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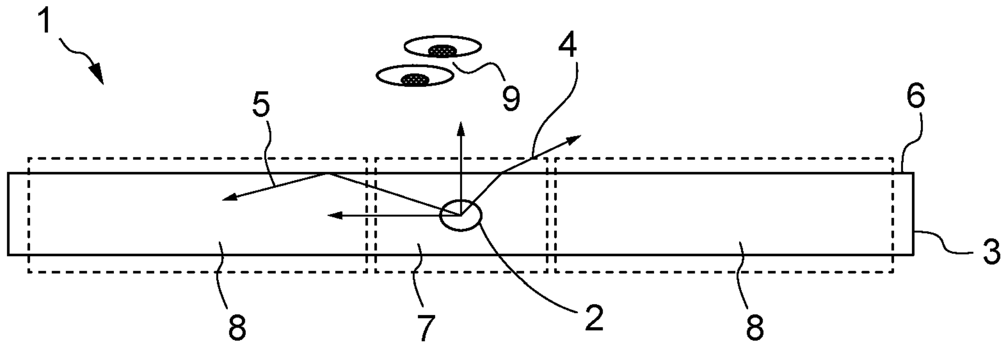

Figure 1

Prior Art

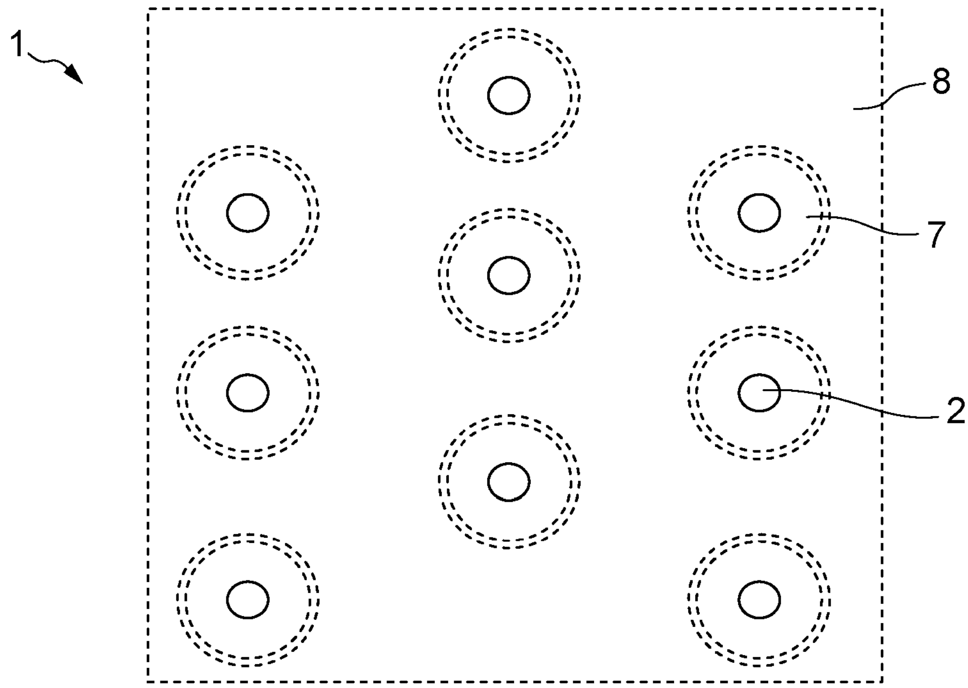

Figure 2

Prior Art

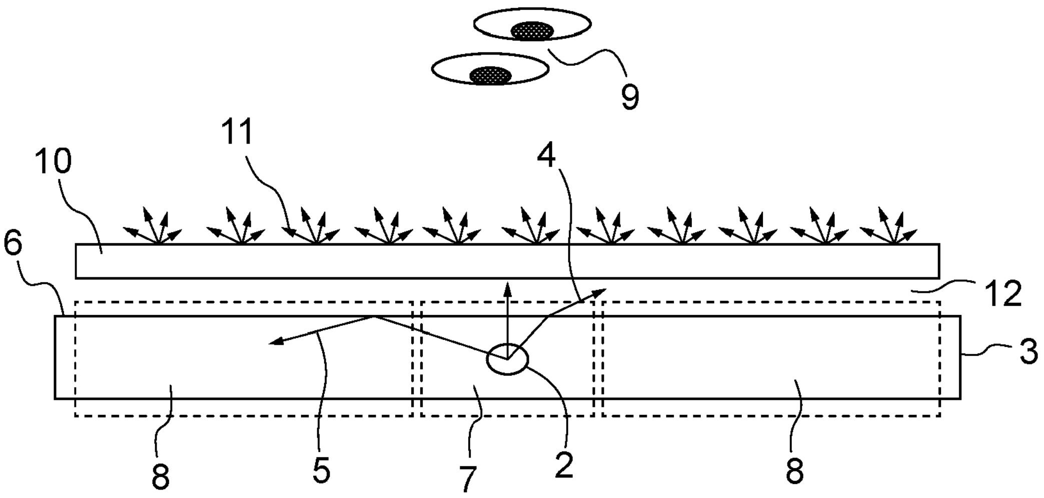

Figure 3
Prior Art

03 12 20

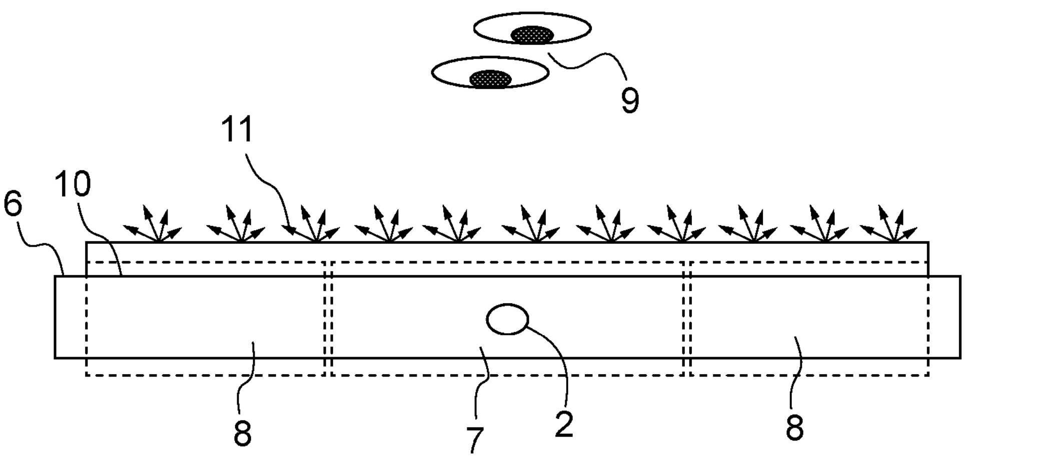

Figure 4
Prior Art

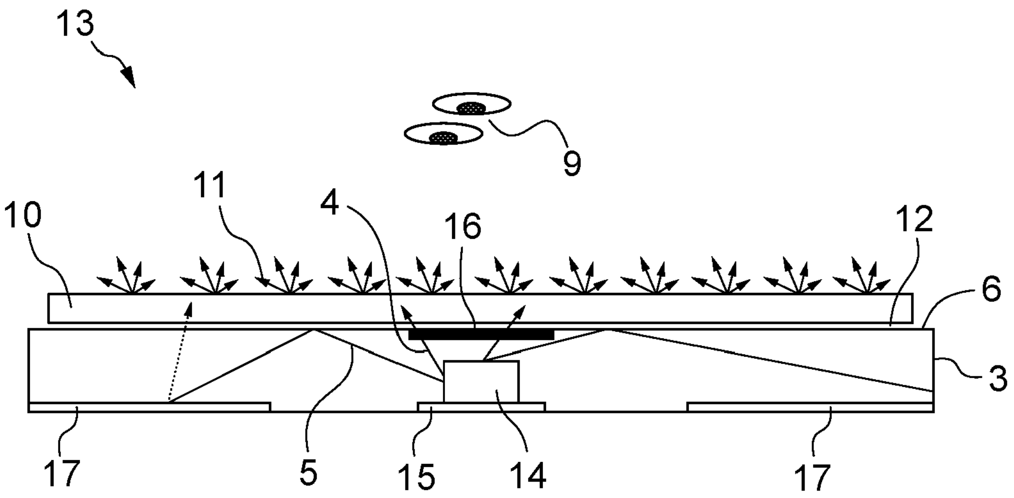

Figure 5

03 12 20

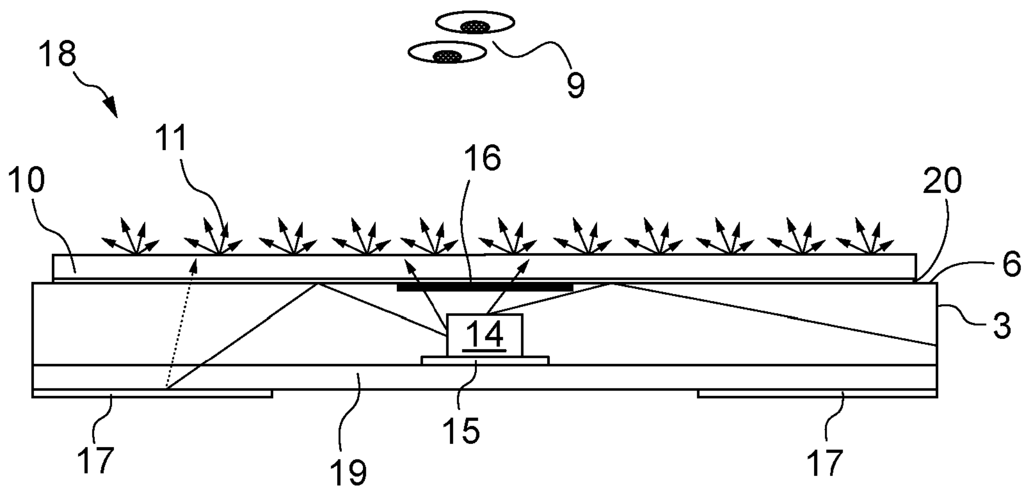

Figure 6

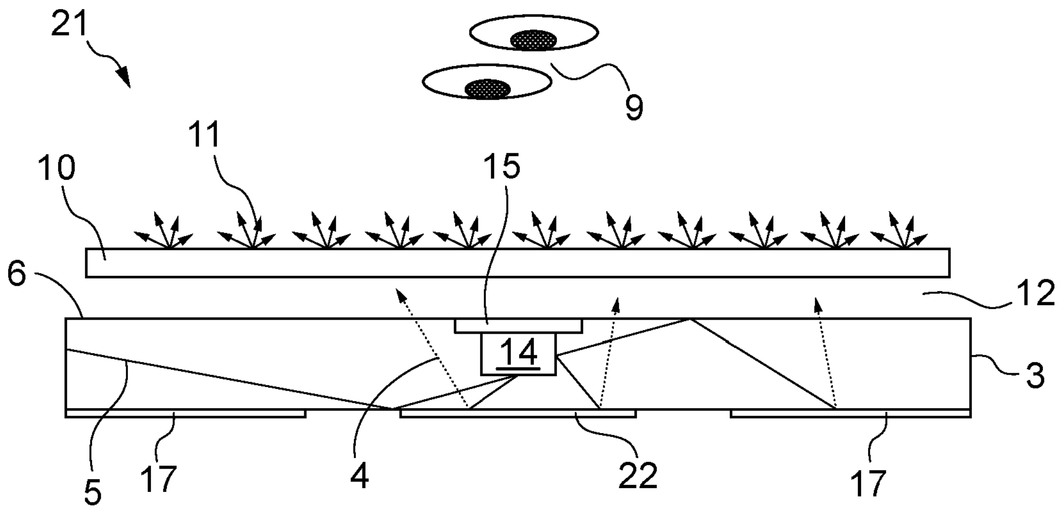

Figure 7

03 12 20

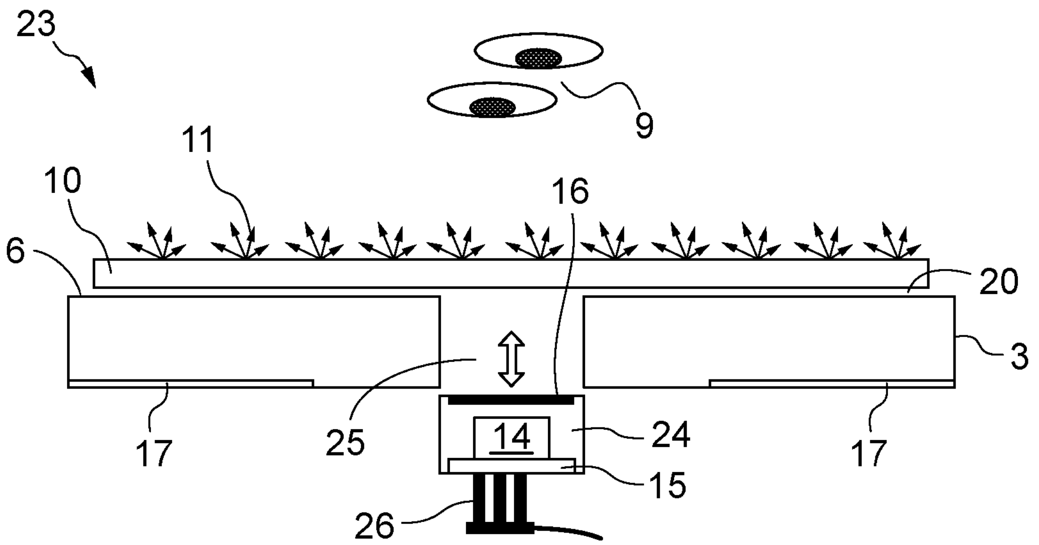

Figure 8

The following terms are registered trade marks and should be read as such wherever they occur in this document:

Osram
Everlight
Makrofol
Melinex,
Lexan

Uniform Lighting Device

The present invention relates to the field of lighting, and in particular, to a uniform lighting device that can be used for illumination, backlighting, signage or display purpose. The described uniform lighting device finds particular application within the field of transportation e.g. the automotive, train and aerospace industries.

Background to the Invention

Lighting is a key means of making interior vehicle spaces, where passengers stand or sit during transportation, more attractive and pleasant environments. One of the most effective ways to deliver light into these environments, while saving space, is to backlight the interior surfaces of the vehicles. As a result, there is a requirement for a uniform, low intensity light level to be provided over a large surface area. This uniform low intensity light level is required in order to keep the glare experienced by passengers being transported within the vehicles to a minimum, whilst also providing a means to attractively decorate and illuminate the interior surfaces.

Due to space and weight constraints within vehicles, any light source solution must be very thin, of the order of ~1mm. In addition, due to vibration and integration constraints, the lighting device must also be capable of being mechanically attached, bonded, joined or moulded onto the internal surface of the vehicle.

A number of light source technologies exist which can be employed within the field of transportation. Two such examples are electroluminescent film and organic light emitting diodes (OLED). Both solutions involve an active light emitting material that covers the entire surface to be backlit. However, both technologies are expensive, have a low reliability and lifetime and so neither are ideally suited as an integrated solution for transportation interiors.

