Abstract: A light-emitting device (100), comprising a plurality of light emitting diodes (107) arranged spaced apart from each other on a substrate (108), is provided. The device further comprises a light guide plate (101) having a front surface (102) and an opposing back surface (103) that is provided with an array of protrusions (104) extending towards said substrate. The light guide plate is arranged such that light emitting diodes are located in spaces formed between adjacent protrusions. The light from the plurality of LEDs will be transmitted in to the light guide plate and will be distributed therein before exiting the light guide plate via the front side thereof. Thus, the present invention provides a light-emitting device that provides well-distributed light from a plurality of point light sources.
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Flat and thin LED-based luminary

FIELD OF THE INVENTION
The present invention relates to a light-emitting device comprising a plurality of mutually spaced apart light emitting diodes arranged on a substrate, and a light guide plate.

BACKGROUND OF THE INVENTION
Especially if applied in, for instance an office or a professional environment, luminaries should fulfill several requirements. Firstly, the light source should have a sufficiently long lifetime. Conventional luminaries are often based on fluorescent tubes, which have a relatively limited lifetime. In a typical office environment, the tubes themselves need to be replaced every 6000 hours. This corresponds to a replacement every 2 years, which adds to the cost of ownership.

Secondly, the light output of the luminary should be robust against dust and other dirt. A luminary that collects dust will become less efficient, since the dirt blocks light. Since cleaning the luminary is an expensive matter, the design should be robust against dust and dirt.

Thirdly, the luminary should satisfy an anti-glare requirement (i.e. the unified glare ratio should be sufficiently small). This anti-glare requirement means that the luminary should not show any bright spots. In particular, there should be no bright spots if the luminary is viewed under an oblique angle. A luminary of the prior art is disclosed in US 6241 358, describing a lighting panel consisting of a set of light guide blocks in tandem arrangement, where a separate fluorescent tube provide light for each light guide block. The light from the fluorescent tubes is transmitted into the respective light guide block, is distributed therein and is transmitted through an output surface of the light guide block.

However, as mentioned above, fluorescent tubes have a limited lifetime and are expensive to replace. Further, the breakdown of a single fluorescent tube in this prior art luminary has a drastic negative impact on the lighting capacity of the lighting panel and on the homogeneity of the light from the lighting panel. Thus, when one of the tubes breaks down, it will be necessary to replace this broken tube immediately.
Further, fluorescent tubes emit a constant spectrum, which limits the color variability capacity of such a lighting panel.

SUMMARY OF THE INVENTION

It is an object of the present invention to at least partly overcome the problems of the prior art and to provide a flat panel lighting device and that has a long lifetime.

The present inventors have found that the above objects may be achieved by means of a light-emitting device accorded to the appended claims. Thus, in one aspect, the present invention relates to a light emitting device comprising a plurality of light emitting diodes (LEDs) arranged spaced apart from each other on a substrate, where the light emitting diodes are arranged to emit light in a general direction along the surface of said substrate. The light emitting device further comprises a light guide plate of a translucent material having a back surface facing said substrate and an opposing front surface, said back surface comprising a first array of protrusions extending towards said substrate, and the light guide plate being arranged such that the light emitting diodes are located in spaces formed between adjacent protrusions. The protrusions provide a light receiving face which transmits light from the light emitting diodes into said light guide plate, and a light reflection face which reflects light in said light guide plate, which light has a directional component along said general direction of light, towards said front surface.

The light from the plurality of LEDs will be transmitted into the light guide plate and will be distributed therein before exiting the light guide plate via the front side thereof. Thus, the present invention provides a light-emitting device that provides well-distributed light from a plurality of point light sources.

The use of light emitting diodes as primary light sources is advantageous as they have a long lifetime. Hence, service intervals will be extended, leading to a lower cost of ownership.

Further, light emitting diodes are capable of emitting light of saturated colors, allowing the light-emitting device to produce light with high color-variability. In embodiments of the present invention, more than one light emitting diode may be located in a single space between two adjacent protrusions.

For example, a plurality of LEDs arranged in such a single space may together form an extended light source, that will not fully be disfunctional in the case one or a few of the LEDs in that plurality of LEDs break down, since the neighboring LEDs will still be in operation.
Further, a plurality of LEDs of different colors, typically independently addressable, may be used in such a single space in order to provide a color variable light-emitting device. In embodiments of the present invention, reflective layers may be arranged at the back surface side of the reflection face of said protrusions of the first array.

Such reflective layer increases the light utilization efficiency, since light exiting the light guide plate via the back surface can be reflected back towards the front surface. Further, it prevents light to be transmitted into the light guide plate via the reflection faces. In embodiments of the present invention, the substrate on which the LEDs are arranged comprises a plurality of mutually spaced apart recesses, and the substrate is arranged such that the protrusions of said light guide plate are at least partly positioned in said recesses.

The arrangement of such recesses in the substrate improves and facilitates the positioning of the light guide plate on the substrate. In embodiments of the present invention, a redirection sheet may be arranged at the front side of said light guide plate, where the redirection sheet has a prism-faced surface facing the front side of the light guide plate.

Such a redirection sheet may be arranged in order to redirect the light exiting the light guide plate into a desired direction. The prism-faced surface of the redirection sheet may comprise a second array of extended mutually parallel protrusions that preferably has a triangularly shaped cross-section.

The tilt angle of the protrusions of the second array may be constant or may vary along the second array.

