Innovation, Sciences et Développement économique Canada
Office de la Propriété Intellectuelle du Canada

Innovation, Science and Economic Development Canada
Canadian Intellectual Property Office

CA 3007002 C 2023/02/07

(11)(21) 3 007 002

(12) BREVET CANADIEN
CANADIAN PATENT

(13) C

(86) **Date de dépôt PCT/PCT Filing Date:** 2017/11/08
(87) **Date publication PCT/PCT Publication Date:** 2018/05/17
(45) **Date de délivrance/Issue Date:** 2023/02/07
(85) **Entrée phase nationale/National Entry:** 2018/05/30
(86) **N° demande PCT/PCT Application No.:** IL 2017/051217
(87) **N° publication PCT/PCT Publication No.:** 2018/087756
(30) **Priorités/Priorities:** 2016/11/08 (US62/418,919); 2017/05/22 (US62/509,369); 2017/07/23 (US62/535,890); 2017/09/12 (IL PCT/IL2017/051028)

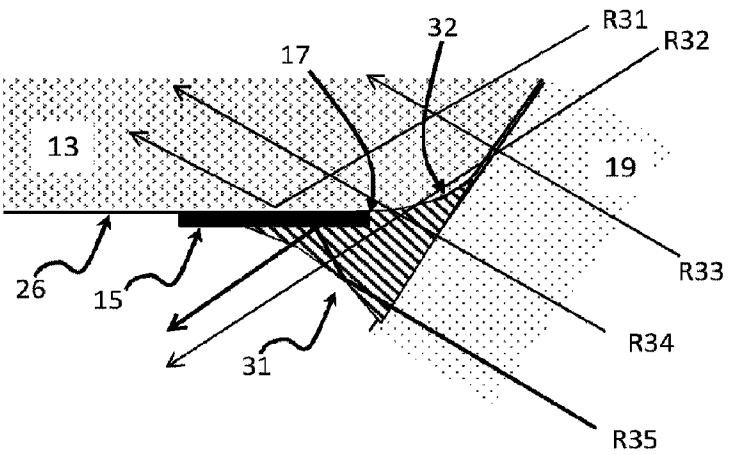
(51) **Cl.Int./Int.Cl.** ***G02B 6/34*** (2006.01), ***G02B 6/26*** (2006.01)

(72) **Inventeurs/Inventors:**
DANZIGER, YOCHAY, IL;
FRIEDMANN, EDGAR, IL

(73) **Propriétaire/Owner:**
LUMUS LTD, IL

(74) **Agent:** INTEGRAL IP

(54) **Titre : DISPOSITIF-GUIDE DE LUMIERE A BORD DE COUPURE OPTIQUE ET PROCEDES DE FABRICATION CORRESPONDANTS**
(54) **Title: LIGHT-GUIDE DEVICE WITH OPTICAL CUTOFF EDGE AND CORRESPONDING PRODUCTION METHODS**



(57) **Abrégé/Abstract:**
A light-guide device includes a light guiding element (13) with a number of faces, including two parallel faces (26), for guiding light by internal reflection. A transparent optical element (19) has an interface surface for attachment to a coupling surface (14) of the light guiding element, and is configured such that light propagating within the transparent optical element passes through the interface surface and the coupling surface (14) so as to propagate within the light guiding element (13). A non-transparent coating (15) is applied to at least part of one or more faces of the light guiding element (13), defining an edge (17) adjacent to, or overlapping, the coupling surface (14) of the light guiding element (13). A quantity of transparent adhesive is deployed between the coupling surface and the interface surface so as to form an optically transmissive interface. An overspill region 31 of the adhesive extends to, and overlaps, the edge (17).

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
17 May 2018 (17.05.2018)

WIPO | PCT

(10) International Publication Number
WO 2018/087756 A1

(51) International Patent Classification:
G02B 6/34 (2006.01) *G02B 6/26* (2006.01)

(21) International Application Number:
PCT/IL2017/051217

(22) International Filing Date:
08 November 2017 (08.11.2017)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

62/418,919	08 November 2016 (08.11.2016)	US
62/509,369	22 May 2017 (22.05.2017)	US
62/535,890	23 July 2017 (23.07.2017)	US
PCT/IL2017/051028	12 September 2017 (12.09.2017)	IL

(63) Related by continuation (CON) or continuation-in-part (CIP) to earlier application:
US PCT/IL2017/051028 (CIP)
Filed on 12 September 2016 (12.09.2016)

(71) Applicant: **LUMUS LTD** [IL/IL]; 8 Pinhas Sapir Street, 7403631 Ness Ziona (IL).

(72) Inventors: **DANZIGER, Yochay**; 2 Rotem St., Kfar Vradim (IL). **FRIEDMANN, Edgar**; Meshek 32, Sdey-Avraham (IL).

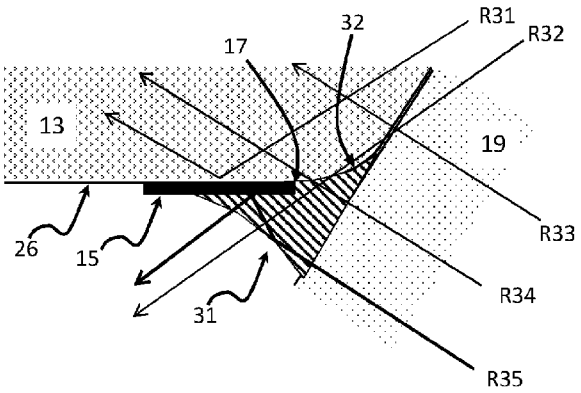
(74) Agent: **FRIEDMAN, Mark**; Moshe Aviv Tower 54th Floor, 7 Jabotinski St., 5252007 Ramat-Gan (IL).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,

(54) Title: LIGHT-GUIDE DEVICE WITH OPTICAL CUTOFF EDGE AND CORRESPONDING PRODUCTION METHODS

FIG. 2C



(57) Abstract: A light-guide device includes a light guiding element (13) with a number of faces, including two parallel faces (26), for guiding light by internal reflection. A transparent optical element (19) has an interface surface for attachment to a coupling surface (14) of the light guiding element, and is configured such that light propagating within the transparent optical element passes through the interface surface and the coupling surface (14) so as to propagate within the light guiding element (13). A non-transparent coating (15) is applied to at least part of one or more faces of the light guiding element (13), defining an edge (17) adjacent to, or overlapping, the coupling surface (14) of the light guiding element (13). A quantity of transparent adhesive is deployed between the coupling surface and the interface surface so as to form an optically transmissive interface. An overspill region 31 of the adhesive extends to, and overlaps, the edge (17).

WO 2018/087756 A1

[Continued on next page]

TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

Light-Guide Device with Optical Cutoff Edge and Corresponding Production Methods

FIELD AND BACKGROUND OF THE INVENTION

The present invention relates to light-guide devices and, in particular, it concerns a light guide device which has a well-defined optical cutoff edge, and corresponding methods for producing such devices.

When manufacturing optical devices, it is often desirable to provide a light guiding device with a complex form in which different regions have surfaces angled with selected non-rectilinear orientations. Examples of such devices relevant to the present invention include, but are not limited to, light guiding elements with coupling-in configurations, and regions of transition between light guiding elements with different transverse dimensions and/or different orientations.

FIGS. 1A and 1B illustrate two examples of devices which include a light guiding element together with a coupling-in prism corresponding to FIGS. 3 and 7, respectively, of PCT Publication No. WO 2015/162611. Referring to the original reference numerals of those drawings in parentheses, each of these devices has a light guiding element (20) with first and second parallel faces (26), and a coupling prism (44, 54) for attachment to the light guiding element so as to provide a suitably angled input surface so that light can be introduced close to the normal to a surface (46, 58) of the prism and then enter the light guide at an angle desired for internal propagation of the light by internal reflection at surfaces (26).

SUMMARY OF THE INVENTION

The present invention is a light guide device and corresponding production methods.

According to the teachings of an embodiment of the present invention there is provided, an apparatus comprising: (a) a light guiding element having a plurality of faces including first and second parallel faces, the light guiding element being configured for guiding light by internal reflection at the first and second parallel faces, one of the plurality of faces providing a coupling surface; (b) a transparent optical element having an interface surface for attachment to the coupling surface, the transparent optical element being configured such that light propagating within the transparent optical element passes through the interface surface and the coupling surface so as to propagate within the light guiding element; (c) a non-transparent coating applied to at least part of at least one of the plurality of faces of the light guiding element, the coating defining an edge adjacent to, or overlapping, the coupling surface of the light guiding element;

and (d) a quantity of transparent adhesive deployed between the coupling surface and the interface surface so as to form an optically transmissive interface, the adhesive extending to, and partially overlapping, the edge.

