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(54) Title: CONDUCTIVE MULTILAYER STACK

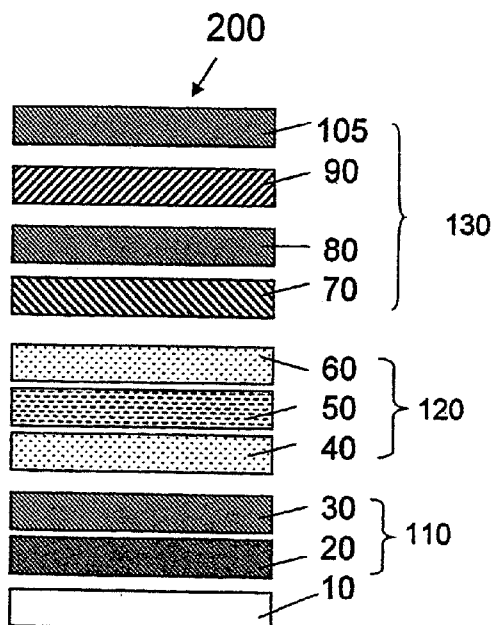


FIGURE 2

(57) Abstract: An electrically conductive multilayer stack having good IR reflection, radar attenuation, static discharge, and other desirable properties includes a coated substrate, a primary conductive layer, and a secondary protective stack having greater durability and functionality than conventional multilayer stacks used to protect aircraft canopies and other substrates. The secondary protective stack includes at least one conductive layer that helps dissipate static charge.



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CONDUCTIVE MULTILAYER STACK

FIELD OF INVENTION

[0001] This invention relates generally to transparent compositions and coated transparencies and laminates incorporating such compositions. More particularly, the invention relates to an electrically conductive coating stack having anti-static or static-dissipative properties.

BACKGROUND OF THE INVENTION

[0002] Modern jet aircraft canopies, such as F-22 stealth fighter canopies, are made of polymeric materials. Such materials are preferred because of their light weight, high strength, and ease of shaping. However, most polymeric materials are not infrared-reflective and do not meet the requirements for stealth jet fighters, such as low surface resistance (high electrical conductivity) and the ability to withstand extreme weather conditions. As a result, both organic and inorganic coatings are employed to impart infrared reflection, conductivity, and other necessary stealth characteristics to the canopy.

[0003] Canopies for stealth jet fighters need to be electrically conductive so that they can drain or dissipate static electricity. A low surface resistance is desired to prevent a buildup of static charge, because static charge interferes with various electromagnetic field and radar attenuation functions of the aircraft.

[0004] FIG. 1 illustrates a conventional multilayer stack for a modern aircraft canopy. The multilayer stack 100' generally includes a substrate base layer 15, a metal conductive layer 120' (including a metal layer 50 and a metal oxide layer 60), a tie layer 90, and a top coat 95. The substrate base layer 15 provides adhesion between the metal conductive layer 120' and an aircraft canopy substrate 10 that lies underneath. In addition, the substrate base layer 15 covers imperfections such as scratches or dents that may exist on the surface of the substrate 10. Suitable materials that can be used for the substrate base layer 15 include UV-curable polymers such as acrylates.

[0005] The metal conductive layer 120' includes a silver layer 50 and a layer of indium tin oxide (ITO) 60 and helps dissipate static charge that can develop during flight and/or from lightning strikes. In addition, the metal conductive layer 120' provides for electromagnetic interference (EMI) shielding and radar attenuation. Since the metal conductive layer 120' is prone to oxidation and degradation upon exposure to moisture, the top coat 95 is typically made of a hydrophobic polymer such as polyurethane and is sufficiently durable and flexible to withstand the thermal contraction and expansion caused by extreme temperature conditions encountered during flight.

[0006] While the prior art multilayer stack provides adequate infrared reflection, EMP protection, and radar attenuation to the canopy, its service life is limited due to delamination

1 and the formation of blue spots on the multilayer stack. In some aircraft, dark blue spots and
signs of delamination are observed after only 25 hours of service, and it is not unusual for the
entire canopy to be replaced after 80 hours of service because of severe delamination and
blue spot formation. The blue spots result from oxidation of the silver layer 50. As moisture
5 penetrates through the top coat 95, it reaches the silver layer 50 and causes it to corrode.

[0007] Despite the advances made to date in aircraft canopy coatings, a need still remains
for electrically conductive coating stacks having greater durability and functionality.

SUMMARY OF THE INVENTION

10 [0008] An electrically conductive multilayer stack having good IR reflection, EMP
protection, radar attenuation, static discharge, weather resistance, and chemical stability is
provided. Conceptually, the multilayer stack can be divided into three parts: a coated
substrate; a primary conductive layer; and a secondary protective stack. Together, the coated
substrate and primary conductive layer are similar to the multilayer stack shown in FIG. 1,
15 with important differences noted herein. Together with the secondary protect stack, the three
parts form an enhanced multilayer stack having greater durability and functionality.

[0009] In one embodiment of the invention, a multilayer stack comprises a coated
substrate, which includes a substrate (e.g., an aircraft canopy), a tie layer, and a base layer; a
primary conductive layer, including first and second metal oxide layers with a metal layer
20 sandwiched in between; and a protective stack, including a tie layer, a barrier layer, another
tie layer, and a conductive topcoat or top layer. The primary conductive layer helps protect
against lightning strikes. It also shields the substrate from electromagnetic interference
(EMI) and provides radar attenuation. The multilayer stack generally has better conductivity
and adhesion to a substrate.

25 [0010] In other embodiments of the invention, the outer protective stack is varied in a
number of ways. For example, in addition to the topcoat being conductive, one or more
additional layers of the outer protective stack layers can be compounded with a conductive
salt, metal oxide, or inherently conductive polymer (ICP).

30 BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The accompanying drawings, together with the specification, illustrate various
aspects and embodiments of the invention.

[0012] FIG. 1 is an exploded, cross-sectional view of a conventional multilayer stack for
an aircraft canopy;

35 [0013] FIG. 2 is an exploded, cross-sectional view of a multilayer stack according to an
embodiment of the present invention; and

[0014] FIG. 3-5 are exploded, cross-sectional views of multilayer stacks according to
various alternate embodiments of the present invention.

