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(11) **EP 1 006 221 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
07.06.2000 Bulletin 2000/23

(51) Int. Cl.⁷: **D01F 8/04**, D01F 8/06,
D01F 8/12, D01F 8/14,
D03D 1/00

(21) Application number: **99124235.5**

(22) Date of filing: **03.12.1999**

(84) Designated Contracting States:
**AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU
MC NL PT SE**
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: **04.12.1998 JP 34534398**

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(54) **Optically functional minute structure and woven fabric with such structure**

(57) A minute structure has at least one of optical functions including a reflection/interference function to visible light ray, a reflection function to infrared ray and a reflection function to ultraviolet ray. The minute structure comprises a plurality of first and second polymer layers which are alternately put on one another in the direction of the thickness to constitute a layer unit, each first polymer layer having an optical refractive index "na" and a thickness "da", and each second polymer layer having an optical refractive index "nb" and a thickness "db".

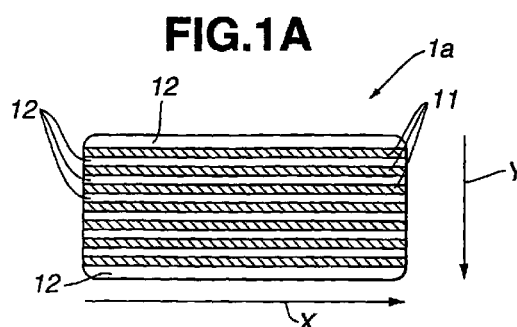
The minute structure is formed to satisfy the following condition:

under the conditions of " $1.3 \leq na$ " and " $1.01 \leq nb/na \leq 1.40$ ", the peak wavelength " λ_1 " of primary reflection satisfies the following formula:

$$\lambda_1 = 2 \times (na \cdot da + nb \cdot db), \text{ and}$$

the ratio " $nb \cdot db/na \cdot da$ " of the optical thickness " $nb \cdot db$ " of the second polymer layer to that " $na \cdot da$ " of the first polymer layer satisfies the following formula:

$$1/40 \leq nb \cdot db/na \cdot da \leq 40.$$



Description**BACKGROUND OF THE INVENTION****1. Field of the Invention**

[0001] The present invention relates to an optically functional minute structure which can show a color by reflection and interference of light rays, and more particularly to fibers and chips of the optically functional minute structure, which are usable as the material of woven fabrics and painting to provide them with an optical function.

2. Description of the Prior Art

[0002] Hitherto, for applying a color tone to various fibers, building materials and paintings and for reflecting ultra-violet and infrared rays, various attempts have been carried out, one being usage of inorganic and/or organic dyes and pigments, and the other being usage of light sparkling material, such as aluminum flake, mica flake and the like which are dispersed into paintings and/or fibers.

[0003] However, nowadays, with user's tendency to high quality, there are increasing demands for graceful and high quality impressive fabric products and painting which have, for example, colors varying with a change in the view angle. To satisfy such demands, some measures have been proposed, one being to provide a minute structure which shows a color by practically using light reflection, interference, diffraction and/or scattering without using dyes and pigments, and the other being to provide a minute structure which shows a deeper and brighter color by combining the above-mentioned optical action and the dyes and pigments.

[0004] These measures are described in for example, Japanese Patent Second Provisional Publication 43-14185, Japanese Patent First Provisional Publication 1-139803, Journal of the Textile Machinery Society of Japan (Vol. 42, No.2, p. 55, published in 1989 and Vol. 42, No.2, p. 160, published in 1989), Japanese Patent First Provisional Publication 59-228042, Japanese Patent Second Provisional Publication 60-24847, Japanese Patent Second Provisional Publication 63-64535, Japanese Patent First Provisional Publication 62-170510, Japanese Patent First Provisional Publication 63-120642, Japanese First Provisional Publication 6-017349, Japanese Patent First Provisional Publication 7-034324 and Japanese Patent First Provisional Publication 7-195603.

SUMMARY OF THE INVENTION

[0005] It is an object of the present invention to provide an optically functional minute structure which can satisfy the users.

[0006] It is another object of the present invention to provide an optically functional minute structure which has improved characteristics in reflection and interference to visible light ray and in reflection to infrared and ultraviolet rays.

[0007] It is still another object of the present invention to provide an optically functional minute structure which is provided by improving an optically functional minute structure as disclosed in the above-mentioned Japanese First Provisional Publication 7-034324.

[0008] It is a further object of the present invention to provide an optically functional minute structure which can be manufactured through a simple production method.

[0009] It is a still further object of the present invention to provide a woven fabric which uses such optically functional minute structures as fibers.

[0010] According to a first aspect of the present invention, there is provided a minute structure having at least one of optical functions including a reflection/interference function to visible light ray, a reflection function to infrared ray and a reflection function to ultraviolet ray. The minute structure comprises a plurality of first and second polymer layers which are alternately put on one another in the direction of the thickness to constitute a layer unit, each first polymer layer having an optical refractive index "na" and a thickness "da", and each second polymer layer having an optical refractive index "nb" and a thickness "db", wherein the minute structure is formed to satisfy the following condition: under the conditions of " $1.3 \leq na$ " and " $1.01 \leq nb/na \leq 1.40$ ", the peak wavelength " λ_1 " of primary reflection satisfies the following formula: $\lambda_1 = 2 \times (na \cdot da + nb \cdot db)$, and the ratio " $nb \cdot db/na \cdot da$ " of the optical thickness " $nb \cdot db$ " of the second polymer layer to that " $na \cdot da$ " of the first polymer layer satisfies the following formula: $1/40 \leq nb \cdot db/na \cdot da \leq 40$.

[0011] According to a second aspect of the present invention, there is provided a woven fabric which comprises a first group of yarns each including a plurality of fibers, each fiber including a plurality of first and second polymer layers which are alternately put on one another in the direction of the thickness to constitute a layer unit, each first polymer layer having an optical refractive index "na" and a thickness "da", and each second polymer layer having an optical refractive index "nb" and a thickness "db", wherein the minute structure is formed to satisfy the following condition:

under the conditions of " $1.3 \leq n_a$ " and " $1.01 \leq n_b/n_a \leq 1.40$ ", the peak wavelength " λ_1 " of primary reflection satisfies the following formula: $\lambda_1 = 2 \times (n_a \cdot d_a + n_b \cdot d_b)$, and the ratio " $n_b \cdot d_b/n_a \cdot d_a$ " of the optical thickness " $n_b \cdot d_b$ " of the second polymer layer to that " $n_a \cdot d_a$ " of the first polymer layer satisfies the following formula: $1/40 \leq n_b \cdot d_b/n_a \cdot d_a \leq 40$, and a second group of yarns each including a plurality of fibers, the first and second group of yarns being woven into the fabric.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Other objects and advantages of the present invention will become apparent from the following description when taken in conjunction with the accompanying drawings, in which:

Figs. 1A to 1D are sectional views of four examples of a first group according to the present invention, wherein a protecting layer is not provided;

Figs. 2A to 2E are sectional views of five examples of a second group according to the invention, wherein a protecting layer is provided;

Figs. 3A and 3B are sectional views of two examples of a third group according to the present invention, wherein much minutely structure is used;

Figs. 4A to 4M are graphs showing the reflection spectrum of a first type minute structure with the optical thickness ratio " n_{bdb}/n_{ada} " of 1, 5, 10, ..., 100 respectively (refractive index ratio " n_b/n_a ": 1.4);

Figs. 5A to 5H are graphs showing the reflection spectrum of a second type minute structure with the optical thickness ratio " n_{bdb}/n_{ada} " of 1, 5, 10, ..., 50 respectively (refractive index ratio " n_b/n_a ": 1.2);

Figs. 6A to 6F are graphs showing the reflection spectrum of a third type minute structure with the optical thickness ratio " n_{bdb}/n_{ada} " of 1, 5, 10, ..., 30 respectively (refractive index ratio " n_b/n_a ": 1.1);

Figs. 7A to 7D are graphs showing the reflection spectrum of a fourth type minute structure with the optical thickness ratio " n_{bdb}/n_{ada} " of 1, 5, 10 and 15 respectively (refractive index ratio " n_b/n_a ": 1.07);

Figs. 8A to 8C are graphs showing the reflection spectrum of a fifth type minute structure with the optical thickness ratio " n_{bdb}/n_{ada} " of 1, 5 and 10 respectively (refractive index ratio " n_b/n_a ": 1.03);

Figs. 9A and 9B are graphs showing the reflection spectrum of a sixth type minute structure with the optical thickness ratio " n_{bdb}/n_{ada} " of 1 and 5 respectively (refractive index ratio " n_b/n_a ": 1.01);

Fig. 10 is a graph showing the relation between the optical thickness ratio of the minute structure and the energy reflectance of the same in case where the peak wavelength (λ_1) of the primary reflection is $0.47 \mu\text{m}$;

Fig. 11 is a graph showing the relation between the optical thickness ratio of the minute structure and the thickness of a layer of the same in case where the refractive index ratio is 1.4;

Fig. 12 is a graph showing the relation between the optical thickness ratio of the minute structure and the energy reflectance of the same, with a protective layer having various thickness, in case where the peak wavelength (λ_1) of a primary reflection is $0.47 \mu\text{m}$;

Fig. 13 is a graph showing one example of the spectral reflectance spectrum of an interference coloring fiber;

Fig. 14 is a graph showing the spectral reflectance spectrum of a plain woven fabric made by combining an interference coloring fiber and a conventional colored fiber, with two variations in the color brightness of the colored fiber;

Fig. 15 is a graph showing the spectral reflectance spectrum of a fabric of an embodiment of the invention and that of a blue-colored fabric made of conventional fibers; and

Fig. 16 is a graph showing the spectral reflectance spectra of fabrics of other embodiments of the present invention.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0013] As will become apparent as the description proceeds, an optically functional minute structure of the present invention comprises a plurality of first and second organic polymer layers which are alternately put on one another in the direction of the thickness. The first layer has a thickness of " d_a " and an optical refractive index of " n_a " that is equal to or greater than 1.3 and the second layer has a thickness of " d_b " and an optical refractive index of " n_b " that is 1.01 to 1.40 times as much as the index " n_a " of the first layer. In the minute structure of the invention, the peak wavelength " λ_1 " of primary reflection is defined to a value that is twice as long as the sum of the optical thickness " $n_a \cdot d_a$ " (that is, $n_a \times d_a$) of the first layer and that " $n_b \cdot d_b$ " of the second layer, and the ratio of the optical thickness " $n_b \cdot d_b$ " of the second layer to that " $n_a \cdot d_a$ " of the first layer, that is, " $n_b \cdot d_b/n_a \cdot d_a$ " is defined to a value that ranges between 1/40 and 40, preferably between 1/15 and 15. With these definitions, the minute structure of the invention achieves a satisfied energy reflectance and shows improvement in reflection and interference characteristics to light ray, and improvement in reflecting characteristics to infrared and ultraviolet rays.

[0014] Referring to Figs. 1A to 3B, there are shown sectional views of various optically functional minute structures 1a to 3b according to the present invention.

[0015] The example 1a of Fig. 1A is an optically functional minute structure, viz., a plastic fiber, which comprises a plurality of first and second organic polymer layers 11 and 12 which are alternately put on one another in the direction of the thickness, that is, in the direction of "Y". The fiber of this example 1a has a generally rectangular cross section, as shown. The first layer 11 has a thickness of "da" and an optical refractive index of "na" that is equal to or greater than 1.3, and the second layer 12 has a thickness of "nb" and an optical refractive index of "nb" that is 1.01 to 1.40 times as much as the index "na" of the first layer 11.

[0016] The examples 1b and 1c of Figs. 1B and 1C are plastic fibers which have oval and circular cross sections respectively. The example 1d of Fig. 1D is a plastic fiber which has a circular cross section and comprises a plurality of first and second tubular polymer layers 11 and 12 which are alternately and concentrically put on one another, as shown.

[0017] Referring to Figs. 2A to 2E, there are shown examples 2a to 2e, viz., plastic fibers, each having a protecting plastic layer 13 applied to the outermost surface of the fiber. The examples 2a and 2b of Figs. 2A and 2B have a rectangular cross section, the examples 2c and 2d of Figs. 2C and 2D have oval and circular cross sections and the example 2e of Fig. 2E has a circular cross section and comprises a plurality of first and second tubular layers 11 and 12 alternatively and concentrically put on one another. Due to provision of the protecting plastic layer 13, undesired peeling of the stacked layers 11 and 12 is assuredly suppressed and abrasion resistance and mechanical strength of the fiber are increased. The protecting plastic layer 13 may be the first layer 11, the second layer 12 or a different plastic layer whose material is different from the materials of the first and second layers 11 and 12. Furthermore, if desired, the protecting layer 13 may be a layer produced by combining the materials of the first and second layers 11 and 12. Preferably, the second plastic layer 12 is used as the protecting layer 13, which has a higher value in the optical refractive index than the first plastic layer 11. Most preferably, for achieving much improved optical function, the protecting layer 13 should be one that has a higher value in the optical refractive index than the second plastic layer 12.

[0018] Referring to Figs. 3A and 3B, there are shown examples 3a and 3b, viz., plastic fibers, which are modifications of the above-mentioned example 1a of Fig. 1A. That is, the example 3a of Fig. 3A is a plastic fiber which comprises a plurality of first thin plastic layers 11 neatly arranged in both vertical "Y" and horizontal "X" directions, each first thin plastic layer 11 being embedded in an integral structure 12 of second plastic layers. In this example 3a, it is only necessary to have the first thin plastic layers 11 regularly arranged in the vertical direction "Y". Of course, in this example, the width "a" of each layer 11 should be longer than the wavelength of the reflected light ray. The example 3a of Fig. 3B is a plastic fiber which comprises a complicatedly shaped integral structure 11 of first thin plastic layers, the integral structure being embedded in an integral structure 12 of second plastic layers. In both the examples 3a and 3b of Figs. 3A and 3B, it is preferable to provide in the horizontal direction "X" so-called light reflecting and interfering areas as much as possible. Thus, these two examples should have a flat structure. Preferably, the flat ratio, viz., the ratio of the width (viz., length in the direction of "X") to the height (viz., length in the direction of "Y") is about 1.5 to 10. If the flat ratio exceeds 15, manufacturing of the plastic fiber becomes very difficult.

[0019] In the above-mentioned optically functional minute structures 1a to 3b of Figs. 1A to 3B, the number "N" of the alternatively stacked first and second layers 11 and 12 should be larger than 5. If the number "N" is less than 5, a satisfied light reflecting and interfering effect is not obtained even though the optical refractive index ratio "nb/na" between the first and second plastic layers 11 and 12 is within the desired range from 1.01 to 1.40. Preferably, the number "N" is from 10 to 150, for achieving the satisfied light reflecting and interfering effect. If the number "N" exceeds 150, a spinneret (not shown) for extruding a melt plastic material of the minute structure becomes very complicated in shape and construction, which causes a poor formation of the alternative arrangement of the two plastic layers 11 and 12.

[0020] It is to be noted that, as is seen from Fig. 1A, a so-called "vertical incidence" of light ray means a light incidence in the direction of "Y", that is, in the direction perpendicular to the horizontal surface of the minute structure.

[0021] The above-mentioned first, second and protecting plastic layers 11, 12 and 13 are constructed of various thermoplastic transparent resins. Of course, such resins should have a high transparency to visible light ray because the minute structure 1 is designed to show a color based on the reflecting and interfering effect when exposed to the visible light ray whose wavelength ranges from 0.38 μm to 0.78 μm . The usable resins are, for example, polyethylene terephthalate (PET), polybutylene terephthalate (PBT), polyethylene naphthalate (PEN), polyester, polyacrylonitrile, polystyrene (PS), polyamide such as nylon (Ny-6) and nylon-66 (Ny-66), polyvinyl alcohol, polycarbonate (PC), polymethylmethacrylate (PMMA), polyether etherketone (PEEK), polyparaphenylene terephthalic amide, polyphenylene sulfide (PPS) and the like. Of course, each layer 11, 12 or 13 can be produced by combining some of the above-mentioned materials, that is, from a copolymer of them.

[0022] The optically functional minute structure of the invention can be produced by means of various methods, which are, for example, vacuum deposition method, electron beam deposition method, ion plating method, molecular beam epitaxial growing method, casting method, spin coating method, plasma polymerization method, Langmuir-Blod-

gett's technique (LB) and the like. Furthermore, for production of fibers of the minute structure, various methods (viz., melting type, wet type and dry type) are usable.

[0023] In case of the vacuum deposition method, a vacuum evaporator equipped with a base plates, two depositing plates and shutters is prepared. Pellet powder for a first polymer and pellet powder for a second polymer are put on the respective depositing plates. The vacuum evaporator is then subjected to an air release to have a vacuum degree of about 10^{-5} Torr and the two depositing plates are heated to respective sublimation temperatures of the first and second polymers. During this, the shutters are alternatively opened and closed to form on the base plate a layered structure, viz., an optically functional minute structure of the present invention. Operation of the shutters is so controlled that the produced minute structure shows a satisfied value (for example, 1, 5) of the optical thickness ratio " $n_b \cdot d_b / n_a \cdot d_a$ ".

[0024] Furthermore, by using a melt spinning machine with a unique spinneret (for example, known static mixer), an elongated minute structure, that is, an optically functional fiber can be produced. In this method, pellets for a first polymer and pellets for a second polymer are heated to be melted and forced to pass through respective nozzles of the spinneret while being controlled in temperature, extrusion speed and fiber forming speed. Of course, the control is so made that the produced fiber shows a satisfied value (for example, 1, 5) of the optical thickness ratio " $n_b \cdot d_b / n_a \cdot d_a$ ".