According to a further feature of an embodiment of the present invention, the coupling surface is provided on one of the first and second parallel faces.

According to a further feature of an embodiment of the present invention, the coating extends between the coupling surface and the interface surface.

According to a further feature of an embodiment of the present invention, the coupling surface is inclined relative to the first and second parallel faces.

According to a further feature of an embodiment of the present invention, the coupling surface and the first parallel face meet at a ground edge, and wherein the edge is non-overlapping with the ground edge.

According to a further feature of an embodiment of the present invention, the adhesive fills a recess formed between the ground edge and the interface surface.

According to a further feature of an embodiment of the present invention, the coupling surface is obliquely inclined relative to the first and second parallel faces.

According to a further feature of an embodiment of the present invention, the coupling surface is perpendicular to the first and second parallel faces.

According to a further feature of an embodiment of the present invention, the interface surface is larger than the coupling surface.

According to a further feature of an embodiment of the present invention, the coating is a metal coating.

According to a further feature of an embodiment of the present invention, the coating is a dielectric coating.

According to a further feature of an embodiment of the present invention, the transparent optical element is a coupling prism configured to provide an input surface oriented for input of light into the light guiding element.

According to a further feature of an embodiment of the present invention, the edge defines an optical cutoff edge for light rays passing from the transparent optical element into the light guiding element.

There is also provided according to the teachings of an embodiment of the present invention, an apparatus comprising: (a) a light guiding element having a plurality of faces including first and second parallel faces, the light guiding element being configured for guiding light by internal reflection at the first and second parallel faces, one of the plurality of faces

providing a coupling surface; (b) a coupling prism having an interface surface adhered to the coupling surface and an input surface for input of light into the light guiding element; and (c) a non-transparent coating applied to at least part of the coupling surface of the light guiding element and extending between the light guiding element and the coupling prism, the coating defining an optical cutoff edge for light passing from the coupling prism through the coupling surface into the light guiding element.

According to a further feature of an embodiment of the present invention, the coupling prism is adhered to the coupling surface of the light guiding element without adhesive.

There is also provided according to the teachings of an embodiment of the present invention, an apparatus comprising: (a) a light guiding element having a plurality of faces including first and second parallel faces, the light guiding element being configured for guiding light by internal reflection at the first and second parallel faces, one of the plurality of faces providing a coupling surface; (b) a coupling prism having an interface surface for attachment to the coupling surface and an input surface for input of light into the light guiding element; and (c) a quantity of transparent adhesive deployed between the coupling surface and the interface surface so as to form an optically transmissive interface, a part of the quantity of adhesive forming a partial filling of an angled recess between the light guiding element and the coupling prism, wherein an air gap extends along one of the faces of the light guiding element beneath the partial filling, the air gap terminating at an edge within the adhesive so as to define an optical cutoff edge adjacent to the coupling surface of the light guiding element.

There is also provided according to the teachings of an embodiment of the present invention, a method for producing an optical assembly, the method comprising: (a) providing a light guiding element having a plurality of faces including first and second parallel faces, the light guiding element being configured for guiding light by internal reflection at the first and second parallel faces; (b) applying a coating to at least part of at least one of the plurality of faces of the light guiding element; (c) grinding the light guiding element along a plane intersecting the coating so as to simultaneously form a coupling surface of the light guiding element and an edge of the coating; and (d) bonding to the coupling surface an interface surface of a transparent optical element, the transparent optical element being configured such that light propagating within the transparent optical element passes through the interface surface and the coupling surface so as to propagate within the light guiding element, wherein the bonding is performed by applying a quantity of a transparent adhesive between the coupling surface and the interface surface, the quantity of adhesive being applied such that, when the coupling surface and the

interface surface are pressed together, an excess of the transparent adhesive overlaps the edge of the coating.

According to a further feature of an embodiment of the present invention, the coating is a non-transparent coating such that the edge defines an optical cutoff edge.

According to a further feature of an embodiment of the present invention, there is also provided a step of selectively removing the coating so as to leave a cutoff edge defined by an edge of an air-gap formed in the transparent adhesive.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is herein described, by way of example only, with reference to the accompanying drawings, wherein:

FIGS. 1A and 1B, described above, correspond to FIGS. 3 and 7, respectively, of PCT Publication No. WO 2015/162611, illustrating light guide devices to which the present invention may advantageously be applied;

FIG. 1C is a schematic isometric view of a light guide device according to an aspect of the present invention in which context the present invention may also be advantageously applied;

FIGS. 2A, 2B and 2C are schematic enlarged cross-sectional partial views of a region of joining of two transparent optical elements illustrating, respectively, the junction without adhesive, with adhesive, and with a protective layer overlapped by adhesive according to an embodiment of the present invention, each view illustrating various light ray paths for each case;

FIGS. 3A-3C are a sequence of schematic isometric views illustrating stages during the production of a light guide device according to an embodiment of the present invention, the views illustrating a light guiding element after application of a coating, after grinding of a coupling surface, and after bonding of a coupling-in prism, respectively;

FIG. 3D is a schematic isometric view of a light guiding element after application of a coating with a pre-formed edge according to an alternative production sequence of certain embodiments of the present invention;

FIGS. 4A and 4B are schematic side views illustrating stages during the production of a further embodiment of the present invention illustrating a light guiding element after application of a coating, and after bonding of a coupling-in prism, respectively;

FIG. 4C is a view similar to FIG. 4B illustrating the overall optical effect of a device resulting from the production process of FIGS. 4A and 4B;

FIGS. 5A-5C are schematic side views illustrating stages during the production of a variant implementation of the device of FIG. 4C;

FIGS. 6A-6C are a sequence of schematic isometric views illustrating stages during the production of a light guide device according to a further embodiment of the present invention, the views illustrating a light guiding element after application of a coating, after grinding of a coupling surface, and after bonding of a coupling-in prism, respectively;

FIG. 6D is a view similar to FIG. 6C illustrating the overall optical effect of a device resulting from the production process of FIGS. 6A-6C;

FIG. 7A is a view similar to FIG. 2C illustrating a further variation of the present invention according to which a coating layer is removed to leave an air gap;

FIG. 7B is a view similar to FIG. 6D illustrating an implementation of that device using an air gap according to FIG. 7A;

FIG. 8A is an isometric view of a light guide device that is a further variant of the devices of FIGS. 1C and 3C, constructed and operative according to the teachings of an embodiment of the present invention;

FIG. 8B is a schematic horizontal cross-sectional view taken through the device of FIG. 8A adjacent to the base of the light guiding element, illustrating propagation of an input image aperture along the light guiding element; and

FIG. 9 is a schematic end view of a light guide device formed from superposition of two light guiding elements, implemented according to the teachings of an aspect of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is a light guide device and corresponding production methods.

The principles and operation of light guide devices according to the present invention may be better understood with reference to the drawings and the accompanying description.

By way of introduction, the present invention relates to a wide range of situations in which two transparent elements are joined, and especially, although not exclusively, where external surfaces of the two elements meet at an angle or step. Joints between transparent elements of an optical system present a number of challenges for practical implementation. Firstly, edges of blocks of transparent material are not perfectly sharp edges, and are modified (distorted) by some radius of curvature, often with some chipping or other defects. The extent of this rounding typically varies depending on the properties of the materials and the type of equipment used. FIG. 2A illustrates a schematic partial cross-sectional enlarged view of a region of joining of two transparent optical elements **13** and **19**, where an edge **32** of one of the elements **13** after grinding exhibits a radius of curvature. This radius of curvature results in

various scattering effects which reduce the overall quality of the optical device. Thus, while rays R11 and R13 pass from optical element **19** to optical element **13** without scattering and propagate as intended along optical element **13**, and ray R15 is excluded from optical element **13**, rays R12 and R14 interact with various intermediate angles of the surface due to the rounding of edge **32**, resulting in scattering of rays at angles other than those corresponding to the device design, with a consequent reduction in signal-to-noise for the overall device.

