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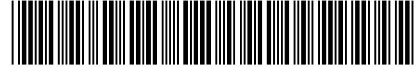

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(54) **METHOD FOR PRODUCING THIN FILM AND THIN FILM FORMING MATERIAL**

VERFAHREN ZUR HERSTELLUNG EINER DÜNNSCHICHT UND MATERIAL ZUR BILDUNG EINER DÜNNSCHICHT

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Description

BACKGROUND

Technical Field

[0001] The present invention relates to a method for producing a thin film and a thin film forming material.

Description of Related Art

[0002] Surfaces of camera lenses and telescope lenses are coated with a thin film in order to reduce the reflected light. To obtain an effect of reducing the reflected light on a single layer film, it is effective that an optical thin film having a refractive index close to the square root of a refractive index of a substrate (particularly referring to the object on which the film is to be formed) is formed on the outermost surface of the substrate. In the case of obtaining an anti-reflection effect to the wide wavelength, it is required to form a multilayer film. Even for such multilayer film, a thin film having a refractive index lower than the square root of a refractive index of the substrate is required in order to enhance an anti-reflection effect to the oblique incident light.

[0003] In order to obtain a thin film having a refractive index lower than the square root of a refractive index of the substrate, it is useful to contain air having a refractive index of 1.0 in the thin film. Thus, optical thin films containing air by various methods including a sol-gel method have been proposed.

[0004] For example, Japanese Unexamined Patent Application Publication No. 2010-38948 discloses an anti-reflection film including: a first layer mainly comprising alumina, which is film-formed by a vacuum vapor deposition method; a second layer formed from at least one material selected from the group consisting of MgF_2 and SiO_2, which is film-formed by a vacuum vapor deposition method; and a third layer formed from an aggregate of mesoporous silica nano-particles on the second layer; in order from a glass substrate side.

[0005] Further, Japanese Unexamined Patent Application Publication No. 2015-222450 discloses an anti-reflection film including: an inorganic base layer formed from an inorganic material; a surface modified layer including an inorganic oxide such as SiO_2; an adhesion layer including a binder such as acrylic resin, which is laminated on the surface modified layer; and a low refractive index layer formed by binding hollow silica particles with the binder; on a substrate.

[0006] International Unexamined Patent Publication No. 2006/030848 discloses a method for producing an optical thin film, in which a mixture of mixing a sol solution in which magnesium fluoride (MgF_2) minute particles are dispersed and an amorphous silicon oxide-based binder is coated on a substrate and subjected to a heat treatment, so that the substrate and the MgF_2 minute particles are bound by the amorphous silicon oxide-based binder, and a large number of voids are formed between the MgF_2 minute particles.

[0007] However, in the optical thin films or the anti-reflection films described in Japanese Unexamined Patent Application Publication No. 2010-38948, Japanese Unexamined Patent Application Publication No. 2015-222450, and International Unexamined Patent Publication No. 2006/030848, the optical thin films are formed by gelating a sol including minute particles and a binder, using a sol-gel method. The thin film formation by the sol-gel method is performed in the air. Thus, in the case of forming a lower layer than the outermost layer in the vacuum, there is a problem in that when the vacuum is released to the air for performing the sol-gel method, foreign substances are easily absorbed and eliminating the foreign substances is then needed. In addition, in order to control a film thickness precisely, it is required to strictly manage variation in the viscosity of the sol with time, and it is necessary to form the thin film while monitoring the viscosity of the sol all the time. Thus, the production method may be complicated. Further, there is also a problem in that, in the case of coating the sol onto a substrate by a dip coating method, an excess amount of the sol is required, and in the case of coating the sol onto a substrate by a spin coating method, it is difficult to coat on a curved surface in a uniform film thickness. Anti-reflection films are also known from EP2657011, US2006/154044, US2008/266661 or EP2259097.

[0008] Accordingly, an embodiment of the present invention is intended to solve the problems as described above, and to provide a method for producing a thin film having a low refractive index and a thin film forming material.

SUMMARY

[0009] The subject-matter of the present invention is as defined in the claims. In accordance with the embodiments of the present invention, a method for producing a thin film having a low refractive index, and a thin film forming material can be provided.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010]

Fig. 1 is a scanning electron microscope (SEM) micrograph showing a surface of a thin film according to Example 1 of the present invention.

Fig. 2 is a SEM micrograph showing a cross section of a thin film according to Example 1 of the present invention.

DETAILED DESCRIPTION

[0011] A method for producing a thin film, a thin film forming material, a thin film, and an article will be hereunder described based on embodiments thereof. The method for producing a thin film, and the thin film forming material are according to the invention. The embodiments shown below are exemplifications for exemplifying the technical idea of the present invention, and the present invention is not limited to these exemplifications. The scope of the present invention is rather as defined in the claims.

Method for Producing Thin Film

[0012] An embodiment of the present invention is a method for producing a thin film including: forming a vapor deposition film by depositing a thin film forming material on a substrate coated by the thin film in a non-oxidizing atmosphere by a physical vapor deposition; and

bringing the vapor deposition film into contact with a first acidic solution containing an acidic substance and having a pH-value in the range of pH 2.5 or more and pH 3.5 or less, to obtain a first thin film having voids,
wherein the thin film forming material is a mixture comprising indium oxide and silicon oxide, in which the indium oxide is contained in a range of 0.23 mol or more and 0.27 mol or less relative to 1 mol of the silicon oxide, the indium oxide is In_2O_3 and the silicon oxide contains 50% by mass or more of silicon monoxide, is used as the thin film forming material.

Thin Film Forming Material

[0013] A thin film forming material according to an embodiment of the present invention is a mixture containing indium oxide and silicon oxide, in which the indium oxide is contained in a range of 0.230 mol or more and 0.270 mol or less with respect to 1 mol of the silicon oxide and the indium oxide is In_2O_3 and the silicon oxide contains 50% by mass or more of silicon monoxide. The thin film forming material is a material for forming the first thin film. A deposition film is formed from the thin film forming material.

[0014] The indium oxide to be used for a raw material of the thin film forming material is indium oxide (III) (In_2O_3). The indium oxide (III) (In_2O_3) may contain inevitable impurities. The content of the indium oxide (III) (In_2O_3) in the indium oxide (III) (In_2O_3) to be used as a raw material is preferably 90% by mass or more, more preferably 95% by mass or more, even more preferably 99% by mass or more.

[0015] The silicon oxide to be used for a raw material of the thin film forming material contains a silicon monoxide (SiO) as a major component. In the present specification, the expression "silicon monoxide (SiO) as a major component" means that the content of the silicon monoxide (SiO) in the silicon oxide as a raw material contains 50% by mass or more. The content of the silicon monoxide (SiO) in the silicon oxide as a raw material contains more preferably 80% by mass or more, even more preferably 90% by mass or more, still more preferably 99% by mass or more.

[0016] The thin film forming material is a mixture containing indium oxide (III) (In_2O_3) and silicon oxide as raw materials, and containing a silicon monoxide (SiO) as a major component of the silicon oxide. The content of the indium oxide (III) (In_2O_3) in the thin film forming material is in a range of 0.230 mol or more and 0.270 mol or less relative to 1 mol of the silicon oxide. Using the thin film forming material, a vapor deposition film containing a silicon dioxide (SiO_2) and indium oxide (I) (In_2O) can be formed on a substrate in a non-oxidizing atmosphere by a physical vapor deposition. In the vapor deposition film, a very low amount of the indium oxide (III) (In_2O_3) and/or indium (In) may be contained. The indium oxide (III) (In_2O_3) contained in the thin film forming material is dissociated into indium oxide (I) (In_2O), indium (In), and oxygen (O) by heating. The silicon monoxide (SiO) contained in the thin film forming material is preferentially reacted with oxygen (O) to generate a silicon dioxide (SiO_2) since a standard formation free energy for oxidizing the silicon monoxide (SiO) is lower than a standard formation free energy for oxidizing the indium oxide (I) (In_2O). Even in the case where the vapor deposition film is formed using the thin film forming material in a non-oxidizing atmosphere, oxygen (O) which is dissociated from the indium oxide (III) (In_2O_3) is preferentially absorbed into the silicon monoxide (SiO) to generate a silicon dioxide (SiO_2). Thus, only small amounts of silicon monoxide (SiO) remain in the vapor deposition film. A first thin film (a thin film) obtained by bringing the vapor deposition film into contact with a first acidic solution does not absorb visible light from the silicon monoxide (SiO) which is of black color. In addition, since the oxygen (O) which is dissociated from the indium oxide (III) (In_2O_3) contained in the thin film forming material is reacted with the silicon monoxide (SiO) to generate the silicon dioxide (SiO_2), generation of the indium oxide (III) (In_2O_3) caused by further

oxidizing the dissociated indium oxide (I) (In_2O) can be suppressed. The indium oxide (I) (In_2O) has very high dissolubility to an acidic substance. Thus, the indium oxide (I) (In_2O) is preferentially eluted by bringing the vapor deposition film into contact with the first acidic solution containing the acidic substance, and the first thin film (the thin film) which has voids satisfying a desired refractive index, and is constituted by the silicon dioxide (SiO_2) as a framework can be then obtained.

[0017] As to the indium (In) generated by dissociating the indium oxide (III) (In_2O_3), an amount of indium (In) gas contained in the atmosphere where the indium oxide (III) (In_2O_3) is dissociated is about 3% by volume to 5% by volume ("Thermodynamics of Oxides" written by Kulikov, I. S. and published by Nisso-Tsushinsya, p. 146, 1987), and an very low amount of the indium (In) may be contained in the atmosphere when the vapor deposition film is formed.

