisture. The layer of radiation-cured polymer protects the inorganic layer and acts to promote adhesion of the subsequent nano-composite layer.

[0012] In yet another embodiment of this barrier structure, a radiation-cured polymer layer is first deposited in vacuum prior to the deposition of the inorganic layer. This crosslinked layer is used to cover defects on the surface of the polymeric substrate, such as to block low molecular weight species (such as oligomers) that interfere with the nucleation and adhesion of the inorganic barrier layer. The remaining layers are then deposited according to either of the processes outlined above.

[0013] All of the barrier structures so described may be laminated onto a device or onto each other to form a barrier sheet that is then used to form the enclosure for a device or any article of manufacture. According to another aspect of the invention, transparent barrier sheets may be laminated with a metal-foil-based opaque barrier sheet on opposite sides of a device, thereby providing transparency on the side where it is required by the operation of the device while retaining the higher and less expensive barrier function of the opaque layer on the other side of the device. In such types of enclosure, the more flexible foil-based barrier sheet can be folded over the transparent barrier sheet to minimize gas and vapor transmission though the edges of the enclosure. An edge protector strip may be used to further protect the seal between barrier sheets.

[0014] According to yet another aspect of the invention, a composite nano-desiccant layer is produced by dispersing desiccant nano-particles in a transparent polymer binder, which may be the thermoplastic layer of the invention, thereby producing a highly water retaining and hydrophilic layer. The polymer nano-desiccant composite is then coated on the surface of the barrier sheet, thus forming a transparent layer that has very high moisture absorption properties. Alternatively, the desiccant nano-particles may be coated directly onto a barrier layer or may be applied to a support transparent resin layer which is added to the barrier sheet. A separate desiccant layer may also be placed between the barrier sheet and the device prior to the lamination process. Still alternatively, a transparent nano-desiccant layer may be coated on the barrier sheet inside the sealing area prior to the lamination process.

[0015] In all cases, the device enclosure produced according to the invention is evacuated prior to the sealing process to remove moisture. In addition, after the device is laminated between two barrier sheets, an edge guard strip with high barrier properties and desiccant features is preferably laminated or otherwise attached over the edges to provide added protection against oxygen and moisture infiltration.

[0016] Various other purposes and advantages of the invention will become clear from its description in the specification that follows and from the novel features particularly pointed out in the appended claims.

Therefore, to the accomplishment of the objectives described above, this invention consists of the features hereinafter illustrated in the drawings, fully described in the detailed description of the preferred embodiment and particularly pointed out in the claims. However, such drawings and description disclose but one of the various ways in which the invention may be practiced.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] Fig. 1 is a schematic representation of a manufacturing apparatus combining a vacuum vapor deposition chamber with an atmospheric deposition unit to produce the composite barrier of the invention.

[0018] Fig. 2 is a schematic view of the multi-layer structure of a composite barrier according to the invention.

[0019] Fig. 3 is a schematic view illustrating a device sandwiched between two barrier sheets of the multi-layer structure of Fig. 2.

[0020] Fig. 4 is a schematic view of another multi-layer structure according to the invention wherein the thermoplastic layer is shown without nano-particles.

[0021] Fig. 5 is a schematic view illustrating a device sandwiched between two barrier sheets of the multi-layer structure of Fig. 4 wherein nano-particles have been added to the thermoplastic layer.

[0022] Fig. 6 is a schematic view of a stacked multi-layer structure of the composite barriers of the invention.

[0023] Fig. 7 is a schematic view of another multi-layer structure according to the invention.

[0024] Fig. 8 illustrates in front elevation and in plan views an optical sensor sandwiched between two sheets of a stacked multi-layer barrier structure manufactured according to the invention.

[0025] Fig. 9 is a schematic view of a device laminated with the stacked multi-layer structure of the invention wherein edge protector strips are used to encapsulate the package.

[0026] Fig. 10 is a schematic view of a device laminated with the stacked multi-layer structure of the invention wherein desiccant layers are added between the device and the laminating sheets.

[0027] Fig. 11 is a schematic view of the device of Fig. 9 wherein desiccant material is added within the edge protector strips.

[0028] Fig. 12 is a schematic view of a laminated device wherein the stacked multi-layer structure of the invention is used to frame and seal a conventional barrier on the transparent side of the device.

DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

[0029] The invention lies in a new combination of barrier layers that is found to provide improved oxygen and moisture barrier performance and greater flexibility of application as a packaging cover over articles with different permeability specifications and transparency requirements. Rather than utilizing a different barrier and a different deposition process tailored to each product specification, the composite barrier of the invention may be used in modular fashion to achieve the desired level of performance for a multitude of package applications. As a result of the invention, articles that need a transparent package with different barrier requirements may be coated with the same process in different multiple-pass operations.

[0030] As used herein, "vacuum deposition" is intended to cover any deposition process wherein a substance is first vaporized under vacuum and then deposited as a thin-film layer over a cold substrate, which could be a web or film of a material with desirable characteristics intended to be incorporated into the final product, or a cold drum in the vapor deposition chamber. Such vacuum deposition processes include sputtering, reactive sputtering and physical vapor deposition as well as conventional flash evaporation. "Atmospheric deposition" is used primarily to refer to processes that do not involve the prior vaporization of the material being deposited, such as, without limitation, extrusion, drawdown or gravure roll coating, but it could also refer to vapor deposition processes carried out at atmospheric pressure, such as disclosed in U.S. Patent No. 6,118,218. The term "monomer" is intended to also include oligomers suitable to practice the disclosed processes within the scope of the invention. The term "thin film" is intended to encompass any layer of material with a thickness in the order of microns or sub-microns, the thickness typically consisting of inorganic or polymeric films produced by vapor deposition processes. "Nano-particles" and "nano-flakes" are terms used to refer to particles of any shape having a nominal diameter in the order of a few hundred nanometers (less than one micron and smaller), and "nano-particles" is used to refer to both nano-particles and nano-flakes. "Nano-composite" layer is used to denote a resin layer containing nano-particles or a nano-particle layer applied to another layer in the composite structure of the invention. The term "desiccant" is used generically to refer to true desiccant materials, as understood in the art, as well as to water-retaining polymers and other water-retaining materials. The term "barrier" material refers to any material used to decrease water and/or oxygen permeability. Finally, nano-particles may consist of barrier material as well as desiccant material, as these have been defined herein.

[0031] Referring to the figures, wherein like parts are identified with like reference numerals and symbols, Fig. 1 illustrates schematically a multi-layer deposition apparatus 10 for practicing the present invention. The apparatus consists of a conventional vacuum vapor-deposition chamber 12 wherein a web or film substrate 14 is passed to receive one or more layers of vapor deposited material. In the preferred embodiment of the invention, the substrate 14 is a polyester or polycarbonate film, with high transmittance and abrasion-resistance characteristics that render it suitable as a protective outer layer for packaging an article of manufacture. Depending on the particular barrier of interest, different conventional vapor deposition units are used in the vacuum chamber 12. For example, the substrate 14 may be passed through an inorganic deposition unit 16, such as a resistive evaporator, or a sputtering or electron beam evaporation unit, wherein a metal, metal oxide, or any other ceramic (transparent or not, depending on the requirements of the application) is deposited to form a thin barrier film (in the order of 100-1000 angstroms). The substrate may then be passed through a conventional flash-evaporation section 18, wherein a monomer, such as an acrylate monomer, is vaporized and deposited over the metallic or ceramic film as a liquid layer upon contact with a cold drum 20. The monomer is also deposited as a thin film about 0.1 to 1.0 micron in thickness. The monomer film is then cured by exposure to an electron-beam or ultraviolet radiation source 22. It is noted that this layer of crosslinked polymer, while preferred, is not necessary to practice the various aspects of the present invention.

[0032] According to the invention, the two-layer barrier so constructed is then removed from the vacuum chamber and, under atmospheric conditions, an additional layer of thermoplastic material is added over the vacuum-deposited polymeric film (or the inorganic film, if no polymeric film is deposited). This layer is deposited using an extrusion or equivalent process in a conventional atmospheric-deposition unit 24 combined with the vacuum chamber 12. This third layer is added to provide a mechanism for laminating the barrier over articles of interest and for stacking multiple barrier layers to improve the barrier characteristics of the final sheet to the desired specifications. To this end, the layer deposited at atmospheric pressure preferably consists of a vinyl polymeric resin in a thickness ranging from 5 to 100 microns.