A further problem arises through the use of optical adhesives, as illustrated here in FIG. 2B. In order to ensure uniform optical properties at the interface, a sufficient quantity of optical adhesive is interposed between the facing surfaces that, after pressing them together, the entire area of the facing surfaces to be joined is covered with adhesive. This typically leads to some outflow of excess adhesive at the extremities of the surfaces to be joined, forming an overspill region **31** which may be of arbitrary size and uncontrolled shape. Since the adhesive is transparent adhesive, and typically also index-matched to the transparent optical elements, overspill region **31** defines additional paths of optical rays which may result in scattering and unwanted angles of ray propagation within optical element **13**. Thus, in the example illustrated here, rays R23 and R24 pass from optical element **19** to optical element **13** without scattering and propagate as intended along optical element **13**, and ray R22 escapes without reaching optical element **13**. However rays R21 and R25 interact with various arbitrarily-angled surfaces of overspill region **31** of the adhesive, resulting in scattering of rays at angles other than those corresponding to the device design, with a consequent reduction in signal-to-noise for the overall device.

According to one aspect of the present invention, as illustrated in FIG. 2C, there is provided an optical device or apparatus which includes two transparent optical elements, typically a light guiding element **13** with a plurality of faces including first and second parallel faces **26** so that light can be guided within element **13** by internal reflection at first and second parallel faces **26**. The second transparent optical element **19** has an interface surface for attachment to a coupling surface of light guiding element **13**. A non-transparent (opaque) coating **15** is applied to at least part of at least one of the faces of light guiding element **13**, in this case, one of the parallel faces **26**. Coating **15** is preferably chosen to provide (or maintain) reflective properties for internal reflection at the surface of the light guiding element, and preferably defines an edge **17** adjacent to, or in some cases described below overlapping, the coupling surface of light guiding element **13**. A quantity of transparent adhesive is deployed between the coupling surface and the interface surface so as to form an optically transmissive interface, the adhesive forming an overspill region **31** which extends to, and partially overlaps, the edge **17**.

As seen in FIG. 2C, the presence of coating **15** according to this exemplary implementation significantly enhances the optical properties of the device. Firstly, due to the presence of coating **15** on the surface of light guiding element **13**, the adhesive of overspill region **31** does not compromise the internal reflection properties of the light guiding element **13**, such that ray R31 is internally reflected within the light guiding element and propagates correctly within the light guiding element. Additionally, edge **17** here serves as an optical cutoff edge, cleanly delineating between rays R31, R33 and R34 which enter the light guiding element undistorted, and rays R32 and R35 which are excluded therefrom. Any stray light that is reflected by irregular surfaces of the adhesive overspill region **31**, such as ray R35, hits the outer surface of coating **15** and is excluded from the light guiding element.

Coating **15** may be formed from any material suitable for application to a surface of an optical element and which provides the required light-blocking properties and provides internally reflective properties of the transparent optical elements. Examples include, but are not limited to, various metal coatings and various dielectric coatings. In one particularly preferred but non-limiting example, a coating of silver protected by a thin sealing layer to prevent oxidation has been found to be particularly effective and suitable for this application.

The present invention is applicable to a wide range of applications in which two transparent optical elements are joined together. A subset of applications of particular importance relates to devices in which light is introduced into a light guiding element **13**, either from another light guiding element or from a coupling-in configuration **19**. Such applications can employ a number of different geometries of attachment, which employ attachment of optical element **19** to various different surfaces of the light guiding element **13**, as illustrated in FIGS. 1A-1C. In FIG. 1A, a coupling-in prism is attached to one of the major parallel surfaces of the light guiding element, while in FIG. 1B, attachment of a prism occurs at an obliquely angled coupling-in surface. Attachment may also occur at an end surface perpendicular to the major surfaces of a light guiding element, such as is illustrated in the novel configuration of FIG. 1C, which relates to a rectangular light guiding element with two pairs of parallel surfaces. Further examples of an implementation of the present invention for each of these geometries may be found below.

The sequence of operations to produce optical devices according to the present invention may vary considerably according to the particular design employed. FIGS. 3A-3C illustrate a sequence of stages of production, corresponding to a method of one particularly preferred, but non-limiting, aspect of the present invention. In this case, production of an optical assembly includes a step of applying a coating **15** to at least part of at least one face of a light guiding

element **13**, which may be a slab-type guiding element with two major parallel faces, or may be a rectangular (including square) light guiding element with two pairs of parallel faces for guiding light through four-fold internal reflection, as shown in FIG. 3A. According to the particularly preferred sequence shown here, light guiding element **13** is then ground along a plane intersecting the coating so as to form simultaneously an end coupling surface **14** and an edge **17** of coating **15**, as shown in FIG. 3B. An interface surface of a transparent optical element, such as a coupling-in prism **19**, is then bonded to coupling surface **14**, so that light propagating within the transparent optical element can pass through the interface surface and the coupling surface so as to propagate within the light guiding element. Bonding of prism **19** to light guiding element **13** is performed by applying a quantity of a transparent adhesive between the coupling surface and the interface surface. The adhesive is applied such that, when the coupling surface and the interface surface are pressed together, an excess of the transparent adhesive overlaps edge **17** of coating **15**, thereby generating a final configuration which is analogous to that described above with reference to FIG. 2C, where the coating prevents the adhesive from adversely affecting the light guiding element properties, and where edge **17** provides a well-defined optical cutoff edge delineating what beams do and do not enter the light guiding element. This approach may be used to advantage for coupling surfaces at any desired angle, including orthogonal coupling surfaces such as that of FIG. 1C and oblique coupling surfaces such as that of FIGS. 3B and 3C.

The simultaneous forming of coupling surface **14** and edge **17** in a grinding/polishing process is considered advantageous in that it ensures correct positioning of edge **17** relative to coupling surface **14**, typically just beyond any non-planar edge effects occurring at the extremity of the coupling surface, such as shown in FIG. 2C, and avoids the need for formation of a sharp edge during the coating process. As a result of this process, coupling surface **14** and one of the parallel faces of the light guiding element meet at a ground edge, and edge **17** of the coating is in non-overlapping relation with the ground edge. A "ground edge" in this context refers to the entire region over which an angular transition occurs which deviates from flat surface.

Alternatively, as illustrated in FIG. 3D, a region of coating **15** may be applied to a light guiding element **13** in such a manner as to define an edge **17** during the application of the coating. Techniques for applying the coatings of the present invention in general, and in particular, for selective application of a layer so as to form a well-defined edge, are known in the art, and can be chosen according to the type of coating used, and the corresponding application technique employed. For example, a protected silver coating or a dielectric coating can be applied by conventional deposition techniques, such as sputter coating or wet chemical deposition, and the shape of the coating can be defined by various conventional techniques

including, but not limited to, lithographic techniques defining a pattern of photoresist, and mechanical masking such as by application of adhesive tape. Application of the coating with a well-defined edge defined during the application process is particularly useful in applications in which another transparent optical element is to be bonded to the light guiding element on one of the major parallel surfaces, such as in the configuration of FIG. 1A. An example of such an application will be described below with reference to FIGS. 4A-4C.

The coatings of the present invention may be applied on one or more surface of one or both of the optical elements to be bonded, and may be applied to either the entirety of the surface(s) or, more preferably, to only a part of the surface(s) which is sufficiently close to the bonding region to be needed for its adhesive-protection properties. Thus, in many implementations, the total area of the coating in the final assembled device is less than half the total surface area of the corresponding surface, and in certain cases, is less than the total area of the bonded surfaces.

In certain applications, coating on only one side, or a subset of the faces, may be sufficient. For example, where two components are to be coupled so that certain surfaces will be flush after coupling, it may be possible to remove excess adhesive effectively after bonding by performing a further polishing step which is effective to resurface the two components in a common plane.

Turning now to FIGS. 4A-4C, these illustrate an implementation of the present invention in which the coupling surface is provided on one of the major parallel faces defining the light guide. In this case, coating **15** is advantageously applied so as to define edge **17**, most preferably in a location which is to be overlapped by the transparent optical element **19** after attachment (FIG. 4B). After attachment of the transparent optical element **19**, the coating is seen to extend between the coupling surface and the interface surface. As a result, any overspill region **31** of adhesive, as well as the ground edge of coupling prism **19**, fall outside the optical cutoff edge **17** such that the adhesive overspill and any imperfections of the coupling prism edge do not adversely affect the optical properties of the device.