1 DETAILED DESCRIPTION OF THE INVENTION

5 [0015] In the following description and in the claims, various layers are described as being "positioned over," "disposed over," or "on" one or more additional layers, and this language simply denotes the relative positions of the layers. Thus, in some embodiments, two adjacent layers are literally right next to each other, while in other embodiments, the same two layers are separated by one or more additional layer(s). In each case, one of the two layers is considered to be "positioned over," "disposed over" or "on" the other layer.

10 [0016] As used herein, the term "coated substrate" refers to a substrate that has been protected (e.g., coated) with one or more layer(s) of metal particles and/or metal oxide to make the substrate conductive. The substrate can be made of glass or plastic, coated or uncoated, and may form a window, a windshield of a car, aircraft, or boat, a building, or another structure.

15 [0017] When various compositions are described, it is to be understood that the stated percentage or amount of each ingredient is provided on a "wet" basis prior to drying or curing, unless specified otherwise. Unless otherwise noted, the percentages are weight percentages (wt%).

20 [0018] Throughout the text and the claims, use of the word "about" in relation to a range of values (e.g., "about 22 to 35 wt%") is intended to modify both the high and low values recited, and reflects the penumbra of variation associated with measurement, significant figures, and interchangeability, all as understood by a person having ordinary skill in the art to which this invention pertains.

25 [0019] A multilayer stack according to one embodiment of the invention is shown in FIG. 2. The multilayer stack 200 is built up on an aircraft canopy or other substrate 10 and includes three main features: the coated substrate 110, a primary conductive layer or stack 120, and a secondary protective stack 130, each of which is comprised of a number of sub-layers that perform one or more functions. The coated substrate includes the aircraft canopy or other substrate 10, an intermediate tie layer 20, and a polymeric base layer 30, each positioned on or over an adjacent layer in the order shown.

30 [0020] Positioned over the coated substrate 110 is the primary conductive layer or stack 120, which includes first and second metal oxide layers 40 and 60 and a conductive metal layer 50 sandwiched there between. The metal layer 50 provides IR reflection, and radar attenuation properties of the multilayer stack. The first and second metal oxide layers 40 and 60 protect the metal layer and help bind it between adjacent polymeric layers of the coated substrate 110 and the secondary protective stack 130.

35 [0021] Positioned over the second metal oxide layer 60 of the primary conductive stack 120 is a secondary protective stack 130, comprised of two tie layers 70 and 90, a barrier layer 80, and a conductive top layer or topcoat 105. The barrier layer 80 prevents moisture from

1 intruding into the primary conductive stack 120. The tie layers improve the bond between the barrier layer and the adjacent metal oxide layer and the top coat.

[0022] The topcoat or top layer 105 is the outer most layer of the multilayer stack 200, and is made of a tough, durable and weather resistant material, yet is sufficiently pliable and
5 flexible to prevent crack formation due to thermal stress. It is conductive and helps dissipate static charge and other electromagnetic forces.

[0023] The multilayer stack 200 provides all the functionality required of a modern stealth aircraft canopy, including radar attenuation, IR reflection, EMI and EMP protection, protection from lightning strikes, weather resistance, and durability. The individual layers
10 that comprise the multilayer stack will now be described.

[0024] The coated substrate 110 includes the substrate 10, a tie layer 20, and a base layer 30. In the case of a modern aircraft canopy, the substrate is typically an organic resin such as polycarbonate or polyacrylate. Hence, the tie layer and base layer are selected to adhere well to such a material. In addition, the base layer 30 couples the canopy to the primary
15 conductive stack 120, and should be capable of bonding thereto. Accordingly, in one embodiment of the invention, the base layer 30 comprises a long chain organopolysiloxane, optionally compounded with a low molecular weight coupling agent such as a silane or siloxane, which improves the adhesion between the base layer 30 and the innermost metal oxide layer 40 of the primary conductive stack 120. Alternatively, the base layer 30 is a
20 thermally-curable polyacrylate coated with an organopolysiloxane.

[0025] In the case where the substrate is a polyacrylate, polycarbonate, or similar organic resin, the tie layer 20 can be an acrylic polymer or mixture of polymers, for example an acrylic polymer made of one or more alkyl acrylates and/or methacrylates, optionally compounded with one or more additional monomers. The layer can be applied to the
25 substrate by gravity coating or another suitable application technique. In gravity coating, a polymeric solution of the tie layer polymer(s) or precursor monomers is prepared, and the solution is applied to the canopy in the center and along a longitudinal axis that extends along the entire length of the canopy. The polymeric solution is then discharged from a nozzle and poured over the canopy at the top, allowing the solution to flow down both sides and thereby
30 coat the surface of the canopy. The solution is applied slowly from one end to another along the longitudinal axis of the canopy, until the entire canopy is coated with a tie layer. Since the coating is formed by gravity, the coating thickness can be controlled by the viscosity of the polymeric solution. An excess of polymeric solution can be used to ensure a consistent layer is formed across the entire canopy. Any excess drips off the canopy and is collected at
35 the bottom, where it can be properly disposed of and/or re-used.

[0026] In another embodiment, multiple streams of the polymeric solution are directed to impinge on the canopy. The solution streams are ejected through one or more nozzles or other outlets, and the polymeric solution is kept at a constant viscosity to control the coating

1 thickness. If the viscosity is too low, insufficient coating can occur, whereas, if the
polymeric solution viscosity is too high, the resulting tie layer coating can be unnecessary
thick, with a consequent increase in cost and weight.

5 [0027] Once the canopy is coated with the tie layer material(s), it is air dried, under
atmospheric conditions and ambient temperatures, and then cured using heat or ultraviolet
light.

[0028] After the tie layer 20 is applied to the substrate 10 and cured, the base layer 30 is
applied by gravity coating or a process similar to that described above. The coated substrate
110 is then allowed to air dry under ambient conditions, and then cured.

10 [0029] The primary conductive stack 120 includes metal oxide layers 40 and 60, with a
metal layer 50 sandwiched in between. Non-limiting examples of suitable metal oxides
include indium tin oxide (ITO), titanium dioxide, zinc oxide, and zinc stannate. In one
embodiment, an indium tin oxide contains about 10 weight percent tin. In general, the metal
oxide should have low absorption, high refractive index, and good chemical durability. The
15 resulting metal oxide layer is transparent and anti-reflective.

