United States Patent

Lipkins

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[54] HOLLOW RETROREFLECTORS

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[52] **U.S. Cl.** **350/102,** 350/288, 350/299

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

[58] **Field of Search** 350/100–109, 288, 350/299, 301, 286, 287; 356/106

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[57] **ABSTRACT**

In one form, a hollow retroreflector is here made of three plates joined together at right angles to each other with only one edge of each plate bonded to a reflecting face of another plate, thereby making non-critical the relationships between the edges of any one of the plates. In another form, one of the three plates has two edges that intersect at a slight obtuse angle that is non-critical, the length of one edge abutting the reflecting face of another plate while the other edge contacts the remaining plate only at a location remote from the common corner of the retroreflector, again involving non-critical edge relationships as to each of the plates of the retroreflector. For stability of the optically flat faces, the plates are made relatively thick and accordingly have relatively wide edges that abut others of the plates. The abutment edges are joined to related reflecting faces by bonding material restricted to a zone that is narrow relative to the width of the abutment edge. The plates have individual corners remote from the common corner of the retroreflector, and a common glass plate is bonded to those individual corners so as to resist deforming stresses that may be imposed on the plates.

12 Claims, 6 Drawing Figures

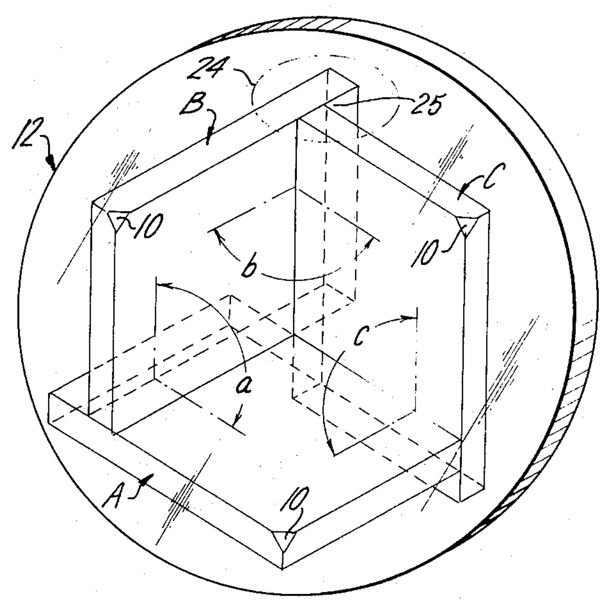

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FIG. 1

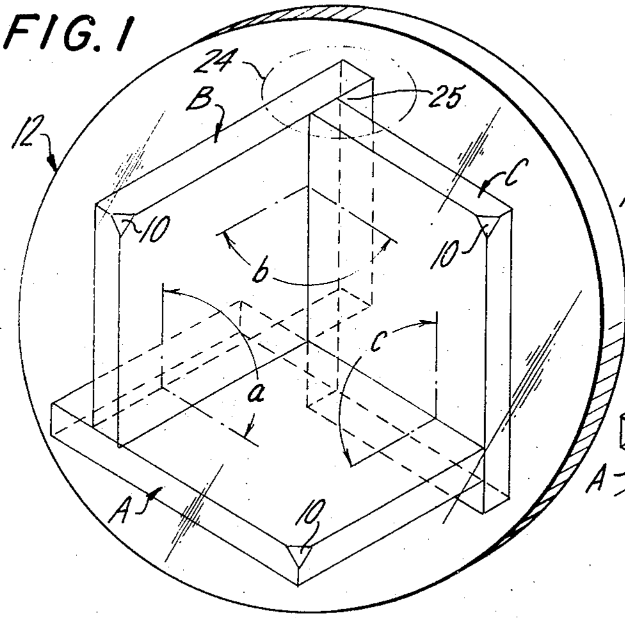
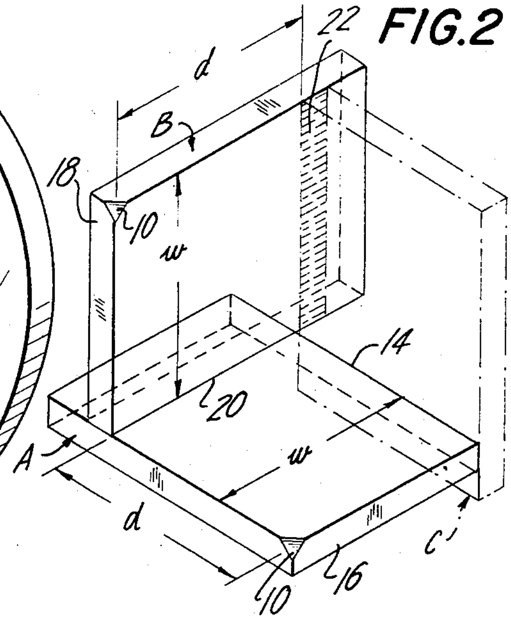