FIG. 4C schematically depicts the overall optical properties of the assembled components. As in a number of other particularly preferred implementations illustrated here, transparent optical element **19** is a coupling prism configured to provide an input surface **18** oriented for input of light into light guiding element **13**. Specifically, for a light guiding element which is implemented as part of a system in which light propagates within the element within a given range of angles, input surface **18** may advantageously be oriented roughly perpendicular to the input ray directions, thereby minimizing distortions. Additionally, employing edge **17** as an

optical cutoff, this configurations can be utilized for "filling" the light guiding element with rays of an image, where a slightly oversized image aperture is "trimmed" by an optical cutoff edge to ensure that the image (and its reflected conjugates) are present at all locations within the light guiding element. For this purpose, edge **17** does not necessarily have to be a straight edge, but should be a cleanly defined edge of whatever shape is desired. Various arrangements for filling of a light guiding element with an image are described in PCT Patent Publication No. WO 2015/162611 for light guiding elements with one pair of parallel faces, and in co-pending PCT Patent Application No. PCT/IL2017/051028 (which was unpublished on the filing date of this application) for light guiding elements with two pairs of parallel faces. In each of those configurations, the optical cutoff edge serving to trim the in-coupled images can advantageously be implemented according to the teachings of the present invention. It will be noted that the trimming edge thickness is defined by the thickness of the coating layer, which is thin, and will generate minimal scattering.

FIGS. 5A-5C illustrate a modified production sequence and final form of an optical assembly functionally similar to that of FIGS. 4A-4C, but in which the optical geometry is enhanced. In this case, light guiding element **13** is coated with coating **15**, as in FIG. 4A. In the next step (FIG. 5B), a rectangular prism **19** is glued on one of the primary parallel faces of light guide element **13**, partly covering the coating **15**. The use of a rectangular prism during assembly facilitates effective pressing together of the prism to the light guiding element, thereby achieve better bonding. The bonded prism and light guiding element are then polished along the dashed line to generate an enhanced device geometry, as depicted in FIG. 5C.

Parenthetically, although described primarily in relation to devices in which optical elements are bonded by use of optical adhesive, it should be noted that certain examples of the present invention can be implemented without adhesive, where alternative bonding techniques are used. The structures of FIGS. 4A-4C and 5A-5C are examples of structures suitable for such an implementation, where the coupling surface of light guiding element **13** and the interface surface of transparent optical element **19** are carefully prepared to a high degree of planarity and then joined by glueless contact bonding ("direct bonding") by bringing the surfaces into direct contact. In such cases, there is no problem of adhesive overspill. However, the technique of providing a coating with an optical cutoff edge extending between the components ensures a high quality optical cutoff, independent of any imperfections in the edge of the coupling prism.

Turning now to FIGS. 6A-6D, these illustrate an exemplary non-limiting process for implementing the present invention in the context of a geometry similar to that of FIG 1B. In this example, light guiding element **13** is first coated with coating **15** as shown in 6A. The end of the

light guiding element is then polished to form the coupling surface, and simultaneously shortens the coated region so as to generate trimming edge **17**, as shown in FIG. 6B. In FIG. 6C, prism **19** is bonded to the coupling surface of the light guiding element **13**, with any adhesive overspill **31** overlying edge **17** and part of coating **15**. In this case, optionally, the interface surface of prism **19** may advantageously be larger than the coupling surface of the light guiding element. FIG. 6D depicts schematically the overall optical structure of the combined assembly, in which edge **17** provides an optical cutoff, and the optical properties are insensitive to imperfections of the angled edges of the elements.

Turning now to FIGS. 7A and 7B, there is shown a further variant implementation of the present invention. In this case, instead of employing an opaque coating to define a cutoff edge, a removable coating **15** is used to protect the light guiding element surfaces during application of adhesive, and to define cutoff edge **17**. After the bonding is complete and the adhesive has solidified, the coating is selectively removed so as to leave a cutoff edge defined by an edge of an air-gap **34** formed in the transparent adhesive.

In this case, the coating/layer does not need to have any particular optical requirements, and is only present during application of adhesive to attach the coupling-in prism **19**. The air-gap **34** is generated after the material of the layer (such as photoresist or wax) has been removed. The optical properties of this configuration including the behavior of the various rays is analogous to the rays illustrated in FIG. 2C, except that reflectance of ray R21 is now by total internal reflection (TIR) of the light guiding element (instead of layer reflectivity) and the reflectance of R25 is by TIR within the adhesive (instead of from an outer surface of the coating). Trimming edge **17** is now determined by the edge of the air-gap, after which the optical path is continuous. The overall optical properties of the device are depicted schematically in FIG. 7B.

The present invention may be implemented in the contexts of optical elements that are bonded at surfaces of any orientation, including at coupling surfaces that are perpendicular to an extensional direction of a light guiding element, such as was illustrated above in FIG. 1C. As mentioned, the invention is also applicable to light guiding elements with two pairs of parallel surface within which rays propagate by four-fold reflection, referred to as a "2D waveguide."

In certain cases, protective layer coatings may be used to advantage on selected surfaces of two elements being bonded. Thus, in FIGS. 8A and 8B, it may be preferably to apply a protective coating on both sides of light guiding element **13** in order to reduce non uniformity that can be caused by a discontinuity between prism **19** and light guiding element **13** (region **37** in FIG. 8A). The coating is shown on both sides of light guiding element **13** as 80f1 and 80f2. By introducing a protective coating layer all around the end of light guiding element **13**

(including 80f1, 80f2 and the other two orthogonal sides) the guidance of the waveguide will be protected from glue spillover or edge non-uniformities from all sides. If the step between prism **19** and light guiding element **13** near 80f2 is small (or doesn't exist) then it is beneficial to also protect the reflectance of the prism **19** from any glue spillover by protecting coating 80f3 as well.

Turning finally to FIG. 9, although illustrated herein primarily in the context of a coupling-in prism attached to a light guiding element, the present invention can equally be applied to other applications such as, for example, where a first light guiding element (or "waveguide") feeds into another. FIG. 9 illustrates one such example in which a rectangular (2D) light guiding element **10** feeds into a slab-type (1D) light guiding element **20**. This configuration corresponds to one of a number of such options described in the aforementioned co-pending PCT Patent Application No. PCT/IL2017/051028 (which was unpublished on the filing date of this application), and the invention can equally be applied to the various variant implementations, with or without a coupling prism, described therein.

Waveguide **10** is slightly larger than waveguide **20** in order to enable complete illumination (filling) of waveguide **20**. The glue **2110** can spillover either or both of waveguides **20** and **10**. Particularly preferred implementations of the present invention thus provide protective coating layers on both waveguides, as illustrated at 40f1, 40f2, 40f3 and 40f4.

To the extent that the appended claims have been drafted without multiple dependencies, this has been done only to accommodate formal requirements in jurisdictions which do not allow such multiple dependencies. It should be noted that all possible combinations of features which would be implied by rendering the claims multiply dependent are explicitly envisaged and should be considered part of the invention.

It will be appreciated that the above descriptions are intended only to serve as examples, and that many other embodiments are possible within the scope of the present invention as defined in the appended claims.

WHAT IS CLAIMED IS:

1. An apparatus comprising:

(a) a light guiding element having a plurality of faces including a pair of parallel faces, said light guiding element being configured for guiding light by internal reflection at said parallel faces, one of said plurality of faces providing a coupling surface;

(b) a transparent optical element having an interface surface for attachment to said coupling surface, said transparent optical element being configured such that light propagating within said transparent optical element passes through said interface surface and said coupling surface so as to propagate within the light guiding element;

(c) a non-transparent coating applied to at least part of at least one of said parallel faces of said light guiding element, said coating defining an edge adjacent to, or overlapping, said coupling surface of said light guiding element; and

(d) a quantity of transparent adhesive deployed between said coupling surface and said interface surface so as to form an optically transmissive interface, said adhesive extending to, and overlapping, said edge,

wherein said edge defines an optical cutoff edge for light rays passing from said transparent optical element into said light guiding element, and wherein said non-transparent coating is configured to generate internal reflection at an underlying region of said at least one of said parallel faces.

2. The apparatus of claim 1, wherein said coupling surface is provided on one of said parallel faces.

3. The apparatus of claim 2, wherein said coating extends between said coupling surface and said interface surface.

4. The apparatus of claim 1, wherein said coupling surface is inclined relative to said parallel faces.

Date reçue/date received 2022-10-11

5. The apparatus of claim 4, wherein said coupling surface and said parallel face meet at a ground edge, and wherein said edge is non-overlapping with said ground edge.

