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APPARATUS FOR UNIFORM ILLUMINATION
EMPLOYING LIGHT DIFFUSER

5 The present invention relates to an apparatus for uniformly, illuminating a desired object, the apparatus including a light diffusing arrangement which diffuses light outwardly of a light transmission element through which light emitted from a light source propagates.

10 Light transmission elements are known in various forms as typified by quartz glass fibers, optical fibers made of plastics including acrylic resin and polycarbonate resin, and fine tubes or flat plates constituted by such fibers. Where it is desired to utilize the light propagating through such a light transmission
15 element for illumination purpose, for example, the light has to be diffused to be routed to the outside from the light transmission element.

Meanwhile, light coming out from such light transmission elements is usable to illuminate the dials of
20 various meters installed in audio instruments, automotive vehicles and the like. For such application, the light is required to irradiate the dial of a meter uniformly over the entire dial surface.

The present invention aims to achieve this desired
25 uniformity of illumination.

In its broadest aspect, the present invention provides an illuminating apparatus comprising:

a light source;

a light transmission element for transmitting light
30 emitted from said light source; and

a plurality of light diffusing members mounted on said light transmission element, said members each having a refractive index different from that of said light transmission element and being arranged to conduct
5 outwardly of said light transmission element light which has passed along said light transmission element, the arrangement being such as to reduce the variation in the illumination by light output by said diffusing members caused by their different spacings from the light source.

10 In one more particular aspect, the present invention provides an apparatus for uniformly illuminating a desired object comprising:

a light source;

a light transmission element through which light
15 emitted from said light source propagates; and

a plurality of light diffusing members located on said light transmission element and each having a refractive index different from that of said light transmission element, said light diffusing members being
20 arranged to diffuse and discharge outwardly of said light transmission element light propagating through said light transmission element, said light diffusing members having thicknesses which decrease progressively from a maximum for a light diffusing member closest to said
25 light source to a minimum for a light diffusing member farthest from said light source.

In a disclosed embodiment the thickness of said light diffusing members reduces in inverse proportion to the distance of the respective light diffusing member
30 from said light source.

Preferably, the refractive index n_1 of the diffusing members and the refractive index n_0 of the light transmission element satisfy the relationship:

$$n_1/n_0 = 0.87 \text{ to } 0.95$$

35 In another more particular aspect, the present invention provides an apparatus for uniformly illuminating a desired object comprising:

a light source;

a light transmission element through which light emitted from said light source propagates; and

an array of light diffusing members located on said
5 light transmission element, said light diffusing members each having a refractive index different from that of said light transmission element and being arranged to diffuse and discharge outwardly of said light transmission element light propagating through said light
10 transmission element, all of said light diffusing members having the same thickness, the density of said array of light diffusing members increasing progressively from a minimum at a position closest to said light source to a maximum at a position farthest from said light source.

15 Preferably, the density of the array increases in proportion to the distance from said light source.

In each aspect, the light transmission element is preferably made of optical fibres.

Reference will now be made to the accompanying
20 drawings, in which:-

Figure 1 is a view of a light diffusing device and illustrates a basic principle of light diffusion employed in the devices according to the present invention;

25 Figure 2 illustrates a first embodiment of an illumination apparatus embodying the present invention;

Figure 3 illustrates other forms of light diffusing members which can be used in an apparatus according to the invention;

30 Figure 4 illustrates a procedure for forming a concave lens-shaped light diffusing element shown in Figure 3;

Figure 5 illustrates further forms of light diffusing members which can be used in an apparatus according to the invention;

35 Figure 6 illustrates a modification to the apparatus, the modification comprising the provision of a

reflective layer on a surface other than that carrying diffusion members;

5 Figure 7 illustrates a procedure for forming a concave lens-shaped double-layer light diffusing layer structure shown in Figure 5;

Figure 8 is a view of an example of conventional apparatuses intended to provide uniform illumination;

10 Figure 9 is a sectional side elevation of a light diffusing apparatus in accordance with the invention for uniform illumination;

Figure 10 is a schematic plan view of another light diffusing apparatus in accordance with the invention for uniform illumination; and

15 Figure 11 is a section along line XI-XI of Figure 10.

While the apparatus for uniform illumination employing a light diffuser of the present invention is susceptible of numerous physical embodiments, depending upon the environment and requirements of use, substantial
20 numbers of the herein shown and described embodiments have been made, tested and used, and all have performed

in an eminently satisfactory manner.

Referring to Figure 1, a principle of light diffusion employed in the embodiments of the present invention is schematically illustrated. The reference numeral 10
5 designates a light source which may be a bulb, fluorescent lamp, laser, light emitting diodes (LED) or output end of a fiber optic bundle or the like. Light emitted from the light source 10 is incident on the adjacent end of a light transmission element 12 having a refractive index n_0 .
10 Typical examples of the light transmission element 12 may be quartz glass fibers, optical fibers made of plastics such as acrylic resin or polycarbonate resin, or fine tube or flat plate made up of such fibers. A light diffusing material, such as silicon resin or epoxy resin, is applied
15 to a surface of the light transmission element 12 to form light diffusing layers 14. Each of these layers 14 has a refractive index n_1 different from that n_0 of the light transmission element 12. The refractive index n_1 is preselected such that its ratio to the refractive index n_0 , n_1/n_0 ,
20 lies within the range of about 0.87-1.3. Thus, light emitted from the light source 10 and conducted through the element 12 is routed to the outside through the respective light diffusing layers 14. It will be seen that a light component having any desired wavelength can be
25 picked up through the diffusing layers 14 if the refractive index n_1 of the diffusing layers 14 is selected accordingly.

Referring to Figure 2, a light diffuser embodying the present invention is shown and in which the same
30 structural parts as those of Figure 1 are designated by like reference numerals. The light diffuser comprises light diffusing sections or members 16, 18 and 20 arranged in succession on the light transmission element 12. The light diffusing section 16 is constituted by a single
35 light diffusing layer 16a having a refractive index n_1 .

The light diffusing section 18 is made up of two light diffusing layers 18a and 18b having refractive indexes n_1 and n_2 , respectively. The light diffusing section 20 is formed by three light diffusing sections 20a, 20b and 20c whose refractive indexes are n_1 , n_2 and n_3 , respectively. If the refractive indexes n_1 , n_2 and n_3 of the respective layers are different from one another, light components of different wavelengths will come out through the respective light diffusing sections 16, 18 and 20. For example, the light diffusing section 16 may provide a light component L_1 necessary for illumination, the light diffusing section 18 a light component L_2 with thermic rays R removed by the diffusing layer 18b by reflection, and the light diffusing section 20 a light component L_3 with thermic rays R and ultraviolet rays V intercepted respectively by the diffusing layers 20b and 20c. It will be readily understood that where the light diffusing sections 16, 18 and 20 are carried on one side of the light transmission element 12, a reflecting layer 22 may be laid on the other side of the light transmission element 12 where the sections 16, 18 and 20 are absent. It will also be clear that where the light from the light source 10 enters the element 12 in parallel thereto, a reflecting layer 24 may be laid on the end of the element 12 opposite to the light input end.

Referring to Figure 3, another form of light diffusing member is shown.

A light diffusing section 26 is in the form of a convex lens having a refractive index n_1 , while a light diffusing section 28 is in the form of a concave lens having the same refractive index n_1 . Light, therefore, will be converged by the light diffusing section 26 and dispersed by the light diffusing section 28. The convex lens can be formed in a desired shape merely by dropping resin

onto the light transmission element 12, the shape depending on the viscosity and surface tension of the resin, its contact angle with the light transmission element 12, etc. The concave lens, on the other hand, can be formed by the procedure generally demonstrated in Figure 4. In Figure 4, a suitable amount of resin with the refractive index n_1 is filled in a bore 32 of a masking film 30 and, after the resin has been hardened, the masking film 30 is removed to leave the concave lens on the light transmission element 12. The curvature of the concave lens depends on the surface tension of the resin, inside diameter of the masking film 30, etc. If desired, each light diffusing section may be formed by a plurality of convex or concave lenses laid one upon the other, as exemplified by the structure shown in Figure 5.

Referring to Figure 5, a light diffusing section 26' comprises a double-layer convex lens structure made up of two lenses 26a and 26b having different refractive indexes n_1 and n_2 , respectively. Likewise, a light diffusing section 28' comprises a double-layer concave lens structure constituted by two lenses 28a and 28b whose refractive indexes are also n_1 and n_2 , respectively. Stratifying a plurality of lenses of different refractive indexes in the manner shown and described will make it possible to pick up a component of a desired wavelength out of the light routed to the light diffusing section. For example, where visible light is emitted from the light source 10 to become incident on the light transmission element 12 which is provided with the double-layer concave structure 28' as shown in Figure 6, the diffusing lens 28a reflects thermic rays R and the lens 28b intercepts ultraviolet rays V. Again, when the light diffusing sections are carried on one side of the light transmission element 12, a reflecting layer 22' may be laid on the other side where the light diffusing sections are absent; when the

light from the light source 10 enters the light transmission element 12 in parallel thereto, a reflecting layer 24' may be laid on the end of the element 12 opposite to the light input end. Figure 7 shows a procedure for forming the concave lens structure or diffusing section 28' on the light transmission element 12, which procedure is essentially similar to the procedure described with reference to Figure 4. In Figure 7, a suitable volume of resin 28a with the refractive index n_1 is charged and hardened in a bore 32' of a masking film 30', then a suitable amount of resin 28b with the refractive index n_2 is hardened on the first resin 28a, and finally the masking film 30' is removed. The curvature of the resulting concave lens structure is determined by the surface tension of the resin, the inside diameter of the masking film, etc.

It will thus be seen that the light diffuser in any one of the foregoing embodiments is capable of selectively discharging a light component having a specific wavelength at a desired position of a light transmission element. For example, light for illumination can be picked up with thermic rays separated therefrom. Such selective separation of light permits an object of illumination to be formed of a material which is rather poor in resistivity and stability to heat and the like though useful in optical function. This ensures a wider range of selection of materials for objects of illumination.

Now, audio and other acoustic instruments carry various kinds of indication plates and level meters which should be uniformly illuminated throughout their surfaces, due to the nature of such equipments. However, the source voltage presently available for an illumination device is supplied by the secondary winding of a transformer and not higher than about 12-24V. This, coupled with the fact that a lamp serving as a light source cannot

be large due to limitations in design and space, makes the intensity of illumination on the indication plates insufficient and uneven regardless of the illumination system, i.e. transmission type or reflection type. Moreover, in an illumination system using LED's or the like as a light source, a number of LED's are required to render the wiring intricate and the cost prohibitive.

In an automotive vehicle, on the other hand, various meters are arranged on an instrument panel in front of the driver's seat. These meters, particularly the speedometer, have to be illuminated to an even intensity distribution over the entire surfaces of their dials. Figure 8 indicates a conventional automotive speedometer and its associated illuminating arrangement. Shown in Figure 8 are a light source 34 in the form of a lamp, a reflector 36 in the form of a mirror, and a dial 38. As well known to the art, the distance between the reflector 36 and the dial 38 is made larger at a point A close to the lamp 34 than at a point B far from the lamp 34, in an effort to achieve an even distribution of intensities. The intensity, however, unavoidably drops in a position remote from the lamp 34 due to the nature particular to such a system, while a substantial space must be allocated in the aspect of structure. Furthermore, the speedometer of the kind concerned requires a disproportionate number of manufacturing steps as well as a disproportionate cost.

Referring to Figures 9-11, there are shown two different embodiments of the light diffuser of the present invention which are designed to serve as an illumination apparatus capable of eliminating all the drawbacks discussed above. In Figure 9, the illumination apparatus comprises a light source 40 similar to the light source employed in the foregoing embodiments, a light transmission element 42 also similar to the one previously described, and a number of light diffusing layers 44

carried on the light transmission element 42. The refractive index n_1 of the diffusing layers 44 is chosen such that its ratio to the refractive index n_0 of the light transmission element 42 lies within the range of 0.87-0.95.

While light from the light source 40 enters the light transmission element 42 and propagates in the direction indicated by an arrow, it comes out through the respective diffusing layers 44 to illuminate a desired object. In this instance, the luminous flux density is high in the area adjacent to the light source 40 but progressively lowered toward the end of the element 42 remote from the light input end. As a result, the amount of discharged light naturally decreases in the area remote from the light source, dis enabling uniform illumination to be accomplished. In light of this, the embodiment shown in Figure 9 has a characteristic feature that the diffusing layers 44 are made progressively thinner from the one closest to the light source over to the one farthest from the same. Such a thickness distribution of the layers 44 is reflected by an amount of light attenuation which progressively decreases from the layer 44 closest to the light source over to the layer 44 farthest from the same, thereby setting up uniform illumination for a desired object. The back surface 46 and/or the end surface 48 of the light transmission element 42 may be constituted by a reflecting mirror surface in order to more effectively utilize the light incident on the element 42, as described in conjunction with the previous embodiments.

Referring to Figures 10 and 11, another embodiment of the present invention includes a plurality of light diffusing layers 50. These layers 50, different from the layers 44 shown in Figure 9, are arranged to such a density which is lowest in a position closest to a light

source 40' and made progressively higher toward a position farthest from the light source 40', though their thicknesses are common to each other. Illumination accomplished with the arrangement of the layers 50 is as even as that achievable with the layers 44.

Various modifications will become possible for those skilled in the art after receiving the teaching of the present disclosure without departing from the scope thereof.

Reference is hereby directed to copending Application No. 8231644 (Serial No. 2112515) from which this present application is divided.



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CLAIMS:-

1. An apparatus for uniformly illuminating a desired object comprising:

a light source;

a light transmission element through which light emitted from said light source propagates; and

a plurality of light diffusing members located on said light transmission element and each having a refractive index different from that of said light transmission element, said light diffusing members being arranged to diffuse and discharge outwardly of said light transmission element light propagating through said light transmission element, said light diffusing members having thicknesses which decrease progressively from a maximum for a light diffusing member closest to said light source to a minimum for a light diffusing member farthest from said light source.

2. An apparatus according to claim 1 wherein the thickness of said light diffusing members reduces in inverse proportion to the distance of the respective light diffusing member from said light source.



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3. An apparatus according to claim 1 or claim 2 wherein at least one of the light diffusing layers has a flat configuration.

4. An apparatus according to claim 3 wherein the refractive index n_1 of the diffusing members and the refractive index n_0 of the light transmission element satisfy the relationship:

$$n_1/n_0 = 0.87 \text{ to } 0.95$$

5. An apparatus for uniformly illuminating a desired object comprising:

a light source;

a light transmission element through which light emitted from said light source propagates; and

an array of light diffusing members located on said light transmission element, said light diffusing members each having a refractive index different from that of said light transmission element and being arranged to diffuse and discharge outwardly of said light transmission element light propagating through said light transmission element, all of said light diffusing members having the same thickness, the density of said array of light diffusing members increasing progressively from a minimum at a position



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closest to said light source to a maximum at a position farthest from said light source.

6. An apparatus according to claim 5 wherein said density of said array increases in proportion to the distance from said light source.

7. An illuminating apparatus comprising:
a light source;
a light transmission element for transmitting light emitted from said light source; and
a plurality of light diffusing members mounted on said light transmission element, said members each having a refractive index different from that of said light transmission element and being arranged to conduct outwardly of said light transmission element light which has passed along said light transmission element, the arrangement being such as to reduce the variation in the illumination by light output by said diffusing members caused by their different spacings from the light source.

8. A light diffusing device as claimed in any preceding claim in which the light transmission element is made of optical fibers.



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9. An illuminating apparatus substantially as hereinbefore described with reference to Figure 9 of the accompanying drawings.

10. An illuminating apparatus substantially as hereinbefore described with reference to Figures 10 and 11 of the accompanying drawings.