[0033] Because the layer deposited at atmospheric pressure is not vaporized, it can be used as a carrier of particles that add desirable properties to the product. For example, metallic nano-particles or nano-flakes can be added advantageously to the thermoplastic layer to further reduce the permeability of the barrier to moisture and oxygen without affecting the atmospheric process of deposition of the resulting mixture over the multi-layer structure produced in the vacuum chamber. The nano-particles or flakes are mixed uniformly into the thermoplastic material (normally prior to its polymerization, although they could also be mixed in the heated polymer) and the polymer is deposited as a hot fluidized film to adhere over the acrylate vapor-deposited layer. In order to retain as much transparency as possible, it is preferred to limit the thickness of the resulting nano-composite layer to about 20 microns. Thus, a composite barrier structure is produced in a semi-continuous process wherein the substrate is first advanced from a feed roller 26 to a take-up roller 28, and then it is passed through an atmospheric deposition unit 24 to yield the multi-layer barrier structure of the invention.

[0034] Fig. 2 illustrates the multi-layer barrier resulting from the dual deposition process described in Fig. 1. It is noted that all layers are shown in the figures for illustration purposes only in thicknesses that are necessarily disproportionate to their actual dimensions. The thin film of metallic barrier 30 is sandwiched between the substrate film 14 and the polymer thin film 32. The thicker thermoplastic layer 34 containing uniformly distributed nano-particles 36 completes the structure in the form of a multi-layer sheet 38 in roll form. This sheet product can then be used to laminate articles of manufacture, such as electronic components, photovoltaic devices, batteries, organic light emitting diodes (OLEDs), displays etc., simply by adhering the thermoplastic layer 34 to the surface of the article, as illustrated in Fig. 3. In addition, the nano-particles or nano-flakes embedded in the thermoplastic layer provide an additional barrier to oxygen and moisture permeability which has been found to improve the performance of conventional barriers to a greater extent than expected while retaining up to 90 percent of the transparency of the thermoplastic layer. Thus, the addition of the thermoplastic layer 34 to the vacuum-deposited barrier layers 30,32 provides the dual advantage of a barrier product that is suitable for lamination without the use of glues and is substantially improved in its permeability-barrier performance while remaining suitable for applications that require transparency. Fig. 4 illustrates the same type barrier wherein the thermoplastic layer (without nano-particles) is deposited directly over the inorganic layer for lamination purposes.

Fig. 5 shows the same barrier with the addition of nano-particles and laminated over a device 40 with electrical leads 42 protruding from the barrier material for connection to a receiving apparatus.

[0035] Another advantage of the barriers of the invention is that they can be readily stacked in multiple composite-barrier layers to reduce permeability essentially to any degree needed for a particular application. It has been found that each additional layer of a barrier such as illustrated in Figs. 2 and 4 produces a comparable and predictable reduction in permeability both to oxygen and moisture. For example, each subsequent layer produces about the same percentage reduction or a progressively reduced percentage of reduction that can be empirically quantified and used as a predictor of performance in a stacked barrier. These properties can be used advantageously to reduce the cumulative permeability to essentially any desired specification. Fig. 6 illustrates a three-layer stack 44 of such a barrier product. (A darker layer is used to illustrate the structural adhesion between layers.) It is noted that because of the presence of a thermoplastic layer 34 in the stack 44, it can be still laminated to an article of manufacture as described above.

[0036] The substrate layer 14, which is intended to constitute the outer layer in a laminated product, is selected according the properties desired for each specific application. For example, if transmittance is important, the substrate may consist of an optical grade polyester or polycarbonate; if thermal stability is important, the substrate may be heat resistant arylite or polycarbonate; etc., as one skilled in the art would readily understand. In general, the substrate is selected, without limitation, from polyesters, polycarbonates, polyarylites, polyphenylene sulfides, polycycloaliphatics, polyacrylates, polystyrenes, polyurethanes, polyolefins, or cellulose-based films, Similarly, the inorganic barrier layer 30 may be selected, without limitation, from aluminum, aluminum oxide, silver, silicon oxide, indium, indium tin oxide (ITO), nickel, gold, metal nitrides (such as aluminum and silicon), oxynitrides (such as aluminum), or metal carbides (such as silicon), as best suited for a particular application. The polymer layer 32 may consist, without limitation, of polyacrylates, polyvinyls, epoxy polymers, polycycloaliphatics, or fluorocarbon polymers. The outer thermoplastic layer 34 may be, without limitation, a polyvinyl acetate, or any polymer from the groups of polybuterates, polyolefin, polyacrylates, polyurethanes, epoxy polymers, polyesters, polycarbonates, polycycloaliphatics, polyvinyl ethers, polyvinyl alcohols, silicones, fluorosilicone polymers, rubbers, or ionic polymers, again based on particular needs or constraints, as may be related to the lamination process. The nano-particles or nano-flakes may consist, without limitation, of alumina, silica, mica, silver, indium, nickel, gold, aluminum suboxide, aluminum oxynitride, titania. Silicon suboxide, silicon carbide, silicon oxynitride, indium zinc oxide or indium tin oxide, or other metal-based particles, preferably less than about 2 microns in average nominal diameter. It is understood that a thermoset polymer containing inorganic nano-particles could also be used to make up the layer 34, but in such case the composite barrier would no longer be suitable for lamination without the use of adhesives, which may not be acceptable for certain applications. Such a thermoset outer layer would have to be prepared by first incorporating the inorganic nano—particles into the liquid monomer, depositing the mixture as a liquid at atmospheric pressure over the vacuum-formed polymeric layer, and then curing the liquid monomer to produce the polymeric thermoset layer.

[0037] It is noted that various combinations of vacuum-deposited inorganic and organic layers and atmospheric-deposited thermoplastic or thermoset layers may be used within the scope of the invention to achieve particular results. For example, an additional radiation-cured polymer layer 46 may be deposited in vacuum over the substrate 14 prior to the deposition of the inorganic layer 30, as illustrated in Fig. 7. This crosslinked layer is used to cover defects on the surface of the polymeric substrate that might interfere with the nucleation and adhesion of the inorganic barrier layer. Such leveling layer preferably consists of a polymer selected from the group consisting of acrylates, vinyl polymers, bicycloaliphatics, diepoxy polymers, fluoropolymers and polysiloxanes, or a combination of them. The leveling layer could also consist of a polymer deposited at atmospheric pressure. The following examples illustrate the invention:

Example 1 (Figure 4)

[0038] An inorganic barrier layer composed of aluminum oxide was deposited by electron beam evaporation on a 15 micron thick film substrate of polyester in a vacuum deposition chamber at a vacuum level about 10^{-4} torr, to form a 200 angstrom of barrier film. A layer of polyvinylidene fluoride thermoplastic polymer was deposited on the aluminum oxide barrier at atmospheric pressure and the one layer barrier sheet structure was measured for moisture barrier. The structure was then laminated onto itself to form a two layer and a four layer barrier sheet. The moisture barrier of the different barrier sheets was as follows:

Barrier	MVTR, 38°C, 90%RH ($g/m^2/day$)
One Layer barrier Sheet	0.3 -0.4
Two layer barrier sheet	0.03
Three layer barrier sheet	<0.001

Example 2

[0039] An inorganic barrier layer composed of indium tin oxide was deposited by a sputtering process over a 125 micron thick film substrate of polyester in a vacuum deposition chamber at a vacuum level of 30 millitorr to form a 500-angstrom barrier film. The resulting structure was then removed from the vacuum chamber and processed at atmospheric pressure to deposit a nano-composite layer of thermoplastic polyurethane deposited over the barrier layer. The thermoplastic polyurethane resin had previously been prepared by mixing aluminum-oxide nano-particles, less than 100 nm in size, in the liquid polyurethane resin (about 10 grams of particles per 90 grams of resin) and curing the coating to produce the nano-composite laminating barrier layer. The resulting barrier produced the following moisture permeability results, alone and in multiple-layer stacks:

Barrier	MVTR, 38°C, 90%RH ($g/m^2/day$)
ITO Barrier Layer only	0.206
Single barrier sheet of ITO/Nanocomposite layer	0.10
Three Layer Barrier sheet	<0.001

Example 3 (Figure 2)

[0040] A 0.5-micron thick radiation-cured acrylate polymer layer was deposited in a vacuum chamber on a 50-micron thick polycarbonate film substrate at a pressure of about 5x10-4 torr. An inorganic barrier layer composed of indium tin oxide was deposited by a sputtering process over the radiation cured polymer layer in a vacuum deposition chamber at a vacuum level of 30 millitorr to form a 500-angstrom barrier film. The resulting structure was removed from the vacuum chamber and processed at atmospheric pressure to deposit a nano-composite layer of thermoplastic polyurethane polymer deposited over the barrier layer. The thermoplastic polyurethane resin had previously been prepared by mixing aluminum-oxide nano-particles, less than 100 nm in size, in the liquid polyurethane resin (about 10 grams of particles per 90 grams of resin) and curing the coating to produce the nano-composite laminating barrier layer. The moisture barrier of the resulting single and double-layer stack yielded the following moisture permeability parameters:

Barrier	MVTR, 38°C, 90%RH (g/m^2/day)
Polycarbonate /radiation cured polymer/ITO/ nano-composite layer of thermoplastic polyurethane	0.03
Barrier sheet with two of the above layers	<0.001

Example 4 (structure B, Figure 2)

[0041] An inorganic barrier layer composed of indium tin oxide was deposited by a sputtering process in a vacuum deposition chamber at a vacuum level of 30 millitorr to form a 500-angstrom barrier film. A 0.5-micron thick radiation-cured acrylate polymer layer was deposited in the vacuum chamber on the inorganic barrier layer at a pressure of about 5x10-4 torr. The resulting structure was removed from the vacuum chamber and processed at atmospheric pressure to deposit a nano-composite layer of thermoplastic polyurethane polymer deposited over the barrier layer. The thermoplastic polyurethane resin had previously been prepared by mixing aluminum-oxide nano-particles, less than 100 nm in size, in the liquid polyurethane resin (about 10 grams of particles per 90 grams of resin) and curing the coating to produce the nano-composite laminating barrier layer. The moisture barrier of the resulting single and double-layer stack yielded the following moisture permeability parameters:

Barrier	MVTR, 38°C, 90%RH (g/m^2/day)
Polycarbonate /ITO/ radiation cured polymer / nano-composite layer of thermoplastic polyurethane	0.05
Barrier sheet with two of the above layers	<0.001

Example 5 (Figure 7)

[0042] A 0.5-micron thick radiation-cured polymer layer was deposited in a vacuum chamber on a 50-micron thick polycarbonate film substrate at a pressure of about $5x10^{-4}$ torr. An inorganic barrier layer composed of indium tin oxide was deposited by a sputtering process over the radiation cured polymer layer in a vacuum deposition chamber at a vacuum level of 30 millitorr to form a 500-angstrom barrier film. A second radiation cured polymer layer was then deposited in vacuum over the inorganic barrier layer. The resulting structure was then removed from the vacuum chamber and processed at atmospheric pressure to deposit a nano-composite layer of thermoplastic polyurethane polymer deposited over the barrier layer. The thermoplastic polyurethane resin had previously been prepared by mixing aluminum-oxide nano-particles, less than 100 nm in size, in the liquid polyurethane resin (about 10 grams of particles per 90 grams of resin) and curing the coating to produce the nano-composite laminating barrier layer. The resulting structure was then measured for moisture barrier. The moisture barrier of the resulting single and double-layer stack yielded the following moisture permeability parameters:

Barrier	MVTR, 38°C, 90%RH ($g/m^2/day$)
Polycarbonate /radiation cured polymer/ITO radiation cured polymer / nano-composite layer of thermoplastic polyurethane	0.01
Barrier sheet with two of the above layers	<0.001

[0043] These results illustrate the improvements produced by the composite barriers of the invention over the prior art and the incremental reduction in permeability yielded by the successive addition of a composite layer to a stack. The functionality of the reduction data can be used to predict the number of layers needed in a stack to produce the desired permeability characteristics. For instance, the barrier of the various structures of Example 2 is particularly suited for the following applications, with the corresponding properties listed below:

Barrier	MVTR, 38°C, 90%RH ($g/m^2/day$)	Application
One Layer barrier Sheet	0.3 -0.4	Food and medical
Two layer barrier sheet	0.03	Electronic parts, EL, batteries, photovoltage and LCD
Three layer barrier sheet	<0.001	OLED, PLED

[0044] Thus, the transparent barrier structures of the invention can be used advantageously to seal and protect electronic and other devices by a process of lamination that completely encloses the device. Because of the thermoplasticity of the atmospheric barrier layer, the barrier is easily adhered to the surface of the device while permitting electrical leads to emerge from the package for connection to receiving apparatus. Where transparency is important for a particular device, multiple-layer structures with nano-particles may be used on the side of the device requiring optical transmittance, while a conventional opaque barrier may be used on the other side. For example, Fig. 8 illustrates a multi-pixel light source 50 (or, equivalently, a light sensor) supported by a substrate 52 and sandwiched between two sheets of a stacked multi-layer structure 54, wherein at least the top portion of the structure is transparent. The electrical leads 56 of the device 50 are conveniently kept in place by the adhering layers of the barrier material.

[0045] Similarly, as illustrated in Fig. 9, an edge seal 58 is formed by the adhesion of the thermoplastic layer in the stacks used to laminate the device. If the device application requires particular structural strength at the edges and avoiding edge separation is crucial to the performance of the device, an edge strip protector 60 may also be installed to frame and encapsulate the package, as shown in the figure.

[0046] As indicated above, a desiccant material may also be combined (preferably with the adhering layer of the invention) to promote drying, dehydration or water/moisture trapping. For example, inorganic desiccants such as calcium chloride particles, calcium sulfate particles, or phosphorus pentoxide particles may be used. Water-retaining polymers such as hydrogels may also be used. Such desiccants and polymers in nano-particle form are preferably deposited as a thin layer between the thermoset radiation-cured polymer and the sealing thermoplastic layer. Alternatively, the desiccant or polymer layer may be deposited between the inorganic barrier layer and the sealing thermoplastic layer. Fig. 10 illustrates a hybrid application wherein a top desiccant layer 62 is placed between the device 50 and a transparent multi-layer top stack 54 manufactured according to the invention. A bottom desiccant layer 64 is similarly placed between the bottom stack and the bottom side of the support substrate 52 for the device 50 and may be combined with an opaque polymeric or inorganic layer (such as a conventional barrier layer), if transparency is not required.

[0047] Desiccant material 66 may also be packed within the edge protector strips 60, as illustrated in Fig. 11. In such cases, these desiccant materials are also used for improving the seal at the edge. Similarly, the water-retaining polymers can be used as well as binders or as dispersing matrices for the inorganic desiccant powders. The desiccant layer can consist of a very thin layer (less than about 0.1 micron) of inorganic desiccant fine powder applied over another barrier layer, or a thin layer (less than about 2.0 micron) of water-retaining polymer applied over another barrier layer, or desiccant fine-powder or polymer nano-particles blended in the thermoplastic sealing layer (up to about 10-micron thick), or desiccant fine powder nano-particles blended in a water-retaining polymer layer (for example, polyacrylamide or phosphate functionalized polyacrylate also in a layer up to about 10-micron thick) and applied over another barrier layer. Such barriers are illustrated in the following examples.

Example 6

[0048] An inorganic barrier layer composed of indium tin oxide was deposited by a sputtering process over a 125 micron film substrate of polyester in a vacuum deposition chamber at a vacuum level of 30 millitorr to form a 500-angstrom barrier film. The resulting structure was removed from the vacuum chamber and processed at atmospheric pressure to deposit a desiccant layer composed of 10% very fine calcium chloride powder in 90% polyacrylamide. After curing, a nano-composite layer of thermoplastic polyurethane polymer was deposited over the desiccant layer. The thermoplastic polyurethane resin had previously been prepared by mixing aluminum-oxide nano-particles, less than 100 nm in size, in liquid polyurethane resin (about 10 grams of particles per 90 grams of resin). The coating was then cured to produce the nano-composite laminating barrier layer. The resulting barrier produced the following moisture permeability results, alone and in multiple-layer stacks:

Barrier	MVTR, 38°C, 90%RH ($g/m^2/day$)
ITO Barrier Layer only	0.206
Single barrier sheet of ITO/ desiccant layer / Nanocomposite layer	0.01
Three Layer Barrier sheet	<0.001

Example 7

[0049] A 0.5-micron thick radiation-cured polymer layer was deposited in a vacuum chamber on a 50-micron thick polycarbonate film substrate at a pressure of about 5x10-4 torr. An inorganic barrier layer composed of indium tin oxide was deposited by a sputtering process over the radiation-cured polymer layer in a vacuum deposition chamber at a vacuum level of 30 millitorr to form a 500-angstrom barrier film. A second radiation cured polymer layer was deposited over the inorganic barrier layer. The material was then removed from the vacuum chamber and processed at atmospheric pressure to deposit a desiccant layer composed of 10% very fine calcium chloride powder in 90% polyacrylamide. The moisture permeability of the barrier in the resulting single and double-layer stacks was undetectable.