[0025] As is described hereinabove, when light rays are directed perpendicular to the minute structure 1a of the invention (see Fig. 1A), the peak wavelength (λ_1) of primary reflection satisfies the following formula:

$$\lambda_1 = 2 \times (n_a \cdot d_a + n_b \cdot d_b) \quad (1)$$

[0026] Accordingly, if, due to selection of the optical thickness " $n_a \cdot d_a$ " of the first plastic layer 11 and that " $n_b \cdot d_b$ " of the second plastic layer 12, the peak wavelength " λ_1 " of the primary reflection shows $0.47 \mu\text{m}$ (viz., visible light area), blue color is shown by the produced minute structure 1. Furthermore, if the peak wavelength " λ_1 " shows $0.62 \mu\text{m}$ (viz., visible light area), red color is shown by the produced minute structure 1. When these minute structures are formed into fibers and woven into a fabric, the fabric can show a color issuing a unique feel of material. Of course, the color shown by the fabric based on the light reflecting and interfering effect is not deteriorated even when washed.

[0027] The infrared spectrum of sunlight ranges from $0.78 \mu\text{m}$ to about $5.0 \mu\text{m}$. Thus, if the peak wavelength " λ_1 " of the primary reflection is set in such range, the infrared ray in the sunlight directed to the minute structure 1 is subjected to a reflecting and interfering effect. This means that a fabric woven from such minute structure 1 (viz., fibers) can effectively shut out the infrared ray of the sunlight. Since the near infrared ray with a spectrum ranging from $0.78 \mu\text{m}$ to about $2.0 \mu\text{m}$ has a high energy, it is preferable to set the peak wavelength " λ_1 " within such range. In this case, the shut out effect against the infrared ray is much increased. If a person wearing such cloth (fabric) walks in a daylight particularly in summer, he or she can feel cool. Furthermore, if such cloth is used as a curtain in a room, temperature control of the room is easily carried out. In a hard work environment, such as a place where blast furnace, combustion furnace, boiler or the like is working, workers have to bear a very high temperature (from several hundreds degrees ($^{\circ}\text{C}$) to about one thousand degrees ($^{\circ}\text{C}$)). In this case, the heat rays from the heat source contain an infrared spectrum ranging from $1.6 \mu\text{m}$ to $20.0 \mu\text{m}$ in wavelength. Accordingly, if the workers wear clothes woven from the optically functional minute fibers which satisfy the peak wavelength " λ_1 " being within such range (viz., $1.6 \mu\text{m}$ to $20.0 \mu\text{m}$ in wavelength), they are assuredly protected from such high heating. That is, the clothes can effectively shut out the infrared ray of such range.

[0028] If the peak wavelength " λ_1 " is set in a ultraviolet area ranging from $0.004 \mu\text{m}$ to $0.40 \mu\text{m}$ in wavelength, articles and goods applied with the minute structures which satisfy such peak wavelength " λ_1 " can effectively shut out ultraviolet ray of such range.

[0029] If desired, several groups of minute structures 1 having different values of " λ_1 " may be put on one another to constitute a so-called multifunctional minute structure. That is, in this case, the multifunctional minute structure can show colors of red and blue and shut out the infrared and ultraviolet rays at the same time.

[0030] Furthermore, if desired, the optically functional minute fibers may be cut into chips for application to span type fabric, paper, painting, cosmetic such as nail polish liquid and the like.

[0031] Tables 1 to 3 show various articles and goods to which the optically functional minute structure of the present invention are practically applicable.

[0032] The present invention will be much clearly understood from the following description.

[0033] The reason why the optical refractive index " n_a " of the first plastic layer 11 is selected to a value equal to or greater than 1.3 is as follows. That is, in general, the optical refractive index of organic polymer is in an area from 1.3 to 1.82, and that of wide-use organic polymer is in an area from 1.35 to 1.75. That is, the value 1.3 indicates the lowermost value of such area. To lower the optical refractive index of organic polymer to the degree of 1.3, addition of fluorine to molecules of the polymer is known. Furthermore, by dispersing particulate of NaF and/or MgF_2 into the polymer, the optical refractive index can be lowered. However, in this case, the transparency and moldability of the polymer become sacrificed.

[0034] Organic polymers that indicate a lower optical refractive index being lower than 1.4 are fluorocarbon resins,

such as, tetrafluoroethylene (PTFE), tetrafluoroethylene • hexafluoropolypropylene (FRP) and the like. While, organic polymers that indicate a higher optical refractive index being higher than 1.6 are polyester resins, such as, polyvinylidene chloride (PVDC) and polyethylene naphthalate (PEN) and polyphenylene sulfide (PPS).

[0035] The reason why the ratio of the optical refractive index "nb" of the second plastic layer 12 to that "na" of the first plastic layer 11, that is, "nb/na" is determined to the range from 1.01 to 1.40 is as follows. First, if the ratio "nb/na" is smaller than 1.01, the energy reflectance differential " ΔR " defined by the energy reflection peak and the background becomes very small causing a failure in showing clear color. Second, if the ratio "nb/na" becomes smaller than 1.01, that is, close to 1.0, undesired phenomenon tends to occur. In fact, the optical refractive index possessed by each polymer is easily affected by surrounding temperature and wavelength of light ray applied to the polymer. This phenomenon is marked in the waveband of near infrared ray and its vicinity. That is, even when the number "N" of the alternatively stacked first and second layers 11 and 12 is much increased, a practical reflection and interference function is not obtained. For these reasons, the lower value of the optical refractive index ratio "nb/na" is determined to 1.01, preferably, to 1.03.

[0036] The reason why the optical refractive index ratio "nb/na" is determined to a value equal to or smaller than 1.4 is as follows. In general, the optical refractive index of organic polymers can be calculated from "Lorentz-Lorentz Equation". From this equation, it is revealed that organic polymers can have about 1.9 as the highest optical refractive index and about 1.35 as the lowest optical reflective index. Thus, the optical refractive index ratio "nb/na", that is, "1.9/1.35" becomes about 1.40 that shows the largest value of the allowable range. To increase the optical refractive index of organic polymer, addition of inorganic filler, pigment, oxides, such as, titanium oxide ($n=2.8$) and chromium oxide ($n=2.5$) and/or hydrosulfides such as cadmium sulfide to the polymer is known. However, in this case, the transparency and moldability of the polymer becomes sacrificed.

[0037] Referring back to the formula of (1), if it is intended to get a minute structure 1 that shows blue color, " λ_1 " is set to 0.47 μm and selection of two plastic layers 11 and 12 and selection of thickness of these layers 11 and 12 are made in a manner to satisfy the formula (1).

[0038] However, through various tests, the inventors have found that the formula (1) has an area that is not practical due to a remarkable change of the energy reflectance at the peak wavelength (λ_1) of the primary reflection. This will become understood from the following.

[0039] Figs. 4A to 4M, 5A to 5H, 6A to 6F, 7A to 7D, 8A to 8C, and 9A and 9B are graphs each showing a calculated energy reflectance with respect to the wavelength (μm) of a light ray directed to first, second, third, fourth, fifth or sixth type minute structure.

[0040] For calculation of the energy reflectance, the following conditions were set. That is, each minute structure had such a structure 2a as shown in Fig. 2A. In all of the types, the optical refractive index "na" of the first plastic layer 11 was 1.53, and that of the protecting plastic layer 13 was also 1.53. The thickness of the protecting layer 13 was 5 μm . The number "N" of the stacked layers of the minute structure was 61, and the peak wavelength " λ_1 " of primary reflection was set to 0.47 μm .

[0041] The graphs of Figs. 4A to 4M show the results of the first type minute structures whose refractive index ratio "nb/na" is all 1.4 but whose optical thickness ratio "nbdb/nada" varies from 1, 5, 10, 15, 20, 30, 40, 50, 60, 70, 80, 90 and 100 respectively.

[0042] As is seen from these graphs, with increase of the optical thickness ratio "nbdb/nada" between the two plastic layers 11 and 12, both the energy reflectance and energy reflectance intensity (that corresponds to the area defined by the spectrum) gradually lower, and as is seen from Figs. 4L and 4M, when the optical thickness ratio "nbdb/nada" comes to 90 or 100, the reflection peak at the peak wavelength " λ_1 " almost disappears. However, as is seen from Fig. 4G, when the ratio "nbdb/nada" is 40, the reflection peak at the wavelength " λ_1 " points about 0.4 that is sufficient for obtaining an effective optical function. That is, in the first type minute structures, in a range of the ratio "nbdb/nada" from 1 to 40, sufficient optical function is obtained.

[0043] The graphs of Figs. 5A to 5H show the results of the second type minute structures whose refractive index ratio "nb/na" is all 1.2 and whose optical thickness ratio "nbdb/nada" varies from 1, 5, 10, 15, 20, 30, 40 and 50 respectively.

[0044] As is seen from a comparison between the above-mentioned Fig. 4A and Fig. 5A, in the second type minute structures is somewhat poor in having a sufficient energy reflectance intensity. As is seen from Fig. 5E, when the ratio "nbdb/nada" is 20, the reflection peak at the wavelength " λ_1 " fails to point the value 0.4. That is, in the second type minute structures, in a range of the ratio "nbdb/nada" from 1 to 15, sufficient optical function is obtained.

[0045] The graphs of Figs. 6A to 6F show the results of the third type minute structures whose refractive index ratio "nb/na" is all 1.1 and whose optical thickness ratio "nbdb/nada" varies from 1, 5, 10, 15, 20 and 30 respectively.

[0046] As is seen Fig. 6C, when the ratio "nbdb/nada" comes to 10, the reflection peak at the wavelength " λ_1 " fails to point the value 0.4. That is, in the third type minute structures, in only the range of the ratio "nbdb/nada" from 1 to 5, sufficient optical function is obtained.

[0047] The graphs of Figs. 7A to 7D show the results of the fourth type minute structures whose refractive index

ratio "nb/na" is all 1.07 and whose optical thickness ratio "nbdb/nada" varies from 1, 5, 10 and 15 respectively.

[0048] As is easily understood from these graphs, in the fourth type minute structures, sufficient optical function is obtained only in the range of the ratio "nbdb/nada" from 1 to 5 like in case of the third type minute structures.

[0049] The graphs of Figs. 8A to 8C show the results of the fifth type minute structures whose refractive index ratio "nb/na" is all 1.03 and whose optical thickness ratio "nbdb/nada" varies from 1, 5 and 10 respectively.

[0050] As is seen from these graphs, in the fifth type minute structures, sufficient optical function is obtained only when the ratio "nbdb/nada" is 1.

[0051] The graphs of Figs. 9A and 9B show the results of the sixth type minute structures whose refractive index ratio "nb/na" is all 1.01 and whose optical thickness ratio "nbdb/nada" varies from 1 to 5 respectively.

[0052] As is seen from these graphs, the sixth type minute structures can not obtain sufficient optical function.

[0053] As is understood from the foregoing, with decrease of the refractive index ratio "nb/na" toward a value 1, the practicable range of the optical thickness ratio "nbdb/nada" becomes narrowed.

[0054] Fig. 10 is a graph showing the relation between the optical thickness ratio of the minute structure and the energy reflectance of the same, which is provided based on the results of the calculations of Figs. 4A to 9B. As is seen from this graph, the curves of the refractive index ratio "nb/na" have each a symmetrical shape with respect to a vertical line passing through the optical thickness ratio "nbdb/nada" of 1. This means that an equal energy reflectance is obtained when the ratio "nbdb/nada" shows 40 and 1/40.

[0055] That is, as shown in the graph, in case of the refractive index ratio "nb/na" being 1.4, the corresponding minute structure can obtain a sufficient energy reflectance of 0.4 even though the optical thickness ratio "nbdb/nada" (viz., 40 and 1/40) is largely different from the value of 1. However, in case of the refractive index ratio "nb/na" being 1.2, a sufficient energy reflectance of 0.4 is obtained only from a minute structure whose optical thickness ratio "nbdb/nada" is in the range from 1/15 to 15. When the refractive index ratio "nb/na" becomes much smaller to the value 1.07 or 1.03, it becomes necessary to bring the optical thickness ratio "nbdb/nada" much close to the value 1.

[0056] As has been mentioned hereinabove, in case of the refractive index ratio "nb/na" being 1.40 (that is, the largest value of the ratio in the condition wherein " $1.3 \leq n_a$ " and " $1.01 \leq n_b/n_a \leq 1.40$ " are established, the minute structure can obtain a sufficient or practical energy reflectance of 0.4 (viz., " $R = 0.4$ "). However, when considering the relation between the optical thickness ratio "nbdb/nada" and the thickness of the layer in the case wherein the refractive index ratio "nb/na" is 1.4, the graph of Fig. 11 shows that the thickness of the first plastic layer (viz., the polymer having a lower refractive index) reduces exponentially with increase of the optical thickness ratio "nbdb/nada", and that when the optical thickness ratio "nbdb/nada" is 40, the thickness of the first plastic layer is 0.004 μm . As is known in the art, formation of such thin layer is quite difficult. Furthermore, it has been revealed that when the thickness of the polymer layer is reduced to the level of 0.004 μm , a practical reflection and interference effect is not obtained. This may be because of poor formation of the surface defined in the polymer layer.

[0057] For the reasons as mentioned hereinabove, the thickness of the first plastic layer should be at least 0.004 μm . Thus, in both the first and second polymer layers, the formula " $1/40 \leq \text{nbdb/nada} \leq 40$ " is needed.

[0058] When the refractive index ratio "nb/na" is 1.4 and the optical thickness ratio "nbdb/nada" is 15 or 1/15, the graph of Fig. 4D shows about 0.9 of the energy reflectance. In this case, as is seen from the graph of Fig. 11, the thickness of the first polymer layer (viz., the polymer having a lower refractive index) is greater than 0.01 μm . The thickness of this level is easily controllable by known melt spinning methods. It has been revealed that the thickness of such level provides the polymer layer with a practical reflection and interference effect.

[0059] For the reasons as mentioned hereinabove, in both the first and second polymer layers, usage of the formula " $1/15 \leq \text{nbdb/nada} \leq 15$ " is preferable.

[0060] It has been further revealed that the polymer fiber 2a of Fig. 2A can exhibit excellent wear and abrasion resistance and excellent energy reflectance. The polymer fiber 2a comprises the alternately put first and second polymer layers 11 and 12 and the protecting layer 13 which covers the unit of the layers 11 and 12.

[0061] This will be understood from the graph of Fig. 12 which shows the relation between the optical thickness ratio "nbdb/nada" and the energy reflectance in case wherein, in the polymer fiber 2a of Fig. 2A, the thickness of the protecting layer 13 varies under a condition wherein the peak wavelength (λ_1) of the primary reflection is 0.47 μm , the refractive index ratio "nb/na" is 1.07 and the number "N" of the stacked layers is 61. As is seen from this graph, when the optical thickness ratio "nbdb/nada" is near 1, the thickness of the protecting layer 13 does substantially no affect on the difference of the energy reflectance. However, when the optical thickness ratio "nbdb/nada" is greater than 1, the thickness of the protecting layer 13 does affect the difference. As is seen, when the thickness of the protecting layer 13 is in the range from 0.5 μm to 20 μm , satisfied energy reflectance is obtained. Preferably, the thickness of the projecting layer 13 is in the range from 3 μm to 30 μm .

[0062] The optically functional minute structure 1 of the present invention is applicable to woven fabrics as a fiber structure. In this case, the woven fabrics exhibit at least one of optical functions, such as the reflection and interference function of visible light ray, the reflection function of infrared ray or the reflection function of ultraviolet ray.

[0063] In the following, some examples of the woven fabrics will be described with reference to the drawings. The

fiber structures possessing such optical functions will be referred to as "interference coloring fiber".

[0064] Fig. 13 is a graph showing the reflectance spectrum of an interference coloring fiber of 8 denier, whose first and second polymer layers are respectively made of polyester and polyamide and whose protecting layer is made of polyester. The number "N" of the stacked layers is 61. As is seen from this graph, in case of this interference coloring fiber, there is a waveband whose reflectance largely exceeds 100% and thus the color shown by the fiber is viewed brightly. This over 100% phenomenon is unique as compared with a case of conventional colored fiber that has no waveband whose reflectance exceeds 100%.

[0065] The interference coloring fiber has colors varying with a change in the view angle, and shows colors due to the interference of light ray. Thus, the colors shown by the interference coloring fiber are clear and allow the viewers to recognize the colors as a so-called view point less fluorescent colors.

[0066] In an interference coloring fiber which comprises an outermost layer that has a reflection and interference function and an inner layer that absorbs light ray whose wavelength is other than a predetermined reflection and interference wavelength, the coloring provided by the reflection and interference wavelength becomes much clear. That is, by combining the interference coloring fiber with natural fiber (wool, hemp, cotton, silk, etc.), regenerated fiber or synthetic fiber, there are produced various woven fabrics with different color feel and different visibility.

[0067] Fig. 14 is a graph showing the reflectance spectrum of two plain woven fabrics each being made by combining an interference coloring fiber and a conventional colored fiber, one fabric having a colored fiber whose luminosity is 3 in Munsell color standard and the other fabric having a colored fiber whose luminosity is 8.7 in Munsell color standard. As will be seen from this graph, when the colored fiber has the luminosity lower than 8.7, the associated woven fabric can provide a viewer with a clear color recognition. It has been revealed that with lowering of the luminosity around the interference coloring fiber, the color feeling becomes much clear.

[0068] In woven fabrics produced by combining an interference coloring fiber with another interference coloring fiber or a white colored conventional fiber, a so-called random lighting tends to occur in the woven fabric caused by a stay of light with a given wavelength, which allows the viewers to recognize the colors as the view point less fluorescent colors.

[0069] The minute structure 1 according to the present invention has the above-mentioned excellent optical functions as well as excellent wear and abrasion resistance. In fact, the fiber structure 1 can be practically applied to blouses, shirts, suits, one-piece dresses, sports clothing, under wears, hats, curtains, laces and automotive covers, and chips provided by cutting the fiber structure 1 into small pieces can be applied to painting, building materials, and cosmetics.