Inorganic light emitting diodes (LEDs) are the most common lighting technology employed for transportation lighting. LEDs are small solid state, semiconductor chip-based devices, that can be designed to emit different colours of light, or when used in combination with colour converting materials, to provide white light. However, LEDs are small points of light, and therefore require an external optical system to turn them into large area, homogeneous lighting surfaces.

The simplest configuration of optical system to achieve the desired large area, homogeneous lighting surface is to deploy the LED devices in a 2D matrix across a printed circuit board (PCB) and then place a diffuser layer on top of the 2D matrix. This is conventionally known as a direct-lit LED backlight. An advantage of the direct-lit LED backlight approach is that each LED is independently addressable, and so a pixelated area light source can be produced. However, such systems require either the LEDs to be very closely packed, which results in high power density and cost per area, or the employment of a very thick optical system (e.g. an air gap and/or diffuser thickness), which then makes them unsuitable for deployment within the limited interior transport spaces. For example, if the LEDs are spaced 20 mm apart, the optical system depth is required to be >20 mm.

It is known in the art to employ light guides to distribute light from a light source to an area that requires illumination. One known type of light-guide is an optical fibre, which is typically made up of a transparent material (glass or plastic) with thin filaments that are capable of transmitting light. An alternative known type of light-guide is a planar light-guide. These are plates or panel light-guides, which are typically formed as thin cuboids.

Both light-guide designs exploit the effects of refraction caused by two materials having different refractive index. In particular, a light-guide transports light from one location to another, by exploiting the effects of total internal reflection experienced by the light propagating within the material when it encounters a boundary surrounding the material. A further useful property of the aforementioned light-guides is their ability to take the light output from an LED and spread it evenly and or change its shape or distribution to achieve a desired result.

One controllable parameter of a light-guide is its numerical aperture (NA). Numerical aperture is defined as the maximum acceptance angle for a light-guide that allows light be coupled into the light-guide. This parameter is dependent upon the refractive index of the light-guide and surrounding media. Light incident upon the light-guide above the maximum angle is not coupled into the light-guide.

