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(54) PLASMA TREATMENT APPARATUS AND SURFACE TREATMENT APPARATUS OF SUBSTRATE

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(57) **ABSTRACT**

A plasma treatment apparatus of the present invention comprises: a plasma generation chamber **34** for activating gas supplied thereto so as to generate plasma; a depressurization chamber **50** which is connected to the plasma generation chamber **34** and which accommodates a member **52** to be plasma-treated; and a diffuser **58** which is provided at a joint part of the plasma generation chamber **34** and the depressurization chamber **50**, which guides the plasma in a direction inclined to a gas flow path of the plasma generation chamber **34**, and which introduces the plasma into the depressurization chamber **50** while diffusing the plasma in the depressurization chamber **50**.

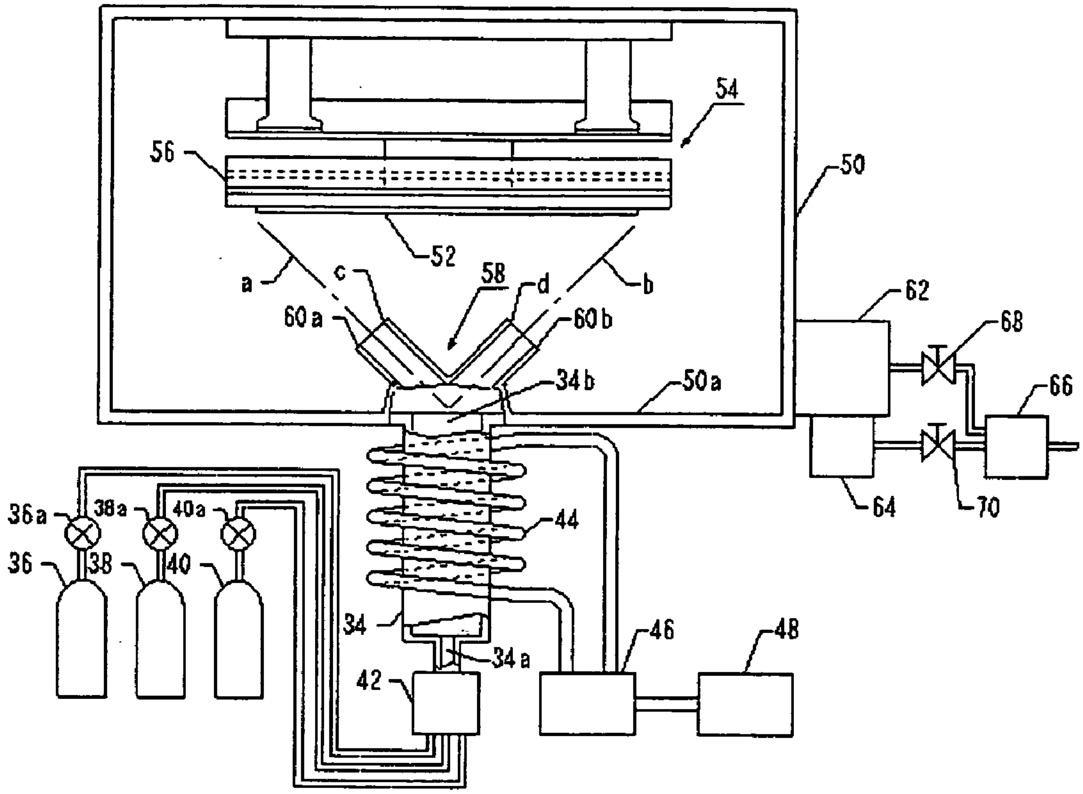
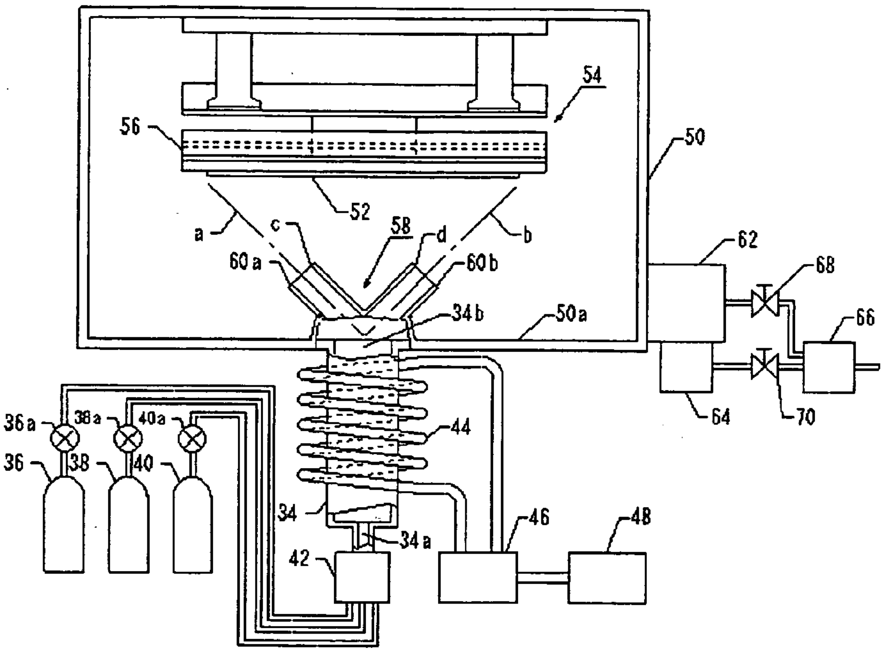


