(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 3 012 348 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
27.04.2016 Bulletin 2016/17

(51) Int Cl.:
C23C 18/12 *(2006.01)*

(21) Application number: **14189864.3**

(22) Date of filing: **22.10.2014**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME

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(54) **Multilyer barrier coating and method to produce a multilayer barrier coating**

(57) Examples of the present disclosure relate to an apparatus for providing a multilayer barrier coating and method for forming the same. The apparatus may comprise: at least a first layer and a third layer formed via a first process; and at least a second layer, between the first and third layers, formed via a second process different to the first process; wherein the first process is a Sol-Gel process. The apparatus may be used to encapsulate an object (not least for example an organic light-emitting display or photovoltaic cell) to provide barrier protection.

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Description

TECHNOLOGICAL FIELD

[0001] Examples of the present disclosure relate to an apparatus and method for multilayer barrier coating. Some examples, though without prejudice to the foregoing, relate to a multilayer thin-film composite barrier coating for encapsulation of an object, not least for example a flexible substrate such as an organic light-emitting display (OLED) or photovoltaic cell.

BACKGROUND

[0002] Conventional barrier coatings are not always optimal. Previous coatings may not provide adequate barrier properties in thin-film form and/or may be too bulky and brittle for long term flexible use as a barrier coating for a flexible substrate, such as flexible OLEDs and flexible active-matrix OLEDs (AMOLEDs) which require a high degree of protection from moisture and oxygen penetration as well as maintaining such protection during long-term flexible use.

[0003] The listing or discussion of any prior-published document or any background in this specification should not necessarily be taken as an acknowledgement that the document or background is part of the state of the art or is common general knowledge. One or more aspects/examples of the present disclosure may or may not address one or more of the background issues.

BRIEF SUMMARY

[0004] The present invention is as set out in the independent claims.

[0005] According to at least some but not necessarily all examples of the disclosure there is provided an apparatus configured to provide a multilayer barrier coating for a surface, the apparatus comprising: at least a first layer and a third layer formed via a first process; and at least a second layer, between the first and third layers, formed via a second process different to the first process; wherein the first process is a Sol-Gel process.

[0006] According to at least some but not necessarily all examples of the disclosure there is provided a method comprising causing, at least in part, actions that result in: forming a first layer of a multilayer barrier coating on a substrate via a first process; forming a second layer of the multilayer barrier coating via a second process different to the first process; forming a third layer of the multilayer barrier coating via the first process, such that the second layer interposes the first and third layers; and wherein the first process is a Sol-Gel process.

[0007] According to at least some but not necessarily all examples of the disclosure there is provided a multilayer barrier coating fabricated by the above method.

[0008] According to at least some but not necessarily all examples of the disclosure there is provided a substrate, device or object (such as, for example, an Organic Light Emitting Diode or a Photovoltaic cell) at least partially encapsulated by the above multilayer barrier coating.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] For a better understanding of various examples of the present disclosure that are useful for understanding the detailed description and certain embodiments of the invention, reference will now be made by way of example only to the accompanying drawings in which:

Figure 1 schematically illustrates an example of a multilayer barrier coating;
Figure 2 schematically illustrates a further example of a multilayer barrier coating;
Figure 3 schematically illustrates a yet further example of a multilayer barrier coating;
Figure 4 schematically illustrates an object encapsulated by a multilayer barrier coating; and
Figure 5 schematically illustrates an example of a method.

DETAILED DESCRIPTION

[0010] The Figures schematically illustrate an apparatus 100 configured to provide a multilayer barrier coating for a surface 201'. The apparatus 100 comprises:

at least a first layer 101 and a third layer 103 formed via a first process; and
at least a second layer 102, between the first and third layers, formed via a second process different to the first process;
wherein the first process is a sol-gel process.

[0011] Without limiting the scope of the claims, an advantage of certain examples of the present disclosure may be to provide a multilayer thin-film composite structure for providing a barrier coating and encapsulation of an object such as, not least for example: an organic light emitting diode (OLED), photovoltaic (PV) cell, packaging (such as food packaging), a membrane or filter (such as a water treatment filter membrane). Examples may also be to provide a barrier coating for a flexible surface such as a: flexible substrate, laminate film, sheet or roll. Examples may also be used for encapsulating objects/articles that require a high degree of protection against contamination or for hygiene purposes, such as, not least for examples in the food industry or medical industry.

[0012] An advantage of certain examples of the present disclosure is that the first layer formed via the sol-gel process provides a hydrophilic primer layer for a subsequently deposited layer (which is formed by a process other than the sol-gel process). Such a hydrophilic primer layer aids the binding/attachment of the subsequently deposited layer, thereby enhancing the robustness of the subsequent layer. Moreover, the first layer provides a planarised/smooth surface onto which the subsequent layer may be deposited. Such a planarising/smoothing layer reduces surface roughness of the underlying surface by encapsulating surface defects so as to provide a smooth planarised surface better suited for forming a subsequent layer which enhances the robustness of the subsequent layer.

[0013] The subsequent (second) layer, formed via a non-sol-gel process, may be selected so as to provide a barrier layer which increases a permeate path length of the overall multilayer barrier coating. The barrier material and deposition process may be selected so as to provide a barrier against gas permeation, e.g. oxygen and water vapour. The third layer, which is formed via the sol-gel process, may provide both mechanical protection to the underlying second layer as well as may prevent leaching of the underlying second layer so as to provide a protective top coating, thereby providing a more robust second layer.

[0014] Advantageously, the interleaving of a non-sol-gel based layer between two sol-gel based layers provides a more robust non-sol-gel based layer which is better able to withstand repeated flexing. Moreover, each of the sol-gel layers themselves acts to increase a permeate path length of the overall multilayer barrier coating. Thus certain examples provide an improved barrier coating with enhanced barrier/penetration/permeation properties and resilience to flexing.

[0015] An example of an apparatus configured to provide a multilayer barrier coating for a surface will now be described with reference to the Figures. Similar reference numerals are used in the Figures to designate similar features. For clarity, all reference numerals are not necessarily displayed in all figures.

[0016] Figure 1 schematically illustrates an apparatus 100 according to an example of the present disclosure. The apparatus 100 comprises a stack of at least a first layer 101, a second layer 102 and a third layer 103. The first and third layers are formed via a sol-gel process, whereas the second layer is formed via a process different from the sol-gel process.