Example 8 (polymer desiccant layer)

[0050] An inorganic barrier layer composed of indium tin oxide was deposited by a sputtering process in a vacuum deposition chamber at a vacuum level of 30 millitorr to form a 500-angstrom barrier film. A 0.5-micron thick radiation-cured acrylate polymer layer was deposited in the vacuum chamber on the inorganic barrier layer at a pressure of about 5x10-4 torr. The resulting structure was removed from the vacuum chamber and processed at atmospheric pressure to deposit a desiccant layer of crosslinked water retaining polyamide deposited over the first polymer layer. Another nano-composite layer of thermoplastic polyurethane polymer was deposited over the desiccant layer. The thermoplastic polyurethane resin had previously been prepared by mixing aluminum-oxide nano-particles, less than 100 nm in size, in the liquid polyurethane resin (about 10 grams of particles per 90 grams of resin) and curing the coating to produce the nano-composite laminating barrier layer. The moisture barrier of the resulting single and double-layer stack yielded the following moisture permeability parameters:

Barrier	MVTR, 38°C, 90%RH ($g/m^2/day$)
Polycarbonate /ITO/ radiation cured polymer / desiccant polymer/ nano-composite layer of thermoplastic polyurethane	0.03
Barrier sheet with two of the above layers	<0.001

[0051] These examples further illustrate the effectiveness of the composite barrier of the invention for different applications. While the vacuum-deposited component of the composite barriers is illustrated throughout mostly as an inorganic-polymeric two-film structure, it is understood that various additional layers could be deposited under vacuum within the scope of the invention. Similarly, the process of stacking the composite barriers using the thermoplastic layer as a binder has been described as a separate operation from the process of manufacture of each single composite barrier, but it could be performed as well by successively repeating the various deposition steps. Moreover, the lamination process using the composite barrier of the invention is preferably conducted under vacuum as well in order to further improve adhesion and eliminate the presence of oxygen from the resulting package. For example, the lamination process may be conducted in vacuum by wrapping two barrier sheets over an article and sealing them in the vacuum chamber, or in atmospheric conditions by introducing a vacuum source (such as a suction tube) within the package formed by the two barrier sheets as the package is being sealed.

[0052] Various changes in the details, steps and components that have been described may be made by those skilled in the art within the principles and scope of the invention herein illustrated and defined in the appended claims. For example, Fig. 12 illustrates a combination of a transparent barrier 70 according to the invention (or a conventional transparent barrier) with one of the multi-layer stacks described above, wherein the latter's thermoplastic layer is used to overlap, enclose and seal the device 50 and the barrier 70 from water and moisture permeability. The top side of the device is covered with the transparent barrier 70, which is framed by the multi-layer barrier of the invention 54 along the edges of the package, while the bottom side may be transparent or not, depending on the operational needs of the device. The thermoplastic layer 34 is used to form a seal 72 between the barrier 70 and the barrier 54, while the overlap seals the edges of the package. Alternatively, a conventional opaque barrier could be used below the device and a transparent barrier sheet according to the invention could be folded downward to overlap, enclose and seal in reverse of the structure illustrated in Fig. 12.

[0053] Therefore, while the present invention has been shown and described herein in what is believed to be the most practical and preferred embodiments, it is recognized that departures can be made therefrom within the scope of the invention, which is not to be limited to the details disclosed herein but is to be accorded the full scope of the claims so as to embrace any and all equivalent processes and products.

We claim:

1. A multi-layer barrier package with 90% or less transparency for a device with a side requiring light exposure, said package comprising, in combination:

a multi-layer barrier sheet including

a substrate film,

an inorganic barrier layer applied over the substrate film; and

a nano-composite layer applied over the inorganic barrier layer;

a device with a side requiring light exposure adhered to said nano-composite layer; and

a barrier structure sealingly connected to said multi-layer barrier sheet so as to encapsulate the device.

2. The barrier package of Claim 1, wherein said nano-composite layer comprises a thermoplastic resin.

3. The barrier package of Claim 1, wherein said nano-composite layer comprises inorganic nano-particles in a thermoplastic resin.

4. The barrier package of Claim 1, wherein said barrier structure is said multi-layer barrier sheet.

5. The barrier package of Claim 2, wherein said barrier structure is said multi-layer barrier sheet.

6. The barrier package of Claim 1, further comprising a desiccant material incorporated within the barrier package.

7. The barrier package of Claim 1, further comprising an edge protector strip sealingly coupling said barrier sheet and barrier structure.

8. The barrier package of Claim 7, further comprising a desiccant material incorporated within the edge protector strip.

9. The barrier package of Claim 1, further including a polymeric layer applied between said inorganic barrier layer and said nano-composite layer.

10. The barrier sheet of Claim 1, further comprising a leveling polymer layer applied between said substrate film and said inorganic barrier layer.

11. The barrier package of Claim 1, wherein said nano-composite layer comprises a thermoplastic resin; and further including a polymeric layer applied between said inorganic barrier layer and said nano-composite layer, and a leveling polymer layer applied between said substrate film and said inorganic barrier layer.

12. The barrier package of Claim 11, further comprising a desiccant material incorporated within the barrier package.

13. The barrier package of Claim 1, wherein said substrate film comprises a material selected from the group consisting of polyesters, polycarbonates, polyarylites, polyphenylene sulfide, polycycloaliphatics,

polyacrylates, polystyrenes, polyurethanes, polyolefins, or cellulose-based films.

14. The barrier package of Claim 1, wherein said inorganic barrier layer comprises a material selected from the group consisting of aluminum, silver, indium, nickel, gold, aluminum oxide, aluminum nitride, aluminum oxynitride, silicon oxides, silicon carbide, silicon nitride, silicon oxynitride, or indium tin oxide.

15. The barrier package of Claim 2, wherein said thermoplastic resin comprises a material selected from the group consisting of polyvinyl acetates, polybuterates, polyolefin, polyacrylates, polyurethanes, epoxy polymers, polyesters, polycarbonates, polycycloaliphatics, polyvinyl ethers, polyvinyl alcohols, silicones, fluorosilicone polymers, rubbers, or ionic polymers.

16. The barrier package of Claim 3, wherein said barrier nano-particles comprise a material selected from the group consisting of alumina, silica, mica, silver, indium, nickel, gold, aluminum suboxide, aluminum oxynitride, titania. silicon suboxide, silicon carbide, silicon oxynitride, indium zinc oxide or indium tin oxide.

17. The barrier package of Claim 9, wherein said polymeric layer comprises a material selected from the group consisting of polyacrylates, polyvinyls, epoxy polymers, polycycloaliphatics, or fluorocarbon polymers.

18. The barrier package of Claim 10, wherein said leveling polymer layer comprises a polymer selected from the group consisting of polyacrylates, vinyl polymers, bicycloaliphatics, diepoxy polymers, fluoropolymers and polysiloxanes.

19. The barrier package of Claim 12, wherein said desiccant material comprises a material selected from the group consisting of calcium chloride, calcium sulfate, phosphorus pentoxide, and water-retaining polymers.

20. A multi-layer barrier sheet with 90% or less transparency comprising, in combination:

a substrate film;

an inorganic barrier layer applied over said substrate layer; and

a nano-composite layer applied over said inorganic barrier layer.

21. The barrier sheet of Claim 20, wherein said substrate film comprises a material selected from the group consisting of polyesters, polycarbonates, polyarylites, polycycloaliphatics, polyphenylene sulfides, polyacrylates, polystyrenes, polyurethanes, polyolefins, or cellulose-based films.

22. The barrier sheet of Claim 20, wherein said inorganic barrier layer comprises a material selected from the group consisting of aluminum, silver, indium, nickel, gold, aluminum oxide, aluminum nitride, aluminum oxynitride, silicon oxides, silicon carbide, silicon nitride, silicon oxynitride, or indium tin oxide.

23. The barrier sheet of Claim 24, wherein said nano-composite layer comprises barrier nano-particles in a thermoplastic resin.

24. The barrier sheet of Claim 23, wherein said thermoplastic resin comprises a material selected from the group consisting of polyvinyl acetates, polybuterates, polyacrylates, polyolefin, polyvinyl alcohols, polyurethanes, epoxy polymers, polyesters, polycarbonates, polycycloaliphatics, polyvinyl ethers, silicones, fluorosilicone polymers, rubbers, or ionic polymers.

25. The barrier sheet of Claim 23, wherein said barrier nano-particles comprise a material selected from the group consisting of alumina, silica, mica, silver, indium, nickel, gold, aluminum suboxide, aluminum oxynitride, silicon suboxide, silicon carbide, silicon oxynitride, indium zinc oxide or indium tin oxide.

26. The barrier sheet of Claim 20, wherein said nano-composite layer comprises desiccant nano-particles in a thermoplastic resin.

27. The barrier sheet of Claim 26, wherein said thermoplastic resin comprises a material selected from the group consisting of polyvinyl acetates, polybuterates, polyacrylates, polyolefins, polyvinyl alcohols, polyurethanes, epoxy polymers, polyesters, polycarbonates, polycycloaliphatics, polyvinyl ethers, silicones, fluorosilicone polymers, rubbers, or ionic polymers.