Fig. 1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56
50
52
a
c
58
d
b
60a
60b
62
68
66
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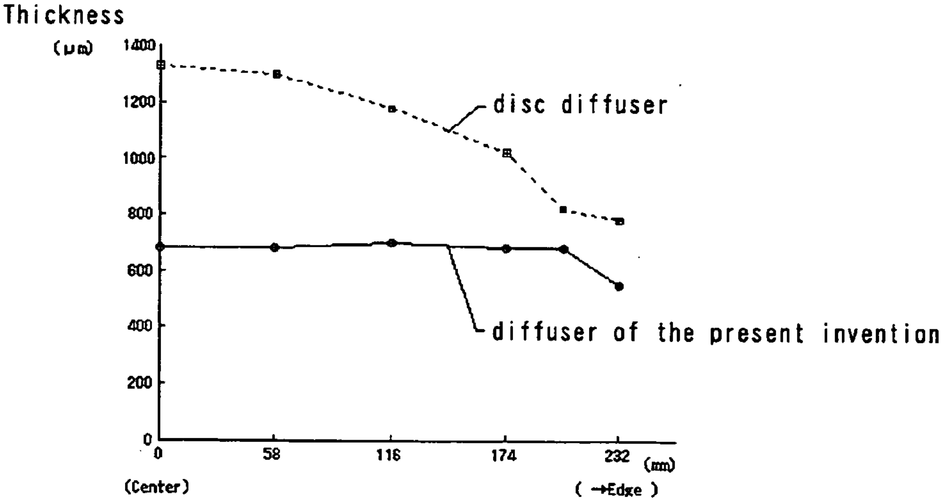
34a
42
64
70

Fig. 2


Thickness
(μm)
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1200
1000
800
600
400
200
0
0
58
116
174
232
(mm)
(Center)
(→Edge)
disc diffuser
diffuser of the present invention

Fig. 3

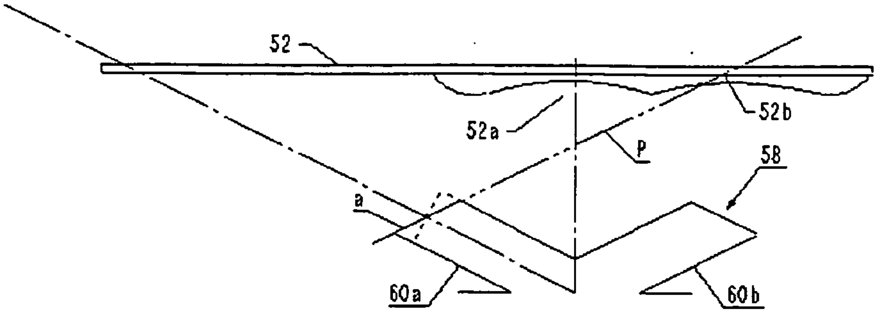


Fig. 4

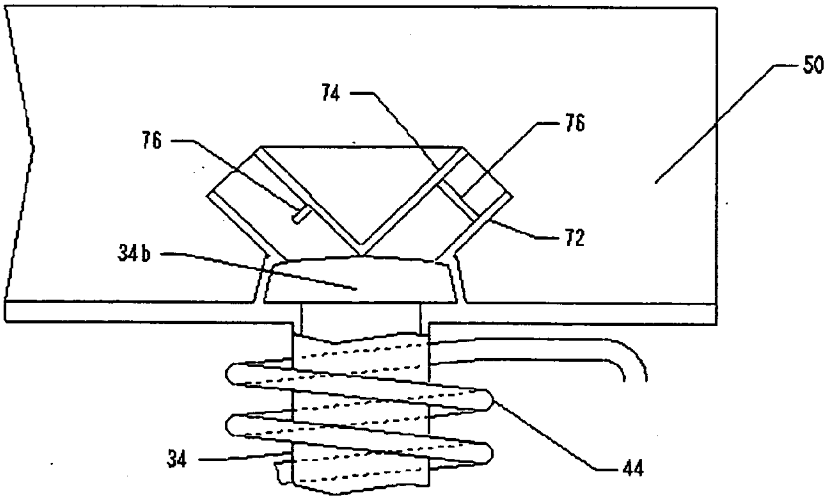
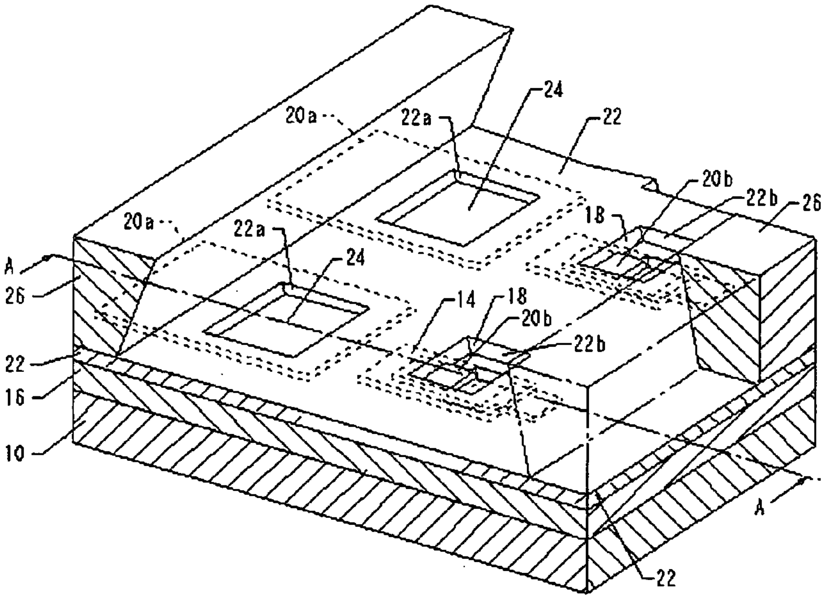


Fig. 5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22a
24
22
20b
22b
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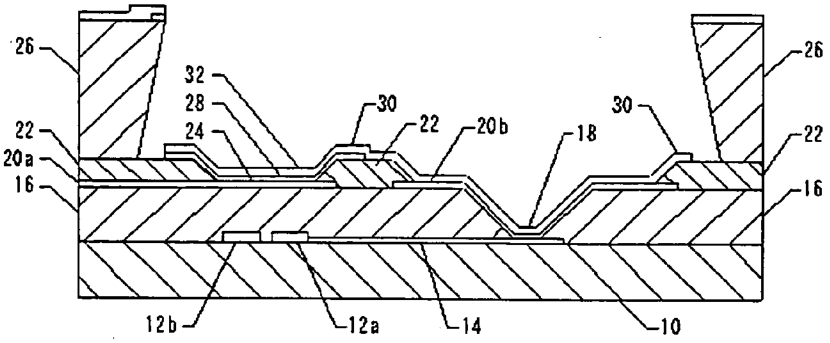
22a
24
A
26
14
18
20b
22b
22
16
10
A
22

Fig. 6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16
12b
12a
14
10

PLASMA TREATMENT APPARATUS AND SURFACE TREATMENT APPARATUS OF SUBSTRATE

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to a plasma treatment apparatus capable of uniformly treating a surface of a substrate having a larger area than a cross sectional area of a plasma introductory part, and a surface treatment apparatus for treating a surface of a substrate by a gas plasma.