[0030] The metal oxide layer 40 is applied to the coated substrate 110 using a suitable
deposition technique, such as physical vapor deposition or a sputtering process. In one
embodiment, it is formed using a magnetron sputtering process in which a high voltage
plasma discharge causes atoms to be ejected from a target, such as an indium tin alloy or
20 indium tin oxide ceramic. The metal atoms then strike the coated substrate and form a thin,
transparent layer of metal oxide. Since the coating is formed on an atomic scale, it is possible
to produce uniform layers of films. For indium tin oxide, the metal oxide layer 40 can be
applied at a relatively moderate temperature, i.e. from room temperature to about 170° F. The
coated substrate 110 is heated to a temperature within that range, and a sufficiently thick
25 layer is deposited thereon.

[0031] Once the first metal oxide layer 40 is applied, the intermediate metal layer 50 is
applied using a physical vapor deposition or sputtering process as described above. In one
embodiment, the metal is silver or a silver alloy, such as silver/palladium or silver/ gold. In
one embodiment, a silver alloy containing 5-10 wt % palladium is used. In another
30 embodiment, a silver/gold alloy containing about 20-60 wt % gold is used. For silver and its
alloys, it can be advantageous to carry out the deposition process at a relatively low
temperature in order to avoid unwanted oxidation of the metal, i.e., about 50° to 100°F.

[0032] After the metal layer 50 is deposited, the outermost metal oxide layer 60 is then
applied, using a process similar to that described above. Optionally, an extra layer of
35 titanium is sputtered on the metal layer 50 to enable the deposition process of the second
metal oxide layer 60 to be carried out at a higher temperature. Titanium acts as oxygen
scavenger and minimizes or eliminates oxygen in the vacuum chamber. This allows the
second metal oxide layer to be deposited at a higher temperature and at a higher oxidation

1 state without corroding or darkening the silver (e.g.) in the metal layer 50. This allows a thicker layer of metal oxide to be built up as the second metal oxide layer 60.

[0033] Optionally, one or more oxides, such as aluminum oxide and zirconium oxide, can be added as additional corrosion barriers, to allow a higher operating temperature during the deposition of the second metal oxide layer. This can actually reduce the coating thickness required of the hydrophobic barrier layer 80 and the secondary protective stack 130, or even eliminate the barrier layer 80 and tie layer 70 altogether.

[0034] After the primary conductive layer 120 is deposited on the coated substrate 110, a secondary protective stack 130 is formed thereon. As shown in FIG. 2, a secondary protective stack 130 according to one embodiment of the invention includes a first tie layer 70, a barrier layer 80, a second tie layer 90, and a top layer or topcoat 105. The barrier layer 80 is made of a hydrophobic material, for example, polyurethanes, fluorinated urethanes, fluoropolymers, fluoroelastomers, polyurethanes, polyolefins, polyamides, polyamines, halo polymers, ethylene propylene rubbers, epoxies, polyesters, and fluorosilicones, and protects the underlying primary conductive stack 120 from moisture and resulting corrosion. The tie layers 70 and 90 are selected to be compatible with the barrier layer 80 and the adjacent primary conductive layer 120 and topcoat 105, respectively. Thus, in one embodiment, the tie layer 70 comprises a polymeric resin that is compatible with the barrier layer 80 and optionally includes an organosiloxane compound, which can interact with and bond to the underlying outermost metal oxide layer 60 of the primary conductive stack 120. Similarly, the tie layer 90 can be made of a polymeric resin compatible with the topcoat 105, and may also include an organosiloxane compound.

[0035] Optionally, before applying the barrier layer 80, a primer coat is applied to improve adhesion between the barrier layer 80 and the tie layer 70. This can also reduce the time required to cure or dry the barrier layer 80, which can improve overall fabrication time of the multilayer stack 200. Suitable primers for this purpose include functional siloxanes, short chain polymerized siloxanes such as dimethylsiloxane, and long chain polysiloxanes. In one embodiment, the primer comprises 3-aminopropyltriethoxy silane mixed in isopropanol at a concentration of less than 2 wt%. It is also possible to include a secondary primer, more viscous than the first primer. The primer(s), as well as the tie layer 70 and 90 and the barrier layer 80, can be applied using gravity coating or another process as described above, or any other suitable technique that enables the multilayer stack 200 to be built up with a desired thickness of individual layers.

[0036] The outer layer of the secondary protective stack 130 comprises a conductive topcoat or top layer 105 made of a durable, weather resistant polymer having sufficient flexibility to retard crack formation due to thermal stress. Conductivity is achieved by compounding the top layer 105 with a conductive metal oxide, a quaternary ammonium salt, an inherently conductive polymer, or another suitable conductive agent. In a nonlimiting

1 example, the polyurethane is formed from a diacetone alcohol solution of a polyol (e.g.,
Polyol 4295, commercially available from Reichhold Chemicals, Inc.), aliphatic
polyisocyanate resin (e.g., Desmodur N-75, commercially available from Bayer), N-
methylpyrrolidone ("NMP"), and a quaternary ammonium salt (e.g., Superstat 463,
5 commercially available from AMCS, Inc.). A representative formulation contains about 25%
solvent, 16% polyol, 24% aliphatic polyisocyanate, 7% NMP, and 23% quaternary
ammonium salt, with small amounts of additional components, such as light stabilizers,
polymerization catalyst, and surfactant.

[0037] A thin topcoat is desirable because it does not add weight to the canopy. On the
10 other hand, a thick layer can provide enhanced protection to the underlying layers and may
aid in dissipating static charge. The topcoat can be applied using gravity coating or a similar
deposition technique as described above.

[0038] Quaternary ammonium salt concentration of about 22 wt % or higher are
representative. At 22 wt%, the salt does not adversely affect topcoat weatherability or light
15 transmission, and can improve the abrasion and rain erosion resistance of the top layer. A
topcoat having a resistance less than about $10^5 \Omega/\square$ is desirable because it allows static charge
to be dissipated without compromising the durability of the coating. In some embodiments,
the concentration of the quaternary ammonium salt is increased until a surface resistance of
 $10^9 \Omega/\square$ or less is reached, i.e., from 22 to 35 wt%, or even as high as 60 wt%.