[0017] The first layer 101 is formed of a material which is deposited via a sol-gel process. The first layer may be provided on a surface (not shown in figure 1) of a substrate thereby acting as a primer layer which may provide both a smooth and a hydrophilic primer layer to the subsequently deposited second layer. The second layer is formed of a material which is deposited via a process different from that of the sol-gel process. The second layer may comprise a conformal coating which may be provided, for example, via Atomic Layer Deposition (ALD) or could alternatively be provided by other coating techniques such as Chemical Vapour Deposition (CVD). The second layer may provide a thin film barrier against permeation of, for example, oxygen, water vapour as well as other permeates and contaminants. The third layer 103 is formed of a material which is deposited via a sol-gel process. The third layer may provide both mechanical protection to the underlying second layer as well may prevent leaching of the second layer thereby forming a protective top coating. Each of the sol-gel layers also acts to increase a permeate path length of the overall multilayer barrier coating and enables barrier performance of the multilayer coating to be maintained even if a defect occurs in the second barrier layer. In certain examples, each layer formed via the sol-gel process may have a thickness of: 10nm-5μm, or preferably 100nm-1000nm, or yet further preferably 300nm-900nm and yet further preferably 600nm-650nm. The apparatus may comprise a plurality of stacked layers alternatively formed of a sol-gel derived material and a material derived/deposited via a process different from that of the sol-gel process. Such "non-sol-gel layers" may have a thickness of: 1nm-100nm, preferably 5nm-20nm, yet further preferably 10nm-15nm.

[0018] Figure 2 shows an example of a further apparatus 200 comprising a multilayer barrier covering a substrate 201. The multilayer barrier comprises the basic unit structure 100 as per figure 1 (namely the three stacked layers 101, 102 and 103 disposed on top of one another, wherein the two sol-gel derived layers 101 and 103 are interposed/interleaved by a non-sol-gel derived layer 102) and additionally comprises a fourth layer 204 and a fifth layer 205. The fourth layer 204 is formed via a process other than a sol-gel process whereas the fifth layer 205 is formed via a sol-gel process. For example, the fourth layer 204 may be formed via the same process as used for the second layer 102. The multilayer barrier coating may be provided to a substrate 201 so as to provide a multilayer barrier coating to a surface 201' of the substrate 201.

[0019] The first layer 101 is applied to a surface 201' of the substrate 201. The substrate may be a flexible substrate (such as not least polyethylene naphthalate (PEN), Polyethylene terephthalate (PET) and polyimide based substrates) and/or a substrate onto which an object to be encapsulated is fabricated, such an object may comprise organic electronics such as an OLED or PV. The first layer helps reduce/avoid irregular peaks in the PEN substrate and provide a smooth

primer layer for the subsequent second layer.

[0020] In the apparatus of figure 2, a sequence of layers is provided, that alternate between a layer formed via a sol-gel process and a layer formed via a different process, such that, in effect, a layer formed via a different process, such as 102 or 204, is "sandwiched" between two layers formed via the sol-gel process, e.g. 101 and 103, or 103 and 205. Advantageously, a lower layer of the 'sandwich' unit structure provides an enhanced surface onto which the interposed layer formed via a different process is deposited, whereas the upper layer of the 'sandwich' unit structure provides protection to the interposed non-sol-gel layer. Moreover, each of the sol-gel layers also improves the overall impermeation properties of the overall multi-layered barrier structure.

[0021] The third layer, in addition to providing diffusion control/increasing the permeate path length and providing a protective layer to the underlying second layer, also provides a planarization/smoothing layer to reduce surface roughness, encapsulating surface defects thereby providing a planarized surface better suited for forming the fourth layer on. Also, the third sol-gel layer provides a hydrophilic layer conducive for forming the fourth layer on.

[0022] Figure 3 shows an alternative structure of a multilayer barrier coating to provide a coating for a surface 201' of a substrate 201. In the apparatus 300, instead of providing a stack of alternating layers formed of a sol-gel derived material and a non-sol-gel derived material, a basic unit structure 100 (comprising the first, second and third layers 101, 102, 103) is formed and a further basic unit structure 100 is formed on top of the first basic unit structure 100. It will be appreciated that additional basic unit structures could also be provided.

[0023] In particular, in the apparatus 300 of figure 3, a first basic unit structure 100 is provided on the substrate 201 by forming first, second and third layers 101, 102, 103 as per the example of figure 1. Furthermore an additional fourth layer 304, formed via a sol-gel process, is provided on top of the third layer 103, which itself has been formed via a sol-gel process. Once the fourth layer has been formed, a fifth layer 305 is provided via a process other than that of the sol-gel process. Finally, a top coating sixth layer 306 is provided which is formed via a sol-gel process. The fourth fifth and six layers define a further unit structure 100.

[0024] Advantageously, the multilayer basic unit structure of first to third layers 101-103 is reproducible on itself such that one can stack/repeat such a unit structure on top of one another. This can enable an easy and cost effective multilayer barrier to be fabricated with enhanced permeability/impenetrability properties or even having particular desired permeability/impenetrability properties by repeating the formation/application of the three layers.

[0025] It will be appreciated that for each of the apparatus 200 and the apparatus 300, yet further additional layers may be provided. For example yet further layers formed via a sol-gel process and via a non-sol-gel process. Since each sol-gel layer and each non sol-gel layer increases permeate path length of the multilayer structure, the addition of yet further sol-gel and non-sol-gel layers provides yet further diffusion control and yet further increase the permeate path length of the overall multilayer structure. Accordingly, additional sol-gel layers and additional non sol-gel layers may be provided so as to provide a requisite degree of diffusion control/permeate path lengths.

[0026] It is envisaged that examples of the present disclosure may enable the provision of low cost encapsulation especially when the multilayer structure is produced via a roll to roll process wherein additional layers of the multilayer structure can be stacked on top of one another by repeating the roll to roll process, or incorporating additional deposition steps in one continuous roll to roll process.

[0027] Figure 4 schematically shows a yet further example of an apparatus 400 in which an object 401, such as a substrate, electronics or organic electronics, packaging, filter... etc. may be at least partially encapsulated by a multilayer barrier coating 402. The multilayer barrier coating 402 comprises alternating layers of sol-gel derived material and non-sol-gel derived material. The at least partial encapsulation may comprise encapsulating at least part or substantially all of one or more sides of the object. Figures 2 and 3 show only a single side of the substrate 201 being encapsulated. However, it is to be appreciated that one or more additional sides may be encapsulated by the multilayer barrier. Indeed the substrate may be totally encapsulated such that it is completely coated on all sides in the multilayer barrier.

[0028] The object to be encapsulated and the multilayer barrier coating itself may be flexible as indicated by the arrow in figure 4.

[0029] The object to be encapsulated may comprise an organic electronic circuit or device such as an organic light emitting diode. The object to be encapsulated may further or alternatively comprise a transistor-based circuit or a transistor array such as a metal-oxide transistor array. Furthermore, the apparatus may be included in a device such as an electronic device or a handheld supportable electronic device such that one or more components of the device or the entire device itself might be encapsulated by the multilayer barrier coating.

[0030] It is to be appreciated that Figure 4 is merely a schematic diagram and is not to scale. Indeed, certain examples of the multilayer barrier coating would have an overall thickness of the order of μm whereas the object to be encapsulated may have dimensions (such as length and width) of the order of mm, cm or meters).