FIG. 2



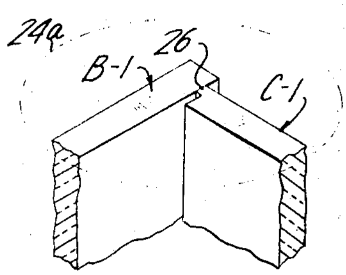
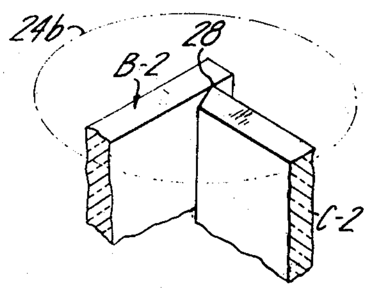


FIG. 3

FIG. 4



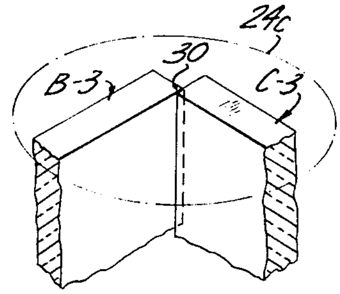
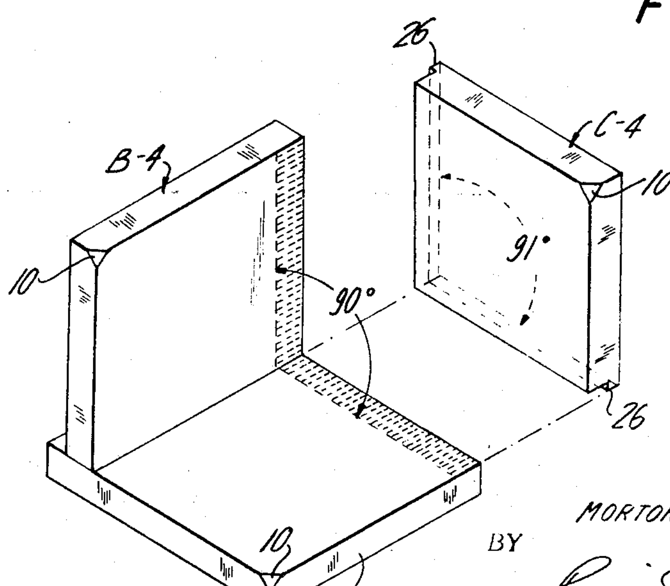


FIG. 5

FIG. 6



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HOLLOW RETROREFLECTORS

Retroreflectors have the essential property of causing incident and reflected light rays to travel along parallel paths. The departure from parallelism is a prime criterion in retroreflector specifications, expressed in minutes or seconds of arc. A common form of retroreflector sometimes called a corner-cube retroreflector, has three optically flat reflecting surfaces that meet at a common corner, the reflecting surfaces being disposed accurately at right angles to each other.

