

United States
Morton et al.

[11] 3,883,731

[45] May 13, 1975

[54] **LIGHT SOURCE WITH HIGH EFFICIENCY
LIGHT COLLECTION MEANS**

1,665,660 4/1928 Foster 240/41.38 R
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[21] Appl. No.: **464,547**

Related U.S. Application Data

[62] Division of Ser. No. 388,376, March 5, 1973, Pat.
No. 3,825,741.

[52] U.S. Cl. **240/41.38 R; 240/106 R**

[51] Int. Cl. **F21v 7/04**

[58] Field of Search... **240/41.35 R, 41.38 R, 41.38 A,
240/106 R**

[56] **References Cited**

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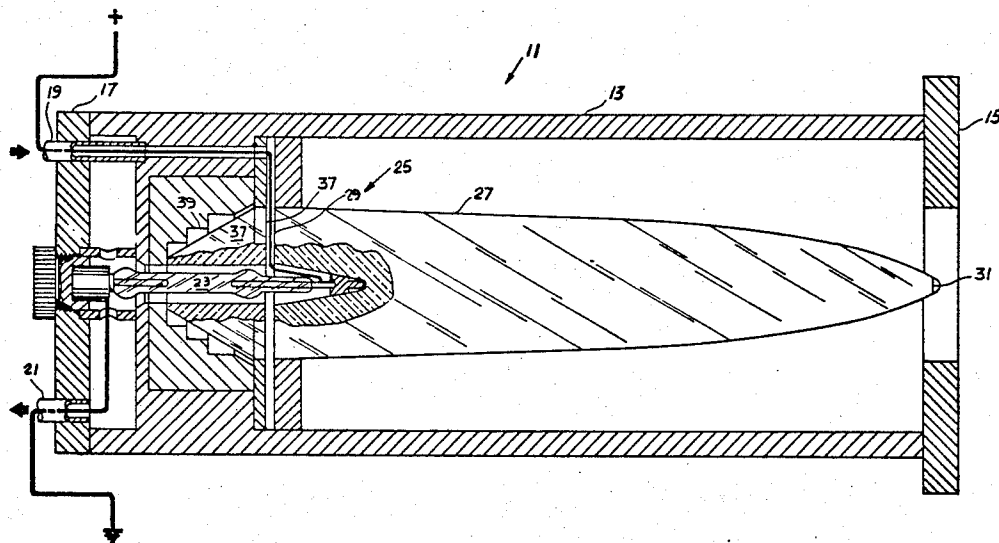
1,081,215 12/1913 Coulson 240/41.38 A

[57]

ABSTRACT

A reflector structure comprising a stepped, annular reflective member which may be formed by a joined series of adjacent, coaxial, annular reflective members of increasing radius, from rear to front, with each annular member provided with a rectangular cross section such that pairs of adjacent members each form at least one annular corner reflector, i.e., a stepped or right angle reflector.