6. The apparatus of claim 5, wherein said adhesive fills a recess formed between said ground edge and said interface surface.

7. The apparatus of claim 4, wherein said coupling surface is obliquely inclined relative to said parallel faces.

8. The apparatus of claim 4, wherein said coupling surface is perpendicular to said parallel faces.

9. The apparatus of claim 1, wherein said interface surface is larger than said coupling surface.

10. The apparatus of claim 1, wherein said coating is a metal coating.

11. The apparatus of claim 1, wherein said coating is a dielectric coating.

12. The apparatus of claim 1, wherein said transparent optical element is a coupling prism configured to provide an input surface oriented for input of light into said light guiding element.

13. An apparatus comprising:

(a) a light guiding element having a plurality of faces including a pair of parallel faces, said light guiding element being configured for guiding light by internal reflection at said parallel faces, one of said plurality of faces providing a coupling surface;

(b) a coupling prism having an interface surface adhered to said coupling surface and an input surface for input of light into the light guiding element; and

(c) a non-transparent coating applied to at least part of said coupling surface of said light guiding element and extending between said light guiding element and said coupling prism, said coating defining an optical cutoff edge for light passing from said coupling prism through said coupling surface into said light guiding element,

Date reçue/date received 2022-10-11

and wherein said non-transparent coating is configured to generate internal reflection at an underlying region of said at least one parallel face.

14. The apparatus of claim 13, wherein said coupling prism is adhered to said coupling surface of said light guiding element without adhesive.

15. An apparatus comprising:

(a) a light guiding element having a plurality of faces including first and second parallel faces, said light guiding element being configured for guiding light by internal reflection at said first and second parallel faces, one of said plurality of faces providing a coupling surface;

(b) a coupling prism having an interface surface for attachment to said coupling surface and an input surface for input of light into the light guiding element; and

(c) a quantity of transparent adhesive deployed between said coupling surface and said interface surface so as to form an optically transmissive interface, a part of said quantity of adhesive forming a partial filling of an angled recess between said light guiding element and said coupling prism,

wherein an air gap extends along one of said faces of said light guiding element beneath said partial filling, said air gap terminating at an edge within said adhesive so as to define an optical cutoff edge adjacent to said coupling surface of said light guiding element.

16. A method for producing an optical assembly, the method comprising:

(a) providing a light guiding element having a plurality of faces including first and second parallel faces, said light guiding element being configured for guiding light by internal reflection at said first and second parallel faces;

(b) applying a coating to at least part of at least one of said plurality of faces of said light guiding element;

(c) grinding said light guiding element along a plane intersecting said coating so as to simultaneously form a coupling surface of said light guiding element and an edge of said coating; and

(d) bonding to said coupling surface an interface surface of a transparent optical element, the transparent optical element being configured such that light propagating within the transparent optical element passes through the interface

Date reçue/date received 2022-10-11

surface and the coupling surface so as to propagate within the light guiding element,

wherein said bonding is performed by applying a quantity of a transparent adhesive between said coupling surface and said interface surface, said quantity of adhesive being applied such that, when said coupling surface and said interface surface are pressed together, an excess of said transparent adhesive overlaps said edge of said coating.

17. The method of claim 16, wherein said coating is a non-transparent coating such that said edge defines an optical cutoff edge.

18. The method of claim 16, further comprising a step of selectively removing said coating so as to leave a cutoff edge defined by an edge of an air-gap formed in said transparent adhesive.

19. A method for producing an optical assembly, the method comprising:

(a) providing a light guiding element having a plurality of faces including a pair of parallel faces, said light guiding element being configured for guiding light by internal reflection at said parallel faces, one of said plurality of faces providing a coupling surface;

(b) applying a non-transparent coating to at least part of at least one of said parallel faces, said non-transparent coating defining an edge adjacent to, or overlapping, said coupling surface of said light guiding element; and

(c) bonding to said coupling surface an interface surface of a transparent optical element, the transparent optical element being configured such that light propagating within the transparent optical element passes through the interface surface and the coupling surface so as to propagate within the light guiding element,

wherein said bonding is performed by applying a quantity of a transparent adhesive between said coupling surface and said interface surface, said quantity of adhesive being applied such that, when said coupling surface and said interface surface are pressed together, an excess of said transparent adhesive overlaps said edge of said coating, and

wherein said edge defines an optical cutoff edge for light rays passing from said transparent optical element into said light guiding element, and wherein said non-transparent coating is

Date reçue/date received 2022-10-11

configured to generate internal reflection at an underlying region of said at least one parallel face including where overlapped by the excess of said transparent adhesive.

20. The method of claim 19, wherein said coupling surface is provided on one of said parallel faces.

Date reçue/date received 2022-10-11

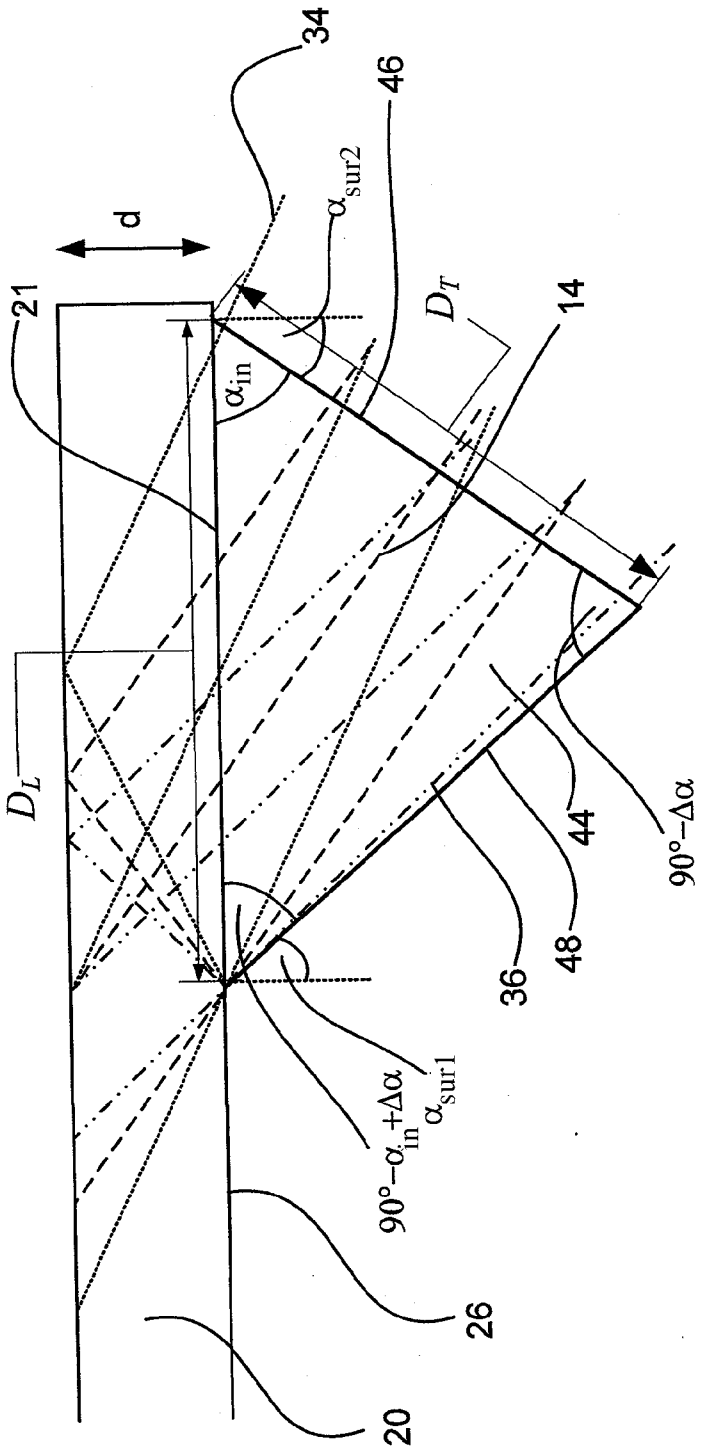


FIG. 1A (PRIOR ART)

FIG. 1B (PRIOR ART)