One form of corner-cube retroreflector is made of a solid transparent block, having three optically flat faces meeting at right angles at a common corner, these retroreflectors sometimes being called "solid corner-cube" retroreflectors. Solid corner-cube retroreflectors are costly, due to the difficulty of producing three optically flat faces critically at right angles to each other on a common block.

The present invention is concerned with "hollow" retroreflectors, or "hollow corner-cube" retroreflectors, as they are sometimes called. This type of retroreflector can be made of three plates joined together and having optically flat reflecting faces arranged at right angles to each other, meeting at the common inside corner of an imaginary cube. The three plates are separately treated to develop the required optical flatness of their reflecting surfaces, and then they are joined in an accurate relationship to meet the angle-of-arc specifications.

A feature of the invention resides in avoidance of critical angles between the edges of any one of the plates in a hollow retroreflector. A further feature of the invention resides in avoidance of any critical flatness of an edge of a plate, and of any critical right-angled relationship between a flat edge and the adjoining reflecting face as to any individual plate making up a hollow retroreflector. Any such critical requirements of a plate represent important items of expense that are avoided here without sacrifice to performance of the resulting retroreflector.

Hollow "corner-cube" retroreflectors fabricated of three plates at right angles to each other are expediently joined together by a bonding material. There is a tendency of the bonding material to induce bending and warping stresses, tending to degrade the performance of the retroreflector. For example, where epoxy cement is used between an abutment edge and the plate it abuts, the cement shrinks as it cures, and as it shrinks, it pulls the abutted plate against the edge surface of the abutted plate. Any angularity between the abutting surfaces, and any deviation from flatness of the edge at the cemented interface, give rise to possible deformations, deformations that can seriously impair the characteristics of the retroreflector. This effect has been reduced to the vanishing point pursuant to another feature of the invention, so that even tight specifications can be met easily. This is realized by making the plates relatively thick and by confining the bonding material to a narrow zone along the relatively wide edge of a plate where that edge abuts, and is cemented to, another plate.

The corner-cube retroreflector could lose some of its initial accuracy if it should be exposed to external stresses. Each plate has a corner that is remote from the common hollow corner formed by the three reflecting plates. A further feature of the invention resides in bonding a glass plate to those remote corners of the three plates, and using that plate as the support of the retroreflector.

The invention involves the foregoing and various additional novel features, objects and advantages, as will be apparent from the following description in detail of the illustrative embodiment of the invention in its various aspects.

In the drawings:

FIG. 1 is a perspective view of a retroreflector embodying various features of the invention.

FIG. 2 is a partly exploded perspective of the embodiment in FIG. 1, omitting the front plate.

FIGS. 3, 4 and 5 are fragmentary perspectives showing modifications of the corner construction at broken-line circle 24 of FIG. 1.

FIG. 6 is a partly exploded perspective of a modification of FIG. 1, omitting the front cover plate.

Referring now to the drawings, a hollow corner-cube retroreflector unit is shown in FIG. 1, embodying several features of the invention.

Plates A, B and C are relatively thick glass plates having optically flat active reflecting surfaces disposed at right angles *a*, *b* and *c* in relation to each other. These angles are established accurately by means of adjustment jigs and measurement apparatus so that they are 90° within a tight tolerance. This tolerance limits the performance of the retroreflector such that the incoming and reflected rays are parallel within a specified angle. This angle can be 5 minutes, or 30 seconds, or it can even be as small as one second of arc. The plates are then cemented as with a suitable epoxy composition and held in adjustment until the cement has cured. The optically flat faces of plates A, B and C are aluminized or otherwise treated to be efficient reflecting surfaces.

