

[54] **METHOD FOR MAKING A CURVED CUBE-CORNER REFLECTOR**
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[73] Assignee: **Amerace Esna Corporation**, Union, N.J.
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[21] Appl. No.: **185,245**
[52] U.S. Cl. **29/416**
[51] Int. Cl. **B23p 17/00**
[58] Field of Search..... 29/416, 400, 155 R, 29/412, DIG. 3

[56] **References Cited**
UNITED STATES PATENTS
2,120,881 6/1938 Assbroicher et al. 29/416
Primary Examiner—Thomas H. Eager
Attorney—Curtis F. Prangley et al.

[57] **ABSTRACT**
The method of making a curved cube-corner reflector includes making a substantially-flat member having a multiplicity of cube-corner elements therein, and then bending the body against a form having a substantially-smooth curved surface so that the reflector assumes the shape of the curved surface.

28 Claims, 58 Drawing Figures

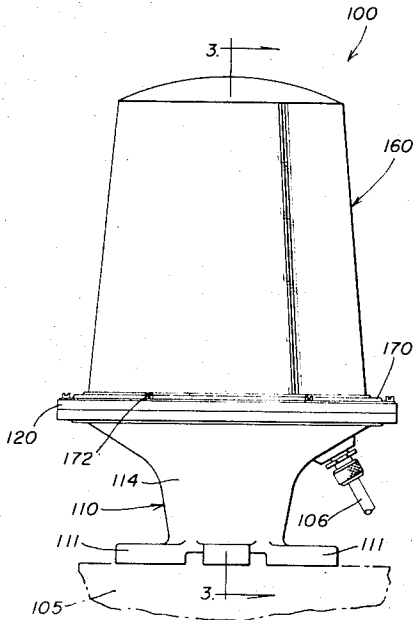


FIG. 1

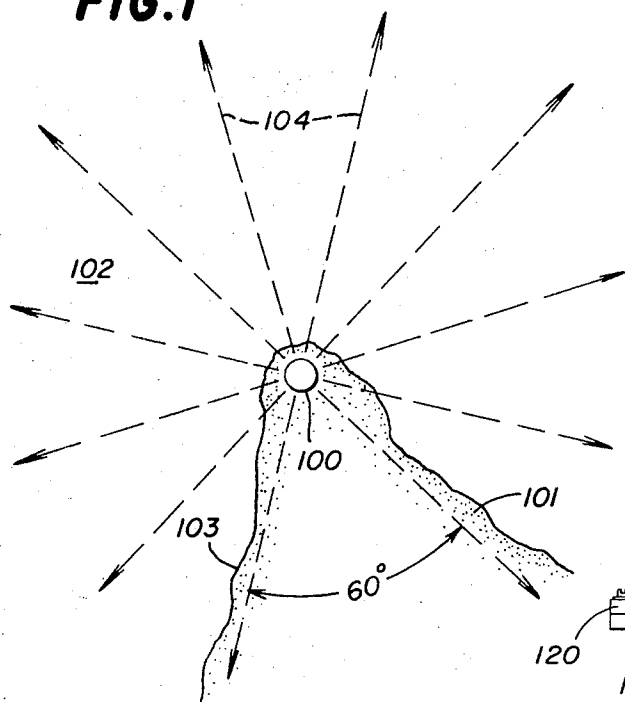


FIG. 2

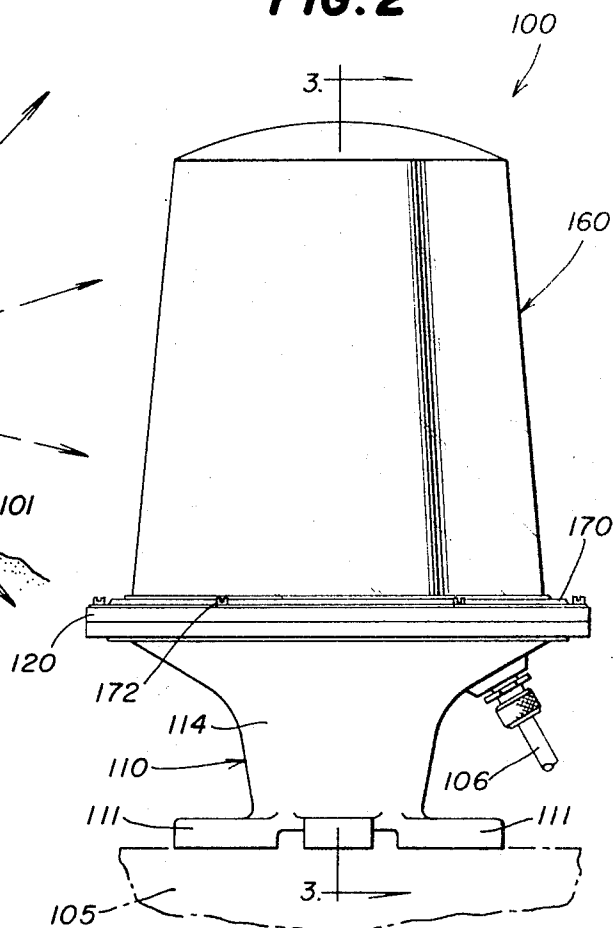