2 Claims, 6 Drawing Figures



3883731
OR IN 240/41.38R

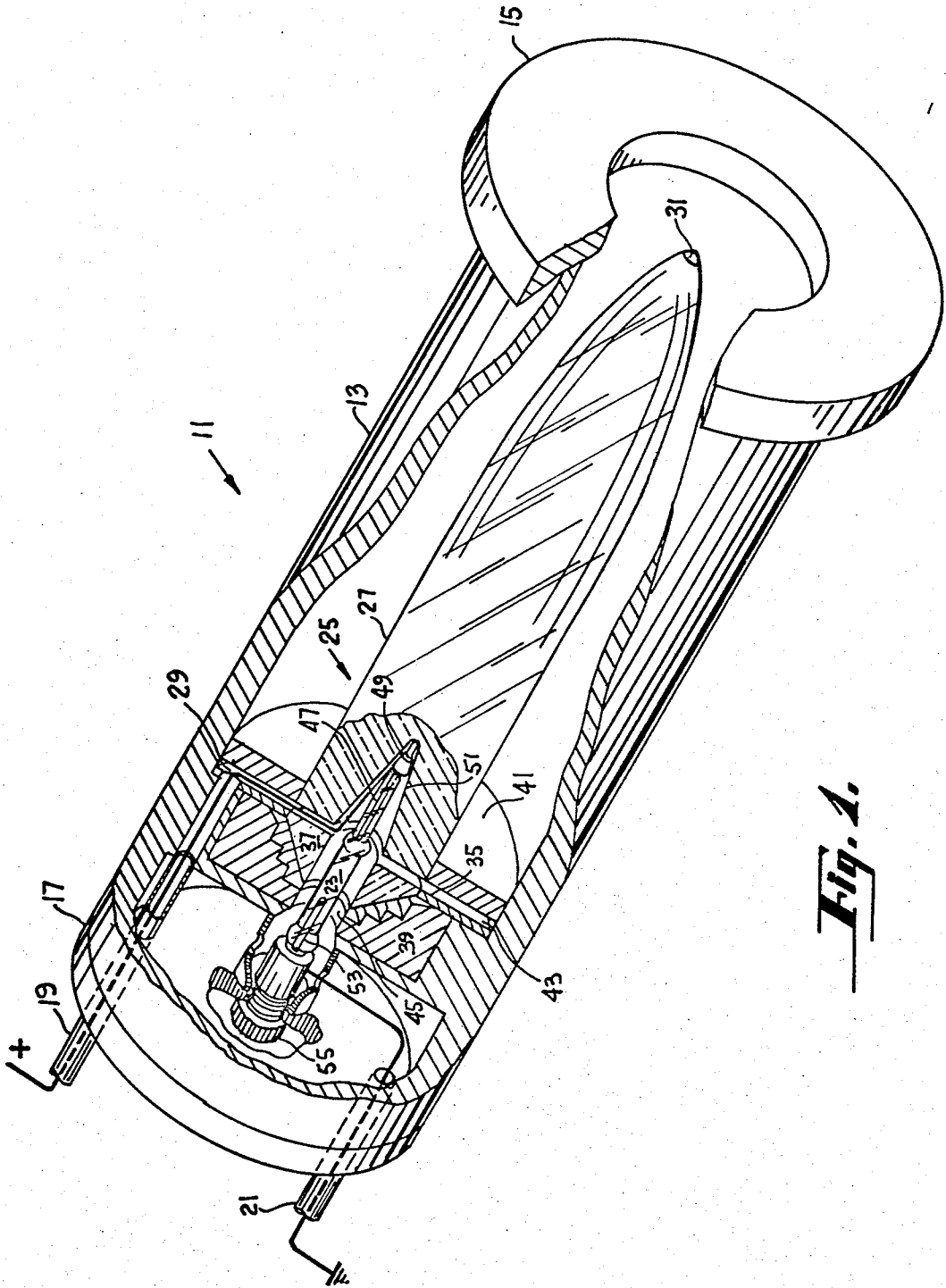


Fig. 1.