[0070] In the following, embodiments of the present invention will be described in detail with reference to the drawings and table.

EMBODIMENTS 1 AND 2:

[0071] Two optically functional minute structures 2a of the type shown in Fig. 2A were produced. For this production, the following steps were carried out. As the first polymer layers 11, polymethylmethacrylate (PMMA, $n_a = 1.49$) was chosen, and as the second polymer layers 12, polyethylene terephthalate copolymerized with 12.5 mole-% of neopentylglycol (Copolymerized PET, $n_b = 1.58$) was chosen. Thus, the refractive index ratio " n_b/n_a " was 1.06. Usage of the polyethylene terephthalate (PET) copolymerized with neopentylglycol as the second polymer layer 12 was intended to improve the compatibility with the polymethylmethacrylate (PMMA) of the first polymer layer 11, that is, to put the compatibility (viz., surface energy) of the copolymerized polyethylene terephthalate layer 12 and that of the polymethylmethacrylate layer 11 close to each other.

[0072] For obtaining blue color (viz., the reflection peak wavelength " λ_1 " = 0.47 μm), two minute structures, viz., first and second interference coloring fibers were designed, each having the number "N" being 61. The first fiber was designed to have the optical thickness ratio " n_{bdb}/n_{ada} " being 1, and the second fiber was designed to have the optical thickness ratio " n_{bdb}/n_{ada} " being 5. Each of the first and second fibers was designed to be covered with a protecting layer 13 of copolymerized polyethylene terephthalate.

[0073] For producing the first and second fibers, a melt spinning machine with a given spinneret ($N = 61$) was used and the spinning was carried out under the conditions of 285 °C of the spinneret and 1000m/min. of the spinning speed. With this, two types of non-elongated fibers were produced. These fibers were then applied to a roller type drawer to be elongated by three times. With this, two elongated fibers having the thickness of about 100 denier/11 filament were produced, which are first and second embodiments of the present invention.

[0074] By using an electron microscope, sections of the two elongated fibers (viz., first and second embodiments) were observed and the thickness of the copolymerized polyethylene terephthalate layer 12 and that of the polymethylmethacrylate layer 11 were measured in each fiber (or embodiment). In addition, the filaments of these fibers were put around a black paper and put into a microspectrophotometer (U-6000 manufactured by HITACHI Co., Ltd.) for evaluating the reflectance spectrum of them at an incident angle of 0° and a receiving angle of 0°. The relative reflectance was

measured based on a value possessed by a standard white board. The feel of color of these elongated fibers was evaluated by visual observation.

[0075] The results of the evaluations are shown in TABLE-4. As is seen from this table, in case of the first fiber (viz., first embodiment) wherein the optical thickness ratio "nbdb/nada" was 1, the relative reflectance showed a value much greater than 200% and the fiber showed a transparently fresh purplish blue, and in case of the second fiber (viz., second embodiment) wherein the optical thickness ratio "nbdb/nada" was 5, the relative reflectance showed a value about 100% and the fiber showed a purplish blue.

EMBODIMENTS 3 AND 4:

[0076] Two optically functional minute structures 2a of the type shown in Fig. 2A were produced. For this production, the following steps were carried out. As the first polymer layers 11, polymethylmethacrylate (PMMA, $n_a = 1.49$) manufactured by Mitsubishi Rayon Co., Ltd. was chosen, and as the second polymer layers 12, polycarbonate (PC, $n_b = 1.59$) manufactured by Teijin Kasei Co., Ltd. was chosen. Thus, the refractive index ratio "nb/na" was 1.07.

[0077] For obtaining blue color (viz., " λ_1 " = 0.47 μm), two minute structures, that is, third and fourth interference coloring fibers were designed, each having the number "N" being 61. The third fiber was designed to have the optical thickness ratio "nbdb/nada" being 1, and the fourth fiber was designed to have the optical thickness ratio "nbdb/nada" being 5. Each of the third and fourth fibers was designed to be covered with a protecting layer 13 of copolymerized polyethylene terephthalate.

[0078] For producing the third and fourth fibers, the melt spinning machine ($N = 61$) was used and the spinning was carried out under the conditions of 290 °C of the spinneret and 1000m/min. of the spinning speed. With this, two types of non-elongated fibers were produced. These fibers were then applied to the roller type drawer to be elongated by three times. With this, two elongated fibers having the thickness of about 100 denier/11 filament were produced, which are third and fourth embodiments of the invention.

[0079] These third and fourth embodiments were applied to the above-mentioned evaluation tests. The results of the evaluations are shown in TABLE-4. As is seen from this table, in case of the third fiber (viz., third embodiment) wherein the optical thickness ratio "nbdb/nada" was 1, the relative reflectance showed a value much greater than 200% and the fiber showed a transparently fresh purplish blue, and in case of the fourth fiber (viz., fourth embodiment) wherein the optical thickness ratio "nbdb/nada" was 5, the relative reflectance showed a value about 100% and the fiber showed a purplish blue.

EMBODIMENT 5:

[0080] An optically functional minute structure 2a of the type shown in Fig. 2A was produced. For this production, the following steps were carried out. As the first polymer layers 11, nylon-6 (Ny-6, $n_a = 1.53$) was chosen, and as the second polymer layer 12, copolymerized polyethylene terephthalate (Copolymerized PET, $n_b = 1.58$) was chosen. Thus, the refractive index ratio "nb/na" was 1.03. Usage of the copolymerized PET as the material of the second polymer layers 12 was intended to improve the compatibility with the Nylon-6 of the first polymer layers 11.

[0081] The copolymerized polyethylene terephthalate was prepared by taking the following steps.

[0082] A plurality of samples were prepared. Each of them was produced as follows.

[0083] 1.0 mole-dimethyl terephthalate, 2.5 mole-ethylene glycol, a given amount of 5-sulfoisophthalic acid sodium, 0.0008 mole-calcium acetate and 0.0002 mole-manganese acetate (both being transesterification catalyst) were mixed in a reaction vessel and stirred while being gradually heated from 150°C to 230°C for achieving a transesterification. After moving a given amount of methanol from the mixture, 0.0012 mole-antimony trioxide (polymerization catalyst) was added to the mixture, and then heating and decompression were gradually carried out while removing produced ethylene glycol from the mixture, and finally, the temperature of the vessel reached to 285°C and the degree of vacuum of the same reached to a value smaller than 1 Torr. By keeping this final condition, the velocity of the mixture was increased. When the velocity came to a certain degree, the viscous mixture in the vessel was drawn into water to get a pellet of copolymerized polyethylene terephthalate. The highest viscosity (viz., limit viscosity) of the copolymerized polyethylene terephthalate then produced was from 0.47 to 0.64.

[0084] By employing the above-mentioned production method, many samples of copolymerized polyethylene terephthalate were produced. Among them, the polyethylene terephthalate with 0.6% copolymerization was selected as a material of the second polymer layer 12. Nylon-6 used as the material of the first polymer layer 11 was one that showed 1.3 as the limit viscosity.

[0085] For obtaining blue color (viz., " λ_1 " = 0.47 μm), one minute structure, that is, a fifth interference coloring fiber was designed, which has the number "N" being 61. The fifth fiber was designed to have the optical thickness ratio "nbdb/nada" being 1. The fifth fiber was designed to be covered with a protecting layer 13 of copolymerized polyethylene terephthalate.

[0086] For producing the fifth fiber, the melt spinning machine (N = 61) was used and the spinning was carried out under the conditions of 290°C of the spinneret and 1000m/min. of the spinning speed. With this, a non-elongated fiber was produced and then the fiber was applied to the roller type drawer to be elongated by three times. With this, an elongated fiber having the thickness of about 100 denier/11 filament was produced, which is a fifth embodiment of the invention.

[0087] The fifth embodiment was applied to the above-mentioned evaluation tests. The results of these tests are shown in TABLE-4. As is seen from this table, in this fifth embodiment, the relative reflectance showed a value about 100% and the fiber showed a purplish blue.

EMBODIMENTS 6 AND 7:

[0088] Two optically functional minute structures 2a of the type shown in Fig. 2A were produced. As the first polymer layers 11, Nylon-6 (Ny-6, $n_a = 1.53$) was chosen, and as the second polymer layers 12, polyethylene terephthalate copolymerized with 1.5 mole-% sulfoisophthalic acid sodium (Copolymerized PET, $n_b = 1.63$) was chosen. Thus, the refractive index ratio " n_b/n_a " was 1.07. Usage of the copolymerized polyethylene terephthalate as the material of the second polymer layers 12 was intended to improve the compatibility with the Nylon-6 of the first polymer layers 11.

[0089] For obtaining blue color (viz., " λ_1 " = 0.47 μ m), two minute structures, that is, sixth and seventh interference coloring fibers were designed, each having the number "N" being 61. The sixth fiber was designed to have the optical thickness ratio " n_{bdb}/n_{ada} " being 1, and the seventh fiber was designed to have the optical thickness ratio " n_{bdb}/n_{ada} " being 5. Each of the sixth and seventh fibers was designed to be covered with a protecting layer 13 of copolymerized polyethylene terephthalate.

[0090] For producing the sixth and seventh fibers, the melt spinning machine (N = 61) was used and the spinning was carried out under the conditions of 287°C of the spinneret and 1000m/min. of the spinning speed. With this, two types of non-elongated fibers were produced. These fibers were then applied to the roller type drawer to be elongated by three times. With this, two elongated fibers having the thickness of about 100 denier/11 filament were produced, which are sixth and seventh embodiments of the invention.

[0091] These sixth and seventh embodiments were applied to the above-mentioned evaluation tests. The results are shown in TABLE-4. As is seen from this table, in case of the sixth fiber (viz., sixth embodiment) wherein the optical thickness ratio " n_{bdb}/n_{ada} " was 1, the relative reflectance showed a value much greater than 200% and the fiber showed a transparently fresh purplish blue, and in case of the seventh fiber (viz., seventh embodiment) wherein the optical thickness ratio " n_{bdb}/n_{ada} " was 5, the relative reflectance showed a value larger than 100% and the fiber showed a purplish blue.

EMBODIMENTS 8 to 11:

[0092] Four optically functional minute structures 2c of the type shown in Fig. 2C were produced. For this production, the following steps were carried out. As the first polymer layers 11, polymethylmethacrylate (PMMA, $n_a = 1.49$) was chosen, and as the second polymer layers 12, polyparaphenylene sulfide (PPS, $n_b = 1.80$) was chosen. Thus, the refractive index ratio " n_b/n_a " was 1.20.

[0093] For obtaining blue color (viz., " λ_1 " = 0.47 μ m), four minute structures, that is, eighth, ninth, tenth and eleventh interference coloring fibers were designed, each having the number "N" being 61. These fibers were designed to have the optical thickness ratio being 1, 5, 10 and 15 respectively. Each of these fibers was designed to be covered with a protecting layer 13 of polyphenylene sulfide (PPS).

[0094] For producing these fibers, the melt spinning machine (N = 61) was used and the spinning was carried out under the conditions of 350°C of the spinneret and 1000m/min. of the spinning speed. With this, four types of non-elongated fibers were produced, and these fibers were applied to the roller type drawer to be elongated by three times. With this, four elongated fibers having the thickness of about 100 denier/11 filament were produced, which are eighth, ninth, tenth and eleventh embodiments of the present invention.

[0095] These embodiments were applied to the above-mentioned evaluation tests. The results are shown in TABLE-4. As is seen from this table, in case of the eighth and ninth embodiments wherein the optical thickness ratio " n_{bdb}/n_{ada} " was 1 and 5, the relative reflectance showed a value much greater than 200% and the fibers showed a transparently fresh greenish blue. In case of the tenth and eleventh embodiments wherein the optical thickness ratio " n_{bdb}/n_{ada} " was 10 and 15, the relative reflectance showed a value greater than 100% and the fibers showed a fresh greenish blue.

EMBODIMENT 12:

[0096] A plain satin fabric was produced. For this production, wefts and warps were prepared. For the warps, black-

ish colored fibers, whose thickness is 66 to 132 denier and whose luminosity is 1 to 3 in Munsell color standard, were used. For producing the wefts, the following steps were carried out. That is, a plurality of interference coloring fibers were produced, each using as the first polymer layers 11 polyamide resin, as the second polymer layers 12 polyester resin and as the protecting layer 13 polyester resin. Each fiber was designed to have the reflection peak wavelength λ_1 being 0.47 μm , the refractive index ratio "nb/na" being 1.07 and the optical thickness ratio "nbdb/nada" being 1. For production of each weft, 11 (eleven) fibers were bound, each having the thickness of 6 to 12 denier. With this, each weft had the thickness of 66 to 132 denier. By weaving the wefts and warps together to produce the plain satin fabric.

[0097] The plain satin fabric thus produced, which is the twelfth embodiment of the invention, was applied to the spectral reflectance test under the condition of an incident angle of 0° and a receiving angle of 0° . For comparison, a conventional blue colored plain satin fabric made of thin fibers of polyester (hue: 2.5PB to 3.5PB, luminosity: 5 to 6, colorfulness: 9) was also applied to such test.

[0098] The results of the tests are shown in the graph of Fig. 15. As is seen from this graph, the plain satin fabric according to the invention showed a very high relative reflectance as compared with the conventional blue satin fabric. In fact, the plain satin fabric showed a very high metallic polish and a clear and deeper color feel. Furthermore, it was revealed that the feel of material of the plain satin fabric was largely changed in accordance with the weaving type and the property (viz., hue, luminosity and colorfulness) of the conventional plain satin fabric that constituted the warps.

EMBODIMENT 13:

[0099] A plain woven fabric similar to the above-mentioned twelfth embodiment was produced. That is, in this thirteenth embodiment, as the wefts, the same interference coloring fibers as those of the twelfth embodiment were used. However, in this thirteenth embodiment, the warps were made of somewhat darkened conventional fibers (hue: 5Y to 5GY, luminosity: about 8.75, colorfulness: about 0.5). By weaving the wefts and warps together, the plain woven fabric was produced.

[0100] The plain woven fabric thus produced, which is the thirteenth embodiment of the invention, was applied to the above-mentioned spectral reflectance test. The results of this test is shown in the graph of Fig. 16. As is understood from Figs. 16 and 15, the fabric of the thirteenth embodiment showed the relative reflectance being higher than that of the conventional blue satin fabric. In fact, the fabric had an improved polish feel. Furthermore, due to usage of the interference coloring fibers, the darkness feel was canceled, and due to presence of rough surface of the fabric against which visible light rays strike in different directions, the feel of material of the fabric was improved.

EMBODIMENTS 14 and 15:

[0101] Two plain woven fabrics similar to the above-mentioned twelfth embodiment were produced, which are fourteenth and fifteenth embodiments of the invention. In these fourteenth and fifteenth embodiments, as the wefts, the same interference coloring fibers as those of the twelfth embodiment were used. However, in the fourteenth embodiment, the warps were made of white conventional fibers (luminosity: 9). In the fifteenth embodiment, the warps were made of the interference coloring fibers. By weaving the respective wefts and warps, the plain woven fabrics of the fourteenth and fifteenth embodiments were produced.

[0102] These two plain woven fabrics were applied to the spectral reflectance test. The results are shown in the graph of Fig. 16. As is seen from this graph, both the fabrics of the fourteenth and fifteenth embodiments showed the relative reflectance being higher than that of the thirteenth embodiment, and the fifteenth embodiment showed the relative reflectance being higher than that of the fourteenth embodiment. Due to presence of rough surfaces of the fabrics against which visible light rays strike in different directions, the feel of colors shown by such fabrics was delicately changed. Furthermore, the colors shown by these fabrics allowed the viewers to recognize the colors as a so-called view point less fluorescent colors.

EMBODIMENT 16:

[0103] In this embodiment, the same interference coloring fibers as those of the twelfth embodiment were twisted into threads and the threads were woven into a pattern of a woven fabric. With this, there was produced on the woven fabric a raised portion where the threads are exposed. For comparison, conventional threads were woven into a pattern of another woven fabric. Visual observation test showed that the raised portion issued a metallic polish and a clear and deeper color feel.

[0104] The entire contents of Japanese Patent Application P10-345343 (filed December 4, 1998) are incorporated herein by reference.

[0105] Although the invention has been described above with reference to certain embodiments of the invention, the invention is not limited to the embodiments described above. Various modifications and variations of the embodi-

ments described above will occur to those skilled in the art, in light of the above teachings.