[0039] At a 60 wt% concentration, the quaternary ammonium salt is still bound within the
20 polymeric matrix of the topcoat 105, but the layer may be undesirably tacky. This can be
countered by including a surface additive, such as a silicone, to the topcoat formulation.
Thus, in one embodiment, a silicone solution having functional groups that orient at the
surface is used. Nonlimiting examples include silicone-modified polyacrylates and
25 polyether-modified poly-dimethylsiloxane, available commercially as BYK[®] 3720 or BYK[®]-
SILCLEAN 3700 from BYK Chemie. In one embodiment, a silicone additive such as
BYK[®]-SILCLEAN 3700 having hydroxyl functionality is incorporated in the topcoat 105.
The polymeric groups of the silicone crosslink and become embedded within the polymeric
matrix of the topcoat while the hydroxyl groups of the silicone migrate to the surface to react
30 with the functional groups of the quaternary ammonium salts, thereby reducing the surface
tackiness. The amount of silicone varies depending on the amounts of quaternary ammonium
salt in the top layer 100. Representative, nonlimiting concentration values include trace
amounts to as high as about 1 % by weight (dry weight), e.g. about 0.1 to about 0.3 dry wt%.

[0040] While BYK[®] 3720 and BYK[®]-SILCLEAN 3700 are both solvent-based additives,
35 aqueous-based surface modifiers can be used in the alternative.

[0041] The surface tackiness problem can be alleviated in an alternative manner by
changing the polymeric components that make up the topcoat 105, e.g., by using a more
reactive polyol or a polymeric material with a lower equivalent weight. In this case,

equivalent weight denotes the amount of reactive functional groups on the polymer chain. Its value corresponds to the weight of solid resin in grams that includes one mole of a functional reactive group attached to the polymer backbone. In other words, the lower the equivalent weight value the less material required to undergo crosslinking reactions through the functional groups. Polyol 4295 has an equivalent weight value of about 295. In one embodiment, Polyol 4295 is replaced with trimethylolpropane (TMP). TMP has three functional groups and has an equivalent weight value of 44.7. The three available functional groups are believed to increase the crosslink density, thereby decreasing or eliminating the surface tackiness. In some embodiments, about 20 to 100 wt% of the 4295 polyol is replaced with TMP.

[0042] In an alternate embodiment, topcoat surface tackiness is addressed by replacing the Polyol 4295 with ethylene glycol (EG), a short chain alkanol having two functional groups. It has an equivalent weight value of about 31. EG tends to be very reactive and can significantly reduce topcoat surface tackiness by increasing the crosslink density. In some embodiments, about 20 to 100 wt% of Polyol 4295 is replaced by EG.

[0043] In some embodiments, a polyethylene glycol (PEG 400) having an equivalent weight of about 198 is utilized to increase conductivity. The PEG is inherently bound in the polymeric matrix and has little or no tendency to migrate to the surface of the topcoat 105. In addition, PEG 400 is soluble in water and is conductive. PEG 400 increases the moisture retention of the topcoat because of its affinity for water. As a result, PEG 400 increases the inherent conductivity of the topcoat 105. PEG 400 also depresses the freezing point of water and hence improves conductivity at low temperatures.

[0044] Nonlimiting examples of alternate formulations include those in which about 20 to 100 wt%, or about 40 to 60 wt%, of the Polyol 4295 is replaced with PEG 400. All such embodiments produce good test results for haze and aesthetic appearance.

[0045] In another embodiment, 35 wt% of the quaternary ammonium salt and 40 wt% of Polyol 4295 is replaced with PEG 400. In yet another embodiment, about 45 to 50 wt% of the quaternary ammonium salt and all of the Polyol 4295 polyol in the topcoat 105 are replaced with PEG 400 and a small amount of non-reactive organic salt.

[0046] Although quaternary ammonium salts can be used at high amounts to improve the conductivity of the topcoat 105, their conductivity can be affected by low temperatures. At -40°F or less there is almost no absorbable moisture and no moisture in the topcoat 105, and a quaternary ammonium salt may not be conductive under such conditions. Therefore, in some embodiments, topcoat conductivity is achieved by incorporating an alternate conductive agent, such as a non-reactive organic salt, a conductive metal oxide, or an inherently conductive polymer (ICP).

[0047] Thus, in one embodiment, the topcoat incorporates a non-reactive organic salt, such as 1-butyl-3-methylimidazolium methyl sulfonate, 1-butyl-3-methylimidazolium methyl

1 sulfate, or 1-butyl-3-methylimidazolium ethyl sulfate into the topcoat matrix. The use of
non-reactive organic salts can lower the electrical resistance of the topcoat by as much as one
order of the magnitude. However, the salts have a tendency to migrate to the surface, causing
haze or blooming problems. In addition, the salts may shed or wash off over time due to
5 abrasion and exposure to the weather elements. Therefore, the salts should only be included
in small amounts, e.g., about 1 to 2 wt%, or 5 wt%. Higher concentrations can be used and
longer retention time can be achieved if the non-reactive organic salts are incorporated in
semi-solid forms or provided with a mechanism or chemical compounds that trap the non-
reactive organic salts in the polymeric matrix of the topcoat 105.

10 **[0048]** In another embodiment, the topcoat 105 is doped with a conductive metal oxide.
The concentration of the conductive metal oxide that is used can vary depending on the type
and particle size of the metal oxides. A topcoat having a high concentration of metal oxides
may have increased hardness and therefore loses its resiliency. This will adversely impact
the rain erosion and abrasion resistance properties of the topcoat. In addition, some
15 conductive metal oxides have a limited resistance to UV light and humidity. They may also
be photocatalytic and may degrade the organic coatings upon exposure to UV light.
Therefore, in one embodiment, nanoparticles of ITO are used. ITO nanoparticles are less
photocatalytic than other metal oxides, and their small particle size enable them to be used in
higher concentrations without adversely impacting the resiliency and durability
20 characteristics of the topcoat. Dispersions of nanoscale ITO particles are commercially
available from Air Products Corporation under the product name "S2I," and from Evonik
(product name "TC8DE," a 20 wt% ethanol ITO dispersion). In one embodiment, the topcoat
105 is doped with about 12 wt% of the ITO particles to get improved conductivity.