[0003] 2. Description of Related Art

[0004] According to a semiconductor apparatus and an OLED (organic light emitting diode) display in which a conductive thin film formed on a substrate, a surface of the conductive thin film is plasma-treated so as to improve or stabilize properties thereof.

[0005] In the OLED display, a thin film containing a fluorescent or phosphorescent organic chemical compound is sandwiched between an anode electrode and a cathode electrode. In the OLED display, positive holes and electrons are injected into the thin film from the anode electrode's side and the cathode electrode's side, respectively, so as to recombine them. Due to energy that is discharged by this recombination, the fluorescent or phosphorescent organic chemical compound is excited to emit light. Accordingly, it is preferable to deposit a plurality of chemical compounds so that ionized potential (Ip) is made smaller from the anode electrode's side toward the cathode electrode's side.

[0006] In addition, in order to enhance a work function of the anode electrode and improve injection of the positive hole, it has been known that a surface of the anode electrode is treated by UV-O_3, O_2 plasma, the like (see patent document **1**, for example).

[0007] **FIG. 5** is a perspective view of a substantial part of a structure of an OLED display during manufacture, and **FIG. 6** is sectional view of a substantial part of the OLED display taken on a line of A-A of **FIG. 5**. In the drawings, a reference numeral **10** denotes an insulating substrate such as glass, and reference numerals **12***a* and **12***b* denote a pair of thin film transistors formed on the insulating substrate **10**. Although not shown in the drawings, many thin film transistors are formed in the form of a matrix. A reference numeral **14** denotes a layer that is connected to an electrode through which a main electric current of the thin film transistor **12***a* passes, for example, a drain electrode wiring layer that is connected to a drain electrode. On the insulating substrate **10**, except for the thin film transistor **12***a*, a source electrode wiring layer through which the main electric current passes, a power source wire, a grounding wire, and a gate electrode wire of the thin film transistor **12***b* are formed, however, they are omitted in the drawings.

[0008] A reference numeral **16** denotes a resin insulating layer which coats the surface of the insulating substrate **10** so as to smooth out the irregularities of the surface of the insulating substrate **10** which are caused by the thin film transistor **12** or the like. The resin insulating layer **16** is formed from an acrylic transparent resin, for example. A reference numeral **18** denotes a through hole that is formed in a portion of the resin insulating layer **16**. A diameter of the through hole **18** is made smaller from an opening top toward a bottom, and the drain electrode wiring layer **14** is exposed at its bottom. Reference numerals **20***a* and **20***b* denote electrode wiring layers formed on the resin insulating layer **16**, respectively. The electrode wiring layer **20***a* is connected to a power source (not shown), while the other electrode wiring layer **20***b* is electrically connected to the drain electrode wiring layer **14** at the bottom of the through hole **18**. Therefore, the electrode wiring layer **20***b* and the thin film transistor **12***a* are electrically connected through the drain electrode wiring layer **14**. A reference numeral **22** denotes an edge insulating layer which coats the surface of the resin insulating layer **16**. In the edge insulating layer **22**, a portion of the electrode wiring layer **20***a* is exposed through a window **22***a* to form an anode electrode **24** and to form a window **22***b* at the through hole **18**. A reference numeral **26** denotes resin deposited layers that are placed opposite to each other and that sandwich an area including the anode electrode **24** and the through hole **18**, and their opposed walls are inversely tapered.

[0009] In **FIG. 6**, a reference numeral **28** denotes an OLED layer formed on the anode electrode **24** and the OLED layer **28** is formed through a metallic mask (not illustrated). In addition, an opening of the resin deposited layer **26** is used as a portion of the mask and an end of the OLED layer **28** is spaced apart from a base portion of the resin deposited layer **26**. A reference numeral **30** denotes a cathode electrode wiring layer formed through a metallic mask (not shown) on the OLED layer **28** and the resin insulating layer **16** except for an anode electrode wiring layer **20**. Further, the cathode electrode wiring layer **30** is formed using the opening of the resin deposited layer **26** as a portion of the mask, and a portion of the cathode electrode wiring layer **30** which overlaps the OLED layer **28** is formed as a cathode electrode **32**. This cathode electrode wiring layer **30** is connected to the drain electrode wiring layer **14** formed on the insulating substrate **10** through the through hole **18** formed in the edge insulating layer **22**.

[0010] Further, the OLED display shown in **FIG. 6** is hermetically sealed by putting the transparent glass substrate thereon. The OLED display is used as a light emitting apparatus or a display unit by releasing the light emitted from the OLED layer **28** from the transparent glass through the cathode electrode wiring layer **30**. Such OLED display is called a top-emission OLED display. In the top-emission OLED display, the light emitted from the OLED layer **28** to the anode electrode **24** is reflected on the surface of the anode electrode **24** so as to enhance the brightness.

[0011] In this display unit, the anode electrode **24** functions as a source for injecting positive holes into the OLED layer **28** and is associated with efficiency of light emission of the OLED layer **28**. Accordingly, as a material of an electrode, a material having a large work function is desired.

[0012] In order to effectively release the light emitted from the OLED layer **28**, a material with high reflectivity is selected for the anode electrode wiring layer **20** and the anode electrode **24**. For example, AlNd or the like is used.