[0031] In certain examples, the apparatus may be embodied in a hand held portable electronic device, such as, mobile telephone, tablet, wearable computing device, a mobile terminal portable digital assistant (PDA), a pager, a mobile computer, a desktop computer, a television, a gaming device, a laptop computer, a camera, a video recorder, GPS device and in other types of electronic systems, which may readily employ examples of the present disclosure. Further-

more, devices may readily employ examples of the present disclosure regardless of their intent to provide mobility. Such electronic devices may additionally provide one or more audio/text/video communication functions (e.g. tele-communication, video-communication, and/or text transmission (Short Message Service (SMS)/ Multimedia Message Service (MMS)/emailing functions), interactive/non-interactive viewing functions (e.g. web-browsing, navigation, TV/program viewing functions), music recording/playing functions (e.g. Moving Picture Experts Group-1 Audio Layer 3 (MP3) or other format and/or (frequency modulation/amplitude modulation) radio broadcast recording/playing), downloading/sending of data functions, image capture function (e.g. using a (e.g. in-built) digital camera), and gaming functions.

[0032] The apparatus may be provided in a module. As used here 'module' refers to a unit or apparatus that excludes certain parts/components that would be added by an end manufacturer or a user. For example, the module may relate to a display module which is added to an electronic device.

[0033] Figure 5 semantically illustrates a flowchart of a method 500 for fabricating a multilayer barrier coating for a surface. In block 501, a first layer is formed on a substrate wherein the first layer is formed via a sol-gel process. In block 502, a second layer is formed on the first layer via a different process to that of the sol-gel process, for example the second layer may be deposited via Atomic Layer Deposition. In block 503, a third layer is formed on top of the second layer via the sol-gel process.

[0034] Optionally, further layers may be applied to the first, second and third layers. The "A" branch of the method relates to forming a multi-layered structure having alternating layers of sol-gel derived material and non-sol-gel derived material. In block 504A, a fourth layer is applied over the third layer via a process other than the sol-gel process. Such a process may correspond to the same process that is used to form the second layer in block 502. In block 505A, a fifth layer is applied over the fourth layer via the sol-gel process. It will be appreciated that further additional layers, i.e. sixth, seventh and so on, may also be formed.

[0035] The "B" branch of the method 500 relates to forming a multi-layered structure having a stack/repetition of the basic unit structure of two layers of sol-gel derived material sandwiching a layer of a non-sol-gel derived material. In block 504B a fourth layer is applied via the sol-gel process followed by block 505B in which a fifth layer is applied which is formed via a differing process and in block 506B, a sixth layer is then provided formed via the sol-gel process. It will be appreciated that further additional basic unit structures may also be formed.

[0036] The flowchart of Figure 5 represents one possible scenario among others. The order of the blocks shown is not absolutely required, so in principle, the various blocks can be performed out of order. Not all the blocks are essential. In certain examples one or more blocks may be performed in a different order or overlapping in time, in series or in parallel one or more blocks may be omitted or added or changed in some combination of ways.

COATING TRIAL MEASUREMENTS

[0037] The following tables provide results from coating trials which have been conducted by coating a PEN substrate with various differing coatings. Table 1 provides measured values of water vapour transmission rates (WVTR), whereas table 2 sets out measured values of oxygen transmission rates (OTR).

[0038] As will be apparent from these tables, coatings of examples of the present disclosure are highlighted which include the basic unit structure of the sandwiching of "non-sol-gel" layers between two sol-gel layers (e.g. Sol-Gel/ALD1 /Sol-Gel and Sol-Gel/ALD2/Sol-Gel) provides improved vapour and oxygen transmission rates.

Table 1: **Water Vapour Transmission Rate**

Coating	**Sample #1**	**Sample #2**
(Uncoated PEN)	1.4 g/m^2/day	1.5 g/m^2/day
ALD1	0.6 g/m^2/day	0.3 g/m^2/day
ALD2	0.1 g/m^2/day	0.1 g/m^2/day
Sol-Gel/ALD1	0.05 g/m^2/day	0.04 g/m^2/day
Sol-Gel/ALD1/Sol-Gel	0.03 g/m^2/day	0.03 g/m^2/day
Sol-Gel/ALD2	0.005 g/m^2/day	0.005 g/m^2/day
Sol-Gel/ALD2/Sol-Gel	0.003 g/m^2/day	0.001 g/m^2/day
WVTR measurements conducted at 38°C and 95% Relative Humidity ALD1=Al_2O_3 ALD 130 cycles ALD2=Al_2O_3 ALD 190 cycles Sol-Gel=Sol-Gel coating composition using TEOS and MEMO precursor (see SOL-GEL PROCESS below)		

Table 2: Oxygen Transmission Rate

Coating	Sample #1	Sample #2
(Uncoated PEN)	1.5 cc/m^2/day	1.4 cc/m^2/day
ALD1	0.05 cc/m^2/day	<0.01 cc/m^2/day
ALD2	<0.01 cc/m^2/day	<0.01 cc/m^2/day
Sol-Gel/ALD1	<0.01 cc/m^2/day	<0.01 cc/m^2/day
Sol-Gel/ALD1/Sol-Gel	0.1 cc/m^2/day*	0.1 cc/m^2/day*
Sol-Gel/ALD2	0.1 cc/m^2/day	0.2 cc/m^2/day
Sol-Gel/ALD2/Sol-Gel	<0.01 cc/m^2/day	<0.01 cc/m^2/day
OTR measurements conducted at 23°C and 88% Relative Humidity ALD1=Al_2O_3 ALD 130 cycles ALD2=Al_2O_3 ALD 190 cycles Sol-Gel=Sol-Gel coating composition using TEOS and MEMO precursor (see SOL-GEL PROCESS below) ** it is noted that the measured values are near the detection limit of the measurement device used in the trial, which may cause some uncertainties in the measurements. Also, these values could be explained by some possible damage to the ALD1 layer during the Sol-Gel process. The thicker ALD2 layer may be more durable in this regard as the values for Sol-Gel/ALD2/Sol-Gel were more consistent. In general, the Sol-Gel coating should further enhance the WVTR and OTR barrier.*		

SOL-GEL PROCESS

[0039] The following is a discussion/overview of the sol-gel process.

[0040] The sol-gel process may involve the evolution of inorganic networks in a continuous liquid phase through the formation of colloidal suspension and following gelation of the sol. The sol-gel process can be used to manufacture various materials, including coatings, powders, monoliths, capsules, fibres or aerogels. Advantages of sol-gel thin films include the homogeneity and purity of the end-products formed at relatively low temperatures.

[0041] Metal or non-metal alkoxides may be used as monomers in a typical sol-gel synthesis for coatings. The sol-gel synthesis can be based on controlled hydrolysis and condensation reactions. Reaction 1 below represents the hydrolysis, where M may be a metal e.g.: silicon, zirconium or titanium and n is a number, e.g. four. Hydrolysis acts as a rapid initial reaction of sol-gel processes, where reactive alkoxide groups (-OR, where R is e.g. CH_3, CH_3CH_2, $CH_3(CH_2)_2$) react with water molecules to form hydroxyl groups (-OH). After the initiation of the reaction, the hydrolysed alkoxides may easily react with each other, forming dimers through the condensation reaction. Water or alcohol may be obtained as a by-product, depending on the reaction mechanism. The condensation reactions are described with Reactions 2 and 3.