The above described, light-guiding approaches have been developed to try and meet the space limitations of backlighting within the field of transportation. One approach has been the employment of woven, optical fibre mats. These systems typically have the light source located separately from the backlighting surface. However, optical fibre mats are expensive and do not easily support a pixelated, uniform area light source.

A second approach is that commonly known as the edge-lit LED backlight approach, see for example US patent publication number US 2004/0136173. Here a machined, printed or moulded, light-guide plate is employed, and the LEDs are mounted along one or more edges. Light is thereafter coupled from the LEDs, into the light-guide plate, before propagating though the light-guide plate. Light extraction features on the surface of the light-guide plate provide a means for the light to exist from the light-guide plate. Correct design of the light extraction features (variation in size, density etc.), gives a homogeneous or uniform backlighting of a surface material or a diffuser layer located across the light-guide plate. A limitation of the edge-lit LED approach is that the LEDs are only located at the edge of the light-guide plate, thus although the light source appears as a uniform area, individual areas or pixels are not addressable.

Another approach is conventionally known as a composite light-guide device, see for example international patent publication number WO 2007/138294. Here, LEDs are distributed in a 2D matrix that is embedded within a light-guide structure. The light-guide structure acts to guide the light from the LEDs in the plane of the light-guide structure. Light extraction features inside or on surface of the composite light-guide device are then employed to provide a means for the light to exit the light-guide structure. The design of the light extraction features (variation in size, density etc.) again provides a means for homogeneously or uniformly backlighting a surface material across the light-guide structure.

One of the challenges of employing a composite light-guide device to produce homogeneous or uniform backlighting structure is the issue of the integrated LEDs being seen as visible “hot spot” artefacts. This issue will now be described in further detail with reference to Figure 1 to 4.