[0013] Thus, it is preferable to form the anode electrode **24** from an electrode material satisfying different properties of the working function and the reflectivity. However, there is no material that satisfies the both properties at the same time and that can be easily handled. Furthermore, in even a proper electrode material, effects of the material may vary depending on its surface condition. ITO and Nickel inherently have large work functions, so that positive holes can be injected therein very well only by cleaning their surfaces through a cleaning processing and then oxidizing the surfaces. However, a drawback to the ITO and Nickel is low reflectivity. In the meanwhile, aluminum and aluminum base alloy have high reflectivity and can be easily handled. However, their working functions are small, so that it is necessary to form a functional organic film after the cleaning processing in order to enhance their working functions.

[0014] For this reason, in the structure during manufacture shown in **FIG. 5**, the surface of the anode electrode **24** is cleaned before forming the OLED layer **28**. Such cleaning enhances the working function and the reflectivity of the anode electrode **24**. Further, in order to increase the working function, an functional organic film is formed on the cleaned surface of the electrode. For example, cleaning process is carried out by ozone UV-O_3 which is generated by applying ultraviolet rays to a substrate to be surface-treated in oxygen atmosphere. In the cleaning using ozone UV-O_3, there are few damages in the resin structures **16**, **22**, and **26** located at the edge of the anode electrode **24**. However, since the functional organic film cannot be formed on the surface of the electrode in succession from the cleaning operation, an additional equipment is needed.

[0015] On the contrary, a plasma treatment apparatus does not require any additional equipment. In the plasma treatment apparatus, the surface of the electrode can be cleaned by oxygen plasma and a functional organic film can be formed on the cleaned surface of the electrode by using a different material gas. In a typical parallel flat plate type plasma treatment apparatus, two parallel electrodes are placed opposite to each other in a depressurization chamber and a substrate is provided between the parallel electrodes. When high-frequency power is applied between the parallel electrodes, gas in the depressurization chamber is reacted and thus plasma is generated. As far as the structure of the apparatus is simple and the substrate can be provided between the parallel plate electrodes, even a large substrate can be uniformly treated.

[0016] In an ECR plasma treatment apparatus, high-density plasma is generated by adding a micro wave and a magnetic filed from an electromagnet in a plasma generation chamber connected to the depressurization chamber and setting intensity of the magnetic field in such a manner that an electron cyclotron resonance condition is satisfied. In the ECR plasma treatment apparatus, a large substrate can also be treated.

[0017] [Document 1] Japanese Unexamined Patent Publication No. (Patent Kokai No.) 08-167479 (1996) (See paragraph [0013]) However, since a portion of coating resin such as the resin insulating layer **16** and the edge insulating layer **22** is exposed when the anode electrode **24** is cleaned, the surface of the coating resin is exposed to plasma. The surface of the coating resin is ruined if the high-density plasma is allowed to directly contact the surface. Particularly, if the surface of the coating resin near the anode electrode **24** is ruined, a portion of the resin that is scraped thereby adheres to the surface of the anode, and brightness of this portion may be lowered or this portion may not emit light (thus, a dark spot is formed). This dark spot portion is enlarged with time. Such enlargement of the dark spot area is accelerated by blinking, and at last, the all the pixels do not emit light. Thus, this exerts adverse effects on a display quality and reliability.

[0018] In the meanwhile, if cleaning of the surfaces of the electrodes formed on the substrate and forming the functional organic film on the electrode surfaces are sequentially carried out using a single apparatus, foreign matter is generated by reaction with plasma gas and deposited in a chamber. Thus-deposited functional organic film material is decomposed during the cleaning process and then adheres to the anode electrode again. Therefore, it is necessary that such deposit is periodically removed from depressurization chamber.

[0019] For such a reason, while the structure of the parallel flat plate type plasma treatment apparatus is simple, there are many problems in both carrying out the cleaning of the surfaces of the electrodes and forming the functional organic film on the electrode surface using the same apparatus.

[0020] On the contrary, in the ECR plasma treatment apparatus, high-density plasma generated at a plasma generation source is diffused in the depressurization chamber in which the substrate is provided so as to expose the substrate to such plasma. Therefore, the ECR plasma treatment apparatus can prevent the damage of the coating resin. However, since the plasma introductory part of the depressurization chamber is away from the substrate, if the opening diameter of the plasma introductory part is small, the plasma introduced in the depressurization chamber is scattered in all directions. Therefore, the electrodes on the flat substrate cannot be uniformly treated in the ECR plasma treatment apparatus and the unevenness of the treatment is severe in the large substrate.

[0021] Therefore, plasma to be introduced in the depressurization chamber is diffused by a diffuser (a diffusion plate) to realize a uniform treatment. Many diffusers have been manufactured by way of trial under various conditions by changing a hole diameter and a space between the holes, for example, and the treatment states have been observed. However, such conventional diffusers cannot solve a big difference in a cleaning level of the electrodes between a center portion and a marginal area of a large substrate. In addition, the ECR plasma treatment apparatus requires an electromagnet and advanced control apparatus, so that the apparatus has a complicated structure and is expensive.

[0022] As a plasma treatment apparatus in which a plasma generation source is connected to a depressurization chamber, there is an apparatus using an inductive coupled plasma (ICP) for generating plasma by a high-frequency electric field. This apparatus is cheaper than the ECR plasma treatment apparatus. However, this apparatus has the same problem as the ECR plasma treatment apparatus because the plasma introductory part of the depressurization chamber is away from the substrate.

[0023] Further, it is also conceivable that a plurality of plasma generation sources are provided in one depressurization chamber and plasma is diffused on one substrate from each plasma generation source. However, it is difficult to control a plurality of plasma generation sources under the same condition. Moreover, maintenance of the apparatus is complicated and the cost of equipment is high.