[0049] It is believed that needle-shaped ITOs can provide the needed conductivity
25 without adversely impacting the resiliency of the topcoat 105. A needle-shaped ITO particle
has a high aspect ratio and, as compared to spherical ITO particles, fewer particles per unit
volume are required to obtain a desired level of conductivity. Other elongated particles such
as carbon nano tubes can also be incorporated in the topcoat 105. Single or multiple-walled
carbon nano tubes are conductive and are not prone to UV degradation. In addition, their size
30 and shape allow them to be incorporated in the topcoat 105 in even smaller amounts to obtain
a desired conductivity. In some embodiments, each carbon nano tube has a diameter of about
10 to about 20 nm and a length of about 1 to 50 μ m.

[0050] In an alternate embodiment, topcoat conductivity is achieved by incorporating an
inherently conductive polymer (ICP) into the topcoat matrix. Conventional ICPs are prone to
35 degradation upon exposure to UV light, and can lose their electrical conductivity. In
addition, commercially available ICPs are often colored and only soluble in water, not
organic solvents and resins. However, a new generation of ICPs, such as polythiophene-

1 based conductive polymers, are transparent, compatible with organic solvents and resins, and more UV-resistant.

[0051] Regardless of the manner by which the multilayer stack is rendered conductive, it is advantageous to achieve a surface resistance of less than or equal to about $10^9 \Omega/\square$ or, more preferably, less than or equal to about $10^5 \Omega/\square$. The overall conductivity of the stack can be further enhanced by doping one or more layers of the secondary protective stack with a conductive agent (e.g., conductive metal oxide, quaternary ammonium salt, ICP, etc.), and/or by adding one or more additional conductive layers.

[0052] A second embodiment of the invention is shown in FIG. 3. A multilayer stack 300 includes a coated substrate 110, a primary conductive layer 120, and a modified secondary protective stack 133. The coated substrate and primary conductive layer are similar to those described above with reference to FIG. 2. The modified secondary protective stack 133 includes first and second tie layers 70' and 90', a barrier layer 80', and a topcoat or top layer 105. In this embodiment, the tie layers 70' and 90' are doped with a conductive metal oxide, such as ITO nanoparticles. In one embodiment (using S2I nanoparticles), such a tie layer exhibited a measured resistance of $10^5 \Omega/\square$ to $10^6 \Omega/\square$. In another embodiment, the tie layer was loaded with 68 wt% TC8DE nanoparticles, and the measured resistance of the layer was $10^4 \Omega/\square$. Optionally, the barrier layer 80' is also conductive, and any charge that is applied to the multilayer stack 200 is likely to be transferred to and dissipated through the main conductive stack 120.

[0053] FIG 4 shows a third embodiment of the invention. A multilayer stack 400 includes a coated substrate 110, a primary conductive stack 120, and a secondary protective stack 135. The latter includes a tie layer 70 and barrier layer 80 as described above; a doped tie layer 90', and a doped topcoat or top layer 105. The tie layer 90' is loaded with about 68 wt% ITO nanoparticles, and the topcoat 105 is loaded with about 35 wt% quaternary ammonium salt. Each of these concentrations can be varied as desired to control the resulting conductivity of the doped layer or the overall secondary protective stack 135. In this embodiment, the risk of premature charring or burnout of the tie layer 90' is decreased, as a conductive path is provided that allows full static dissipation throughout the secondary protective stack 135.

[0054] FIG 5 shows another embodiment of the invention. A multilayer stack 500 includes a coated substrate 110, a primary conductive stack 120, and a secondary protective stack 137, the latter including a tie layer 70, a barrier layer 80 as described above, an additional metal oxide layer 85, and a doped tie layer 90'. In one embodiment, the metal oxide layer 85 is an ITO layer. The doped tie layer 90' is also doped with ITO particles or, alternatively, with another conductive material as described herein. In this embodiment, since all of the organic layers on top of the metal oxide layer 85 are conductive, any charge

1 that is applied to the multilayer stack 500 is transmitted down to the conductive metal oxide layer 85, which allows the charge to be dissipated.

Example 1

5 **[0055]** A polycarbonate canopy is prepared and then lightly abraded to increase its surface roughness and surface area for receiving a primer (3-aminopropyltriethoxy silane, an adhesion promoter). The primer is gravity coated onto the canopy. Next, a polymeric solution (FX-430, produced by PPG Industries, Inc., Pittsburgh, PA) is applied to the canopy by flow coating. The polymeric solution is poured from the top of the canopy and from one end to another, allowing the solution to flow down and coat the canopy by gravity flow.

10 Excess polymeric solution is allowed to flow down into a dripping pan and is collected for proper disposal.

[0056] After the entire outer surface of the canopy has been coated, it is cured in a heated oven at 220°F for 4 hours. After the coating is cured, the canopy is abraded to increase its surface area for receiving the next coating layer. The abraded canopy is dusted and wiped
15 clean, and then cleaned with an excess of Isopropanol (IPA) and dried thoroughly. A silane basecoat is then applied by flow coating, followed by a layer of a base coat (FX-419, produced by PPG Industries, Inc.). The coated canopy is then cured in a preheated oven at a temperature of 190°F for 2 hours. After curing, the canopy is thoroughly cleaned to remove dust particles and particulates that may have accumulated on the surface.

20 **[0057]** The cleaned canopy is then placed in a vacuum chamber. The pressure in the vacuum chamber is reduced and the chamber is heated to 170°F. Two metal oxide layers and one metal layer are deposited on the coated canopy using magnetron sputtering. First, a layer of ITO is formed, and then the temperature is decreased to 90°F so that silver can be deposited onto the canopy. After a layer of silver is formed, a second layer of ITO is
25 deposited on top of the silver layer while keeping the temperature of the chamber constant at 90°F. The canopy is then removed from the chamber and then cleaned to remove any contaminants that may adhere to the surface. Another primer coating (an adhesion promoter) and a second polymeric coating (FX-325, produced by PPG Industries, Inc.) are then applied. The coatings are cured and the surface is again abraded gently before receiving two
30 additional primer coats (adhesion promoters one and two).