Any mechanical force imposed at the projecting corners **10** could deflect and deform the optically flat surfaces so as to impair the performance of the device. This represents a danger of practical importance even in an example where plates A, B and C are ⅝ inch thick and have square reflecting surfaces measuring only 2 inches along each margin. A plate of glass **12** is fixed to corners **10** with epoxy cement. Corners **10** have small flats confronting plate **12** as shown, to provide a small but appreciable area for the cement. In practice, plate **12** may be larger than shown, and plural corner-cube retroreflector units are often assembled close to each other on a common plate **12** which then forms a protective cover for a sealed enclosure (not shown) containing the corner-cube units. Plate **12** can then serve as a common support for those units, largely isolating the retroreflectors from deforming stresses. Plate **12** should be of an optical quality such as not to disturb the parallelism of the incoming and reflected light rays, and it should be thick enough for physical stability.

It is notable in FIG. 1 that only one edge of each plate A, B and C abuts the flat face of another plate. Thus, plates A, B and C have respective edges abutting the flat faces of plates C, A and B, respectively. Notably, the angles between the edges of any one plate do not affect the accuracy of the retroreflector. Consequently there is no need to form an accurate right-angled relationship between any two edges of any of the plates. This represents an important manufacturing economy.

Plates A and B are assembled as shown in FIG. 2. Each plate has a width *w* that is made with ordinary mechanical accuracy, that is, with no concern for accuracy to optical standards. Plate B is disposed on plate A with one end of plate B projecting across a side edge **14** of plate A (see FIG. 2) at a distance *d* from the front edge **16** of plate A and approximately parallel to that edge. Edge **14** is also approximately at a distance *d* from the edge **18** of plate B. By means of a suitable adjusting jig, and with the help of suitable measuring apparatus, the reflecting surfaces of plates A and B are disposed at 90° to each other, within a specified standard of accuracy. During this adjustment, plate B rocks about its lower edge **20**.

Plate C is shown in phantom lines in FIG. 2. It is brought into assembly with plates A and B as shown in FIG. 1. Plate C is adjusted about the edge **14** of plate A so that there is a right angle between their reflecting surfaces, while all three of the plates are held by a suitable adjusting jig. Also, plate B is adjusted for right-angled relationship between the reflecting surfaces of plates B and C by moving plate B about an axis at the shaded area **22** of FIG. 2. This is where the edge of plate C abuts the reflecting surface of plate B. It is thus possible for each of the plates to have exposed, active reflecting square surfaces, 2 inches square for example, by making one dimension of each plate two inches and the crosswise dimension a little longer than two inches. With the right-angled relationships established, cement is applied suitably to join plate **12** to points **10** of the three plates. The united plates are removed from the adjustment jig when the cement has set firmly. Metallizing of the reflecting surfaces is carried out at a convenient phase of the fabrication, or, as a preferable practice, the metallizing can be done before the plates are assembled.

The use of thick plates is desirable for initial and permanent optical flatness of the reflecting surfaces. The area of plate B that is confronted by plate C in the finished corner-cube is shaded to represent the usual area of the cemented joint. If the end of plate C were truly an optical flat and if it were at right angles to its own broad reflecting face, then such a cemented joint might be satisfactory. To the extent of any departure of the joint-forming edge of plate C from optical flatness, and to the extent that such edge departs from right angles in relation to the reflecting surface of plate C, and assuming that plates B and C are assembled accurately so that angle *b* is a right angle, then the cement would create bending and warping stresses tending to deform even relatively thick glass plates. This difficulty is avoided by confining the cement to a slender zone or stripe, compared to the much greater width of the abutment area **22** corresponding to the thickness of the glass plates. This is achieved in any of the following ways.

In FIGS. **1** and **2**, each of the plates projects to the rear of the plate that abuts it. This projection is somewhat exaggerated in the drawing for more effective illustration. After the plates are assembled and held in a jig, a fine stripe of cement such as a normally viscous epoxy cement is laid down along the corners formed by the abutting plates, those corners remote from the active reflecting surfaces of the corner-cube. For example, cement is applied along the corner **25** (see circle **24**) formed by the front face of plate B and the rear face of plate C. This may be called an "inside corner", in contrast to familiar "outside corners", such as those formed at the intersections of the faces and the edges of each plate illustrated. Then most of the cement is removed as by a wiping stroke along the stripe of cement with a cotton swab so as to leave only a little fillet of cement. Such application of cement results in an excellent joint, having ample strength and producing only a minimal amount of stress during the curing of the cement. It is a joint that does not depend on costly high precision in making the abutment edge of each plate flat and at right angles to the reflecting face of its own plate within standards of optical precision.