SUMMARY OF THE INVENTION

[**0024**] In order to solve the above problems, we have eventually found the present invention. Accordingly, an object of the present invention is to provide a plasma treatment apparatus which comprises: a plasma generation chamber for activating gas supplied thereto so as to generate plasma; a depressurization chamber which is connected to the plasma generation chamber and which accommodates a member to be plasma-treated; and a diffuser which is provided at a joint part of the plasma generation chamber and the depressurization chamber, which guides the plasma in a direction inclined to a gas flow path of the plasma generation chamber, and which introduces the plasma into the depressurization chamber while diffusing the plasma in the depressurization chamber.

[**0025**] Further, the present invention provides a surface treatment apparatus which comprises: a plasma generation chamber for activating gas supplied thereto so as to generate plasma; a depressurization chamber which is connected to the plasma generation chamber and which accommodates a substrate with a conductive thin film and an organic thin film formed on a main surface thereof; and a diffuser which is provided at a joint part of the plasma generation chamber and the depressurization chamber, which guides the plasma in a direction inclined to a gas flow path of the plasma generation chamber, and which introduces the plasma into the depressurization chamber while diffusing the plasma in the depressurization chamber, wherein a surface of the conductive thin film formed on the substrate is treated using different gas plasma by successively feeding different material gases to the plasma generation chamber.

BRIEF DESCRIPTION OF THE DRAWINGS

[**0026**] **FIG. 1** is a sectional side view of a substantial part of a plasma treatment system of the present invention.

[**0027**] **FIG. 2** is a graph for comparing thicknesses of organic films between a conventional system and a system of the present invention.

[**0028**] **FIG. 3** is a sectional side view for showing a shape of an opening end of a diffuser.

[**0029**] **FIG. 4** is a enlarged sectional side view of a substantial part of a variation of the diffuser.

[**0030**] **FIG. 5** is a sectional side view of a substantial part of an OLED display.

[**0031**] **FIG. 6** is a perspective view of a substantial part of a structure of the OLED display during manufacture.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[**0032**] An embodiment of the present invention will be described below with reference to **FIG. 1**. In **FIG. 1**, a reference numeral **34** denotes a plasma generation chamber for generating plasma by activating gas supplied thereto. In the plasma generation chamber **34**, a plurality of gas cylinders **36**, **38**, **40** which is opened and closed by valves **36***a*, **38***a*, and **40***a* are connected through a flow rate controller **42** to a gas inlet **34***a* which is provided at a lower end of the chamber **34**. A reference numeral **44** denotes an induction coil that is wound around the plasma generation chamber **34**. The induction coil **44** is connected to a high frequency oscillator **48** through a matching circuit **46**. When a high frequency current flows through the induction coil **44**, the gas supplied in the plasma generation chamber **34** is excited into plasma. A reference numeral **50** denotes a depressurization chamber. In the depressurization chamber **50**, a gate (not shown) is disposed at a peripheral surface thereof. The plasma generation chamber **34** is connected to a bottom **50***a* of the chamber **50**, and the plasma gas is supplied from a plasma inlet (plasma introductory part) **34***b*. A reference numeral **52** denotes a substrate (a member to be plasma-treated) whose surface is coated with resin and in which conductive thin film is provided on a substantial part of the resin coating. The surface of the conductive thin film is cleaned by contacting it with the plasma gas (a detailed explanation is herein omitted). A reference numeral **54** denotes a substrate supporting means for supporting the substrate **52** with the conductive thin film formation surface down. To the substrate supporting means **54**, a moving mechanism **56** for moving the substrate **52** in a horizontal direction, a swinging mechanism for swinging a main surface of the substrate **52** with respect to a horizontal plane, a rotation mechanism for rotating the substrate around a rotational axis perpendicular to the horizontal plane, and heating means for heating the substrate (not shown) or the like are provided when necessary.

[**0033**] A reference numeral **58** denotes a diffuser that is a characteristic of the present invention. The diffuser **58** is provided at a joint part of the plasma generation chamber **34** and the depressurization chamber **50** and diffuses the plasma introduced in the depressurization chamber **50** over the whole surface of the substrate **52**. According to the illustrated example, two tubular bodies **60***a* and **60***b* inclined relative to the surface of the substrate **52** guide the plasma in an inclined direction. One end side of the tubular body **60***a* and one end side of the tubular body **60***b* are in intimate contact with each other and are connected to the plasma inlet **34***b* of the plasma generation chamber **34**, while the other end sides of the tubular bodies **60***a* and **60***b* are separated from each other. Respective axes a and b shown by a dashed line in the drawing are extended to the ends of the substrate **52** so that extensions of the axes a and b intersect with the ends of the substrate **52**. Respective axes a and b are inclined at 45 degrees relative to the horizontal plane, and opening ends c and d of the tubular bodies **60***a* and **60***b* substantially perpendicularly intersect these axes a and b. Thus, the substrate **52** and the opening ends c and d are not arranged parallel to each other. The illustrated tubular bodies **60***a* and **60***b* are circular in cross section.

[**0034**] A reference numeral **62** denotes a pressure controller for controlling a pressure within the depressurization chamber **50**, and a reference numeral **64** denotes a turbo-molecular pump that is connected to the pressure controller **62**. A reference numeral **66** denotes a dry pump. The pressure controller **62** and the turbo-molecular pump **64** are connected to the dry pump **66** through a valve **68** and a valve **70**, respectively, so as to depressurize the depressurization chamber **50**.

[**0035**] The operation of the above-described plasma treatment apparatus will be described below. First, a substrate (a member to be plasma-treated) **52** is prepared. As is the case with the structure of the OLED display during manufacture shown in **FIG. 6**, in the substrate **52**, a conductive pattern formed on an insulating substrate is covered with a coating resin and a portion of the conductive pattern is exposed through a window formed in a substantial part of this coating resin so as to form a conductive thin film (anode electrode). In the substrate **52**, in order to enhance the working function of the surface of the anode electrode and increase the efficiency of positive hole injection, the surface of the conductive thin film is cleaned and then oxidized, and then a coating made of organic material is formed on the conductive thin film.