[0058] After the first adhesion promoter (FX-384) is dried, the canopy is primed with a second adhesion promoter (FX-408, produced by PPG Industries, Inc.). The surface is abraded again to receive a barrier coating (FX-426, produced by PPG Industries, Inc.). It is then cured, abraded again, and then cleaned thoroughly before another adhesion promoter
35 (FX-408) and polymeric layer (FX-325) are applied. The canopy is then cured and abraded to receive another adhesion promoter. A topcoat (FX-422, produced by PPG Industries, Inc.) is then applied and allowed to cure.

[0059] *Comparative Example*

[0060] A control sample is coated with various layers using the same method of flow coating, surface treatment, and curing described in Example 1. However, the control sample is only coated with an organic base coat followed by a sputtering process in which only one layer of silver and one layer of ITO are deposited. An acrylic solution is then applied over the ITO layer, followed by a topcoat.

[0061] The results of performance tests on Example 1 and the Comparative Example ("Control") are summarized in Table 1 below.

[0062] **Table 1. Test Performance**

Property		Control	Ex. 1
Light Transmission	%	64-66	63-68
Bayer Abrasion	% loss	4.5	<1
Steam Resistance	hours	0.5	>24
QUV Weathering	weeks	4	12
4-Point Bend	cycles	1-10	10-67
Salt Fog + SO ₂	days	2	>7
Rain Erosion	% loss	1-15	0

[0063] As can be seen in Table 1, Example 1 performed substantially better than the control in nearly every category. Although both samples have 100% adhesion at the beginning of the test, the QUV weathering test results indicate that Example 1 has better adhesion, as it has no signs of delamination until week number 12. Even after 12 weeks of exposure to QUV weathering, there are no signs of blue spot formation in Example 1. Conversely, the Control shows blue spots only after 1 week of QUV exposure. This indicates that the main conductive stack of Example 1 is well protected, as there are no signs of moisture penetrating to the metal layer.

[0064] Multilayer 400 performed significantly better in customer precipitation static testing.

[0065] Table 2 below shows apparent resistance measurements for various embodiments of multilayer stacks according to the invention. The apparent resistance is a resistance of the whole multilayer stack, measured at the top layer 100. The first line in Table 2 shows the apparent resistance measurements of three different multilayer stacks having a tie layer 90 that is not doped with any anti-static agent (i.e. ITO). However, each top layer 100 has a different concentration of anti-static agent. The first sample (i.e. row one and column one) has no anti-static agent and has a measured apparent resistance of 10^{12} Ohm/square. The second sample (row one and column two), which has 22 wt% quaternary ammonium salt ("SS") in the top layer 100, has a measured apparent resistance of 10^{10} to 10^{11} Ohm/square.

The third sample (row one and column three), which has 35 wt% SS, has a measured apparent resistance of 10^{10} to 10^{11} Ohm/square. The second line in Table 3 shows the apparent resistance measurements of three different multilayer stacks having a tie layer 90 that is doped with the same concentration of ITO and a top layer 100 doped with different concentrations of the anti-static agent (i.e. from 0 to 35 wt% SS).

[0066] As can be seen in the first column, there is no change in the apparent resistance when the top layer 100 is not doped with an anti-static agent, and the underlying tie layer 90 is doped with ITO. This is expected as the top layer 100 is not conductive. As an electrical current is applied to the top layer 100, the charge accumulates on the surface and cannot be transmitted anywhere, even when the underlying tie layer 90 is conductive. However, as the concentration of the anti-static agent increases, the apparent resistance decreases accordingly. The measured apparent resistance is further decreased as both layers are doped with high concentrations of anti-static agents (i.e., the sample in row two and column three has a measured apparent resistance of 10^6 to 10^7 Ohm/square, as compared to 10^{12} Ohm/square for an un-doped sample shown in row one and column one).

Table 2. Measured Resistance (Ohm/square) at the Top Layer 100

Tie Layer 90	Top Layer 100		
	with no SS	with 22% SS	with 35% SS
With no anti-static agent	10^{12}	$10^{12} - 10^{11}$	$10^9 - 10^{10}$
With anti-static agent (10^4 Ω /square)	10^{12}	$10^7 - 10^8$	$10^6 - 10^7$

Note: SS = quaternary ammonium salt

[0067] Although various embodiments of the invention have been described, additional modifications and variations will be apparent to those skilled in the art. For example, the multilayer stack can have additional tie layers or primers, alternate thicknesses, additional components, etc. Also, as the individual layers that comprise the multilayer stack are formed, they can be cleaned before the next adjacent layer is deposited. For example, the canopy can be cleaned with a solvent such as acetone, and then dried to remove any surface water, which could cause premature crosslinking of the polysiloxane of the base layer 30. The invention is not limited to the embodiments specifically disclosed, and the multilayer stacks, their layers, and compositions may be modified without departing from the invention, which is limited only by the appended claims and equivalents thereof.

1 **[0068]** WHAT IS CLAIMED IS:

1. An electrically conductive multilayer stack, comprising:
a coated substrate;
5 a primary conductive layer containing a metal oxide and a metal layer,
disposed over the coated substrate; and
a secondary protective stack including at least one conductive layer, disposed
over the primary conductive layer.
- 10 2. The multilayer stack of claim 1, wherein the substrate is an aircraft canopy.
3. The multilayer stack of claim 1, wherein the coated substrate comprises a
substrate, a tie layer disposed over the substrate, and a substrate base layer disposed over the
tie layer.
- 15 4. The multilayer stack of claim 3, wherein the base layer comprises an
organopolysiloxane.
5. The multilayer stack of claim 4, wherein the organopolysiloxane is
20 compounded with a silane or siloxane.
6. The multilayer stack of claim 1, wherein the primary conductive layer
comprises a first metal oxide layer, a metal layer disposed over the first metal oxide layer,
and a second metal oxide layer disposed over the metal layer.
- 25 7. The multilayer stack of claim 6, wherein the first and second metal oxide
layers are comprised of indium tin oxide, titanium dioxide, zinc oxide, or zinc stannate.
8. The multilayer stack of claim 6, wherein the first and second metal oxide
30 layers comprise indium tin oxide.
9. The multilayer stack of claim 6, wherein the metal layer comprises silver or a
silver alloy.
- 35 10. The multilayer stack of claim 9, wherein the silver alloy comprises
silver/palladium or silver/gold.