[0018] In the case where the indium (In) is present in the vapor dissociated from the indium oxide (III) (In_2O_3), since a standard formation free energy for oxidizing the indium (In) to the indium oxide (III) (In_2O_3) is much lower than a standard formation free energy for oxidizing the silicon monoxide (SiO) to the silicon dioxide (SiO_2), it may cause indium oxide (III) (In_2O_3) which is generated again by reacting the indium (In) with oxygen, to be contained in the vapor deposition film.

[0019] However, in the vapor deposition film which is formed using the thin film forming material comprising the indium oxide (III) (In_2O_3) and the silicon monoxide (SiO), in which the indium oxide is contained in a range of 0.230 mol or more and 0.270 mol or less relative to 1 mol of the silicon oxide, only a very low amount of the indium oxide (III) (In_2O_3) and/or indium (In) is contained, as described below.

[0020] In the case where the indium oxide (III) (In_2O_3) is present in the vapor deposition film, when the first thin film is further immersed into the strong acidic solution having a pH 2.0 or less, a refractive index of the first thin film is decreased even if a transparent first thin film may be obtained by bringing the vapor deposition film into contact with the first acidic solution. In the case where a refractive index of the first thin film which is brought into contact with a strong acidic solution is decreased, it can be confirmed that the indium oxide (III) (In_2O_3) remains in the first thin film. In the case of containing the indium (In) in the vapor deposition film, when the vapor deposition film is brought into contact with the first acidic solution, the color of the thin film is changed from black to gray, and thereafter becomes transparent. Thus, it can be confirmed that the indium (In) remains in the vapor deposition film.

[0021] When a molar ratio of the indium oxide (III) (In_2O_3) contained in the thin film forming material relative to 1 mol of the silicon oxide is less than 0.230, a silicon monoxide (SiO) which is not oxidized remains in the vapor deposition film since the content of the indium oxide (III) (In_2O_3) in the thin film forming material is too small. When the silicon monoxide (SiO) remains in the vapor deposition film, the silicon monoxide (SiO) is not eluted even by bringing the vapor deposition film into contact with the first acidic solution, and the silicon monoxide (SiO) which is of black color remains in the obtained first thin film (the thin film). Remaining the silicon monoxide (SiO) in the first thin film (the thin film) causes absorption of visible light by the silicon monoxide (SiO) in the first thin film (the thin film) to be increased. Also, when the silicon monoxide (SiO) which is not oxidized remains in the vapor deposition film, the silicon monoxide (SiO) is not eluted from the vapor deposition film even by bringing the vapor deposition film into contact with the first acidic solution. Thus, desired voids are not formed, and a first thin film (the thin film) having voids, which satisfies a desired refractive index, is hardly formed.

[0022] When a molar ratio of the indium oxide (III) (In_2O_3) contained in the thin film forming material relative to 1 mol of the silicon oxide is more than 0.270, a large amount of indium oxide (I) (In_2O) and/or indium (In) is generated in the vapor deposition film since the content of the indium oxide (III) (In_2O_3) is too large. Thus, in the case of bringing the vapor deposition film into contact with the first acidic solution, since the content of the elutable indium oxide (I) (In_2O) and/or indium (In) is too large, the number of voids becomes too large, strength of the first thin film (the thin film) which is constituted by the silicon dioxide (SiO_2) as a framework is decreased, and the first thin film is then easily detached from the substrate. Further, due to excess oxygen generated by dissociating the excess indium oxide (III) (In_2O_3), the indium oxide (I) (In_2O) and/or indium (In) is oxidized to form indium oxide (III) (In_2O_3), and a refractive index of the first thin film may be increased.

[0023] A molar ratio of the indium oxide (III) (In_2O_3) contained in the thin film forming material relative to 1 mol of the silicon oxide is in a range of 0.230 or more and 0.270 or less, preferably in a range of 0.240 or more and 0.270 or less, more preferably in a range of 0.240 or more and 0.265 or less, even more preferably in a range of 0.250 or more and 0.260 or less, still more preferably in a range of 0.252 or more and 0.258 or less.

[0024] The thin film forming material is preferably a sintered mixture (sintered body) obtained by: mixing indium oxide (III) (In_2O_3) and silicon oxide (SiO or SiO_2) so as to provide a raw material mixture such that the content of the indium oxide is in a range of 0.230 mol or more and 0.270 mol or less relative to 1 mol of the silicon oxide; press-molding the raw material mixture to form a molded article; and thereafter, calcining the molded article. By using the sintered mixture (sintered body) as the thin film forming material, the thin film forming material is nearly uniformly vaporized by a physical vapor deposition, and the vapor deposition film, in which the indium oxide (I) (In_2O) generated by heat decomposing the indium oxide (III) (In_2O_3) and the silicon dioxide (SiO_2) are nearly uniformly mixed, can be nearly evenly deposited on a surface of the substrate.

[0025] It is preferable that the molded article formed by press-molding the raw material mixture is calcined in an inert

atmosphere. The inert atmosphere is a kind of a non-oxidizing atmosphere. The non-oxidizing atmosphere encompasses an inert atmosphere, a reducing atmosphere, and a vacuum, and may be any mixture of one or more atmospheres of these. The inert atmosphere means an atmosphere containing argon (Ar) and helium (He) as main components in the atmosphere. The inert atmosphere may inevitably contain oxygen as an impurity. In the present specification, when an oxygen concentration contained in the atmosphere is 15% by volume or less, the atmosphere is referred to as the inert atmosphere. The oxygen concentration in the inert atmosphere is preferably 10% by volume or less, more preferably 5% by volume or less, even more preferably 1% by volume or less. The oxygen concentration in the inert atmosphere is preferably as small as possible. Thus, the oxygen concentration in the inert atmosphere is furthermore preferably 0.1% by volume or less, particularly preferably 0.01% by volume or less, most preferably 0.001% by volume or less (10 ppm by volume or less). By calcining the solid article formed by press-molding the raw material mixture in the inert atmosphere, the excess content of oxides in the thin film forming material can be kept as low as possible.

[0026] A temperature at which the raw material mixture is calcined to form the sintered body is preferably in a range of 500°C or more and 900°C or less, more preferably in a range of 600°C or more and 880°C or less, even more preferably in a range of 700°C or more and 850°C or less. When the temperature for calcining the raw material mixture is more than the upper limit value, a metal indium (In), which is reduced from the indium oxide (III) (In_2O_3), is dissolved and evaporated, and thus a thin film forming material having an intended composition cannot be obtained. When the temperature for calcining the raw material mixture is less than the lower limit value, there is a concern that the sintered mixture (sintered body) as the thin film forming material may be broken by the thermal stress during the vapor deposition since the strength of the sintered body thus obtained by calcining is insufficient. When the sintered body as the thin film forming material is broken during the vapor deposition, there are cases where a stable vapor deposition film cannot be film-formed, since the amount of evaporation is largely changed.

Step of Forming Vapor Deposition Film

[0027] In the producing method according to an embodiment of the present invention, the thin film forming material is deposited on the substrate in a non-oxidizing atmosphere by a physical vapor deposition, thereby forming a vapor deposition film.

[0028] Examples of the physical vapor deposition may include an electron beam vapor deposition, a resistance heating vapor deposition, an ion plating, and a sputtering. Among others, it is preferable to use the electron beam vapor deposition or the resistance heating vapor deposition, and it is more preferable to use the electron beam vapor deposition. With the electron beam vapor deposition or the resistance heating vapor deposition, a vapor deposition film can be uniformly formed even at a large surface area or a curved surface having a small radius of curvature. In addition, the electron beam vapor deposition has superior thermal efficiency since the thin film forming material is heated by directly irradiating with an electron beam. Thus, even a thin film forming material such as an oxide having a high melting point and low thermal conductivity can be efficiently vaporized, and a vapor deposition film having a stable composition, based on a composition of the thin film forming material, can be then formed on the substrate in a relatively short time. Further, the vapor deposition film may be formed using an ion assist. In the case of using the ion assist, an ion-beam assisted deposition (IAD), having an ion source for the assist in film-forming of the vapor deposition film, in which the vapor deposition film is formed using an ion gun (ion-beam) while acceleratively irradiating the substrate with gas ions, may be used. The ion source for the ion-beam assist is preferably inert gas ion. An example of the inert gas ion for the ion-beam assist may be an Ar ion or a He ion, and the Ar ion is preferable.

[0029] Since the silicon monoxide (SiO) contained in the thin film forming material is a black oxide, there are cases where the silicon monoxide (SiO) which is of black color is contained in the vapor deposition film when the vapor deposition film is film-formed in a non-oxidizing atmosphere, and thus a thin film using the vapor deposition film cannot be used as a thin film. The reason why the vapor deposition film is nevertheless formed in a non-oxidizing atmosphere, is because the silicon monoxide (SiO) is preferentially reacted with oxygen to generate a silicon dioxide (SiO_2), and generation of the indium oxide (III) (In_2O_3) having low dissolubility relative to the acidic solution can be suppressed. Since the silicon monoxide (SiO) is more easily oxidized than indium oxide (I) (In_2O), the silicon monoxide (SiO) is preferentially oxidized by the oxygen which is dissociated from the indium oxide (III) (In_2O_3) contained in the thin film forming material, thereby forming a silicon dioxide (SiO_2). On the other hand, the indium oxide (I) (In_2O) is hardly oxidized, and thus the indium oxide (III) (In_2O_3) formed by oxidizing the indium oxide (I) (In_2O) is hardly generated.