[**0036**] This substrate **52** is placed in the depressurization chamber **50** and then the chamber **50** is hermetically sealed. The substrate **52** placed in the depressurization chamber **50** is set at an earth potential or a proper bias potential.

[**0037**] Next, the valve **68** is opened to operate the dry pump **66** and to depressurize the depressurization chamber **50**. Then, the valve **70** is opened to operate the turbo-molecular pump **64**, and the valve **68** is closed to depressurize the depressurization chamber **50** sufficiently. When the depressurization chamber **50** is sufficiently depressurized, the gas cylinders **36** to **40** are opened or closed selectively by controlling the opening and closing of the valves **36***a* to **40***a*, predetermined gas is fed into the plasma generating chamber **34**, and the pressure in the depressurization chamber **50** is maintained at a predetermined value by the flow rate controller **42**. Under such condition, when a high frequency current flows through the induction coil **44** and an induction magnet field is generated in the plasma generation chamber **34**, the material gas is oscillated at a high frequency and thus plasma is generated.

[**0038**] When an oxygen gas is supplied as the material gas, O_2 plasma is fed into the depressurization chamber **50** through the diffuser **58**. This oxygen decomposes and removes contamination adhering to the surface of the electrode formed on the surface of the substrate **52**, and further, it oxidizes the cleaned surface of the electrode.

[**0039**] When the aforementioned operation is completed, a functional organic layer is formed on the cleaned surface of the conductive thin film. Therefore, the supply of the oxygen gas is stopped, the current flow to the induction coil **44** is temporarily stopped, and the oxygen gas remaining in the depressurization chamber **50** is discharged. After checking that the pressure is sufficiently decreased and the oxygen gas is sufficiently discharged, a gas to be used as a material for forming an organic film is supplied to the plasma generation chamber **34**.

[**0040**] If $C_xH_yF_z$ ($x>1$, $y\geqq0$, $z\geqq2$) is used as the gas to be used as a material for forming an organic film, a functional organic film that is mainly composed of CF_x can be formed on the substrate **52** having the conductive thin film. The gas to be used as a material for forming an organic film is supplied to the plasma generation chamber **34**. When a current flows through the induction coil **44** again, plasma gas is fed into the depressurization chamber **50** through the diffuser **58**. On the surface of the substrate **52** having the conductive thin film on which an organic layer is formed, the functional organic film is formed.

[**0041**] Thus, by successively treating the substrate **52** using various material gases, it is possible to perform cleaning of the surface of the conductive thin film and forming the coating resin in one depressurization chamber without changing the substrate.

[**0042**] When such successive operations are completed, the current flow to the induction coil **44** is stopped, and the supply of the gas to be used as a material for forming an organic film is stopped. After a nitrogen gas is supplied into the depressurization chamber **50** to bring back the depressurization chamber **50** to the atmosphere pressure, the substrate **52** is taken out from the depressurized chamber **50**. Then, the depressurization chamber **50** is hermetically sealed and sufficiently depressurized, and the gas made by mixing the oxygen gas as a main gas with an argon gas or the like is fed to the plasma generation chamber **34**. The depressurization chamber **50** is maintained at a constant pressure, a current is passed through the induction coil **44** so as to generate plasma, and the generated plasma is supplied to the depressurization chamber **50** through the diffuser **58**.

[**0043**] By conducting such operation, organic films deposited on an inner wall of the plasma generation chamber **34**, inner walls of the tubular bodies **60***a* and **60***b* of the diffuser **58**, and an inner wall of the depressurization chamber **50** are decomposed by O_2-plasma gas, and this decomposition gas is discharged from the depressurization chamber **50** to the outside.

[**0044**] After removing the functional organic film in this way, the current flow to the induction coil **44** is stopped, the supply of the oxygen gas or the like is stopped, the depressurization chamber **50** is brought back to the atmosphere pressure by supplying nitrogen gas thereto, and the depressurization chamber **50** is opened. After that, a new substrate **52** is put into the depressurization chamber **50** and is subjected to the above-described operations.

[**0045**] In the plasma treatment apparatus according to the present invention, the cleaning of the substrate **52** in the depressurization chamber **50** by O_2-plasma and the depositing of the organic film on the substrate **52** can be successively conducted. The organic film adhering to the inner wall or the like of the diffuser during the depositing process can be decompounded by O_2-plasma and removed from the depressurization chamber **50** prior to cleaning a new substrate. Therefore, the operations can be repeated without posing any problem to the cleaning operation of the new substrate.

[**0046**] The diffuser **58** is composed of the tubular bodies **60***a* and **60***b*. The axes of the respective tubular bodies **60***a* and **60***b* are inclined relative to the axis of the plasma generation chamber **34**. The cross sectional areas of the openings of the respective tubular bodies **60***a* and **60***b* are smaller than the cross sectional area of the plasma inlet **34***b*.

[**0047**] Gas is supplied into the plasma generation chamber **34** and the depressurization chamber **50** is depressurized by the pumps **64** and **66**. For this reason, there is a pressure gradient in a gas flow path between the diffuser **58**, the depressurization chamber **50**, and the pump **66**. Therefore, the gas supplied to the plasma generation chamber **34** is drawn into the depressurization chamber **50** from the opening end of the diffuser **58** and then diffused in the depressurization chamber **50**.

[**0048**] In this time, the gas in the depressurization chamber behaves as an elastic body. Since molecules of the gas repeatedly collide against each other or against the wall of the chamber, their moving direction is changed. Accordingly, the gas in the tubular diffuser **58** flows in a direction synthesized from the moving direction controlled by the pressure gradient and the moving direction changed by the collision.

[0049] Therefore, the plasma gas generated in the plasma generation chamber **34** enters into the tubular bodies **60***a* and **60***b* from various directions relative to their axes. Then, the plasma gas is guided through the tubular bodies **60***a* and **60***b* towards the depressurization chamber **50** while reflecting and swirling inside the tubular bodies **60***a* and **60***b*, and then it is discharged from the tubular bodies **60***a* and **60***b* into the depressurization chamber **50**.