M(OR)n + H2O -> M(OH)(OR)n-1+ROH (Reaction1)

M(OH)(OR)n-1 + M(OR)n -> (OR)n-1MOM(OR)n-1 + ROH (Reaction 2)

2M(OH)(OR)n-1 -> (OR)n-1MOM(OR)n-1 + H2O (Reaction 3)

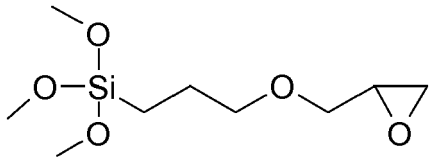
[0042] The alkoxide monomers may have a different reactivity, which can be related to the partial charge of the metal or the non-metal alkoxide. The reactivity of the monomers in hydrolysis and condensation reactions can be accelerated or hindered by using catalysts or by increasing or decreasing the reaction temperature.

[0043] The sol-gel hybrid coating composition may typically be formed using components that are capable of producing cross-linked networks. These compositions include at least one curable component, i.e. a precursor, preferably selected from UV or thermally curable components. Particularly, such precursors may be selected from unsaturated organic compounds, metal alkoxides, metal salts, epoxy monomers and acid monomers, for example vinyl, acrylates, methacrylates, silanes and silicates, as well as their derivatives. Most suitably, the precursors may be selected from vinyl, acrylates, methacrylates and silicates, or their derivatives. Preferred derivatives are alkyl and alkoxyl derivatives.

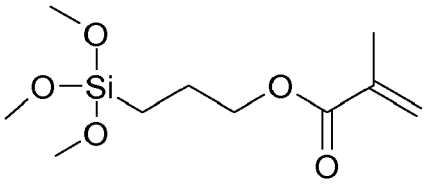
[0044] To provide a coating that strongly attaches to a substrate, preferably by covalent attachment or by strong physical interaction, one can use coating components that have reactive covalent-bond-forming end-groups (in addition

to the cross-linking groups), such as alkoxide groups, or end-groups that bind to the functional groups of the substrate surface using hydrogen bonds or van der Waals forces, such as silane end-groups or double or triple bonds, preferred ones may be silane groups. These may bind particularly to hydroxyl groups on the substrate surface.

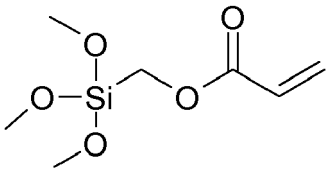
[0045] Examples of suitable sol-gel formulations or precursors for a sol-gel composition for forming a coating layer via the sol-gel process include but are not limited to:



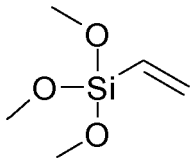
glycidoxypropyl trimethoxysilane (GLYMO)



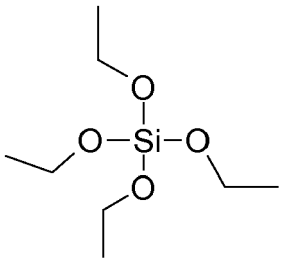
methacryloxypropyl trimethoxysilane (MEMO)



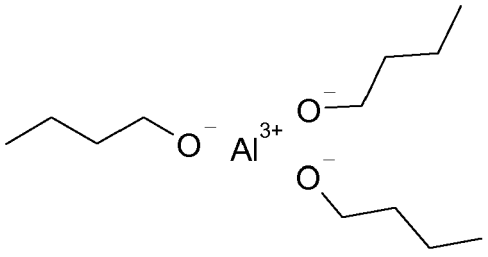
(3-Acryloyloxypropyl) trimethoxysilane (AKTMS)



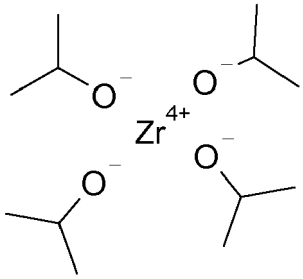
vinyltrimethoxysilane (VMTES)



tetraethoxysilane (TEOS)



aluminium n-butoxide



zirconium isopropoxide

[0046] The sol-gel coating composition may be applied onto a substrate's surface in the form of a sol-gel, which may be formed, for example, by dispersing the precursors of the coating composition in any common solvent, such as water or an organic solvent, preferably water or an alcohol or a mixture thereof, most suitably a mixture of water and an alcohol. Such a mixture (sol-gel liquid) is typically prepared by mixing the solvents into a water content of ≤50 vol%. The optional

alcohol is particularly selected from lower alcohols, including methanol, ethanol, n-propanol and isopropanol.

[0047] When using a solvent in forming the sol-gel, the obtained sol-gel can have any solids content between 5-95 percent by weight w-%, preferably between 20-50 w-%. However, it is possible to use also particularly high solids contents, such as contents of 50-95 w-%, or even 75-95 w-%, since the curing step or the optional separate drying step(s) will cause evaporation of any excess solvent.

[0048] The application of the coating composition on the substrate may be carried out using any appropriate technique, for example using spray or spin coating, more preferably with the coating composition in a sol-gel form. The sol-gel may be formed, for example, as described above.

[0049] The curing may be, in turn, carried out using thermal or UV curing. Further, it can be operated at atmospheric temperature and pressure. The curing causes the precursor component(s) of the coating composition to react and solidify, but causes also drying of the coating composition.

[0050] However, it is preferred to carry out at least one drying step, particularly two or more drying steps, prior to the curing. Suitable alternatives for the drying step are any drying procedures based on evaporation, such as air drying and drying by IR or UV radiation. Most suitably, at least two separate drying steps (in addition to the curing step) are carried out, which generally utilize two or more different techniques, such as air drying and IR drying. The drying temperature depends on the applied technique. Preferably, a low temperature (i.e. close to room temperature) is selected, such as a temperature within the range of 25-100 °C.

[0051] The thickness of the thus obtained final cured coating derived via the sol-gel process is adjustable, but is preferably within the range of 100 nm to 5 μm. The previously described advantages of a sol-gel derived layer can be obtained even with thin coatings, the thicknesses are particularly adjusted to be within the range of 100 to 1000 nm, most suitably 300 to 900 nm.

[0052] The examples of the present disclosure and the accompanying claims may be suitably combined in any manner apparent to one of ordinary skill in the art.

[0053] Features described in the preceding description may be used in combinations other than the combinations explicitly described.

[0054] Although functions have been described with reference to certain features, those functions may be performable by other features whether described or not.

[0055] Although features have been described with reference to certain examples, those features may also be present in other examples whether described or not.

[0056] Although various examples of the present disclosure have been described in the preceding paragraphs with reference to various examples, it should be appreciated that modifications to the examples given can be made without departing from the scope of the invention as set out in the claims.