TABLE-1

FORM OF MINUTE STRUCTURE	USE	APPLIED ARTICLES & GOODS
FIBER (REFLECTION & INTERFERENCE FUNCTION)		STITCH YARN; SEWING THREAD; MACHINE SEWING THREAD; RIBBON; PACKING THREAD; FISHING GUT; FEATHER JIG; ARTIFICIAL BAIT; ROPE; ARTIFICIAL HAIR; BRUSH; ETC.,
FABRICS (REFLECTION & INTERFERENCE FUNCTION) (INFRARED RAY REFLECTION FUNCTION) (ULTRAVIOLET RAY REFLECTION FUNCTION)	CLOTHING	EUROPEAN CLOTHING; JAPANESE CLOTHING; UNDERWEAR; COAT; STOCKING; BELT; SCARF; HEADBAND; JAPANESE GIRDLE; GIRDLE FASTENER; STAGE COSTUME; NECKTIE; PARTY DRESS; ETC.,
	INTERIOR	CURTAIN; WALL & CEILING CLOTH; CARPET; CHAIR COVER; TABLE CLOTH; BLIND; TAPESTRY; THICK CURTAIN; ETC.,
	PERSONAL BELONGINGS	JAPANESE WRAPPING CLOTH; JAPANESE TOWEL; HAT; FOLDING FAN; SHOES; WOODEN CLOGS; JAPANESE SANDALS; FOOTWEAR; JAPANESE SMALL ARTICLES; UMBRELLA; PARASOL; BAG; WATCH STRAP; GLASSES; WIG; ETC.,
	LEISURE & SPORTS	UNIFORMS; TENNIS WEAR; SWIMSUIT; WET SUIT; SKI & SKATE WEAR; CAR SEAT; SHOES; TENT; RUCK SACK; SAIL; ETC.,
	ART & EDUCATION	PAINTING MATERIALS; PICTURE BOOK; ETC.,
	DAILY NECESSARIES, HOUSEHOLD ELECTRIC APPLIANCES & ORNAMENT	DISH TOWEL; FLOOR CLOTH; ELECTRIC CORD; BEDDING; TATAMI MAT; LIGHTING; COVERLET FOR JAPANESE FOOT WARMER; ARTIFICIAL FLOWER; ORNAMENTAL HAIR PIN; CORSAGE; RIBBON; ART FLOWER; ETC.,
	INDUSTRY (AGRICULTURE & ARCHITECTURE)	SPECIFIC WAVELENGTH WAVE CONTROL CLOTH; INFRARED RAY SHUTTING CLOTH; CAUTION SIGN; ELECTRONIC PARTS (RGB ELEMENT OF COLOR FILTER FOR LIQUID-CRYSTAL DISPLAY AND/OR PLASMA DISPLAY PANEL (COATING TYPE & WEAVING TYPE); RGB ELEMENT OF COLOR FILTER SCREEN FOR PROJECTOR (COATING TYPE & WEAVING TYPE); ETC.,
CHIPPED FIBER (REFLECTION & INTERFERENCE FUNCTION) - MIXED WITH PULP FOR MAKING PAPER -	PAPER PRODUCTS	SLIDING DOOR; PAPER SLIDING DOOR; WALL PAPER; POSTCARD; NOTEBOOK; LETTER PAPER; ENVELOPE; CHRISTMAS CARD; BINDING FOR BOOK & MAGAZINE; VESSELS; PACKING; PACKING TOOL; BLANK FORM; LAMP SHADE; ETC.,

TABLE-2

FORM OF MINUTE STRUCTURE	USE	APPLIED ARTICLES & GOODS
CHIPPED FIBER (REFLECTION & INTERFERENCE FUNCTION) (INFRA-RED RAY REFLECTION FUNCTION) (ULTRAVIOLET RAY REFLECTION FUNCTION)	NON WOVEN FABRICS	SUBSTANTIALLY SAME AS THOSE OF CLOTH IN TABLE-1
CHIPPED FIBER (REFLECTION & INTERFERENCE FUNCTION) (INFRA-RED RAY REFLECTION FUNCTION) (ULTRAVIOLET RAY REFLECTION FUNCTION) -SCATTERED ONTO SUBSTRATE AND FIXED-	SURFACE DECORATION	WALL PAPER; MOUNTING; PLASTIC TILE; TABLE WEAR; FLOWER VASE; EARTHENWARE; DAILY NECESSARIES SUCH AS TABLE, CHAIR OR THE LIKE; HOUSE HOLD ELECTRIC APPLIANCES; LURE; TOYS; PLASTIC MODEL; SKIS; SNOW BOARD; SURF BOARD; INTERIOR OF CAR, RAILWAY CAR SHIP AND PLANE; PEN; FOUNTAIN PEN; WRITING BRUSH; PENCIL; PENCIL CASE; CASES; NAME BOARD; DOCUMENT CASE; SIGN BOARD; TRAFFIC SIGNAL; BINDING FOR BOOK & MAGAZINE; PICTURE FRAME; SAND PICTURE; JIGSAW PUZZLE; SURFACE COVER FOR PLASTIC, METAL, WOOD, GLASS AND CERAMIC MEMBERS; ETC.,
CHIPPED FIBER (REFLECTION & INTERFERENCE FUNCTION) (INFRA-RED RAY REFLECTION FUNCTION) (ULTRAVIOLET RAY REFLECTION FUNCTION) -MIXED WITH BASE OF PAINT-	PAINTING	TABLE WEAR; FLOWER VASE; EARTHENWARE; TABLE; CHAIR; HOUSEHOLD ELECTRIC APPLIANCES; LURE; TOYS; PLASTIC MODEL; MUSICAL INSTRUMENT; RACKETS; SKIS; SNOW BOARD; SURF BOARD; INTERIOR OF CAR, RAILWAY CAR, SHIP AND PLANEL; PEN; FOUNTAIN PEN; PENCIL; PENCIL CASE; CASES; DOCUMENT CASE; PAINTING MATERIALS; STAGE COSTUME; INTERIOR & EXTERIOR OF HOUSE; NAME BOARD; SIGN BOARD; TRAFFIC SIGNAL; SURFACE COVER FOR PLASTIC, METAL, WOOD, GLASS AND CERAMIC MEMBERS; ETC.,
	COSMETICS	HAIR SPLAY; FOUNDATION; NAIL POLISH; HAIR DYE; EYE SHADOW, ETC.,

TABLE-3

FORM OF MINUTE STRUCTURE	USE	APPLIED ARTICLES & GOODS
CHIPPED FIBER (REFLECTION& INTERFERENCE FUNCTION) - EMBEDDED IN PLASTIC MATERIAL AND THE LIKE - -	COVERING MATERIAL	TABLE WEAR; FLOWER VASE; TABLE; CHAIR; HOUSEHOLD ELECTRIC APPLIANCES; LURE; TOYS; PLASTIC MODEL; MUSICAL INSTRUMENT; SKIS; SNOW BOARD; SURF BOARD; INTERIOR OF CAR, RAILWAY CAR, SHIP AND PLANE; PENCIL CASE; CASES; DOCUMENT CASE; SURFACE DECORATING SHEET; ETC.,
CHIPPED FIBER (REFLECTION& INTERFERENCE FUNCTION) - PUT BETWEEN TRANSPARENT FILMS OR GLASS PLATES - -	DECORATING MATERIAL	SIGN BOARD; TRAFFIC SIGNAL; WINDOW; CASES; LABEL; ADHESIVE TAPE; ETC.,

TABLE-4

5	EMBODIMENT	2ND POLYMER LAYER/1ST POLYMER LAYER nbdb/nada	OPTICAL THICKNESS RATIO	MEASURED THICKNESS OF LAYER (μM)		RELATIVE REFLECTANCE (%)	COLOR FEELING
10				COPOLYMERIZED PET LAYER	PMMA LAYER		
15	1	COPOLYMERIZED PET/PMMA (REFRACTIVE INDEX RATIO= 1.06)	1	0.072	0.077	228	TRANSPARENTLY FRESH PURPLISH BLUE
	2		5	0.122	0.026	102	PURPLISH BLUE
				PC LAYER	PMMA LAYER		
20	3	PC/PMMA (REFRACTIVE INDEX RATIO=1.07)	1	0.072	0.078	236	TRANSPARENTLY FRESH PURPLISH BLUE
	4		5	0.120	0.026	106	PURPLISH BLUE
25				COPOLYMERIZED PET LAYER	NY-6 LAYER		
30	5	COPOLYMERIZED PET/NY-6 (REFRACTIVE INDEX RATIO=1.03)	1	0.074	0.076	102	PURPLISH BLUE
				COPOLYMERIZED PET LAYER	NY-6 LAYER		
35	6	COPOLYMERIZED PET/NY-6 (REFRACTIVE INDEX RATIO=1.07)	1	0.073	0.076	241	TRANSPARENTLY FRESH PURPLISH BLUE
	7		5	0.118	0.025	113	PURPLISH BLUE
40				PPS LAYER	PMMA LAYER		
	8		1	0.064	0.077	272	TRANSPARENTLY FRESH GREENISH BLUE
45	9	PPS/PMMA (REFRACTIVE INDEX RATIO=1.20)	5	0.107	0.025	251	TRANSPARENTLY FRESH GREENISH BLUE
	10		10	0.116	0.014	209	FRESH GREENISH BLUE
50	11		15	0.120	0.010	135	FRESH GREENISH BLUE

Claims

1. A minute structure having at least one of optical functions including a reflection/interference function to visible light ray, a reflection function to infrared ray and a reflection function to ultraviolet ray, said minute structure comprising:

a plurality of first and second polymer layers which are alternately put on one another in the direction of the thickness to constitute a layer unit, each first polymer layer having an optical refractive index "na" and a thickness "da", and each second polymer layer having an optical refractive index "nb" and a thickness "db", wherein said minute structure is formed to satisfy the following condition:

under the conditions of " $1.3 \leq na$ " and " $1.01 \leq nb/na \leq 1.40$ ", the peak wavelength " λ_1 " of primary reflection satisfies the following formula:

$$\lambda_1 = 2 \times (na \cdot da + nb \cdot db), \text{ and}$$

the ratio " $nb \cdot db/na \cdot da$ " of the optical thickness " $nb \cdot db$ " of the second polymer layer to that " $na \cdot da$ " of the first polymer layer satisfies the following formula:

$$1/40 \leq nb \cdot db/na \cdot da \leq 40.$$

2. A minute structure as claimed in Claim 1, in which the ratio " $nb \cdot db/na \cdot da$ " satisfies the following formula:

$$1/15 \leq nb \cdot db/na \cdot da \leq 15.$$

3. A minute structure as claimed in Claim 1, further comprising a protecting polymer layer which intimately covers said layer unit, said protecting polymer layer being one of said first polymer layer, said second polymer layer, a third polymer layer different from said first and second polymer layers and a combination layer which is produced by combining at least two of said first, second and third polymer layers.

4. A minute structure as claimed in Claim 3, in which said protecting polymer layer is the second polymer layer whose optical refractive index is higher than that of the first polymer layer or the third polymer layer whose optical refractive index is higher than the second polymer layer.

5. A minute structure as claimed in Claim 3, in which said protecting polymer layer has a thickness ranging from approximately 0.5 μm to approximately 20 μm .

6. A minute structure as claimed in Claim 1, in which each of said first and second polymer layers is made of a thermoplastic resin.

7. A minute structure as claimed in 6, in which each of said first and second polymer layers is made of polyester resin, polyamide resin, polyolefine resin, vinyl resin, polyether-ketone resin, polysulfide resin, fluoro-resin, polycarbonate resin or copolymer of at least two of these resins.

8. A minute structure as claimed in Claim 6, in which said first polymer layer is made of fluoro-resin and in which said second polymer layer is made of polyester resin, polyvinyl chloride resin, polymethyl methacrylate resin, polycarbonate resin or polyphenylene sulfide resin.

9. A minute structure as claimed in Claim 9, in which said first polymer layer is made of polymethyl methacrylate resin and in which said second polymer layer is made of polyethylene terephthalate.

10. A minute structure as claimed in Claim 6, in which said first polymer layer is made of polyamide resin and in which said second polymer layer is made of polyethylene naphthalate copolymerized with sulfoisophthalic acid.

11. A minute structure as claimed in Claim 6, in which at least one of said first and second polymer layers contains a material that improves a compatibility between the first and second polymer layers.

12. A minute structure as claimed in Claim 11, in which the material for improving the compatibility is a complex fiber forming material which is made of metallic salt of alkyl benzene sulfonate acid or polyester amide.

13. A minute structure as claimed in Claim 6, in which one of said first and second polymer layers contains polyethylene terephthalate as a main component, and in which dicarboxylic acid component forming said polyethylene terephthalate is phthalic acid or isophthalic acid, and in which a part of ligand of said phthalic acid or isophthalic acid is provided with a coordination function by means of cationic agent.

14. A minute structure as claimed in Claim 13, in which said cationic agent is metallic salt of sulfonic acid.

15. A minute structure as claimed in Claim 6, in which one of said first and second polymer layers contains polyethylene terephthalate as a main component, and in which dicarboxylic acid component forming said polyethylene terephthalate contains as a part thereof metallic salt of sulfoisophthalic acid.

16. A minute structure as claimed in Claim 1, in which said minute structure has a major axis along which said minute structure extends, so that the minute structure is in the shape of an elongate fiber.

17. A minute structure as claimed in Claim as claimed in Claim 16, in which said minute structure is in the shape of chip.

18. A woven fabric comprising:

first group of yarns each including a plurality of fibers, each fiber including a plurality of first and second polymer layers which are alternately put on one another in the direction of the thickness to constitute a layer unit, each first polymer layer having an optical refractive index "na" and a thickness "da", and each second polymer layer having an optical refractive index "nb" and a thickness "db", wherein said minute structure is formed to satisfy the following condition: under the conditions of " $1.3 \leq na$ " and " $1.01 \leq nb/na \leq 1.40$ ", the peak wavelength " λ_1 " of primary reflection satisfies the following formula: $\lambda_1 = 2 \times (na \cdot da + nb \cdot db)$, and the ratio " $nb \cdot db/na \cdot da$ " of the optical thickness " $nb \cdot db$ " of the second polymer layer to that " $na \cdot da$ " of the first polymer layer satisfies the following formula: $1/40 \leq nb \cdot db/na \cdot da \leq 40$, and a second group of yarns each including a plurality of fibers, said first and second group of yarns being woven into the fabric.

19. A woven fabric as claimed in Claim 18, in which each of said second group of yarns includes a plurality of natural fibers, artificial fibers or mixed fibers of the natural and artificial fibers.

20. A woven fabric as claimed in Claim 19, in which each fiber of said first group of yarns is an interference coloring fiber.

21. A woven fabric as claimed in Claim 20, in which each fiber of said second group of yarns has a luminosity that is lower than 8.7.

22. A woven fabric as claimed in Claim 21, in which the fibers of said first group of yarns further include natural fibers, artificial fibers or mixed fibers of the natural and artificial fibers, the fibers being twisted to constitute said wefts.

23. A woven fabric as claimed in Claim 18, in which each of the fibers of said second group of yarns is made of the same fiber as said first group of yarns.

24. A woven fabric as claimed in Claim 18, in which said first and second groups of yarns constitute wefts and warps of said fabric respectively.

25. A woven fabric as claimed in Claim 18, in which said second group of yarns are made of whitish fibers.

26. A woven fabric as claimed in Claim 18, in which the first group of yarns are woven into the fabric to form an embroidered pattern on the fabric.