[0050] The plasma gas enters into the tubular bodies **60***a* and **60***b* from various directions and reflects on the inner walls of the respective tubular bodies **60***a* and **60***b* in various directions. Therefore, the gas moves in various directions at the opening ends of respective tubular bodies **60***a* and **60***b*. However, the gas discharged from the opening ends is released from the guide of the tubular body **60**, so that the gas moves substantially straight ahead in the same direction as is discharged.

[0051] Some of the plasma gas discharged from the opening ends of the respective tubular bodies **60***a* and **60***b* may move in substantially parallel with the surface of the opening end of each tubular body.

[0052] Therefore, a diameter and a length of the diffuser **58** are set in such a manner that the extensions of the respective axis of the respective tubular bodies **60***a* and **60***b* intersect with the ends of the substrate **52** and the extensions of the surfaces of the opening ends of the respective tubular bodies intersect the center part of the substrate **52**. It is preferable that the diameter and the length of the diffuser **58** are set in such a manner that the areas which are exposed to the plasma gas discharged from the respective tubular bodies **60***a* and **60***b* overlap at the center part. Thus, even if the axes of the tubular bodies **60***a* and **60***b* and the opening ends substantially perpendicularly intersect each other, the whole area of the substrate **52** can be exposed to the plasma gas.

[0053] In order to check an advantage of the apparatus of the present invention, various disc diffusers with a diameter of 150 mm, in which many holes are formed concentrically, were prepared. It was found out that the plasma current is 0.07 mA or less when the hole diameter is 3 mm or less, and the plasma current is about 1.2 mA when the hole diameter is 5 mm or 10 mm. Therefore, a diffuser with holes of 10 mm in diameter is used for making comparison with the diffuser to be used in the apparatus of the present invention. In the diffuser **58** to be used in the apparatus of the present invention, two tubular bodies **60***a* and **60***b* of 50 mm in diameter are used, one end side of the tubular body **60** is in intimate contact with one end side of the tubular body **60***b*, the respective axes of the tubular bodies **60***a* and **60***b* perpendicularly intersect each other, and axial lengths from this intersecting point to other end sides of the tubular bodies **60***a* and **60***b* are defined as 200 mm.

[0054] The plasma generation chamber **34** is 80 mm in outer diameter, a tubular body with a diameter of 150 mm and with a height of 40 mm is connected onto the plasma inlet **34***b* within the depressurization chamber **50**, and each diffuser is connected to the upper end of the tubular body. The substrate **52** is attached horizontally to the bottom surface of the depressurization chamber **50** in such a manner that the height of the substrate **52** is adjustable. For example, the substrate **52** having a size of 325×465 mm is placed at a height of 400 mm.

[0055] **FIG. 2** shows a film thickness of the functional organic film (in a range from the center toward the edges of the substrate **52**) that is formed on the substrate **52** under the above-described conditions. The thickness of the film that is formed by using the disc diffuser (which is a diffuser for comparison with the diffuser to be used in the present invention) is changed from 1,330 nm to 780 nm from the center toward the respective edges of the substrate. Thus, the difference in thickness between the center and the respective edges is 550 nm. In this case, the distance from the center toward the respective edges of the substrate is 215 mm. Thus, the film is the thickest at its center and gradually becomes thinner toward the edges. The thickness of the film is dramatically decreased at a position about 170 nm or more apart from the center. The thickness uniformity of the film over the entire substrate is about 45% and thus the thickness of the film varies widely.

[0056] On the contrary, in the apparatus of the present invention, the thickness of the film is kept between 680 nm±10 from the center part toward the edges of the substrate. The thickness of the film is decreased from 670 nm to 550 nm in a range of 30 mm around the peripheral surface of the substrate. Thus, the difference in thickness is 130 nm. The thickness uniformity of the film over the entire substrate is bout 4.6%, and therefore, variations in thickness can be minimized.

[0057] In the plasma treatment apparatus according to the present invention, the plasma gas can be substantially uniformly applied to a large substrate from its center to its edges. Therefore, it is possible to form an organic film of substantially uniform thickness from its center toward its edges.

[0058] Therefore, in the plasma treatment apparatus of the present invention, where the anode electrodes formed on the substrates are cleaned and then the functional organic film is formed on the cleaned anode electrodes, cleaning of the surfaces of the electrodes formed on the substrate and forming the functional organic film on the electrode surfaces are sequentially carried out using a single apparatus, and thus operating efficiency can be improved.

[0059] Further, although the conductive thin films which function as the electrodes on the substrate are formed on portions of the coating resin and therefore O_2-plasma gas for cleaning the electrodes is exposed not only to the surfaces of the electrodes but also to the surface of the coating resin, the plasma gas generated in the plasma generation chamber **34** passes through the diffuser **58** and is diffused in the depressurization chamber **50**. In this way, the surfaces of the electrodes can be cleaned without damaging the coating resin. Moreover, since the smoothness of the coating resin is maintained, a display unit having no dark spots, an excellent display quality, and a high reliability can be realized.

[0060] Further, according to the apparatus of the present invention, even if the substrate **52** is upsized so as to use it for a large display unit or the like, the entire surface of the substrate can be uniformly treated, and there is no difference in display quality between the center and the edges of the substrate. Therefore, the present invention can minimize variations in quality and can realize a serious cost reduction.

[0061] In the diffuser **58** according to the above-described embodiment, the angles of inclination of the tubular bodies **60***a* and **60***b* are set at 45 degrees. When the height of the substrate **52** is kept constant and the angles of the inclination of the tubular bodies are set at 45 degrees or less, a larger substrate can be treated as the inclination angles are smaller. However, the center part of the substrate is likely to be insufficiently cleaned and the film cannot be formed sufficiently. Thus, the substrate may not be treated uniformly. Alternatively, when the angles of inclination of the tubular bodies are set at 45 degrees or more, a larger substrate cannot be treated as the inclination angles are larger. In addition, since the opening ends of the two tubular bodies are close to each other, the center part of the substrate is double-treated by the two tubular bodies and thus treated too much. Therefore, it is preferable that the angles of the inclination of the tubular bodies **60***a* and **60***b* are set at 20 to 70 degrees. The diameter and the length of each tubular body may be set in accordance with the inclination angle.