[0030] The non-oxidizing atmosphere in forming the vapor deposition film encompasses an inert atmosphere, a reducing atmosphere, and a vacuum, and may be any mixture of one or more atmospheres of these. The inert atmosphere denotes an inert atmosphere where the oxygen concentration contained in the atmosphere is 15% by volume or less, as well as an inert atmosphere where the molded article formed by press-molding the raw material mixture is calcined. The reducing atmosphere denotes an atmosphere mainly comprising a mixture gas containing hydrogen or carbon monoxide in the atmosphere. The main component in an atmosphere means one or more components comprised in the atmosphere at 50% by volume or more. When two or more components are comprised as the main component, it is

sufficient that the total amount of two or more components is comprised in the atmosphere 50% by volume or more. The vacuum denotes an atmosphere where the pressure is 1.0×10^{-5} Pa or more and 1.0×10^{-2} Pa or less. In the present specification, the vacuum denotes an atmosphere where, without introducing inert gases such as argon (Ar) gas and helium (He) gas as main components in the inert atmosphere, or a mixture gas containing hydrogen or carbon monoxide into the atmosphere, the pressure is 1.0×10^{-5} Pa or more and 1.0×10^{-2} Pa or less, and the oxygen concentration is 15% by volume or less. In the case where the non-oxidizing atmosphere is a vacuum, a gas component in the atmosphere is mainly steam.

[0031] When the non-oxidizing atmosphere in forming the vapor deposition film is the reducing atmosphere where the mixture gas containing hydrogen and carbon monoxide is introduced, or the vacuum, a molar ratio of the indium oxide relative to the silicon oxide (In_2O_3/SiO) becomes relatively high. Even in the case of increasing the amount of oxygen generated from the thin film forming material in the steam, the hydrogen or the carbon monoxide contained in the mixture gas in the atmosphere, or the hydrogen contained in the vacuum is preferentially oxidized earlier than oxidizing the indium oxide (I) (In_2O) generated from the thin film forming material, and thus generation of the indium oxide (III) (In_2O_3) in the vapor deposition film can be suppressed.

[0032] An oxygen concentration in the non-oxidizing atmosphere in forming the vapor deposition film may be 15% by volume or less, preferably 10% by volume or less, more preferably 5% by volume or less, even more preferably 1% by volume or less. In order to obtain a first thin film having a desired refractive index, the lower oxygen concentration in the non-oxidizing atmosphere in film-forming the vapor deposition film, the more preferable. Thus, the oxygen concentration in the non-oxidizing atmosphere in film-forming the vapor deposition film is furthermore preferably 0.1% by volume or less, particularly preferably 0.01% by volume or less, most preferably 0.001% by volume or less (10 ppm by volume or less). When the oxygen concentration in the non-oxidizing atmosphere in forming the vapor deposition film is high, the generated indium oxide (I) (In_2O) and/or indium (In) is oxidized again, indium oxide (III) (In_2O_3) is generated in the vapor deposition film, the indium oxide (III) (In_2O_3) is not eluted even by bringing the vapor deposition film into contact with a first acidic solution and remains in the vapor deposition film, and thus there are cases where a thin film having a desired low refractive index cannot be obtained. A refractive index of the indium oxide (III) (In_2O_3) is about 2.0 and is relatively high. When the indium oxide (III) (In_2O_3) remains in the vapor deposition film, a thin film having a desired low refractive index cannot be obtained. On the other hand, when the oxygen concentration in the non-oxidizing atmosphere in forming the vapor deposition film is low, because of less oxygen in the atmosphere, it can be suppressed that the indium oxide (I) (In_2O) generated from the thin film forming material is oxidized again by the oxygen in the atmosphere and indium oxide (III) is then generated in the vapor deposition film.

[0033] A pressure in the non-oxidizing atmosphere in forming the vapor deposition film differs depending on the type of physical vapor deposition to be used. In the case of using an electron beam vapor deposition as the physical vapor deposition, an atmospheric pressure in forming the vapor deposition film on the substrate is preferably 1.0×10^{-5} Pa or more and 5.0×10^{-2} Pa or less, more preferably 1.0×10^{-5} Pa or more and 1.0×10^{-2} Pa or less, even more preferably 5.0×10^{-5} Pa or more and 1.0×10^{-2} Pa or less. In the case where the non-oxidizing atmosphere is a vacuum, a pressure in the vacuum atmosphere, in which an inert gas or a mixture gas is not introduced in the atmosphere, may be 1.0×10^{-5} Pa or more and 1.0×10^{-2} Pa or less. When the atmospheric pressure in forming the vapor deposition film is in the above range, it can be suppressed that the indium oxide (I) (In_2O) generated from the thin film forming material is oxidized again by the oxygen in the atmosphere and indium oxide (III) (In_2O_3) is then generated in the vapor deposition film. The pressure in the non-oxidizing atmosphere in forming the vapor deposition film can be controlled, for example, by introducing an inert gas such as argon or a mixture gas into a vapor deposition apparatus.

[0034] In the producing method according to an embodiment of the present invention, a substrate may be formed from glass, or may be formed from plastic. An example of the glass may be optical glass. Examples of the plastic may include polyester-based resins, acrylic-based resins, polycarbonate-based resins, polyamide-based resins, polyimide-based resins, polyethersulfone-based resins, polysulfone-based resins, and polyolefin-based resins. Aform of the substrate may be, for example, a flat-shaped substrate or a lens-shaped substrate having a curved surface, or may be a flexible sheet. In the producing method according to an embodiment of the present invention, a vapor deposition film can be formed even at a relatively low temperature. Thus, the thin film having a low refractive index can be formed even if the substrate is formed from a material having low heat resistance.

Step of Bringing into Contact with First Acidic Solution

[0035] The producing method according to an embodiment of the present invention includes bringing the vapor deposition film into contact with a first acidic solution comprising an acidic substance in a range of pH 2.5 or more and pH 3.5 or less so as to obtain a first thin film having voids.

[0036] The vapor deposition film, which is formed on the substrate by a physical vapor deposition using a mixture containing indium oxide and silicon oxide as a thin film forming material, in which the indium oxide is contained in a range of 0.230 mol or more and 0.270 mol or less relative to 1 mol of the silicon oxide, contains a silicon dioxide (SiO_2)

and indium oxide (I) (In_2O). Among the substances constituting the vapor deposition film, the indium oxide (I) (In_2O) and/or indium (In) has very high dissolubility to an acidic substance. Thus, even if the acidic substance contained in the first acidic solution is a weak acidic substance, the indium oxide (I) (In_2O) and/or indium (In) is preferentially eluted by bringing the vapor deposition film into contact with the first acidic solution in a range of pH 2.5 or more and pH 3.5 or less, and a first thin film (a thin film) having voids satisfying a desired refractive index, in which the framework is constituted of the silicon dioxide (SiO_2), can be obtained.

[0037] Even in the case where a film having another composition, which is different from the vapor deposition film, is laminated on the vapor deposition film in order to form a multilayer film, since the acidic substance contained in the first acidic solution is a weak acidic substance, the indium oxide (I) (In_2O) and/or indium (In) in the vapor deposition film is eluted to form a framework composed of the silicon dioxide (SiO_2) without influencing the film having another composition, and thus the first thin film (the thin film) having a desired refractive index can be obtained. An example of the composition of the film to be laminated on the vapor deposition film may be, for example, another composition containing alumina.

[0038] In the first thin film (the thin film) obtained by the producing method according to an embodiment of the present invention, the indium oxide (I) (In_2O) and/or indium (In), which is easily eluted, can be almost entirely eluted from inside of the vapor deposition film by bringing the vapor deposition film into contact with the first acidic solution, voids are then generated between the remaining silicon dioxide (SiO_2), which serves as the framework, by the elution of the indium oxide (I) (In_2O) and/or indium (In), and thus the first thin film (the thin film) having a high voidage and a low refractive index can be formed.

[0039] There are cases where the vapor deposition film contains indium oxide (III) (In_2O_3) and/or indium (In). Even in that case, the amount of the indium oxide (III) (In_2O_3) and/or indium (In) contained in the vapor deposition film is a very low amount of the extent to which the refractive index of the first thin film is decreased by about 0.01 after bringing the first thin film into contact with a strong acidic solution having a pH 2.0 or less. The very low amount of the extent to which the refractive index of the first thin film is decreased by about 0.01 is an amount of the extent to which the voidage of the first thin film is increased by about 3% by liberating a very low amount of the silicon dioxide (SiO_2) together with the very low amount of the indium oxide (III) (In_2O_3).

[0040] A part of the silicon dioxide (SiO_2) in the vapor deposition film is surrounded by the indium oxide (I) (In_2O) and/or indium (In). Thus, the part of the silicon dioxide (SiO_2) surrounded by the indium oxide (I) may be also liberated from the vapor deposition film at the same time when the indium oxide (I) (In_2O) and/or indium (In) is eluted from the vapor deposition film. When the first thin film is brought into contact with a strong acidic solution having a pH 2.0 or less, the very low amount of the silicon dioxide (SiO_2) surrounded by the indium oxide (I) (In_2O) and/or indium (In), together with the very low amount of the indium oxide (III) (In_2O_3) contained in the first thin film, are liberated, the refractive index of the first thin film is then decreased by about 0.01, and the voidage thereof is increased by about 3%.

[0041] The color of the indium oxide (I) (In_2O) is black, and thus when the indium oxide (I) (In_2O) remains in the first thin film (the thin film), the first thin film (the thin film) absorbs visible light. For example, by measuring an absorptivity {100 - (transmittance + reflectance)} of the thin film with a spectrometer, it can be confirmed that the absorption rate of the thin film is increased when the thin film absorbs visible light, and the indium oxide (I) (In_2O) and/or indium (In) remains in the thin film when the absorption rate is increased.

[0042] Examples of the acidic substance contained in the first acidic solution may include inorganic acids such as hydrochloric acid, sulfuric acid, and nitric acid, and organic acids such as acetic acid, citric acid, and oxalic acid. The acidic substance is preferably an acid having a buffer action and having a plurality of acid dissociation constant, more preferably citric acid or oxalic acid which serves as a weak acidic substance. In the acid having no buffer action, a pH value thereof is apt to rise, and thus the acid treatment time tends to require a long time.