Figure 1 presents a two-dimensional, cross sectional side view of a composite light-guide device, depicted generally be reference numeral 1 while Figure 2 presents a plan view of the composite light-guide device 1 of Figure 1(a).

As can be seen from Figure 1, a light source 2 is presented embedded within a planar light-guide 3. Light emitted from the light source 2 has range of angles. In Figure 1, two different classes of light ray are presented namely, light rays 4 that do not get coupled into the planar light-guide 3 and light rays 5 that do get coupled into the planar light-guide 3. The reason that two classes of light rays 4 and 5 exist is a direct result of the effects of total internal reflection i.e. the combined effects of the angle of propagation of the light emitted from the light source 2 when taken in conjunction the wavelength of the light and the refractive index of planar light-guide 3 and the surrounding media. A light ray 5 emitted from the light source 2 at an angle greater than the angle of total internal reflection will be coupled into the planar light-guide 3 while light rays 5 emitted at an angle less than the angle of total internal reflection will not be coupled into the planar light-guide 3 and thus exit the device via a light output surface 6.

The region around the light source 2 where light rays 4 emitted from the light source 2 are not coupled into the planar light-guide 3 is depicted generally be reference numeral 7 while, the region around the light source 2 where light rays 5 emitted from the light source

2 are coupled into the planar light-guide 3 is depicted generally be reference numeral 8. As a result of the above, regions 7 appear brighter to an observer 9 viewing the light output surface 6 of the composite light-guide device 1 relative to regions 8 and thus are seen as a visible “hot spot” artefact, producing an overall non-uniform appearance to the observer 9.

In order to reduce the effects of the visible “hot spot” artefact being seen by the observer 9 it is known to locate a diffuser 10 between the observer 9 and the light output surface 6 so producing a more uniform light output 11,. Figures 3 and 4 present cross sectional side views of the composite light-guide device 1 of Figure 1 with two different arrangements for incorporating the diffuser 10, namely Figure 3 shows an arrangement that incorporates an air gap 12 between the diffuser 10 and the light output surface 6; while Figure 4 shows an arrangement where the diffuser 10 is optically bonded to the light output surface 6.

As previously discussed with reference to direct-lit LED backlights, the effectiveness of a diffuser 10 in producing a uniform light output 11 is limited by how thick this component, and any associated air gap 12, can be made. The applicants have been unable to design a composite light-guide device 1 that satisfactorily removes the effects visible “hot spot” artefact while meeting the space limitations of backlighting within the field of transportation. Significantly, when the diffuser 10 is optically bonded to the composite light-guide1 (see Figure 4) in an attempt to reduce the overall thickness of the device, the applicants found that the area of the “hot spot” regions 7 actually increases. This was a direct result of the difference in the refractive index of the air gap 12 and the material from which the diffuser 10 was formed.

Summary of the Invention

It is therefore an object of an embodiment of the present invention to provide an alternative lighting device that provides a uniform, low intensity light output over a large surface area.

It is a further object of an embodiment of the present invention to provide a uniform lighting device that is thinner than those uniform lighting devices known in the art.

According to a first aspect of the present invention there is provided a uniform lighting device comprising one or more light sources embedded within a planar light-guide, the planar light-guide having a light output surface,

wherein the one or more light sources and the planar light-guide combine to produce

a non-coupled light region of the planar light-guide around the one or more light sources, wherein light rays emitted from the associated one or more light sources exit the planar light-guide via the light output surface without being coupled into the planar light-guide,

and

a coupled light region of the planar light-guide around the one or more light sources, wherein light rays emitted from the associated one or more light sources are coupled into the planar light-guide,

the uniform lighting device further comprising

a light reduction medium located within the non-coupled light region to reduce the intensity of the non-coupled light rays exiting from the non-coupled light region via the light output surface,

and

a light extracting medium located within the coupled light region to extract coupled light rays from the coupled light region via the light output surface

wherein the one or more light sources comprises a light emitting diode (LED) electrically and mechanically mounted onto a printed circuit board (PCB) embedded within the planar light-guide such that the PCB is located between the LED and the light output surface.

The combined effects of the light reduction medium and the light extracting medium is such that the spatial intensity distribution of the reduced light intensity within the non-coupled regions can be balanced with the spatial intensity distribution of the light emitted from the light output surface within the coupled light regions. The overall result is a uniform light output that does not exhibit any visible “hot spot”, or indeed “dark spot”, artefacts being seen by the observer.

The light reduction medium preferably extends over the whole area, or at least a substantial part of the area, of the non-coupled light regions. It may be located on the light output surface or embedded within the planar light-guide.

The light reduction medium preferably comprises an ink layer, a dye layer, a thin film or other absorbing or reflecting medium or material. The light reduction medium may comprise a specular or non-specular reflector, such as a metal film or white ink. If an absorption ink is employed this may be printed to be semi-transparent or with small holes, to allow a small amount of light to be emitted and so avoid a “dark spot” artefact being seen by an observer.

Optionally, the light reduction medium is arranged to vary the amount of light reflected or absorbed depending on the spatial distance from the associated one or more light sources. This has the advantage of increasing the uniformity of light emitted from the light output surface within the non-coupled light regions. Variation of the amount of light reflected or absorbed may be achieved by incorporating a patterned formed from dots or holes within the light reduction medium.

The light extracting medium preferably extends over the whole area, or at least a substantial part of the area, of the coupled light regions. It may be located upon a surface of the planar light-guide opposite to the light output surface. Alternatively, the light extracting medium may be located on the light output surface, embedded within the planar light-guide or comprise a combination of two or more of these locations.

The light extracting medium preferably comprises a light scattering medium. It may be patterned or provided as a thin layer.

It is preferable for the light extracting medium to be patterned into a dot matrix. The dot matrix may comprise a regular or irregular array of dots. The irregular array may comprise dots of varying radius and or varying separation.

Most preferably the one or more light sources are independently addressable.

The PCB may be a transparent or non-transparent PCB.

Preferably, the LEDs are of a type designed to emit light from all five surfaces that are not in contact with the PCB. Alternatively, the LEDs comprise top emitting or side emitting LEDs. If the LED package consists of more than one LED chip, then preferably, the transparent material of the LED is of a diffusing material, so to improve the colour mixing of the light from the more than one LED chips.