[0062] In the aforementioned embodiment, an angle between the axis and the opening end of each tubular body is set at 90 degrees (or 45 degrees relative to the substrate **52**) when the inclination angle of each tubular body is 45 degrees. However, this angle may also vary in accordance with the inclination angle of each tubular body. As shown in **FIG. 3**, in an area **52***a* which ranges from the center part of the substrate **52** to the outside ends thereof, assume that an opposite area from the tubular body **60***a* is an area **52***b* and a surface which intersects the area **52***b* is a virtual surface P. A surface of the tubular body **60***a* which is intersected by the virtual surface P can be defined as the opening end of the tubular body **60***a*. When the inclination angle of the tubular body **60***a* is 45 degrees, the opening end of the tubular body is inclined at about 45 degrees relative to the substrate **52**. However, when the inclination angle of the tubular body **60***a* is less than 45 degrees, the opening end of the tubular body **60***a* is inclined at less than 45 degrees to the substrate **52**. Thus, as the inclination angle is smaller, the opening end becomes closer to horizontal to the substrate **52**. When the inclination angle of the tubular body **60***a* is more than 45 degrees, the opening end of the tubular body **60***a* is inclined at more than 45 degrees to the substrate **52**. Therefore, as the inclination angle is larger, the opening end becomes closer to vertical to the substrate. The opening end of the tubular body **60***a* may be formed not only in a manner that the entire surface of the opening end contacts the virtual surface P but also in a manner that a portion of the opening end contacts the virtual surface P.

[0063] In the aforementioned embodiment, two tubular bodies **60***a* and **60***b* whose both ends are the same in diameter are used as the diffuser **58**. However, as the tubular bodies **60***a* and **60***b*, a tubular whose both ends are different in diameter can also be used. In this case, if the opening end with a larger diameter is located at the plasma inlet **34***b*'s side and the opening end with a smaller diameter is located at the depressurization chamber **50**'s side, the plasma gas can be more complicatedly moved in the diffuser **58**, and therefore, preferable diffusion of the plasma gas can be obtained in the depressurization chamber **50**. Alternatively, if the opening end with a smaller diameter is located at the plasma inlet **34***b*'s side and the opening end with a larger diameter is located at the depressurization chamber **50**'s side, the adhesion of the organic film material to the inner walls of the tubular body **60***a* and **60***b* can be reduced.

[0064] In the aforementioned embodiment, two tubular bodies **60***a* and **60***b* are arranged in a substantial V shape or a substantial Y shape. However, the number of the tubular body may be two or more. Alternatively, for example, as shown in **FIG. 4**, two conical plates **72** and **74** may be arranged parallel to each other. In this case, a space between the conical plates **72** and **74** are used as a path of plasma gas. A vertex of the conical plate **72** is cut off so as to connect the plate **72** to the plasma inlet **34***b*. The distance between the conical plates **72** and **74** is kept constant by a support post **76**. By using a thin rod as the support post **76**, the plasma gas can be fed to the depressurization chamber **50** in all directions. Alternatively, by using a quadrant rod as the support post **76**, an opening area of the plasma inlet and the direction that the opening of the plasma inlet faces can be restricted. The tubular bodies **60***a* and **60***b* may be not only a cylindrical body but also a polygonal tubular body.

[0065] In the aforementioned embodiment, the cleaning of the member to be plasma-treated and the forming of the organic film are successively carried out by changing material gas for plasma. However, the apparatus of the present invention can also be applied to only one of the operations: cleaning of the member to be plasma-treated or forming of the organic film. Further, the member to be plasma-treated is not limited to an in-process substrate to be used for an OLED display, but it can be a any member which requires the cleaning operation or the organic film forming operation.

[0066] While the embodiments of the present invention have thus been described with reference to the drawings, it should be understood that the present invention is not limited to the aforementioned embodiments. Various changes, modifications, and improvements can be made to the embodiments on the basis of knowledge of those skilled in the art without departing from the scope of the present invention. This application claims priority from Japanese Patent Application No. 2003-302815, which is incorporated herein by reference.

What is claimed is:

1. A plasma treatment apparatus comprising:

a plasma generation chamber for activating gas supplied thereto so as to generate plasma;

a depressurization chamber connected to the plasma generation chamber and accommodating a member to be plasma-treated; and

a diffuser for guiding the plasma in a direction inclined to a gas flow path of the plasma generation chamber and for introducing the plasma into the depressurization chamber while diffusing the plasma in the depressurization chamber, said diffuser provided at a joint part of the plasma generation chamber and the depressurization chamber.

2. The plasma treatment apparatus according to claim 1, wherein said diffuser is composed of a plurality of tubular bodies, and one end side of each tubular body is in intimate contact with one end side of another tubular body and is connected to the plasma generation chamber, while the other end sides of the respective tubular bodies are separated from each other.

3. The plasma treatment apparatus according to claim 1, wherein an angle between an opening end which is opened in the depressurization chamber and an axis of each tubular body is determined in accordance with an angle of inclination of each tubular body.

4. The plasma treatment apparatus according to claim 1, wherein said tubular body is cylindrically shaped.

5. A surface treatment apparatus, comprising:

a plasma generation chamber for activating gas supplied thereto so as to generate plasma;

a depressurization chamber connected to the plasma generation chamber and accommodating a substrate with a conductive thin film and an organic thin film formed on a main surface thereof; and

a diffuser for guiding the plasma in a direction inclined to a gas flow path of the plasma generation chamber and for introducing the plasma into the depressurization chamber while diffusing the plasma in the depressurization chamber, said diffuser provided at a joint part of the plasma generation chamber and the depressurization chamber,

wherein a surface of the conductive thin film formed on the substrate is treated using different gas plasma by successively feeding different material gases to the plasma generation chamber.

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