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Brian Toth

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(54) [TITLE OF THE INVENTION] LIGHT-CONFINING STRUCTURE AND PHOTODETECTOR USING THE SAME

(57) [ABSTRACT]
[PURPOSE] To provide a light-confining structure which reduces surface reflection and enables efficient light confinement.
[CONSTITUTION] A transition layer 2 having recesses and protrusions is provided on the front surface of a substrate 3, and the repeating width 7 of the recesses and protrusions is made to be not greater than the wavelength of main light 4 to be confined. Recesses and protrusions 8 and 9 are preferably provided on the rear surface of the substrate 3. The refractive index of the transition layer 2 is varied so as to approach the refractive index of the substrate toward the substrate side from the opposite side as the substrate.

FIG. 7

2...TRANSITION LAYER
4...LIGHT
7...REPEATING WIDTH
8, 9...RECESSES AND PROTRUSIONS

[SCOPE OF THE PATENT CLAIMS]

[CLAIM 1] A light-confining structure comprising a substrate and a transition layer having recesses and protrusions provided on the substrate front surface, wherein a repeating width of the recesses and protrusions is not greater than a wavelength of main light to be confined.

[CLAIM 2] The light-confining structure according to claim 1, wherein a refractive index of the transition layer varies so as to approach a refractive index of the substrate toward the substrate side from the opposite side as the substrate.

[CLAIM 3] The light-confining structure according to claim 1, wherein the transition layer comprises a first material portion having recesses and protrusions disposed on the substrate side and a second material portion having corresponding recesses and protrusions of the opposite orientation disposed on the opposite side as the substrate; and a refractive index of the first material is the same as the refractive index of the substrate or is closer to the refractive index of the substrate than the refractive index of the second material.

[CLAIM 4] The light-confining structure according to claim 3, wherein a shape of the recesses and protrusions is configured so that an area occupying a plane of the second material portion decreases toward the substrate direction from the surface of the transition layer.

[CLAIM 5] The light-confining structure according to claim 4, wherein a shape of the recesses and protrusions is configured so that a ratio at which the area occupying the plane the second material portion decreases toward the substrate direction from the surface of the transition layer is greater near the front surface than near the rear surface of the transition layer.

[CLAIM 6] The light-confining structure according to claim 1, wherein the recesses and protrusions have a substantially triangular cross-sectional shape.

[CLAIM 7] The light-confining structure according to any one of claims 1 to 6, wherein the main light to be confined is visible light, and the repeating width of the recesses and protrusions is not greater than 1 μm.

[CLAIM 8] The light-confining structure according to any one of claims 1 to 7, wherein the substrate has, on the rear surface thereof, second recesses and protrusions having a repeating width greater than the wavelength of the light to be confined.

[CLAIM 9] The light-confining structure according to any one of claims 1 to 8, wherein the substrate has a light-reflecting layer on the rear surface thereof.

[CLAIM 10] A photodetector using the light-confining structure according to any one of claims 1 to 7, wherein the substrate is of a first conductivity type, and the photodetector has an second conductivity type region provided on the substrate and an electrode connected thereto.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[INDUSTRIAL FIELD OF APPLICATION] The present invention relates to a light-confining structure to be used in a light-receiving device such as a light sensor or photovoltaic device or a light-to-light conversion device such as a photoexcitation laser, and a photodetector using the same.

[0002]

[CONVENTIONAL TECHNOLOGY] When irradiating a substrate with light and then using this to perform light-to-light conversion, light-to-electricity conversion, or the like, the efficiency of each type of conversion can be increased by effectively introducing light into the substrate and confining the light inside the substrate without allowing it to escape to the outside of the substrate. To do so, the reduction of the refractive index of light on the substrate surface and the confinement of light incident inside the substrate are crucial.

[0003] Conventionally, the reduction of the refractive index of incident light on the substrate surface has been achieved using an antireflection film or surface recesses and protrusions of a size of around a few tens of μm. In addition, as described in SID 89 DIGEST p270 (1989) or Japanese Patent Application No. H03-54371, an antireflection film having minute surface recesses and protrusions formed using fine SiO_2 and MgF_2 powders has been used.

[0004]

[PROBLEM TO BE SOLVED BY THE INVENTION] The conventional method using an antireflection film described above was problematic in that it was not possible to sufficiently reduce the refractive index when the wavelength of incident light varied over a wide range or the angle of incidence of light varied substantially. Moreover, the method using surface recesses and protrusions of a size of around a few tens of μm was problematic in that, since the optical path is bent substantially by refraction when light is incident on the substrate, it is difficult to perform light confinement using recesses and protrusions formed on the rear surface. Further, when an antireflection film having minute surface recesses and protrusions formed using a fine SiO_2 powder or the like was used, there was a problem in that it was difficult to make the refractive reflex very low because the refractive index of the substrate or the shape of the minute surface recesses and protrusions was not taken into consideration.

[0005] An object of the present invention is to provide a light-confining structure which reduces surface reflection and enables efficient light confinement, and a photodetector using the same.

[0006]

[MEANS FOR SOLVING THE PROBLEM] To achieve the object described above, the light-confining structure of the present invention comprises a substrate and a transition layer having recesses and protrusions provided on the substrate front surface, wherein the repeating width of the recesses and protrusions is not greater than the wavelength of main light to be confined.

[0007] The refractive index of the transition layer preferably varies so as to approach the refractive index of the substrate toward the substrate side from the opposite side as the substrate. When the refractive index varies continuously in the substrate direction from the exterior of the substrate, a refractive index that is much lower than that of an antireflection film consisting of a thin interference film formed from several layers can be achieved over a wide range of wavelengths.

[0008] In addition, it is preferable for the transition layer to comprise a first material portion having recesses and protrusions disposed on the substrate side and a second material portion having corresponding recesses and protrusions of the opposite orientation disposed on the opposite side as the substrate; and for the refractive index of the first material to be the same as the refractive index of the substrate or to be closer to the refractive index of the substrate than the refractive index of the second material. The first material portion may be formed using the substrate itself – for example, it may be a portion in which recesses and protrusions are formed on the surface of the substrate, or it may be a portion in which another material is affixed to the surface of the substrate. The second material portion may be air or may have a structure in which the spaces between the recesses and protrusions of the surface of the substrate are filled with another material.

[0009] The shape of the recesses and protrusions is preferably configured so that the area occupying the plane of the second material portion decreases toward the substrate direction from the surface of the transition layer. The repeating width of the recesses and protrusions is preferably not greater than 1 μm when the main light to be confined is visible light.

[0010] In addition, the light-confining structure of the present invention may be provided with, on the rear surface thereof, second recesses and protrusions having a repeating width greater than the wavelength of the light to be confined. Further, a light-reflecting layer may be provided on the rear surface of the substrate.