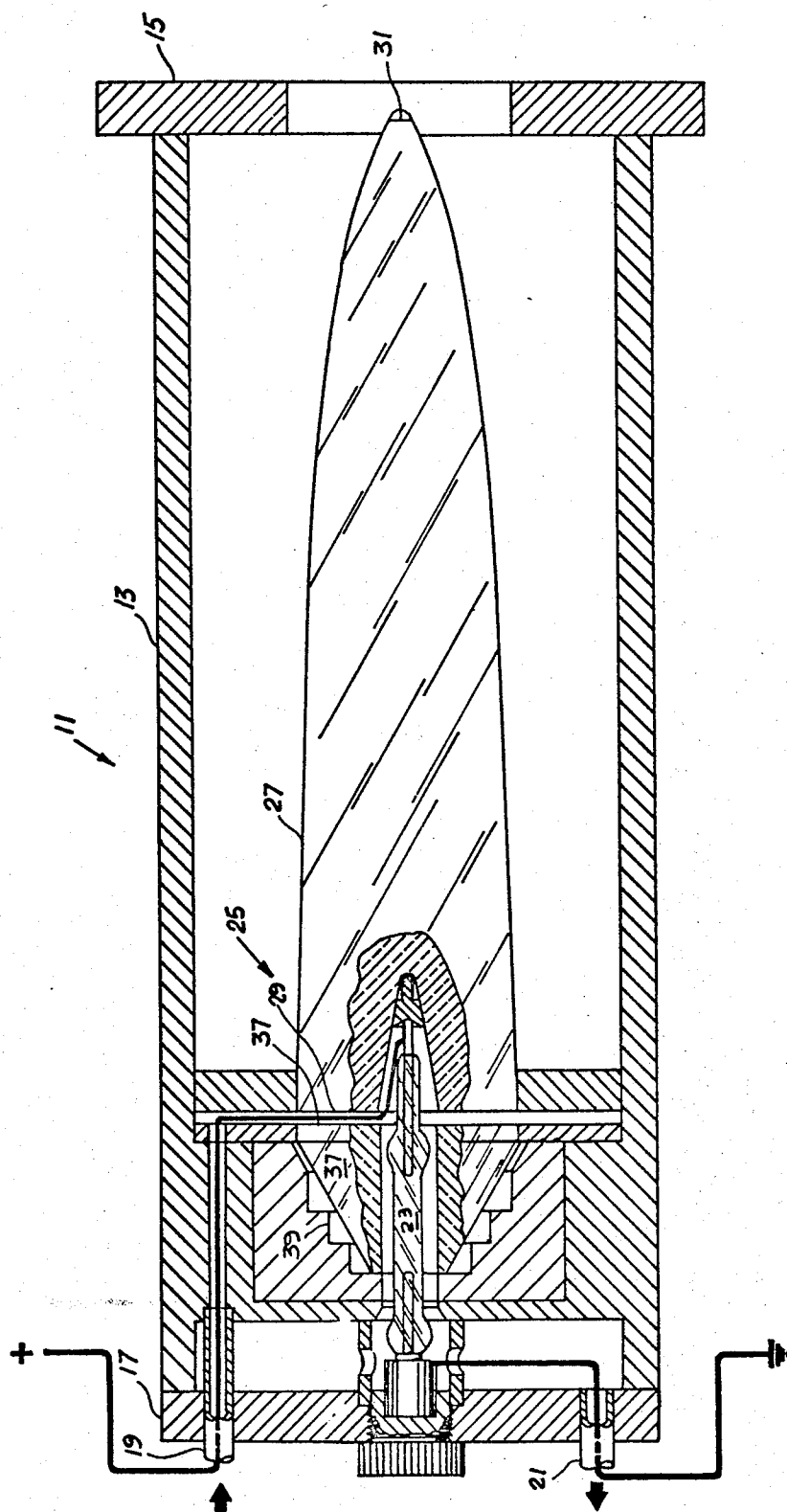


Fig. 2.