[0043] The pH value of the first acidic solution is in a range of pH 2.5 or more and pH 3.5 or less, preferably in a range of pH 2.7 or more and pH 3.2 or less. When the pH value of the solution containing an acidic substance is lower than 2.5, adhesion between the obtained first thin film and the substrate becomes low, and the first thin film may be detached from the substrate after bringing into contact with the solution containing the acidic substance. When the pH value of the first acidic solution is more than 3.5, it is not preferable in that, since a dissolution rate of the indium oxide (I) (In_2O) and/or indium (In) contained in the vapor deposition film becomes low, it takes a long time until all the indium oxide (I) (In_2O) and/or indium (In) are eluted, and the production efficiency is then lowered.

[0044] It is sufficient that the temperature at which the vapor deposition film is brought into contact with the first acidic solution is room temperature. The room temperature is in a range of 15°C or more and 28°C or less, preferably in a range of 15°C or more and 25°C or less. When the temperature at which the vapor deposition film is brought into contact with the first acidic solution is high, the elution of the indium oxide (I) (In_2O) and/or indium (In) can be promoted, the contact time can be shortened, and thus it is preferable for the production. When the temperature is too high, a solvent in the first acidic solution is evaporated, and the pH value is decreased. Thus, the producing cost may be increased since a sealed container or equipment for adjusting the pH by continuous monitoring is required. When the temperature is too low, the producing cost may be increased since a cooling apparatus may be required.

[0045] The time to bring the vapor deposition film into contact with the first acidic solution may be a time period after

which the whole thin film becomes transparent.

[0046] Examples of the method for bringing the vapor deposition film into contact with the first acidic solution may generally include a method in which the substrate, on which the vapor deposition film is formed, is immersed in the first acidic solution, and a method in which only the vapor deposition film, which is formed on the substrate, is immersed in the first acidic solution. In the method for immersing the vapor deposition film in the first acidic solution, the indium oxide (I) (In_2O) and/or indium (In) in the vapor deposition film is eluted after a predetermined time has elapsed. The indium oxide (I) (In_2O) and/or indium (In) in the vapor deposition film is eluted, and in some cases the silicon dioxide (SiO_2), which is covered with the indium oxide (I) (In_2O) and/or indium (In), is eluted together with the indium oxide (I) (In_2O) and/or indium (In), thereby obtaining a thin film having voids.

First Thin Film: Thin Film

[0047] The first thin film produced by the method according to an embodiment of the present invention is a thin film comprising silicon oxide, in which the refractive index is 1.300 or less, and the first thin film has a voidage in a range of 30% or more and 90% or less. The first thin film is preferably an optical thin film. The first thin film (the thin film) is a thin film having voids formed by eluting the indium oxide (I) (In_2O) and/or indium (In) from the vapor deposition film containing the silicon dioxide (SiO_2) and the indium oxide (I) (In_2O) and/or indium (In), in which the silicon dioxide (SiO_2) serves as a framework, and the refractive index is 1.300 or less. The refractive index of the first thin film (the thin film) is preferably 1.250 or less, more preferably 1.200 or less, even more preferably 1.170 or less. The first thin film (the thin film) is constituted that the indium oxide (I) (In_2O) and/or indium (In) constituting the vapor deposition film is eluted to form many voids, and the remained silicon dioxide (SiO_2) not having been eluted serves as a framework. There is a case in which the first thin film contains a very low amount of the indium oxide (III) (In_2O_3) other than the silicon dioxide (SiO_2) constituting the framework. The content is an amount of the extent to which the refractive index of the first thin film is decreased by about 0.01 after bringing the first thin film after being treated with the first acidic solution into contact with a strong acidic solution having a pH 2.0 or less.

[0048] In the first thin film as a thin film, the refractive index is 1.300 or less, and thus the anti-reflection effect can be enhanced throughout the whole visible region.

[0049] The refractive index of the thin film can be obtained by measuring a reflection spectrum with a spectrometer, and by measuring a minimum value of a reflected light intensity as a reflectance when an incident light intensity is taken as 100, followed by calculating from the measured minimum value of the reflectance using Fresnel coefficients.

[0050] In the first thin film having voids as a thin film, the voidage is in a range of 30% or more and 90% or less. When the voidage of the first thin film is 30% or more, the refractive index of the thin film can be lowered, and when the voidage of the first thin film is 90% or less, the refractive index of the thin film can be lowered while having an intensity for retaining the thin film formed on the substrate. In the first thin film as a thin film, the voidage is more preferably in a range of 40% or more and 90% or less, even more preferably in a range of 50% or more and 90% or less, still more preferably 60% or more and 85% or less. The voidage of the thin film (total porosity: Vp) can be determined using a Lorentz-Lorenz formula, based on the Examples described later.

Obtaining Second Thin Film Formed by Silica-Coating First Thin Film

[0051] The producing method according to an embodiment of the present invention preferably includes coating a surface of the first thin film with a silica-coat forming material and heat-treating a coated thin film to obtain a second thin film. The term silica as used in the present application refers to SiO_2, while the term silicon oxide refers to oxides of Si in general and includes, e.g., SiO and SiO_2 The second thin film is formed by silica-coating the first thin film formed on the substrate, and includes the first thin film and silica for coating the first thin film. In the producing method according to an embodiment of the present invention, it is preferable that the silica-coat forming material is coated on a surface of the first thin film such that a silica-coat is formed on the whole of the first thin film having voids, and thereafter, the coated thin film is subjected to a heat treatment. A thickness of the silica-coating is from 0.1 nm to 30 nm. When the thickness of the silica-coating is too thin, a strength of the thin film will be insufficient. When the thickness of the silica-coating is too thick, the refractive index of the thin film will be high.

[0052] The silica-coat forming material preferably contains a silicon alkoxide. The silica-coat is preferably formed by a sol-gel method. The silicon alkoxide is preferably a silane compound having two or more alkoxyl groups. Specifically, it is preferable to use at least one silane compound selected from the group consisting of dimethyldiethoxysilane, diethyldiethoxysilane, methyltrimethoxysilane, methyltriethoxysilane, phenyltriethoxysilane, 3-glycidoxypropyltrimethoxysilane (GPTMS), tetramethoxysilane (TMOS), tetraethoxysilane (TEOS), tetraisopropoxysilane, and tetrabutoxysilane.

[0053] The silica-coat forming material preferably contains a solvent for improving the film-formation. Examples of the solvent may include: alcohols such as methanol, ethanol, isopropyl alcohol, and butanol; and ketones such as acetone, methyl ethyl ketone, cyclohexanone, and isophorone. One solvent may be used alone, or two or more kinds of the

solvents may be used in combination. The silica-coat forming material preferably contains the silicon alkoxide and the solvent, and preferably a second acidic solution.

[0054] In the case where the silica-coat forming material contains the silicon alkoxide, the producing method according to an embodiment of the present invention includes adding a second acidic solution to the silica-coat forming material for hydrolyzing the silicon alkoxide. The pH value of the second acidic solution is preferably in a range of pH 0.8 or more and pH 1.8 or less, more preferably in a range of pH 1.0 or more and pH 1.5 or less. The mass ratio of the silicon alkoxide, the solvent, the second acidic solution (silicon alkoxide : solvent : second acidic solution) is preferably 0.5g : 8.5g to 20.0g : 0.21g to .86, more preferably 0.5g : 11.0g to 16.0g : 0.30g to 0.64g.

[0055] When the pH value of the second acidic solution to be added to the silica-coat forming material falls within the range of pH 0.8 or more and pH 1.8 or less, in the case where the silicon alkoxide is contained in the silica-coat forming material, the silicon alkoxide can be hydrolyzed, and thereafter can be subjected to a dehydration condensation. By coating a surface of the first thin film with the silica-coat forming material, a second thin film formed by silica-coating the first thin film can be obtained. The second thin film includes the first thin film and silica which is coated thereon, and thus sufficient film strength can be obtained. When the pH value of the second acidic solution to be added to the silica-coat forming material is less than pH 0.8 or more than pH 1.8, particle growth of the particles generated by the dehydration condensation of the silicon alkoxide is excessively promoted during the dehydration condensation, and thus the silica-coat for covering the surface of the first thin film is hardly obtained. The acidic substance contained in the second acidic solution to be added to the silica-coat forming material is preferably at least one selected from hydrochloric acid, sulfuric acid, oxalic acid, and acetic acid.

[0056] Examples of the method for coating the silica-coat forming material may include a spin coat method, a dip coat method, a spray coat method, a flow coat method, a bar coat method, a reverse coat method, a gravure coat method, and a printing method.

[0057] The temperature for the heat treatment after coating the silica-coat forming material on the surface of the first thin film may be a temperature capable of forming the silica-coat, preferably in a range of 250°C or higher and 350°C or lower, more preferably in a range of 280°C or higher and 320°C or lower. The time for the heat treatment may be a time period sufficient to form the silica-coat, preferably in a range of 0.5 hours or longer and 3 hours or shorter, more preferably in a range of 0.5 hours or longer and 2 hours or shorter.

Second Thin Film Formed by Silica-Coating First Thin Film: Thin Film

[0058] It is preferable that the second thin film formed by silica-coating the first thin film includes silicon oxide, and the refractive index is 1.380 or less. The second thin film is preferably an optical thin film.

[0059] The second thin film as a thin film is formed by silica-coating so as to cover a surface of the silicon dioxide (SiO_2) serving as a framework of the first thin film. Since the silicon dioxide (SiO_2) serving as a framework of the first thin film has voids, it is presumed that the surface has a mesh shape, and silica is coated along the surface. The second thin film as a thin film is formed by silica-coating the surface of the first thin film, thereby having sufficient film strength.