[0011] Further, the photodetector of the present invention uses the light-confining structure described above, wherein when the substrate is given a first conductivity type, a second conductivity type region of the opposite conductivity type as the first conductivity type is provided on the substrate, a first conductivity type region of an even higher concentration is preferable provided on the substrate, and an electrode for connecting the regions is provided.

[0012]

[EFFECT] The effect of the present invention will be described using FIGS. 1 to 6. FIGS. 1(a) and (b) are a partial perspective view of the vicinity of the front surface of a substrate and a cross-sectional view thereof. When light 4 is incident on a substrate 3 from an external medium 1 and a repeating width 7 of recesses and protrusions of the surface of the substrate is smaller than the wavelength of the light, there is an optical effect that is the same as the case in which the refractive index of a transition layer 2 varies continuously toward the substrate from the front surface. That is, as illustrated in the drawings, when the ratio of a second medium 5 to a first medium 6 varies gradually toward the substrate, a transition layer 2 is formed which is equivalent to a film in which the refractive index varies linearly from the refractive index of the second medium 5 to the refractive index of the first medium 6.

[0013] The state of change in the refractive index within the transition layer is determined by the manner in which first medium and the second medium are mixed. In a film consisting of two types of mediums, the effective refractive index thereof is expressed by the average value of the respective mediums. As illustrated in FIGS. 2(a), (b), (c), (d), (e), and (f), when the respective first medium 6 has a shape such as a rectangle, triangular groove, pyramid, semispherical shape, spherical shape, or inverted pyramid shape and the refractive index of the second medium 5 is set to 1.0 while the refractive index of the first medium 6 is set to 3.5, the effective refractive index is as illustrated in FIG. 3.

[0014] The calculated refractive index for a pyramid and spherical shape when the refractive index of the external medium 1 is set to 1.0, the refractive index of the second medium 5 is set to 1.0, the refractive index of the first medium 6 is set to 3.5, and the refractive index of the substrate 3 is set to 3.5 is illustrated in FIG. 4. FIGS. 4(a) and (b) illustrate the refractive index in the case of a pyramid shape, and FIGS. 4(c) and (d) illustrate the refractive index of a spherical shape in a linear scale and a logarithmic scale, respectively. In the case of a pyramid shape, a somewhat high refractive index is observed when the film thickness of the transition layer is 40 nm, but a very low refractive index is observed when the film thickness is greater than this. In the case of a spherical shape, the refractive index exceeds 10% on average at any film thickness, and a slightly higher refractive index is observed in comparison to a pyramid shape.

[0015] FIG. 5 illustrates the relationship between the amount of light absorption and the film thickness of the transition layer in the case of a pyramid shape. The illustrated results are calculated for a case in which the refractive index of the external medium 1 is set to 1.0, the refractive index of the first medium 6 is set to 3.5, the refractive index of the substrate 3 is set to 3.5, and the refractive index of the of the second medium 5 is set to 1.0 and 1.5. In each case, the amount of light absorption becomes large when the film thickness of the transition layer is around a few hundred nm, and there is approximately 100% absorption at film thicknesses greater than this.

[0016] FIG. 6 illustrates the relationship between the amount of light absorption and the film thickness of the transition layer in the case of each shape. The illustrated results are calculated for a case in which the refractive index of the external medium 1 is set to 1.0, the refractive index of the of the second medium 5 is set to 1.0, the refractive index of the first medium 6 is set to 3.5, and the refractive index of the of the substrate 3 is set to 3.5. The amount of light absorption at each film thickness is greatest with a pyramid shape, and a high amount of absorption is observed up to an inverted pyramid shape. However, with a rectangular and spherical shape, the amount of light absorption is not large, even when the film thickness of the transition layer is increased. This result demonstrates that the amount of light absorption is large when the shape of the first medium is such that it rises upward to the right in FIG. 3. In addition, the fact that a pyramid shape which rises upward to the right and has a falling convex curve in FIG. 3, in particular, demonstrates that a shape in which the ratio of decrease in area in the substrate direction of the second medium 5 near the front surface of the transition layer 2 is greater than the ratio of decrease near the rear surface of the transition layer 2 is preferable, as in the case of a pyramid shape, a polygonal pyramid shape, a cone, or a shape obtained by rotating a line segment downward.

[0017] The specific substrate shape will be described using FIG. 7. As illustrated in FIG. 7(a), a transition layer 2 consisting of recesses and protrusions with a small repeating width 7 is provided on a substrate. As a result, the refractive index of the transition layer 2 varies continuously from the refractive index of the outside air to the refractive index of the substrate 3 from top to bottom. This transition layer allows light 4 that is incident on the substrate 3 to reach the inside of the substrate without being substantially reflected by the substrate surface. In addition, since the repeating width 7 is smaller than the wavelength of the incident light, the incident light proceeds directly to the rear surface of the substrate at the angle of incidence without being reflected diagonally by the inclined surfaces formed by the recesses and protrusions of the front surface of the substrate.

[0018] By forming recesses and protrusions 8 having a repeating width that is larger than the wavelength of the incident light with a period such as that illustrated in FIG. 7(b) on the substrate, light that is reflected by the rear surface advances diagonally through the inside of the substrate and reaches the front surface of the substrate. When the angle of incidence at this time is greater than a critical angle, the light is completely reflected and proceeds back through the inside of the substrate. In this way, incident light is efficiently confined in the substrate 3. In addition, by forming irregular recesses and protrusions 9 having a repeating width that is larger than the wavelength of the incident light on the rear surface, as illustrated in FIG. 7(c), light is scattered and reflected by the rear surface, and most of the light has an angle of incidence that is greater than the critical angle when it reaches the front surface of the substrate, allowing the incident light to be efficiently confined in the substrate 3. In these configurations, forming a reflective mirror on the rear surface makes it possible to more reliably reflect light with the rear surface.

[0019]

[EXAMPLES] <Example 1> An example of the present invention will be described using FIG. 8. In this example, pyramids 11 which constitute a transition layer and have a regular width and size are formed on a silicon substrate 3 in which the surface is a (100) plane. The pyramids can be easily formed by masking the rear surface and processing only the front surface with an alkaline etching solution. In addition, minute pyramids 11 not larger than 1 μm can be easily formed by processing using as an etching solution a heated aqueous solution containing ammonia or hydrazine as a main component.

[0020] The average size of the pyramids 11 on the front surface of the silicon substrate 3 obtained in this way was around 0.3 μm according to measurements with an SEM (scanning electron microscope). When the surface reflectance of the silicon substrate was measured, the surface reflectance decreased dramatically in the wavelength range of 0.4 to 1.1 μm. When a film formed from a thin oxide film was provided on the front surface of the silicon substrate 3, the change in the refractive index inside the transition layer 2 became rapid, and the reflectance of the front surface dropped further.