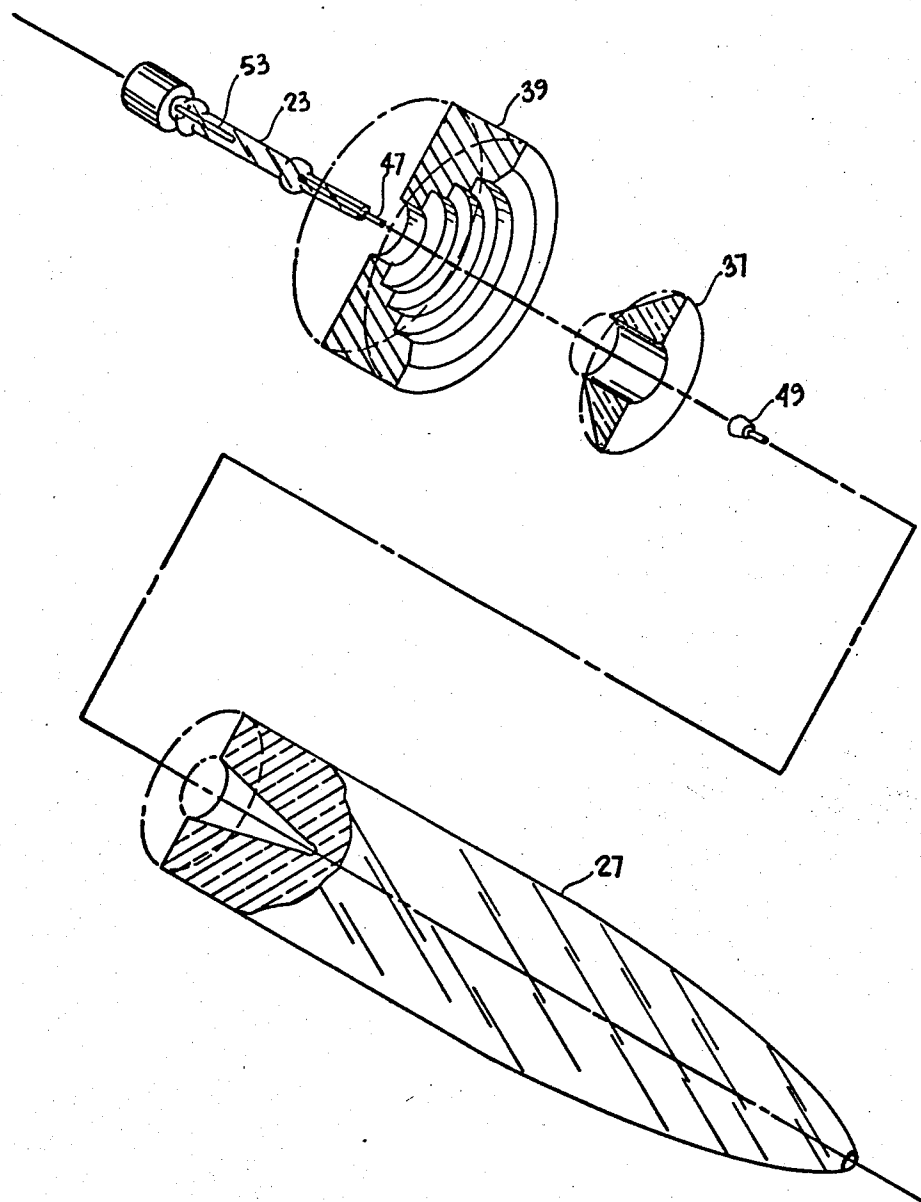


Fig. 3.

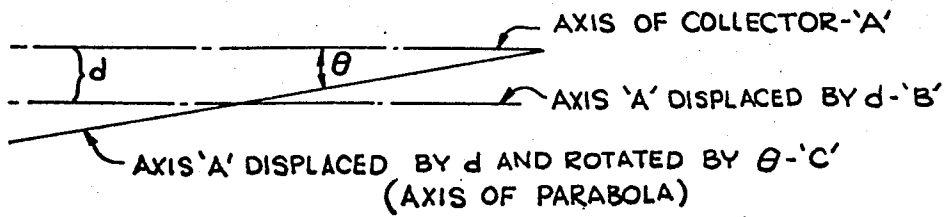


FIG. 4.