[0060] The refractive index of the second thin film as a thin film is as low as 1.380 or less, and is a refractive index equal to or lower than 1.380 which is a refractive index of magnesium fluoride (MgF_2) known as a conventional low refractive material. Since the refractive index of the second thin film is as low as 1.380 or less, for example, when optical glass or plastic is used as a substrate, the refractive index of the second thin film becomes a value close to the square root of the refractive index of the substrate (from about 1.200 to about 1.300), and thus the anti-reflection effect can be enhanced. The refractive index of the second thin film formed by silica-coating the first thin film is preferably 1.380 or less, more preferably 1.300 or less, even more preferably 1.250 or less, still more preferably 1.200 or less.

Article

[0061] An article, which is preferably an optical member, including the thin film obtained by the method according to the present invention and the substrate, can be utilized as the articles for astronomic telescopes, glass lenses, cameras, band pass filters, disc drive devices equipped with optical pickup parts such as a beam splitter, display devices equipped with high definition liquid crystal panels, etc. Further, by utilizing the thin film for extraction parts of outgoing light in a light emitting device, injection of the outgoing light from the light emitting device can be promoted. Thus, enhancement of the light extraction efficiency and reduction of the heat generation can be expected.

EXAMPLES

[0062] The present invention is hereunder specifically described by reference to the following Examples. However, the present invention is not limited to these Examples.

Example 1

Production of Thin Film Forming Material

[0063] 160 g of indium oxide (III) powder (In_2O_3) (purity: 99.99% by mass) and 100 g of silicon monoxide powder (SiO) (purity: 99.9% by mass) were introduced into a nylon pod having a capacity of 1 L, a nylon ball having a diameter of 20 mm (ϕ20) was introduced thereto together with these powders, and the introduced raw materials were mixed for 30 minutes while loosening the aggregated powder to obtain a raw material mixture. A molar ratio of the indium oxide relative to 1 mol of the silicon oxide (a molar ratio of In_2O_3/SiO) was 0.254. The raw material mixture was taken out from the pod, and was press-molded to form a molded body. The molded body was calcined at 800°C for 2 hours in an inert atmosphere (argon (Ar): 99.99% by volume) to obtain a thin film forming material (sintered body) 1.

Production of First Vapor Deposition Film

[0064] As a substrate, a disc-shaped double-face polishing plate glass (BK-7, manufactured by SCHOTT AG) was used. The substrate and the thin film forming material 1 were set in a vapor deposition apparatus. In a state where the pressure in the vapor deposition apparatus was reduced to 1.0×10^{-4} Pa, the thin film forming material 1 was irradiated with electron beam (JEBG-102UH0, manufactured by JEOL Ltd.) at 140 mA, thereby forming a vapor deposition film containing indium oxide (I) (In_2O) and a silicon dioxide (SiO_2) on one face of the substrate serving as a substrate. The temperature of the substrate in film-forming was set at 100°C. An ion-beam assisted deposition (IAD) (acceleration voltage value - acceleration current value = 900 V - 900 mA) using Ar ions which are released from an ion gun (NIS-150, manufactured by Shincron Co., Ltd.) in film-forming was used. In order to prevent a charge-up of the substrate, a neutralizer (RFN-2, with a bias current value of 1,000 mA, manufactured by Shincron Co., Ltd.) was simultaneously used.

Production of First Thin Film Having Voids

[0065] An oxalic acid solution having a pH 3.2 was used as a first acidic solution. The substrate on which the vapor deposition film was formed was immersed in the oxalic acid solution at room temperature, and indium oxide (I) (In_2O) was preferentially eluted from the vapor deposition film, thereby producing a first thin film having voids. A contact time (immersion time) between the vapor deposition film and the acidic solution was set to 90 minutes to obtain a first thin film having no absorption of visible light. A refractive index of the obtained first thin film having voids was measured according to the method described later. The first thin film having voids, in which the refractive index was 1.091, was obtained. The amount of indium oxide (III) (In_2O_3) and/or indium (In) contained in the first thin film was an amount in which the refractive index of the first thin film was decreased by 0.011 after bringing the first thin film into contact with the strong acidic solution having a pH 2.0 or less, and an amount in which the voidage was increased by around 3% (both amounts include a removed silicon dioxide (SiO_2)).

Production of Second Thin Film

[0066] As a silica-coat forming material, 0.5 g of tetraethoxysilane (TEOS, manufactured by Shin-Etsu Chemical Co., Ltd.) was added into 12.85 g of dehydrated ethanol, and thereafter, 0.47 g of hydrochloric acid having a pH 1.0 as a second acidic solution was added thereto. The prepared liquid was then mixed for 24 hours to produce a silica-coat forming material. The silica-coat forming material was dripped on the surface of the first thin film having voids, and impregnated the surface of the first thin film. Thereafter, excess silica-coat forming material was eliminated from the surface of the first thin film by rotating the first thin film, the surface of the first thin film was coated with the silica-coat forming material, and the first thin film was retained at 300°C for 1 hour, thereby producing a second thin film formed by silica-coating the first thin film. A refractive index of the obtained second thin film was 1.139.

Example 2

[0067] 155 g of In_2O_3 powder and 100 g of SiO powder (a molar ratio of In_2O_3/SiO was 0.246) were mixed, and the mixture was sintered in the same manner as in Example 1 to obtain a thin film forming material 2. A first thin film having voids was produced in the same manner as in Example 1 except that the thin film forming material 2 was used, and the silica-coating was not formed. A refractive index of the obtained thin film was 1.140.

Example 3

[0068] A first thin film having voids was produced in the same manner as in Example 1 except that an oxalic acid

solution having a pH 2.5 was used as the first acidic solution, and the silica-coating was not formed. A refractive index of the obtained thin film was 1.094.

Example 4

[0069] A first thin film having voids was produced in the same manner as in Example 1 except that an oxalic acid solution having a pH 2.7 was used as the first acidic solution, and the silica-coating was not formed. A refractive index of the obtained thin film was 1.093.

Example 5

[0070] A first thin film having voids was produced in the same manner as in Example 1 except that an oxalic acid solution having a pH 3.5 was used as the first acidic solution, and the silica-coating was not formed. A refractive index of the obtained thin film was 1.092.

Example 6

[0071] A first thin film having voids was produced in the same manner as in Example 1 except that a hydrochloric acid solution having a pH 3.0 was used as the first acidic solution, and the silica-coating was not formed. A refractive index of the obtained thin film was 1.095.

Example 7

[0072] A first thin film having voids was produced in the same manner as in Example 2 except that the ion-beam assisted deposition using Ar ions was not used, and the silica-coating was not formed. A refractive index of the obtained thin film was 1.266.

Comparative Example 1

[0073] 140 g of In_2O_3 powder and 100 g of SiO powder (a molar ratio of In_2O_3/SiO was 0.222) were mixed, and the mixture was sintered in the same manner as in Example 7 to obtain a thin film forming material 3. A thin film having voids was produced in the same manner as in Example 7 except that the thin film forming material 3 was used, and the silica-coating was not formed. A refractive index of the obtained thin film was 1.321.

Comparative Example 2

[0074] 180 g of In_2O_3 powder and 100 g of SiO powder (a molar ratio of In_2O_3/SiO was 0.286) were mixed, and the mixture was sintered in the same manner as in Example 1 to obtain a thin film forming material 4. A vapor deposition film was produced in the same manner as in Example 1 except that the thin film forming material 4 was used, and the vapor deposition film was brought into contact with the same first acidic solution as in Example 1. However, the vapor deposition film was detached from the substrate after the acid treatment, and thus a thin film having voids could not be obtained.

Comparative Example 3

[0075] A vapor deposition film was produced in the same manner as in Example 1 except that an oxalic acid solution having a pH 2.0 was used as the first acidic solution, and the vapor deposition film was brought into contact with the same first acidic solution as in Example 1. However, the vapor deposition film was detached from the substrate after the acid treatment, and thus a thin film having voids could not be obtained.

Comparative Example 4

[0076] A first thin film having voids was produced in the same manner as in Example 1 except that an oxalic acid solution having a pH 4.0 was used as the first acidic solution, and the silica-coating was not formed. The obtained thin film did not become transparent.

Evaluation of Thin Film

[0077] The first thin films which are thin films obtained in Examples and Comparative Examples were evaluated as follows. The results are shown in Table 1.

5

Refractive Index

[0078] A reflection spectrum of the thin film having voids in each of Examples was measured using a spectrometer (U-4100, with an incident angle of 5°, manufactured by Hitachi High-Technologies Corp.). A minimum value of a reflected

10 light intensity was measured as a reflectance when an incident light intensity was taken as 100. A refractive index was then calculated from the measured reflectance using Fresnel coefficients. The temperature of measured the thin film sample is room temperature, room temperature is in a range 18°C to 25°C.

[0079] In each of Examples, the double-face polishing glass is used as the substrate serving as a substrate, which forms the thin film, and thus the reflectance R' obtained from the measurement contains multiple repeated reflection

15 including rear-face reflection. Since the measured reflectance R' contains the multiple repeated reflection, a reflectance R of the thin film can be represented by the following formula (1).

$$R' = \frac{R_0 + R - 2R_0 R}{1 - R_0 R} \qquad (1)$$

20

[0080] In the formula (1), the parameter R_0 represents a reflectance of the substrate. The reflectance R was calculated from the actually measured reflectance R' based on the formula (1). The reflectance R of the thin film is a reflectance without considering a reflection from the rear-face.

25 **[0081]** When using a Fresnel coefficient, the reflectance R of the thin film can be calculated from a refractive index n_m of the substrate and a refractive index n of the thin film, and can be represented by the following formula (2).

$$R = \frac{(n^2 - n_m)^2}{(n^2 + n_m)^2} \qquad (2)$$

30

[0082] Here, in the case where a refractive index in the air is approximated to 1 and the refractive index n of the thin film is higher than the square root of the refractive index n_m of the substrate, the refractive index n of the thin film can be represented by the following formula (3).

