

[54] **RETRODIRECTIVE REFLECTOR VISIBLE OVER WIDE RANGE OF OBSERVATION ANGLES**

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[51] Int. Cl. **G02b 5/12**

[58] Field of Search **350/97-109; 404/9-16**

[56] **References Cited**

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[57] ABSTRACT

The reflector is constructed of transparent material and has a plurality of reflector elements at the rear and a light-receiving face at the front. Each reflector element has three faces intersecting at three edges, three dihedral angles being respectively defined by the intersection of adjacent faces. Two of the dihedral angles of all of the reflector elements are substantially 90°. The third dihedral angle of at least some of the reflector elements is substantially greater than the angle of the other two dihedral angles, so that light reflected by the reflector is diverged into an elongated pattern.

5 Claims, 11 Drawing Figures

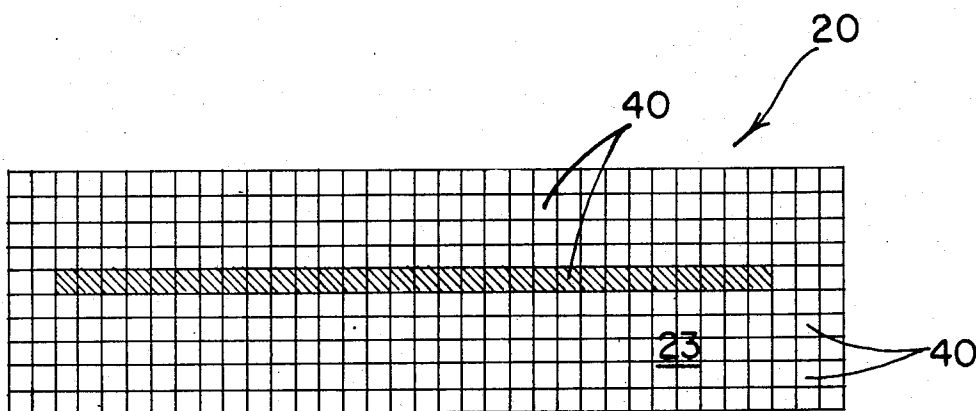


FIG. 1

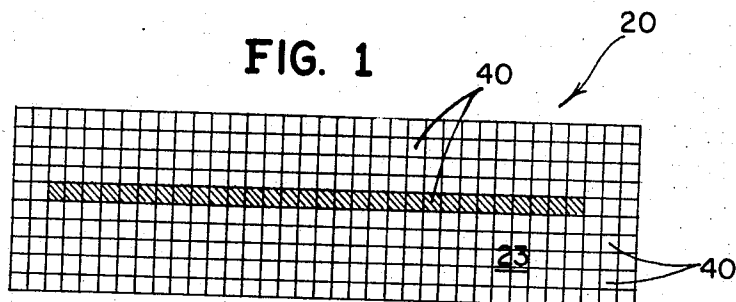


FIG. 2

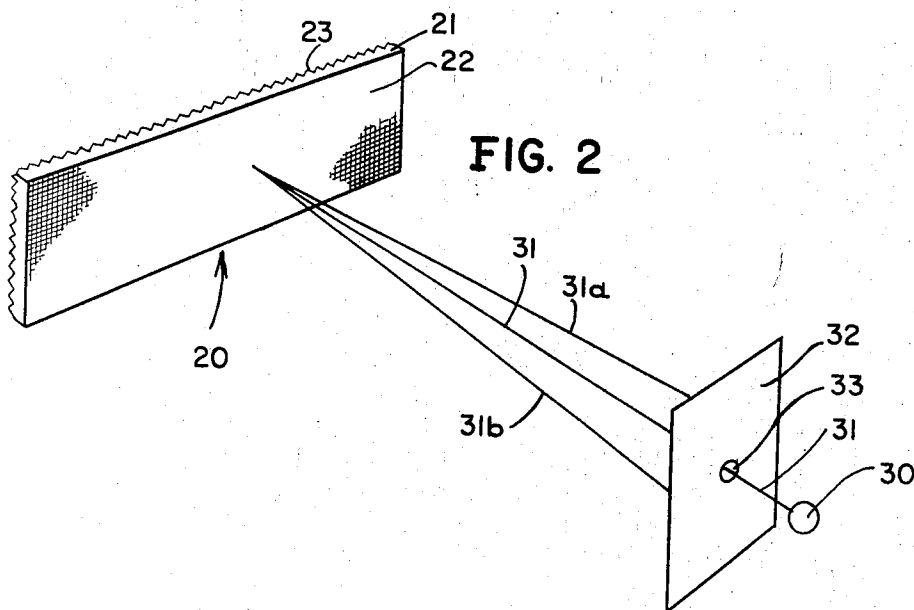


FIG. 3

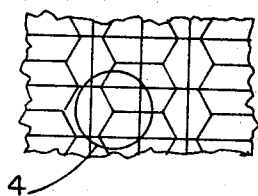


FIG. 4

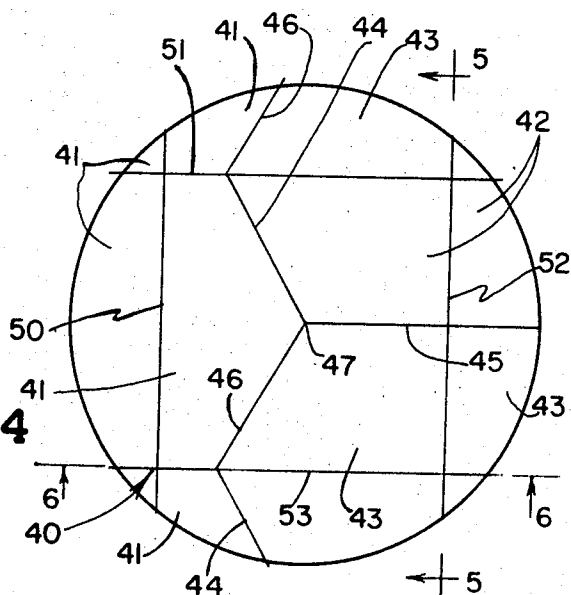


FIG. 5

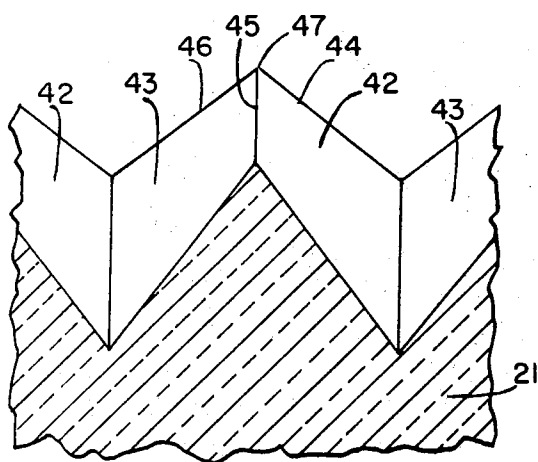


FIG. 6

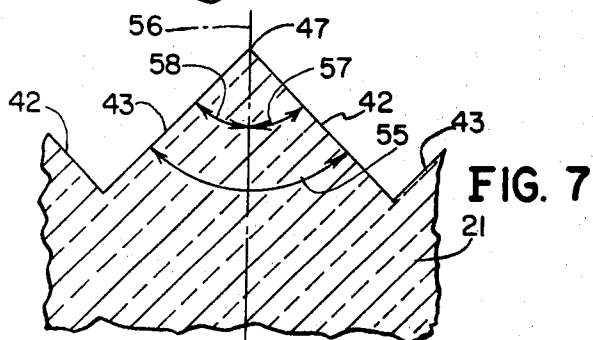
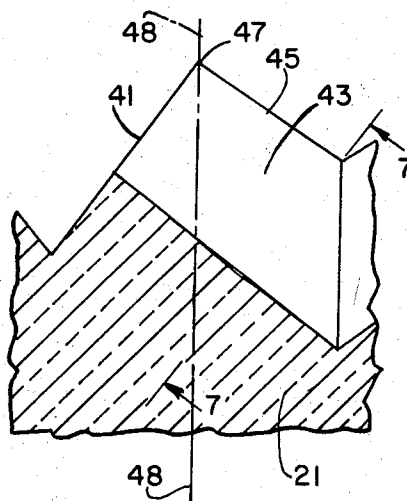


FIG. 7

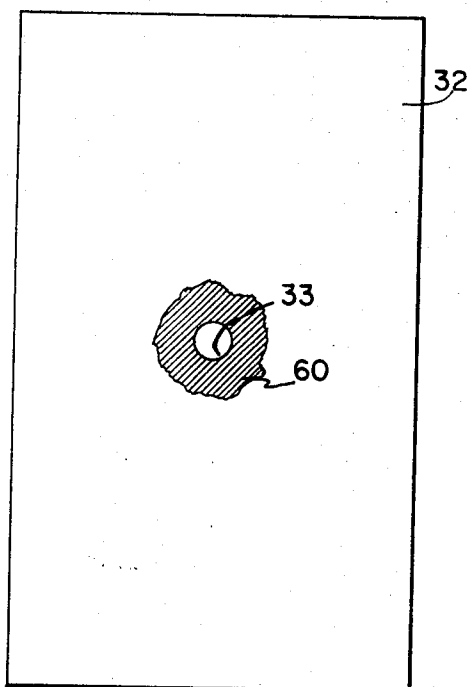


FIG. 8

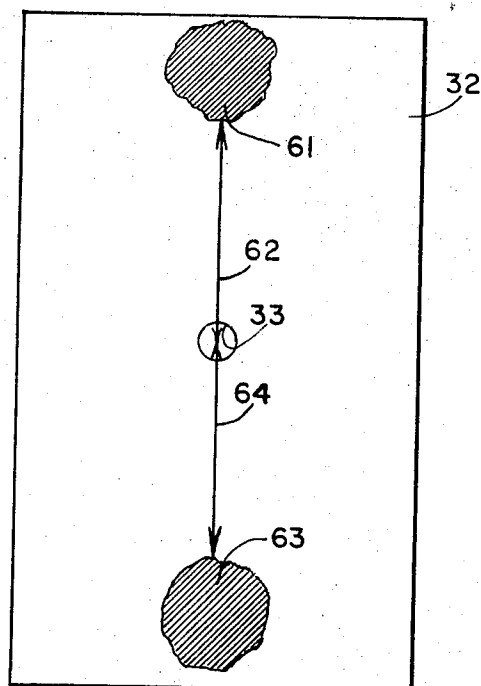
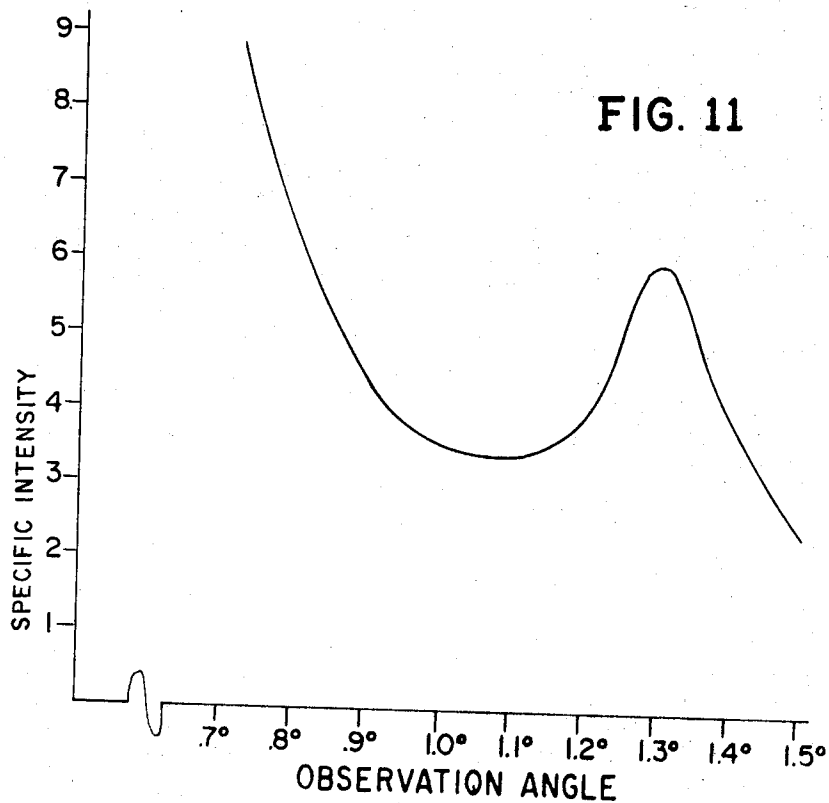
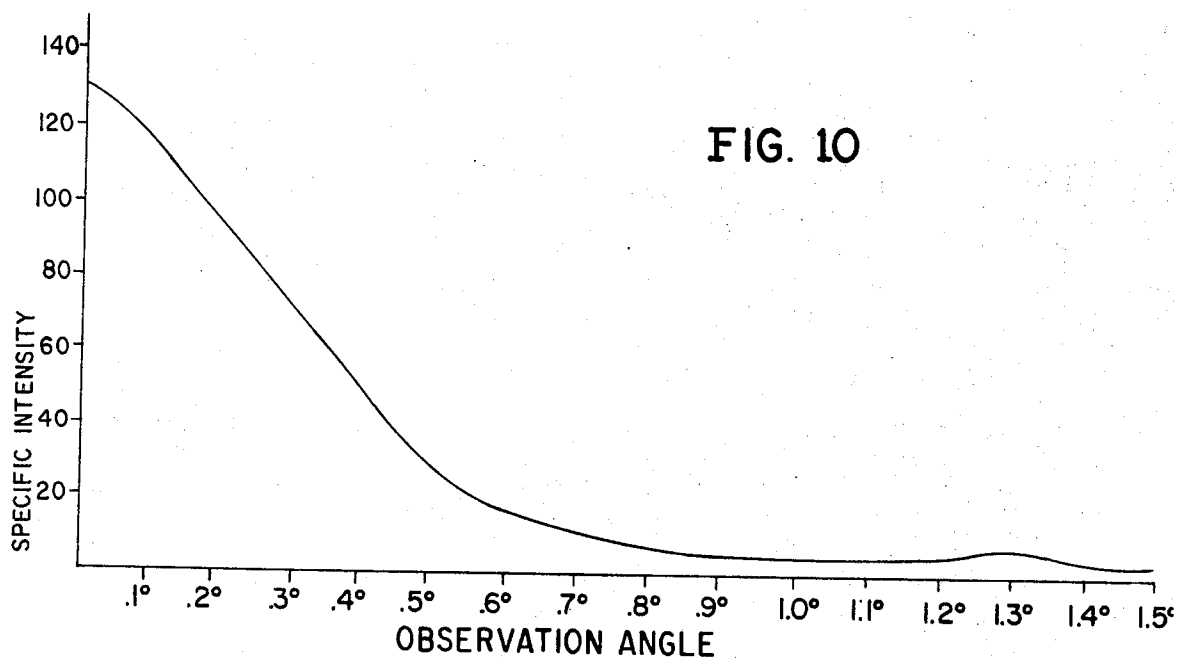


FIG. 9



RETRODIRECTIVE REFLECTOR VISIBLE OVER WIDE RANGE OF OBSERVATION ANGLES

BACKGROUND OF THE INVENTION

A cube-corner retrodirective reflector operates to reflect incident light substantially back to the source of the light. Theoretically a beam emanating from the source and striking such a cube-corner reflector will travel back toward the source essentially along the path of the incident light. If such an "ideal" reflector were mounted on a roadway to be impinged by light emanating from a vehicle head lamp, the reflected light would be directed substantially back to the head lamp. The reflector would appear dark to the driver of the vehicle, since no light would be directed to his eyes.

However, a cube-corner reflector does not have such perfect characteristics but rather, the reflected light takes the form of a narrow cone. This conical pattern is due to inaccuracies in the reflector elements, particularly curvature in the cube-corner faces thereof. The cone is defined by an angle of divergence (angle between cone element and cone axis) at any point within which the specific intensity of the reflected light exceeds a selected value.

The observation angle is defined as the angle between a viewer's line of sight to the reflector and a line from the source to the reflector. In certain instances, it is necessary that a cube-corner reflector reflect more light at substantial observation angles, such as 1.5°. Adding curvature to the cube-corner faces to increase the divergence angle to 1.5° is not satisfactory, since the intensity of light at observation angles of between 0° and 0.5° would be much too low. One solution has been to place prismatic elements or cylindrical surfaces on the front surface of the reflector, which are respectively aligned with selected ones of the cube-corner elements on the back surface. These prismatic elements serve to change the axis along which a peak response is achieved, that is, the nominal divergence axis, from 0° to another value, such as 1.3°. One disadvantage in this approach is that precise registry between the prismatic element and its associated cube-corner reflector element is necessary, but is difficult to achieve. The use of cylindrical surfaces modifies the divergence angle, with the attendant disadvantage above noted.

SUMMARY OF THE INVENTION

It is, therefore, an important object of the present invention to provide a retrodirective reflector which has high reflectivity at greater-than-usual observation angles.

Another object is to provide a retrodirective reflector which has high reflectivity at greater-than-usual observation angles but does not require the use of prismatic formations or the like on the front surface.

Still another object is to provide a reflector which has good response at small observation angles, specifically between 0° and 0.5°, yet has an improved response at greater observation angles, such as 1.5°.

Yet another object is to provide a reflector in which the reflector elements are constructed to have nominal divergence axes at different angles, that is, the nominal divergence axes of some reflector elements are arranged at an angle of 0°, the nominal divergence axes of other reflector elements are arranged at another angle, say 1.3°, and perhaps the nominal divergence axes

of still other reflector elements are arranged at other angles.

In summary, there is provided a retrodirective reflector for retrodirectively reflecting light in an elongated pattern, the reflector comprising a body of transparent material having a light-receiving front face, and a plurality of retrodirective reflector elements at the rear of the body, each of the reflector elements having first and second and third faces intersecting to form first and second and third dihedral angles, the edges respectively defined by the first dihedral angles lying in parallel first planes, the second and third dihedral angles of each reflector element being substantially 90°, the first dihedral angle of at least some of the reflector elements being substantially greater than the associated second and third dihedral angles, whereby light reflected by the reflector is diverged to a greater extent in planes perpendicular to the first plane than in planes parallel to the first plane.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view of the rear surface of a reflector incorporating the features of the present invention, some of the reflector elements being shaded to denote those having nominal divergence axes at angles other than substantially 0°;

FIG. 2 is a schematic view of the reflector of FIG. 1, being impinged by incident light and illustrating the manner in which the reflected light strikes a receiving member, such as a sheet of film;

FIG. 3 is an enlarged fragmentary view of a portion of the rear surface of the reflector of FIG. 1 on an enlarged scale and showing a group of the reflector elements;

FIG. 4 is a greatly enlarged view of the reflector element in the circle marked 4 of FIG. 3;

FIG. 5 is a view in cross section, taken along the line 5—5 of FIG. 4;

FIG. 6 is a view in cross section, taken along the line 6—6 of FIG. 4;

FIG. 7 is a view in cross section, taken along the line 7—7 of FIG. 6;

FIG. 8 depicts a pattern produced by light reflected from a "standard" reflector element;

FIG. 9 depicts a pattern produced by light reflected from a "unique" reflector element incorporating one of the features of the present invention;

FIG. 10 depicts a curve plotting specific intensity against observation angle for the reflector of FIG. 1; and

FIG. 11 is an exploded view of a portion of the curve of FIG. 10.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Turning now to the drawings and more particularly to FIG. 1 thereof, there is shown a reflector 20 incorporating therein the features of the present invention. The reflector 20 comprises a body 21 of transparent material formed of a synthetic organic plastic resin, the preferred resin being methyl methacrylate. The body 21 has a smooth front face 22 which is also flat in the embodiment shown. The body 21 is provided with a configured rear 23 schematically shown in FIG. 1. As will be described presently, the configured rear 23 is made up of a multiplicity of retrodirective reflector elements 40 (represented by shaded and unshaded

squares) which serve to return the incoming ray back toward the source. In the specific form illustrated, the reflector 20 has 320 unshaded reflector elements 40 (hereinafter characterized as "standard" reflector elements) and 30 shaded reflector elements 40 (hereinafter characterized as "unique" reflector elements).

Turning to FIG. 2, the manner in which the reflector 20 operates will be described. There is schematically depicted a source of light 30 which emits a ray 31. The ray 31 passes through a hole 33 in a sheet of film 32. The ray 31 passes through the front face 22 of the reflector 20, through its body 21 to strike the configured rear 23. Because of imperfections in the reflector 20, particularly in the flatness of the faces which make up the reflector elements, some of the light, as represented by the rays 31a and 31b, diverges. Thus, the returning light beam is in the form of a cone. The cone is defined by an angle of divergence (angle between an element of the cone and its axis) at any point within which the specific intensity of the reflected light exceeds a selected value. Depending upon the quality of the reflector, the angle of divergence will vary.

Reference is now made to FIGS. 3-6 which illustrate the details of each of the reflector elements that make up the configured rear 23 of the reflector. The reflector element is designated by the number 40 and includes three faces 41, 42, and 43 which intersect along edges 44, 45, and 46. The faces 41, 42, 43 are inclined away from a common peak or apex. 47. The reflector element 40 has an axis 48.

Each reflector element 40 is square, although the outline could be rectangular, hexagonal, etc. Each reflector element 40 has one side 50 which is recilinear and is contained by the face 41. The end of the edge 44 divides a second side 51 into shorter and longer portions; the edge 45 intersects a third side 52 and divides it into portions of equal length; and the edge 46 intersects a fourth side 53 and divides it into longer and shorter portions. In each reflector element 40, the angle between the faces 41 and 42 is substantially 90°; similarly, in each reflector element 40, the angle between the faces 41 and 43 is also substantially 90°. Finally, most of the reflector elements 40 also have an angle of substantially 90° between the faces 42 and 43, which are the "standard" reflector elements 40 that are unshaded in FIG. 1. An angle can exceed 90° by as much as 6' or 7' and still be "substantially" 90°.

The "unique" reflector elements 40 (those shaded in FIG. 1) have an angle between the faces 42 and 43 substantially greater than the angle between the faces 41 and 42 and the angle between the faces 41 and 43; for example, the angle between the faces 42 and 43 can be 90°30'. The angle between the faces 41 and 42 and the angle between the faces 41 and 43 remains substantially 90°. In either event, because the edge 45 is and remains substantially perpendicular to the face 41, the above-described swivel of the face 42 does not affect the angle it forms with the face 41.

Referring specifically to FIG. 7, the angle 55 between the faces 42 and 43 is substantially greater than the angles between the faces 41-42 and 41-43. The phantom line marked 56 represents an end view of a plane passing through the edge 45 and the element axis 48. The face 42 forms an angle 57 with the plane 56; and the face 43 forms an angle 58 with the plane 56. If the angle 55 is 90°30', the angles 57 and 58 may each be 45°15', in which case both faces 42 and 43 would have

been swiveled in opposite directions about the edge 45. Alternatively, one of the faces, for example, 43, may remain fixed, so that it forms an angle of 45° with respect to the plane 56 and the other face 42 is swiveled about the edge 45 to furnish the desired angle. If the angle 55 was 90°30', the angle 57 would be selected to be 45°30'.

Reference is now made to FIGS. 8 and 9 to describe the manner in which the reflected light pattern is affected by changing the angle 55. FIG. 8 illustrates a piece of film 32 which has been exposed to a light beam reflected by a "standard" reflector element 40. An irregular area 60 centered about the hole 33 represents light reflected from the reflector 20. Since the light diverges, as exemplified by the rays 31a and 31b in FIG. 2, the light will not be concentrated at the center of the hole 33, but, rather, will have some finite size. The intensity at the center of the returning beam will have a maximum value; the farther from the center, the lower the intensity of the beam. Accordingly, the size of the area 60 will be determined by the time the film 32 is exposed. Because the angles between the faces 41-42, 42-43, and 41-43 are substantially 90°, the "nominal divergence axis" along which the intensity of the returning light beam is greatest, is at an angle of substantially 0°. The light reflected by a "standard" element is in the pattern of a narrow, cone having a given angle of divergence.

On the other hand, for the "unique" reflector elements 40 in which the angle 55 between the faces 42 and 43 is, for example 90°30' (the angles between the faces 41-42 and 41-43 are substantially at 90°), the pattern illustrated in FIG. 9 results. The exposed areas are displaced in a direction normal to planes containing the edges 45 and the element axes 48. If these planes are horizontal, which is the orientation illustrated in FIG. 3, then the displacement takes place vertically. The reflected light will cause an area 61 displaced upwardly a distance 62 from the center of the hole 33. Similarly, the reflected light will cause an area 63 displaced downwardly from the center of the hole 33 a distance 64. By measuring the distances 62 and 64 and knowing the distance the film 32 is from the reflector 20, the angle of the nominal divergence axis can be calculated. With the angle between the faces 42 and 43 about 90°30', the angle of the nominal divergence axis in each direction is about 1.3°. It is at this angle (up and down) where the peak light response is achieved. In much the same way as the irregular area 60 in FIG. 8 represented varying intensities of the beam about a nominal divergence area at 0°, the areas 61 and 63 represent varying intensities of the beam about a nominal divergence axis at an angle of 1.3°.

Turning now to FIG. 10, further details of the above-described operation will be described. FIG. 10 depicts a curve, plotting specific intensity, measured in candle power per foot candle of incident light, against observation angle for the reflector 20. The reflector 20 furnished 130 candle power per foot candle of incident light at an observation angle of 0° (line of sight aligned with nominal divergence axis of "standard" reflector elements 40). The specific intensity decreased to 20 at an observation angle of 0.5°. Thus, the nominal divergence axis of the 320 "standard" reflector elements 40 in FIG. 1 is at an angle of 0°.

The presence of the "unique" reflector elements 40 having one 90°30' angle provides a second peak in spe-

cific intensity at 1.3°. FIG. 11 is a vertically expanded version of the curve of FIG. 10 in the region of observation angles from 0.7° to 1.5°. In other words, the nominal divergence axes of the "unique" reflector elements 40 are at an angle of 1.3°. The reflected light is in the form of cones centered about such axes. The value of the specific intensity at 1.3 is dependent on the number of "unique" reflector elements. Thus, if the number of "unique" reflector elements were increased, the specific intensity at 1.3° would increase. Assuming a fixed area accommodating 350 reflector elements 40 in all, increasing the number of "unique" elements by 30 would result in a decrease by 30 of the number of "standard" reflector elements. The latter would result in a decrease in specific intensity of about 10% at the lower observation angles.

The reflector 20 thus has a peak response at about 0°, due to the "standard" reflector elements and another peak response at 1.3°, due to the "unique" reflector elements.