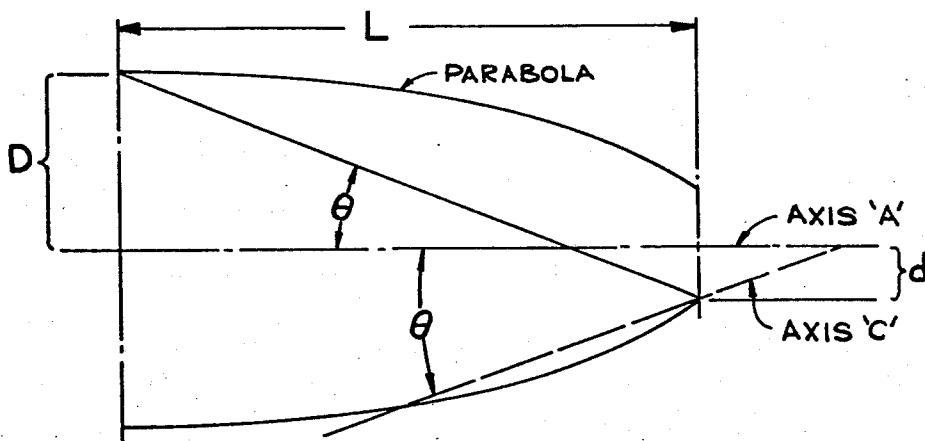


FIG. 5.

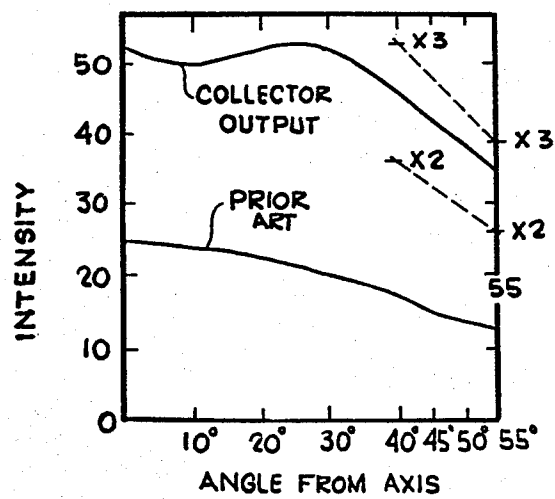


FIG. 6.

LIGHT SOURCE WITH HIGH EFFICIENCY LIGHT COLLECTION MEANS

This is a division of application, Ser. No. 338,376, filed Mar. 5, 1973, now U.S. Pat. No. 3,825,741.

FIELD OF THE INVENTION

The present invention relates to high intensity light sources, and more particularly to a light source which is surrounded by a high efficiency light collector for collecting both forwardly and rearwardly dispersed light into a beam.

Prior Art

High intensity lights, especially arc lamps, are used extensively in such applications as the projection of movies, in street lights and in the manufacture of television tube screens. With regard to making TV tube screens, the manufacturing process usually involves developing a pattern of phosphor dots on the screen by illuminating a photo-resistive surface through apertures in a shadow mask. The apertures correspond to locations of a desired color phosphor.

To shorten the time required to bring out the desired phosphor in the TV tube screen manufacturing process, a higher intensity light source is required. It would be advantageous to increase the light intensity without necessarily increasing the source strength, e.g., by enhancing the efficiency of the light delivered from a source to a corresponding output beam.

Previously, it has been known that in order to form a beam, a light source may be surrounded by a compound reflector, of which the forward portion is a hemisphere and the rearward portion is semi-elliptical with a small aperture in the hemisphere at one focus of the ellipse, with the light source being at the other focus of the ellipse. Light from the source is directed rearwardly to the semi-elliptical reflector where the light is then directed to the opposite focus of the ellipse, i.e., the output aperture.

The configuration of the source at one elliptical focus and output aperture at the other focus is geometrically ideal only when the source is small compared to the output aperture. In the case of an extended source, such as a typical arc tube, the geometrically ideal conditions just described do not apply. For example, if a small output aperture is required, any error in the source position, such as due to arc wander or misalignment, causes large variations in light output distribution. Further, the image of the extended source undergoes a paraxial magnification which is usually significant. Quite apart from the large off-axis aberrations introduced by an elliptical reflector, the increased image size greatly reduces the amount of light available at the output aperture.