35

$$n = \left\{ \frac{n_m (1 + \sqrt{R})}{1 - \sqrt{R}} \right\}^{\frac{1}{2}} \quad \text{when } n > \sqrt{n_m} \qquad (3)$$

40

[0083] In the case where the refractive index n of the thin film is lower than the square root of the refractive index n_m of the substrate, the refractive index n of the thin film can be represented by the following formula (4).

45

$$n = \left\{ \frac{n_m (1 - \sqrt{R})}{1 + \sqrt{R}} \right\}^{\frac{1}{2}} \quad \text{when } n < \sqrt{n_m} \qquad (4)$$

[0084] The refractive indices n of the first thin film and the second thin film, each serving as a thin film, were calculated

50 based on the formulae (1) to (4). As to the refractive index n of the thin film, the document "Basic Theory of Optical Thin Film - Fresnel Coefficient and Characteristic Matrix-" written by Mitsunobu Kobiyama and published by Optronics Co., Ltd. on February 25, 2011 (enlarged and revised edition - first copy) was referred to.

Voidage (%)

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[0085] Voidages (total porosity: Vp) of the first thin film and the second thin film, each serving as a thin film, were determined using a Lorentz-Lorenz formula as shown in the following formula (5). In the formula (5), the parameter n_f represents an observed refractive index of the thin film, and the parameter n_b represents a refractive index of the

framework of the thin film. The refractive index n_f of the thin film is a refractive index of the thin film having voids which is determined based on the formulae (1) to (4). The refractive index n_b of the framework of the thin film was determined using a refractive index (1.460) of a silicon dioxide (SiO_2), since the framework of the thin film was mainly constituted by the silicon dioxide (SiO_2).

$$\mathrm{Vp} = 1 - \frac{(n_f^2-1)}{(n_f^2+2)}\left(\frac{(n_b^2-1)}{(n_b^2+2)}\right)^{-1} \qquad (5)$$

Absorption rate (%)

[0086] An absorption rate of the thin film having voids in each of Examples was measured using a spectrometer (U-4100, with an incident angle of 5°, manufactured by Hitachi High-Technologies Corp.). A reflected light intensity and a transmitted light intensity were measured when an incident light intensity was taken as 100, and a value subtracting the measured values from the incident light intensity of 100 was measured as the absorption rate. Since the absorption rate becomes high at the short wavelength side, an average value of 390 to 410 nm was adopted.

Table 1

	in_2O_3/SiO Molar ratio	IAD	First acidic solution		First thin film (without silica-coat)	
			Kind of acidic substance	pH	Refractive index	Voidage (%)
Example 1	0.254	used	oxalic acid	3.2	1.091	78.2
Example 2	0.246	used	oxalic acid	3.2	1.140	66.8
Example 3	0.254	used	oxalic acid	2.5	1.094	77.5
Example 4	0.254	used	oxalic acid	2.7	1.093	77.8
Example 5	0.254	used	oxalic acid	3.5	1.092	78.0
Example 6	0.254	used	hydrochloric acid	3.0	1.095	77.3
Example 7	0.246	not used	oxalic acid	3.2	1.266	42.6
Comparative Example 1	0.222	not used	oxalic acid	3.2	1.321	27.4
Comparative Example 2	0.286	used	oxalic acid	3.2	disappeared after acid treatment	-
Comparative Example 3	0.254	used	oxalic acid	2.0	disappeared after acid treatment	-
Comparative Example 4	0.254	used	oxalic acid	4.0	remained as black	-

[0087] As shown in Table 1, the refractive index of the first thin film obtained in each of Examples 1 to 7 could be lowered to 1.300 or less. In the first thin film using the ion-beam assisted deposition (IAD) with Ar ions in each of Examples 1 to 6, the refractive index could be further lowered to 1.170 or less. As to the first thin film obtained in Example 1, when measuring the absorption rate from the transmittance and the reflectance using a spectrometer, it could be confirmed that the absorption rate was sufficiently low, the indium oxide (I) (In_2O) and/or indium (In) which is/are black was not present in the thin film, and all of the indium oxide (I) (In_2O) and/or indium (In) in the thin film were eluted by contact with the acidic substance. It could be also confirmed that, in the first thin film obtained in Example 1, the black silicon monoxide (SiO) was not present.

[0088] As shown in Comparative Example 1, the molar ratio of the thin film forming material (In_2O_3/SiO) was 0.222. When the molar ratio of the thin film forming material (In_2O_3/SiO) was below 0.230, the refractive index of the first thin film was 1.321, and was not 1.300 or less. As shown in Comparative Example 2, the molar ratio of the thin film forming material (In_2O_3/SiO) was 0.286. When the molar ratio of the thin film forming material (In_2O_3/SiO) was more than 0.270,

the vapor deposition film was detached by contact with the first acidic solution, and the first thin film having voids could not be formed at a desired area of the substrate.

[0089] As shown in Comparative Example 3, when the pH value of the first acidic solution was too low, the vapor deposition film was detached after the contact, and the first thin film having voids could not be formed at a desired area of the substrate. Further, as shown in Comparative Example 4, when the pH value of the first acidic solution was too high, a black substance was found in the first thin film, and thus the indium oxide (I) (In_2O) and/or indium (In), which was the black substance, could not be eluted.

[0090] Next, Examples 8 to 14, each explaining the second thin film formed by silica-coating the first thin film, will be described, and be discussed with reference to Example 1.

Example 8

[0091] A second thin film which was silica-coated with the first thin film was produced in the same manner as in Example 1 except that a hydrochloric acid solution having a pH 1.5 was used as the second acidic solution to be added to the silica-coat forming material. A refractive index of the obtained second thin film was 1.171.

Example 9

[0092] A second thin film which was silica-coated with the first thin film was produced in the same manner as in Example 1 except that 3-glycidoxypropyltrimethoxysilane (GPTMS) was used as the silicon alkoxide of the silica-coat forming material. A refractive index of the obtained second thin film was 1.178.

Example 10

[0093] A second thin film which was silica-coated with the first thin film was produced in the same manner as in Example 1 except that a hydrochloric acid solution having a pH 0.5 was used as the second acidic solution to be added to the silica-coat forming material. A refractive index of the obtained second thin film was 1.159.

Example 11

[0094] A second thin film which was silica-coated with the first thin film was produced in the same manner as in Example 1 except that a hydrochloric acid solution having a pH 2.0 was used as the second acidic solution to be added to the silica-coat forming material. A refractive index of the obtained second thin film was 1.151.

Example 12

[0095] A second thin film which was silica-coated with the first thin film was produced in the same manner as in Example 1 except that a hydrochloric acid solution having a pH 3.0 was used as the second acidic solution to be added to the silica-coat forming material. A refractive index of the obtained second thin film was 1.100.

Example 13

[0096] A second thin film which was silica-coated with the first thin film was produced in the same manner as in Example 1 except that a hydrochloric acid solution having a pH 4.0 was used as the second acidic solution to be added to the silica-coat forming material. A refractive index of the obtained second thin film was 1.120.

Example 14

[0097] A second thin film which was silica-coated with the first thin film was produced in the same manner as in Example 1 except that a hydrochloric acid solution having a pH 5.0 was used as the second acidic solution to be added to the silica-coat forming material. A refractive index of the obtained second thin film was 1.107.

Evaluation of Thin Film

[0098] As an evaluation of the second thin film obtained in each of Examples 1 and 8 to 14, the refractive index and the voidage were evaluated in the same manner as the evaluation of the first thin film in Example 1. The results are shown in Table 2.

Film Strength Test

[0099] A sheet of lens-cleaning paper was overlapped on the second thin film formed by silica-coating the first thin film. Using a pencil hardness tester (according to JIS K 5600, scratch hardness (pencil method)), a disk of 1 cm^2 using in the pencil hardness tester was moved 20 cycles on the lens-cleaning paper in a dry method while applying a load of 500 g/cm^2. The lens-cleaning paper was removed, and the surface of the second thin film was visually observed. The state of the surface thereof was evaluated by the following criteria. A state in which a scratch or a color change of reflected light was found was judged as bad (B), and a state in which a change on the surface of the second thin film was not found was judged as good (G). The results are shown in Table 2. Even the thin films which were evaluated as bad (B) had a superior film strength as compared to the thin films having no silica-coat.

SEM Micrograph

[0100] Using a scanning electron microscope (SEM), SEM micrographs of the second thin film which was silica-coated with the first thin film were obtained. Fig. 1 is a SEM micrograph showing a surface of the second thin film in Example 1, and Fig. 2 is a SEM micrograph showing a cross section of the second thin film in Example 1.

Table 2

	In_2O_3/ SiO Molar ratio	First acidic solution		First thin film (without silica-coat)		Silica-coat		Second thin film (first thin film + silica-coat)		Film strength evaluation
		Kind of acidic substance	pH	Refractive index	Voidage (%)	Silica source	pH	Refractive index	Voidage (%)	
Example 1	0.254	oxalic acid	3.2	1.091	78.2	TEOS	1.0	1.139	67.1	G
Example 8	0.254	oxalic acid	3.2	1.090	78.5	TEOS	1.5	1.171	59.8	G
Example 9	0.254	oxalic acid	3.2	1.094	77.5	GPTMS	1.5	1.178	58.2	G
Example 10	0.254	oxalic acid	3.2	1.096	77.1	TEOS	0.5	1.159	62.5	B
Example 11	0.254	oxalic acid	3.2	1.094	77.5	TEOS	2.0	1.151	64.3	B
Example 12	0.254	oxalic acid	3.2	1.095	77.3	TEOS	3.0	1.100	76.1	B
Example 13	0.254	oxalic acid	3.2	1.098	76.6	TEOS	4.0	1.120	71.5	B
Example 14	0.254	oxalic acid	3.2	1.096	77.1	TEOS	5.0	1.107	74.5	B

[0101] As shown in Table 2, the refractive index of the first thin film obtained in each of Examples 1 and 8 to 14 was 1.300 or less, and more specifically the refractive index could be lowered as being 1.098 or less. As to the second thin film formed by silica-coating the first thin film produced in each of Examples 1 and 8 to 14, the refractive index was 1.380 or less, more specifically 1.178 or less, and could be lower than the refractive index (1.380) of magnesium fluoride (MgF_2) known as a conventional low refractive material.