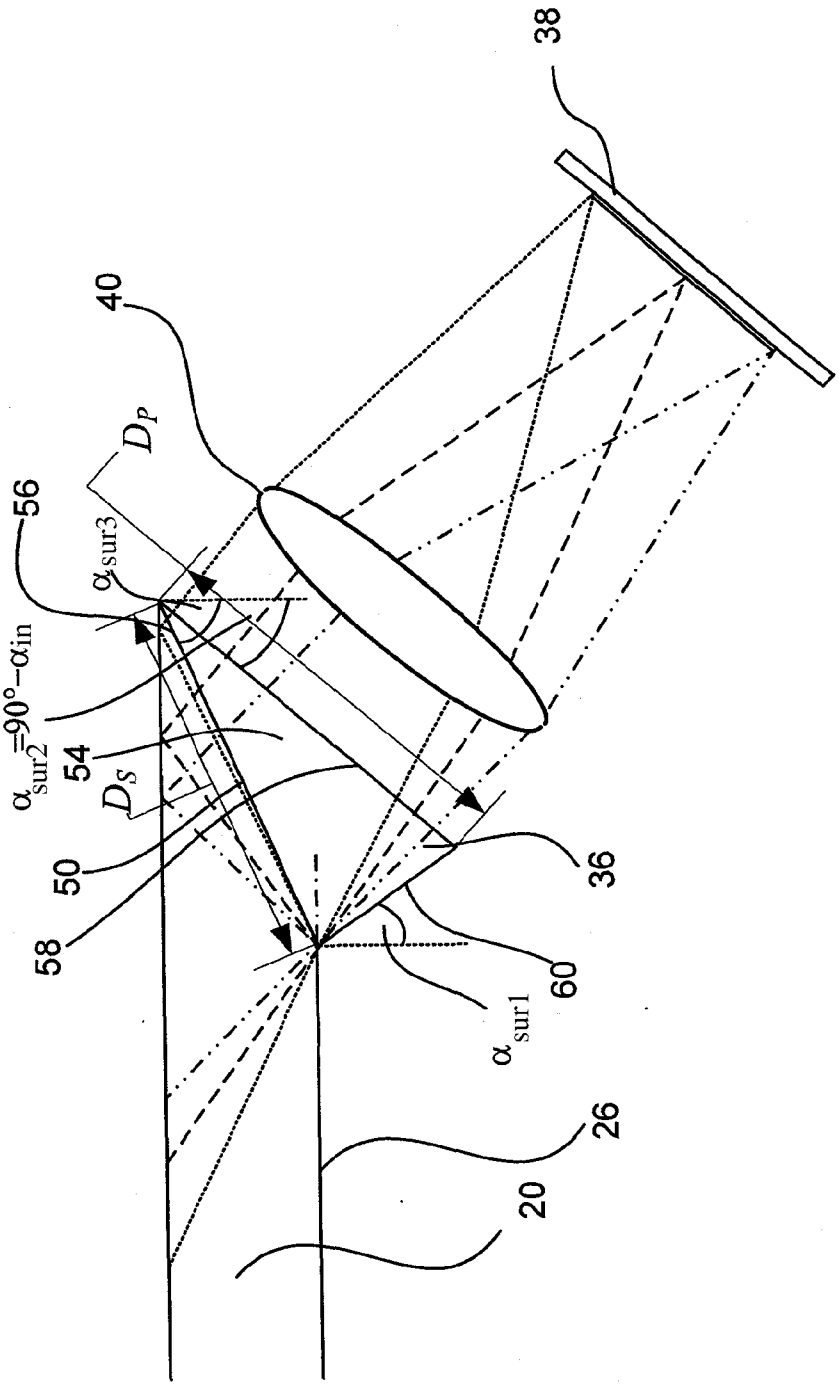


FIG. 1C

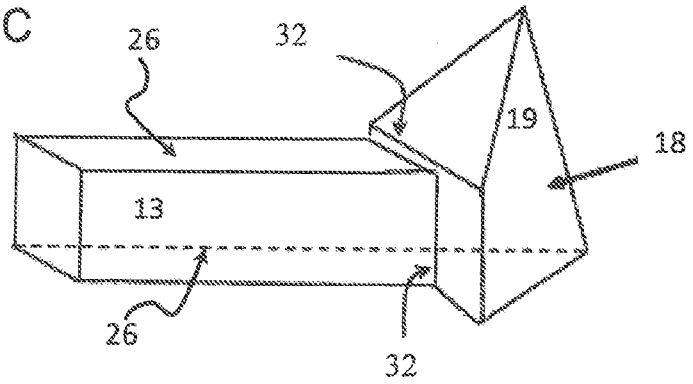


FIG. 2A

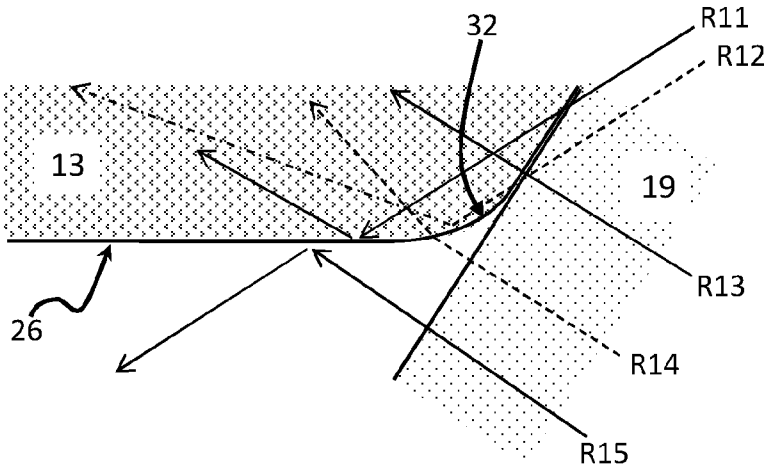


FIG. 2B

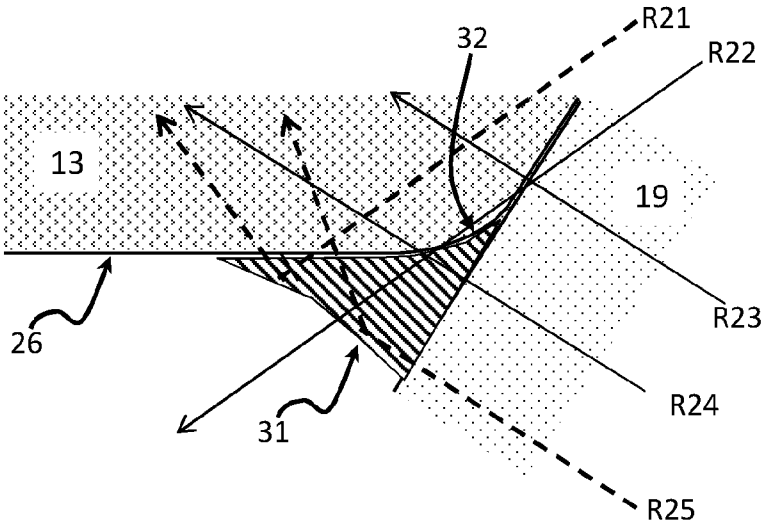


FIG. 2C

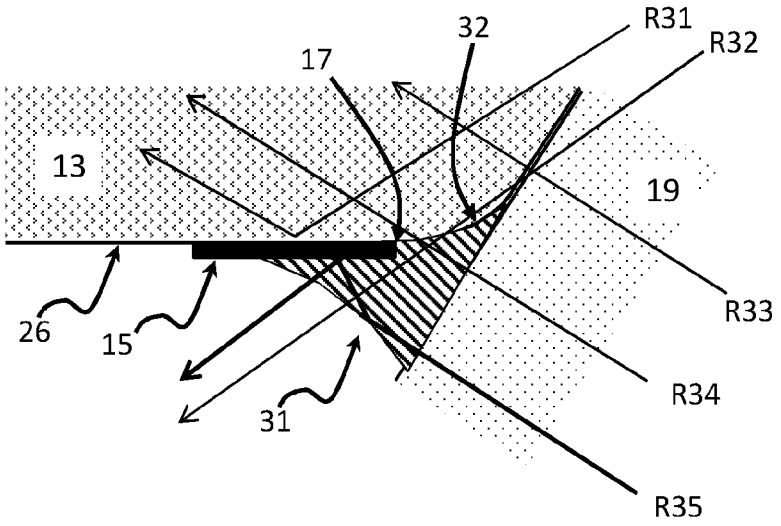


FIG. 3A

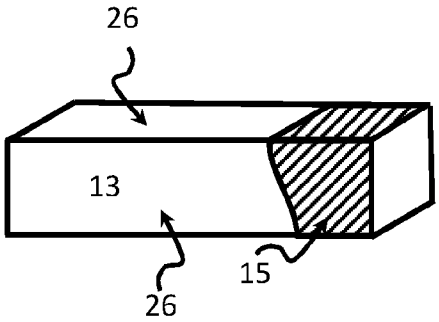


FIG. 3B

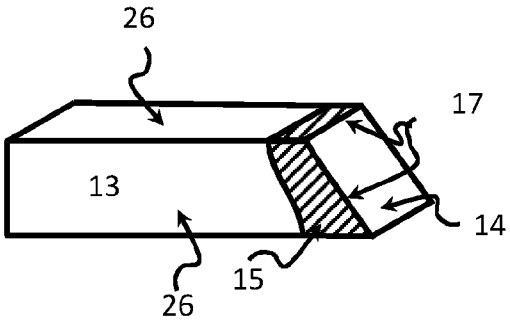


FIG. 3C

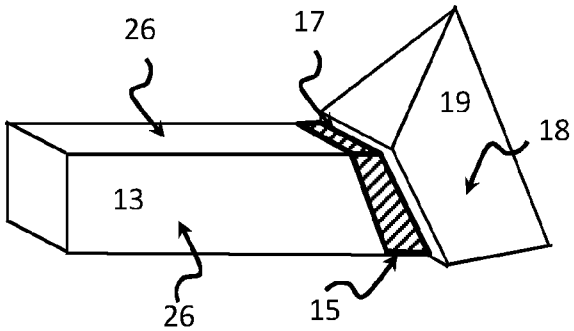


FIG. 3D

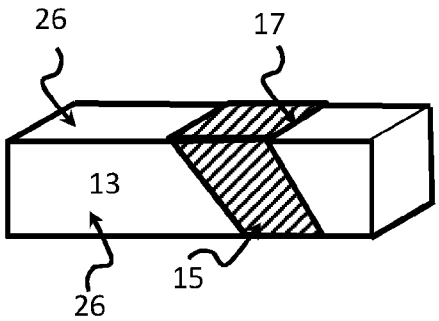