Light sources, in general, radiate a certain specific energy per unit surface area. To increase the total lamp output one must increase the surface area of the light source. In the case of an arc lamp, output is a function of arc length and diameter. Many applications, however, require that the output aperture be of a specific, small size. This requires a collection system which efficiently images an extended source into a small aperture and disperses it in a controlled manner.

It is our object to provide a compact high intensity light source with a high efficiency collector which utilizes internal light reflection for production of an in-

tense output beam by imaging an extended source through a small aperture and then dispersing this light through a wide field with an even distribution.

SUMMARY OF THE INVENTION

The above objects are achieved by utilizing a high intensity arc source which emits light in all directions and a light collector of the light conducting type which is disposed in a surrounding relationship about the light source. The energy per unit area is spread over the surface area of the light collector by imbedding the light source within the collector with a forward and a rearward portion of the collector. The forward or output portion of the collector is defined by a surface which is curved in a light converging contour with complete internal light reflection extending from a large light receiving aperture and narrowing toward a smaller axial output aperture such that light from the source is reflected by internal reflection toward the output aperture. The rearward portion is adjacent to the forward portion and has surface characteristics for forwardly reflecting light from the source into the forward portion of the collector as light emerges rearwardly from the source. In this manner substantially all of the light which emerges from the source is directed into the forward portion of the light collector for convergence at the output aperture.

Because the high intensity arc source is virtually imbedded in the material of the light collector, it is necessary to cool the arc source. To do this, a coolant is introduced between the forward and rearward portions of the light collector through a discoidal chamber which preserves the radial symmetry of the apparatus thereby minimizing internal rearward reflection. The coolant is circulated past the light source and is then removed cooled and recirculated.

This light source has application wherever high intensity arc sources are required such as in the manufacture of color TV tubes for exposing the phosphor dot pattern thereon, for projecting color motion pictures, et cetera.

DESCRIPTION OF THE FIGURES

FIG. 1 is a perspective view of the apparatus of the present invention with a partial cutaway section.

FIG. 2 is a side sectional view of the apparatus shown in FIG. 1.

FIG. 3 is an exploded view of the light collector of the present invention.

FIG. 4 is a plan showing alignment of the axis of the light collector in three successive positions.

FIG. 5 is a plan for construction of the parabolic light collector based upon alignment of the axis of the collector shown in FIG. 4.

FIG. 6 is a graph comparing the output of the present apparatus to the prior art.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In FIGS. 1 and 2, the light collector 11 is shown to include an outer housing 13, having a front-end 15 which is defined by an annular flange and a back-end 17 which is penetrated by conduits 19 and 21. The prime function of the housing 13 is to provide support for the internal structure of the light source and collector.

The structure of the light source and collector includes a conventional arc tube 23 of the type wherein an arc discharge is created between opposed electrodes. The alignment of the arc tube 23 extends along the axis of housing 13. The function of the apparatus described herein is to collect as much light as possible from the extended source, arc tube 23, and deliver this light through output aperture 31.

The light collector 25 includes a forward portion 27 which is light-conductive as explained hereinafter and which converges from a larger diameter light receiving input aperture 29 at one end of the forward portion 27 proximate to the arc tube 23 and extends toward a smaller axial output aperture 31 at an opposite end.

A rearwardly extending portion of light collector 25 includes conical member 37 and reflector member 39. Conical member 37 has an output surface 35 with a diameter generally matching the diameter of the light input aperture 29 of forward portion 27. The conical member 37 co-axially surrounds a substantial part of the arc tube 23. Conical member 37 has a surface inclined to arc source 23 to reflect light from source 23 into forward portion 27. The surface of conical member 37 is reflective merely because of differences in the index of refraction between the material of conical member 37, e.g. quartz, and the surrounding medium, e.g. air.