FIG. 22A

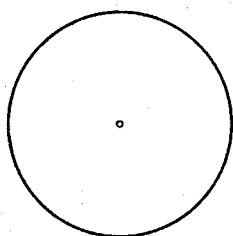


FIG. 22B

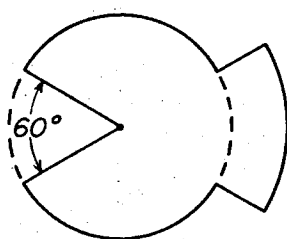


FIG. 22C

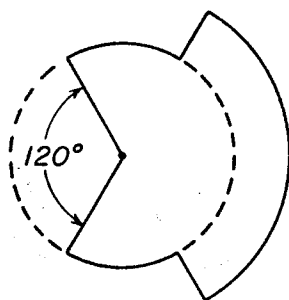


FIG. 22D

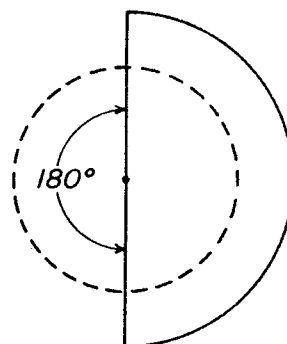


FIG. 4

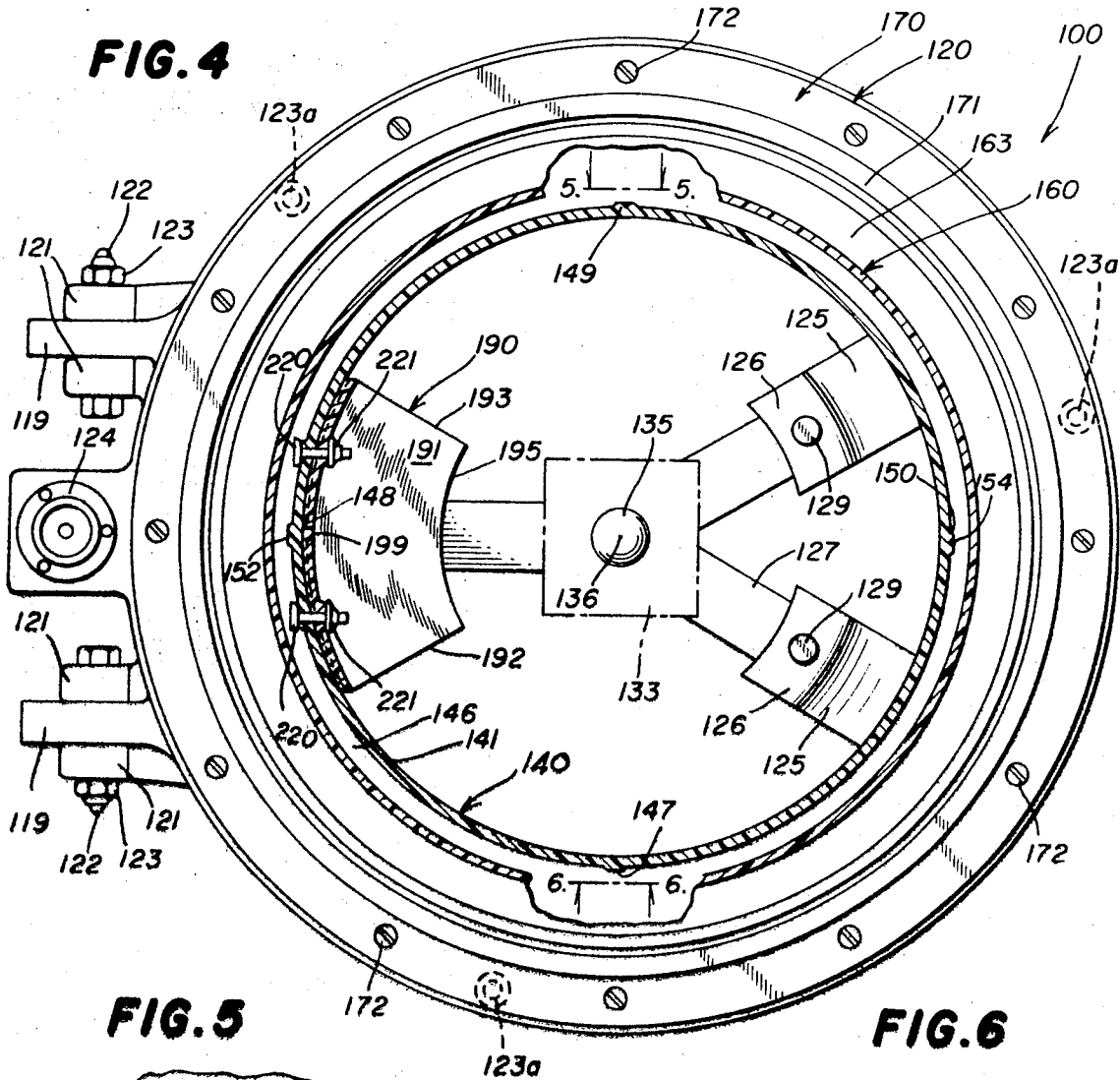


FIG. 5

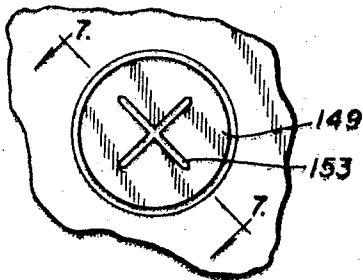


FIG. 7

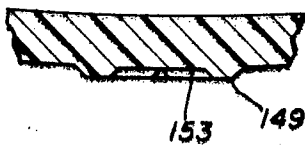


FIG. 6

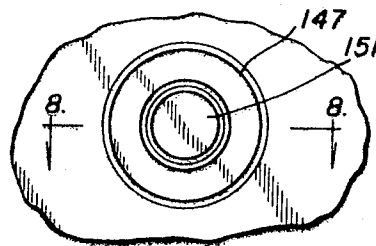


FIG. 8

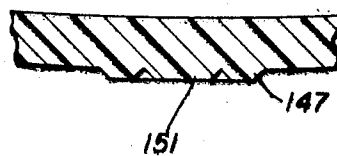


FIG. 9

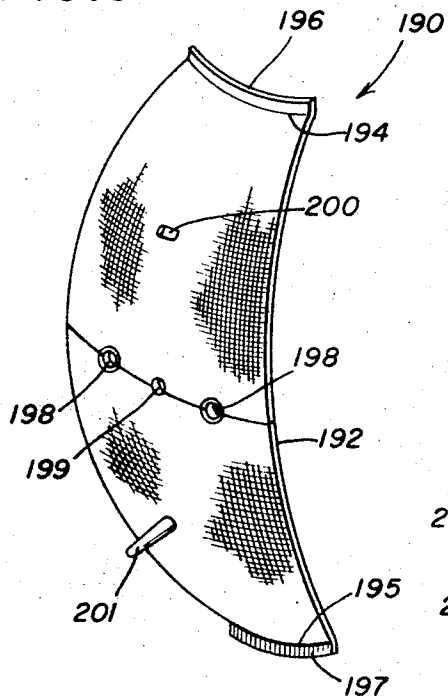


FIG. 10

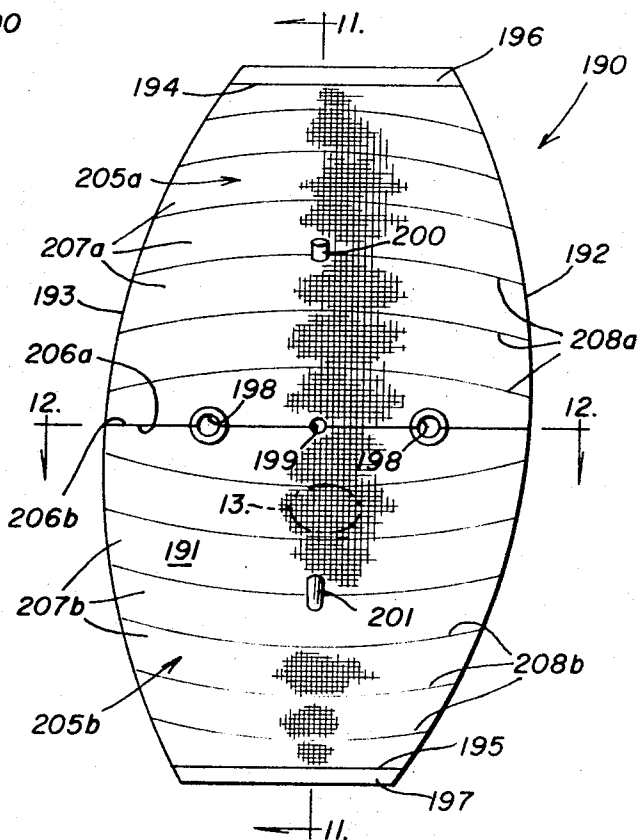


FIG. 11

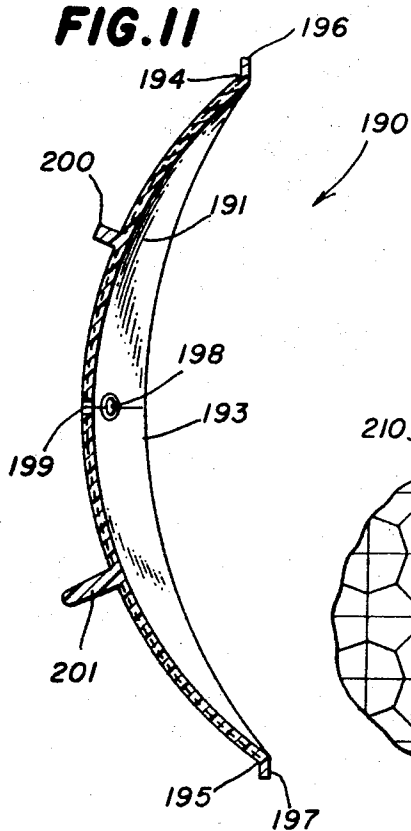


FIG. 12

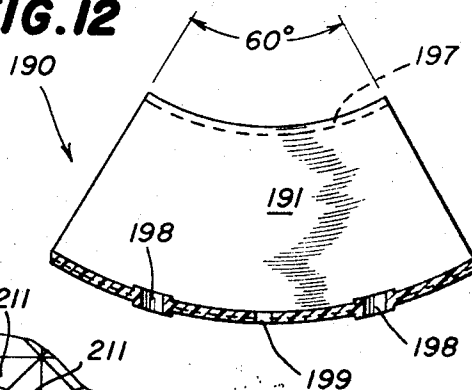


FIG. 13

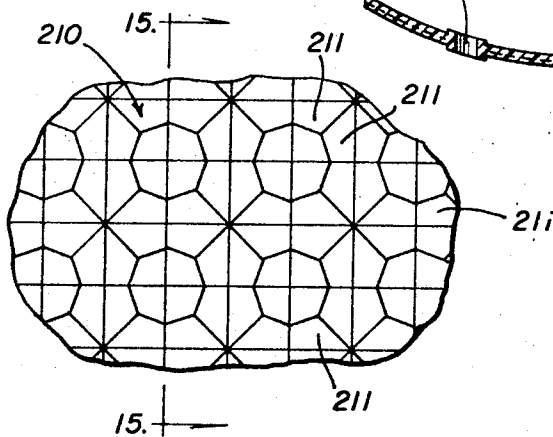


FIG. 15

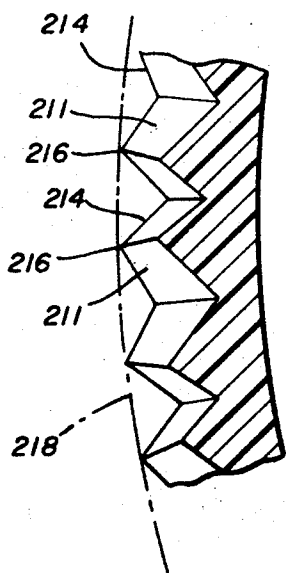


FIG. 14

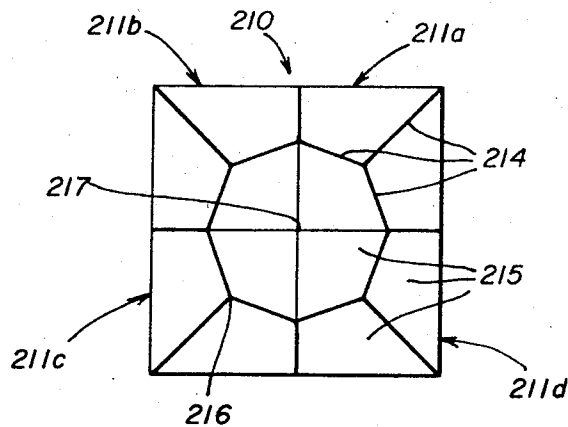


FIG. 16

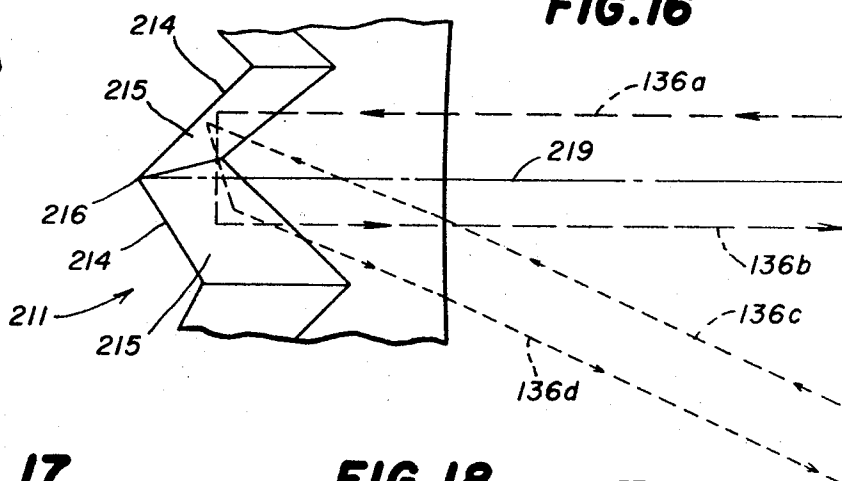


FIG. 17

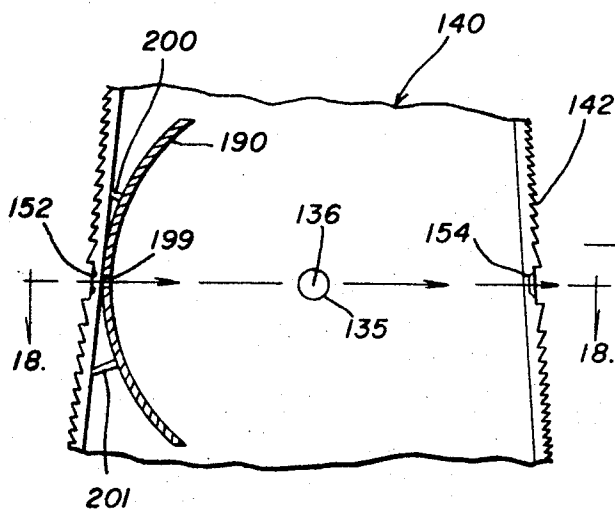


FIG. 18

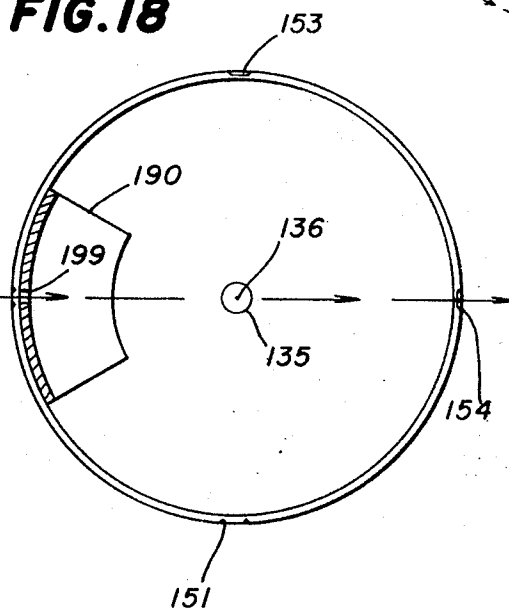


**FIG.
19**

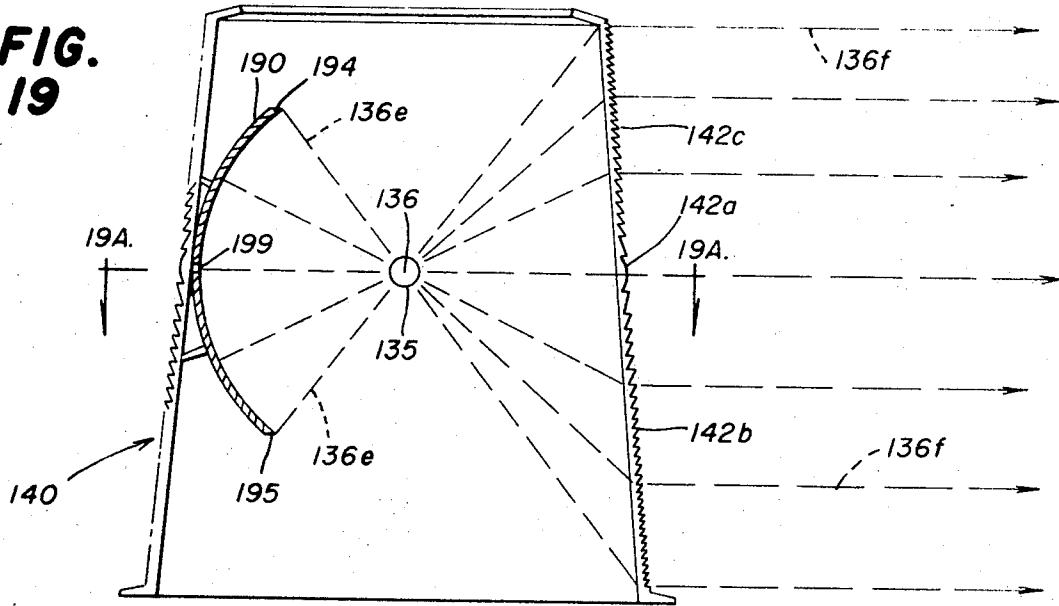