The planar light-guide may be made from a layer of transparent material such glass or a polymer resin.

The uniform lighting device may further comprise a diffuser arranged to diffuse light exiting the light output surface. An air gap may be incorporated between the diffuser and the light output surface. Alternatively, the diffuser may be optically bonded to the light output surface.

The uniform lighting device may further comprise a transparent substrate upon which the one or more light sources are mounted. Preferably the refractive index of the transparent substrate is less than or equal to the refractive index of the planar light guide.

Optionally, a section of the planar light-guide located around the one or more light sources is formed as a separate mechanical component that is removably mounted within an aperture formed in the planar light-guide.

The uniform lighting device may further comprise an electrical connector may be located on the opposite side of the PCB to which the LED is mounted.

The uniform lighting device may further comprise a reflector arranged such that the planar light-guide is located between the reflector and the light output surface. The reflector may be located within the non-coupled light region to reflect uncoupled light rays towards the light output surface. The reflector recycles light and improves efficiency. The reflector can be separated from the light-guide by an air gap or attached onto the surface. To improve the uniformity control, the reflector can be attached with a low refractive index layer, which increases the Numerical Aperture of the light-guide attached to the reflector.

According to a second aspect of the present invention there is provided a method of forming a uniform lighting device, the method comprising

-embedding one or more light sources within a planar light-guide, the planar light-guide having a light output surface,

-combining the one or more light sources and the planar light-guide to produce a non-coupled light region of the planar light-guide around the one or more light sources, wherein light rays emitted from the associated one or more light sources exit the planar light-guide via the light output surface without being coupled into the planar light-guide, and

a coupled light region of the planar light-guide around the one or more light sources, wherein light rays emitted from the associated one or more light sources are coupled into - the planar light-guide,

-providing a light reduction medium located within the non-coupled light region to reduce the intensity of the non-coupled light rays exiting from the non-coupled light region via the light output surface, and

-providing a light extracting medium located within the coupled light region to extract coupled light rays from the coupled light region via the light output surface,

wherein

-embedding one or more light sources comprises embedding a light emitting diode electrically and mechanically mounted onto a printed circuit board (PCB) such that the PCB is located between the light source and the light output surface.

The light reduction medium is preferably provided over the whole area, or at least a substantial part of the area, of the non-coupled light regions. It may be provided on the light output surface or embedded within the planar light-guide.

Optionally, the light reduction medium is arranged to vary the amount of light reflected or absorbed depending on the spatial distance from the associated one or more light sources. Variation of the amount of light reflected or absorbed may be achieved by providing a patterned formed from dots or holes within the light reduction medium.

The light extracting medium is preferably provided over the whole area, or at least a substantial part of the area, of the coupled light regions. It may be provided upon a surface of the planar light-guide opposite to the light output surface. Alternatively, the light extracting medium may be provided on the light output surface, embedded within the planar light-guide or comprise a combination of two or more of these locations.

Optionally, the light extraction medium is arranged to vary the amount of light extracted depending on the spatial distance from the associated one or more light sources. Variation of the amount of light extracted may be achieved by providing a patterned formed from dots or holes within the light extraction medium.

The method of forming a uniform lighting device may further comprise providing a diffuser arranged to diffuse light exiting the light output surface.

The method of forming a uniform lighting device may further comprise providing a transparent substrate upon which the one or more light sources are mounted. Preferably the refractive index of the transparent substrate is less than or equal to the refractive index of the planar light guide.

The method of forming a uniform lighting device may further comprise providing a reflector arranged such that the planar light-guide is located between the reflector and the light output surface. The reflector may be located within the non-coupled light region to reflect uncoupled light rays towards the light output surface.

Embodiments of the second aspect of the invention may include one or more features of the first aspect of the invention or its embodiments, or vice versa.

<u>Brief Description of the Drawings</u>

There will now be described, by way of example only, various embodiments of the invention with reference to the drawings, of which:

Figure 1 presents a two-dimensional, cross sectional side view of a composite light-guide device known in the art;

Figure 2 presents a plan view of the composite light-guide device of Figure 1;

Figure 3 presents a two-dimensional, cross sectional side view of an alternative composite light-guide device known in the art;

Figure 4 presents a two-dimensional, cross sectional side view of a further alternative composite light-guide device known in the art;

Figure 5 presents a two-dimensional, cross sectional side view of uniform lighting device in accordance with an embodiment of the present invention;

Figure 6 presents a two-dimensional, cross sectional side view of uniform lighting device in accordance with an alternative embodiment of the present invention;

Figure 7 presents a two-dimensional, cross sectional side view of uniform lighting device in accordance with a further alternative embodiment of the present invention; and

Figure 8 presents a two-dimensional, cross sectional side view of uniform lighting device in accordance with a yet further alternative embodiment of the present invention.

In the description which follows, like parts are marked throughout the specification and drawings with the same reference numerals. The drawings are not necessarily to scale and the proportions of certain parts have been exaggerated to better illustrate details and features of embodiments of the invention.

<u>Detailed Description of Preferred Embodiments</u>

Figure 5 presents a two-dimensional, cross sectional side view of a uniform lighting device 13 in accordance with an embodiment of the present invention. The uniform lighting device 13 comprises one or more light sources 2 embedded within a planar light-guide 3 (although, for ease of understanding, only one is shown in Figure 5).

In the presently described embodiment, the light sources 2 comprise a light emitting diode (LED) 14 electrically and mechanically mounted onto a printed circuit board (PCB) 15. Preferably, the LEDs 14 are of a type designed to emit light from all five surfaces that are not in contact with the PCB 15. A Chip Scale Package (CSP) LED (e.g. an OSRAM (RTM) CHIPLED® 0402, LW QH8G that emits white light) or an RGB LED such as Everlight (RTM) EAST1616RGBA0 are two example LEDs 14 that may be incorporated within the uniform lighting device 13. Both these LEDs 14 are low power and have dimension of ~1 mm.

The sixth surface of the LEDs 14 is where the electrical contacts are located. The LED electrical contacts are used to electrically and mechanically mount the LEDs 14, with conventional solder, onto metal pads located on the PCB 15.

The PCB 15 may comprise a thin, non-transparent PCB, made from a 0.4 mm thick FR4 or a 0.15 mm thick polyimide substrate. The metal pads connect with copper wires/traces which have been etched at a size of typically < 1 mm. It is preferable for the PCB 15 to have a small surface area relative to the planar light-guide 3 and be cut into stripes, small circular modules or into a grid structure.

The planar light-guide 3 that encapsulates the light sources 2 is made from a layer of transparent material such as glass or a polymer resin, such as acrylic, polymethyl methacrylate (PMMA), polycarbonate, silicone or polyurethane. The transparent planar light-guide 3 is arranged to cover all the LEDs 14 on the PCB 15 and define the light output surface 6 for the uniform lighting device 13. The planar light-guide 3 may have a thickness up to 3 mm depending on the particular LEDs 14 employed within the uniform lighting device 13.

As can be seen from Figure 5, light is emitted from the LEDs 14 over a range of angles. The emitted light can therefore again be classed into those light rays 4 that do not get coupled into the planar light-guide 3 and those light rays 5 that do get coupled into the planar light-guide 3. As a result, non-coupled light regions 7 and coupled light regions 8 are formed within the uniform lighting device 13.

A light reduction medium 16 is applied within non-coupled light regions 7 to provide a means for reducing the intensity of the light emitted from the light output surface 6 within these regions 7. The light reduction medium 16 preferably extends over the whole area, or at least a substantial part of the area, of the non-coupled light regions 7. It may be located on the light output surface 6 as shown in Figure 5, embedded within the planar light-guide 3, or comprise a combination of both locations. The light reduction medium 16 is therefore employed to absorb or reflect a portion of the light rays 4 in order to avoid any visible “hot spot” artefacts being seen by an observer 9 while still allowing a portion of the light rays 4 to be emitted from the light output surface 6 within these regions 7.

The light reduction medium 16 preferably comprises an ink layer, a dye layer, a thin film or other absorbing or reflecting medium or material. The light reduction medium 16 may comprise a specular or non-specular reflector, such as a metal film or white ink. If a black absorption ink is employed this may be printed to be semi-transparent or with small holes, to allow a small amount of light to be emitted and so avoid a “dark spot” artefact being seen by an observer 9.

Optionally, the light reduction medium 16 is arranged to vary the amount of light reflected or absorbed depending on the spatial distance from the light sources 2. This has the advantage of increasing the uniformity of light emitted from the light output surface 6 within regions 7. This may be achieved by incorporating a patterned formed from dots or holes within the light reduction medium 16.

By contrast, in the coupled light regions 8, located at a distance from the light sources 2, a light extracting medium 17 is provided which provides a means for extracting light rays 5 from the planar light-guide 3, via the light output surface 6. In the presently described embodiment, the light extracting medium 17 is located upon a surface of the planar light-guide 3 opposite to the light output surface 6. It will however be appreciated that in alternative embodiments the light extracting medium 17 could be located on the light output surface 6, embedded within the planar light-guide 3 or comprise a combination of two or more of these locations.

The light extracting medium 17 preferably comprises a light scattering medium. It may be patterned or provided as a thin layer.

In order to increase uniformity of the light emitted from the light output surface 6 within the coupled light regions 8 it is preferable for the light extracting medium 17 to be patterned into a dot matrix. The dot matrix may comprise a regular or irregular array of dots. The irregular array may comprise dots of varying radius and or varying separation.

It will be appreciated by the skilled reader that the combined effects of the light reduction medium 16 and the light extracting medium 17 is such that the spatial intensity distribution of the reduction in light intensity within the non-coupled regions 7 can be balanced with the spatial intensity distribution of the light emitted from the light output surface 6 within the coupled light regions 8. The overall result is a uniform light output that does not exhibit any visible “hot spot”, or indeed “dark spot”, artefacts being seen by the observer 9.

It should be noted that each the light source 2 of the uniform lighting device 13 can be made independently addressable. Thus, the uniform lighting device 13 provides for independent control of the intensity of each the light source 2 which provides the uniform lighting device 13 with the ability to be employed to produce a pixelated area light source.

As can be seen from Figure 5, the uniform lighting device 13 may further comprise a diffuser 10 and air gap 12 based optical system located between the light output surface 6 and the observer 9 in order to further improve the uniformity of the light output 11 from the uniform lighting device 13. Because of above described combined effects of the light reduction medium 16 and the light extracting medium 17, the diffuser can be significantly thinner than those employed in the prior art. For example, the diffuser may comprise a polycarbonate film such as Makrofol (RTM) DX cool, that is 3mm thick, and is 70% light transmitting.

The uniform lighting device 13 presented in Figure 5 may be formed by placing the PCB 15 in a Reactive Injection Mould (RIM) or regular injection moulding machine, to have the planar light guide 3 moulded around it. The diffuser 10 can then be joined together with the planar light guide 3 in the moulding machine. The light reduction medium 16 and the light extracting medium 17 can then be printed onto the planar light guide 3. Alternatively, the light extracting medium 17 comprises a refractive surface feature that is patterned into the mould tool and transferred onto the planar light guide 3 during the moulding process.

It will be appreciated that the surfaces of the PCB 15 around the LEDs 14 may also be modified to reflect or absorb light and so improve the balance of light rays 4 emitted from the light output surface 6 in the non-coupled light regions 7, with the light rays 5 extracted from the coupled light regions 8. In a similar manner, the shape and size of the PCB 15 can be selected to further improve the uniformity of output light 11 from the uniform lighting device 13. The surfaces of the PCB can be coated with low refractive index material, to decouple the light-guiding from the non-transparent PCB surface.

In alternative embodiments, the light reduction medium 16 or the light extracting medium 17 may be located on a surface of the PCB 15.

In further alternative embodiments, the PCB 15 may comprise a thin, transparent PCB. As such, the refractive index of the transparent PCB 15 can be selected to adjust the surface area of the non-coupled light regions 7. In this embodiment, the light reduction medium

16, or the light extracting medium 17, can be located on a surface of, or within, the transparent PCB 15.

The uniform lighting device 13 can be made with an LED pitch of > 50 mm while maintaining an overall system thickness of less than < 10mm while maintain a highly uniform light output 11. As a result, the uniform lighting device 13 is ideally suited to be employed within the field of transportation.

Figure 6 presents a two-dimensional, cross sectional side view of an alternative embodiment of the uniform lighting device 18. This embodiment shares a number of features in common with the uniform lighting device 13 presented in Figure 5 and so these common elements are marked with the same reference numerals.

The first difference between the uniform lighting device 13 presented in Figure 5 and the uniform lighting device 18 presented in Figure 6 is the inclusion of a transparent substrate 19 employed to act as a carrier for the light sources 2 and the light extracting medium 17. In order to further increase the effectiveness of the device in generating a uniform light output 11 it is preferable for the refractive index of the transparent substrate 19 to be less than or equal to the refractive index of the planar light guide 3. With this arrangement the light rays 5 coupled into the planar light guide 3 are guided within a composite structure formed by the planar light guide 3 and the transparent substrate 19.

In the presently described embodiment the transparent substrate 19 comprises a thin (0.1 mm to 0.2 mm) polymer film made from PET Melinex (RTM) 506. In alternative embodiments, other polymer films known to those skilled in the art may be employed for the transparent substrate 19 e.g. polycarbonate Lexan (RTM) 8040.

The second difference between the uniform lighting device 13 presented in Figure 5 and the uniform lighting device 18 presented in Figure 6 is the fact that the diffuser 10 is bonded directly onto the light output surface 6 of the planar light guide 3 by means of an adhesive layer 20 e.g. a pressure sensitive lamination adhesive. Such an arrangement results in the uniform lighting device 18 being thinner than the uniform lighting device 13 presented in Figure 5. As discussed above this arrangement also results in an increase in the surface area of the non-coupled light regions 7. However, this increase can be compensated for by introducing a corresponding increasing the surface area covered by the light reduction medium 16. In addition, the surface area of the non-coupled light regions 7 can be reduced by ensuring that the refractive index of the adhesive layer 20 is lower than the refractive index of the planar light guide 3.

It will be appreciated that further alternatives may be made to the uniform lighting device 18 presented in Figure 6. For example, the transparent substrate 19 may be employed to function as the PCB for the LEDs 14. Electrical tracks would then printed or etched directly onto the transparent substrate 19 and the LEDs 14 would then be mounted onto these electrical tracks with silver epoxy, other conducting adhesives or a low temperature solder.

Figure 7 presents a two-dimensional, cross sectional side view of a yet further alternative embodiment of the uniform lighting device 21. This embodiment again shares a number of features in common with the uniform lighting device 13 presented in Figure 5 and so these common elements are again marked with the same reference numerals.

The main difference between the uniform lighting device 21 and the one presented in Figure 5 is the orientation of light sources 2 embedded within a planar light-guide 3. In this embodiment, the light sources 2 are arranged such that the PCB 15 lies in the plane of, or adjacent to, the light output surface 6 i.e. the light sources 2 can be considered to be upside down, or rotated through 180°, relative to the light sources 2 of the uniform lighting device 13 presented in Figure 5. With this arrangement the PCB 15 provides the function of the light reduction medium 16.

A second difference is the presence of a reflector 22 located within the non-coupled light region 7. The reflector 22 is employed to reflect the light rays 4 that are not coupled into the planar light-guide 3, and which would otherwise exit the planar light guide 3 via the surface opposite to the light output surface 6, back towards the light output surface 6. The reflector recycles light and improves efficiency. The reflector can be separated from the light-guide by an air gap or attached onto the surface. The reflector can be bonded onto the light-guide surface with a low refractive index material to increase the numerical aperture of the light-guide around the light source and improve coupling and uniformity controllability.

Figure 8 presents a two-dimensional, cross sectional side view of a yet further alternative embodiment of the uniform lighting device 23. This embodiment again shares a number of features in common with the uniform lighting device 13 presented in Figure 5 and so these common elements are again marked with the same reference numerals.

In this embodiment, a sections 24 of the planar light-guide 3 located around the light sources 2 are formed as a separate mechanical component. As such, an LED 14 and its associated PCB 15 and light reduction medium 17 can be inserted into a complementary aperture 25 located in the planar light-guide 3 during manufacture. As shown in Figure 8, an electrical connector 26 may be located on the underside of the PCB 15.

This embodiment provides a means for replacing a light source 2 if there is an LED 14 failure or other mechanical failure within the device. The LED mounted on the PCB or with another electrical connection solution, can be bonded permanently or temporarily into the aperture, by means of a transparent adhesive or other polymer.

Although the above described embodiments have been described in conjunction with LEDs 14 designed to emit light from all five surfaces that are not in contact with the PCB 15 it will be appreciated by the skilled reader that any alternative LED known to those skilled in the art may alternatively be employed e.g. top emitting or side emitting LEDs. If the LED package consists of more than one LED chip, then preferably, the transparent material of the LED is of a diffusing material, so as to improve the colour mixing of the light from the more than one LED chips.

In addition, a reflector (not shown) may be incorporated such that the planar light-guide 3 is located between the reflector and the light output surface 6. Incorporation of the reflector ensures that all light from the uniform lighting devices is effectively directed towards the observer 9.

The present invention provides a number of alternative uniform lighting devices, capable of providing low intensity light level over a large surface area, to those known in the art.

A significant advantage of the present invention is that the uniform lighting devices can be made much thinner than those devices known in the art without introducing the problematic features of “hot spot” or “dark spot” artefacts i.e. a thin device can be produced that exhibits a highly uniform light output over a large surface area.

The disclosed uniform lighting devices are also cheaper to manufacture, and have a higher reliability and lifetime, than alternative solutions known in the art.

Since the uniform lighting devices comprise a plurality of individual light sources, they exhibit the further advantage that each light source can be made independently addressable, and so a pixelated area light source can be produced.

As a result of the above described advantages, the uniform lighting devices of the present invention find particular application within the field of transportation e.g. the automotive, train and aerospace industries where there is a requirement for a thin, robust device that is capable of being mechanically attached, bonded, joined or moulded onto the internal surface of the vehicle.

Throughout the specification, unless the context demands otherwise, the terms “comprise” or “include”, or variations such as “comprises” or “comprising”, “includes” or “including” will be understood to imply the inclusion of a stated integer or group of integers, but not the exclusion of any other integer or group of integers. Furthermore, unless the context demands otherwise, the term “or” will be interpreted as being inclusive not exclusive.

The foregoing description of the invention has been presented for the purposes of illustration and description and is not intended to be exhaustive or to limit the invention to the precise form disclosed. The described embodiments were chosen and described in order to best explain the principles of the invention and its practical application to thereby enable others skilled in the art to best utilise the invention in various embodiments and with various modifications as are suited to the particular use contemplated. Therefore, further modifications or improvements may be incorporated without departing from the scope of the invention as defined by the appended claims.

Claims:

1. A uniform lighting device comprising one or more light sources embedded within a planar light-guide, the planar light-guide having a planar light output surface, wherein the one or more light sources and the planar light-guide combine to produce a non-coupled light region of the planar light-guide around the one or more light sources, wherein light rays emitted from the associated one or more light sources exit the planar light-guide via the planar light output surface without being coupled into the planar light-guide, and a coupled light region of the planar light-guide around the one or more light sources, wherein light rays emitted from the associated one or more light sources are coupled into the planar light-guide,
 the uniform lighting device further comprising
 a light reduction medium located within the non-coupled light region and extending over the whole area of the non-coupled light region but not into the coupled light region to reduce the intensity of the non-coupled light rays exiting from the non-coupled light region via the planar light output surface, and a light extracting medium located within the coupled light region to extract coupled light rays from the coupled light region via the planar light output surface
 wherein
 the spatial intensity distribution of the reduced light intensity within the non-coupled region is balanced with the spatial intensity distribution of the light emitted from the light output surface within the coupled light region.

2. A uniform lighting device as claimed in claim 1 wherein the light reduction medium comprises an ink layer or a dye layer or a thin film or other absorbing or reflecting medium or material.

3. A uniform lighting device as claimed in either of claims 1 or 2 wherein the light reduction medium is located on the light output surface, embedded within the planar light-guide, or comprises a combination of both locations.

4. A uniform lighting device as claimed in any of the preceding of claims wherein the light extracting medium extends over the whole area, or at least a substantial part of the area, of the coupled light regions.

5. A uniform lighting device as claimed in any of the preceding of claims wherein the light extracting medium are located upon a surface of the planar light-guide opposite to the planar light output surface or on the planar light output surface or embedded within the planar light-guide or comprise a combination of two or more of these locations.

6. A uniform lighting device as claimed in any of the preceding of claims wherein the light reduction medium and or the light extracting medium are arranged to vary the amount of light reflected or absorbed depending on the spatial distance from the associated one or more light sources.

7. A uniform lighting device as claimed in any of the preceding of claims wherein the one or more light sources comprise a light emitting diode electrically and mechanically mounted onto a printed circuit board (PCB).

8. A uniform lighting device as claimed in claim 7 wherein the PCB comprises a transparent or non-transparent PCB.

9. A uniform lighting device as claimed in any of the preceding claims wherein the uniform lighting device further comprise a diffuser arranged to diffuse light exiting the planar light output surface.

10. A uniform lighting device as claimed in claim 9 wherein an air gap is incorporated between the diffuser and the planar light output surface.

11. A uniform lighting device as claimed in claim 9 wherein the diffuser is optically bonded to the planar light output surface.

12. A uniform lighting device as claimed in any of the preceding claims wherein the uniform lighting device further comprises a transparent substrate upon which the one or more light sources are mounted wherein the refractive index of the transparent substrate is less than or equal to the refractive index of the planar light guide.

13. A uniform lighting device as claimed in any of the claims 7 to 12 wherein the one or more light sources are embedded within a planar light-guide such that the PCB is located between the LED and the planar light output surface.

14. A uniform lighting device as claimed in any of the preceding claims wherein a section of the planar light-guide located around the one or more light sources is formed as a separate mechanical component that is removably mounted within an aperture formed in the planar light-guide.

15. A uniform lighting device as claimed in any of the preceding claims wherein the uniform lighting device further comprises a reflector arranged such that the planar light-guide is located between the reflector and the planar light output surface.

16. A method of forming a uniform lighting device, the method comprising:
-embedding one or more light sources within a planar light-guide, the planar light-guide having a planar light output surface,
-combining the one or more light sources and the planar light-guide to produce
a non-coupled light region of the planar light-guide around the one or more light sources, wherein light rays emitted from the associated one or more light sources exit the planar light-guide via the planar light output surface without being coupled into the planar light-guide, and
a coupled light region of the planar light-guide around the one or more light sources, wherein light rays emitted from the associated one or more light sources are coupled into -the planar light-guide,
-providing a light reduction medium located within the non-coupled light region and extending over the whole area of the non-coupled light region but not into the coupled light region to reduce the intensity of the non-coupled light rays exiting from the non-coupled light region via the planar light output surface, and
-providing a light extracting medium located within the coupled light region to extract coupled light rays from the coupled light region via the planar light output surface wherein
the spatial intensity distribution of the reduced light intensity within the non-coupled region is balanced with the spatial intensity distribution of the light emitted from the light output surface within the coupled light region.

17. A method of forming a uniform lighting device as claimed in claim 16 wherein the providing the light reduction medium comprises providing an ink layer or a dye layer or a thin film or other absorbing or reflecting medium or material.

18. A method of forming a uniform lighting device as claimed in either of claims 16 or 17 wherein the light reduction medium is provided on the light output surface, embedded within the planar light-guide, or comprise a combination of both locations.

19. A method of forming a uniform lighting device as claimed in any of claims 16 to 18 wherein the light extracting medium is provided over the whole area, or at least a substantial part of the area, of the coupled light regions.

20. A method of forming a uniform lighting device as claimed in any of claims 16 to 19 wherein the light extracting medium is provided upon a surface of the planar light-guide opposite to the planar light output surface, on the planar light output surface, embedded within the planar light-guide or comprise a combination of two or more of these locations.

21. A method of forming a uniform lighting device as claimed in any of claims 16 to 20 wherein the light reduction medium and or the light extracting medium is arranged to vary the amount of light reflected or absorbed depending on the spatial distance from the associated one or more light sources.

22. A method of forming a uniform lighting device as claimed in any of claims 16 to 21 wherein embedding the one or more light sources within the planar light-guide comprises embedding a light emitting diode electrically and mechanically mounted onto a printed circuit board (PCB).

23. A method of forming a uniform lighting device as claimed in claim 22 wherein the one or more light sources are embedded within a planar light-guide such that the PCB is located between the LED and the planar light output surface.

24. A method of forming a uniform lighting device as claimed in any of claims 16 to 23 wherein the method further comprises providing a diffuser arranged to diffuse light exiting the planar light output surface.

25. A method of forming a uniform lighting device as claimed in any of claims 16 to 24 wherein the method further comprises providing a transparent substrate upon which the one or more light sources are mounted wherein the refractive index of the transparent substrate is less than or equal to the refractive index of the planar light guide.