[0021] <Example 2> Another example of the present invention will be described using FIG. 9. In this example, minute recesses and protrusions 11' of irregular size having cross sections that were primarily triangular were formed on a silicon substrate 3. The minute recesses and protrusions 11' were formed by a deposited film using CVD (chemical vapor deposition). The material of the film that was used was a material that is transparent and has a relatively high refractive index such as ITO or ZnO_2. The size of the minute recesses and protrusions 11' was set on average to around 0.5 μm by controlling the deposition speed, temperature, gas pressure, and the like. In addition, the spaces between the minute recesses and protrusions 11' were filled with a filling material (not illustrated) to protect the front surface. A material with a relatively small refractive index such as SiO_2 was formed on the filling material by means of spin coating, CVD, or the like. The reflectance of the front surface of this silicon substrate also decreased dramatically in the wavelength range of 0.4 to 1.1 μm.

[0022] <Example 3> Yet another example of the present invention will be described using FIG. 10. In this example, V-grooves 13 with a repeating width of 2 μm were formed on the rear surface of the silicon substrate 3 described in Example 2. As a result, light incident from the front surface is reflected by the rear surface and is completely reflected when it reaches the front surface again, allowing the light to be confined inside the silicon substrate. The V-grooves 13 were easily formed using an etching mask using an ordinary photoresist. In this case, a printing resist may also be used instead of a photoresist. In addition, the shape of the rear surface is not limited to V-grooves and may be a shape such as inverted pyramids or semispherical shapes as long as the size is such that the repeating width is greater than the wavelength of the incident light. A rear surface reflecting mirror 14 was also formed to increase the rear surface reflectance.

[0023] <Example 4> Yet another example will be described using FIG. 11. In this example, pyramidal recesses and protrusions 15 were formed on the rear surface of a silicon substrate 3. Transparent glass was used for the material of the recesses and protrusions 15, and the glass was adhered to the silicon substrate 3. As a result, a light-trapping structure was easily formed by processing the silicon substrate 3. In addition, as in Example 3, a rear surface reflecting mirror (not illustrated) was formed.

[0024] <Example 5> An example of a photodetector will be described using FIG. 12. As in Example 3, minute recesses and protrusions 11' of irregular size having cross sections that were primarily triangular were formed on a p-type silicon substrate 21, and V-grooves having a repeating width of 2 μm were formed on the rear surface (the rear surface reflecting mirror illustrated in Example 3 was not formed). Next, a high-concentration p-type layer 19 and a high-concentration n-type layer 20 were formed by thermal diffusion, and a passivation oxide film 18 was formed on the front and rear surfaces of the p-type silicon substrate 21 (the oxide film of the front surface is not illustrated). Holes were formed in the oxide film 18 at prescribed positions, and electrodes 16 and 17 were formed by vacuum deposition, resulting in the formation of a photodetector. This photodetector exhibited a photoelectric conversion efficiency that was improved over a conventional photodetector not provided with a transition layer consisting of minute recesses and protrusions 11'.

[0025] Note that photodetectors were similarly formed using p-type silicon substrates having transition layers with minute recesses and protrusions of shapes other than those described above – that is, a triangular groove shape, a spherical shape, a semispherical shape, an inverted pyramid shape, and a rectangular shape – and all of the photodetectors exhibited photoelectric conversion efficiency that was improved over a conventional photodetector.

[0026] Silicon was used as a substrate in the above examples, but it goes without saying that any material other than silicon may also be used, including single crystals such as gallium arsenide, indium phosphorus, CuInS, and CdS, polycrystals, amorphous monoatoms, semiconductors such as multicomponent systems, and insulating materials such as glass and plastic. In addition, the structures of the front surface recesses and protrusions and the rear surface recesses and protrusions may be combinations of any of the structures described above, and it goes without saying that the cross-sectional shapes of the recesses and protrusions may be the shapes described in FIG. 2 or any similar regular or irregular shapes.

[0027]

[EFFECT OF THE INVENTION] By using the structure of the present invention, it is possible to effectively confine light when it is necessary to effectively confine light in a light-receiving device such as a light sensor or photovoltaic device or a light-to-light conversion device such as a photoexcitation laser. In addition, the photodetector of the present invention, which uses such a light-confining structure, exhibited improved photoelectric conversion efficiency.

[BRIEF DESCRIPTION OF THE DRAWINGS]

FIG. 1 is a conceptual diagram for explaining the principle of the present invention.

FIG. 2 is a conceptual diagram for explaining the principle of the present invention.

FIG. 3 illustrates an example of calculation results for explaining the effect of the present invention.

FIG. 4 illustrates an example of calculation results for explaining the effect of the present invention.

FIG. 5 illustrates an example of calculation results for explaining the effect of the present invention.

FIG. 6 illustrates an example of calculation results for explaining the effect of the present invention.

FIG. 7 is a conceptual diagram for explaining the principle of the present invention.

FIG. 8 is a cross-sectional schematic view of an example of the light-confining structure of the present invention.

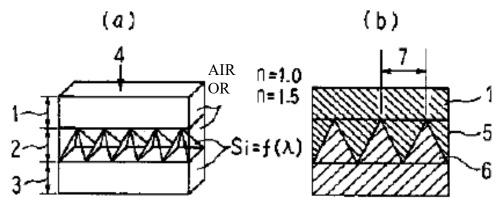
FIG. 9 is a cross-sectional schematic view and a perspective view of another example of the light-confining structure of the present invention.
FIG. 10 is a perspective view of an example of the light-confining structure of the present invention.
FIG. 11 is a perspective view of an example of the light-confining structure of the present invention.
FIG. 12 is a perspective view of an example of the photodetector of the present invention.

[EXPLANATION OF SYMBOLS]

1...External medium
2...Transition layer
3...Substrate
4...Light
5...Second medium
6...First medium
7...Repeating width
8, 9, 15...Recessions and protrusions
11...Pyramid
11'...Minute recessions and protrusions
13...V-groove
14...Rear surface reflecting mirror
16, 17...Electrodes
18...Oxide film
19...High-concentration p-type layer
20...High-concentration n-type layer
21...p-type silicon substrate

[FIG. 1]