FIG. 4A

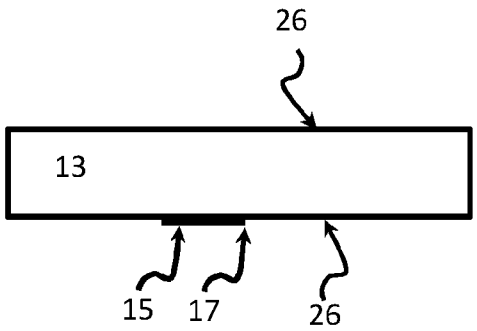


FIG. 4B

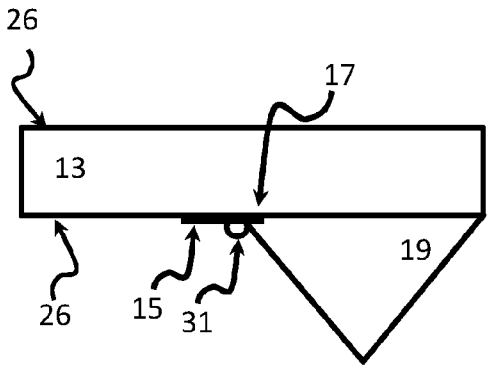


FIG. 4C

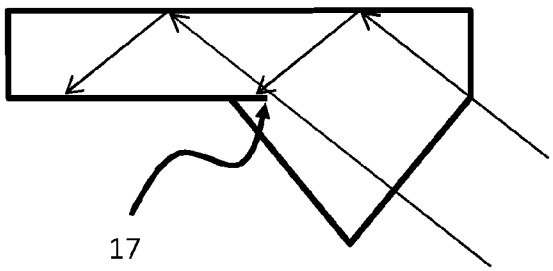


FIG. 5A

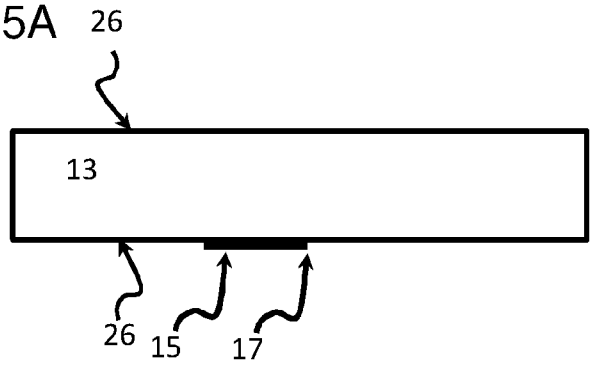


FIG. 5B

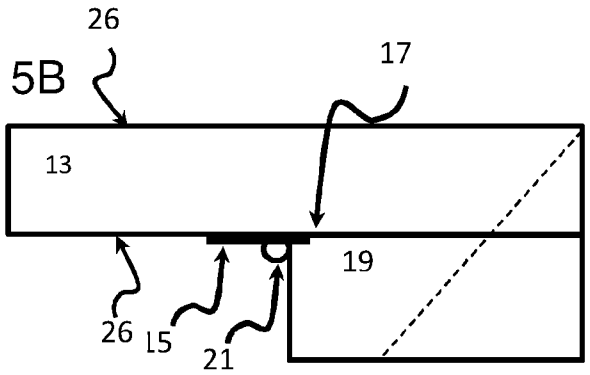


FIG. 5C

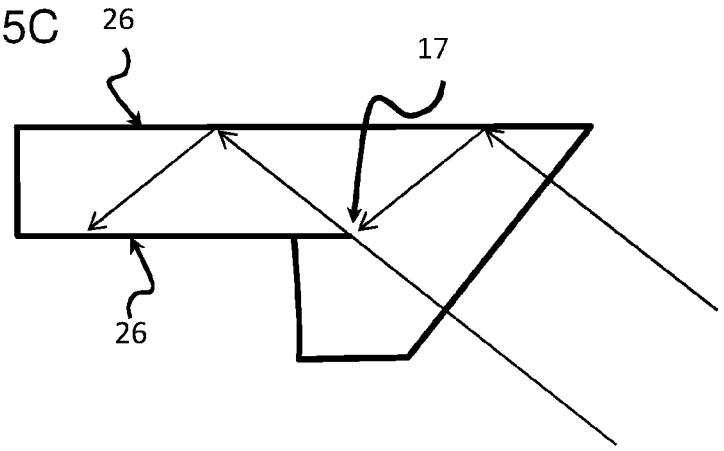


FIG. 6A

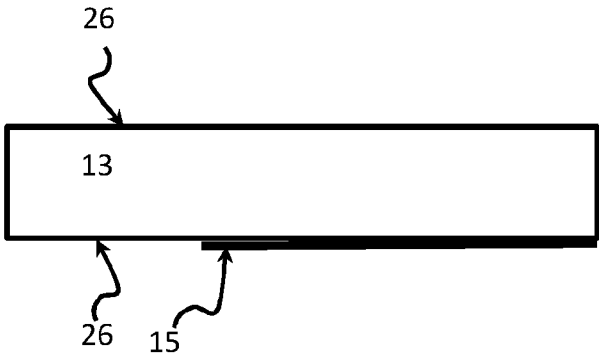


FIG. 6B

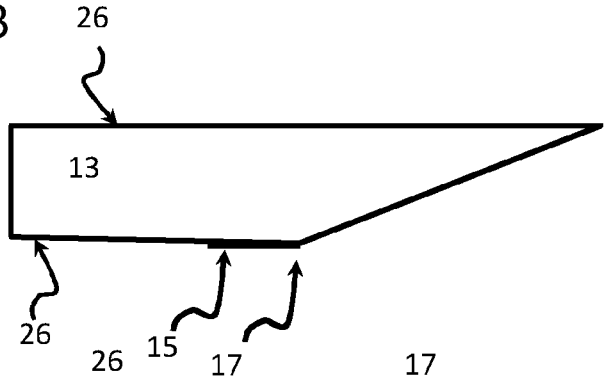


FIG. 6C