[0057] The term 'comprise' is used in this document with an inclusive not an exclusive meaning. That is any reference to X comprising Y indicates that X may comprise only one Y or may comprise more than one Y. If it is intended to use 'comprise' with an exclusive meaning then it will be made clear in the context by referring to "comprising only one ..." or by using "consisting".

[0058] In this description, reference has been made to forming first, second, third layers and so on. It should be appreciated that each consecutive layer may be directly applied to the previous layer. However in certain examples it should also be appreciated that any number or combination of intervening layers could be provided and may exist between the first, and second layer or the second and third layer and so on (including no intervening layers).

[0059] In this description, reference has been made to various examples. The description of features or functions in relation to an example indicates that those features or functions are present in that example. The use of the term 'example' or 'for example' or 'may' in the text denotes, whether explicitly stated or not, that such features or functions are present in at least the described example, whether described as an example or not, and that they can be, but are not necessarily, present in some or all other examples. Thus 'example', 'for example' or 'may' refers to a particular instance in a class of examples. A property of the instance can be a property of only that instance or a property of the class or a property of a sub-class of the class that includes some but not all of the instances in the class.

[0060] Whilst endeavouring in the foregoing specification to draw attention to those features of examples of the present disclosure believed to be of particular importance it should be understood that the applicant claims protection in respect of any patentable feature or combination of features hereinbefore referred to and/or shown in the drawings whether or not particular emphasis has been placed thereon.

Claims

1. An apparatus configured to provide a multilayer barrier coating for a surface, the apparatus comprising:

   at least a first layer and a third layer formed via a first process; and

at least a second layer, between the first and third layers, formed via a second process different to the first process; wherein the first process is a Sol-Gel process.

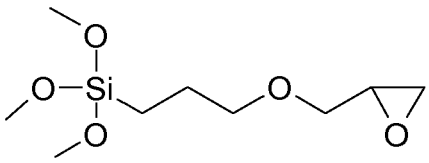
2. The apparatus of claim 1, further comprising:

at least a fifth layer formed via the first process; and
at least a fourth layer, between the third and fifth layers, formed via a process different to the first process.

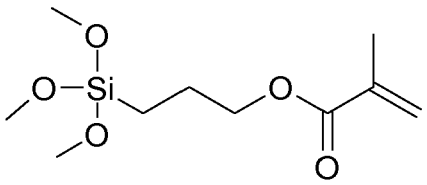
3. The apparatus of claim 1, further comprising:

at least a fourth and sixth layer formed via the first process; and
at least a fifth layer, between the fourth and sixth layers, formed via a process different to the first process.

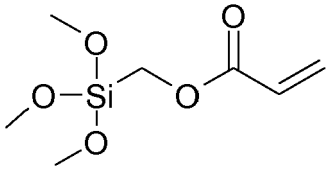
4. The apparatus of any one or more of the previous claims, wherein the Sol-Gel process involves a Sol-Gel precursor comprising at least one or more of the following:



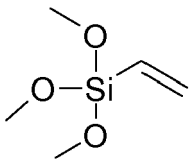
glycidoxypropyl trimethoxysilane (GLYMO)



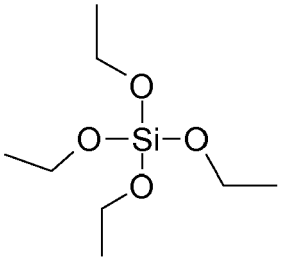
methacryloxypropyl trimethoxysilane (MEMO)



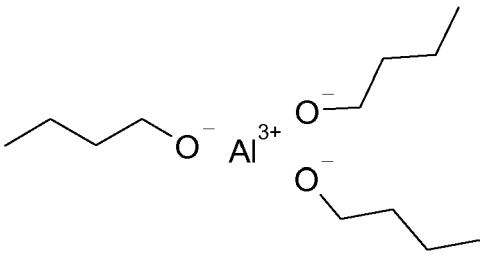
(3-Acryloyloxypropyl) trimethoxysilane (AKTMS)



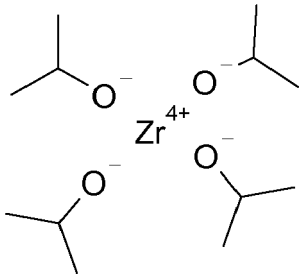
vinyltrimethoxysilane (VMTES)



tetraethoxysilane (TEOS)



aluminium n-butoxide



zirconium isopropoxide.

5. The apparatus of any one or more of the previous claims, wherein each of the layers formed via the Sol-Gel process has a thickness of: 100nm - 5μm, preferably 100nm - 1,000nm, yet further preferably 300nm - 900nm, and yet further preferably 600nm - 650nm.

6. The apparatus of any one or more of the previous claims, wherein the apparatus comprises a plurality of stacked layers alternatively formed of:

a material derived by the Sol-Gel process, and
a material not derived by the Sol-Gel process.

7. The apparatus of any one or more of the previous claims, wherein each of the layers formed via the process different to the Sol-Gel process has a thickness of: 1 nm - 100 nm, preferably 5 nm -20 nm, yet further preferably 10 nm - 15 nm.

8. The apparatus of any one or more of the previous claims, wherein the process different to the Sol-Gel process is an Atomic Layer Deposition process.

9. The apparatus of any one or more of the previous claims, further comprising a substrate and preferably wherein the substrate is flexible.

10. The apparatus of claim 9, wherein the apparatus at least partially encapsulates at least one side of the substrate.

11. An object at least partially protected or encapsulated by the apparatus of any one or more of the previous claims.

12. An Organic Light Emitting Diode, a Photovoltaic cell, a transistor-based circuit or a transistor array at least partially encapsulated by the apparatus as claimed in any one or more of the previous claims.

13. A hand held electronic device comprising the apparatus as claimed in any one or more of the previous claims.

14. A method comprising causing, at least in part, actions that result in:

forming a first layer of a multilayer barrier coating on a substrate via a first process;
forming a second layer of the multilayer barrier coating via a second process different to the first process;
forming a third layer of the multilayer barrier coating via the first process, such that the second layer interposes the first and third layers; and
wherein the first process is a Sol-Gel process.