FIG.1A

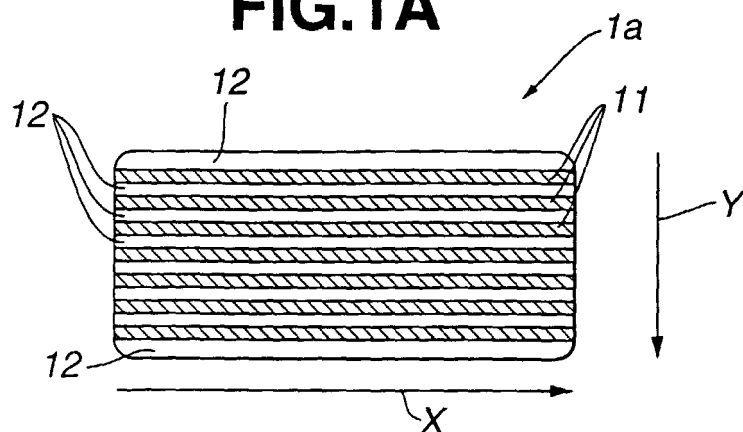


FIG.1B

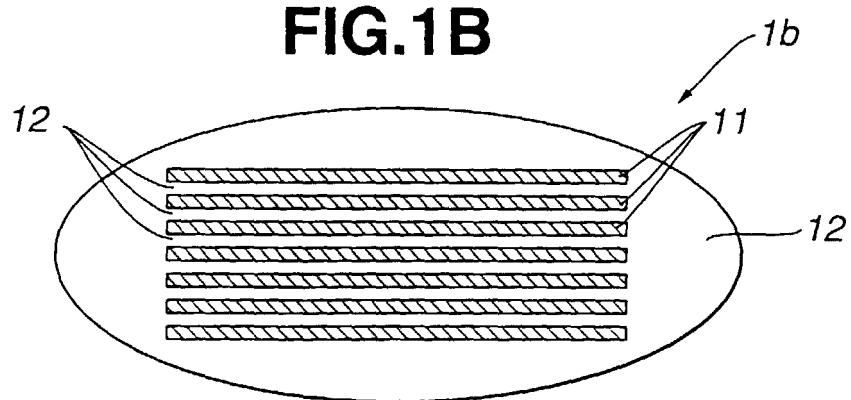


FIG.1C

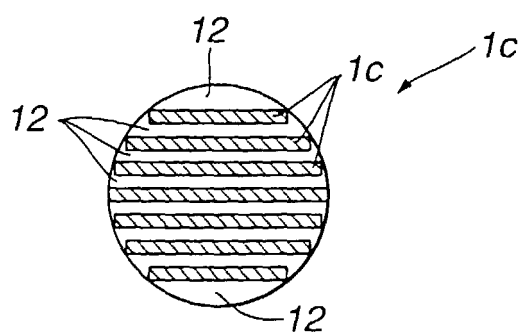


FIG.1D

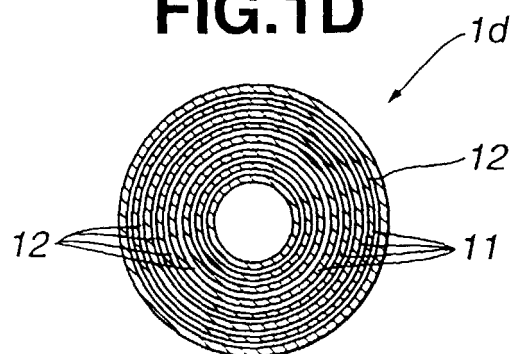


FIG.2A

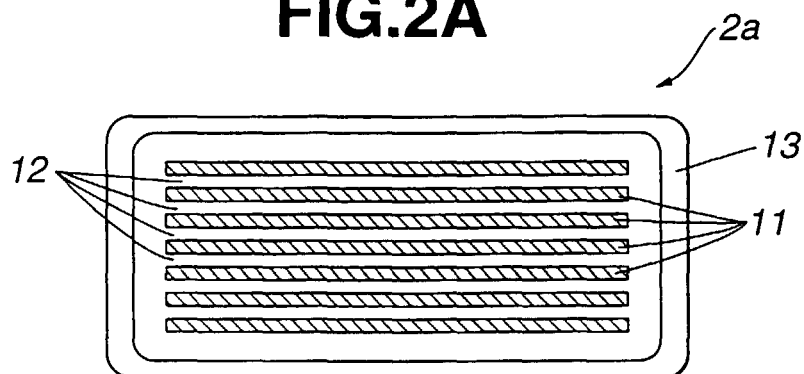


FIG.2B

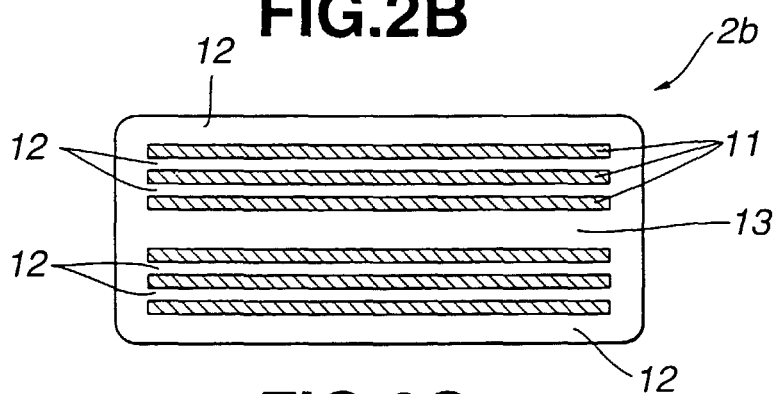


FIG.2C

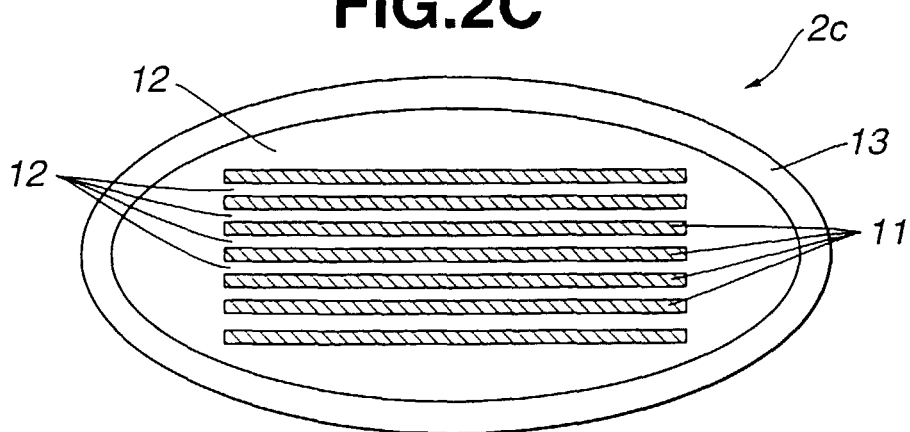


FIG.2D

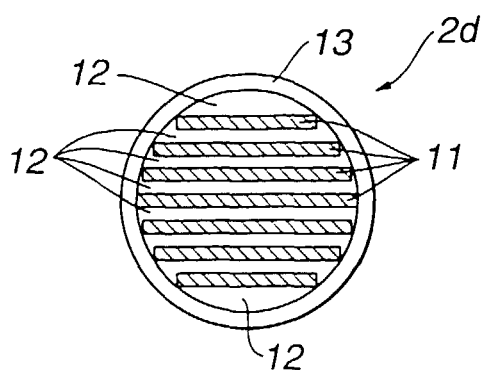


FIG.2E

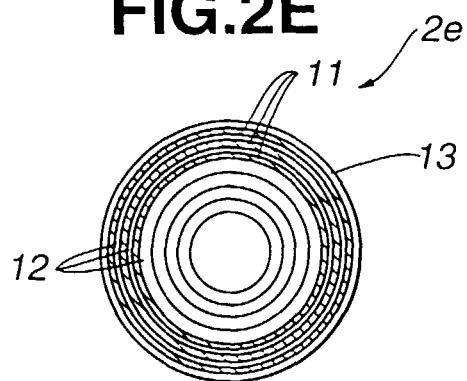


FIG.3A

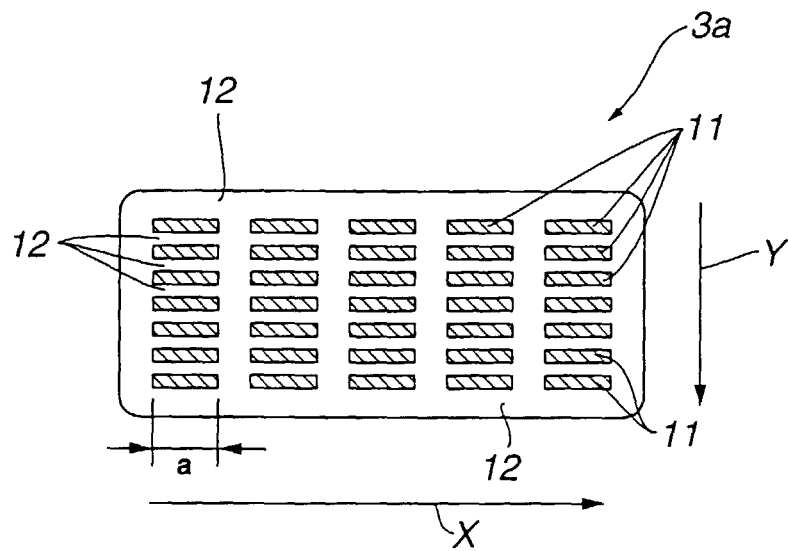


FIG.3B

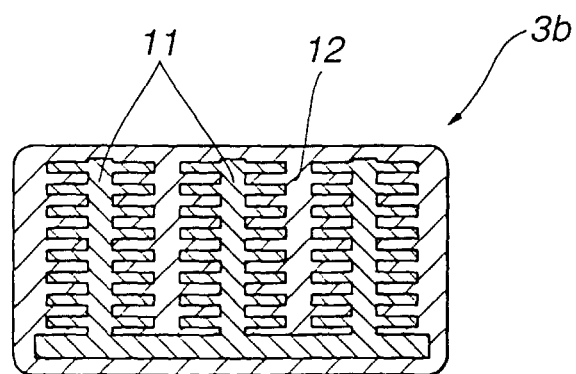


FIG.4A

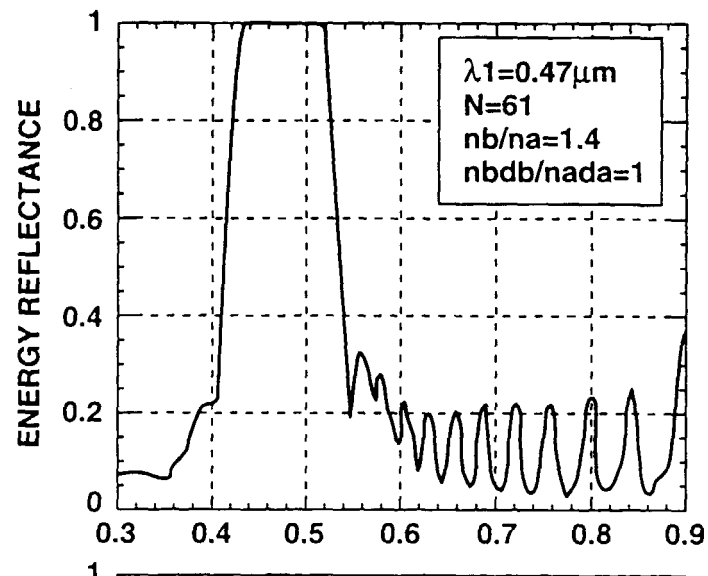


FIG.4B

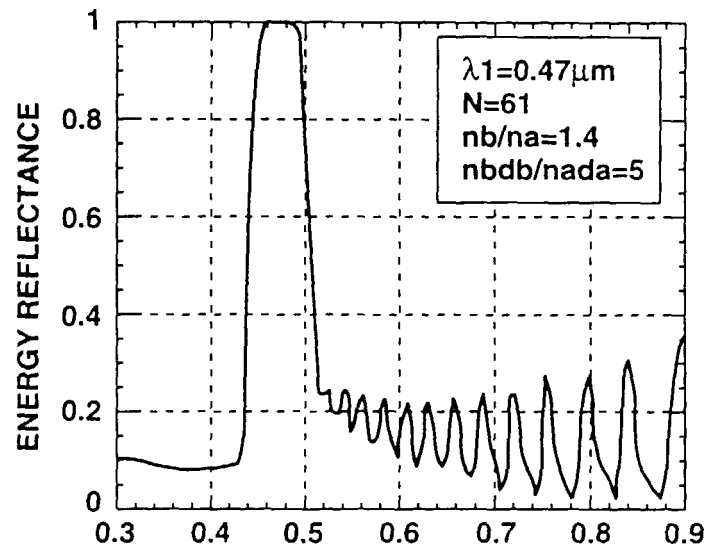


FIG.4C

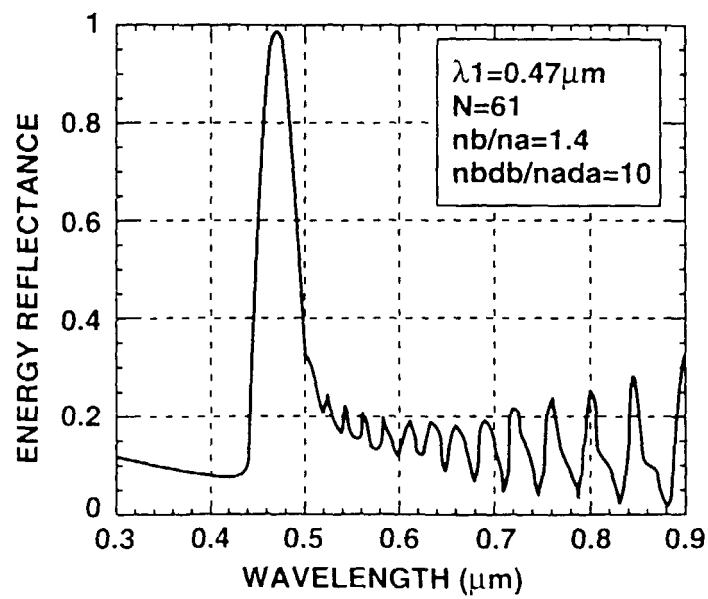


FIG.4D

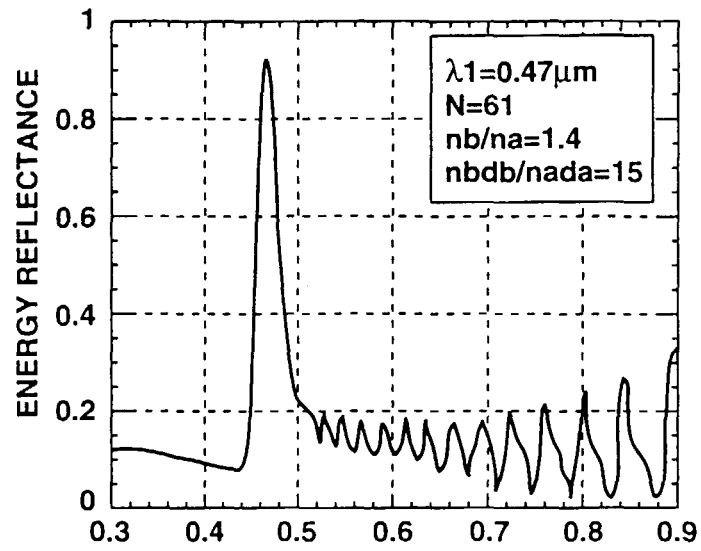


FIG.4E

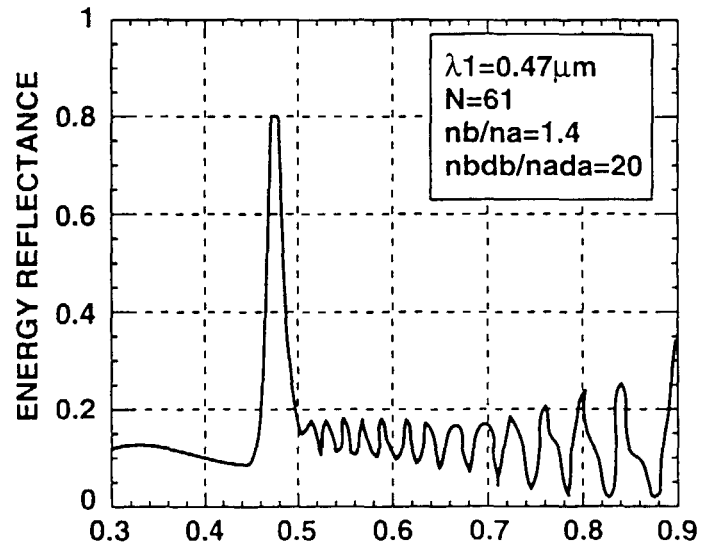


FIG.4F

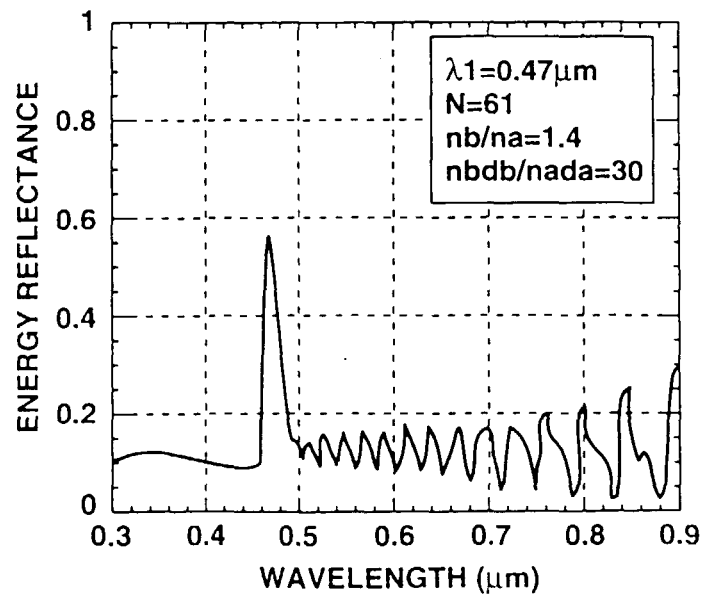


FIG.4G

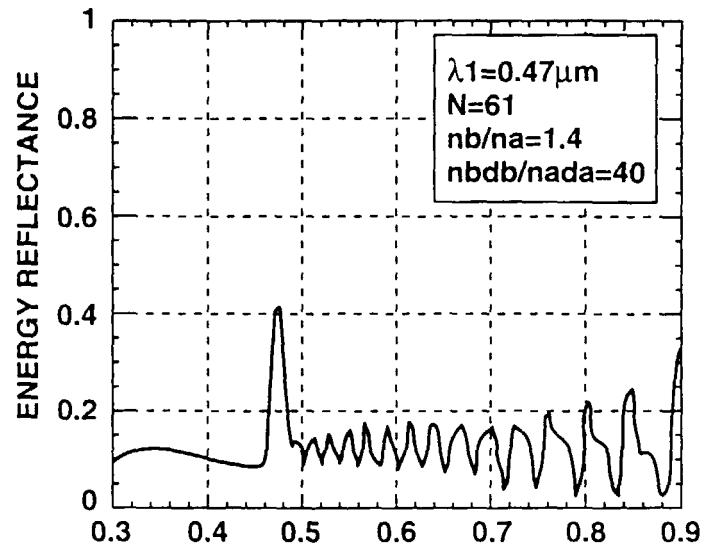


FIG.4H

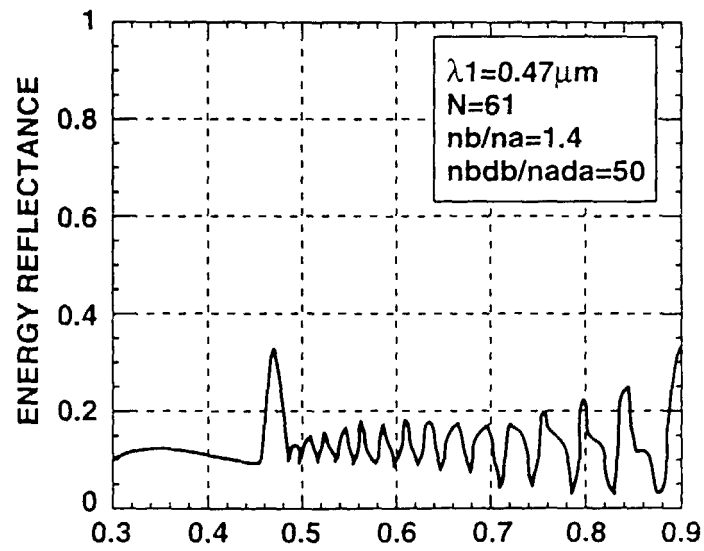


FIG.4 I