[0102] Even in the case of using the silica-coat forming material to which the second acidic solution having a pH 1.0 was added as shown in Example 1, in the case of using the silica-coat forming material to which the second acidic solution having a pH 1.5 was added as shown in Example 8, and in the case of using the silica-coat forming material containing 3-glycidoxypropyltrimethoxysilane (GPTMS) as shown in Example 9, the obtained second thin films exhibited sufficient film strength.

[0103] When the silica-coat forming material to which the second acidic solution having a high pH value higher than 1.8 was added as shown in Examples 11 to 14, and when the silica-coat forming material to which the second acidic solution having a low pH value lower than 0.8 was added as shown in Example 10, the second thin films could not exhibit sufficient film strength.

[0104] As shown in Fig.1, in the first thin film obtained in Example 1, voids formed by eluting the indium oxide (I) (In_2O) are present in the framework constituted by the silicon dioxide (SiO_2). As shown in Fig.2, when observing a cross section of the second thin film formed by silica-coating the first thin film obtained in Example 1, it can be confirmed that the framework formed by the silicon dioxide (SiO_2) is serially formed from the substrate to the surface of the thin film, and has a different shape from a thin film constituted by, for example, an aggregate of silica particles.

[0105] With the method for producing a thin film according to an embodiment of the present invention, a thin film having a low refractive index can relatively easily be produced, and a thin film, which can be utilized for not only camera lenses but also high definition liquid crystal panels etc., can be provided. The thin film can be utilized as articles for astronomic telescopes, glass lenses, cameras, band pass filters, disc drive devices equipped with optical pickup parts such as a beam splitter, display devices equipped with high definition liquid crystal panels, etc.

Claims

1. A method for producing a thin film comprising:

   forming a vapor deposition film by depositing a thin film forming material on a substrate in a non-oxidizing atmosphere by a physical vapor deposition; and
   bringing the vapor deposition film into contact with a first acidic solution comprising an acidic substance and having a pH-value in the range of pH 2.5 or more and pH 3.5 or less, to obtain a first thin film having voids,
   wherein the thin film forming material is a mixture comprising indium oxide and silicon oxide, in which the indium oxide is contained in a range of 0.230 mol or more and 0.270 mol or less relative to 1 mol of the silicon oxide,
   wherein the indium oxide is In_2O_3 and the silicon oxide contains 50% by mass or more of silicon monoxide, and
   wherein the refractive index of the first thin film is 1.300 or less and the first thin film has a voidage in a range of 30% or more and 90% or less.

2. The method for producing the thin film according to claim 1, further comprising the following steps:

   coating a surface of the first thin film with a silica-coat forming material and
   heat-treating the coated thin film to obtain a second thin film.

3. The method for producing the thin film according to claim 1 or 2, wherein the refractive index of the first thin film is 1.250 or less, preferably 1.200 or less, more preferably 1.170 or less.

4. The method for producing the thin film according to any one of claims 1 to 3, wherein the voidage of the first thin film is in a range of 40% or more and 90% or less, preferably in a range of 50% or more and 90% or less, more preferably 60% or more and 85% or less.

5. The method for producing the thin film according to any one of claims 1 to 4, wherein the vapor deposition film is brought into contact with the first acidic solution at room temperature.

6. The method for producing the thin film according to any one of claims 2 to 5, wherein the silica-coat forming material comprises a silicon alkoxide.

7. The method for producing the thin film according to any one of claims 2 to 6, further comprising the following step: adding a second acidic solution to the silica-coat forming material, wherein a pH-value of the second acidic solution is in a range of pH 0.8 or more and pH 1.8 or less.

8. A material for forming a thin film, wherein the material comprises a mixture comprising indium oxide and silicon oxide, wherein the indium oxide is comprised in a range of 0.230 mol or more and 0.270 mol or less relative to 1 mol of the silicon oxide, wherein the indium oxide is In_2O_3 and the silicon oxide contains 50% by mass or more of silicon monoxide.

9. The material according to claim 8, wherein the molar ratio of the In_2O_3 contained in the thin film forming material, relative to 1 mol of the silicon oxide, is in a range of 0.240 or more and 0.270 or less, preferably in a range of 0.240 or more and 0.265 or less, more preferably in a range of 0.250 or more and 0.260 or less, even more preferably in a range of 0.252 or more and 0.258 or less.

Patentansprüche

1. Ein Verfahren zur Herstellung einer dünnen Schicht, umfassend:

   Herstellen einer Gasphasenabscheidungsschicht, indem ein dünnschichtbildendes Material auf einem Substrat in einer nichtoxidierenden Atmosphäre durch eine physikalische Gasphasenabscheidung abgeschieden wird; und
   in Kontakt bringen der Gasphasenabscheidungsschicht mit einer ersten sauren Lösung, die einen sauren Stoff umfasst und deren pH-Wert im Bereich von pH 2,5 oder mehr und pH 3,5 oder weniger liegt, um eine erste Dünnschicht mit Hohlräumen zu erhalten,
   wobei das dünnschichtbildende Material ein Indiumoxid und Siliziumoxid umfassendes Gemisch ist, in welchem das Indiumoxid in einem Bereich von 0,230 mol oder mehr und 0,270 mol oder weniger bezogen auf 1 mol des Siliziumoxids enthalten ist,
   wobei das Indiumoxid In_2O_3 ist und das Siliziumoxid zu 50 Massen-% oder mehr Siliziummonoxid enthält und wobei der Brechungsindex der ersten dünnen Schicht 1,300 oder weniger beträgt und die erste dünne Schicht einen Hohlraumanteil in einem Bereich von 30% oder mehr und 90% oder weniger aufweist.

2. Das Verfahren zur Herstelllung der dünnen Schicht gemäß Anspruch 1, zusätzlich die folgenden Schritte umfassend:

   Beschichten der Oberfläche der ersten dünnen Schicht mit einem Silicabeschichtungs-bildenden Material und Wärmebehandeln der beschichteten dünnen Schicht um eine zweite dünne Schicht zu erhalten.

3. Das Verfahren zur Herstellung der dünnen Schicht gemäß Anspruch 1 oder 2, wobei der Brechungsindex der ersten dünnen Schicht 1,250 oder weniger, bevorzugt 1,200 oder weniger, stärker bevorzugt 1,170 oder weniger, beträgt.

4. Das Verfahren zur Herstellung der dünnen Schicht gemäß einem der Ansprüche 1 bis 3, wobei der Hohlraumanteil der ersten dünnen Schicht in einem Bereich von 40% oder mehr und 90% oder weniger, bevorzugt in einem Bereich von 50% oder mehr und 90% oder weniger, stärker bevorzugt 60% oder mehr und 85% oder weniger, liegt.

5. Das Verfahren zur Herstellung der dünnen Schicht gemäß einem der Ansprüche 1 bis 4, wobei die Gasphasenabscheidungsschicht bei Raumtemperatur mit der ersten sauren Lösung in Kontakt gebracht wird.

6. Das Verfahren zur Herstellung der dünnen Schicht gemäß einem der Ansprüche 2 bis 5, wobei das Silicabeschichtungs-bildende Material ein Siliziumalkoholat umfasst.

7. Das Verfahren zur Herstellung der dünnen Schicht gemäß einem der Ansprüche 2 bis 6, zusätzlich den folgenden Schritt umfassend:
   Zugeben einer zweiten sauren Lösung zum Silicabeschichtungs-bildenden Material, wobei ein pH-Wert der zweiten sauren Lösung in einem Bereich von pH 0,8 oder mehr und pH 1,8 oder weniger liegt.

8. Ein Material zur Herstellung einer dünnen Schicht, wobei das Material ein Indiumoxid und Siliziumoxid umfassendes Gemisch umfasst, wobei das Indiumoxid in einem Bereich von 0,230 mol oder mehr und 0,270 mol oder weniger bezogen auf 1 mol des Siliziumoxids umfasst ist, wobei das Indiumoxid In_2O_3 ist und das Siliziumoxid zu 50 Massen-

% oder mehr Siliziummonoxid enthält.

9. Das Material gemäß Anspruch 8, wobei das Molverhältnis des In_2O_3, das im dünnschichtbildenden Material enthalten ist, bezogen auf 1 mol des Siliziumoxids in einem Bereich von 0,240 oder mehr und 0,270 oder weniger, bevorzugt in einem Bereich von 0,240 oder mehr und 0,265 oder weniger, stärker bevorzugt in einem Bereich von 0,250 oder mehr und 0,260 oder weniger, noch stärker bevorzugt in einem Bereich von 0,252 oder mehr und 0,258 oder weniger, liegt.