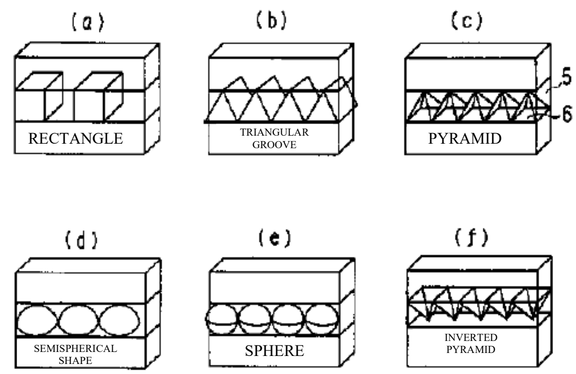
FIG. 1



1...EXTERNAL MEDIUM
2...TRANSITION LAYER
3...SUBSTRATE
4...LIGHT
5...SECOND MEDIUM
6...FIRST MEDIUM

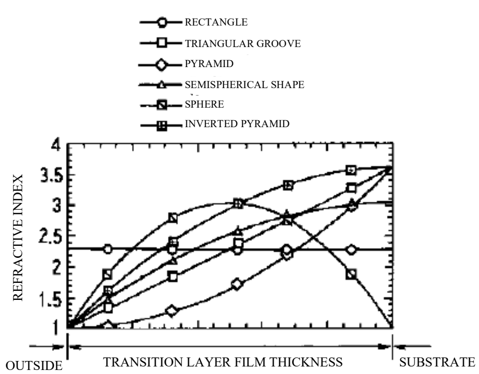
[FIG. 2]

FIG. 2



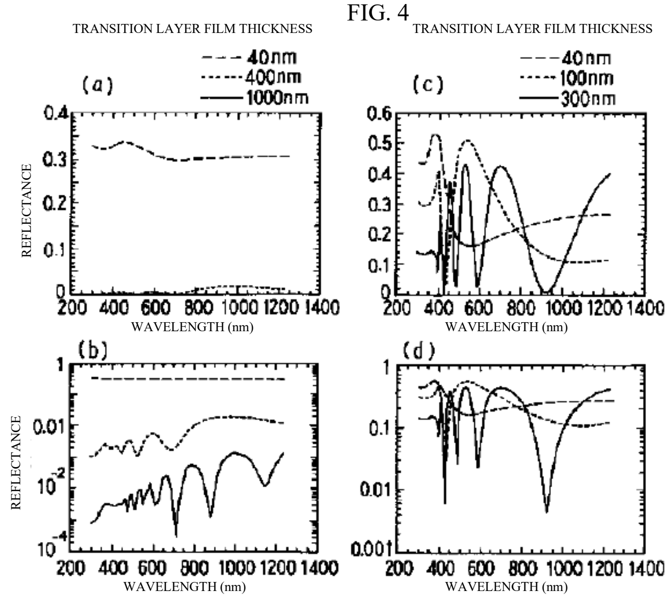
[FIG. 3]

FIG. 3



[FIG. 4]

FIG. 4



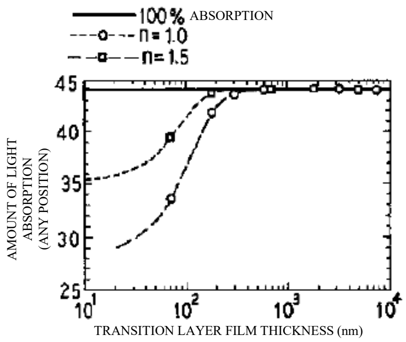
[FIG. 8]

FIG. 8

3...SUBSTRATE
11...PYRAMID

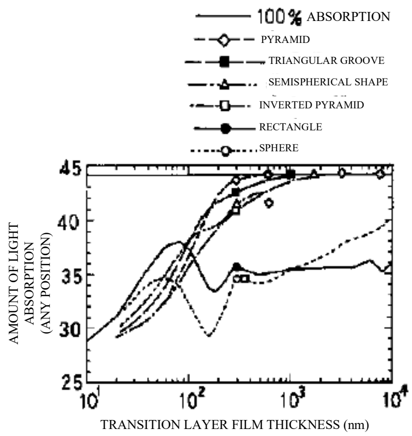
[FIG. 5]

FIG. 5



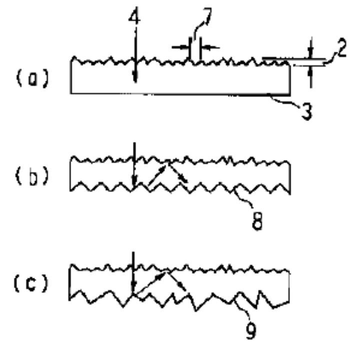
[FIG. 6]

FIG. 6



[FIG. 7]

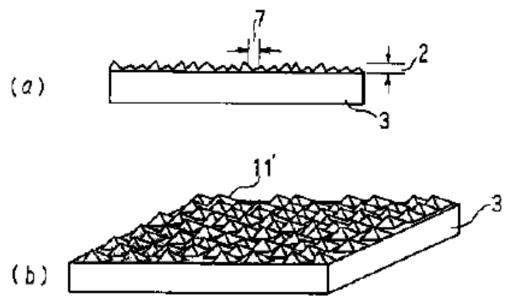
FIG. 7



2...TRANSITION LAYER
4...LIGHT
7...REPEATING WIDTH
8, 9...RECESSIONS AND PROTRUSIONS

[FIG. 9]

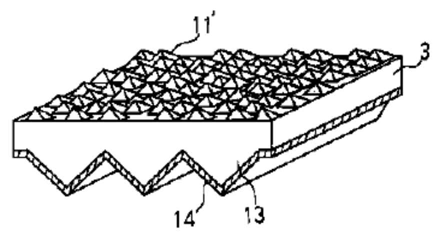
FIG. 9



11'...MINUTE RECESSIONS AND PROTRUSIONS

[FIG. 10]

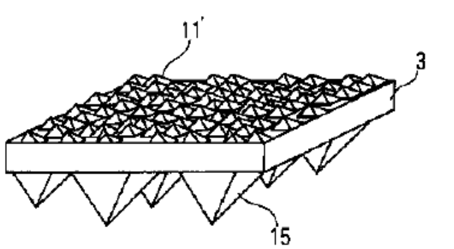
FIG. 10



11'...MINUTE RECESSIONS AND PROTRUSIONS
13...V-GROOVE
14...REAR SURFACE REFLECTING MIRROR

[FIG. 11]

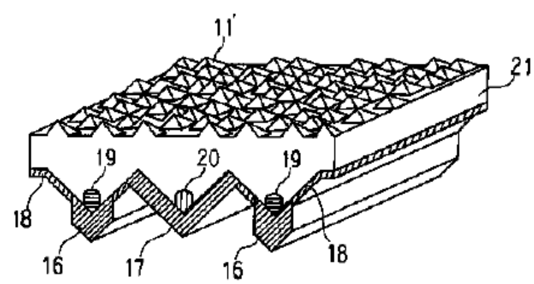
FIG. 11



11'...MINUTE RECESSIONS AND PROTRUSIONS
15...RECESSIONS AND PROTRUSIONS

[FIG. 12]

FIG. 12



11'...MINUTE RECESSIONS AND PROTRUSIONS
16, 17...ELECTRODES
18...OXIDE LAYER
19...HIGH-CONCENTRATION p-TYPE LAYER
20...HIGH-CONCENTRATION n-TYPE LAYER
21...p-TYPE SILICON SUBSTRATE