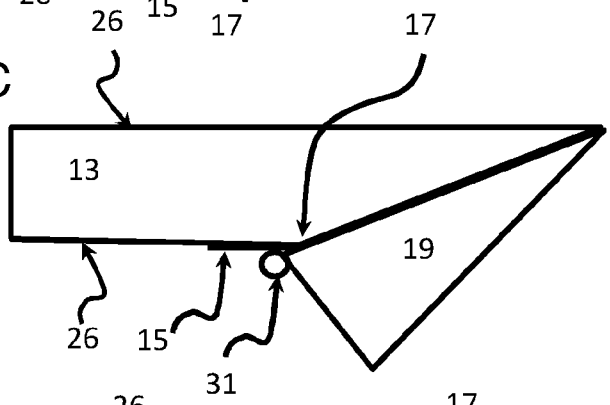


FIG. 6D

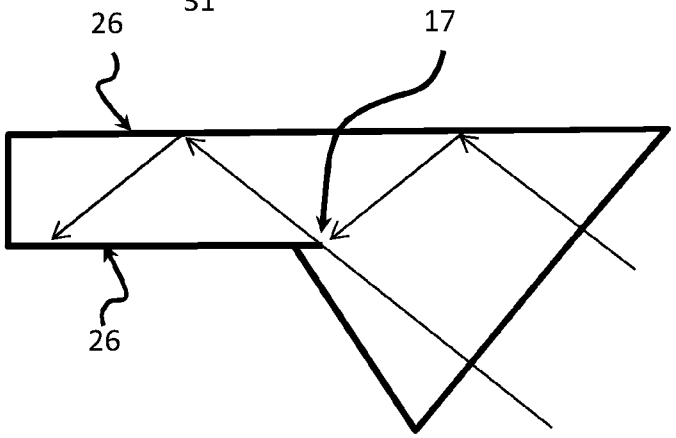


FIG. 7A

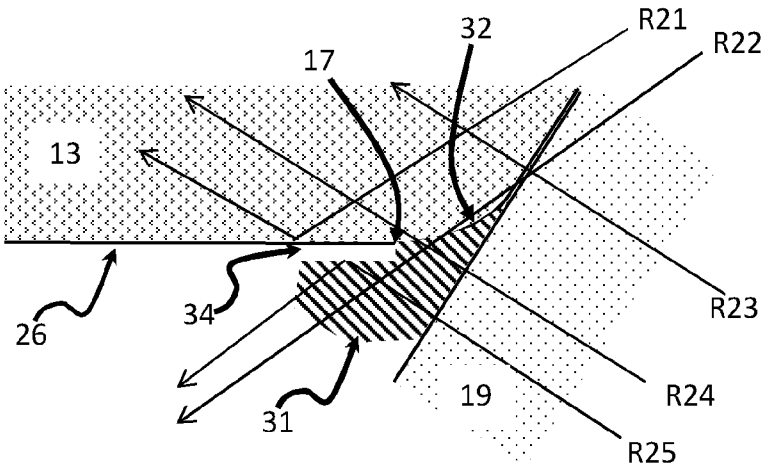


FIG. 7B

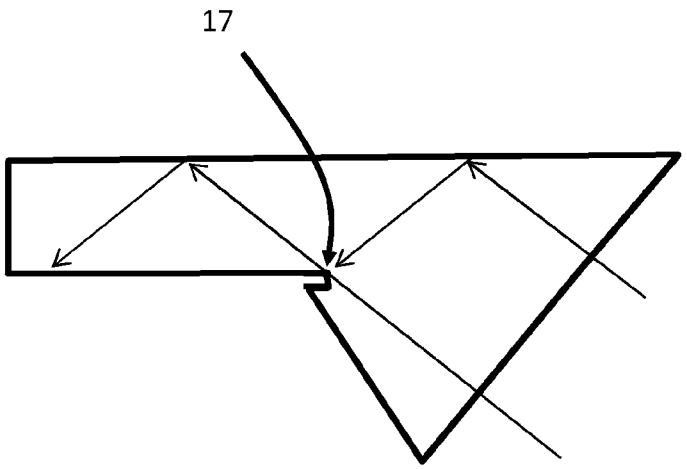


FIG. 8A

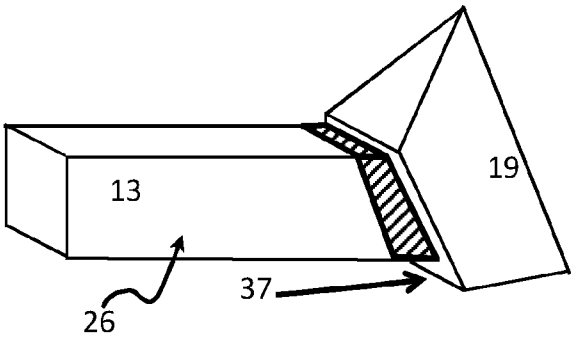


FIG. 8B

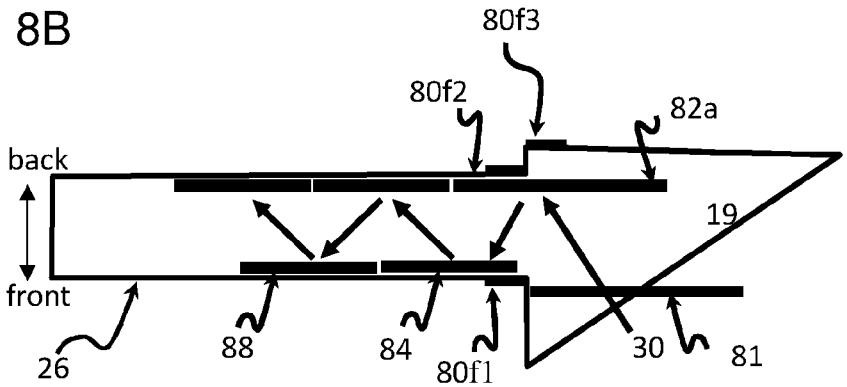
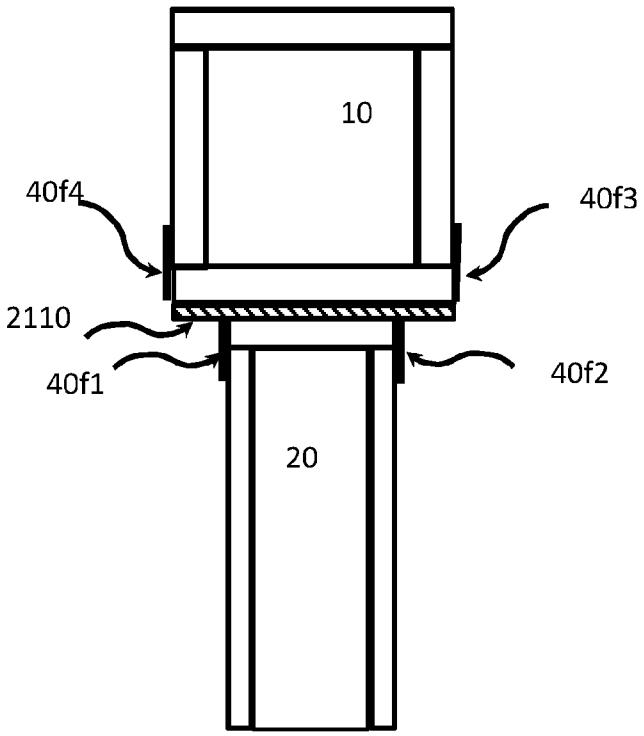
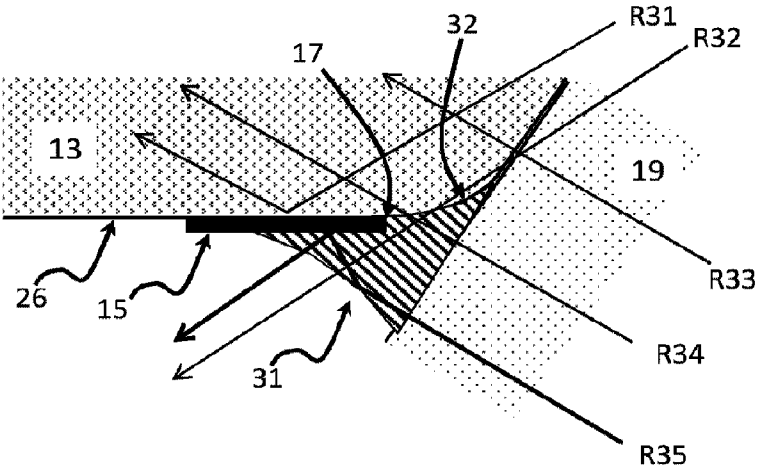


FIG. 9




32
R31
R32
17
13
19
R33
26
15
R34
31
R35