Conical member 37 is constructed on the basis of the following criteria. The cone angle is centered on the most intensive portion of the fan-shaped light output distribution from arc tube 23. The cone angle should be as small as possible to avoid the need for a large input aperture for the forward portion 27 of light collector 25. Further, rearwardly directed light should be forwardly reflected with only one reflection, to the maximum extent possible. In practice, an angle of about 35° has been found best to achieve these criteria. The index of refraction of rearward portion 33 should be the same as forward portion 27 and greater than the ambient index of refraction surrounding the body.

Most of the light which escapes conical member 37 is traveling either radially outwardly perpendicular to arc tube 23 or in a rearward direction, i.e., toward back end 17 of housing 13. A reflector member 39 coaxially surrounds conical member 37 for reflecting light escaping from the conical member back into the conical member for passage into the forward portion 27 of light collector 25. As shown in the drawing, reflector member 39 comprises a series of annular steps which are made reflective by polishing or metalizing. One method of making reflector member 39 is to take a series of annular quartz or aluminum discs of increasing radii and adhere them together with a temperature resistant adhesive means. Then the stepped portions of the annular rings is made reflective by depositing an aluminum coating thereon in the case of quartz or by polishing the surface in the case of aluminum. The height and width of the staircase formed by the annular rings of increasing diameter should be approximately equal so that optimum corner reflection can be achieved. The staircase configuration is but one means for reflecting escaping light back into the light collector.

The trajectories of light rays from arc source 23 may be summarized as follows. A small portion of the light from arc tube 23 which exits the tube in a forward direction at acute angles with respect to the axis of housing 13 will pass directly into the forward portion 27 of

the light collector. Most of the light from arc source 23 will emerge generally perpendicular to the axis of arc source 23. Most of this light will be internally reflected in conical member 37 and then pass into forward portion 27. The remaining light will pass through conical member 37 onto reflector member 39 and be reflected back into conical member 37. At this point the light will be reflected from another part of conical member 37 or pass directly into forward portion 27. The subsequent reflection from another part of conical member 37 increases the probability that the light will pass into forward portion 27. If it does not, the process is repeated.

The surface of the forward portion 27 of light collector 25 is parabolic as far as output aperture 31 where the parabola may be, but is not necessarily, truncated. Beyond output aperture 31, a dispersing lens is used. Such a lens may be parabolic or may be any standard dispersing lens. The general shape of the surface of forward portion 27 as well as the size of the output aperture may be determined in accord with the principles set forth in the article "Light Collection within the Framework of Geometrical Optics" by Roland Winston, *Journal of the Optical Society of America*, Volume 60, No. 2, pages 245-247 (February, 1970) and described herein.

The forward portion 27 of light collector 25 has an index of refraction higher than the ambient index of refraction and is made of a truncated light transmissive substance. Quartz is preferred because of its ability to withstand high temperatures and because of its optical uniformity. The shape of forward portion 27 is selected to achieve substantially total internal reflection.

The forward surface 27 of light collector 25 is generated by rotating a parabola about an optical axis. However, the parabola is first displaced from its axis, the A axis in FIG. 4 by a perpendicular distance equal to the radius of the output aperture 31, designated by d in FIG. 4, so that there is a new axis, B, parallel to the A axis. The B axis is now rotated by an angle ϕ , the angle whose sine is equal to the radius of the output aperture 31, d , divided by the radius of the input aperture, D . The new rotated axis is designated as the C axis in FIG. 4. The length of the parabola, L , is equal to $(d+D) \cot \theta$, as set forth in the Winston article, cited above. The parabola which has been displaced from and tilted with respect to the A axis is now rotated about the A axis to form a solid of revolution, as shown in FIG. 5.

By this means, all rays incident on the forward surface 27 at an angle equal to θ will be brought to a focus at the edge of the output aperture 31; all rays incident at an angle less than θ will focus beyond the output aperture 31 and thus pass through the system; all rays incident at an angle greater than θ will be internally reflected until the rays pass through the system.