Revendications

1. Méthode pour produire un film mince comprenant :

la formation d'un film déposé en phase vapeur par dépôt d'un matériau formant un film mince sur un substrat dans une atmosphère non oxydante par dépôt physique en phase vapeur ; et
mise en contact du film déposé en phase vapeur avec une première solution acide comprenant une substance acide et ayant une valeur de pH située dans la plage de pH 2,5 ou plus et pH 3,5 ou moins, pour obtenir un premier film mince ayant des vides,
dans laquelle le matériau formant un film mince est un mélange comprenant de l'oxyde d'indium et de l'oxyde de silicium, dans lequel l'oxyde d'indium est contenu à raison de 0,230 mole ou plus et 0,270 mole ou moins pour 1 mole de l'oxyde de silicium,
dans laquelle l'oxyde d'indium est In_2O_3 et l'oxyde de silicium contient 50 % en masse ou plus de monoxyde de silicium, et
dans laquelle l'indice de réfraction du premier film mince est de 1,300 ou moins et le premier film mince a une porosité située dans la plage de 30 % ou plus et 90 % ou moins.

2. Méthode pour produire le film mince selon la revendication 1, comprenant en outre les étapes suivantes :
revêtement d'une surface du premier film mince avec un matériau formant un revêtement de silice et traitement à la chaleur du film mince revêtu pour obtenir un deuxième film mince,

3. Méthode pour produire le film mince selon la revendication 1 ou 2, dans laquelle l'indice de réfraction du premier film mince est de 1,250 ou moins, de préférence de 1,200 ou moins, mieux encore de 1,170 ou moins,

4. Méthode pour produire le film mince selon l'une quelconque des revendications 1 à 3, dans laquelle la porosité du premier film mince est située dans la plage de 40 % ou plus et 90 % ou moins, de préférence dans la plage de 50 % ou plus et 90 % ou moins, mieux encore de 60 % ou plus et 85 % ou moins,

5. Méthode pour produire le film mince selon l'une quelconque des revendications 1 à 4, dans laquelle le film déposé en phase vapeur est mis en contact avec la première solution acide à température ambiante,

6. Méthode pour produire le film mince selon l'une quelconque des revendications 2 à 5, dans laquelle le matériau formant un revêtement de silice comprend un alcoolate de silicium,

7. Méthode pour produire le film mince selon l'une quelconque des revendications 2 à 6, comprenant en outre l'étape suivante :
ajout d'une deuxième solution acide au matériau formant un revêtement de silice, dans laquelle la valeur de pH de la deuxième solution acide est située dans la plage de pH 0,8 ou plus et pH 1,8 ou moins,

8. Matériau pour former un film mince, dans lequel le matériau comprend un mélange comprenant de l'oxyde d'indium et de l'oxyde de silicium, dans lequel l'oxyde d'indium est présent à raison de 0,230 mole ou plus et 0,270 mole ou moins pour 1 mole de l'oxyde de silicium, dans lequel l'oxyde d'indium est In_2O_3 et l'oxyde de silicium contient 50 % en masse ou plus de monoxyde de silicium,

9. Matériau selon la revendication 8, dans lequel le rapport molaire du In_2O_3 contenu dans le matériau formant un film mince, pour 1 mole de l'oxyde de silicium, est situé dans la plage de 0,240 ou plus et 0,270 ou moins, de préférence dans la plage de 0,240 ou plus et 0,265 ou moins, mieux encore dans la plage de 0,250 ou plus et 0,260 ou moins, plus particulièrement dans la plage de 0,252 ou plus et 0,258 ou moins,

FIG. 1

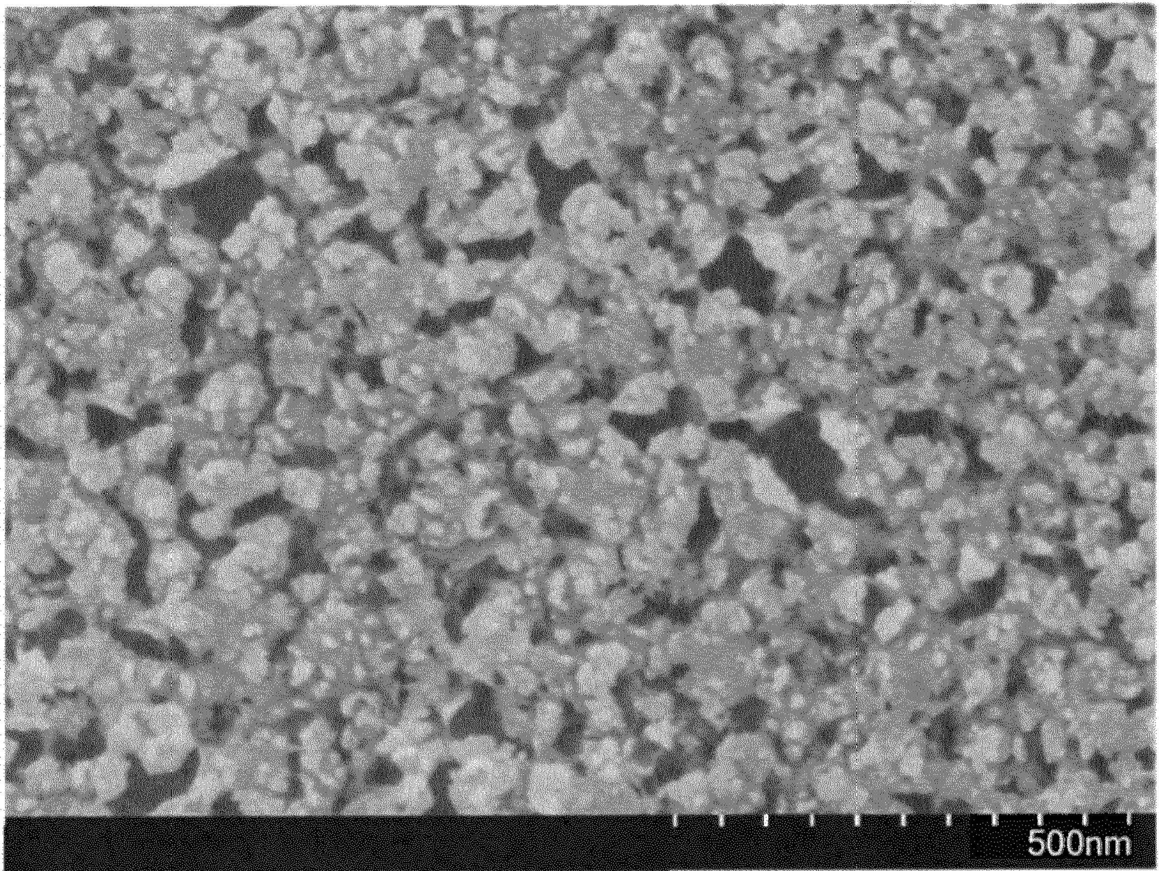
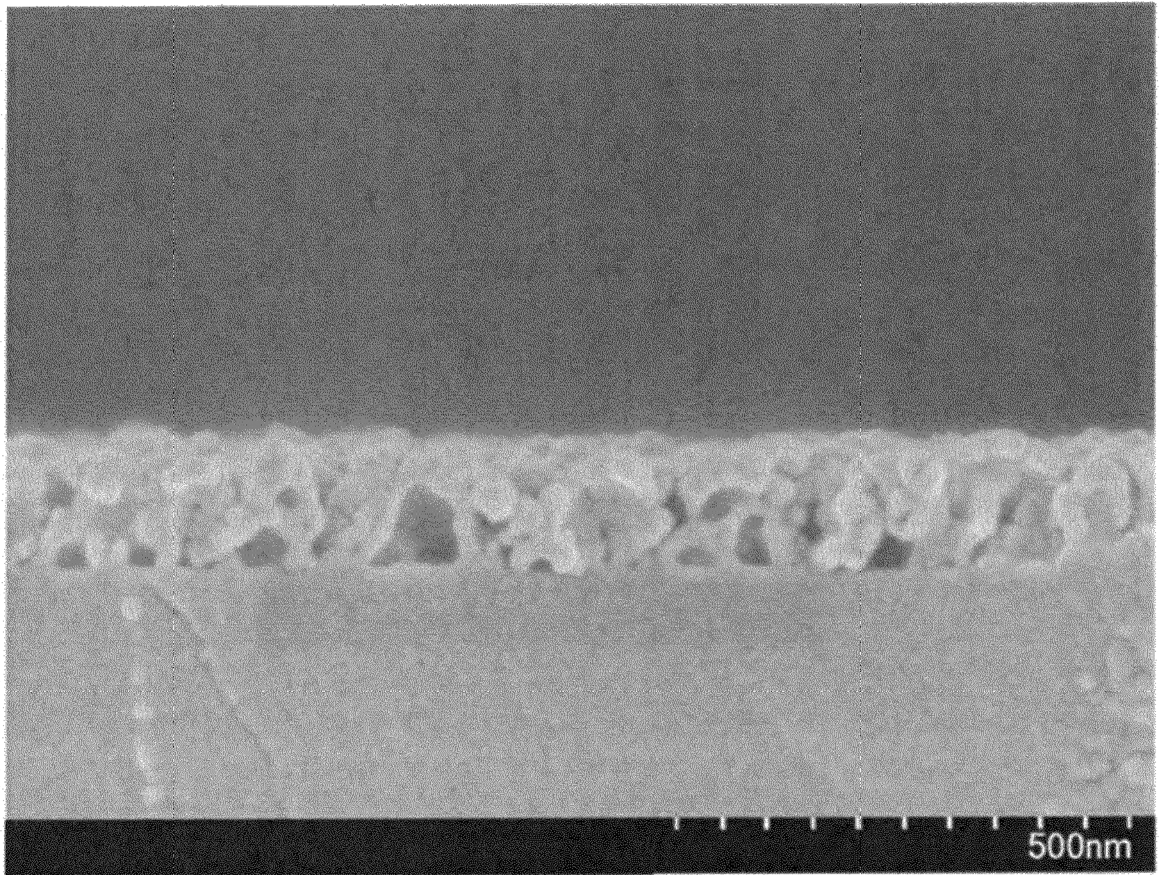


FIG. 2



REFERENCES CITED IN THE DESCRIPTION

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