15. A multilayer barrier coating fabricated by the method of claim 14.

Figure 1

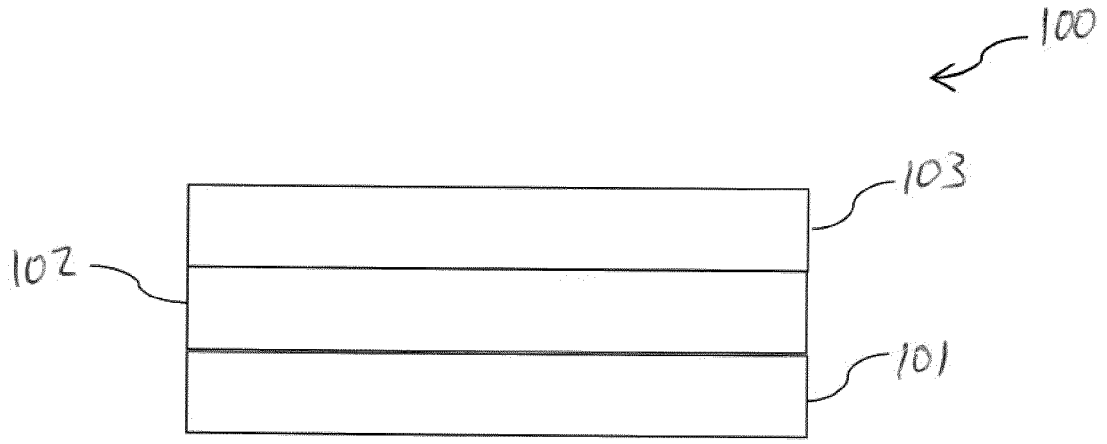


Figure 2

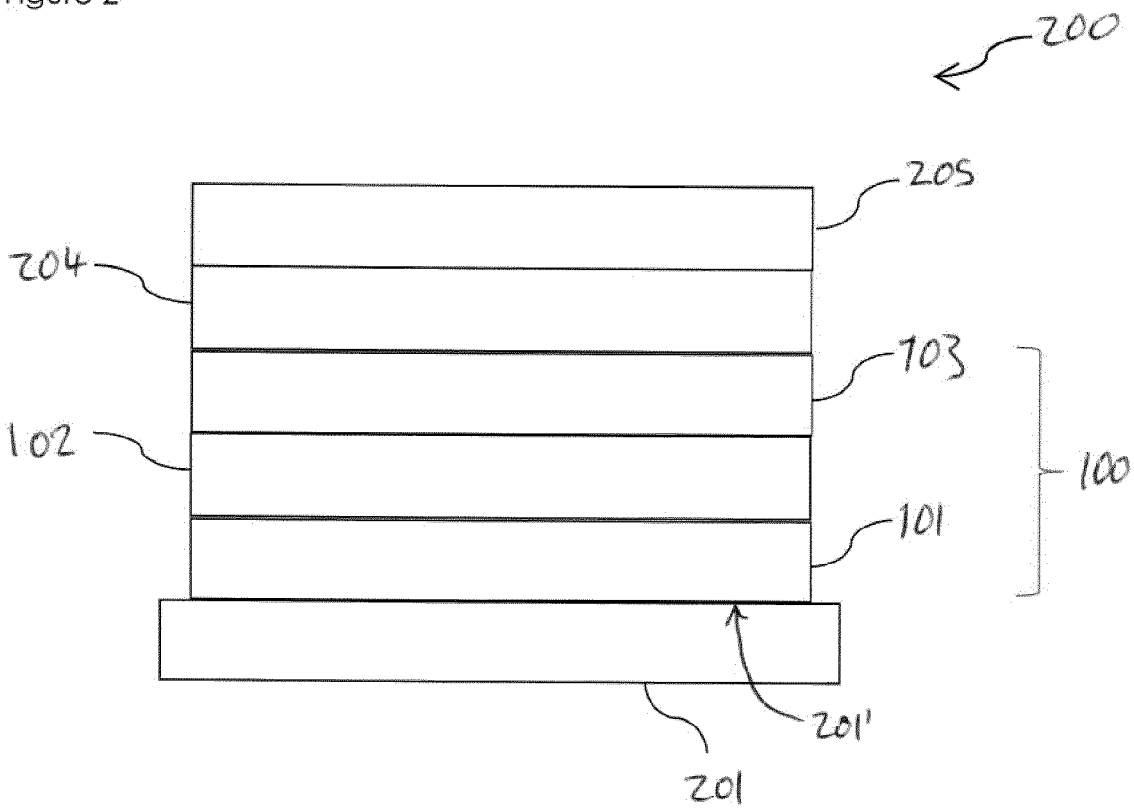


Figure 3

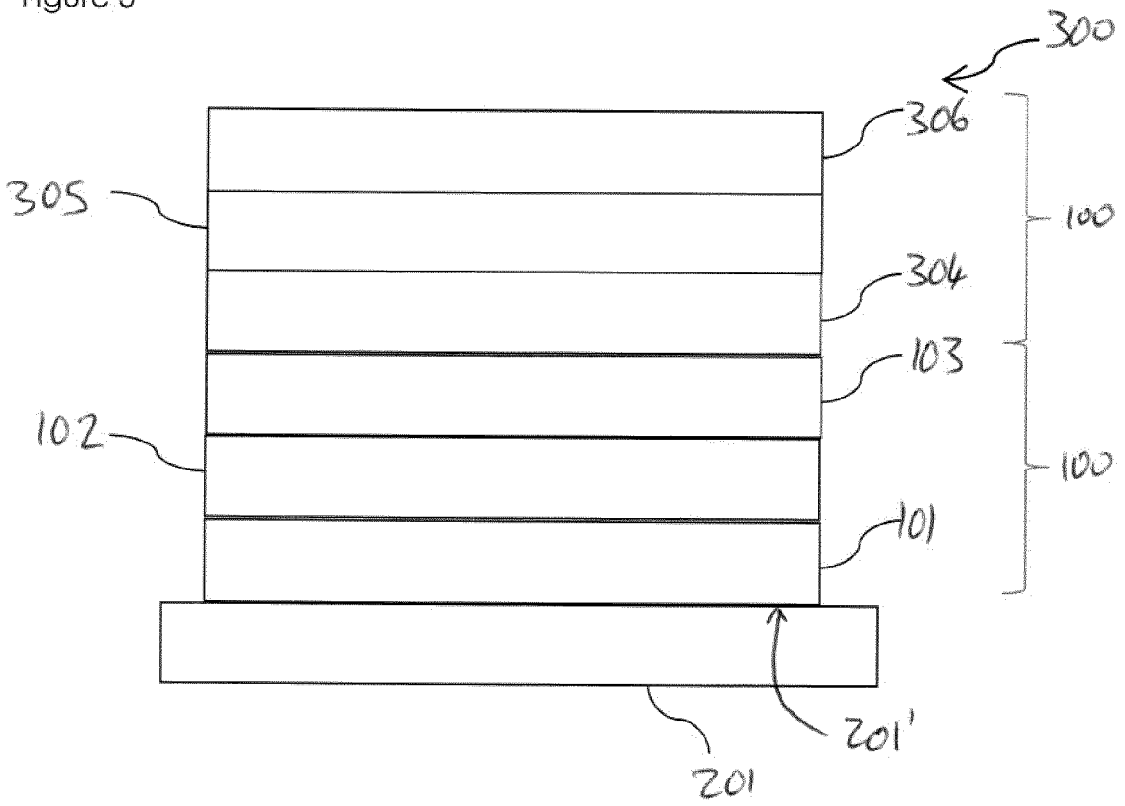


Figure 4

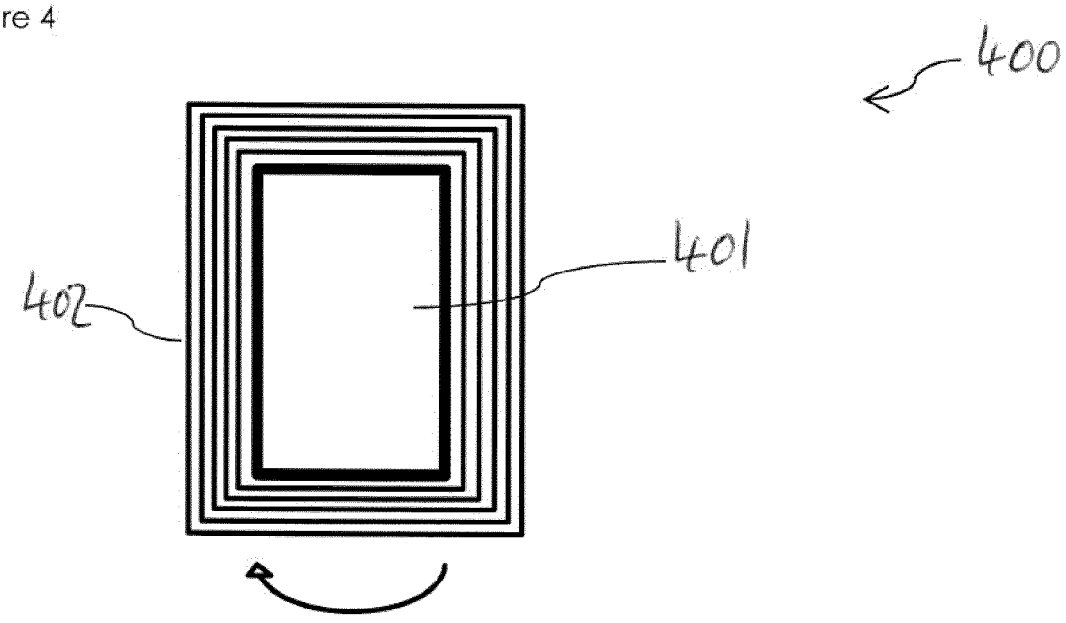
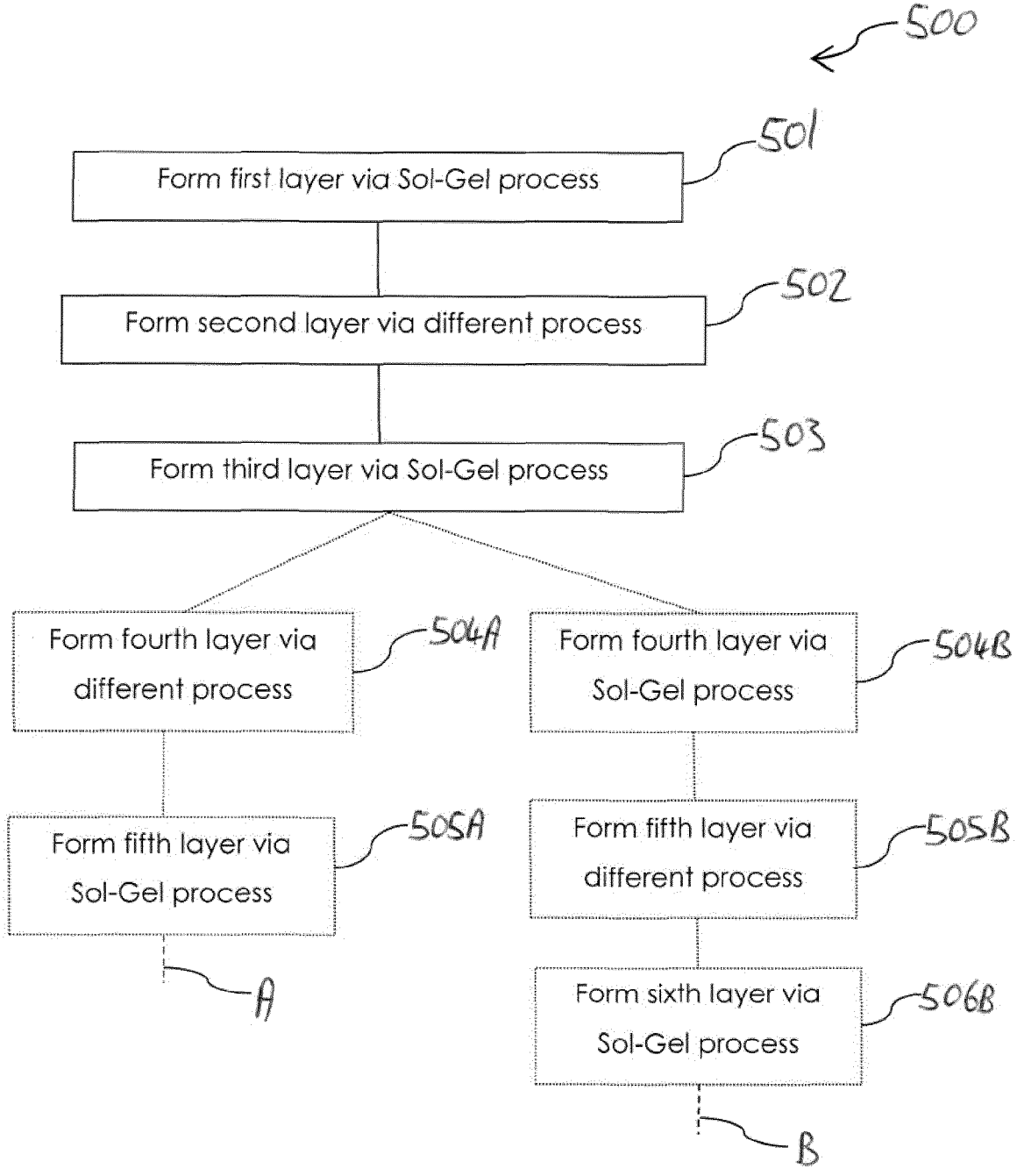


Figure 5


500
501
Form first layer via Sol-Gel process
502
Form second layer via different process
503
Form third layer via Sol-Gel process
504A
Form fourth layer via different process
504B
Form fourth layer via Sol-Gel process
505A
Form fifth layer via Sol-Gel process
505B
Form fifth layer via different process
A
506B
Form sixth layer via Sol-Gel process
B

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PARTIAL EUROPEAN SEARCH REPORT

under Rule 62a and/or 63 of the European Patent Convention. This report shall be considered, for the purposes of subsequent proceedings, as the European search report

Application Number
EP 14 18 9864

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2010/021691 A1 (LEE KWANG HEE [KR] ET AL) 28 January 2010 (2010-01-28) * abstract * * figure 2 * * example 1 * * paragraphs [0006], [0038], [0049], [0050], [0061], [0063] * * paragraphs [0070], [0091] - [0093], [0099] * -----	1,2,4-14	INV. C23C18/12
X	US 2014/113129 A1 (ASAL MURAD ABU [DE] ET AL) 24 April 2014 (2014-04-24) * example * * abstract * * figures 1, 4 * * paragraphs [0030], [0057], [0064] * -----	1-3,5-7, 9-11,14	
X	US 2012/220069 A1 (LIN CHING-FUH [TW] ET AL) 30 August 2012 (2012-08-30) * abstract * * figure 1E * * example 1 * * paragraphs [0005], [0019] - [0021] * ----- -/--	1,5-7, 9-14	

TECHNICAL FIELDS SEARCHED (IPC)
C23C

INCOMPLETE SEARCH

The Search Division considers that the present application, or one or more of its claims, does/do not comply with the EPC so that only a partial search (R.62a, 63) has been carried out.