FIG. 19A

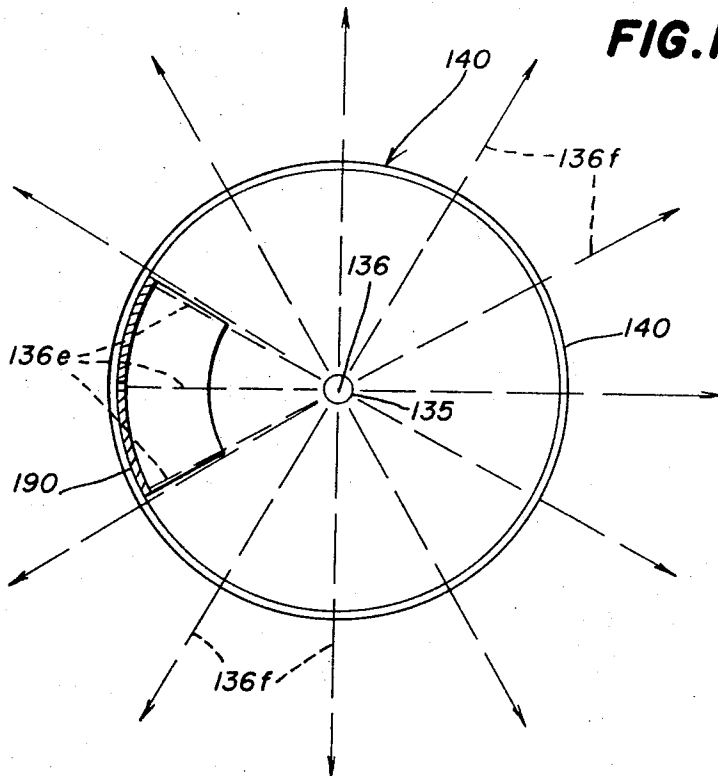


FIG.20

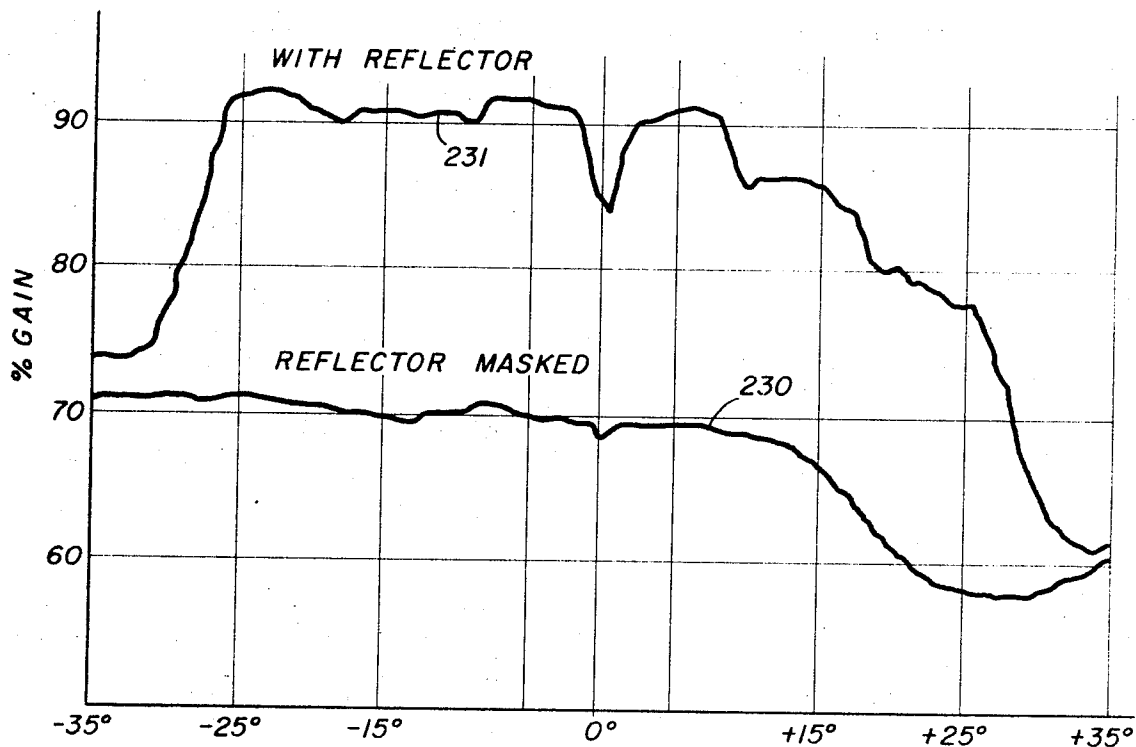


FIG.21

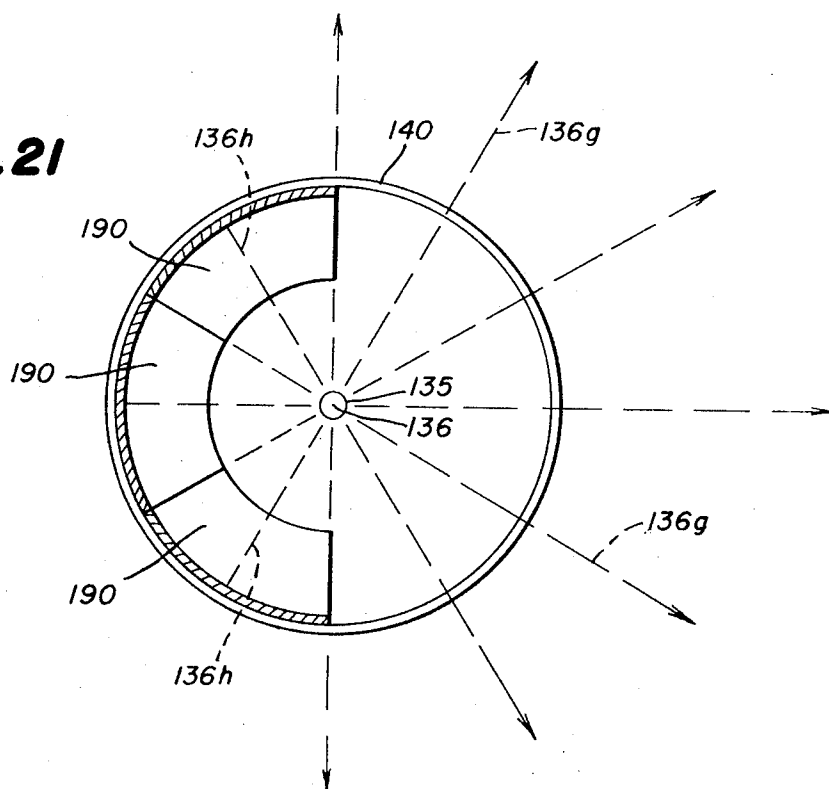


FIG. 23

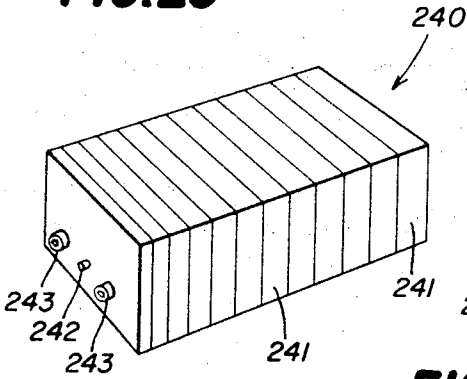


FIG. 24

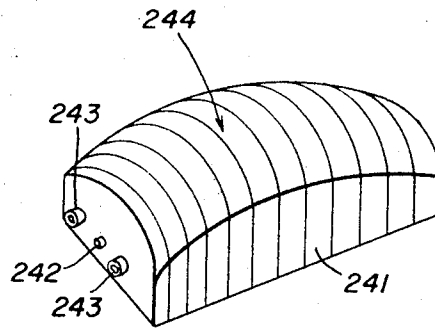


FIG. 25

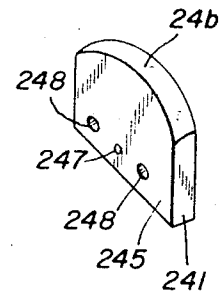


FIG. 26

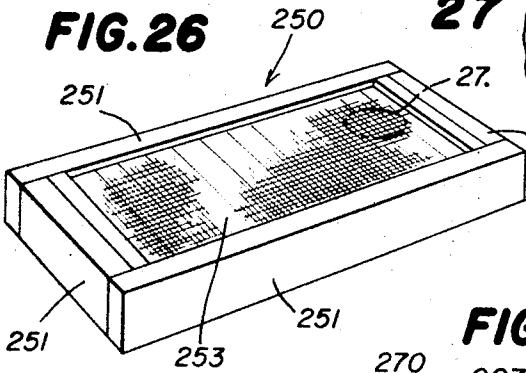


FIG. 27

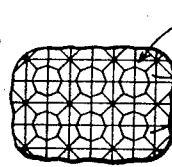


FIG. 29

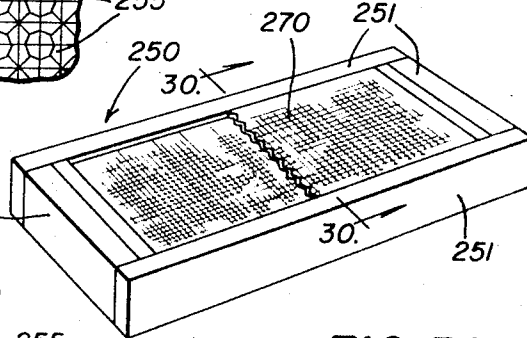


FIG. 31

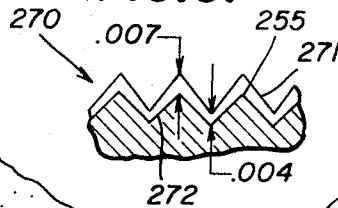


FIG. 30

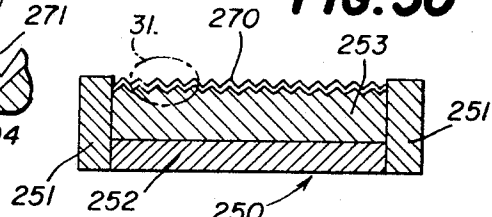


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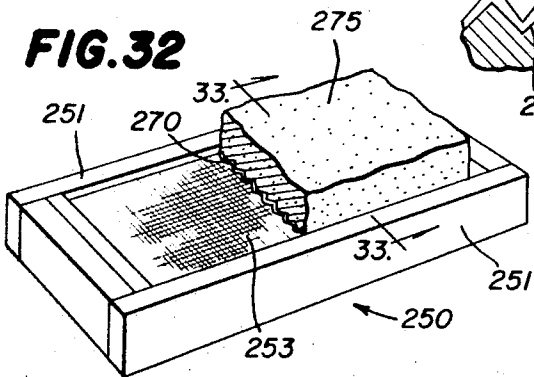


FIG. 33

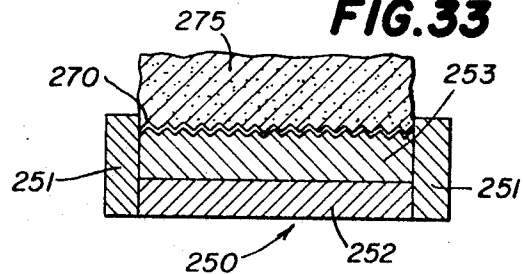


FIG. 28

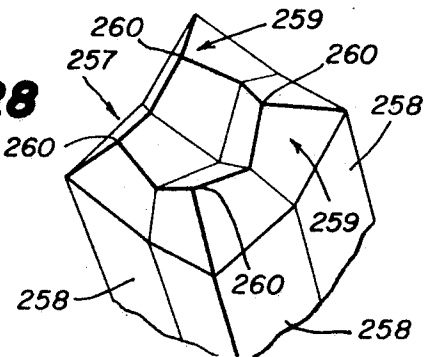


FIG. 34

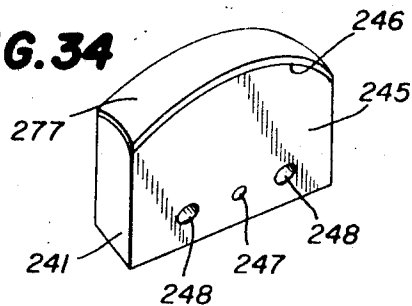


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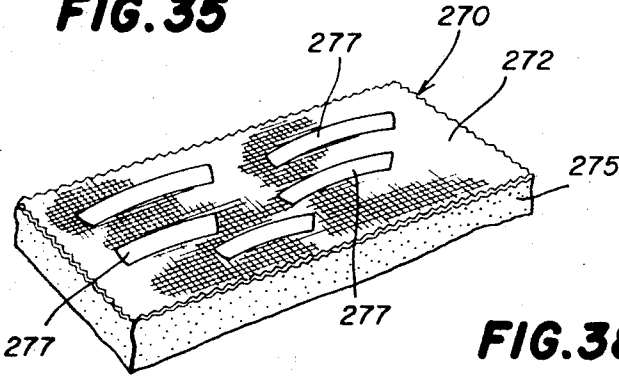


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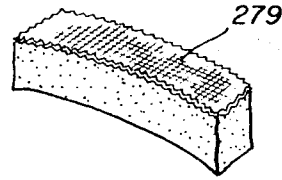