The forward portion 27 of light collector 25 is cantilevered into position by an annular member 41 whose inside diameter matches the maximum diameter of the annular member 41 which corresponds to the inside diameter of the housing 13. The forward portion 27 of light collector 25 is connected to annular member 41 by means of a high temperature adhesive. Annular member 41 is made of aluminum with a polished surface adjacent to the light collector. Note that the annular member 41 provides the only contact with the forward portion of the light collector.

A disk shaped cavity 43 exists between light receiving aperture 29 and the conical member 37 of light collector 25 by spacing the two members slightly. The cavity 43 communicates on one side of the housing with first conduit 19 and on an opposite side of the cavity with a second conduit 21. The central portion of cavity 43 opens into a plenum, 45, in which the arc tube 23 resides. Coolant is introduced into the first conduit 19 at a low temperature and is pumped into cavity 43 for circulation into plenum 45 wherein the coolant removes heat from arc tube 23 and then flows toward second conduit 21 at a higher temperature for subsequent removal from the apparatus and recirculation after heat is removed.

Disk shaped cavity 43 is positioned between conical member 37, forward portion 27 and the arc source 23 so that all light originating from arc source 23 passes through the disk shaped cavity 43 before entering forward portion 27. The coolant in the cavity 43 therefore filters all light entering forward portion 27. Specific filtering effects are achieved by selecting a suitable coolant. For example, mineral oil with an appropriate red dye will filter infra red so that optical radiation which would otherwise heat the apparatus is filtered out. The heat absorbed by the liquid filter is removed outside of the apparatus in heat exchangers. Liquid dyes having filtration qualities suitable for filtering desired optical bandwidths have been developed for laser technology and are well known in the art. The index of refraction of the liquid should match the index of the light collector.

Arc tube 23 includes a positive electrode 47 which is held in place against an insulator 49 at the end of an axial notch 51 in the central portion of the light receiving aperture 29 of the forward portion 27 of the light collector. The axial notch is conical and extends to a depth such that a part of the tube resides in the notch, as shown in FIG. 3. The positive electrode 47 is connected by means of an insulated cable running through the plenum into first conduit 19 and thence to a high-voltage power supply. A negative electrode 53 opposite the positive electrode 47 is connected by means of an

insulated cable to the opposite or ground side of a power supply with respect to the positive electrode 47. The entire tube is held in place by a removable plug 55 such that the tube can be replaced when it is worn out. The plug 55 is seated in the back end 17 of housing 13.

FIG. 6 shows a plot of light intensity versus output angle from the axis of a light collector. For a typical prior art light collector with an arc source, the lower curve represents the output. Intensity has been measured in arbitrary units. The collector output of the present device is shown in the upper curve using the same arc source as in the prior art device. The two dashed curves represent twice and three times the intensity of the lower curve. Thus it is seen that the output of the present device images the source with an efficiency significantly greater than the prior art.

What is claimed is:

1. A reflector for an axial light source comprising, a conical light transmissive body having a first index of refraction, said conical body having an axially extending aperture therethrough for accommodating a coaxially extending light source, an apex end and an output end opposite the apex end, and a conical surface inclined with respect to a coaxially extending light source at an angle for forwardly reflecting light rays directed thereon;

reflector means surrounding said conical surface and spaced therefrom for reflecting light escaping from said conical body back into said body; and

a medium having a second index of refraction greater than the first index of refraction within the space between said conical body and said reflector means, said medium surrounding the conical body and being in interface therewith.

2. The apparatus of claim 19 wherein said reflector means comprises a series of juxtaposed annular mirrors of decreasing radii from the conical output end to the apex end, coaxial with said conical surface for reflecting light rays directed from a coaxially extending light source toward said conical apex.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,883,731 Dated May 13, 1975

Inventor(s) Harvey L. Morton and Bradley H. Oland

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 4, line 41, "ø" should read "θ"

In Claim 2, first line: "The apparatus of claim 19" should read "The apparatus of claim 1"

Signed and Sealed this

twenty-second Day of July 1975

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks