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— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

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(54) **Title**: LIGHTGUIDE INCLUDING EXTRACTORS WITH DIRECTIONALLY DEPENDENT EXTRACTION EFFICIENCY

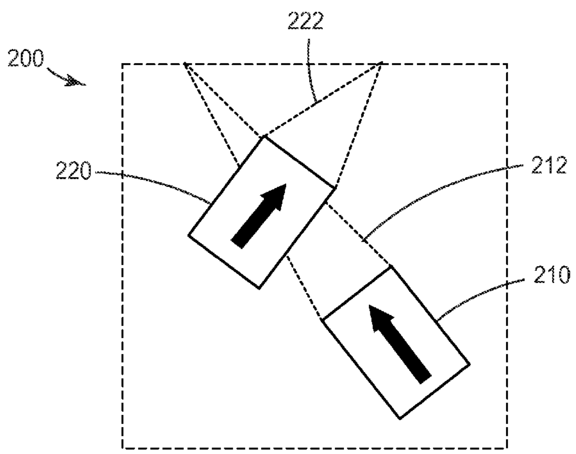

FIG. 2

(57) **Abstract**: Lightguides are disclosed. In particular, lightguides including extractors with directionally dependent extraction efficiency are disclosed. The lightguide may include a series or array of directionally dependent light extractors. Certain configurations enabling the display of indicia and exemplary light extractor shapes are also disclosed.

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LIGHTGUIDE INCLUDING EXTRACTORS WITH DIRECTIONALLY DEPENDENT EXTRACTION EFFICIENCY

Background

Lightguides are used to transport light through total internal reflection. Lightguides include extractors which divert or reflect light such that the light can pass out of the lightguide and in some cases be viewed by a viewer. The configuration of the extractors affects characteristics of the overall illumination viewable from systems including these lightguides.

Summary

In one aspect, the present disclosure relates to a lightguide. The lightguide includes first and second discrete spaced apart light extractors disposed on a major surface of the lightguide and configured to preferentially extract light when receiving light rays propagating within the lightguide along respective first and second ranges of optical paths, the preferentially extracted light rays exiting the lightguide along a range of viewing angles with respective minimum first and second extraction efficiencies, the second light extractor being disposed on a first optical path within the first range of optical paths, where a light ray propagating along the first optical path and extracted by the second light extractor exits the lightguide within the range of viewing angles with a third extraction efficiency substantially less than the minimum first extraction efficiency. In some embodiments, the third extraction efficiency is substantially less than the minimum second extraction efficiency.

In another aspect, the present disclosure relates to a lightguide including first and second discrete spaced apart light extractors disposed on a major surface of the lightguide, the first light extractor configured to preferentially extract light when receiving light rays propagating within the lightguide along a first range of optical paths, the preferentially extracted light rays exiting the lightguide along a first range of viewing angles with a minimum first extraction efficiency, the second light extractor disposed on a first optical path within the first range of optical paths. A light ray propagating along the first optical

path and extracted by the second light extractor exits the lightguide within the first range of viewing angles with a second extraction efficiency substantially less than the minimum first extraction efficiency. In some embodiments, the range of viewing angles is within 20 degrees from a normal of the lightguide.

In yet another aspect, the present disclosure relates to a lightguide including first and second discrete spaced apart light extractors disposed on a major surface of the lightguide, the first light extractor configured to receive and extract a first light ray from a first edge location of the lightguide along a first optical path extending between the first edge location and the first light extractor, the extracted first light ray exiting the lightguide along a first viewing direction with a first extraction efficiency. The second light extractor is disposed on the first optical path and extracts the first light ray with a second extraction efficiency substantially less than the first extraction efficiency.

In another aspect, the present disclosure relates to a lightguide including first and second discrete spaced apart light extractors disposed on a major surface of the lightguide and configured to receive and extract respective first and second light rays from respective spaced part first and second edge locations of the lightguide along respective first and second optical paths extending between the respective first and second edge locations and the respective first and second light extractors, the extracted first and second light rays exiting the lightguide with respective first and second extraction efficiencies. The second light extractor is disposed on the first optical path and extracts the first light ray with a third extraction efficiency substantially less than the first and second extraction efficiencies.

In yet another aspect, the present disclosure relates to a lightguide including first and second discrete spaced apart light extractors disposed on a major surface of the lightguide and configured to preferentially extract light when receiving light rays propagating within the lightguide along respective first and second ranges of optical paths, each optical path in one of the first and second optical paths intersecting each optical path in the other one of the first and second optical paths.

In another aspect, the present disclosure relates to a lightguide including first and second discrete spaced apart light extractors disposed on a major surface of the lightguide and configured to receive and extract respective first and second light rays from respective spaced part first and second edge locations of the lightguide along respective and intersecting first and second optical paths extending between the respective first and second edge locations and the respective first and second light extractors. The extracted first and second light rays exit the lightguide with respective first and second extraction efficiencies, the first light extractor extracts a light ray received from the second edge location with an extraction efficiency substantially less than the first extraction efficiency, and the second light extractor extracts a light ray received from the first edge location with an extraction efficiency substantially less than the second extraction efficiency.

In some embodiments, the first and second discrete spaced apart light extractors are disposed on a same major surface. In some embodiments, at least one of the first and second light extractors is a wedge. In some embodiments, at least one of the first and second light extractors is a wedge with a positive or negative cylindrical sag. In some embodiments, at least one of the first and second light extractors is one of an asphere or a truncated asphere.

In one aspect, the present disclosure relates to a lightguide. The lightguide includes a plurality of spaced apart clusters of light extractors disposed on a major surface of the lightguide, each cluster of light extractors including at least first and second light extractors configured to preferentially extract light when receiving light rays propagating within the lightguide along respective first and second ranges of optical paths, no optical path in one of the first and second optical paths intersecting an optical path in the other one of the first and second optical paths.

In another aspect, the present disclosure relates to a lightguide including a plurality of groups of light extractors configured to extract light propagating within the lightguide to form an indicium for viewing. Each group of light extractors is configured to extract light to form a different portion of the indicium and each group of light extractors is configured to preferentially extract light received from a different corresponding edge location of the lightguide with an associated minimum extraction efficiency, such that each light extractor in any group of light extractors that receives a light ray from an edge location that corresponds to another group of light extractors, extracts the received light with an extraction efficiency that is substantially less than the minimum extraction efficiency associated with the another group of light extractors.

In yet another aspect, the present disclosure relates to a lightguide including a plurality of groups of light extractors extracting light propagating within the lightguide from a plurality of discrete spaced apart light sources disposed along one or more edges of the lightguide to form an image. There may be a one-to one correspondence between the plurality of groups of light extractors and the plurality of discrete spaced apart light sources. Each group of light extractors extracts light received from the corresponding light source with an associated minimum extraction efficiency and at least one light extractor in each group of light extractors receiving light from a light source corresponding to another group of light extractors and extracting the received light with an extraction efficiency that is substantially less than the minimum extraction efficiencies associated with the group of light extractors and the another group of light extractors

In another aspect, the present disclosure relates to a lightguide including a plurality of discrete spaced apart light extractors. The light extractors are configured to extract light propagating within the lightguide, the extracted light forming substantially overlapping first and second images at an emission surface of the lightguide, where each light extractor extracts light that is primarily part of only one of the first and second images.

In yet another aspect, the present disclosure relates to a lightguide including pluralities of first and second light extractors disposed on a major surface of the lightguide. The plurality of first light extractors extracts light propagating within the lightguide from one or more first light sources disposed along one or more edges of the lightguide with a minimum first extraction efficiency to form a first image at an emission surface of the lightguide and the plurality of second light extractors extracting light propagating within the lightguide from one or more second light sources disposed along one or more edges of the lightguide with a minimum second extraction efficiency to form a second image at the emission surface of the lightguide. The one or more first light sources are different than the one or more second light sources and the first and second images are non-overlapping. At least one first light extractor receives and extracts light propagating within the lightguide from the one or more second light sources with a light extraction efficiency substantially less than the minimum first extraction efficiency and at least one second light extractor receives and extracts light propagating within the lightguide from the one or more first light sources with a light extraction efficiency substantially less than the minimum second extraction efficiency. In some embodiments, the at least one first light extractor receives and extracts light propagating within the lightguide from the one or more second light sources with a light extraction efficiency substantially less than the minimum second extraction efficiency. In some embodiments, the at least one second light extractor receives and extracts light propagating within the lightguide from the one or more first light sources with a light extraction efficiency substantially less than the minimum first extraction efficiency.

In another aspect, the present disclosure relates to a lightguide including first and second discrete spaced apart light extractors disposed on a major surface of the lightguide and configured to preferentially extract light with respective minimum first and second extraction efficiencies when light rays propagating within the lightguide are received by the first and second light extractors from their input faces, at least one light ray that is preferentially extracted by the first light extractor being received by the second light extractor from a face other than the input face of the second light extractor before being received by the first light extractor from the input face of the first light extractor. The at least one light ray is extracted by the second light extractor with an extraction efficiency that is substantially less than the minimum first extraction efficiency.

Brief Description of the Drawings

FIG. 1 is a top perspective view of a wedge light extractor having directionally dependent extraction efficiency.

FIG. 2 is a top plan view of a lightguide including extractors with directionally dependent extraction efficiencies.

FIG. 3 is a top plan view of the lightguide of FIG. 2 receiving light from an edge location.

FIG. 4 is a top plan view of another lightguide including extractors with directionally dependent extraction efficiencies.

FIG. 5 is a top plan view of the lightguide of FIG. 4 receiving light from two edge locations.

FIG. 6 is a top plan view of a lightguide including clusters of extractors with directionally dependent extraction efficiencies.

FIG. 7 is a top plan view of another lightguide including clusters of extractors with directionally dependent extraction efficiencies.

FIG. 8 is a top plan view of a lightguide including extractors with directionally dependent extraction efficiencies.

FIG. 9 is a top plan view of another lightguide including extractors with directionally dependent extraction efficiencies.

Detailed Description

FIG. 1 is a top perspective view of a light extractor having directionally dependent extraction efficiency. Extractor **100** includes top face **110** and side face **120**. To provide an example of directionally dependent extraction efficiency, first incident ray **130** and second incident ray **140** are shown. An axis passing through extractor **100** is provided for illustrative purposes, providing a reference for the azimuthal orientation of extractor **100**.

The shape of extractor **100** may cause first incident ray **130** and second incident ray **140** to behave differently. Extractor **100**, for example, if provided within a lightguide such that the index of refraction of or within extractor **100** is less than or substantially less than (e.g, in the case of air) the index of refraction of the lightguide, that may cause first incident ray **130**, having a high incidence angle on top face **110**, to be totally internally reflected off top face **110**. Assuming extractor **100** is oriented or aligned such that the reference axis represents the thickness dimension of the lightguide, reflected ray **132** may be decoupled from being totally internally reflected or transported within the lightguide and exit the lightguide. In other words, reflected ray **132** is extracted. The interaction of incident light on the faces of extractor **100** may be modeled and predicted by the extractor shape and relative indices of refraction between extractor and lightguide. In contrast, second incident ray **140** is incident on side face **120** at a very low incidence angle, in this example near-normal incidence. Therefore, second incident ray **140** is transmitted through extractor **100**. Transmitted ray **142**, having no significant change in direction within the lightguide, may remain and continue to be transported within the lightguide. In some embodiments, second incident ray **140** may be reflected, nonetheless remaining within the lightguide, possibly incident on other extractors.

Extraction efficiency for an individual extractor may, at least for purposes of this application, be described as the ratio of light incident on an extractor to light extracted by that extractor. Note that this characteristic is independent of size (at least within reasonable size scales) and dependent largely on shape. Total extraction efficiency for an individual extractor describes the ratio of light incident on an extractor from any azimuthal direction and incidence angle. It also may be useful to characterize a light extractor—in particular an azimuthally asymmetric light extractor—as having directionally dependent extraction efficiencies. For example, the extractor in FIG. 1 may have a first extraction efficiency for light incident along the azimuthal direction of first incident ray **130**, while having a second, substantially less extraction efficiency for light incident along the azimuthal direction of second incident ray **140**. From another perspective, light may be extracted at different efficiencies depending on the input face of the extractor on which it is incident. First incident ray **130** and second incident ray **140** are substantially orthogonal and represent cases with significant differences in extraction efficiencies. In many embodiments, extraction efficiencies may instead vary smoothly or continuously as a function of azimuthal incidence direction from a lower extraction efficiency to a higher extraction efficiency and vice versa. Extractor efficiency may also, similarly, be a function of polar angle of incidence. In some cases, it may be useful to characterize useful extracted light as being extracted light within a certain angle from the normal or viewing direction (reference axis in FIG. 1), such as 20 degrees.

Extractor **100** is depicted as a wedge in FIG. 1, but may instead be many suitable shapes. For example, the shape of the faces, such as top face **110** may be designed or configured to have a positive or negative cylindrical sag. Light may be extracted within a range of extraction angles or viewing directions. Changing the shape of the faces of extractor **100**, in particular preferentially extracting faces such as, in the configuration of FIG. 1, top face **110**, may shift, widen, narrow, or even split the range of viewing angles from light extracted by extractor **100**. In some embodiments, extractor **100** may be designed to preferentially extract light within a range of viewing angles, such as a 20 degree solid angle from the normal. Extractor **100** may be shorter, thinner, wider, or longer than the exemplary extractor shown in FIG. 1. Extractor **100** may have a face that is multifaceted, curved, concave, convex, spherical, aspherical, or any combination thereof. Extractor **100** may have one or more truncated features or faces. Truncation may occur along either a horizontal plane, a vertical plane, or some other plane. In some cases, truncation along a horizontal plane may affect total extraction efficiency, while truncation along a vertical plane may affect aziumuthal or direction dependent extraction efficiency. Exemplary shapes include wedges, wedges with positive or negative cylindrical sag, concave-concave wedges (concave surfaces as both top and side faces, concave-convex wedges (concave surface as one and convex surface as the other of top and side faces), aspheres, trimmed or truncated aspheres or sections thereof, and the like.

In some embodiments, as in FIG. 1, extractor **100** may have one input face from which light is extracted with a higher efficiency. In other embodiments, extractor **100** may have a plurality of input faces from which light is extracted with a higher efficiency. In some embodiments, the term face may be inappropriate, because extractor **100** has a smooth curved shape. Nonetheless, in these cases, segments or portions of extractor **100** may have higher extraction efficiencies than other segments or portions of the extractor. For some extractors, it is appropriate to characterize them as preferentially extracting light along a range of optical paths. The range of optical paths may be characterized by the range of angles of incident light for which an extractor has a certain minimum extraction efficiency. This minimum efficiency may be 50%, 70%, 80%, 90%, 95%, or 99% of incident light, depending on the application.

Extractor **100** may be any suitable size. Although extractor efficiency is independent of the size of the extractor, the size of the extractor affects the total intensity of light extracted at that point. Further, design considerations such as resolvability of extractors by the human eye, speckle effects, and manufacturability may be factors in determining a desirable and suitable size or range of sizes for the extractors.

FIG. 2 is a top plan view of a lightguide including extractors with directionally dependent extraction efficiencies. Lightguide **200** includes first extractor **210** preferentially extracting first range of optical paths **212**, and second extractor **220** preferentially extracting second range of optical paths **222**. For the purposes of this application, or at least in terms of the figures within this application, the convention of an arrow indicating the extractor orientation by pointing toward the optical path or incident direction of greatest extraction efficiency is adopted. The range of optical paths associated with an extractor represents those paths that have an extraction efficiency over a minimum extraction efficiency. Depending on the particulars of the shape and design of the extractors, the range of associated optical paths need not be a continuous range. Moreover, the ranges of optical paths appear only two-dimensional because FIG. 2 is a plan view, however, the range of optical paths may have any three-dimensional shape, also controlled by careful design of extractor shape.

Lightguide **200** is shown with dotted line edges to indicate that the specific boundaries of the lightguide are not critical. Lightguide **200**, however, may be made from any suitable material, including acrylic, polymeric materials, glass, and others. In some embodiments, lightguide **200** is formed from the same piece of material as the extractors, the extractors being an indentation or protrusion of the lightguide.

A replication tool may be used to fabricate the lightguides described herein. The replication tool, which may comprise metal, silicon, or other suitable materials includes the negative of the lightguide features including the protruded or recessed light extractors. The metal replication tool may be made from a master by electroplating or electroforming the metal, such as nickel, against the master and subsequently removing the master. A silicone replication tool can be made by curing a silicone resin against the master and subsequently removing the master.

The masters may be formed using a multi-photon (or, specifically, two-photon) photolithographic process which is described in, for example, U.S. Patent No. 7,941,013 (Marttila et al.), which has been incorporated by reference herein. The multi-photon photolithographic process involves imagewise exposing at least a portion of a photoreactive composition to light sufficient to cause simultaneous absorption of at least two photons, thereby inducing at least one acid- or radical-initiated chemical reaction where the composition is exposed to the light, the imagewise exposing being carried out in a pattern that is effective to define at least the surface of a plurality of light extraction structures.

First extractor **210** and second extractor **220** may be the same shape or they may be different shapes. Depending on the desired application, the extractors may be similarly sized or they may have different sizes. First extractor **210** preferentially extracts light propagating within the lightguide along first range of optical paths **212**. Correspondingly, second extractor **220** preferentially extracts light propagating within the lightguide along second range of optical paths **222**. In FIG. 2, second extractor **220** is disposed on at least an optical path of the first range of optical paths.

Thus, light propagating within lightguide **200** may be propagating along one of the optical paths in first range of optical paths **212** that is incident on second extractor **220**.

However, because second extractor **220** is not oriented to preferentially extract light propagating within first range of optical paths **212**, that light is extracted with an efficiency substantially less than light propagating within lightguide **200** that is incident on first extractor **210**. In other words, light propagating within first range of optical paths **212** is extracted from second extractor **220** with an extraction efficiency that is substantially less than light propagating within first range of optical paths **212** extracted from first extractor **210**. In some embodiments, substantially no light along an optical path within first range of optical paths **212** may be extracted by second extractor **220**, while substantially all light along an optical path within first range of optical paths **212** may be extracted by first extractor **210**.

FIG. 3 depicts the lightguide of FIG. 2 but with edges and a light source. Lightguide **300** includes first extractor **310** preferentially extracting first range of optical paths **312** and second extractor **320** preferentially extracting second range of optical paths **322**. Light source **330** is positioned along an edge or at an edge location of lightguide **300**. Light source generates ray **332**, incident on both second extractor **320** and first extractor **310**. As in FIG. 2, second extractor **320** is disposed along at least one of first range of optical paths **312** associated with first extractor **310**.

Light source **330** is meant to be a generic illumination location (or apparent illumination location in the case of virtual images or reflected light) and is provided for better illustration of the general principles of lightguide **300**. Light source **330**, while depicted as a circle, may have any dimensional extent and may be any suitable light source or set of light sources, including LEDs, CCFLs, or incandescent bulbs. In some embodiments light source **330** may be or include a source of ambient light. Light source **330** may emit or generate light in any wavelength or range of wavelengths.

Ray **332**, generated by light source **330**, is propagating within lightguide **300** along one of first range of optical paths **312**. Second extractor **320** is disposed along that path, and ray **332** is incident on a non-preferentially extracting face of second extractor **320** and is not propagating along one of second range of optical paths **322**. Therefore, second extractor **320** extracts, if at all, ray **332** with a low extraction efficiency. In some cases, ray **332** is transmitted through second extractor **320** without significant deviation. In some embodiments, ray **332** may be 90% transmitted and 10% extracted, and different designs for the extractor shapes, particularly on the non-preferentially extracting face or faces, will provide different proportions. Ray **332** is then incident on first extractor **310**, more specifically on a preferentially extracting face of first extractor **310**, and may be extracted with a high extraction efficiency, or at least in some cases substantially higher than the extraction efficiency of second extractor **320** for the same ray or optical path from light source **330**.

FIG. 4 is a top plan view of another lightguide including extractors with directionally dependent extraction efficiencies. Lightguide **400** includes first extractor **410** associated with first range of optical paths **412** and second extractor **420** associated with second range of optical paths **422**. In the configuration of FIG. 4, each optical path in first range of optical paths **412** and second range of optical paths **420** intersect.

FIG. 5 is a top plan view of the lightguide depicted in FIG. 4, with the addition of edges and light sources to facilitate understanding of the general functioning principles of the lightguide. Lightguide **500** includes first extractor **510** and second extractor **520**, associated as in FIG. 4 with first range of optical paths **512** and second range of optical paths **522**, respectively. Disposed along or proximate edges of lightguide **500** are first light source **530** and second light source **540**. As in FIG. 3, the shapes and precise location of the light sources were selected for ease of illustration and should be understood to provide merely exemplary edge locations.

First light source **530** at a first edge location generates both first light ray **532** and second light ray **534**. First light ray **532** propagates along one of first range of optical paths **512**, while second light ray **534** is not propagating along either first range of optical paths **512** or second range of optical paths **522**. First light ray **532** is incident on first extractor **510** and is extracted with a certain first extraction efficiency. Second light ray **534** is incident on second extractor **520** and is extracted with an extraction efficiency substantially less than the first extraction efficiency.

Similarly, second light source **540** at a second edge location generates both third light ray **542** and fourth light ray **544**. Third light ray propagates along one of second range of optical paths **522** while fourth light ray **544** is not propagating along either first range of optical paths **512** or second range of optical paths **522**. Third light ray **542** is incident on second light extractor **520** and is extracted with a certain second extraction efficiency. Fourth light ray **544** is incident on first extractor **510** and is extracted with an extraction efficiency substantially less than the second extraction efficiency.

The concept depicted in the configuration of FIG. 5 may in some embodiments be utilized to selectively illuminate certain portions of lightguide **500**. For example, if light comes from first light source **530** but not second light source **540** (e.g., first light source **530** is powered but second light source **540** is not), then the comparatively higher extraction efficiency of first extractor **510** vis-à-vis first light source **530** results in that extractor extracting more light than second extractor **520**. Correspondingly, light coming from second light source **540** but not first light source **530** results in second extractor **520** extracting more light than first extractor **510**.

FIG. 6 is a top plan view of a lightguide including clusters of extractors with directionally dependent extraction efficiencies. Lightguide **600** includes first cluster **620**, second cluster **630**, first light source **640**, second light source **650**, and third light source **660**. The light sources are placed to represent hypothetical edge locations for ease of explanation. FIG. 6 adopts the conventions of the previous figures for indicating the preferential direction of the light extractors within the clusters; however, for the ease of illustration the ranges of optical paths associated with each extractor is not shown.

First cluster **620** and second cluster **630** may have the same or similar number of light extractors or they might each have different numbers of light extractors. In some embodiments, the size or shape of extractors within first cluster **620** and second cluster **630** may vary to compensate for their position within lightguide **600**; in some cases, this variation may help the uniformity of the extracted light. First cluster **620** and second cluster **630** will have a minimum of a plurality of light extractors, but may have any suitable number of light extractors. In some embodiments, each light extractor within a cluster of light extractors may have a different orientation. In some embodiments, several light extractors within each cluster of light extractors may have the same orientation.

Because of the complicated optical interaction between the clusters in lightguide **600** and the light sources disposed in exemplary edge locations, explanatory light rays are not provided to illustrate the optical path between these sources and each individual light extractor or each cluster. In some embodiments, however, no optical paths in the respective associated ranges of optical paths for each extractor in a cluster intersect one another. In some embodiments, no optical paths in the respective associate ranges of optical paths for each of two extractors in a cluster intersect one another. First light source **640**, second light source **650**, and third light source **660** may be selectively driven or powered to create interesting optical effects. For example, if first light source **640** is driven or powered, generating light incident on the clusters of light extractors depicted within lightguide **600**, the three extractors within a cluster may extract the light with different extraction efficiencies. Similarly, if first light source **640** and second light source **650** are made to generate light, light from those two light sources may appear to be combined to a viewer where clusters having extractors preferentially extract light propagating in the lightguide from the edge locations of each of first light source **640** and second light source **650**. Alternatively, no light from one, the other, or neither of first light source **640** and second light source **650** may appear where clusters lack one or both of the light extractors oriented to preferentially extract light from those directions.

This configuration—combined with, in some embodiments, a third light source **660** (or more) and careful extractor design and arrangement on lightguide **600**—may result in tremendous design flexibility in displaying information. For example, the light sources may be selectively or sequentially driven, with each orientation of light extractor being distributed differently within the lightguide. A different overall extraction pattern is different for each edge location of the light source. For example, particularly in cases where all light sources emit the same or similar color light, selective illumination of each of the light sources may provide different effects. For example, the extractor clusters may extract a lot of light, less light, or very little light, depending on the distribution of extractor orientations across the clusters and the edge location of the light source. In effect, the selective driving of the light sources may act as a dimmer for otherwise undimmable light sources. Two or more light sources may be driven simultaneously as well, giving even more control over various brightness levels. If the light sources are different colors or have different wavelength ranges, the light sources can be separately driven to provide the appearance of different colors resulting from the controlled and predictable combination of light from the light sources at the clusters. In some embodiments, the distribution of the extractor orientation across the clusters may be such that the powering of a light source will make an image, indicium, logo, or security, verification, or authentication feature appear, which would otherwise be invisible or substantially invisible under illumination from other edge locations. Each orientation of extractor may be distributed through the clusters to make an animation as the light sources are cycled. Timers, microprocessors, or other input devices may be used to control the illumination of the light sources. In some embodiments, the illumination of the light sources and hence the appearance of a particularly imagewise extractor pattern may be programmable, switchable, or otherwise controllable through user input.

FIG. 7 is a plan view of another lightguide including clusters of extractors with directionally dependent extraction efficiencies. Lightguide **700**, similar to lightguide **600** in FIG. 6, has clusters of similarly oriented light extractors as first indicium **710** and second indicium **720**. Also positioned at an edge location are first light source **740** and second light source **750**. First light source **740** generates first light ray **742** and second light ray **744**. Second light source **750** generates third light ray **752**.

The dashed lines in lightguide **700**, besides the dashed lines for the lightguide to deemphasize the specific dimensions of lightguide **700**, represent the approximate boundaries of the indicium, which are simplified for the ease of illustration. Any shape or size is possible with an arrangement of similarly oriented light extractors, such as any suitable logo, shape, word, or other indicium. The operation of lightguide **700** is similar to lightguide **600** of FIG. 6, with light being extracted differently based on the orientation of the directionally dependent light extractors and the edge location of the light source. For example, first indicium **710** receives light from first light source **740** as second ray **744** and from second light source **750** as third ray **752**. The extractors of first indicium **710** are oriented, however, to preferentially extract light along optical paths from first light source **740**, while extracting light along optical paths from second light source **750** at a substantially lower efficiency. Therefore, for example, if first light source **740** emitted blue light and second light source **750** emitted red light, and the two were emitting light simultaneously, first indicium **710** would extract the blue light at a much higher efficiency than the red light. Therefore, that portion of lightguide **700** corresponding to first indicium **710** would appear blue.

Similarly, second indicium **720** receives light from both first light source **740** as first ray **742** and from second light source **750** as third ray **752** (at least, that portion of third ray **752** that is not redirected or extracted by the extractors of first indicium **710**). However, the extractors of second indicium **720** are configured to extract light along optical paths from second light source **750** at a much higher efficiency than light along optical paths from first light source **740**. Thus, when the hypothetical described for first indicium **710** is applied to second indicium **720**—that is, first light source **740** emits blue light and second light source **750** emits red light, second indicium **720** would appear red. Note that in some embodiments, because of the directionally dependent extraction properties of the extractors of lightguide **700**, if the light sources were driven simultaneously, first indicium **710** may appear blue while second indicium **720** may appear red, with very little cross-talk or color mixing. Similarly, one or the other indicium may be illuminated with the other feature remaining substantially invisible. In some embodiments, an overall indicium on the lightguide is composed of non-overlapping segments, such as first indicium **710** and second indicium **720**. There may be a one-to-one correspondence between the non-overlapping segments and the clusters of extractors, as substantially shown in FIG. 7.

FIG. 8 is a top plan view of a lightguide including extractors with directionally dependent extraction efficiencies. Lightguide **800** includes a variety of light extractors, which are not individually labeled or identified in this figure. Further, first light source **810**, second light source, **820**, and third light source **830** are disposed at different edge locations. As for FIGS. 6–7, light from each light source edge location may illuminate a different subset of light extractors in lightguide **800**. In this way, lightguide **800** may be configured such that different images, logos, or extractor patterns are visible depending on which edge location light from the light sources originates. Because extraction efficiency is not necessarily binary (all light being extracted or all light being transmitted or reflected within the lightguide), an extractor may be oriented to extract light at an intermediate efficiency from two or more edge locations.

FIG. 9 is a top plan view of another lightguide including extractors with directionally dependent extraction efficiencies. Lightguide **900** includes a plurality of extractors which are not individually labeled or identified. First light source **910** and second light source **920** are disposed at different edge locations. Similar to FIGS. 6–8, light from each light source edge location may illuminate a different subset of light extractors in lightguide **900**. FIG. 9 depicts a superimposed pattern. For example, light from first light source **910** may provide substantially uniform illumination over the depicted portion of lightguide **900**. Alternatively or in addition, light from second light source **920** may provide illumination only in the subset depicted with its light extractors oriented to preferentially extract light from the edge location of second light source **920**. In a sense, light from first light source **910** forms a first image at the emission surface of lightguide **900** while light from second light source **920** forms a second image at the emission surface of the lightguide. Applications for this configuration include, for example, in the case of an automotive taillight, turn signals superimposed on running lights, which can be run simultaneously or separately and with different intensities and patterns. Other applications—for example, signage, general or decorating illumination including lamps and luminaires, transparent lighting such as sunroofs, windows, and skylights that can be selectively illuminated—are contemplated and may include the lightguides and configurations described herein. Further, such applications may alternatively or additionally include elements described in conjunction with other figures, for example, those described in FIGS. 6–8.

Descriptions for elements in figures should be understood to apply equally to corresponding elements in other figures, unless indicated otherwise. The present invention should not be considered limited to the particular embodiments described above, as such embodiments are described in detail in order to facilitate explanation of various aspects of the invention. Rather, the present invention should be understood to cover all aspects of the invention, including various modifications, equivalent processes, and alternative devices falling within the scope of the invention as defined by the appended claims and their equivalents.

What is claimed is:

1. A lightguide comprising first and second discrete spaced apart light extractors disposed on a major surface of the lightguide and configured to preferentially extract light when receiving light rays propagating within the lightguide along respective first and second ranges of optical paths, the preferentially extracted light rays exiting the lightguide along a range of viewing angles with respective minimum first and second extraction efficiencies, the second light extractor being disposed on a first optical path within the first range of optical paths, wherein a light ray propagating along the first optical path and extracted by the second light extractor exits the lightguide within the range of viewing angles with a third extraction efficiency substantially less than the minimum first extraction efficiency.

2. The lightguide of claim 1, wherein the third extraction efficiency is substantially less than the minimum second extraction efficiency.

3. A lightguide comprising first and second discrete spaced apart light extractors disposed on a major surface of the lightguide, the first light extractor configured to preferentially extract light when receiving light rays propagating within the lightguide along a first range of optical paths, the preferentially extracted light rays exiting the lightguide along a first range of viewing angles with a minimum first extraction efficiency, the second light extractor disposed on a first optical path within the first range of optical paths, wherein a light ray propagating along the first optical path and extracted by the second light extractor exits the lightguide within the first range of viewing angles with a second extraction efficiency substantially less than the minimum first extraction efficiency.

4. A lightguide comprising first and second discrete spaced apart light extractors disposed on a major surface of the lightguide, the first light extractor configured to receive and extract a first light ray from a first edge location of the lightguide along a first optical path extending between the first edge location and the first light extractor, the extracted

first light ray exiting the lightguide along a first viewing direction with a first extraction efficiency, the second light extractor disposed on the first optical path and extracting the first light ray with a second extraction efficiency substantially less than the first extraction efficiency.

5. A lightguide comprising first and second discrete spaced apart light extractors disposed on a major surface of the lightguide and configured to receive and extract respective first and second light rays from respective spaced part first and second edge locations of the lightguide along respective first and second optical paths extending between the respective first and second edge locations and the respective first and second light extractors, the extracted first and second light rays exiting the lightguide with respective first and second extraction efficiencies, the second light extractor disposed on the first optical path and extracting the first light ray with a third extraction efficiency substantially less than the first and second extraction efficiencies.

6. A lightguide comprising first and second discrete spaced apart light extractors disposed on a major surface of the lightguide and configured to preferentially extract light when receiving light rays propagating within the lightguide along respective first and second ranges of optical paths, each optical path in one of the first and second optical paths intersecting each optical path in the other one of the first and second optical paths.

7. A lightguide comprising first and second discrete spaced apart light extractors disposed on a major surface of the lightguide and configured to receive and extract respective first and second light rays from respective spaced part first and second edge locations of the lightguide along respective and intersecting first and second optical paths extending between the respective first and second edge locations and the respective first and second light extractors, the extracted first and second light rays exiting the lightguide with respective first and second extraction efficiencies, the first light extractor extracting a light ray received from the second edge location with an extraction efficiency substantially less than the first extraction efficiency, the second light extractor extracting a light ray received from the first edge location with an extraction efficiency substantially less than the second extraction efficiency.

8. The lightguide as in any of claims 1–7, wherein the first and second discrete spaced apart light extractors are disposed on a same major surface.

9. The lightguide as in any of claims 1–7, wherein the range of viewing angles is within 20 degrees of a normal to the lightguide.

10. The lightguide as in any of claims 1–7, wherein at least one of the first and second light extractors is a wedge.

11. The lightguide of claim 10, wherein at least one of the first and second light extractors is a wedge with a positive or negative cylindrical sag.

12. The lightguide as in any of claims 1–7, wherein at least one of the first and second light extractors is one of an asphere or a truncated asphere.

13. A lightguide comprising a plurality of spaced apart clusters of light extractors disposed on a major surface of the lightguide, each cluster of light extractors comprising at least first and second light extractors configured to preferentially extract light when receiving light rays propagating within the lightguide along respective first and second ranges of optical paths, no optical path in one of the first and second optical paths intersecting an optical path in the other one of the first and second optical paths.

14. A lightguide comprising a plurality of groups of light extractors configured to extract light propagating within the lightguide to form an indicium for viewing, each group of light extractors configured to extract light to form a different portion of the indicium, each group of light extractors configured to preferentially extract light received from a different corresponding edge location of the lightguide with an associated minimum extraction efficiency, such that each light extractor in any group of light extractors that receives a light ray from an edge location that corresponds to another group of light extractors, extracts the received light with an extraction efficiency that is

substantially less than the minimum extraction efficiency associated with the another group of light extractors.

15. A lightguide comprising a plurality of groups of light extractors extracting light propagating within the lightguide from a plurality of discrete spaced apart light sources disposed along one or more edges of the lightguide to form an image, there being a one-to one correspondence between the plurality of groups of light extractors and the plurality of discrete spaced apart light sources, each group of light extractors extracting light received from the corresponding light source with an associated minimum extraction efficiency, at least one light extractor in each group of light extractors receiving light from a light source corresponding to another group of light extractors and extracting the received light with an extraction efficiency that is substantially less than the minimum extraction efficiencies associated with the group of light extractors and the another group of light extractors.

16. A lightguide comprising a plurality of discrete spaced apart light extractors configured to extract light propagating within the lightguide, the extracted light forming substantially overlapping first and second images at an emission surface of the lightguide, wherein each light extractor extracts light that is primarily part of only one of the first and second images.

17. A lightguide comprising pluralities of first and second light extractors disposed on a major surface of the lightguide, the plurality of first light extractors extracting light propagating within the lightguide from one or more first light sources disposed along one or more edges of the lightguide with a minimum first extraction efficiency to form a first image at an emission surface of the lightguide, the plurality of second light extractors extracting light propagating within the lightguide from one or more second light sources disposed along one or more edges of the lightguide with a minimum second extraction efficiency to form a second image at the emission surface of the lightguide, the one or more first light sources being different than the one or more second light sources, the first and second images being non-overlapping, at least one first light extractor receiving and extracting light propagating within the lightguide from the one or more second light sources with a light extraction efficiency substantially less than the minimum first

extraction efficiency, at least one second light extractor receiving and extracting light propagating within the lightguide from the one or more first light sources with a light extraction efficiency substantially less than the minimum second extraction efficiency.

18. The lightguide of claim 17, wherein the at least one first light extractor receives and extracts light propagating within the lightguide from the one or more second light sources with a light extraction efficiency substantially less than the minimum second extraction efficiency.

19. The lightguide of claim 17, wherein the at least one second light extractor receives and extracts light propagating within the lightguide from the one or more first light sources with a light extraction efficiency substantially less than the minimum first extraction efficiency.

20. A lightguide comprising first and second discrete spaced apart light extractors disposed on a major surface of the lightguide and configured to preferentially extract light with respective minimum first and second extraction efficiencies when light rays propagating within the lightguide are received by the first and second light extractors from their input faces, at least one light ray that is preferentially extracted by the first light extractor being received by the second light extractor from a face other than the input face of the second light extractor before being received by the first light extractor from the input face of the first light extractor, the at least one light ray being extracted by the second light extractor with an extraction efficiency that is substantially less than the minimum first extraction efficiency.

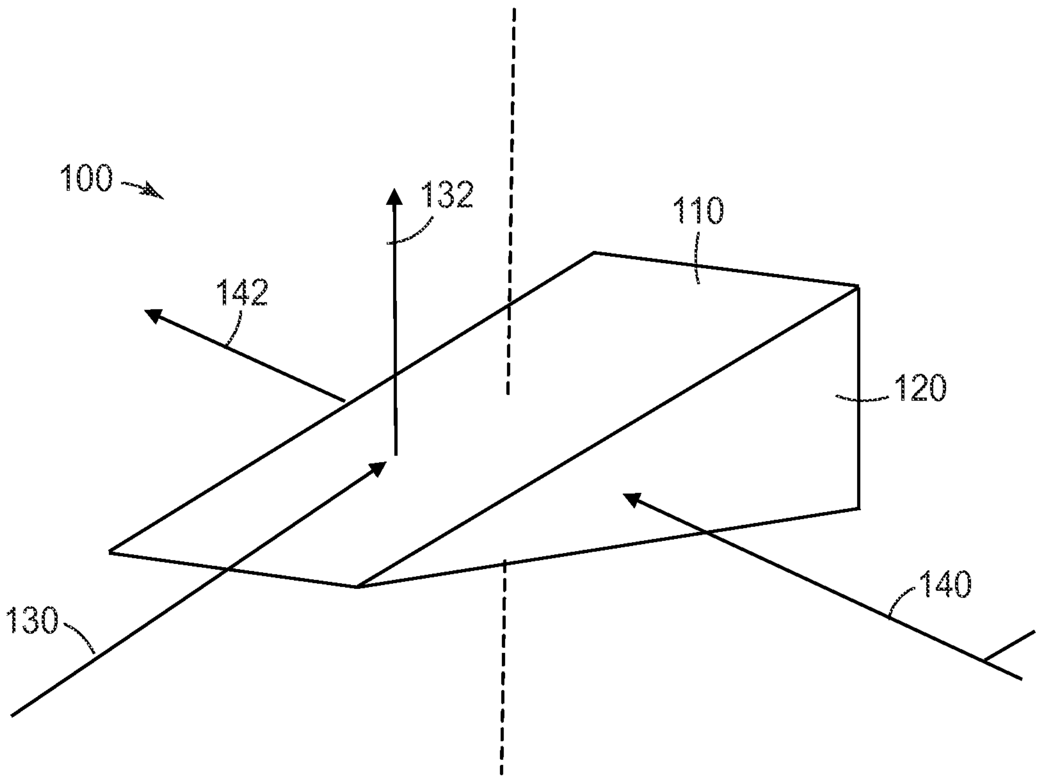


FIG. 1

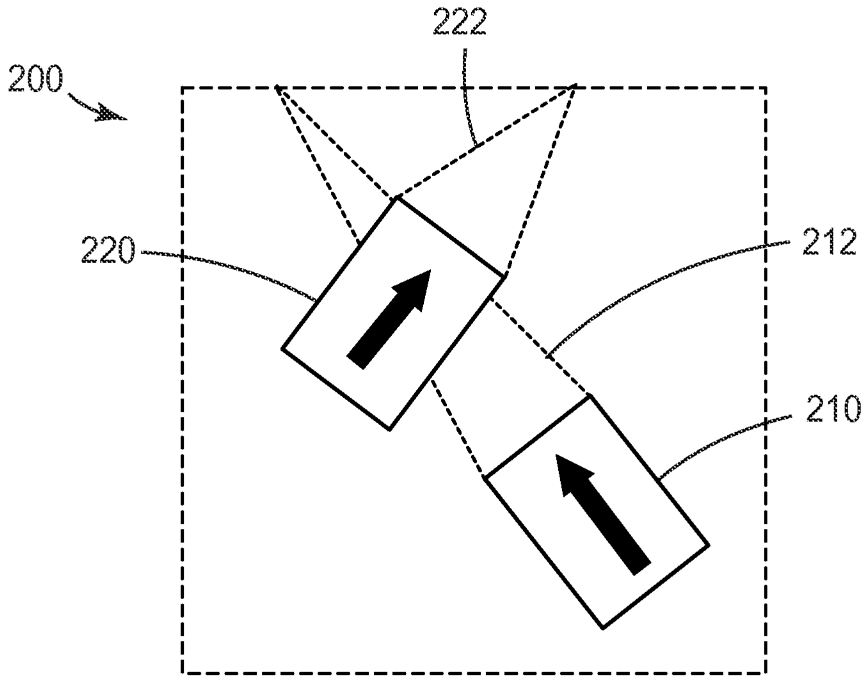


FIG. 2

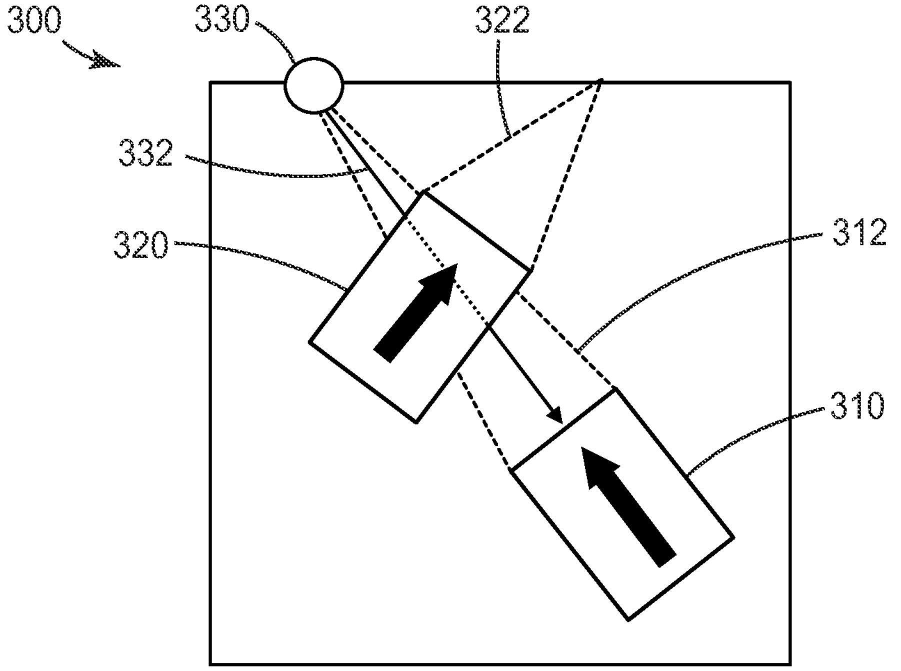


FIG. 3

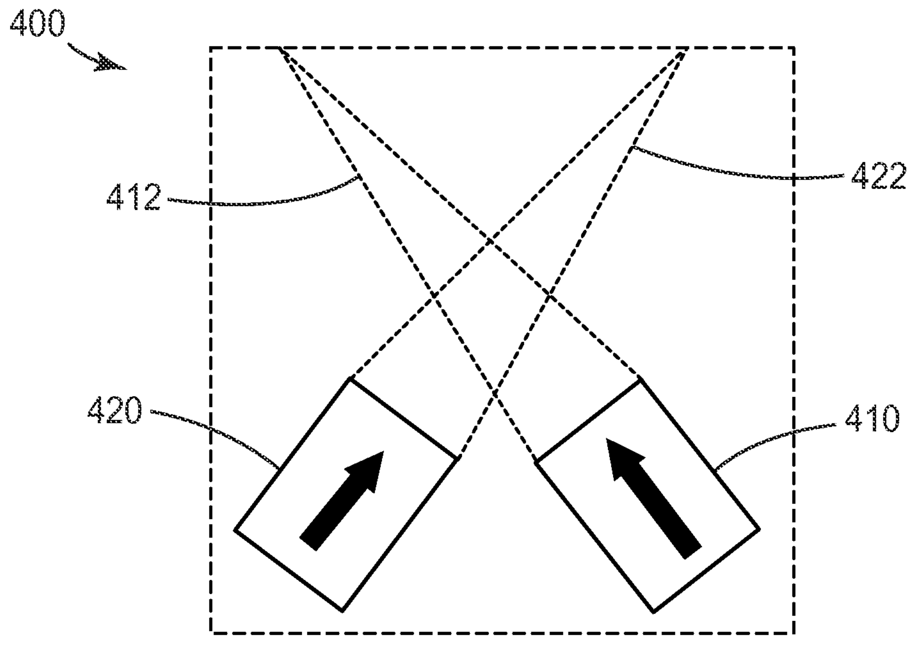
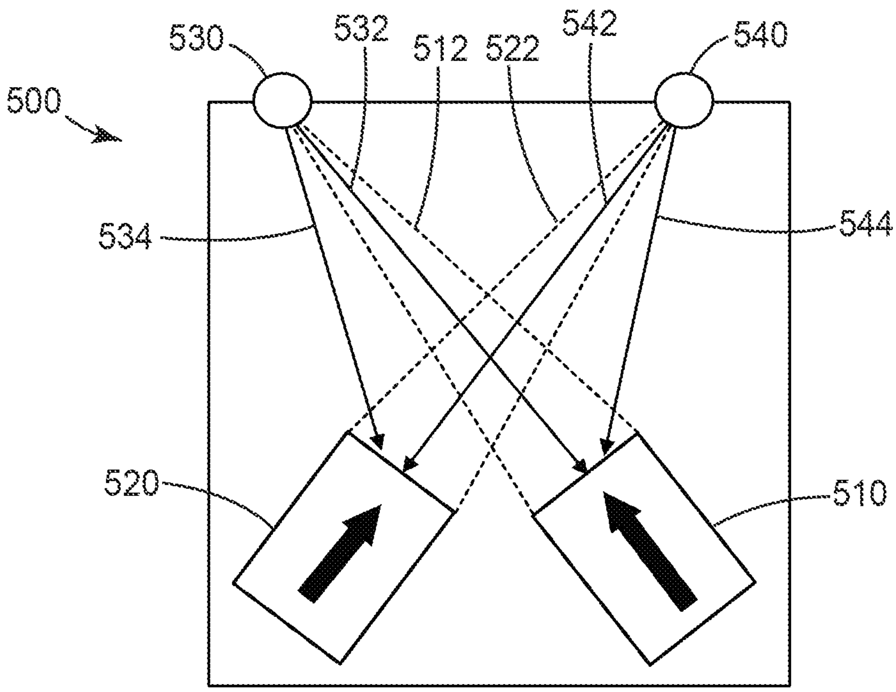


FIG. 4


530
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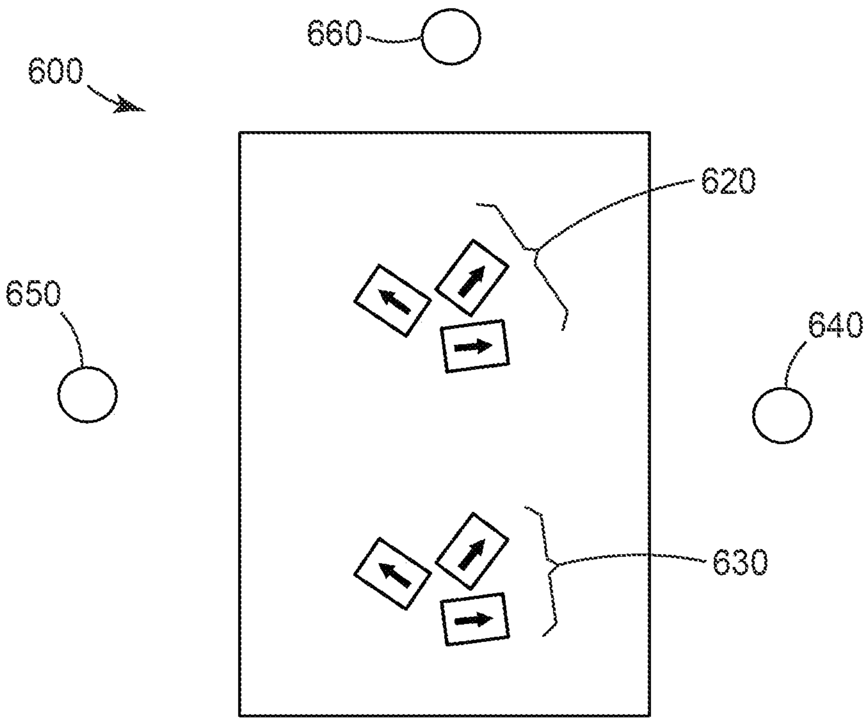
510

FIG. 5


660
600
620
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640
630

FIG. 6

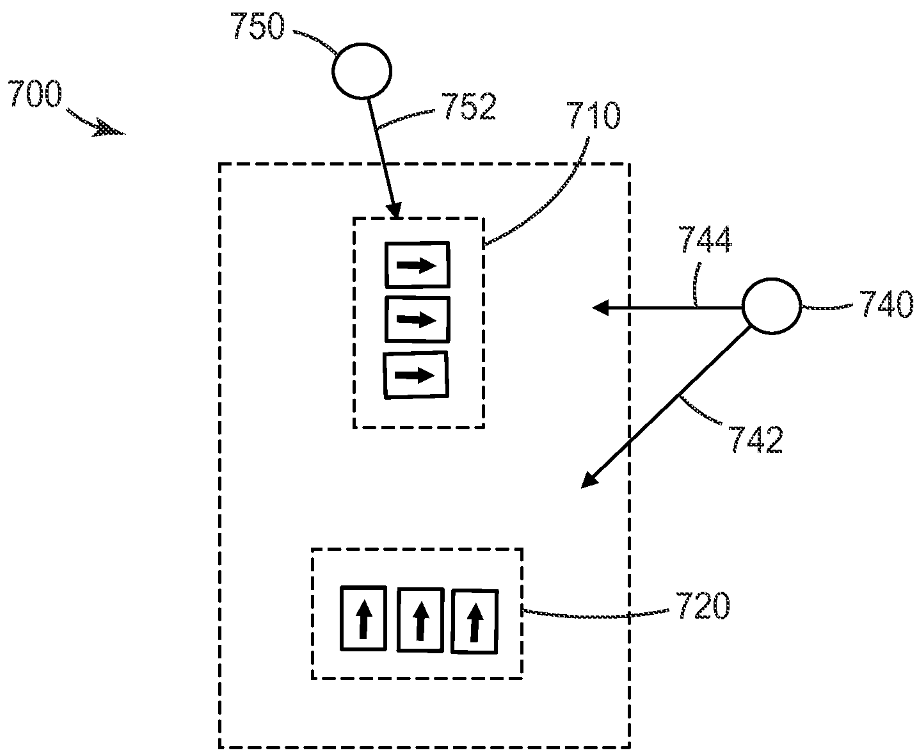

FIG. 7

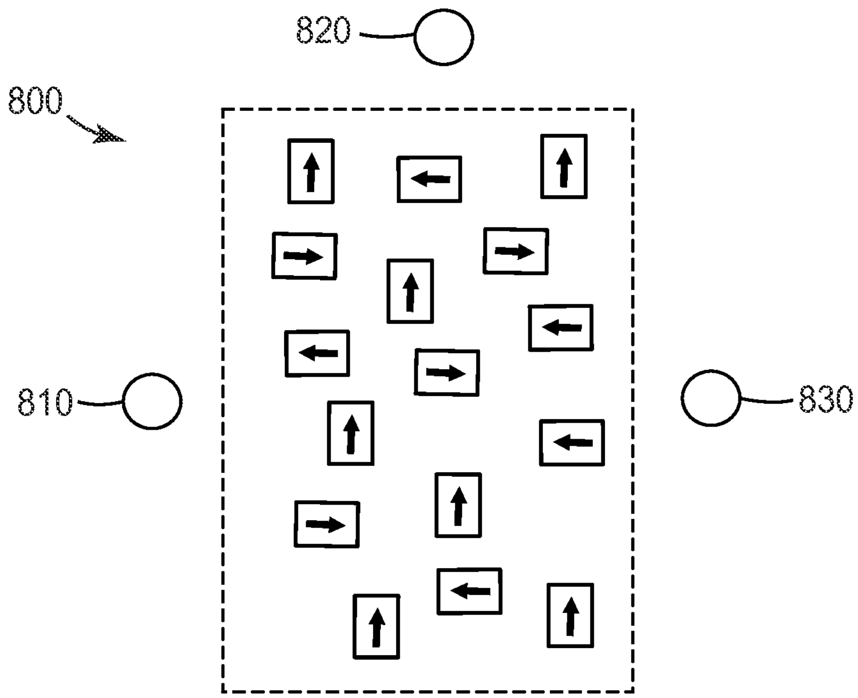

FIG. 8

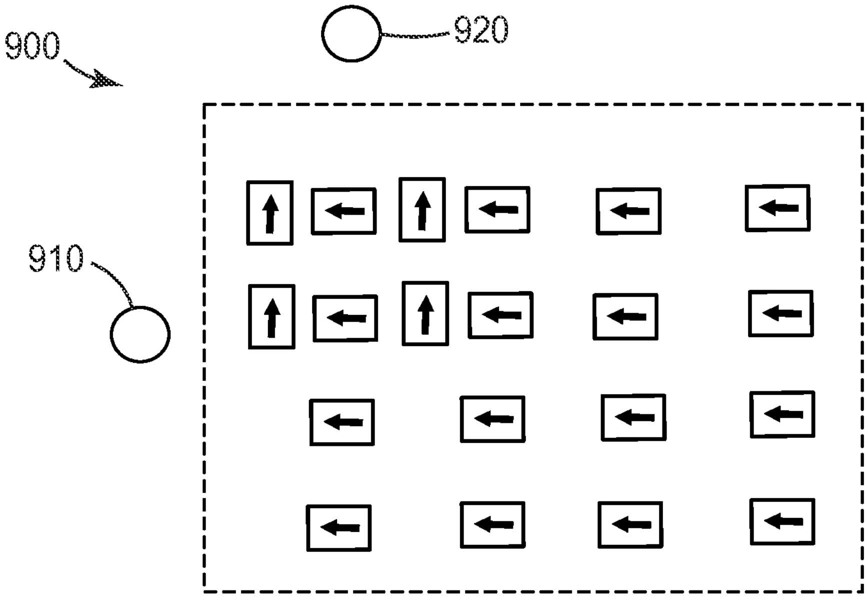

FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/072649

A. CLASSIFICATION OF SUBJECT MATTER

G02B 6/00(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G02B 6/00; G02B 26/08; F21V 7/22; G02B 6/26; B60Q 1/00; F21V 8/00; F21V 5/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: lightguide, extractor, cluster, efficiency

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013-0182457 A1 (MCCOLLUM) 18 July 2013 See abstract, paragraphs [0012]-[0035] and figures 3-7.	1-12,14-20
Y		13
Y	US 2013-0063980 A1 (ENDER) 14 March 2013 See abstract, paragraphs [0050]-[0051] and figures 5B-5C.	13
A	US 2012-0099343 A1 (ENDER) 26 April 2012 See abstract, paragraphs [0030]-[0031] and figures 1-4D.	1-20
A	US 2009-0244690 A1 (LEE) 01 October 2009 See abstract, paragraphs [0036]-[0037] and figures 3A-3D.	1-20
A	US 2006-0115214 A1 (CASSARLY) 01 June 2006 See abstract and figures 5a-6f.	1-20

☐ Further documents are listed in the continuation of Box C.   ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 April 2015 (22.04.2015)	**22 April 2015 (22.04.2015)**

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2014/072649

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