Claims searched completely :

Claims searched incompletely :

Claims not searched :

Reason for the limitation of the search:

see sheet C

Place of search	Date of completion of the search	Examiner
The Hague	30 June 2015	Lange, Ronny

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04E07)

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PARTIAL EUROPEAN SEARCH REPORT

Application Number
EP 14 18 9864

DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (IPC)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
X	US 6 410 173 B1 (ARFSTEN NANNING J [US] ET AL) 25 June 2002 (2002-06-25) * abstract * * figure 4 * * column 4, line 29 - column 5, line 21 * * column 6, lines 28-63 * * column 11, line 66 - column 12, line 27 * -----	1,4-6, 9-11,14	
A	US 2010/132762 A1 (GRAHAM JR SAMUEL [US] ET AL) 3 June 2010 (2010-06-03) * abstract * * figure 1 * * paragraph [0007] * -----	8	TECHNICAL FIELDS SEARCHED (IPC)
A	WO 2014/102166 A1 (AKZO NOBEL COATINGS INT BV [NL]) 3 July 2014 (2014-07-03) * abstract * * example 5 * -----	4	
A	DE 10 2009 017822 A1 (EVONIK DEGUSSA GMBH [DE]) 21 October 2010 (2010-10-21) * abstract * * paragraph [0030] * -----	4	

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INCOMPLETE SEARCH
SHEET C

Application Number
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Claim(s) completely searchable:
-

Claim(s) searched incompletely:
1-14

Claim(s) not searched:
15

Reason for the limitation of the search (non-patentable invention(s)):

Article 84 and Rule 63 EPC
The Search Division considers that the claims on file do not comply with Article 84 and Rule 63 EPC because independent claims 1, 14 and 15 are not clear.
Independent claim 1
Present claim 1 relates to an apparatus configured to provide a multilayer barrier coating for a surface, the apparatus comprising: at least a first layer and a third layer formed via a first process; and at least a second layer, between the first and third layers, formed via a second process different to the first process; wherein the first process is a Sol-Gel process.
The wording "apparatus configured to provide a multilayer barrier coating" seems to relate to an apparatus for fabricating a multilayer barrier coating. However the describing features of claim 1 relate to the multilayer barrier coating itself. In addition according to the description the apparatus of the invention consists in the multilayer barrier coating or a device encapsulated by such a coating (Figures 1-4; Page 5, line 7 - Page 10, line 21).
Independent claim 14
Present claim 14 relates to a method for forming a multilayer barrier coating. The wording "A method comprising causing, at least in part, actions that result in : forming a first layer [...]" is unclear. It is not apparent whether the steps of the method are the actions that result in the formation of the layers or whether the steps of the method comprise the "forming steps".
In addition said actions are undefined and the wording attempts to define the subject-matter in terms of the result to be achieved ("actions that result in"). Such a definition is only allowable under the conditions elaborated in the Guidelines F-IV, 4.10. In this instance, however, such a formulation is not allowable because it appears possible to define the subject-matter in more concrete terms, viz. in terms of how the effect is to be achieved.
Furthermore the wording "at least in parts" is unclear. The wording leaves the reader in doubt as to the extend of the actions necessary to achieve the technical effect of method claim 14, thereby rendering the definition of the subject-matter of said claim unclear (Article 84 EPC).
This non-compliance with the substantive provisions is such that a meaningful search of the whole claimed subject-matter of claim 1-14 can not be carried out (Rule 63 EPC).
For all the above reasons the Search Division limits the scope of the search of claims 1 and 14 to the following subject-matter, whilst claim 15 is not searched.
Claim 1

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INCOMPLETE SEARCH SHEET C

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An apparatus comprising at least a first layer and a third layer formed via a first process; and at least a second layer, between the first and third layers, formed via a second process different to the first process; wherein the first process is a Sol-Gel process.
Claim 14:
A method comprising the following steps: forming a first layer of a multilayer barrier coating on a substrate via a first process; forming a second layer of the multilayer barrier coating via a second process different to the first process; forming a third layer of the multilayer barrier coating via the first process, such that the second layer interposes the first and third layers; and wherein the first process is a Sol-Gel process.

Further limitation of the search

Claim(s) completely searchable:
-

Claim(s) searched incompletely:
1-14

Claim(s) not searched:
15

Reason for the limitation of the search:

Rule 43(2) and Rule 62a EPC
Furthermore, the Search Division considers that the claims on file (as filed with letter of 19-12-2013) do not comply with Rule 43(2) and Rule 62a EPC for the following reasons:
Independent claims 1 and 15
Claims 1 and 15 have been drafted as separate independent product claims. Under Article 84 in combination with Rule 43(2) EPC, an application may contain more than one independent claim in a particular category only if the subject-matter claimed falls within one or more of the exceptional situations set out in paragraph (a), (b) or (c) of Rule 43(2) EPC. This is not the case in the present application, however, for the following reasons:
Claims 1 and 15 both comprise the general concept of a multilayer barrier coating having three distinct layers, the first and the third layer being formed by a Sol-Gel process and the second layer being formed by another process different form the Sol-Gel process.
From the examples of the present application and the description it is evident that the subject-matter of claims 1 and 15 do not represent alternative solutions to a particular problem in the meaning of Rule 43(2)(c) EPC, because claims 1 and 15 both refer to the same solution which is just claimed with a different wording.
In addition claims 1 and 15 do neither represent a plurality of interrelated products nor do not represent a plurality of different inventive uses of a product or device in the meaning of Rules 43(2)a and 43(2)(b) EPC, because they refer to an entity and not to a use of a product or device.
Consequently, the present application does not fulfill the requirements

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INCOMPLETE SEARCH
SHEET C

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of Rule 43(2) EPC.
For all the above reasons the Search Division limits the scope of the search of claims 1 and 14 to the following subject-matter, whilst claim 15 is not searched.
Claim 1:
An apparatus comprising at least a first layer and a third layer formed via a first process; and at least a second layer, between the first and third layers, formed via a second process different to the first process; wherein the first process is a Sol-Gel process.
Claim 14:
A method comprising the following steps: forming a first layer of a multilayer barrier coating on a substrate via a first process; forming a second layer of the multilayer barrier coating via a second process different to the first process; forming a third layer of the multilayer barrier coating via the first process, such that the second layer interposes the first and third layers; and wherein the first process is a Sol-Gel process.

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 14 18 9864

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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30-06-2015

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		WO 2010121872 A1	28-10-2010

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82