FIG. 38

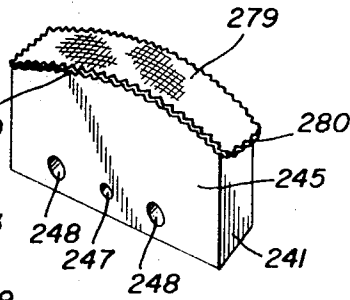


FIG. 37

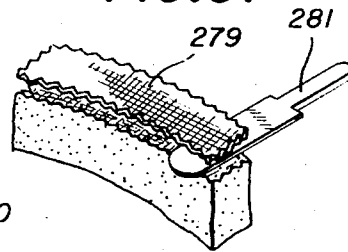


FIG. 39

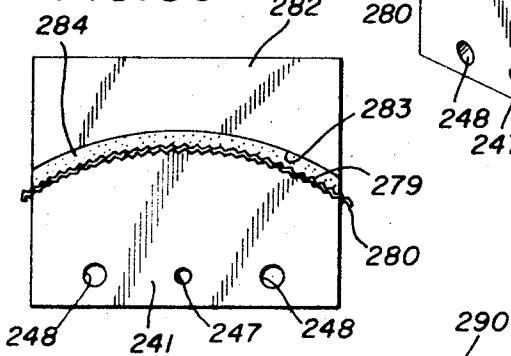


FIG. 40

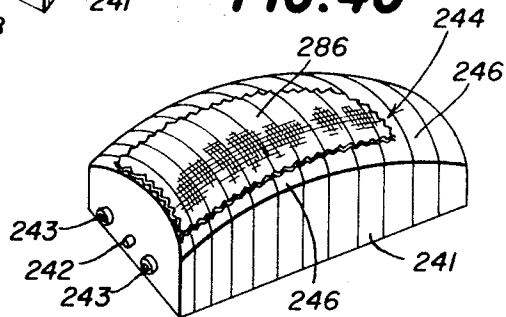


FIG. 41

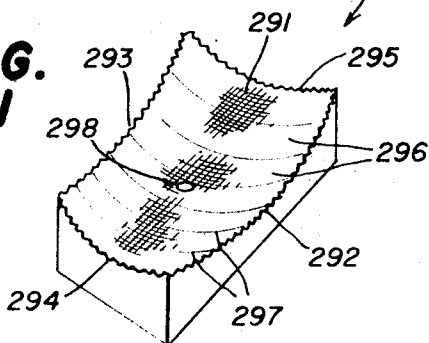


FIG. 42

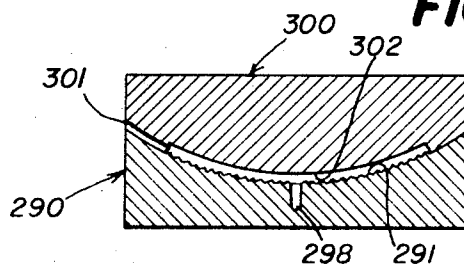


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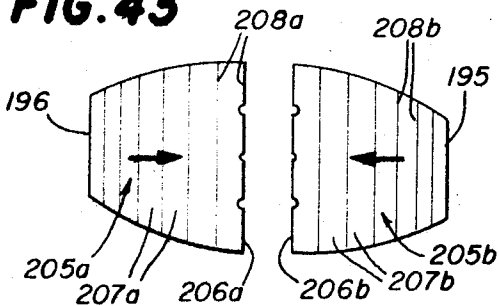


FIG. 44

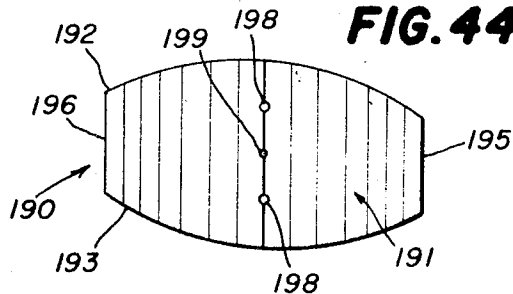


FIG. 45

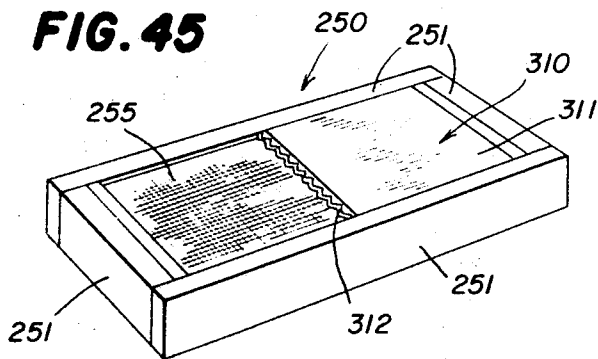


FIG. 46

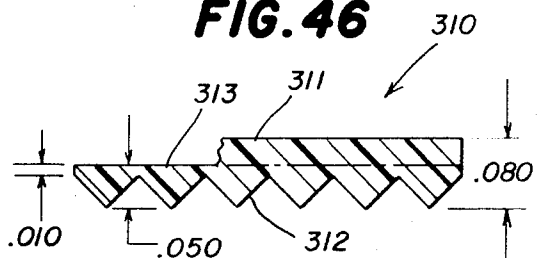


FIG. 47

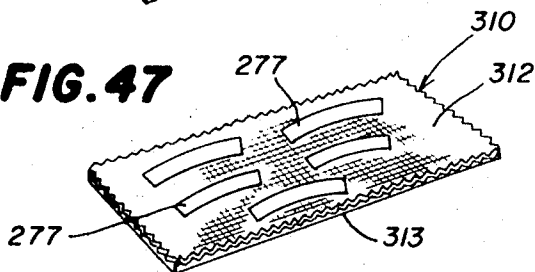


FIG. 48

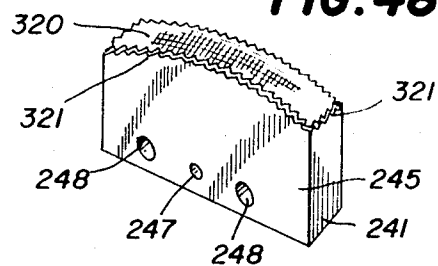


FIG. 49

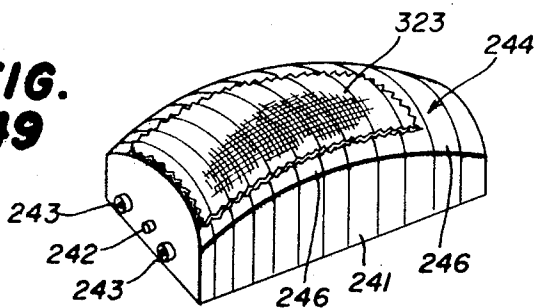


FIG. 50

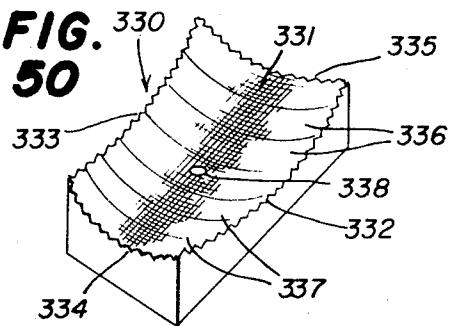


FIG. 51

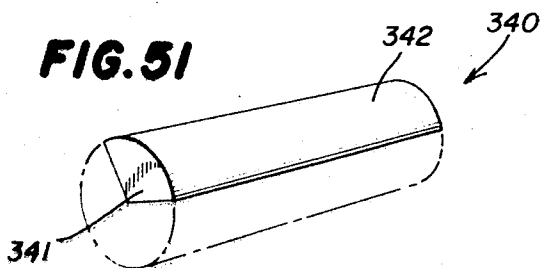


FIG. 52

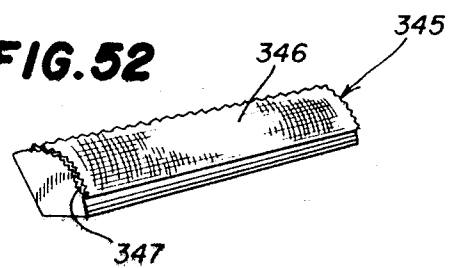


FIG. 53

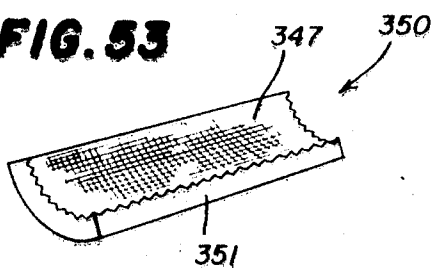
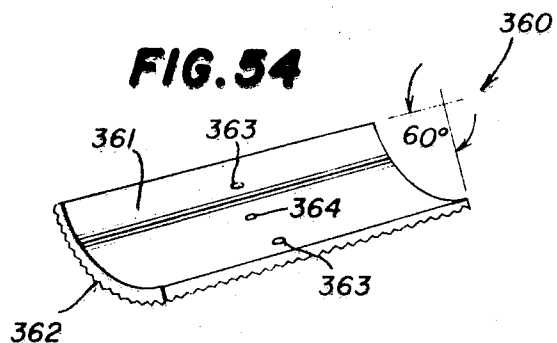


FIG. 54



METHOD FOR MAKING A CURVED CUBE-CORNER REFLECTOR

An important object is to provide a method for making a cube-corner reflector in which the axes are normal to the imaginary curved surface defined by the apexes of the cube-corner elements.

Another object is to provide a method for making a part-spherical reflector having a multiplicity of cube-corner elements therein, the axes of which are radially directed.

There is provided a method of making a mold for a reflector having cube-corner elements therein, the method comprising making a plate-like body having a multiplicity of elements therein, each of the elements having three mutually-perpendicular faces which define a cube corner, providing a form having a substantially-smooth curved surface of the desired final shape of the reflector, bending the body against the form, so that the body essentially assumes the shape of the curved surface, rigidifying the body to enable it to retain the curvature thereof.

In a preferred form, the method of making the mold comprises the steps of providing a die having a multiplicity of cube-corner cavities respectively with apexes lying substantially in a plane, electroforming against the die to provide a metal member having a multiplicity of cube-corner projections therein, removing the member from the die, providing a form having a form surface of a selected curvature, cutting the form into a plurality of segments each having a portion of the form surface, cutting the member into a plurality of pieces respectively having shapes of the form surface portions, bending the pieces respectively onto the associated form surface portions such that the projections are directed outwardly, securing the pieces respectively to the associated form surface portions, securing the segments together, so that the pieces present a multiplicity of cube-corner projections respectively with apexes defining a surface corresponding substantially to the form surface, electroforming against the last-mentioned cube-corner projections to provide a mold having a multiplicity of cube-corner cavities therein respectively with apexes defining a surface corresponding to the form surface.

With the foregoing and other objects in view which will appear as the description proceeds, the invention consists of certain novel steps and certain features of construction, and a combination of parts hereinafter fully described, illustrated in the accompanying drawings, and particularly pointed out in the appended claims, it being understood that various changes in the steps and in the form, proportion, size, and minor details of the structure may be made without departing from the spirit or sacrificing any of the advantages of the invention.

For the purpose of facilitating an understanding of the invention, there is illustrated in the accompanying drawings preferred embodiments thereof, from an inspection of which, when considered in connection with the following description, the invention, its mode of construction, assembly and operation, and many of its advantages should be readily understood and appreciated.

FIG. 1 is a schematic view of a shore line, with a marine lantern mounted adjacent thereto, which marine

lantern incorporates therein the various features of the present invention;

FIG. 2 is an elevational view of the marine lantern illustrated in FIG. 1, on an enlarged scale;

FIG. 3 is a view in vertical section of the marine lantern in FIG. 2, on an enlarged scale, taken along the line 3—3;

FIG. 4 is a view in horizontal section of the marine lantern in FIG. 3, taken along the line 4—4 thereof;

FIG. 5 is a fragmentary view, on an enlarged scale, taken along the line 5—5 of FIG. 4, and illustrating one of the sighting markers;

FIG. 6 is a fragmentary view, on an enlarged scale taken along the line 6—6 of FIG. 4, and illustrating one of the sighting windows;

FIG. 7 is a sectional view, taken through the sighting marker of FIG. 5, along the line 7—7 thereof;

FIG. 8 is a sectional view, taken through the sighting window of FIG. 6, along the line 8—8 thereof;

FIG. 9 is a perspective view of the cube-corner reflector used in the lantern of FIGS. 1—8;

FIG. 10 is a rear elevational view of the reflector;

FIG. 11 is a view in vertical section of the reflector, taken along the line 11—11 of FIG. 10;

FIG. 12 is a view in horizontal cross section, taken along the line 12—12 of FIG. 10.