The fact that only the angle 55 between the faces 42 and 43 is increased is significant in that the spread or divergence of the light beam takes place in only one direction (in planes perpendicular to the planes containing the edges 45).

The combination of the "standard" and "unique" reflector elements results in an elongated light pattern, the top and bottom of which is defined by the exposed areas illustrated in FIG. 9. The central portion of this pattern will have an area corresponding to the darkened area in FIG. 8. It should be appreciated that, without the presence of the "unique" reflector elements, the value of specific intensity at a divergence angle of 1.5° would be substantially less than the value of two candle power per foot candle incident light indicated on the graph of FIG. 11.

It is to be understood that the total number of reflector elements 40 in the reflector 20, and the ratio in the number of "standard" elements to the number of "unique" elements control the values of specific intensity. The curves illustrated in FIG. 10 and 11 are merely exemplary. Thus, while the "standard" reflector elements in the instant embodiment have angles of substantially 90°, so as to furnish a nominal divergence axis at an angle of substantially 0°, all three angles can be as much as a few minutes greater than 90°, so that the nominal divergence axis angle would be as much as a few tenths of a degree. Similarly, the angle 55 associated with the "unique" reflector elements 40 can have any value substantially greater than the other two angles, depending upon at what angle the nominal divergence axis or peak value of specific intensity is required.

In essence the "unique" reflector elements 40 have a divergence angle characteristic similar to the divergence angle characteristic of the "standard" reflector elements, except the nominal divergence axis has been shifted from 0° to some other value such as 1.3°. The result is that the "standard" reflector elements 40 enable the reflector 20 to be visible at the usual small observation angles, while the "unique" reflector elements

40 enable the reflector 20 to be visible at greater observation angles. If desired, reflector elements having nominal divergence axes at other angles may be employed. For example, reflector elements 40 having a nominal divergence axis at an angle of 0.8° may be provided to increase the response of the reflector 20 at that angle. Reflector elements having nominal divergence axes at several intermediate angles will flatten out the curves of FIGS. 10 and 11.

The angle of divergence or spread of the curves in FIGS. 10 and 11 in the region of the peak response can be controlled by modifying the faces of the reflector elements 40. By adding some cylindrical curvature thereto, the spread may be increased.

The reflector 20 may be mounted so that planes containing the edges 45 of the reflector elements 40 are arranged horizontally. In that case displacement of the nominal divergence axes occurs in vertical planes.

It is believed that the invention, its mode of construction, and many of its advantages should readily be understood from the foregoing without further description, and it should also be manifest that while a preferred embodiment of the invention has been shown and described for illustrative purposes the structural details are, nevertheless, capable of wide variation within the purview of the invention as defined in the appended claims.

What is claimed is:

1. A retrodirective reflector for retrodirectively reflecting light in an elongated pattern, said reflector comprising a body of transparent material having a light-receiving front face, and a plurality of retrodirective reflector elements at the rear of said body, each of said reflector elements having first and second and third faces intersecting to form first and second and third dihedral angles, the edges respectively defined by said first dihedral angles lying in parallel first planes, said second and third dihedral angles of each reflector element being substantially 90°, said first dihedral angle of at least some of said reflector elements being substantially greater than the associated second and third dihedral angles, whereby the light reflected by said reflector is diverged to a greater extent in planes perpendicular to said first planes than in planes parallel to said first planes.

2. The retrodirective reflector set forth in claim 1, wherein said first dihedral angle of others of said reflector elements is substantially 90°.

3. The retrodirective reflector set forth in claim 1, wherein said first dihedral angle of said some reflector elements is about 90°30'.

4. The retrodirective reflector set forth in claim 1, wherein said first dihedral angle of said some reflector elements is such as to cause the light reflected thereby to have a peak specific intensity at an angle of about 1.3° in planes perpendicular to said first planes.

5. The retrodirective reflector set forth in claim 1, wherein said faces have cylindrical formations thereon to modify the amount of light spread furnished by said reflector.

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