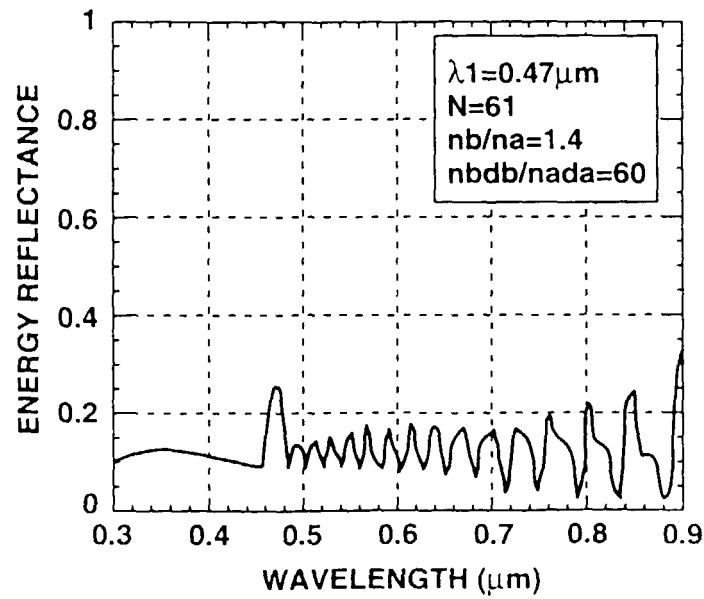


FIG.4J

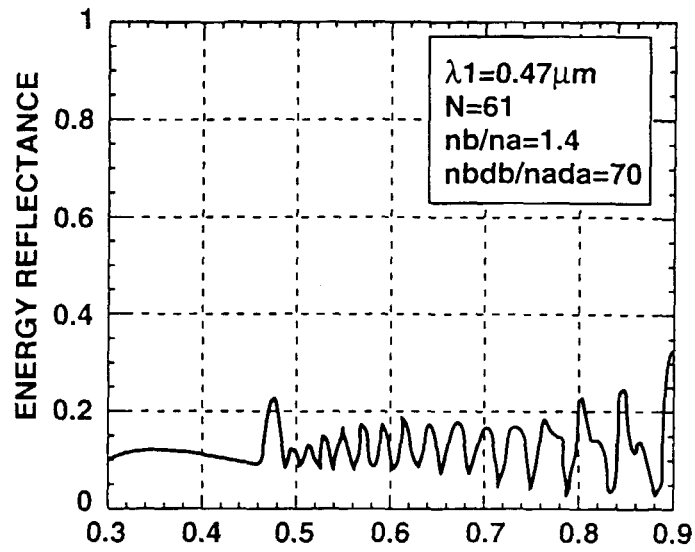


FIG.4K

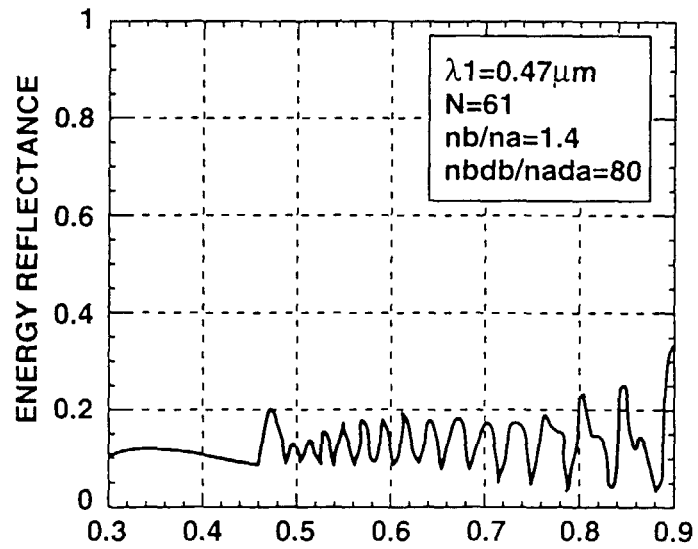


FIG.4L

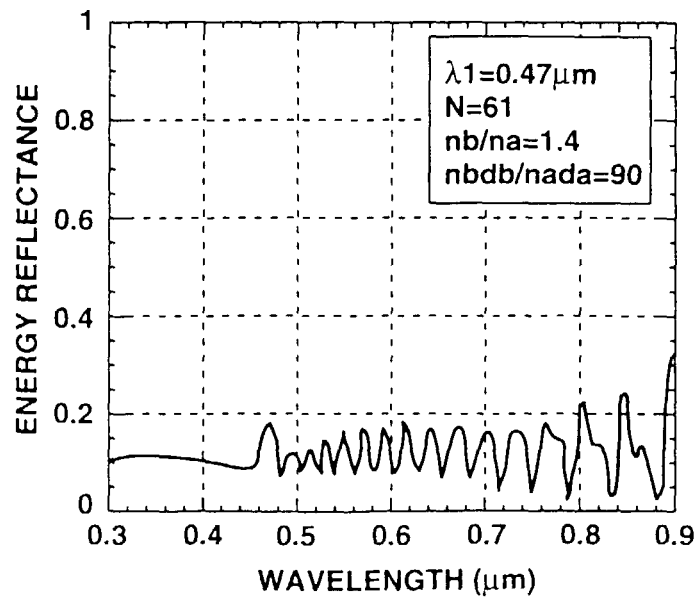


FIG.4M

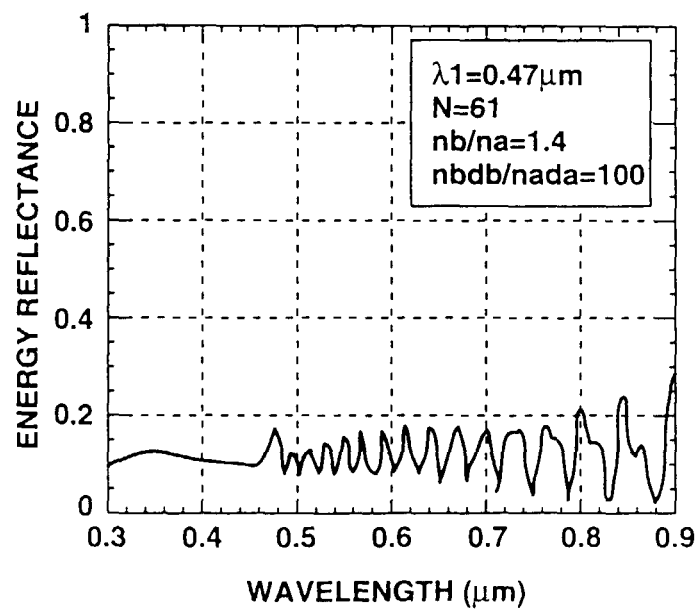


FIG.5A

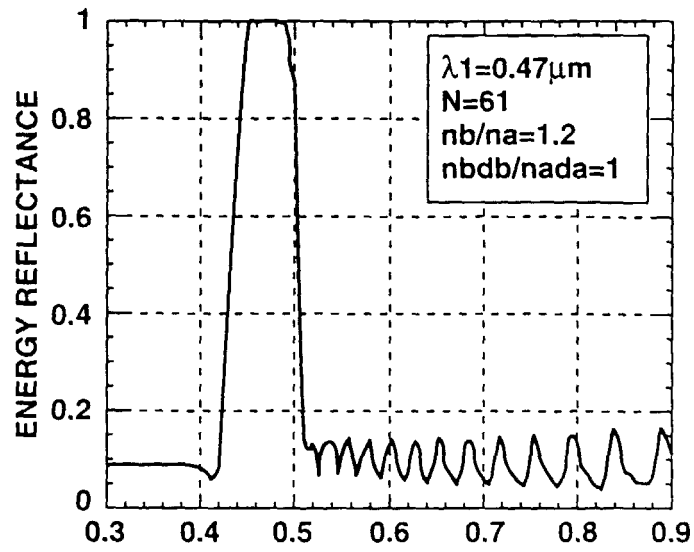


FIG.5B

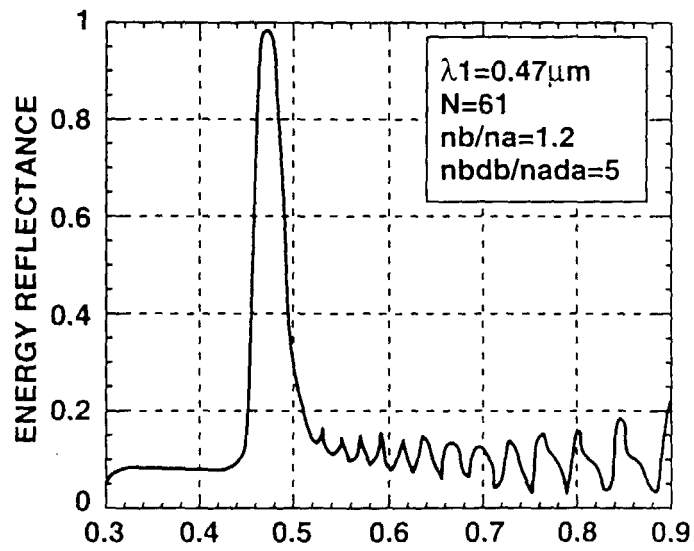


FIG.5C

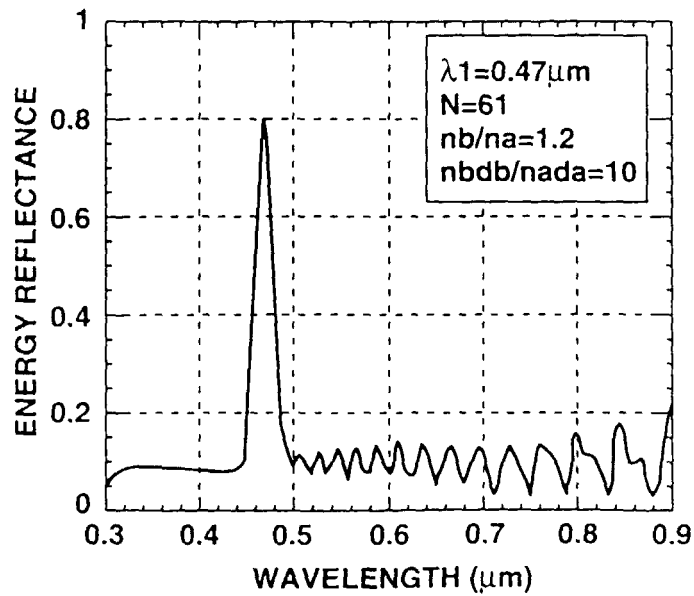


FIG.5D

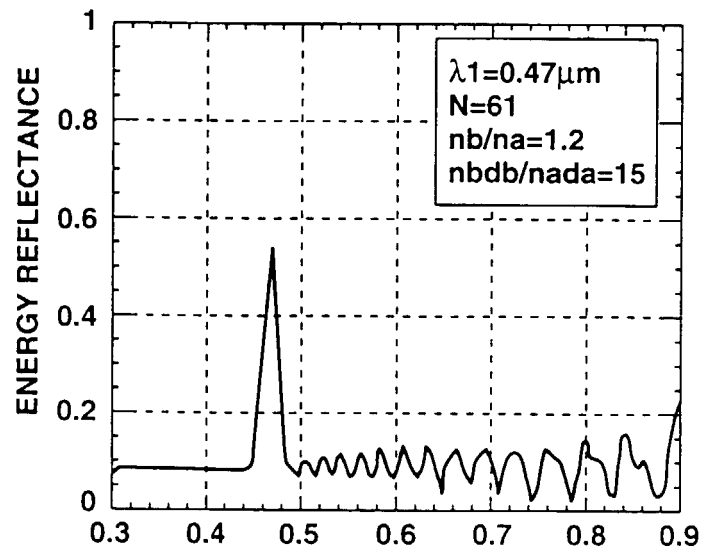


FIG.5E

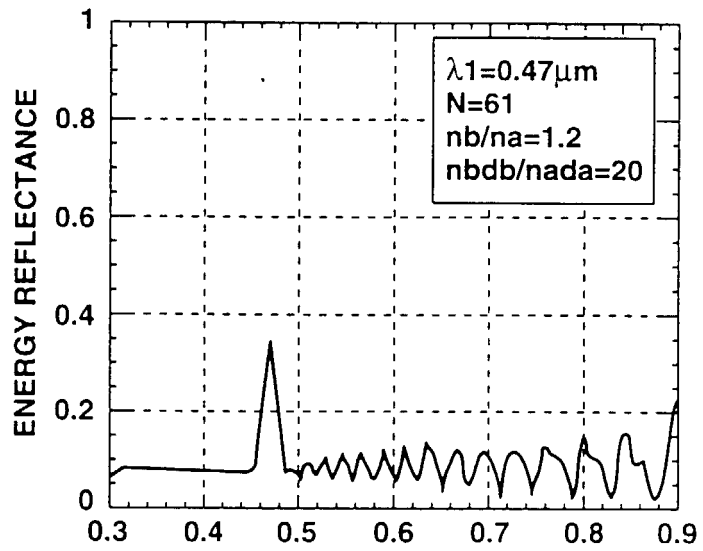


FIG.5F

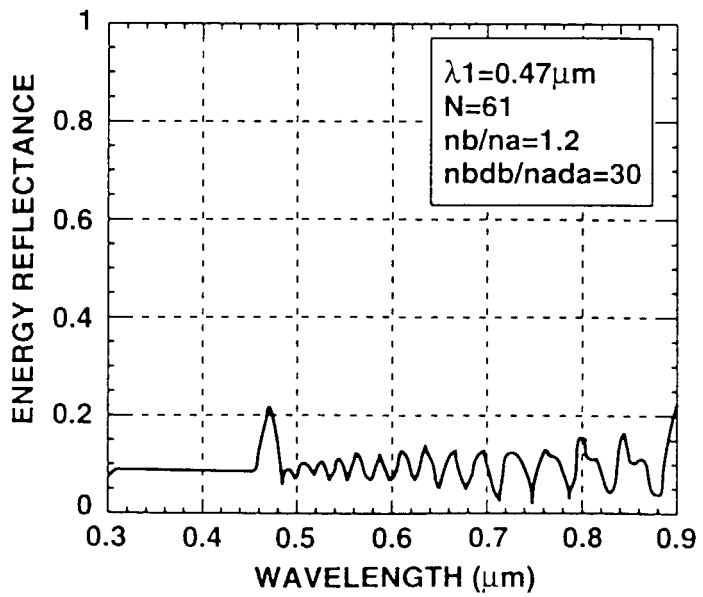


FIG.5G

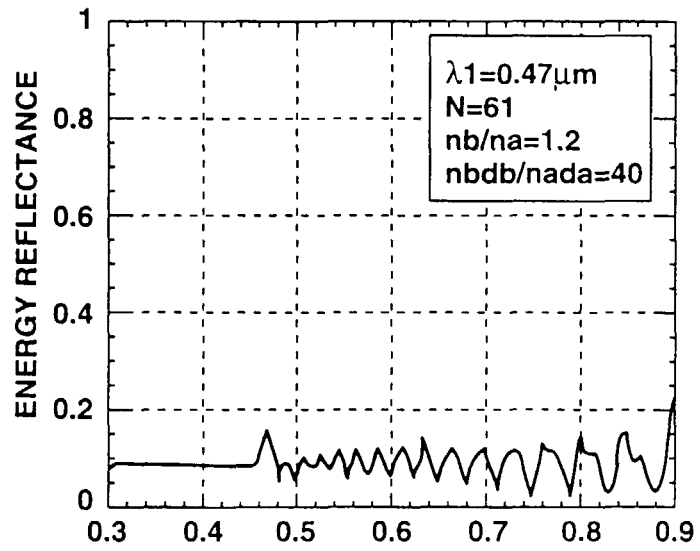


FIG.5H

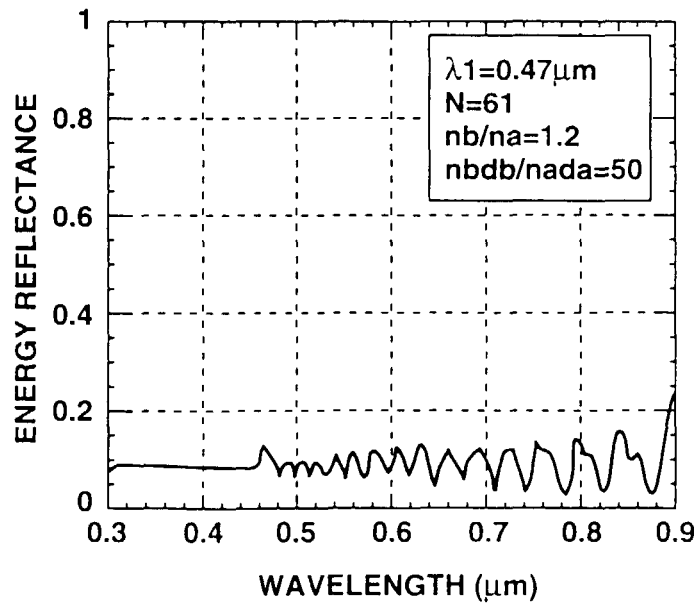


FIG.6A

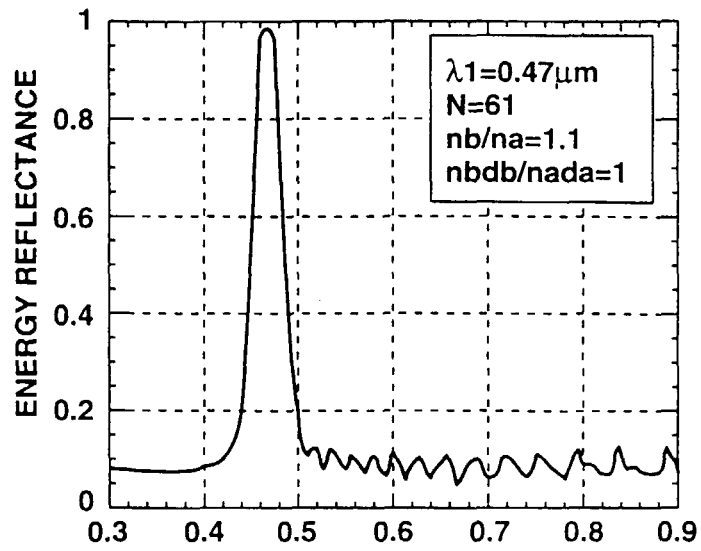


FIG.6B

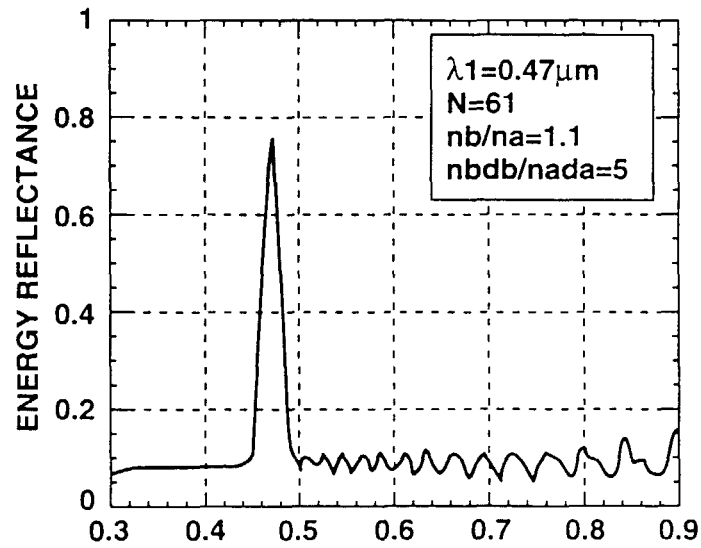


FIG.6C

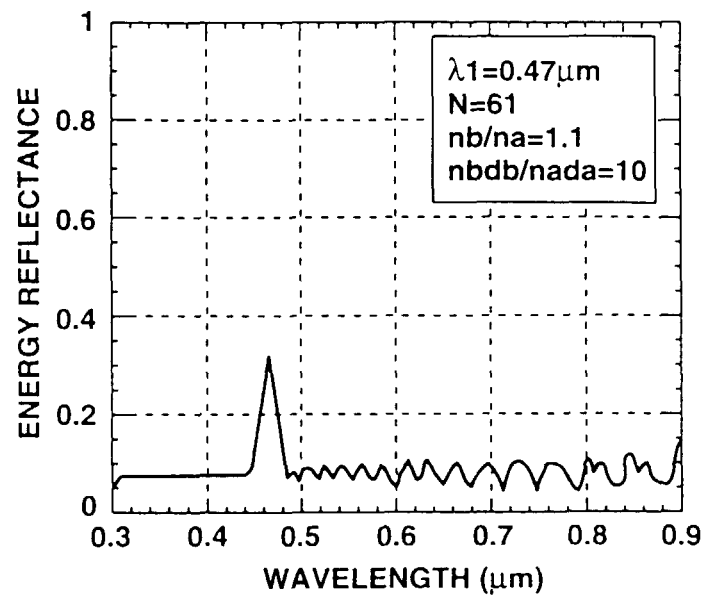


FIG.6D

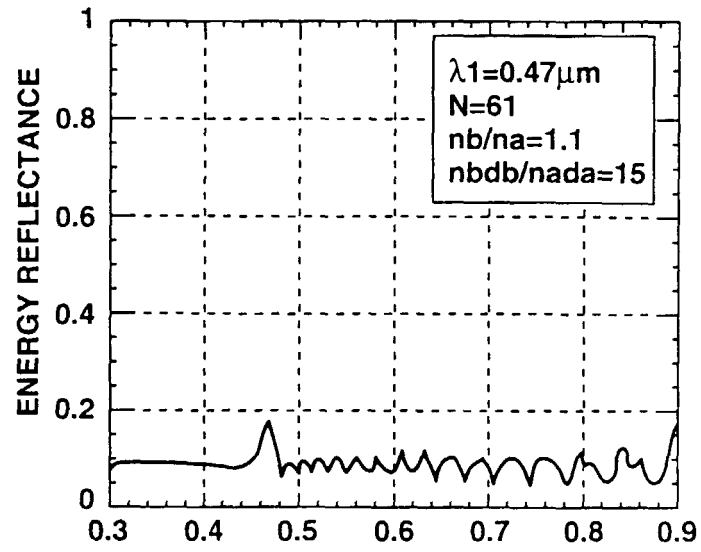


FIG.6E

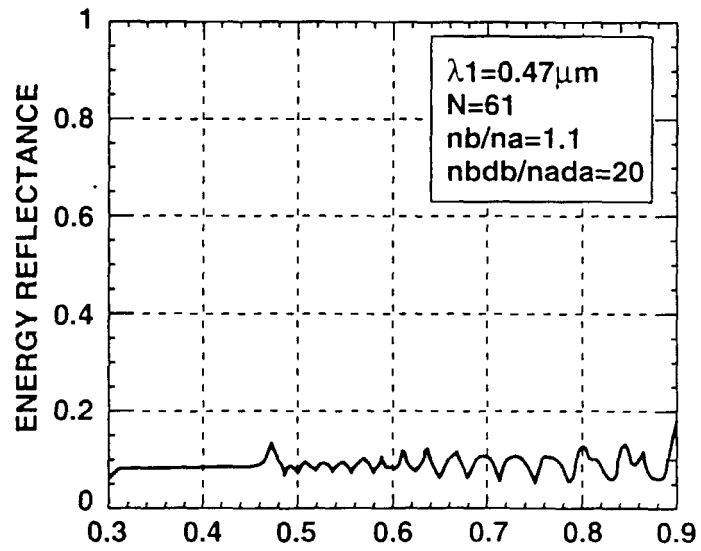


FIG.6F

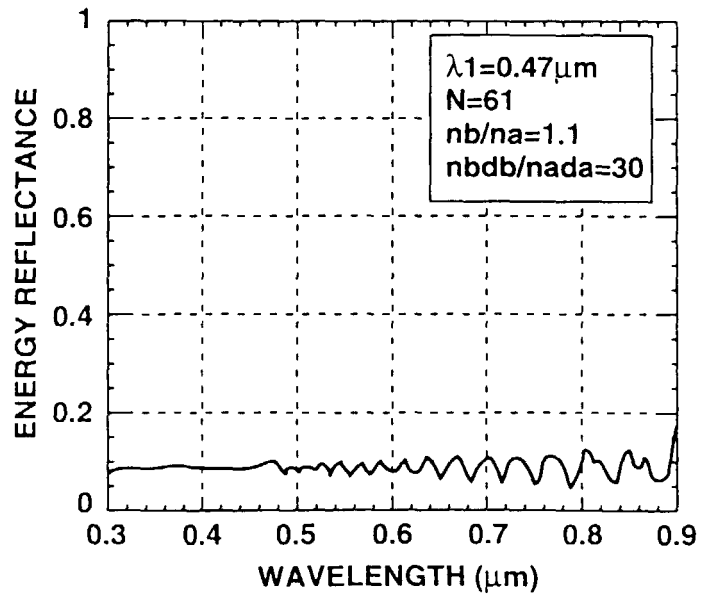


FIG.7A

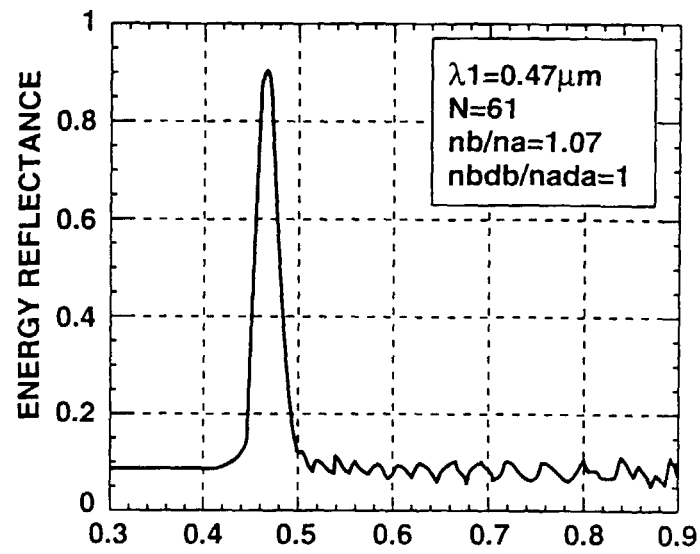