FIG. 13 is a fragmentary view, on an enlarged scale, of the portion of FIG. 10 within the circle labeled 13, and showing a plurality of cube-corner reflecting units;

FIG. 14 illustrates one of the reflecting units of FIG. 13 on an enlarged scale;

FIG. 15 is a view in vertical section on an enlarged scale, taken along the line 15—15 of FIG. 13;

FIG. 16 is a representation of the manner in which a single cube-corner element retrodirectively returns light;

FIG. 17 is a schematic sectional view showing the fresnel lens and the reflector and illustrating how the light source is positioned with respect thereto;

FIG. 18 is a horizontal section, taken along the line 18—18 of FIG. 17;

FIG. 19 is a schematic view of the collimating lens and cube-corner reflector, illustrating the manner in which these two elements redirect light from the source thereof;

FIG. 19A is a horizontal section taken along the line 19A—19A of FIG. 19;

FIG. 20 illustrates a graph comparing the light intensity at various angular positions with and without the cube-corner reflector;

FIG. 21 is a view showing use of three reflectors mounted on the fresnel lens;

FIG. 22A schematically depicts the candlepower distribution of a marine lantern without the reflector incorporating the features of the instant invention;

FIG. 22B schematically depicts a candlepower distribution of a marine lantern utilizing one reflector which incorporates the features of the present invention;

FIG. 22C schematically depicts a candlepower distribution of a marine lantern utilizing two reflectors each of which incorporates the features of the present invention;

FIG. 22D schematically depicts a candlepower distribution of a marine lantern utilizing three reflectors each of which incorporates the features of the present invention;

FIG. 23 illustrates a block of material cut into segments;

FIG. 24 illustrates a segmented block with a part spherical surface formed thereon;

FIG. 25 illustrates one of the segments of FIG. 24;

FIG. 26 illustrates a die having a multiplicity of cube-corner cavities;

FIG. 27 illustrates, on an enlarged scale, the portion of FIG. 26 within the circle labeled 27, illustrating some of the cavities;

FIG. 28 illustrates a bundle of four pins each having a square outline and a cube-corner element on the end;

FIG. 29 illustrates the die having a thin electroforming thereon, the electroforming having been cut away for purposes of illustration;

FIG. 30 is a sectional view, on an enlarged scale, taken along the line 30—30 of FIG. 29;

FIG. 31 is a view, on an enlarged scale, of the portion of FIG. 30 within the circle labeled 31;

FIG. 32 is a view of the electroform of the die and an epoxy backing on the electroform;

FIG. 33 is a view in vertical section, on an enlarged scale, taken along the line 33—33 of FIG. 32;

FIG. 34 illustrates one of the segments shown in FIG. 24, with a piece of tape having been applied to the part-spherical surface thereof;

FIG. 35 illustrates the backed up electroform member with a number of pieces of tape thereon;

FIG. 36 illustrates a piece of the backed up electroformed member after it has been cut out along the tape margin;

FIG. 37 illustrates the manner in which the electroformed member is removed from the epoxy backing;

FIG. 38 illustrates the electroformed member being bent to conform to the curved surface of one segment;

FIG. 39 illustrates a pressure block being used to secure the electroformed member to the segment;

FIG. 40 illustrates the segments secured together, respectively having the associated electroformed members secured thereto;

FIG. 41 illustrates a mold made by electroforming against the outer surface of the article shown in FIG. 40;

FIG. 42 illustrates a die assembly utilizing the mold of FIG. 41 to produce molded parts;

FIG. 43 illustrates two reflector sections molded in the mold of FIG. 42;

FIG. 44 illustrates the two sections secured together to provide a unitary reflector;

FIG. 45 illustrates the first step in an alternative process of making a curved cube-corner reflector, and depicts a cube-corner mold having thereon a portion of a plastic part molded thereon;

FIG. 46 illustrates that a portion of the smooth rear surface of the reflector has been removed;

FIG. 47 illustrates a number of pieces of tape on the molded reflector;

FIG. 48 illustrates a cutout from the reflector 47 being bent to the shape of the curved surface of one of the segments;

FIG. 49 illustrates the segments secured together respectively having the associated molded members secured thereto;

FIG. 50 illustrates a mold made by electroforming against the outer surface of the article shown in FIG. 49;

FIG. 51 illustrates a step in a process by which a part-cylindrical reflector may be made, and depicts a portion of a cylinder;

FIG. 52 illustrates a thin electroformed member bent to conform to the shape of the outer surface of the cylinder of FIG. 51;

FIG. 53 illustrates a mold made by electroforming against the outer surface of the article shown in FIG. 52; and

FIG. 54 illustrates a part-cylindrical reflector molded against the mold shown in FIG. 53.

Turning now to the drawings, and more particularly to FIG. 1 thereof, the details of the instant invention will be described. There is shown in FIG. 1 a marine lantern 100 which is positioned on the shore 101 adjacent a body of water 102, the shore line 103 between the shore and the water being irregular as indicated. The purpose of the marine lantern 100 in this particular installation is to establish a reference point on the shore. Thus, light that is directed over the shore 101 would be useless in accomplishing this objective. The marine lantern 100 includes means, to be described in detail hereinafter, which reduce the amount of light directed onto the shore 101 and maximize the amount of light 104 directed over the water 102.

Turning now to FIGS. 2 and 4, the details of construction of the marine lantern 100 will be described. The marine lantern 100 is mounted on a foundation 105 which is in place on the shore 101. A power cable 106 provides power to the light source located within the lantern 100.

The marine lantern 100 comprises a base 110, which base 110 includes a set of four outwardly-directed feet 111 spaced 90° from each other. In the outer end of each foot 111 is an opening 112 through which is passed a bolt 113 into the foundation 105 so as to secure the marine lantern 100 thereto. The base 110 further includes a wall 114 which flares upwardly and outwardly. Near the upper end of the flared wall 114 at diametrically-opposite points thereon is a pair of upwardly-directed studs 115 and associated wing nuts 116. The studs 115 and the wing nuts 116 secure a bracket 117 in the base 110, which bracket 117 may carry a flasher assembly 118. The flasher assembly 118 is shown in phantom, since this is a well-known mechanism and may or may not be utilized, depending upon whether it is desired to provide a flashing light or a continuous light. Projecting outwardly from the top of the wall 114 are two sets of spaced-apart ears 119.

The marine lantern 100 further comprise a frame member 120 which is generally round in outline, a pair of laterally-spaced-apart ears 121 being directed outwardly and respectively into the spaces between the two sets of ears 119. A bolt 122 and a nut 123 pivotally mount each ear 119 and the associated pair of ears 121, whereby to pivotally mount the frame member 120 onto the base 110. The frame member 120 can be pivoted counterclockwise, as shown in FIG. 3, to expose the interior of the base 110 to gain access to the flasher assembly 118. There is also provided three screws 123a which respectively threadably engage the outermost portion of the flared wall 114 and the frame member 120, thereby to secure the frame member 120 to the base 110. In order to pivot the frame member 120, the screws 123a would have to be removed. The frame member 120 also carries a level 124 which permits the installer of the marine lantern 100 to adjust the mount-

ing therefor, so that the lantern 100 is perfectly level.

The frame member 120 includes three arms 125, each directed upwardly and inwardly and terminating in a substantially-horizontal portion 126. In order to mount a bracket 127, there is provided three threaded bolts 128 respectively passing downwardly through the horizontal portions 126. Each bolt 128 has a head 129 and passes through a compression spring 130, through an associated opening in the bracket 127, through a bushing 131, and threadably engaging a wing nut 132. The bracket 127 is adapted to carry a bulb-changer mechanism 133. The bulb-changer mechanism 133 is shown in phantom, since it may be of standard construction and does not form part of the instant invention. The bulb-changer mechanism 133 operates sequentially to replace a burnt-out bulb with a fresh bulb. One of the sockets 134 is shown carrying a bulb 135, which bulb 135 has a filament 136. The wing nuts are used to accurately position the filament 136 in a manner to be explained hereinafter. For the present, it should be noted that tightening the wing nuts 132 brings the filament 136 upwardly, and loosening them causes the filament 136 to move downwardly by virtue of the force exerted by the springs 130. Of course, by selectively adjusting the wing nuts 132, the filament 136 can be tilted, in addition to being moved upwardly and downwardly. Also, there is provided a slightly-larger opening in each horizontal portion 126, to enable lateral movement of the filament 136.

The marine lantern 100 further comprises a fresnel lens 140 in the shape of the frustum of a cone, which, in the embodiment shown, has a very slight deviation from a perfect cylinder. The purpose of inclining the wall defining the lens 140 is to provide the proper draft angle to enable the part to be withdrawable from the mold therefor. The interior surface 141 of the lens 140 is also frustoconical in shape and is substantially smooth. Formed on the outer surface of the lens 140 is a plurality of dioptric rings 142 extending from an upper end 143 to a lower end 144, which dioptric rings are of basically known construction, whereby the details of construction thereof will not be described. There is provided a central dioptric ring 142a, a number of lower dioptric rings 142b between the central dioptric ring 142a and the lower end 144, and a lesser number of upper dioptric rings 142c between the central dioptric ring 142a and the upper end 143. The focal point of the dioptric rings 142 is located in a plane passing through the center of the central dioptric ring 142a, at the point of intersection with the conical axis of the lens 140. The upper end 143 terminates in a lip 145 that is directed inwardly and slightly upwardly, and the lower end 144 terminates in a flange 146 directed outwardly. As is best seen in FIGS. 3 to 8, there is provided in the central dioptric ring 142a four bosses 147, 148, 149 and 150 respectively spaced at 90° intervals. Thus, the boss 147 is diametrically opposite the boss 149 and the boss 148 is diametrically opposite the boss 150, all located in the central dioptric element 142a. Formed in the boss 147 is a window 151, in the boss 148 a window 152, in the boss 149 an X-shaped mark 153, and in the boss 150 an X-shaped mark 154. The outer surface of the windows 151 and 152 are curved to match the curvature of the interior surface 141 so that light therethrough is substantially undeviated. The windows 151 and 152 and the X-shaped marks 153 and

154 are used accurately to position the filament 136 of the bulb 135, as will be explained hereinafter.

The marine lantern 100 further comprises a cover 160 which is constructed of transparent material and includes a frustoconical side wall 161 having substantially smooth inner and outer surfaces. The top of the side wall 161 merges into a convex top wall 162, and the bottom of the side wall 161 merges into a flange 163 that is outwardly directed. Formed in the inside of the flange 163 is an annular recess defining a shoulder 164.

The cover 160 is slightly wider than the lens 140, but has the same general slope to the side walls, whereby, when the cover 160 is in place, there is a space between the dioptric elements 142 and the cover 160. The shoulder 164 on the flange 163 rests against the upper surface of the flange 146 on the lens 140. There is provided an annular clamping ring 170 having an offset portion 171 bearing against the upper surface of the flange 163 and is secured to the frame member 120 by means of a plurality of screws 172.

The lantern 100 further comprises a reflector 190. Turning now to FIGS. 9 to 12, the details of the reflector 190 will be described. The reflector 190 has a front surface 191 which is substantially smooth and is part spherical in form with a given center of curvature. The reflector 190 has a pair of side edges 192 and 193 respectively lying in planes containing the center of curvature of the front surface 191. The reflector 190 further has a pair of end edges 194 and 195 respectively lying in chordal planes which are disposed parallel to each other and do not pass through the center of the curvature of the front surface 191. For reasons to be explained hereinafter, the planes which contain the side edges 192 and 193 are not perpendicular to the planes which contain the end edges 194 and 195, and, accordingly, the reflector 190 is slightly skewed. If desired, narrow flanges 196 and 197 may be formed respectively on the end edges 194 and 195 to facilitate stripping the reflector 190 from the mold. Formed in the reflector 190 is a pair of laterally-spaced-apart mounting holes 198 midway between the end edges 194 and 195. Disposed midway between the mounting holes 198 is a sighting hole 199. There is also provided a pair of fingers 200 and 201 directed rearwardly and located on a line passing through the sighting hole 199 and perpendicular to the line joining the mounting holes 198, the fingers 200 and 201 being equidistant from the sighting hole 199. For reasons to be explained subsequently, the finger 200 is about one-half the length of the finger 201.