28. The barrier sheet of Claim 26, wherein said desiccant nano-particles comprise a material selected from the group consisting of calcium chloride, calcium sulfate, phosphorus pentoxide, and water-retaining polymers.

29. The barrier sheet of Claim 20, wherein said nano-composite layer comprises a desiccant material.

30. The barrier sheet of Claim 20, wherein said nano-composite layer comprises barrier nano-particles in an adhesive layer.

31. The barrier sheet of Claim 20, wherein said nano-composite layer comprises a desiccant material in an adhesive layer.

32. The barrier sheet of Claim 20, wherein said substrate film comprises a material selected from the group consisting of polyesters, polycarbonates, polyarylites, polycycloaliphatics, polyacrylates, polyfenylene sulfides, polystyrenes, polyurethanes, polyolefins, or cellulose-based films; said inorganic barrier layer comprises a material selected from the group consisting of aluminum, silver, indium, nickel, gold, aluminum oxide, aluminum nitride, aluminum oxynitride, silicon oxides, silicon carbide, silicon nitride, silicon oxynitride, or indium zinc, oxide, indium tin oxide; and said nano-composite layer comprises barrier nano-particles in a thermoplastic resin that comprises a material selected from the group consisting of polyvinyl acetates, polybuterates, polyolefins, polyvinyl alcohol, polyacrylates, polyurethanes, epoxy polymers, polyesters, polycarbonates,

polycycloaliphatics, polyvinyl ethers, silicones, fluorosilicone polymers, rubbers, or ionic polymers.

33. The barrier sheet of Claim 20, further including a polymeric layer applied between said inorganic barrier layer and said nano-composite layer.

34. The barrier sheet of Claim 33, wherein said polymeric layer comprises a material selected from the group consisting of polyacrylates, polyvinyls, epoxy polymers, polycycloaliphatics, or fluorocarbon polymers.

35. The barrier sheet of Claim 20, further comprising a leveling polymer layer applied between said substrate film and said inorganic barrier layer.

36. The barrier sheet of Claim 33, further comprising a leveling polymer layer applied between said substrate film and said inorganic barrier layer.

37. The barrier sheet of Claim 20, further comprising a desiccant material incorporated within the barrier sheet.

38. The barrier sheet of Claim 33, further comprising a desiccant material incorporated within the barrier sheet.

39. The barrier sheet of Claim 35, further comprising a desiccant material incorporated within the barrier sheet.

40. The barrier sheet of Claim 36, further comprising a desiccant material incorporated within the barrier sheet.

41. A process for manufacturing a multi-layer barrier with 90% or less transparency comprising the following steps:

vacuum depositing an inorganic material to produce an inorganic barrier layer over a substrate film; and

applying a nano-composite layer over said inorganic barrier layer at atmospheric pressure.

42. The process of Claim 41, wherein said nano-composite layer comprises barrier nano-particles in a thermoplastic resin layer.

43. The process of Claim 41, further comprising the steps of vacuum depositing a monomer to produce a liquid film over said inorganic barrier layer and exposing the liquid film to a radiation source to produce a polymeric layer prior to the step of applying said nano-composite layer.

44. The process of Claim 41, further comprising the step of depositing a leveling monomer to produce a leveling liquid film over said substrate film to produce a leveling polymer layer prior to the step of vacuum depositing said inorganic material.

45. The process of Claim 43, further comprising the steps of vacuum depositing a leveling monomer to produce a leveling liquid film over said substrate film and exposing the leveling liquid film to a radiation source to produce a leveling polymer layer prior to the step of vacuum depositing said inorganic material.

46. The process of Claim 41, wherein said substrate film comprises a material selected from the group consisting of polyesters, polycarbonates, polyarylites, polycycloaliphatics, polyacrylates, polyfenylene sulfides, polystyrenes, polyurethanes, polyolefins, or cellulose-based films.

47. The process of Claim 41, wherein said inorganic barrier layer comprises a material selected from the group consisting of aluminum, silver, indium, nickel, gold, aluminum oxide, aluminum nitride, aluminum oxynitride, silicon oxides, silicon carbide, silicon nitride, silicon oxynitride, indium zinc oxide or indium tin oxide.

48. The process of Claim 42, wherein said inorganic barrier nano-particles comprise a material selected from the group consisting of alumina, silica, mica, silver, indium, nickel, gold, aluminum suboxide, aluminum oxynitride, silicon suboxide, silicon carbide, silicon oxynitride, indium zinc oxide or indium tin oxide.

49. The process of Claim 42, wherein said thermoplastic resin comprises a material selected from the group consisting of polyvinyl acetates, polybuterates, polyacrylates, polyurethanes, polyolefins, polyvinyl alcohols, epoxy polymers, polyesters, polycarbonates, polycycloaliphatics, polyvinyl ethers, silicones, fluorosilicone polymers, rubbers, or ionic polymers.

50. The process of Claim 43, wherein said polymeric layer comprises a material selected from the group consisting of

polyacrylates, polyvinyls, epoxy polymers, polycycloaliphatics, or fluorocarbon polymers.

51. The process of Claim 44, wherein said leveling polymer layer comprises a polymer selected from the group consisting of polyacrylates, vinyl polymers, bicycloaliphatics, diepoxy polymers, fluoropolymers and polysiloxanes.

52. The process of Claim 41, further comprising the step of incorporating a desiccant material within said multi-layer barrier.

53. A multi-layer barrier prepared according to the process of Claim 41.

54. A multi-layer barrier prepared according to the process of Claim 42.

55. A multi-layer barrier prepared according to the process of Claim 43.

56. A multi-layer barrier prepared according to the process of Claim 44.

57. A multi-layer barrier prepared according to the process of Claim 45.

58. A multi-layer barrier prepared according to the process of Claim 42.

59. A method of manufacturing a multi-layer barrier sheet comprising the steps of:

vacuum depositing an inorganic material to produce an inorganic barrier layer over a substrate film; and

melting a thermoplastic resin and depositing said resin over said inorganic barrier layer at atmospheric pressure to form an outer thermoplastic resin layer;

thereby providing a multi-layer composite barrier; and then

stacking a plurality of layers of said multi-layer composite barrier using said thermoplastic resin layer as a bonding agent to form said multi-layer barrier sheet.

60. The method of Claim 59, further comprising the step of incorporating inorganic nano-particles within said thermoplastic resin layer.

61. The process of Claim 59, further comprising the steps of vacuum depositing a monomer to produce a liquid film over said inorganic barrier layer and exposing the liquid film to a radiation source to produce a polymeric layer prior to the step of depositing said thermoplastic resin.

62. The process of Claim 61, further comprising the step of incorporating inorganic nano-particles within said thermoplastic layer.

63. The process of Claim 59, further comprising the step of depositing a monomer to produce a liquid film over said substrate film to produce a leveling polymer layer prior to the step of vacuum depositing said inorganic material.

64. The process of Claim 61, further comprising the steps of vacuum depositing a leveling monomer to produce a leveling liquid film over said substrate film and exposing the leveling liquid film to a radiation source to produce a leveling polymer layer prior to the step of vacuum depositing said inorganic material.

65. The process of Claim 64, further comprising the step of incorporating inorganic nano-particles within said thermoplastic layer.

66. The process of Claim 61, further comprising the step of incorporating a desiccant material within said barrier sheet.

67. The process of Claim 59, further comprising the step of protecting an article with said barrier sheet by laminating the barrier sheet over the article using said thermoplastic resin layer as a bonding agent to form a barrier enclosure.

68. The process of Claim 61, further comprising the step of protecting an article with said barrier sheet by laminating the barrier sheet over the article using said thermoplastic resin layer as a bonding agent to form a barrier enclosure.

69. The process of Claim 63, further comprising the step of protecting an article with said barrier sheet by laminating the barrier sheet over the article using said thermoplastic resin layer as a bonding agent to form a barrier enclosure.

70. The process of Claim 64, further comprising the step of protecting an article with said barrier sheet by laminating the barrier sheet over the article using said thermoplastic resin layer as a bonding agent to form a barrier enclosure.

71. The process of Claim 65, further comprising the step of protecting an article with said barrier sheet by laminating the barrier sheet over the article using said thermoplastic resin layer as a bonding agent to form a barrier enclosure.

72. The process of Claim 66, further comprising the step of protecting an article with said barrier sheet by laminating the barrier sheet over the article using said thermoplastic resin layer as a bonding agent to form a barrier enclosure.