FIG.7B

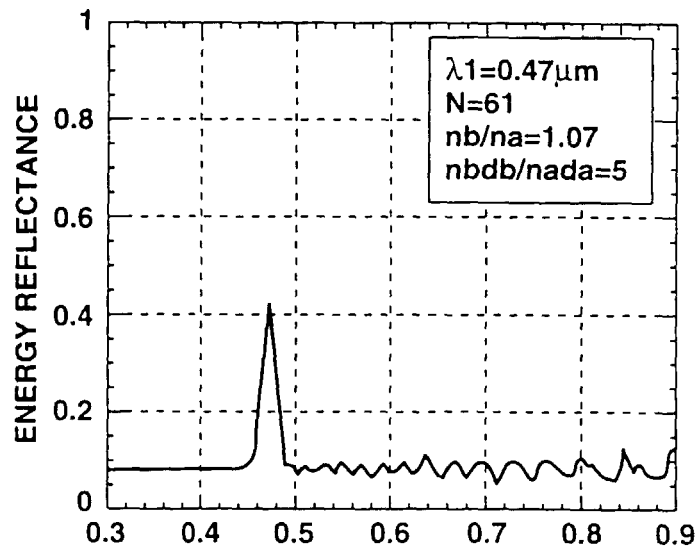


FIG.7C

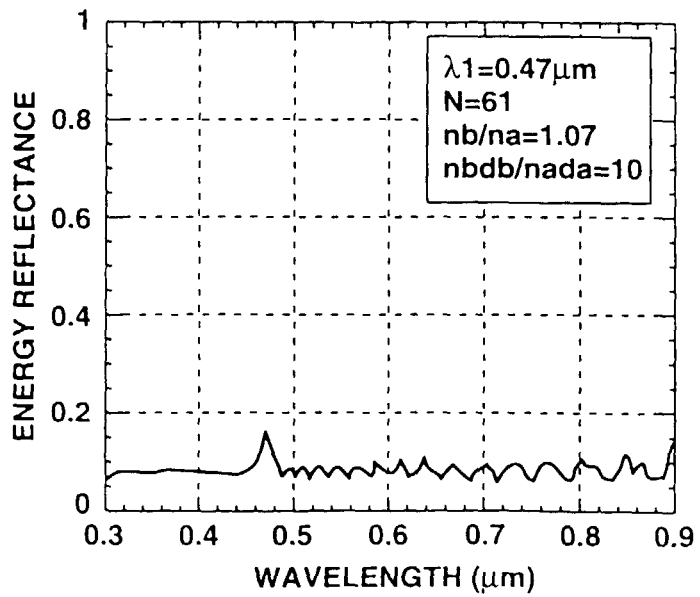


FIG.7D

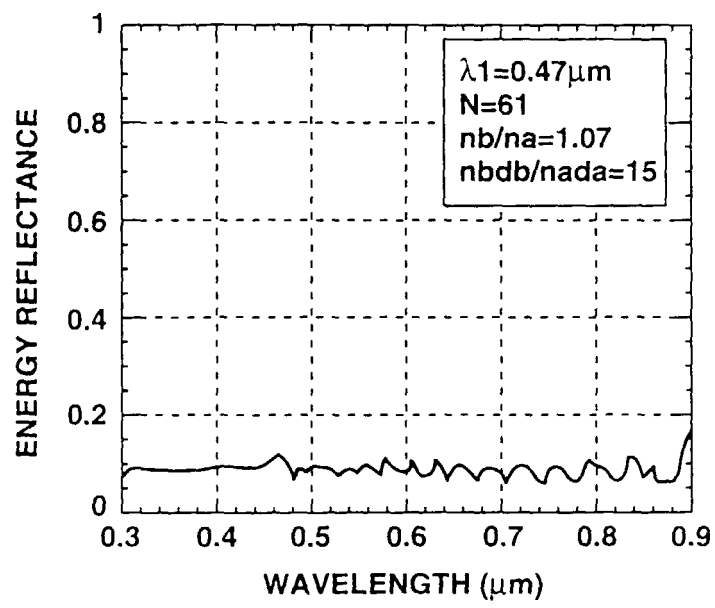


FIG.8A

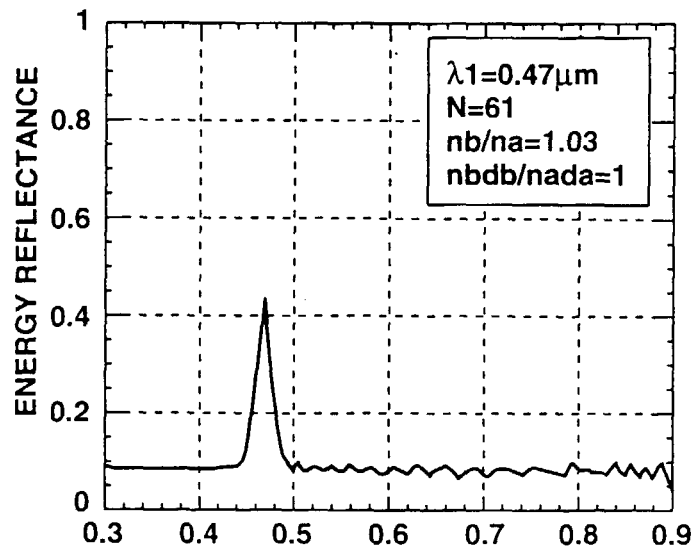


FIG.8B

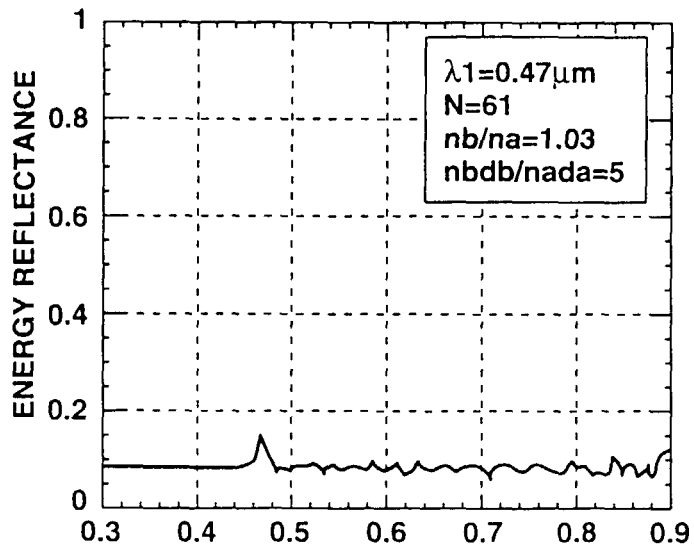


FIG.8C

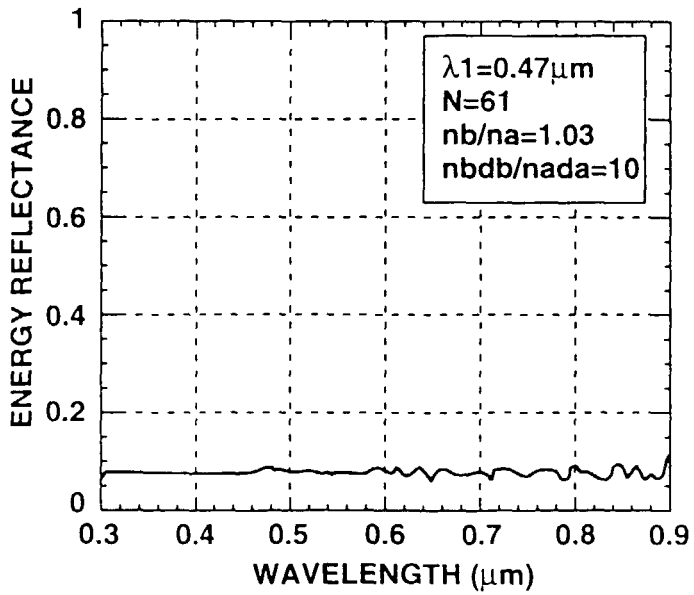


FIG.9A

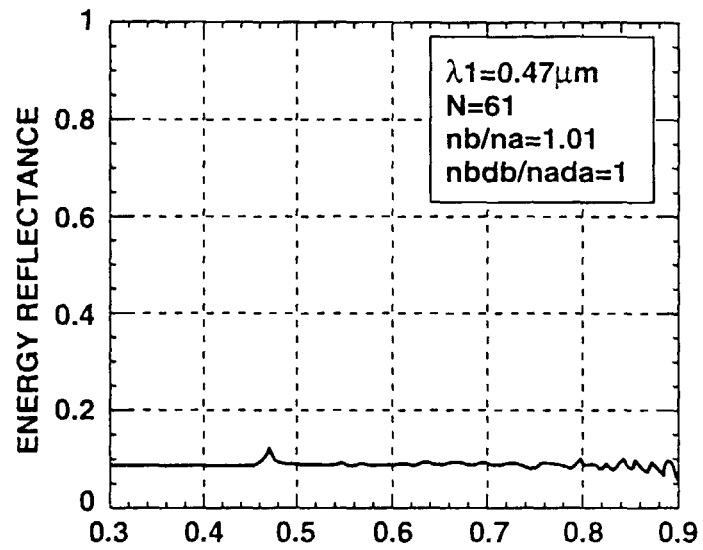


FIG.9B

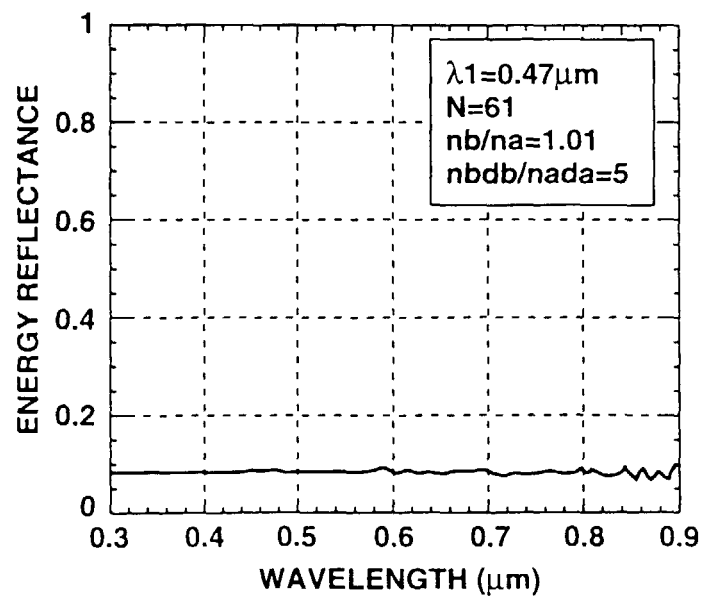


FIG.10

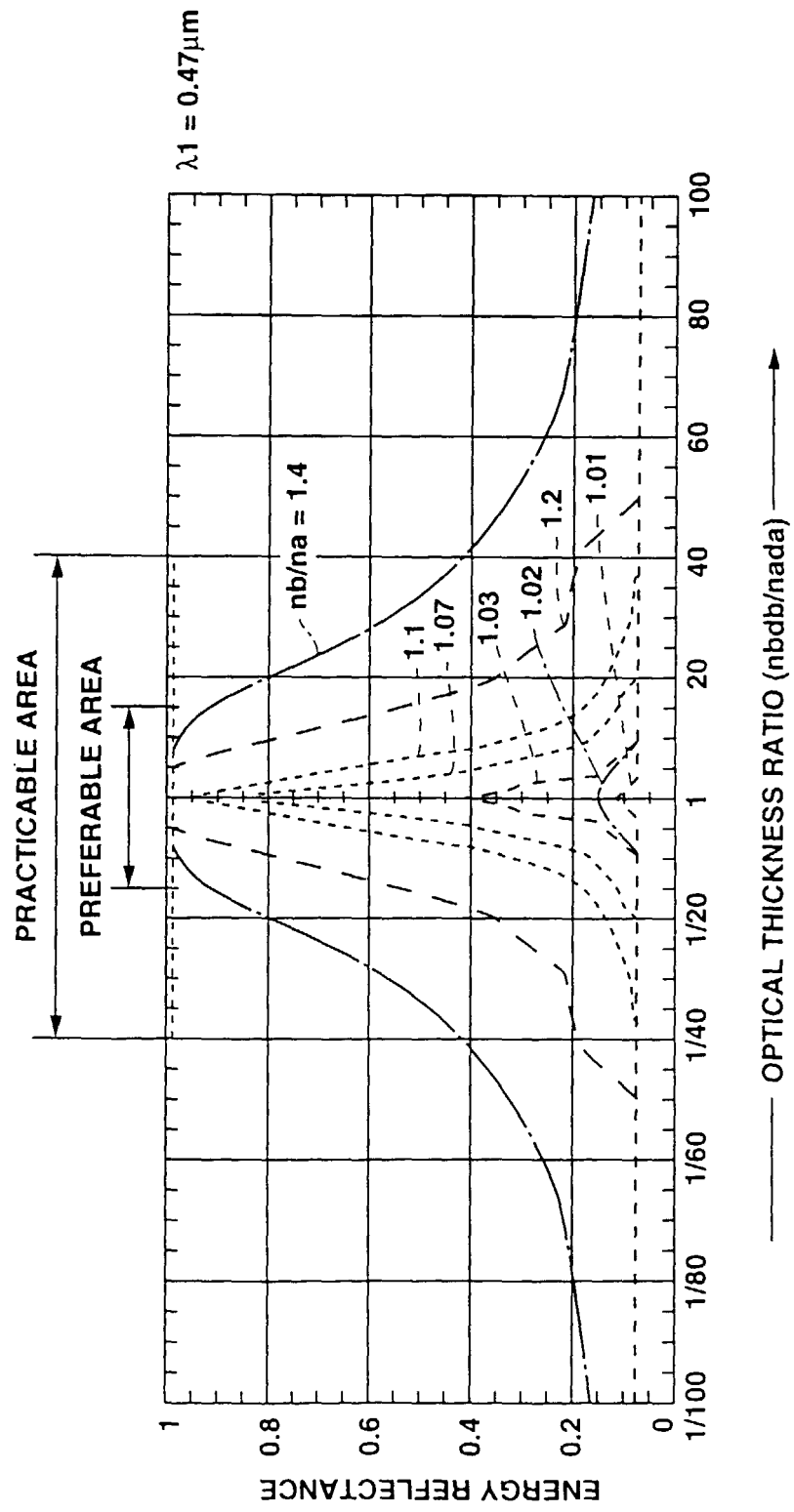


FIG.11

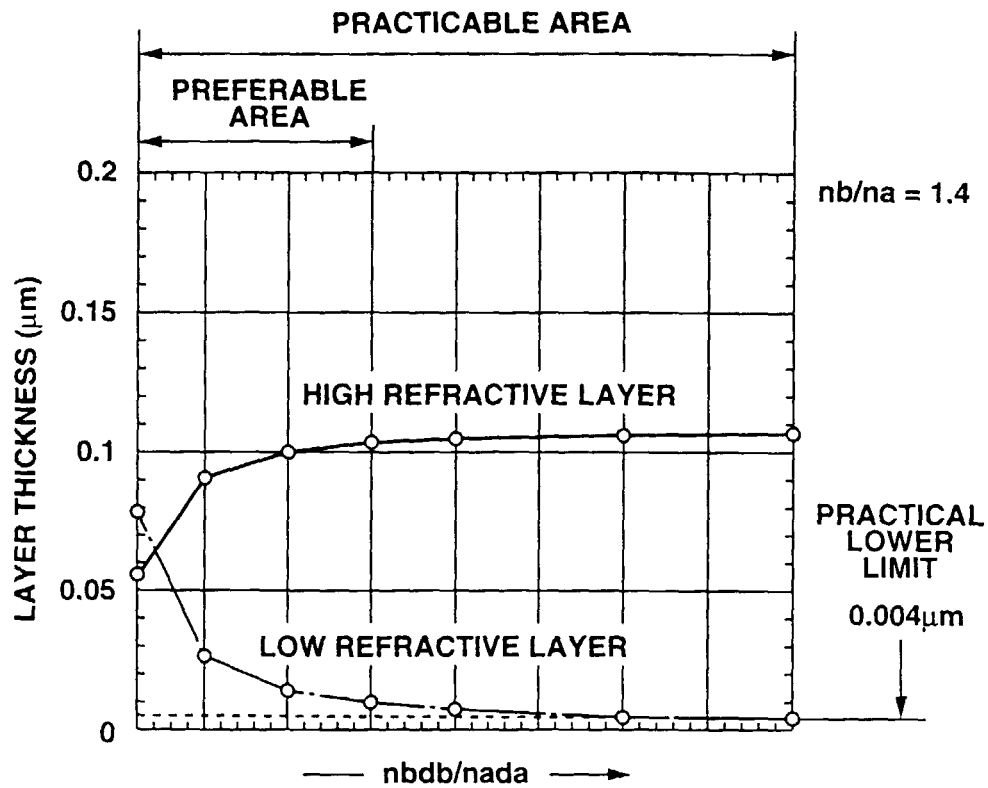


FIG.12

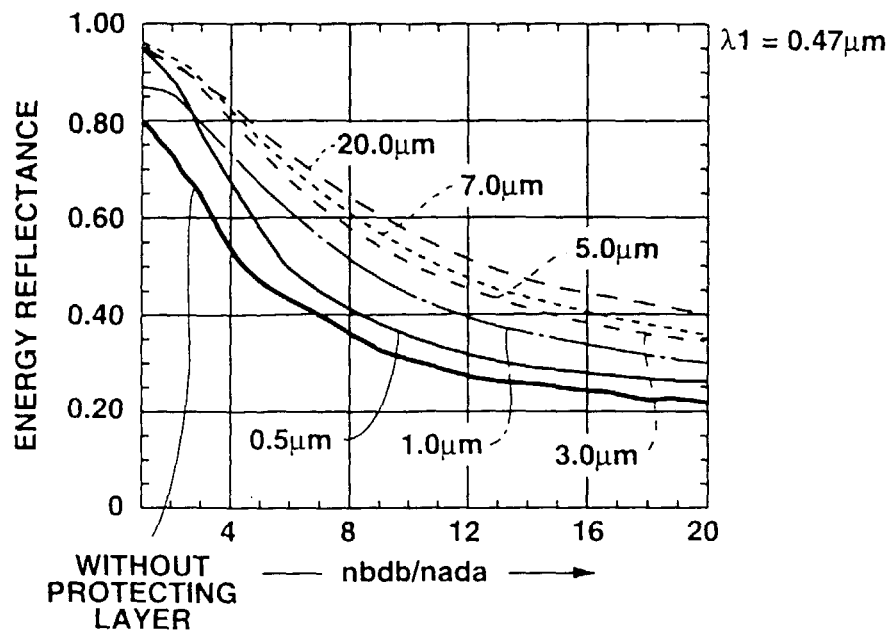


FIG.13

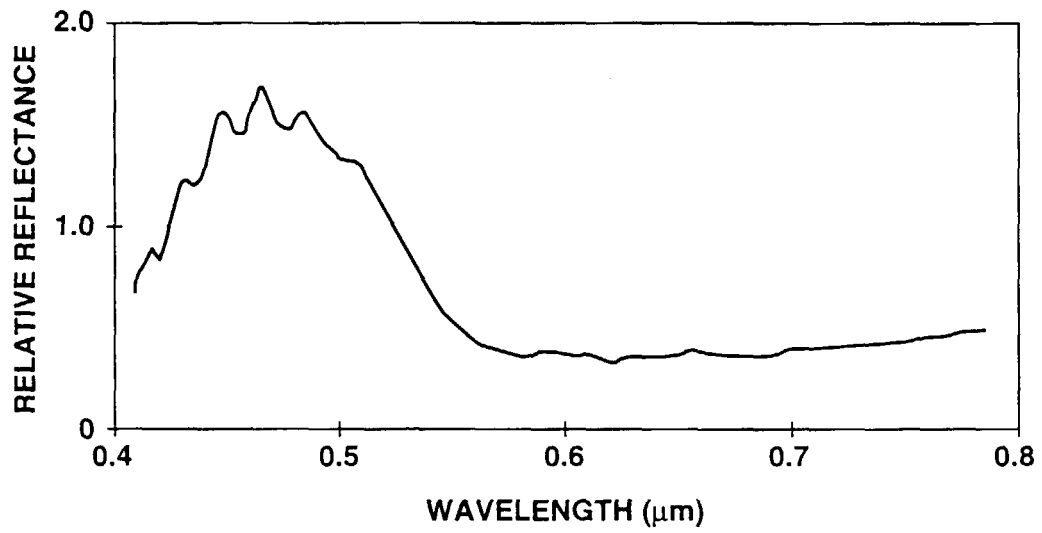


FIG.14

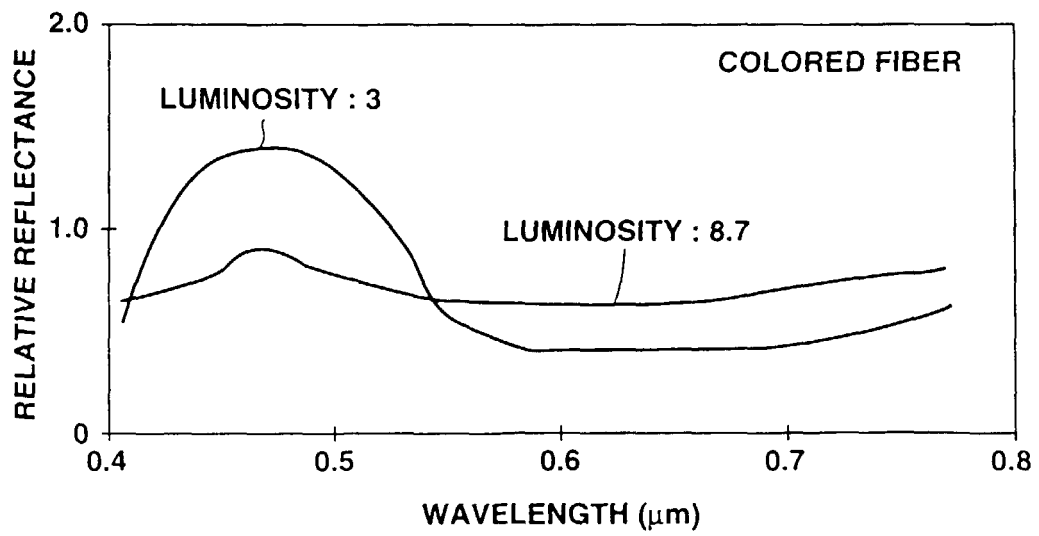


FIG.15

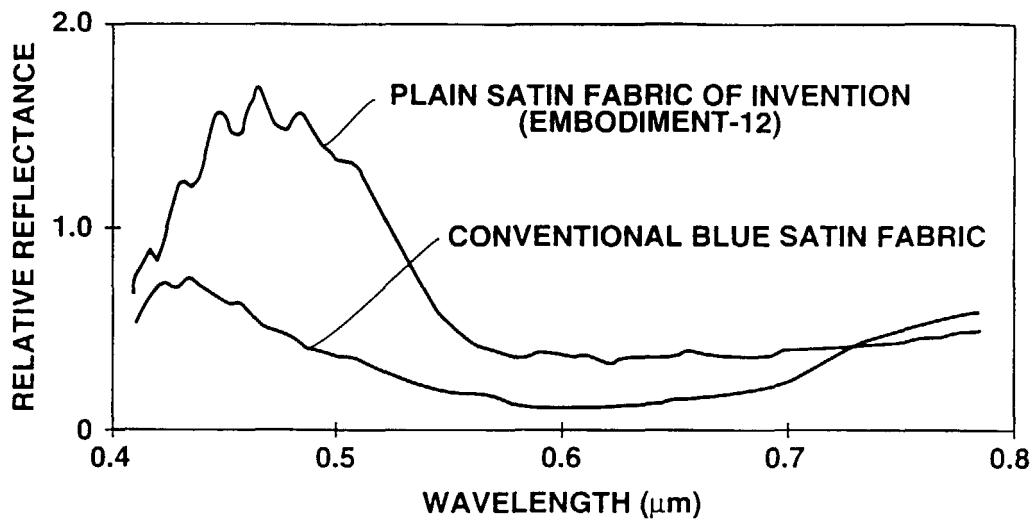
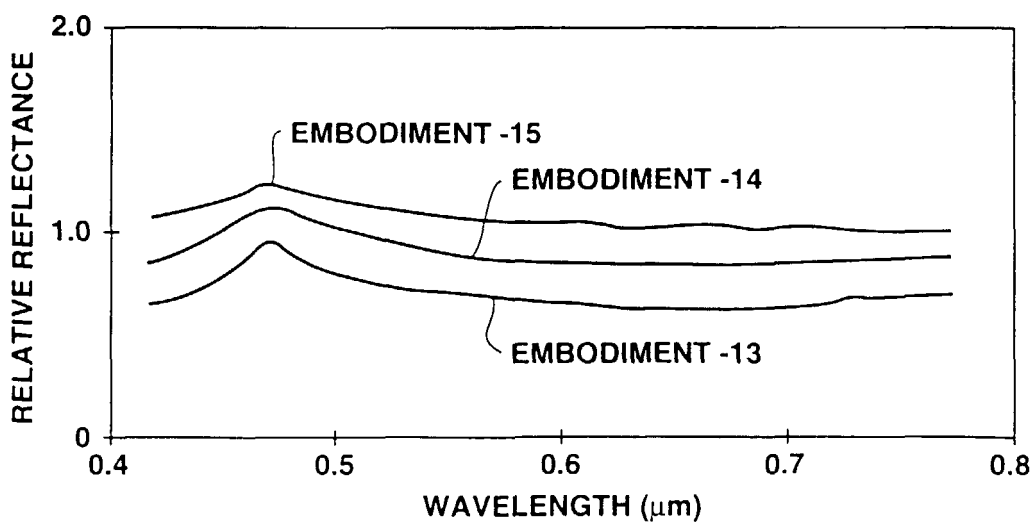


FIG.16





European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 99 12 4235

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
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A	& WO 98 46815 A		
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A	WO 98 50609 A (TANAKA PRECIOUS METAL IND ; SAKIHARA AKIO (JP); ASANO MAKOTO (JP);) 12 November 1998 (1998-11-12) * the whole document *	1-26	
A	EP 0 877 103 A (TANAKA PRECIOUS METAL IND ; NISSAN MOTOR (JP); TEIJIN LTD (JP)) 11 November 1998 (1998-11-11) * the whole document *	1-26	TECHNICAL FIELDS SEARCHED (Int.Cl.7) D01F D01D D03D
A	WO 97 21855 A (NISSAN MOTOR ; TANAKA PRECIOUS METAL IND (JP); SHIMIZU SUSUMU (JP);) 19 June 1997 (1997-06-19) * the whole document *	1-26	
A	US 5 472 798 A (KUMAZAWA KINYA ET AL) 5 December 1995 (1995-12-05) * the whole document *	1-26	
D	& JP 07 034324 A		
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 1 March 2000	Examiner Tarrida Torrell, J
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 99 12 4235

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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01-03-2000

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