Three other arrangements are shown in FIGS. **3**, **4** and **5** for avoiding cement-induced warping by confining the cement to a narrow zone along the relatively wide end of each plate that abuts another. In all three, only a relatively narrow portion of the edge of each thick plate abuts the reflecting surface of another plate. Thus, plate B–1 (FIG. **3**) is abutted by a narrow rib **26** of plate C1. Plate C–2 (FIG. **4**) has an edge surface that forms an obtuse angle to its reflecting surface so as to have an abutment edge **28** of slightly less than 90° for engaging the reflecting surface of plate B–2. Plate B–3 has only a narrow strip, e.g., 0.050 inch, confronted and abutted by a corresponding strip **30** of plate C–3. The width of the abutment zone is limited to only a small part of the width of the edge surface of plate C–3.

Each of these forms of joint is contemplated as part of the corner-cube reflector unit in FIG. **1**. When plates are to be assembled, the limited abutment portion of each abutment edge is given a thin coat of cement and the parts are assembled in a jig, adjusted and allowed to cure. As an alternative, a fine fillet of cement is applied to the "inside" corner of the joints as described above in connection with FIGS. **1** and **2**, remote from the active reflecting surfaces.

A further approach to the problem is shown in FIG. **6**. Plates A–**4** and B–**4** are assembled with a suitably narrow abutment region, and adjusted about the abutment region as a fulcrum to the required 90° between reflecting faces. The use of ribs **26** to limit the width of the abutment region is illustrative. Plate C–**4** has two ribs **26** at a slightly obtuse angle to each other, about 91° for example. With one of the plates held in an adjustment fixture, one of these ribs is placed against plate A–**4** and plate C–**4** is shifted in its own plane until a corner of the other rib **26** engages plate B–**4**. Plate C–**4** is then adjusted about each of its ribs so as to be at right angles to plates A–**4** and B–**4**. Cement is applied to the parts of all three ribs where they abut a reflecting surface, and the excess is wiped away. After curing,the corner-cube of FIG. **4** may be mounted on a glass plate **12** (FIG. **1**) and additional corner-cubes may be mounted on that glass plate in a cluster. If the bottom rib **26** (as shown) of plate C–**4** abuts plate A–**4** along its length, then only the end of rib **26** remote from plate A–**4** engages plate B–**4**. It is only at the location of this engagement that cement should be used, to avoid significant shrinking forces.

In the preceding discussion of various forms of construction, the edges of any given plate that abut another plate are assumed to be straight. However, the standard of accuracy of such straightness and of the flatness of an abutment edge surface is relatively non-critical, nowhere nearly as critical as the standards used in preparing surfaces for optical performance.

The abutment edges engage reflecting surfaces of other plates, thereby obscuring some of the reflection area. The "active" reflecting face of a plate is a term used herein to identify the surfaces of plates A, B and C that contribute to the performance of the retroreflector, from this point of view disregarding the continuation of each reflecting surface into the joint-forming part of the structure. The term "inside corner" is used above in describing the use of cement. That term refers to a corner formed by the planes of two surfaces that intersect in the manner of inside wall surfaces meeting at the corner of a rectangular room. This is in contradistinction to an "outside corner" such as is found on a solid cube.

The preferred material considered above is an epoxy cement, but other bonding materials such as glass frit and solder are alternatives that may be preferred by some, in some situations.

The foregoing represents the preferred embodiment of the invention in its various aspects, including a number of alternatives. However, to those skilled in the art, various other alternatives and various other applications of the novel features will be apparent and therefore the invention should be construed broadly in accordance with its full spirit and scope.