73. A method of manufacturing a multi-layer barrier package for a device comprising the steps of:

vacuum depositing an inorganic material to produce an inorganic barrier layer over a substrate layer; and

depositing a thermoplastic resin over said inorganic barrier layer at atmospheric pressure to form an outer thermoplastic resin layer;

thereby providing a multi-layer composite barrier; and then

laminating the multi-layer composite barrier over the device using said thermoplastic resin layer as a bonding agent to form a barrier enclosure.

74. The method of Claim 73, further comprising the step of incorporating inorganic nano-particles within said thermoplastic resin layer.

75. The method of Claim 73, further comprising the steps of vacuum depositing a monomer to produce a liquid film over said inorganic barrier film and exposing the liquid film to a radiation source to produce a polymeric layer prior to the step of depositing said thermoplastic resin.

76. The method of Claim 73, further comprising the steps of depositing a leveling monomer to produce a leveling liquid film over said substrate film to produce a leveling polymer layer prior to the step of vacuum depositing said inorganic material.

77. The method of Claim 73, further comprising the step of incorporating a desiccant material within said barrier enclosure.

78. The process of Claim 73, wherein said barrier enclosure includes another barrier layer in addition to said multi-layer composite barrier laminated over the device.

79. The process of Claim 73, wherein said barrier enclosure is produced while applying a vacuum to said device.

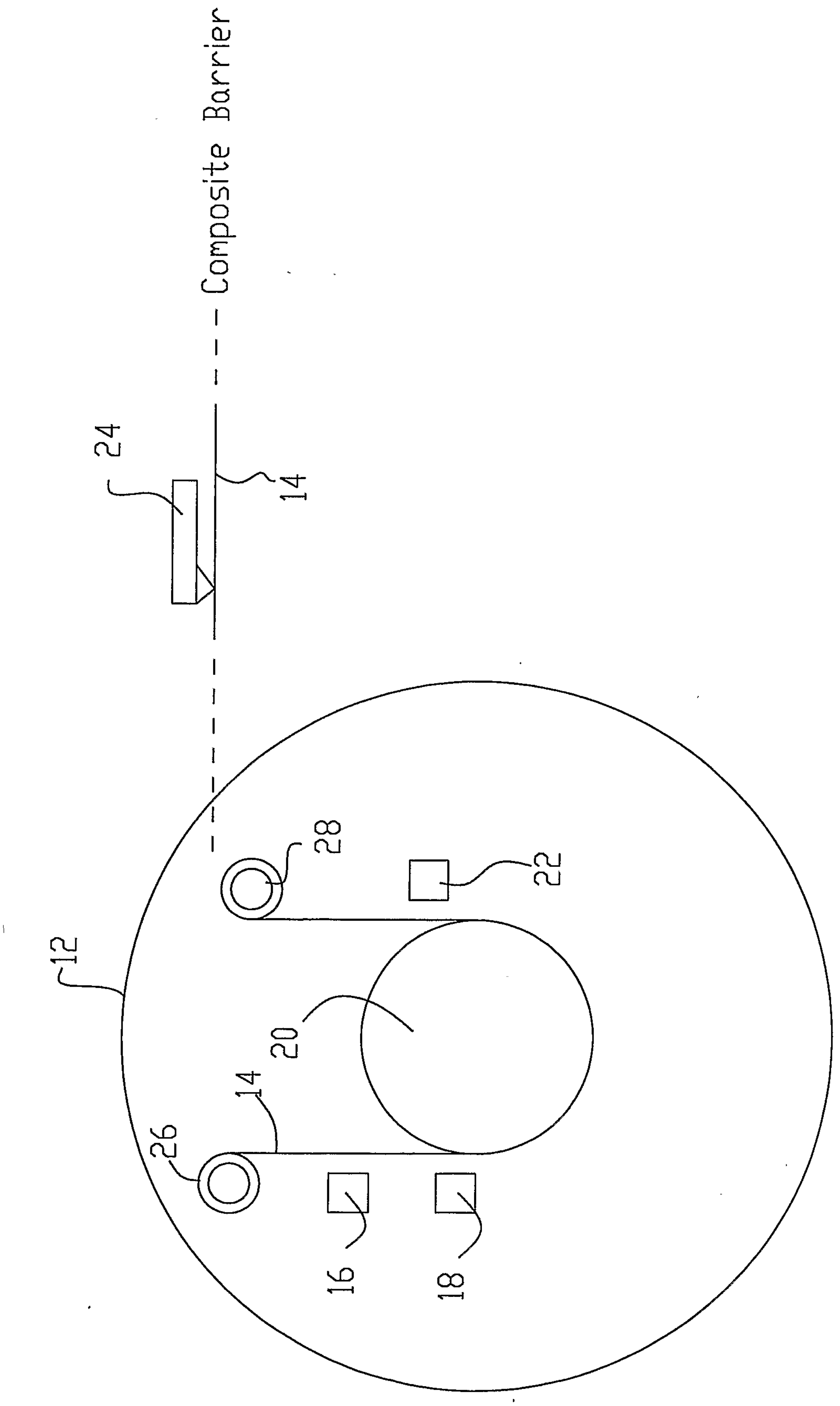

FIG. 1

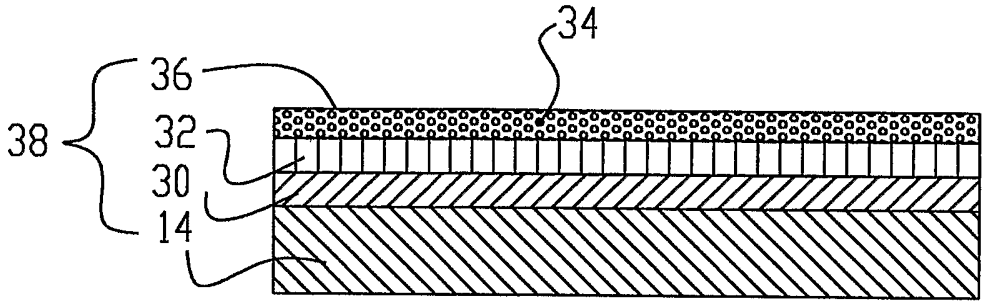

FIG. 2

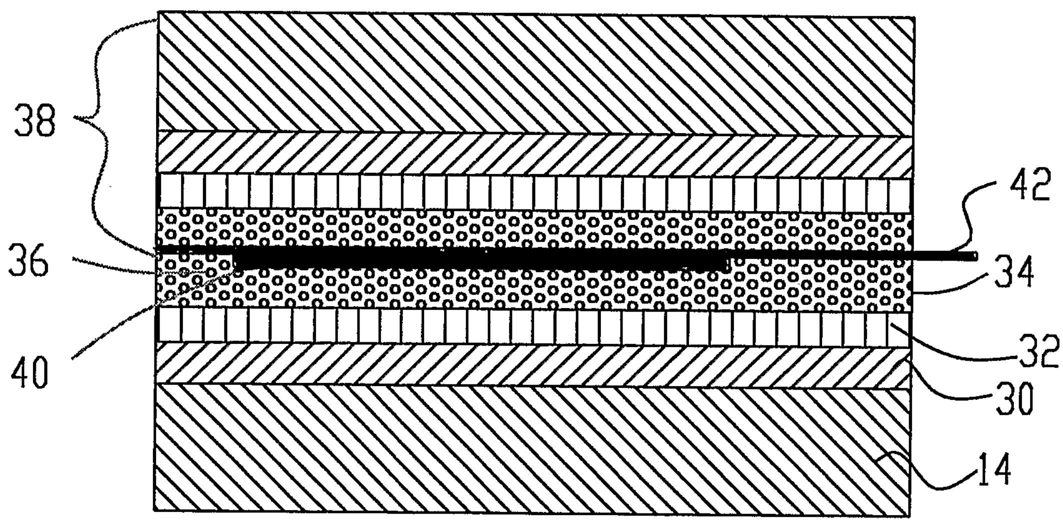

FIG. 3

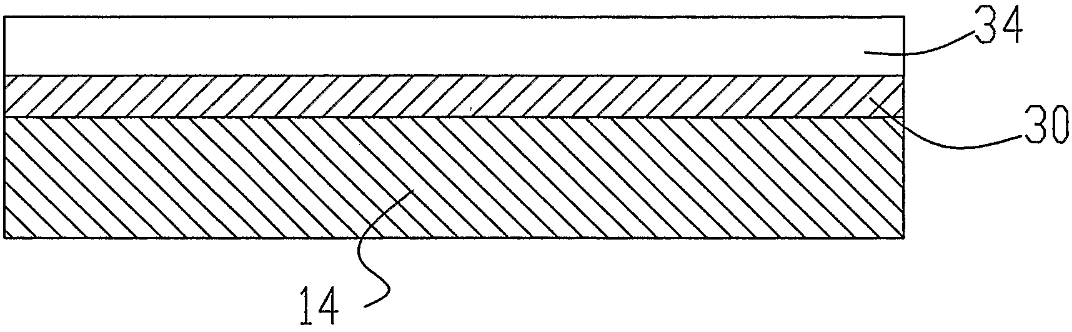

FIG. 4

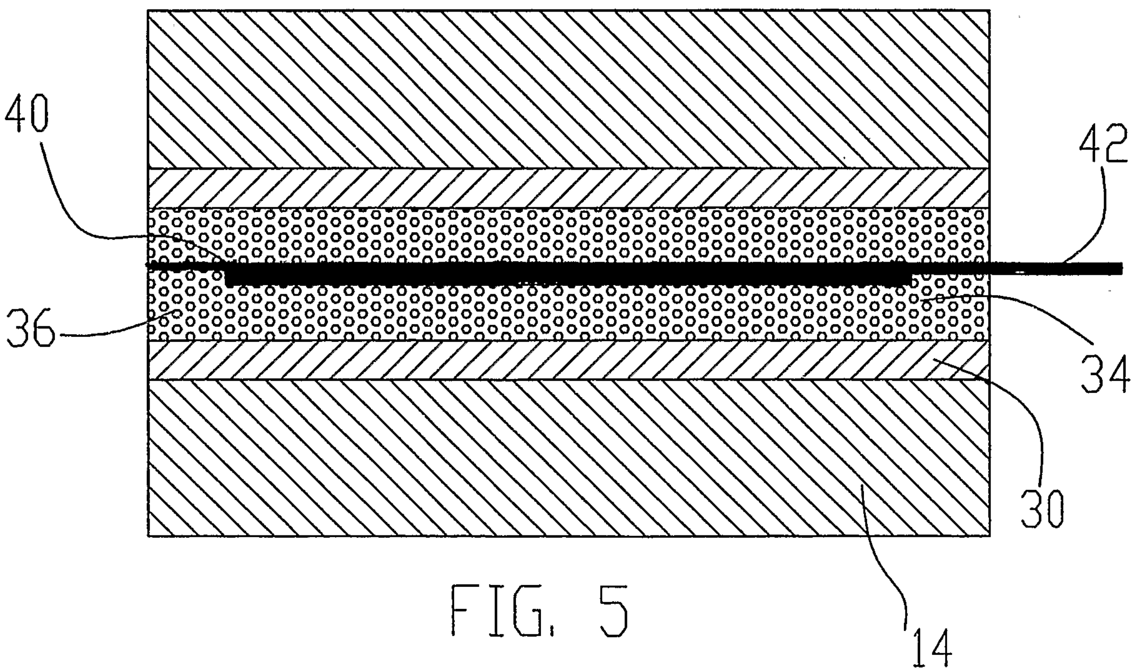

FIG. 5

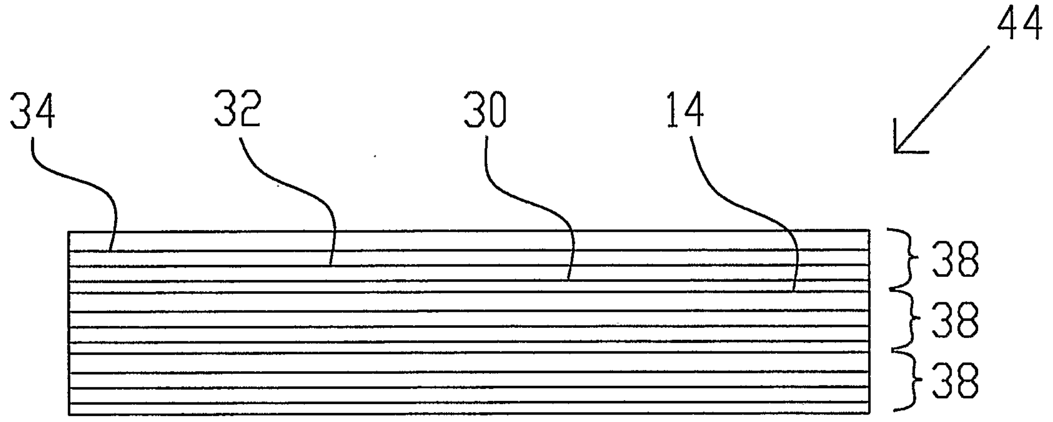

FIG. 6

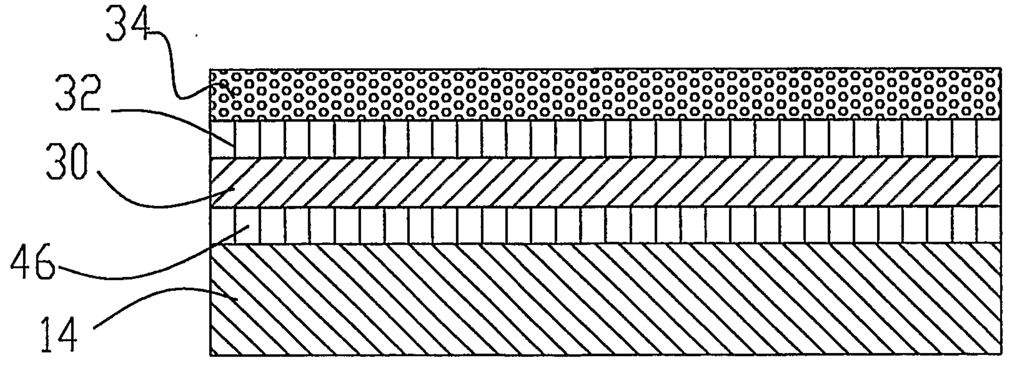

FIG. 7

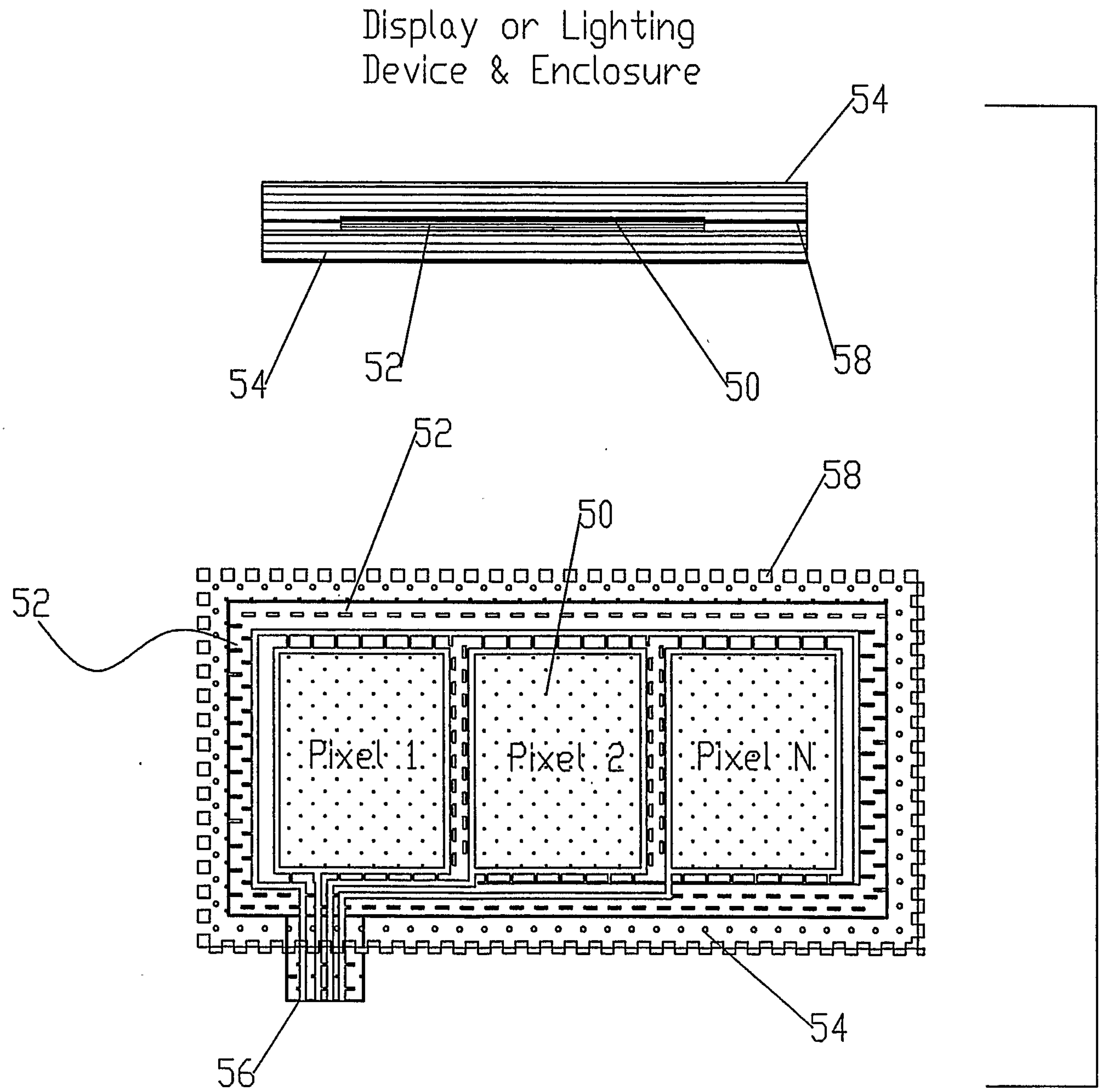
Display or Lighting
Device & Enclosure
54
54
52
50
58
52
58
50
52
Pixel 1
Pixel 2
Pixel N
54
56