Continued from the front page

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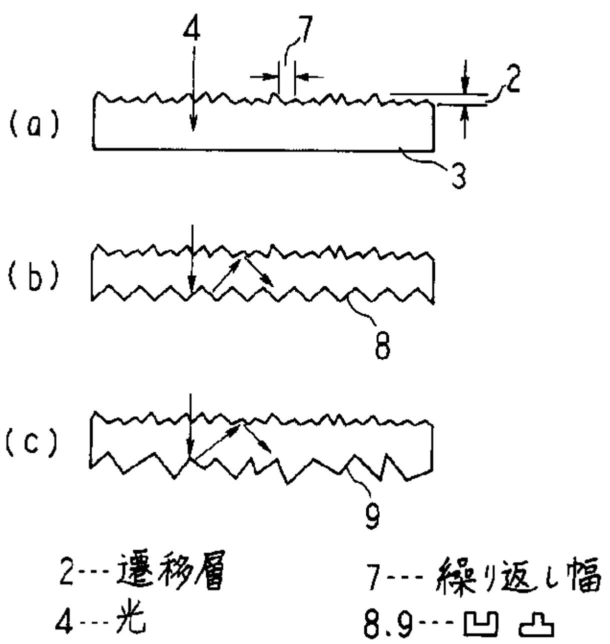
最終頁に続く

(54)【発明の名称】　光閉込め構造及びそれを用いた受光素子

(57)【要約】
【目的】表面反射を低減し、光閉じ込めを有効に行なうことができる光閉込め構造を提供すること。
【構成】基板３の表面に、凹凸を有する遷移層２を設け、この凹凸の繰り返し幅７を光閉じ込めを行なう主な光４の波長以下とする。基板３の裏面に凹凸８、９を設けることが好ましい。遷移層２の屈折率は、基板側と逆の側から基板側に向かって、基板の屈折率に近づくように変化させる。

図７



【特許請求の範囲】
【請求項１】基板及び該基板表面に設けられた、凹凸を有する遷移層からなり、該凹凸の繰り返し幅は、光閉じ込めを行なう主な光の波長以下であることを特徴とする光閉込め構造。
【請求項２】請求項１記載の光閉込め構造において、上記遷移層の屈折率は、基板側と逆の側から基板側に向かって、基板の屈折率に近づくように変化することを特徴とする光閉込め構造。
【請求項３】請求項１記載の光閉込め構造において、上記遷移層は、基板側に配置された凹凸を有する第１の材質の部分と、これに対応する逆向きの凹凸を有し、基板と逆の側に配置された第２の材質の部分とよりなり、該第１の材質の屈折率は、基板の屈折率と同じか又は該第２の材質の屈折率よりも基板の屈折率に近いことを特徴とする光閉込め構造。
【請求項４】請求項３記載の光閉込め構造において、上記凹凸の形状を、上記第２の材質の部分の平面上に占める面積が上記遷移層の表面から基板の方向に向かって減少するように構成することを特徴とする光閉込め構造。
【請求項５】請求項４記載の光閉込め構造において、上記凹凸の形状を、上記第２の材質の部分の平面上に占める面積の上記遷移層の表面から基板の方向に向かって減少する割合が遷移層の裏面付近より表面付近で大きいように構成することを特徴とする光閉込め構造。
【請求項６】請求項１記載の光閉込め構造において、上記凹凸は、その断面形状が実質的に三角であることを特徴とする光閉込め構造。
【請求項７】請求項１から６のいずれか一に記載の光閉込め構造において、上記光閉じ込めを行なう主な光は、可視光であり、上記凹凸の繰り返し幅は、１μm以下であることを特徴とする光閉込め構造。
【請求項８】請求項１から７のいずれか一に記載の光閉込め構造において、上記基板は、その裏面に光閉じ込めを行なう主な光の波長より大きな繰返し幅を持つ第２の凹凸を有することを特徴とする光閉込め構造。
【請求項９】請求項１から８のいずれか一に記載の光閉込め構造において、上記基板は、その裏面に光反射層を有することを特徴とする光閉込め構造。
【請求項１０】請求項１から７のいずれか一に記載の光閉込め構造を用いた受光素子であって、上記基板は第１導電型であり、上記基板に設けられた第２導電型領域及びこれと接続する電極を有することを特徴とする受光素子。

【発明の詳細な説明】
【０００１】
【産業上の利用分野】本発明は、光センサー、光電変換装置等の受光装置や光励起レーザー等の光－光変換装置等に用いる光閉込め構造及びそれを用いた受光素子に関する。
【０００２】
【従来の技術】光を基板に入射し、これを用いて光－光変換、光－電気変換等を行なう場合、基板内に光を効果的に取り込み、この光を基板外に逃すことなく、基板内に閉じ込めることにより、上記の各変換の効率を高くすることができる。これを行なうためには、基板表面での光の反射率の低減及び基板内に入射した光の閉じ込めが重要である。
【０００３】従来、基板表面での入射光の反射率の低減は、反射防止膜や数十μmの大きさの表面凹凸等を用いて行なわれていた。また、エス　アイ　ディー　８９　ダイジェスト　２７０頁（１９８９）（ＳＩＤ　８９　ＤＩＧＥＳＴ　ｐ２７０（１９８９））や特願平３－５４３７１に述べられているように、微細なSiO_2、MgF_2粒を用いた表面微細凹凸による反射防止膜を用いることが行なわれていた。
【０００４】
【発明が解決しようとする課題】上記従来の反射防止膜を用いる方法は、入射光の波長が広範囲に及んだり、光の入射角が大きく変化する場合には充分に反射率を下げることが出来ないという問題があった。また、数十μmの大きさの表面凹凸を用いる方法は、光が基板に入射したときに屈折で光路が大きく曲げられるため、裏面に形成された凹凸を用て光閉じ込めを行なうことは難しいという問題があった。また、微細なSiO_2粒等を用いた表面微細凹凸による反射防止膜を用いた場合は、基板の屈折率や表面微細凹凸形状について考慮していないため、反射率を非常に低くすることは困難であるという問題があった。
【０００５】本発明の目的は、表面反射を低減し、光閉じ込めを有効に行なうことができる光閉込め構造及びそれを用いた受光素子を提供することにある。
【０００６】
【課題を解決するための手段】上記目的を達成するために、本発明の光閉込め構造は、基板及び基板表面に設けられた、凹凸を有する遷移層からなり、この凹凸の繰り返し幅を光閉じ込めを行なう主な光の波長以下とするように構成する。
【０００７】この遷移層の屈折率は、基板側と逆の側から基板側に向かって、基板の屈折率に近づくように変化することが好ましい。このように屈折率が基板外部から、基板方向に連続的に変化することにより、数層で形成された干渉薄膜による反射防止膜に比べはるかに低い反射率を、波長の広い範囲に渡って得ることが出来る。
【０００８】また、この遷移層は、基板側に配置された凹凸を有する第１の材質の部分と、これに対応する逆向きの凹凸を有し、基板と逆の側に配置された第２の材質の部分とより構成し、第１の材質の屈折率を基板の屈折率と同じか又は第２の材質の屈折率よりも基板の屈折率に近くすることが好ましい。第１の材質の部分は、基板