What is claimed is:

1. A hollow retroreflector including three plates having optically flat reflecting faces disposed at right angles to each other to form a hollow retroreflector, one edge only of each of said plates abutting and being joined by bonding material to the reflecting face of another of said plates and each of said plates accordingly having the reflecting face thereof joined to an edge of only one other plate of said three plates, said bonding material being confined essentially to a fillet between each of said plates and the plate abutted thereby.

2. A hollow retroreflector including three plates having optically flat reflecting faces disposed at right angles to each other to form a hollow retroreflector, one edge only of each of said plates abutting and being joined by bonding material to the reflecting face of another of said plates and each of said plates accordingly having the reflecting face thereof joined to an edge of only one other plate of said three plates, each of said plates being of relatively thick glass and therefore having relatively wide edges, said bonding material being confined to a zone that is relatively narrow compared with the thickness of the plates, for minimizing distortion of the plates that might be caused by the bonding material.

3. A hollow retroreflector pursuant to claim **2**, wherein the surface of each abutting edge is essentially flat and said abutment edge of each plate and the reflecting face of that plate form an obtuse angle.

4. A hollow retroreflector pursuant to claim **2**, wherein said abutting edge of each plate has a rib extending therealong, for limiting the engagement of any abutting edge with the opposed face of another said plate.

5. A hollow retroreflector pursuant to claim **2**, wherein each reflecting face abutted by the edge of another of said plates ends at an edge thereof that is spaced from the reflecting face of the abutting plate by a relatively narrow zone compared with the width of the abutting edge, the extent of abutment of each plate by the plate which abuts it being limited to said relatively narrow zone.

6. A hollow retroreflector including first, second and third plates each having an optically flat reflecting face, the reflecting faces of said three plates being disposed at right angles to each other to form a hollow retroreflector, first means securing an edge of one of said first and second plates to the reflecting face of the other of said first and second plates, said third plate having first and second edges opposed to the reflecting faces of said first and second plates, said first and second edges intersecting to form a slightly obtuse angle therebetween, second means securing the reflecting face of said first plate to said first edge along the length thereof, and means securing the reflecting face of said second plate to said second edge only at a location remote from the intersection of the first and second edges.

7. A hollow retroreflector in accordance with claim **6**, wherein said plates are relatively thick and have relatively wide edges, and wherein bonding material forms each of said securing means, the bonding material of said first and second securing means being confined to a relatively narrow zone along its related edge.

8. A hollow retroreflector including three plates having respective optically flat reflecting faces, said plates being joined together at right angles to each other to form a hollow retroreflector having a common corner, each of said plates having a corner remote from said common corner, and a transparent plate joined to the remote corners of said three plates.

9. A hollow retroreflector in accordance with claim **8**, wherein each of said three plates is joined to the other two by bonding material extending along the abutment edges of each of the plates, the bonding material being confined to a zone that is relatively narrow compared to the width of said abutment edge.

10. A hollow retroreflector in accordance with claim **8**, wherein said plates are relatively thick and wherein certain of the edges thereof abut respective reflecting faces of others of said plates, each abutting edge being relatively wide and being joined to its related reflecting face by bonding material extending along such edge and being confined to a zone that is relatively narrow compared to the width of such edge.

11. A hollow retroreflector including three plates having optically flat reflecting faces joined together at right angles to each other to form a hollow retroreflector, said plates being relatively thick, certain of the edges of said plates individually abutting respective reflecting faces of others of said plates and being joined thereto by bonding material, said bonding material at each abutment being confined to a zone that is relatively narrow compared to the width of the abutment edge.

12. A hollow retroreflector in accordance with claim **10**, wherein each plate having an abutting edge and the plate abutted thereby form an inside corner remote from the active reflecting faces of the retroreflector, the bonding material being confined to a fillet extending along said inside corner.

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