The reflector 190 is divided into a pair of symmetric sections 205a and 205b which are substantially identical. The ensuing remarks will be directed to the section 205a but it is to be understood the remarks are equally pertinent in respect to the section 205b. The section 205a has side edges which respectively lie in planes containing the center of curvature of the section's front surface and has a longer end edge 206a which also lies in a plane containing the center of curvature of the front surface 191, the plane containing the edge 206a and the plane containing the end edge 194 being substantially parallel. The surface 205a is divided into a plurality of zones 207a separated by boundary lines 208a. The planes containing the boundary lines 208a are disposed parallel to one another and do not pass through the center of curvature of the front surface

191. The end edges 206a and 206b are welded together to provide the unitary reflector 190 depicted. The side edges of the section 205a merge and are continuations of the corresponding side edges of the section 205b, thereby to provide the side edges 192 and 193.

In the form shown, the angular extent of the reflector 190 measured between the side edges 192 and 193 is about 60°, and the angular extent of the reflector 190 between the end edges 194 and 195 is about 110°. Since the side edges 192 and 193 of the reflector 190 lie in planes containing the center of curvature of front surface 191, two or more such reflectors may be butted together, side by side, so as to increase the angular extent from side edge to side edge. Further details on this embellishment will be described hereinafter.

Formed in the rear surface of the reflector 190 is a plurality of juxtaposed reflector units 210, the details of which are most clearly shown in FIGS. 13, 14, and 15, each reflecting unit 210 being composed of four retro-directive reflector elements 211 (a, b, c, and d). Each reflector element 211 is square in outline and is identical to every other element 211. Each element 211 has three faces 215 inclined from a common apex 216. Two faces 215 intersect along an edge 214 extending from the apex 216 to one corner of the square boundary forming the outline of the element 211. The other intersections between adjacent faces 215 extend from the apex 216 to a point at the side of the square boundary of the element 211. The faces 215 extend substantially at right angles to each other to form a portion of a cube, and, hence, the reflector elements will hereinafter be referred to as cube-corner elements. It is to be understood, however, that a cube-corner element is not limited to one having faces of equal area but solely indicates that three faces are perpendicular to one another.

The point 217 constitutes the center of the reflecting unit 210. The element 211a is rotated 90° with respect to the element 211b, the element 211b is rotated 90° with respect to the element 211c, the element 211c is rotated 90° with respect to element 211d, and the element 211d is rotated 90° with respect to the element 211a. Each reflecting unit 211 provides four interior cube corners, the adjacent elements of which are oriented 90° relative to each other. Each reflector element, such as, for example, the reflector element 211, has a cube axis 219 (see also FIG. 16), which cube axis is an imaginary line drawn through the apex 216 with respect to which the three faces 215 are symmetrically arranged and with respect to which the three edges 214 are symmetrically arranged. Thus, each face 215 forms an angle of 35° 16' with the cube axis, and each edge 214 forms an angle of 54° 44' with the cube axis.

As is best seen in FIG. 15, the apexes 216 of the reflector elements 211 define an imaginary surface 218 which is substantially part spherical and substantially parallel to the front surface 191 of the reflector 190. The cube axis of each reflector element 211 is substantially perpendicular to the tangent to the imaginary surface 218 at the apex of that reflector element 211. The imaginary surface 218 in any given zone 207a is curved in the direction of elongation so as to be parallel to the associated portion of the front surface 191. However, for reasons to be explained hereinafter, the imaginary surface 218 in the direction normal to the direction of elongation is substantially flat. Thus, by increasing the number of zones 207a, the better the entire imaginary

surface 218 approximates the surface of a sphere. However, the greater the number of zones 207a, the more boundary lines 208a, which boundary lines 208a adversely affect the immediately-adjacent reflector elements 211.

It should be apparent that with this type of construction the cube axes of the reflector elements 211 are all substantially radially directed, that is, aligned with the center of curvature of the front surface 191 and substantially with the center of the center of curvature of the imaginary surface 218. Light emanating from a light source positioned at that center of curvature will impinge the reflector elements and will be retrodirectively returned by the reflector elements 211 back to the source. This mode of operation is particularly shown in FIG. 16 wherein a filament 136 constituting a light source emits a ray of light 136a directed parallel to the cube axis 219 of the reflector element 211, which ray strikes one of the faces 215 of that reflector element 211. In a known way, the light ray 136a strikes the other faces 215 of that reflector element 211 and is returned as a light ray 136b disposed parallel to the ray 136a and to the cube axis 219. Although the light is shown returning to a point spaced from the filament 136, it should be understood that the reflector element 211, in practice, is very tiny, on the order of 0.040 inch, so that the maximum displacement of the returned light from the source would be 0.040 inch.

If the filament 136 is displaced downwardly so as to emit a ray of light 136c which is not parallel to the cube axis 219, but is rather at an acute angle with respect thereto, the reflector element 211 redirects the ray 136c so as to return as a ray 136d, again parallel to the incoming ray 136c but displaced therefrom by a maximum of 0.040 inch. As long as the angle formed by the incoming ray 136c and the cube axis 219 is less than a critical angle, the reflected ray 136d will return substantially to the source. In a cube-corner reflector, in which the front surface is smooth and a cube corner projects from the rear surface, and is composed of methyl methacrylate resin, this critical angle is about 19°. Thus, as long as the incoming ray forms an angle of $\pm 19^\circ$ with respect to the cube axis 219, the light will be returned substantially to the source thereof. This feature, as will be explained further, facilitates placement of the bulb 135. Specifically, if the filament 136 is precisely at the center of curvature of the reflector 190, all the light rays which impinge on the reflector 190 will be retrodirectively returned to the filament 136, since the cube axes 219 are radially directed. However, even if the filament 136 is slightly removed from the center of curvature, the light will still be returned by the reflector 190 to the filament 136 by virtue of the phenomenon described with respect to FIG. 16.

Referring now to FIGS. 3 and 4, the manner in which the reflector 190 is mounted will be described. A pair of openings is drilled in the central dioptric ring 142a respectively on either side of the boss 148. The reflector 190 is then placed in position as shown such that the outer ends of the fingers 200 and 201 engage the interior surface 141 of the lens 140. The finger 200 is shorter than the finger 201, as the result of the lens 140 having a frustoconical shape. A pair of headed studs 220 is inserted through the holes just formed in the central dioptric ring 142a and through the mounting holes 198 in the reflector 190. A pair of push-on fasteners

221 is applied respectively to the headed studs 220 to secure the reflector 190 in place. In this condition, the sighting hole 199 in the reflector 190 will be aligned with the window 152.

The manner in which the light bulb 135 is positioned in the marine lantern 100 will be described. Referring first to FIGS. 3 and 4, the installer removes the screws 123a to permit the frame member 120 to be pivoted and expose the wing nuts 132. The installer looks through the window 152 which is aligned with the sighting hole 199 in the reflector 190, the X-shaped mark 154 being diametrically opposite the window 152. The installer looks through the window 152 and adjusts the wing nuts 132 to raise or lower the changer mechanism 133 until the filament 136 of the bulb 135 is aligned with the X-shaped mark 154. The changer mechanism 133 can be moved laterally to enable lateral alignment of the filament 136. Then, the installer looks through the window 151 and readjusts the wing nuts 132 until the filament 136 is in alignment with the X-shaped mark 153. Since this latter adjustment may have affected the initial adjustment, the installer then looks through the window 152 and so on until the filament 136 is aligned in both directions. When that occurs, the filament 136 is precisely at the intersection of the conical axis of the lens 140 and the plane passing through the central dioptric ring 142a. It is important that the filament 136 be accurately placed in respect to the dioptric rings 142, which is accomplished as above explained. If the filament 136 is not located at the focal point of the dioptric rings 142, the light will not be properly collimated by the lens 140.

As previously explained, the reflector 190 is so designed that its center of curvature will fall generally at the focal point of the dioptric rings 142. Thus, positioning the filament 136 accurately, as above described with reference to FIGS. 17 and 18, to place it at the focal point of the dioptric rings 142, results in the filament 136 being also approximately at the center of curvature of the reflector 190. However, the placement of the filament 136 with respect to the reflector 190 is not critical, by virtue of the ability of a cube-corner reflector element to return light to its source within an angle of as much as $\pm 19^\circ$. It should be understood that, if the reflector 190 had a simple spherical surface, the filament 136 would have to be placed accurately with respect to both the dioptric rings 142 and the reflector 190, an almost impossible task, since there is only one degree of freedom to satisfy two parameters.

Referring now to FIGS. 19 and 19A, the details as to the manner in which the marine lantern 100 functions will be described. Light rays 136e from the filament 136 strike the reflector 190, and, by virtue of its retrodirective reflecting capabilities, those light rays are returned back to the filament 136, so as to reinforce the light therefrom. The light rays 136e being emitted directly by the filament 136 and/or reinforced by light reflected by the reflector 190 strike the interior surface 141 of the lens 140 and are refracted and then refracted again when they strike the dioptric rings 142, so as to emerge as light rays 136f disposed horizontally. Thus, the lens 140 serves to condense in at least one direction (that is, vertically in the form shown) the light emitted by the filament 136. Although only light rays 136f are shown in FIG. 20, it is to be understood that the lens 140 emits a solid beam of light extending from the uppermost light ray 136f to the lowermost light ray

136f. If the angular extent of the reflector 190 measured in the horizontal plane is 60° , then the angular extent of the beam would be about 300° , there being no light emitted in the region of the reflector 190. Thus, in the region where no light is needed, light is not emitted, but, rather, is used to reinforce and intensify the light emitted in the useful region. Accordingly, the wattage of the bulb 135 may be less than what would be needed if the reflector 190 were not used, or the same wattage bulb could be used and thereby increase the intensity of the light within the desired region.

The angular extent of the reflector 190 in the vertical direction (in the direction of its elongation) is such that a light ray 136e from the filament 136 that strikes the upper end edge 194 will be retrodirectively reflected back to the source and thence to the lowermost dioptric ring 142. Stated in another way, a point on the upper end edge 194 of the reflector 190, the filament 136, and a point on the lowermost dioptric ring 142 should lie in a straight line. Similarly, a point on the lower end edge 195 of the reflector 190, the filament 136, and a point on the uppermost dioptric ring 142 should lie in a straight line. If the angular extent of the reflector 190 were any greater, the light rays striking the extremities of the reflector 190 would be retrodirectively reflected back through the filament 136 and then along a path which does not intersect the lens 140.

In order that each point on the upper end edge 194 of the reflector 190 have a corresponding point on the lowermost dioptric rings 142, the upper end edge 194 should lie in a plane parallel to the horizontal planes which define the upper and lower boundaries dioptric rings 142. Similarly, the lower end edge 195 of the reflector 190 should lie in a horizontal plane parallel to the planes defining the dioptric rings 142.

It should be pointed out that if the light bulb 135 is sufficiently close to the lens 140, some of the dioptric rings would have to be of the catadioptric type in which both reflection and refraction occurs to bend the rays sufficiently.

Referring to FIG. 20, which plots angular position as the abscissa and light level readings as the ordinate, the curve 230 represents the condition when the reflector 190 is masked. The curve 230 deviates from a theoretically flat curve due to shielding by the bulb support and nonuniform output by the bulb 135. The curve 231 represents the condition with the reflector 190 unmasked. Within approximately the 60° opposite the 60° range of the reflector 190, there is substantial improvement in light output. It should be understood that the ordinate does not represent actual light levels but rather relative meter readings. Thus there is about a 30 percent improvement in light intensity within the 60° opposite the 60° range of the reflector 190.

The dip in the curve 231 at 0° is due to the discontinuities in the reflector 190 caused by the sighting hole 199 and the fingers 200 and 201.

The marine lantern 100 is constructed to be usable in an environment such as shown in FIG. 1, that is, on a piece of land that juts into the water and only a narrow angular region does not require light. If the region not requiring light were expanded, additional reflectors 190 can be utilized. Reference is made to FIG. 21 which illustrates three reflectors 190 arranged side by side and all mounted to the lens 140. In this case, light rays 136h from the filament 136 directed toward the left, as viewed in FIG. 21, will strike one of the reflectors

tors 190 and retrodirectively will be returned to the filament 136. Light emanating directly from the filament 136 or being retrodirectively returned thereto is emanated in the form of rays 136g. Thus, light which is otherwise wasted is returned to the filament 136, to reinforce the light therefrom that is directed to the desired region.