そのものを用いて形成されたもの、例えば、基板表面に凹凸を形成したものでもよく、基板表面に他の材質のものを付けたものでもよい。第２の材質の部分は、空気であってもよく、他の材質のもので基板表面の凹凸の間を埋めた構造であってもよい。

【０００９】この凹凸の形状は、第２の材質の部分の平面上に占める面積が遷移層の表面から基板の方向に向かって減少するように構成することが好ましい。凹凸の繰り返し幅は、光閉じ込めを行なう主な光が可視光であるとき、１μm以下とすることが好ましい。

【００１０】また、本発明の光閉込め構造は、基板の裏面に光閉じ込めを行なう主な光の波長より大きな繰返し幅を持つ第２の凹凸を設けることが出来る。さらに、基板の裏面に光反射層を設けることが出来る。

【００１１】さらに本発明の受光素子は、上記の光閉込め構造を用い、基板を第１導電型とするとき、第１導電型と逆の導電型の第２導電型領域を基板に設け、望ましくはさらに高濃度の第１導電型領域を基板に設け、これらと接続する電極を設けて構成される。

【００１２】

【作用】図１～６を用いて本発明の作用を説明する。図１（ａ）、（ｂ）は、基板表面近傍の部分斜視図及びその断面図である。基板３に外部媒質１から光４が入射する場合、基板表面の凹凸の繰り返し幅７が光の波長より小さいと、光学的には、遷移層２の屈折率が表面から基板に向って連続的に変化した場合と同様に作用する。つまり、図のように第２の媒質５と第１の媒質６の割合が基板に向って次第に変化する場合に、第２の媒質５の持つ屈折率から第１の媒質６の持つ屈折率に、屈折率が直線的に変化する膜と等価な遷移層２が形成される。

【００１３】屈折率の遷移層内での変化の様子は、第１の媒質と第２の媒質の混ざり方で決定される。２種類の媒質で構成される膜ではその実効的な屈折率は各々の媒質の平均値で表される。図２（ａ）、（ｂ）、（ｃ）、（ｄ）、（ｅ）、（ｆ）に示すように、それぞれ第１の媒質６が、矩形、三角溝、ピラミッド、半球、球、逆ピラミッド等の形状を持つ場合には、第２の媒質５の屈折率を１．０、第１の媒質６の屈折率を３．５とすると、図３に示す様な実効的な屈折率を持つことになる。

【００１４】また、ピラミッドと球の形状について外部媒質１の屈折率１．０、第２の媒質５の屈折率を１．０、第１の媒質６の屈折率を３．５、基板３の屈折率を３．５とした場合の反射率の計算値を図４に示す。図４（ａ）、（ｂ）はピラミッド形状のときの反射率を、図４（ｃ）、（ｄ）は球形状のときの反射率をそれぞれリニアースケールとログスケールで示したものである。ピラミッド形状では遷移層膜厚が４０ｎｍではやや高い反射率を示すが、これより厚い膜厚では非常に低い反射率を示している。球形では、いずれの膜厚においても平均で１０％を越える反射率になっており、ピラミッド形状に比べると若干高い反射率を示している。

【００１５】図５に、ピラミッド形状での吸収光量と遷移層膜厚との関係を示す。外部媒質１の屈折率１．０、第１の媒質６の屈折率を３．５、基板３の屈折率を３．５とし第２の媒質５の屈折率が１．０、１．５の場合について計算した結果を示す。いずれの場合も、遷移層の膜厚が数百ｎｍ前後で吸収光量が大きくなりこれより厚い膜厚ではほぼ１００％吸収する。

【００１６】図６に、各形状での吸収光量と遷移膜厚との関係を示す。外部媒質１の屈折率１．０、第２の媒質５の屈折率を１．０、第１の媒質６の屈折率を３．５、基板３の屈折率を３．５とした場合について計算した結果を示す。各膜厚での光吸収量はピラミッド形状で一番高く、逆ピラミッドまではそれぞれ高い吸収量を示している。しかし、矩形と球形では遷移層膜厚を厚くしてもあまり光吸収量は大きくならない。この結果は、第１の媒質の形状が、図３で右上がりである様な形状をしているものが光吸収量が大きい事を示している。また、特に図３で右上がりで下に凸の曲線を持つピラミッド形状がよい結果を示す事から、本遷移層の第１の媒質６の形状はピラミッド形状、多角錐、円錐や下に凸の線分を回転して得られる形状の様に、遷移層２表面付近での第２の媒質５の基板方向への面積の減少の割合が遷移層２裏面付近でのその減少の割合より大きい形状が好ましいことが分かった。

【００１７】具体的な基板形状を、図７を用いて説明する。図７（ａ）に示すように、基板上に繰り返し幅７が小さい凹凸から成る遷移層２を設ける。これにより、遷移層２の屈折率は上から下に向って外気の屈折率から基板３の屈折率まで連続的に変化する。この遷移層により基板３に入射する光４は、基板表面でほとんど反射することなく基板内へ入射する。また、繰り返し幅７が入射光の波長より小さいため、入射した光は基板表面の凹凸により形成される斜面で斜めに反射されることなく入射した角度で基板裏面まで直進する。

【００１８】この基板に、図７（ｂ）のような周期的で、入射光の波長より大きい繰り返し幅を持つ凹凸８を形成することにより、裏面で反射された光が斜めに基板内を進み、基板表面へ達する。このときの入射角度が臨界角より大きい場合、光は全反射されて再び基板内を進む。このようにして、一度入射した光は基板３に効率よく閉じ込められる。また、図７（ｃ）のように裏面に入射光の波長より大きい繰り返し幅を持つ不規則な凹凸９を形成することにより、裏面で光が散乱反射され、大部分の光が基板表面に達したときに臨界角より大きい入射角を持つため、基板内へ再び反射されて、入射した光が基板３に効率よく閉じ込められる。これらの構成では、裏面に反射鏡を形成することで、より確実に裏面で光を反射することができる。

【００１９】

【実施例】〈実施例１〉図８を用いて本発明の一実施例を説明する。本実施例では、表面が（１００）面シリコン基板３の上に、遷移層を構成する、規則的な幅、大きさのピラミッド１１を形成した。このピラミッドは、裏面をマスクして、表面だけをアルカリ性のエッチング液で加工することにより容易に形成することができる。また、アンモニヤやヒドラジンを主成分とする加熱した水溶液をエッチング液として用いて、加工を行なうことにより１μm以下の微小なピラミッド１１を容易に形成することが出来る。