1 11. The multilayer stack of claim 6, wherein the metal layer is coated with a layer of titanium.

5 12. The multilayer stack of claim 1, wherein the secondary protective stack includes a first tie layer, a hydrophobic barrier layer disposed over the first tie layer, a second tie layer disposed over the barrier layer, and a conductive topcoat disposed over the second tie layer.

10 13. The multilayer stack of claim 12, wherein the first tie layer comprises a material compatible with a metal oxide and the barrier layer.

 14. The multilayer stack of claim 12, wherein the second tie layer comprises a material compatible with the barrier layer and the topcoat.

15 15. The multilayer stack of claim 12, wherein the barrier layer comprises a material selected from the group consisting of polyurethanes, fluorinated urethanes, fluoropolymers, fluoroelastomers, polyurethanes, polyolefins, polyamides, polyamines, halopolymers, ethylene propylene rubbers, epoxies, polyesters, and fluorosilicones.

20 16. The multilayer stack of claim 12, further comprising a primer coat between the first tie layer and the barrier layer.

 17. The multilayer stack of claim 16, wherein the primer coat comprises 3-aminopropyltriethoxy silane.

25 18. The multilayer stack of claim 12, wherein the topcoat comprises a polyurethane formed from a polyol, aliphatic polyisocyanate resin, Di acytone alcohol, and a conductive agent.

30 19. The multilayer stack of claim 18, wherein the conductive agent comprises a quaternary ammonium salt, a conductive metal oxide, or an inherently conductive polymer.

 20. The multilayer stack of claim 19, wherein the conductive agent comprises a quaternary ammonium salt.

35 21. The multilayer stack of claim 20, wherein the quaternary ammonium salt is provided in the topcoat at a concentration of from about 22 to 60 wt%.

1 22. The multilayer stack of claim 21, wherein the quaternary ammonium salt concentration is about 22 to 35 wt%.

5 23. The multilayer stack of claim 20, wherein the quaternary ammonium salt is provided in the topcoat at a concentration of greater than or equal to 60 wt%.

10 24. The multilayer stack of claim 18, wherein the conductive agent comprises a non-reactive organic salt selected from the group consisting of 1-butyl-3-methylimidazolium methyl sulfonate, 1-butyl-3-methylimidazolium methyl sulfate, and 1-butyl-3-methylimidazolium ethyl sulfate.

 25. The multilayer stack of claim 24, wherein the non-reactive organic salt is present at a concentration of about 1 to 5 wt%.

15 26. The multilayer stack of claim 12, wherein the conductive agent comprises a conductive metal oxide.

20 27. The multilayer stack of claim 26, wherein the conductive metal oxide comprises indium tin oxide.

 28. The multilayer stack of claim 27, wherein the indium tin oxide is provided as nanoparticles.

25 29. The multilayer stack of claim 12, wherein the conductive agent comprises an inherently conductive polymer.

 30. The multilayer stack of claim 29, wherein the inherently conductive polymer comprises a polythiophene-based polymer.

30 31. The multilayer stack of claim 30, wherein the polythiophene-based polymer is poly(3,4-ethylene dioxathiophene)-poly(styrene sulfonate).

35 32. The multilayer stack of claim 12, wherein the first tie layer, second tie layer, and/or barrier layer contain a conductive agent selected from the group consisting of quaternary ammonium salts, conductive metal oxides, and inherently conductive polymers.

 33. The multilayer stack of claim 12, wherein the first tie layer contains a conductive metal oxide.

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34. The multilayer stack of claim 12, wherein the second tie layer contains a conductive metal oxide.

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35. The multilayer stack of claim 12, wherein the barrier layer contains a conductive metal oxide.

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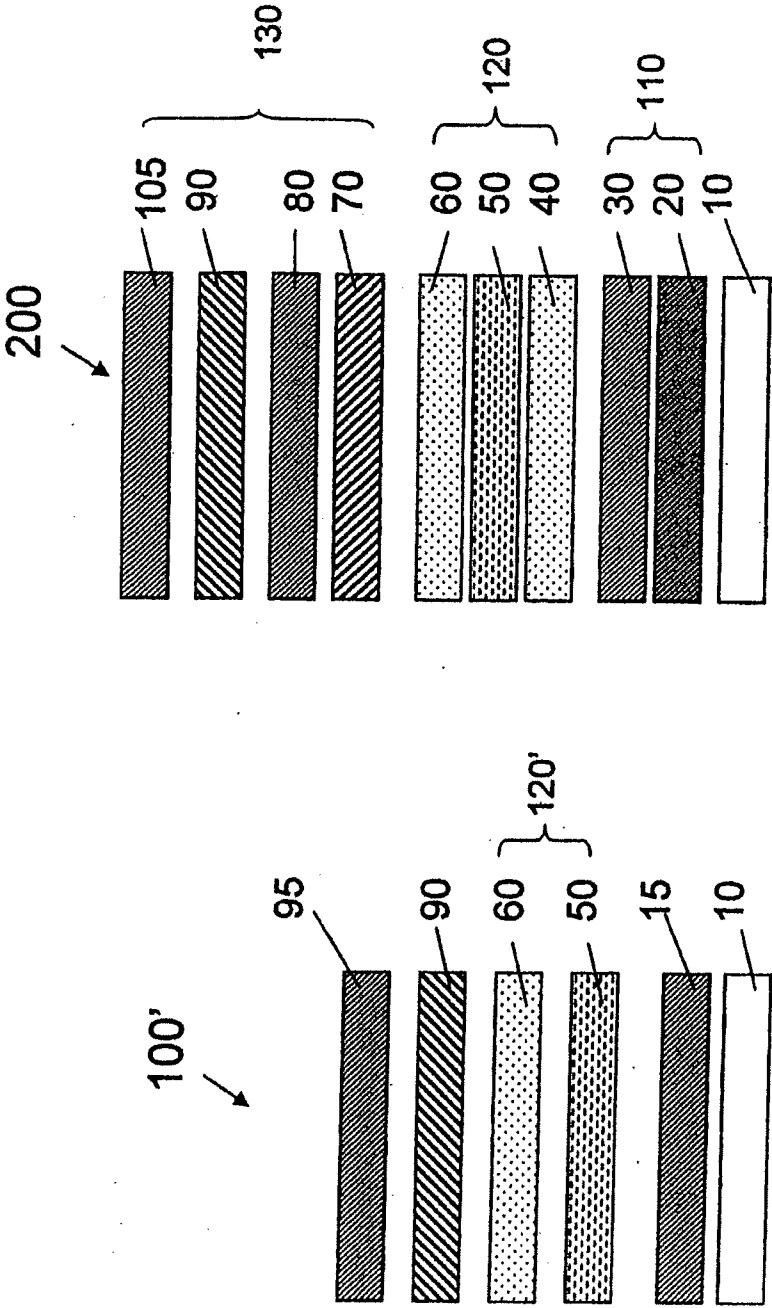