In lining up the bulb 135 when three reflectors are mounted in the marine lantern 100, the middle reflector 190 will be in the same position as that shown for the single-reflector embodiment of FIGS. 1 to 20. Accordingly, the window 152 is aligned with the hole 199 in the middle reflector 190, thereby permitting to enable viewing of the X-shaped mark 154. The window 151 is disposed immediately to the right of the lowermost reflector as viewed in FIG. 21, and the X-shaped mark 153 is immediately to the right of the uppermost reflector 190 as viewed in FIG. 21. Accordingly, there is provided a line of vision between the window 151 and the X-shaped mark 153 to permit the requisite adjustment of the bulb 135.

It is to be understood that two reflectors 190 may be utilized and it would, of course, depend upon the specific need as to whether one, two, or three reflectors 190 would be required. With no reflectors, the light distribution will be as shown in FIG. 22A. With one reflector a 60° zone will be blacked out and the light projected into the opposite 60° zone will be intensified (see FIG. 22B). With two reflectors, a 120° zone is blacked out and the light projected into the opposite 120° zone is intensified (see FIG. 22C). With three reflectors, a 180° zone is blacked out and the light projected into the remaining 180° zone is intensified (see FIG. 22D). Of course, whatever zone is blacked out will appear dark so as not to be a nuisance to persons living in the area near the marine lantern. Also, by preventing light from being projected into an unnecessary zone and utilizing that light in another zone, a lesser wattage light bulb may be utilized and still achieve the same light intensity, at least in a portion of the zone. Of course, a lesser wattage light bulb consumes less power and therefore costs less to operate. If a battery is used, this would mean an increased life for the battery.

As was previously explained, the planes respectively containing the side edges 192 and 193 of the reflector 190 are not perpendicular to the plane passing through the holes 198 and 199, that is, a horizontal plane. Thus, when the reflector 190 is mounted, such that the holes 198 and 199 are horizontal, the side edges 192 and 193 are skewed, that is, the planes containing these side edges are not arranged vertically. When two or more reflectors 190 are butted together, the side edge 192 of one of the reflectors will abut and perfectly match the side edge 193 of the other reflector 190. In this way, the juncture between the adjacent reflectors 190 is not disposed in a vertical plane. If the line were in a vertical plane, a viewer, standing at a point on a line passing through the filament 136 and that vertical line, would see a substantial decrease in light intensity over that which he would see on either side of that point.

The zones 207a and 207b are horizontally arranged for similar reasons. If the zones were vertically arranged, then the boundaries 208a and 208b would be disposed in vertical planes, and there would be a number of angular positions at which the light intensity would be substantially reduced. By arranging these zones 207a and 207b horizontally, the amount of light

at any angular position is only very slightly affected, since the viewer sees a narrow, vertically-arranged strip of light which appears vertically continuous by virtue of the action of the dioptric rings 142.

By constructing the edges 194 and 195 such that they are in planes parallel to each other and horizontally disposed when the reflector 190 is mounted in use, when two or more reflectors 190 are butted together, the upper and lower edges will continue to be in horizontal planes. This means that each point on the upper edge of the reflectors 190 will have a corresponding point on the lowermost dioptric ring 142. Similarly, each point on the lower edge of the abutting reflectors 190 will have a corresponding point on the uppermost dioptric ring 142.

In practice, the Fersnel lens 140 does not collimate the light perfectly, first, because the dioptric rings 142 are not perfect in formation and, second, because the filament 136 is not a point source of light. Rather, it has length so that a ray of light emitted from one portion of the filament would be deviated slightly when it is retrodirectively reflected by the reflector 190. The inaccuracies in the dioptric rings 142 and the fact that the filament 136 is not a perfect point source, causes the beam from the marine lantern 100 to spread vertically slightly.

Although the reflector 190 finds particular use in a marine lantern 100 of the type described, it is to be understood that such reflector has a great number of other uses. The reflector may, for example, be cylindrical, in which case the imaginary surface defined by the apexes of the cube-corner elements is part cylindrical, and the cube axes would be perpendicular to the imaginary surface. Also, it is to be noted that although the reflector 190 has cube-corner elements of a square outline, elements having a hexagonal outline or a triangular outline are contemplated, although the square outline is preferred.

Turning now to FIGS. 23 to 44, the details of the method for making the reflector 190 will be described. Referring specifically to FIG. 23, there is shown a block 240 in the shape of a rectangular parallelepiped. The block 240 is divided into twelve segments 241, the width of each of which increases from left to right, as viewed in FIG. 23. A rod 242 is positioned through the segments 241 and another pair of rods with threaded ends are also positioned through the segments 241, nuts 243 being threaded onto the rods. The rods hold the segments 241, as shown. A part-spherical surface 244 is formed on the top surface of the block 240, as shown in FIG. 24. Each segment 241 has a pair of sides 245 lying in parallel planes, whereby the upper surface of each segment 241 defines a zone 246. The thickness of the segments 241 varies in order that the lateral (measured transverse to the sides 245) arc length of each zone 246 is equal. Thus, a segment 241 with substantial angle will be thinner than a segment 241 with less angle.

The next step is to form a cube-corner member. To that end, there is provided a die 250, as shown in FIG. 26, having four side walls 251 rectangularly arranged and a bottom wall 252. Mounted within the side walls 251 is a part 253 having therein a multiplicity of cube-corner units 254 (FIG. 27). Each cube-corner unit has four cube-corner cavities 255, each being rotated 90° with respect to the adjacent cube-corner cavity. Each cube-corner cavity 255 is comparable to that shown in

FIGS. 13 through 16, but, however, in the form of a cavity instead of a projection. To make the part 253, an array of pins are held together. Reference is made to FIG. 28 which illustrates a single pin bundle 257 made up of four pins 258, each having a square outline and a cube-corner projection 259 at the outer end thereof. Each cube-corner projection 259 is made up of three mutually-perpendicular faces 261 having a common apex 260. When a number of the pin bundles 257 are grouped together, they may be placed in a plating tank in which nickel or the like is deposited or electroformed onto the cube-corner projections 259. After a period of time, a sufficient thickness of material has been electroformed onto the cube-corner projections to render the electroform self-supporting. At that time, it is pried off of the pins 258, and the electroforming that is separated therefrom, after being cut and otherwise treated, becomes the part 253 in the die 250. Of course, the steps of electroforming are known in the art, whereby the above description is a sketchy one, simply to describe the over-all process. It is to be understood that there may be a great many steps in the process of forming the pins into the desired array, all the way up to obtaining a rectangular electroform for use in the die 250.

The exposed surface of the part 253 which has therein the cube-corner cavities 255 is then plated with chrome or other suitable separating medium. The die 250 is then inserted into a plating tank, whereby nickel or other plating material is deposited or electroformed onto the chrome-plated surface of the die 250. The plating is carried on for a sufficient amount of time to generate a metal member having a crudely-configured rear surface 271 and a precisely configured front surface 272 (FIGS. 29 and 30). In a construction of the present invention, the thickness of the metal member 270 was 0.007 inches in the areas of the apexes of the cube-corner elements 255 and 0.004 inches in the region of the valleys of the cube-corner projections 255. This variant thickness is a characteristic of the electroforming process. Of course, the front surface 272 has therein a multiplicity of cube-corner projections, like the pin bundle shown in FIG. 28.

Turning now to FIGS. 32 and 33, an epoxy backing 275 is applied to the rear surface 271 of the metal member 270. In order to obtain the desired shape of the epoxy 275 when it dries, a suitably-shaped form should be provided. The epoxy 275 assures that the metal member 270 will retain its shape during subsequent steps, particularly prying it off the die 250.

Referring to FIG. 34, the next step involves placing a piece of tape 277 on the zone 246 of each segment 241. The tape 277 is then cut so as to conform precisely to the zone 246. The tape is then removed and is applied to the configured surface 272 of the epoxy-backed metal member 270. Five such pieces of tape are shown in FIG. 35 thereby additional epoxy-backed metal members 270 would have to be provided to cover the other seven segments. The configured surface 272 is then painted, preferably by spray. The pieces of tape are then removed, and the epoxy-backed metal member 270 is then cut along the boundaries between the painted and unpainted areas. Preferably, each piece 279 (FIG. 36) thus cut out, is slightly larger than the zone 246 of the associated segment 241. Each epoxy-backed piece 279 is then heated to soften the epoxy 275 and then a tool 281, such as shown in FIG. 37, is

used to separate the piece 279 from its epoxy backing. As depicted in FIG. 38, the piece 279 is then bent onto the zone 246 of the associated segment 241. It should be understood that each zone 246 is part spherical and, as a practical matter, it is impossible to bend the piece 279 both longitudinally and laterally entirely to conform to the zone 246. Instead, the piece 279 is bent only longitudinally to conform to the zone 246 in that direction, and the piece 279 is left essentially flat in the later direction. By constructing the segments 241 to be reasonably narrow, the over-all lateral surface will approximate a spherical curvature.

Referring now to FIG. 39, there is provided a press 282 having a concave surface 283 to which is secured a rubber strip 284. Adhesive is then applied to the rear surface 271 of the piece 279 and to the zone of the associated segment 241. The press 282 is positioned, as shown in FIG. 39, and pressure applied thereto and maintained until the piece 279 is secured. Since the piece 279 was cut over-size, its edges 280 overhang the associated zone, which edges 280 are then ground, so that the piece 279 has precisely the right shape.

A similar process to that depicted in FIGS. 36-39 is performed in respect to each piece 279 and each segment 241. The segments 241 are then reassembled, as shown in FIG. 40. The outer surface of each piece 279 becomes a continuation of the outer surface of the adjacent piece 279, thereby forming a continuous configured surface 286 having a multiplicity of cube-corner projections thereon.

Turning now to FIG. 40, the exposed surface 286 is covered with chrome or other suitable separating medium. After the unit shown in FIG. 40 is suitably masked, it is inserted in the plating tank to plate a quantity of nickel or other material onto the surface 286. After a suitable thickness of nickel has built up, the unit shown in FIG. 40 may be removed, the front surface of the built-up part masked and then returned to the plating tank for back up. The completed mold 290 is shown in FIG. 41. The mold 290 has a configured front surface 291 consisting of a multiplicity of cube-corner cavities. The mold 290 has a pair of side edges 292 and 293 respectively lying in planes containing the center of curvature of the surface 291. The mold 290 further has a pair of end edges 294 and 295 respectively lying in chordal planes which are disposed parallel to each other and do not pass through the center of curvature of the surface 291. The front surface 291 is divided into a plurality of zones 296, separated by boundary lines 297. The planes containing the boundary lines 297 are disposed parallel to one another and do not pass through the center of curvature of the surface 291. The boundary lines 297 result from the slight discontinuities from the various pieces 279 that make up the surface 286. Of course, each zone 296 is spherically curved in the longitudinal direction, but is flattened in the lateral direction, since that is the basic shape of the pieces 279 which make up the surface 286. A hole 298 is formed in the mold 290, which hole 298 forms the fingers 200 and 201 in the finished product. Suitable projections may be mounted at the end edge 295 to enable formation of the holes 198 and 199 in the completed product.

Turning now to FIG. 42, the mold member 290 provides the lower half of a mold assembly incorporating an upper mold member 300. The mold member 300 has a smooth part-spherical surface 302 and a gate 301.

When in position, as shown in FIG. 42, molten acrylic is admitted into the space between the configured surface 291 of the mold member 290 and the smooth surface 302 on the mold member 300, in the usual manner. After the mold member 300 is separated from the mold member 290, a reflector section 205a (FIG. 43) is withdrawn. A second molding cycle is performed, utilizing the mold assembly shown in FIG. 42 to provide a second reflector section 205b. The reflector section 205b is an exact duplicate of the section 205a, but is oriented 180° with respect to section 205a, all as shown in FIG. 42. As previously explained, the sections respectively have longer edges 206a and 206b, both of which lie in planes containing the same center of curvature, whereby they may be mated, as shown in FIG. 44, and then welded together. The reflector 190 shown in FIG. 44 is a reflector previously described herein, except for the absence of flanges on the outer end edges 194 and 195. If desired, these ends, which are used for stripping purposes, would be added during the molding operation. Each reflector 190 is made in two sections 205a and 205b so as not to exceed the draft angle necessary to withdraw the part from the mold.

The boundary lines 208a and 208b result from the corresponding boundary lines 297 in the mold member 290. Each zone 207a and 207b will be part-spherical in the longitudinal direction, but substantially flattened laterally since that is the characteristic of the mold member 290.