【００２０】このようにして得られたシリコン基板３の表面のピラミッド１１の平均のサイズは、ＳＥＭ（走査型電子顕微鏡）による測定では約０．３μmであった。このシリコン基板の表面反射率を測定したところ、０．４～１．１μmの波長範囲で表面反射率が著しく低下した。また、シリコン基板３表面に薄い酸化膜による皮膜を設けたところ、遷移層２内の屈折率の変化が急峻になり、さらに表面反射率が低下した。

【００２１】〈実施例２〉図９を用いて本発明の他の実施例を説明する。本実施例ではシリコン基板３の上に断面が主に三角形をした、不規則な大きさの微小凹凸１１’を形成した。微小凹凸１１’はＣＶＤ（化学気相成長）法を用いた堆積膜により形成した。膜の材質は、ＩＴＯ、ZnO_2等の透明で比較的屈折率の高い材料を用いた。微小凹凸１１’のサイズは堆積速度や温度、ガス圧等により平均で約０．５μmにすることが出来た。また、表面保護を兼ねて充填材（図示せず）で微小凹凸１１’の間を埋めた。この充填材にはSiO_2等の屈折率の比較的小さい材料をスピン塗布法やＣＶＤ法等で形成した。このシリコン基板の表面反射率も０．４～１．１μmの波長範囲で著しく低下した。

【００２２】〈実施例３〉図１０を用いて本発明のさらに他の実施例を説明する。本実施例では、実施例２で述べたシリコン基板３の裏面に繰り返し幅が２μmのＶ溝１３を形成した。これにより、表面から入射した光は、裏面で反射され、再び表面に達すると全反射され、シリコン基板内に閉じ込められる。Ｖ溝１３は通常のホトレジストを用いたエッチングマスクを用いて容易に形成することが出来た。この場合、ホトレジストでなく印刷レジストでもよい。また、裏面形状はＶ溝のみならず逆ピラミッドや半円等の形状でもよく、その繰り返し幅が入射光の波長より大きいサイズであればよい。また、裏面での反射率を高めるために裏面反射鏡１４を形成した。

【００２３】〈実施例４〉図１１を用いて本発明のさらに他の実施例を説明する。本実施例では、シリコン基板３の裏面にピラミッド状の凹凸１５を形成した。この凹凸１５の材質には透明なガラスを用い、シリコン基板３に接着した。これにより、シリコン基板３を加工することなく容易に光トラップ構造を形成する事が出来た。また、実施例３と同じように、裏面反射鏡（図示せず）を形成した。

【００２４】〈実施例５〉図１２を用いて本発明の受光素子の一実施例を説明する。実施例３と同様に、ｐ型シリコン基板２１の上に、断面が主に三角形をした、不規則な大きさの微小凹凸１１’を、裏面に繰り返し幅が２μmのＶ溝を形成した（実施例３に示した裏面反射鏡は形成しない）。次に、高濃度ｐ型層１９、高濃度ｎ型層２０を熱拡散法で形成し、ｐ型シリコン基板２１の表面及び裏面にパッシベーシヨン酸化膜１８（表面の酸化膜は図示せず）を設け、所定の位置の酸化膜１８に穴開けして、電極１６、１７を真空蒸着法により形成し、受光素子を形成した。この受光素子は、微小凹凸１１’からなる遷移層を設けない従来の受光素子よりも光電変換効率が向上した。

【００２５】なお、上記以外の形状の微小凹凸、すなわち、三角溝、球、半球、逆ピラミッド、矩形を有する遷移層を持つｐ型シリコン基板を用いて、同様に受光素子を形成したが、いずれも従来の受光素子よりも光電変換効率が向上した。

【００２６】以上の実施例で基板としてシリコンを用いたが、シリコンの他に、ガリウムヒソ、インジュウムリン、ＣｕＩｎＳ、ＣｄＳ等の単結晶、多結晶、非晶質の単原子、多元系等の半導体や、ガラス、プラスチック等の絶縁性のもの等、どのような材質のものであってもよいことは言うまでもない。また、表面凹凸、裏面凹凸の構造は上記で説明した構造のいずれかの組み合わせであってもよく、凹凸の断面形状も、図２で説明した形状や、それに類似した規則的、不規則ないかなる形状であってもよいことは言うまでもない。

【００２７】

【発明の効果】本発明の構造を用いることにより、光センサー、受電変換装置等の受光装置や光励起レーザー等の光－光変換装置等において光を有効に閉じ込める必要がある場合に、有効に光閉じ込めを行なうことが出来た。また、このような光閉込め構造を用いた本発明の受光素子は、光電変換効率を向上させることが出来た。

【図面の簡単な説明】

【図１】本発明の原理を説明する概念図。

【図２】本発明の原理を説明する概念図。

【図３】本発明の効果を説明する計算結果の一例を示す図。

【図４】本発明の効果を説明する計算結果の一例を示す図。

【図５】本発明の効果を説明する計算結果の一例を示す図。

【図６】本発明の効果を説明する計算結果の一例を示す図。

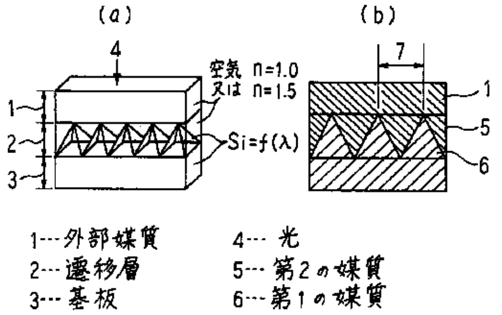
【図７】本発明の原理を説明する概念図。

【図８】本発明の光閉込め構造の一実施例の断面模式図。

【図９】本発明の光閉込め構造の他の実施例の断面模式図及び斜視図。
【図１０】本発明の光閉込め構造の一実施例の斜視図。
【図１１】本発明の光閉込め構造の一実施例の斜視図。
【図１２】本発明の受光素子の一実施例の斜視図。
【符号の説明】
１…外部媒質
２…遷移層
３…基板
４…光
５…第２の媒質
６…第１の媒質
７…繰り返し幅
８、９、１５…凹凸
１１…ピラミッド
１１’…微小凹凸
１３…Ｖ溝
１４…裏面反射鏡
１６、１７…電極
１８…酸化膜
１９…高濃度ｐ型層
２０…高濃度ｎ型層
２１…ｐ型シリコン基板