FIGURE 2

FIGURE 1
(Prior Art)

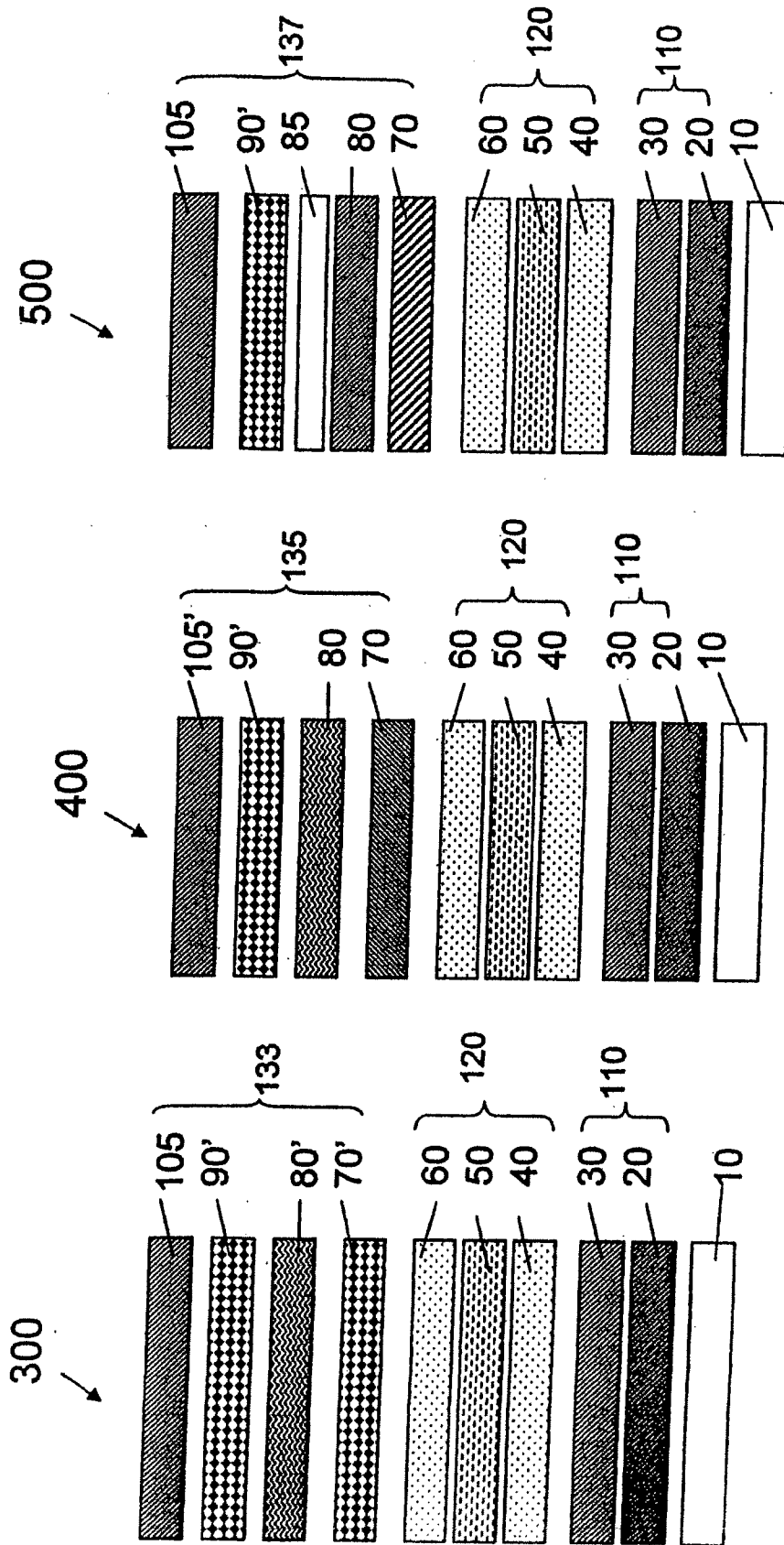


FIGURE 3

FIGURE 4

FIGURE 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2009/052015

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G02F1/15 (2009.01)

USPC - 359/265

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) - G02F1/15 (2009.01)

USPC -359/265

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Patbase

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2007/0002421 A1 (RUKAVINA et al) 04 January 2007 (04.01.2007) entire document	1-9, 12-15, 26, 27
Y		10, 11, 16-25, 28-35
Y	US 2008/0073622 A1 (HOUSEL) 27 March 2008 (27.03.2008) entire document	18-25
Y	US 5,859,722 A (SUGA et al) 12 January 1999 (12.01.1999) entire document	16, 17, 29, 30-32, 35
Y	US 4,465,736 A (NISHIHARA et al) 14 August 1984 (14.08.1984) entire document	10,11
Y	US 5,780,160 A (ALLEMAND et al) 14 July 1998 (14.07.1998) entire document	33, 34
Y	US 2007/0224340 A1 (HATTA et al) 27 September 2007 (27.09.2007) entire document	28
Y	US 2007/0249088 A1 (OHMORI et al) 25 October 2007 (25.10.2007) entire document	31

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

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Date of the actual completion of the international search

10 September 2009

Date of mailing of the international search report

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