Turning now to FIGS. 45-50, the details of a second method of making a curved reflector will be described. The same die 250 utilized in the first process is also used in this alternative process. Acrylic is molded onto the surface, having the cube-corner cavities 255, to provide a reflector 310 having an over-all thickness, for example, of 0.080 inch, as shown in the right-hand side of FIG. 46. The reflector 310 has a flat rear surface 311 and has a configured front surface 312 which has therein a multiplicity of cube-corner projections, much like the pin bundle shown in FIG. 28. The rear surface 311 may then be ground down, if desired, the resulting surface being labeled with a number 313. Of course, FIG. 46 represents the grinding process while it is being performed, so that, when completed, the entire rear surface will be at a level represented by the number 313. The amount of grinding would be that necessary to render the reflector 310 substantially pliable. If the overlay (distance between the surface 313 and the lowest point in the surface 312) were about 0.010 inch, the reflector 310 would be sufficiently pliable.

As was done in respect to the first process described, pieces of tape 277 are respectively applied to the zones 246 of the segments 241. After the tape 277 is cut to conform precisely to the associated zone 246, it is removed and applied to the configured surface 312 of the reflector 310, as shown in FIG. 47. Five such pieces of tape respectively conforming to different ones of the segments 241 are applied to the surface 312. The configured surface 312 is then painted, and the pieces of tape are removed. The reflector 310 is then cut along the boundaries between the painted and unpainted areas. Preferably, each piece 320 (FIG. 48) thus cut out, is slightly larger than the zone 246 of the associated segment 241. As depicted in FIG. 48, each piece 320 is then bent onto the zone 246 of the associated segment 241. It should be understood that each zone 246

is part-spherical and, as a practical matter, it is impossible to bend the piece 320 both longitudinally and laterally entirely to conform to the zone 246. Instead, the piece 320 is bent only longitudinally to conform to the zone 246 in that direction, and the piece 320 is left essentially flat in the lateral direction. The fact that the pieces 320 are relatively narrow results in the over-all lateral surface approximating a spherical curvature. Adhesive is applied to the rear surface of the piece 320 and to the zone of the associated segment 241. A press similar to the press 282 is used to hold the piece 320 until it is secured. Since the piece 320 was cut oversize, its edges 321 overhang the associated zone, which edges 321 are then ground, so that the piece 320 has precisely the desired shape.

A similar process is performed in respect to each piece 320 and each segment 241. The segments are then reassembled, as shown in FIG. 49. The outer surface of each piece 320 thereby becomes a continuation of the outer surface of the adjacent piece 320, thereby forming a configured surface 323 having a multiplicity of cube corner projections thereof.

The exposed surface 323 is made conductive by depositing thereon a metallic medium by vacuum metalizing or other process. After the unit shown in FIG. 49 is suitably masked, it is inserted in the plating tank to plate a quantity of nickel or other material onto the surface 323. After a suitable thickness of nickel has been built up, the unit shown in FIG. 49 may be removed, the front surface of the build-up part masked and then returned to the plating tank for back up. The completed mold member 330 is shown in FIG. 50. The mold member 330 has a configured front surface 331 consisting of a multiplicity of cube-corner cavities. The mold member 290 has a pair of side edges 332 and 333 respectively lying in planes containing the center of curvature of the surface 331. The mold member 330 further has a pair of end edges 334 and 335 respectively lying in chordal planes which are disposed parallel to each other and do not pass through the center of curvature of the surface 331. The front surface 331 is divided into a plurality of zones 336, separated by boundary lines 337. The planes containing the boundary lines 337 are disposed parallel to one another and do not pass through the center of curvature of the surface 331. The boundary lines 337 result from the slight discontinuities from the various pieces 320 that make up the surface 323. Of course, each zone 336 is spherically curved in the longitudinal direction but is flattened in the lateral direction since that is the basic shape of the pieces 320 which make up the surface 323. A hole 338 is formed in the mold member 330, which hole 338 forms the fingers 200 and 201 in the finished product. Suitable projections may be mounted at the end edge 335 to enable formation of the holes 198 and 199 in the completed product.

Turning now to FIGS. 51-54, there will be explained a second alternative process for making a curved reflector incorporating therein the features of the present invention. This particular embodiment is useful in making a reflector which is curved in but one direction as opposed to a spherical reflector which is curved in more than one direction. FIG. 51 illustrates a cylinder 340 and a segment 341 thereof, having a part-cylindrical surface 342. A plurality of pins, such as those shown in FIG. 28, are arranged in an array, as previously explained. The array is placed in a plating

tank to enable a quantity of nickel or the like to be deposited or electroformed onto the cube-corner projections 259 of the pins 258. The electroforming operation is continued until a thickness of, for example, 0.007 inch is obtained. The array of pins 258 and the electroform secured thereto are then withdrawn from the tank and an epoxy or the like is applied to the electroform so as to retain its shape while it is being pried off the pins 258. The electroform and epoxy cast thereon are then removed from the pins. The metal member 345 thusly formed has a rear surface 346 and a front surface 347, which front surface 347 has a multiplicity of cube-corner cavities therein, having the general arrangement shown in FIG. 27. The metal member 345 is then placed with the surface 347 on the part-cylindrical surface 342 and bent to conform to the shape thereof. The member 345 is placed into the plating tank to apply additional nickel onto the surface 346 to back up the member 345. Referring to FIG. 53, the mold 350 thusly formed has a surface 347 with a multiplicity of cube-corner cavities therein. The mold 350 is then placed in a molding machine into which is applied acrylic. The reflector 360 thus formed is shown in FIG. 54, having a smooth front surface 361 and a configured rear surface 362 with a multiplicity of cube-corner projections thereon. Suitable studs or the like may be provided in the mold for forming holes 363 and 364. The reflector 360, as shown in FIG. 54, has an angular extent of 60°, although any desirable size may be provided. Light from a light source, such as, for example, an elongated fluorescent light disposed along the axis of the cylindrical reflector 360 will strike the reflector 360 and be retrodirectively returned to the source.

It is believed that the invention, its mode of construction and assembly, and many of its advantages should be readily understood from the foregoing without further description, and it should also be manifest that, while the 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 method of making a mold for use in producing a curved reflector having cube-corner elements therein, said method comprising making a substantially-flat plate-like member having a multiplicity of cube-corner elements therein, providing a form having a curved surface with the desired final shape of the reflector, bending said member against said form so that the member essentially assumes the shape of the curved surface, forming a mold from said curved member.

2. The method set forth in claim 1, wherein said member is made of plastic.

3. The method set forth in claim 1, wherein said member is made of plastic having a substantially-flat rear surface and a front surface having cube-corner elements therein, said rear surface being ground to render the plate-like member sufficiently thin to be bendable against the form.

4. The method set forth in claim 1, wherein said plate-like member is constructed of metal.

5. The method set forth in claim 1, wherein the surface generated on said form is substantially smooth.

6. The method set forth in claim 1, wherein said form is provided with a part-spherical surface.

7. The method set forth in claim 1, wherein said form is provided with a part-cylindrical surface.

8. The method set forth in claim 1, wherein said member is bent against said form with the cube-corner elements engaging the curved surface.

9. The method set forth in claim 1, wherein said member is bent against said form with the cube-corner elements directed away from the curved surface.

10. The method set forth in claim 1, wherein the mold is formed from said curved surface by applying a backing to said bent member.

11. The method set forth in claim 1, wherein the mold is formed from said curved surface by electroforming against said bent member.

12. A method for making a mold for use in producing a curved reflector having cube-corner elements therein, said method comprising the steps of making a substantially-flat plate-like member having a multiplicity of cube-corner elements therein, providing a form having a form surface of a selected curvature, cutting said form into a plurality of segments each having a portion of said form surface, cutting said member into a plurality of pieces respectively having shapes of said form surface portions, bending said pieces respectively onto the associated form surface portions, and forming a mold from said bent pieces.

13. The method set forth in claim 12, wherein said form surface is part spherical, whereby the apexes of the cube-corner cavities in said mold define a part-spherical surface.

14. The method set forth in claim 12, wherein the sides of each of said segments are respectively defined by substantially parallel surfaces.

15. The method set forth in claim 12, wherein the arc lengths of said form surface portions measured in a plane substantially normal to the direction in which said segments are cut are substantially equal.

16. The method set forth in claim 12, wherein said member is cut into a plurality of pieces respectively slightly larger than the corresponding form surface portions, the margin of each of said pieces then being ground to conform precisely to the shape of the corresponding form surface.

17. A method of making a mold for use in producing a curved reflector having cube-corner elements therein, said method comprising making a substantially-flat plate-like member having a multiplicity of cube-corner elements therein, providing a form having a form surface of a selected curvature, cutting said form into a plurality of segments each having a portion of said form surface, applying a flexible material to each of said form surface portions, cutting said flexible material to provide lengths of flexible material conforming to the shape respectively of the form surface portions, placing said lengths of flexible material respectively on different regions of said member, cutting said member around the lengths of flexible material thereon to provide a plurality of pieces respectively having shapes of said form surface portions, bending said pieces respectively onto the associated form surface portions, forming a mold from said bent pieces.

18. The method for making a mold set forth in claim 17, wherein said flexible material is tape.

19. The method for making a mold set forth in claim 17, wherein the surface of said member is painted after said lengths of material have been applied thereto, said lengths of material then being removed, and said mem-

ber being cut adjacent to the boundaries between the painted and nonpainted areas.

20. A method of making a mold for use in producing a curved reflector having cube-corner elements therein, said method comprising the steps of providing a die having a multiplicity of cube-corner elements respectively with apexes lying substantially in a plane, electroforming against said die to provide a metal member having a multiplicity of cube-corner elements therein, removing said member from said die, providing a form having a form surface of a selected curvature, cutting said form into a plurality of segments each having a portion of said form surface, cutting said member into a plurality of pieces respectively having shapes of said form surface portions, bending said pieces respectively onto the associated form surface portions, and forming a mold from said bent pieces.

21. A method of making a mold for use in producing a curved reflector having cube-corner elements therein, said method comprising making a substantially-flat plate-like member having a multiplicity of cube-corner elements therein, providing a form having a form surface of a selected curvature, cutting said form into a plurality of segments each having a portion of said form surface, cutting said member into a plurality of pieces respectively having shapes of said form surface portions, bending said pieces respectively onto the associated form surface portions, securing said pieces respectively to the associated form surface portions, securing said segments together so that said pieces present a surface with a multiplicity of cube-corner elements respectively with apexes defining a surface corresponding substantially to said form surface, forming against said last-mentioned cube-corner elements a mold having a multiplicity of cube-corner elements therein respectively with apexes defining a surface corresponding to said form surface.

22. The method for making a mold set forth in claim 21, and further comprising making a body having an engagement surface that approximately mates with one of said form surface portions, securing said pieces by placing adhesive on the surface thereof without said projections, placing said piece on the associated form surface portion, placing said body on said piece with said engagement surface on the surface of said piece having said projections, and pressing said body toward

said segment.

23. The method set forth in claim 21, wherein the cube-corner elements in said member are cube-corner projections, whereby the cube-corner elements on said mold are cube-corner projections.

24. The method set forth in claim 21, wherein said cube-corner elements on said pieces are projections directed away from said form surface.

25. The method for making a mold set forth in claim 21, wherein said member is removed from said die by first applying epoxy and then prying said metal member from said die.

26. The method set forth in claim 21, wherein said member is removed from said die by first applying epoxy and then prying said metal member from said die, removing said epoxy after said member has been cut into said plurality of pieces.

27. A method of making a mold for use in producing a curved reflector having cube-corner elements therein, said method comprising the steps of providing a die having a multiplicity of cube-corner elements respectively with apexes lying substantially in a plane, molding plastic against said die to provide a plastic member having a multiplicity of cube-corner elements therein, removing said member from said die, providing a form having a form surface of a selected curvature, cutting said form into a plurality of segments each having a portion of said form surface, cutting said member into a plurality of pieces respectively having shapes of said form surface portions, bending said pieces respectively onto the associated form surface portions, securing said segments together so that said pieces present a surface with a multiplicity of cube-corner elements respectively with apexes defining a surface corresponding substantially to said form surface, applying a conductive coating to said last-mentioned surface, electroforming against said conductive coating to provide a mold having a multiplicity of cube-corner elements therein respectively with apexes defining a surface corresponding to said form surface.

28. The method for making a mold set forth in claim 27, wherein grinding the surface of said molded member opposite said cube-corner elements to render said member substantially pliable.

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