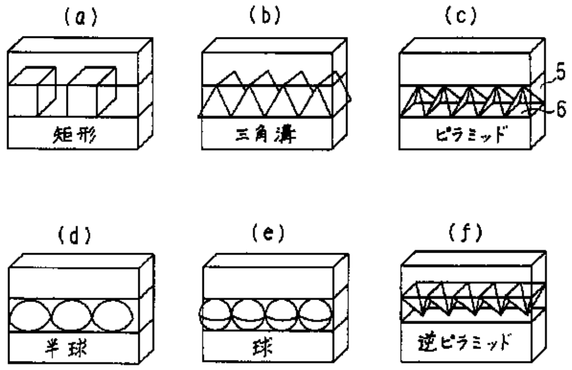
【図１】

図1



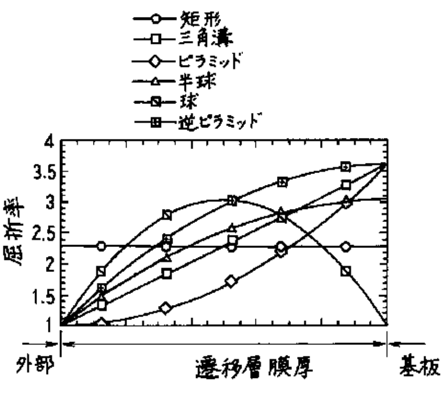
【図２】

図2



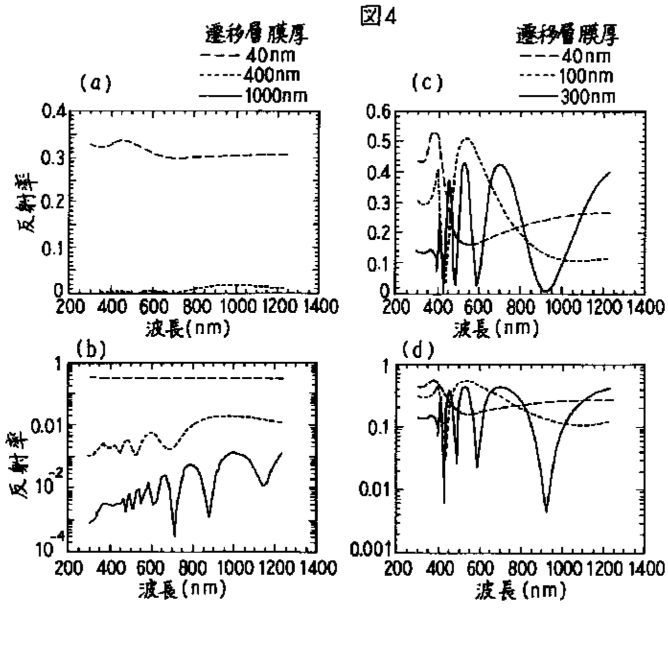
【図３】

図3



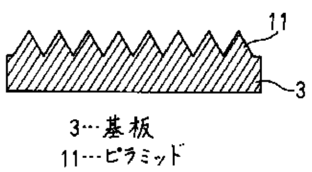
【図４】

図4



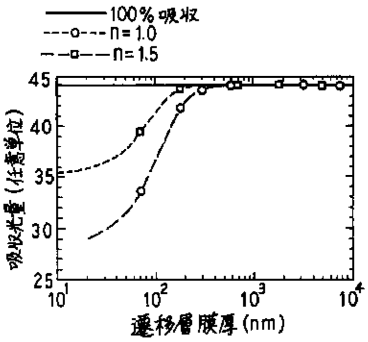
【図８】

図8



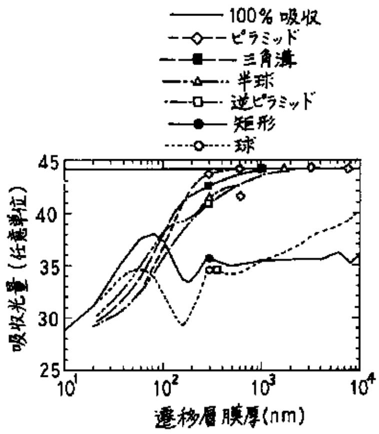
【図5】

図5



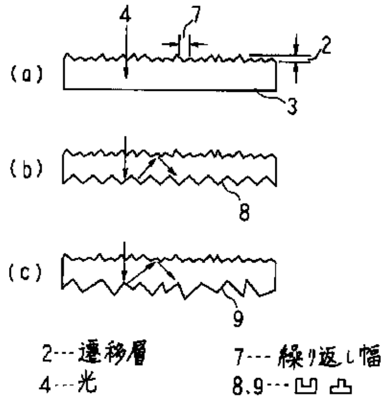
【図6】

図6



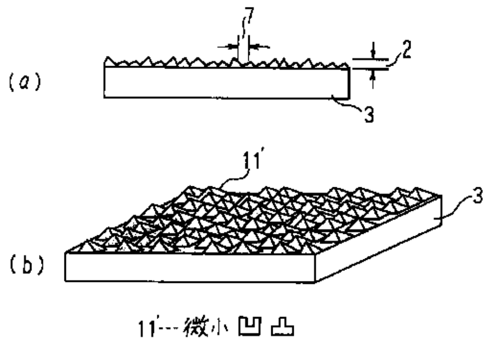
【図7】

図7



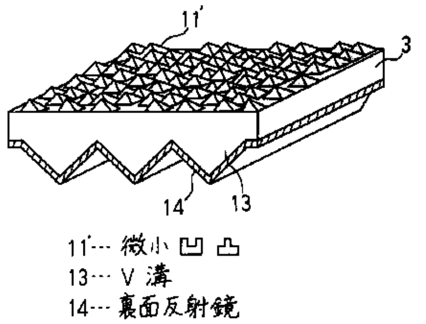
【図9】

図9



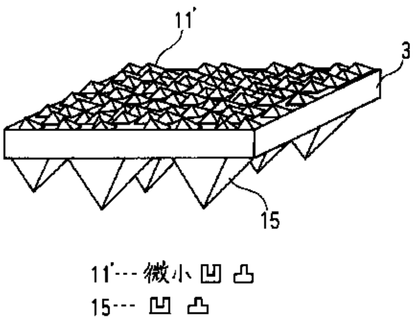
【図10】

図10



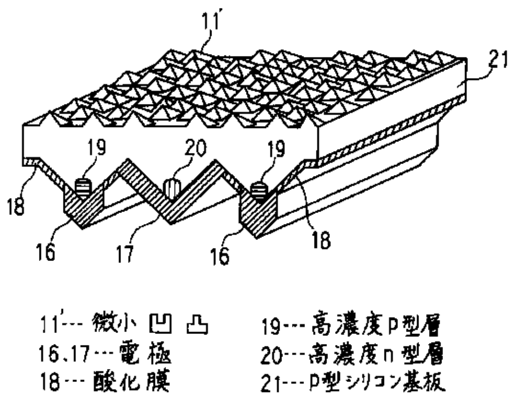
【図11】

図11



【図12】

図12



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