FIG. 8

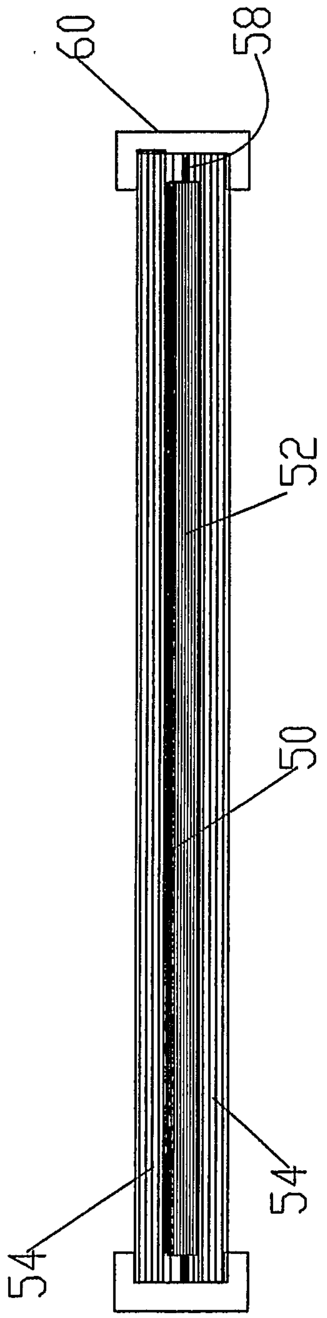

FIG. 9

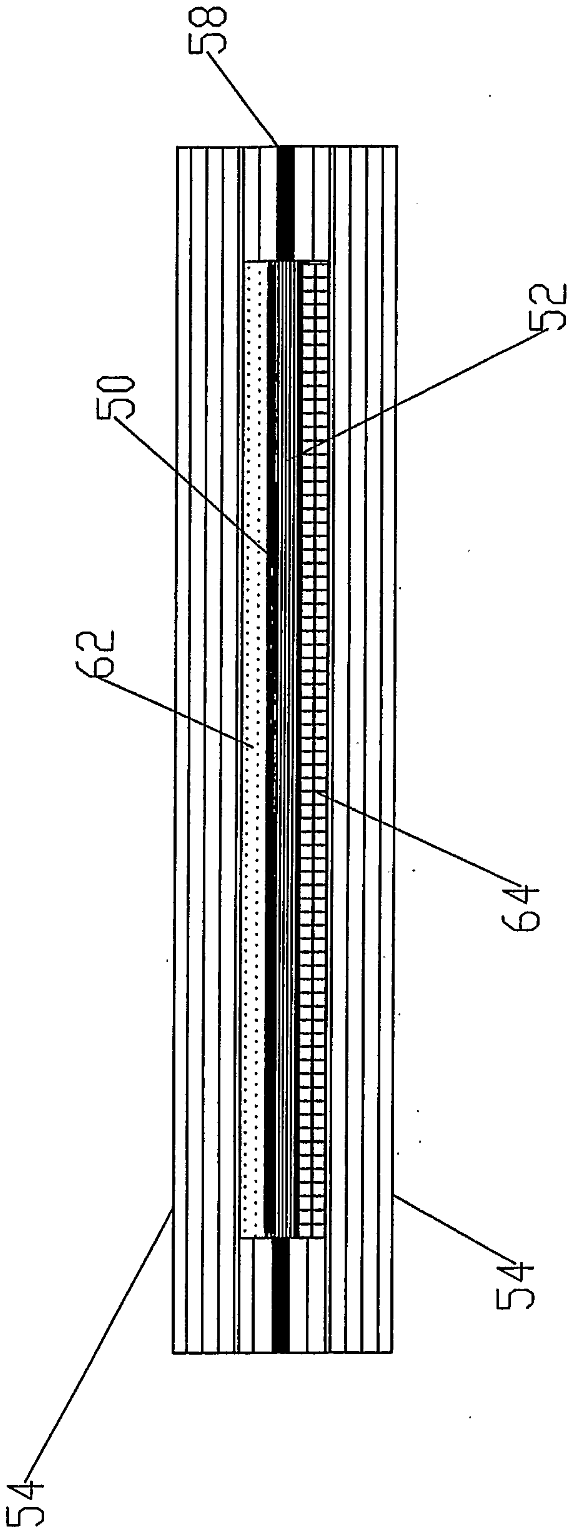

FIG. 10

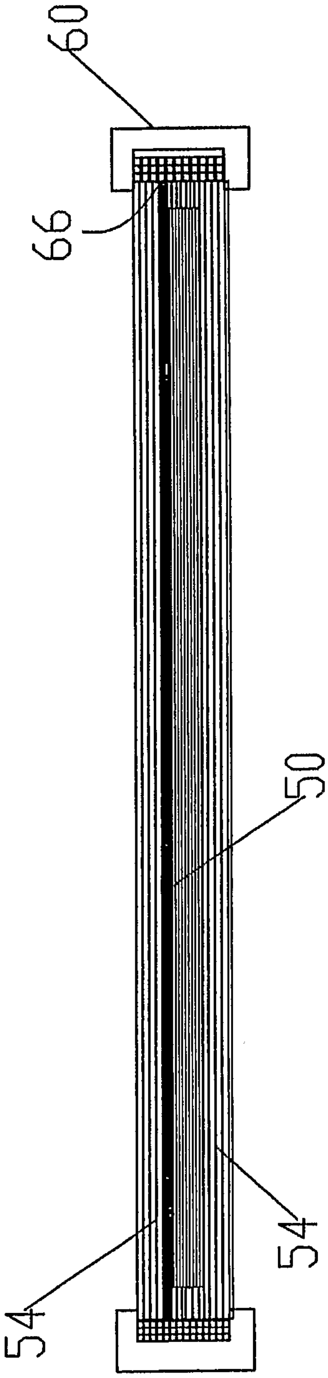

FIG. 11

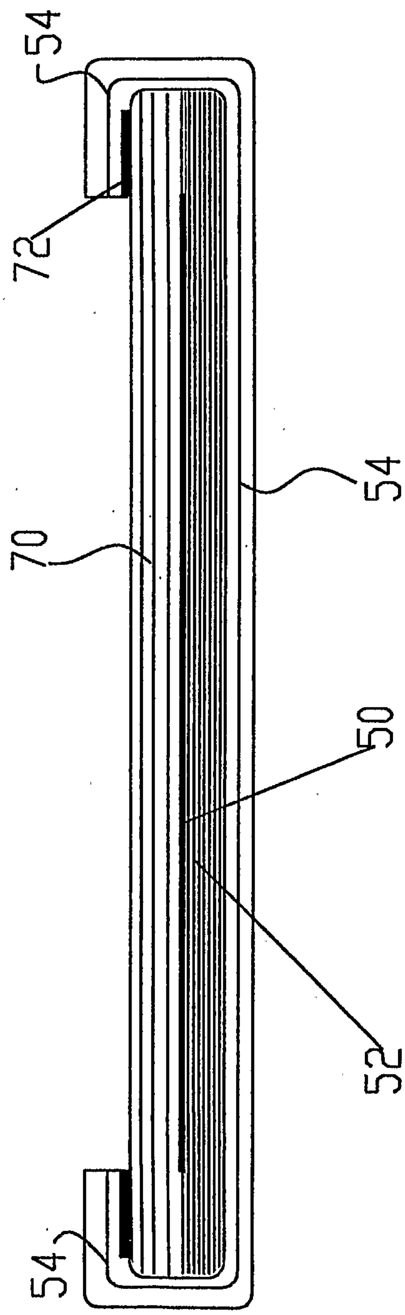

FIG. 12