**BRIEF DESCRIPTION OF THE DRAWINGS**

This and other aspects of the present invention will now be described in more detail, with reference to the appended drawings showing currently preferred embodiments of the invention.

Figure 1a illustrates, in cross-sectional view, an embodiment of a light-emitting device of the present invention.

Figure 1b illustrates, in perspective view, the embodiment of figure 1a.

Figure 2 illustrates another embodiment of a light-emitting device of the present invention.

Figure 3 illustrates yet another embodiment of a light emitting device of the present invention.
DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

A light emitting device 100 of one embodiment of the present invention is illustrated in figure 1a, and comprises an array of a plurality of light emitting diodes (LEDs) 107, arranged mutually spaced apart on a substrate 108.

The light emitting diodes 107 are arranged to emit light in essentially the same general direction L, essentially along the surface of the substrate 108, and in the direction of the array of the LEDs.

LEDs capable of emitting light in a general direction essentially along the surface of the substrate that they are mounted on are especially suitable for use in the present invention. Examples of such diodes are those commonly known as side emitting diodes. The term "light emitting diode", herein abbreviated "LED" refers however to any type of light emitting diode known to those skilled in the art, and encompasses, but is not limited to, inorganic based LEDs, organic based LEDs (OLEDs and polyLEDs) and laser diodes.

The light-emitting device 100 further comprises a light guide plate 101 of a translucent material having a front surface 102 and an opposing back surface 103 facing the light emitting diodes 107. The light guide plate is arranged to receive light from the light emitting diodes via the back surface 103, to distribute the received light and to transmit the distributed light to the surroundings via the front surface 102.

Suitable materials for use in the light guide plate 101 include translucent materials such as, but not limited to, polymeric materials, i.e. PMMA or polycarbonate, ceramic materials and glass materials.

The back surface 103 of the light guide plate 101 presents a first array of protrusions 104 extending towards the substrate 108. Between each two adjacent protrusions 104 is formed a space, and the light guide plate 101 is arranged such that the array of protrusions 104 is aligned to the array of light emitting diodes 107 on the substrate such that the LEDs 107 are located in the so formed spaces between adjacent protrusions 104.

The protrusions 104 are designed to have a light receiving face 105, through which face light from the light emitting diodes 107 is transmitted into the light guide plate 101. The protrusions 104 also has a light reflection face 106, typically the alternate face of the protrusion, on which face light, that has been transmitted into the light guide 101, is reflected towards the front surface of the light guide plate.

Typically, the protrusions have a triangularly shaped cross-section, preferably as illustrated in figure 1a, being asymmetric such that the receiving face 105 has a steeper slope than the reflection face 106.
Typically, the angle $\angle C$ between the receiving face 105 and the front surface 102 of the light guide plate 101 is larger than the angle $\angle \beta$ between the reflection face 106 and the front surface 102.

The angle $\angle C$ is typically in the range of from 60 to 90°, and the angle $\angle \beta$ is typically in the range of from 1 to 15°.

The pitch of the protrusions 104 of the light guide plate 101, i.e. the repetitive distance between adjacent protrusions, is typically in the range of from 1 to 30 mm, for example about 10 to 20 mm.

In operation, light from the light emitting diodes 107 is transmitted into the light guide plate via the receiving faces 105 of the protrusions 104. When traveling in the light guide plate, the light will alternately encounter the front surface 102 of the light guide plate or a reflection face 106 of a protrusion.

Depending on the angle of incidence upon encountering the front surface 102, and according to Snell's law of refraction, the light is transmitted out of the light guide plate 101, or is reflected back (total internal reflection) into the light guide plate, towards the back surface 103 where it will encounter a reflection face 106 for reflection again towards the front surface 102. Due to the angle between the front surface 102 and the reflection face 106, the incidence angle at this following encounter with the front surface 102 will be lower than the incidence angle at the preceding encounter, until the incidence angle eventually becomes lower than the critical angle for transmission out of the light guide.

However, light will also be able to exit the light guide through the back surface 103 of the light guide plate, when the angle of incidence on the reflection faces 106 so allows. In order to utilize also light being transmitted out of the light guide plate at the back surface, it may be advantageous to provide the substrate 108, on which the light emitting diodes 107 are arranged, with a reflective coating or the like in order to reflect this light back towards and into the light guide plate 101.

In addition, the reflection faces 106 may be provided with a reflective coating 109. Light transmitted out of the light guide plate via the reflection faces 106 will be reflected back towards the front surface of the light guide plate. This will enhance the light utilization efficiency of the device.

Such reflective layer 109 may for example consist of a foil made of a reflecting material, and may be arranged between the reflection face 106 and the substrate 108, typically near the reflection face 106, or as a reflective coating on the back surface side.
of the reflection surface 106. Preferably, the reflective layer 109 consists of a reflective foil positioned against the reflection face 106.

Such a reflective layer 109 may also prevent stray light from the light emitting diodes 107 to enter the light guide plate via the reflection faces 106 of the protrusions 104.

As is shown in figure 1b, the array of mutually spaced apart LEDs 107 may be an array of mutually spaced apart rows, where each row comprises multiple LEDs. The array of protrusions 104 may be an array of extended, mutually parallel protrusions, where a whole row, i.e. more than one light emitting diode, is located in a single space between two adjacent protrusions. Thus, more than one light emitting diode 107 provides light to the receiving face 105.

For example, the multiple LEDs 107 forming a row and providing light to a single receiving face 105 may act as a spatially extended, linear, light source. If one of these light emitting diodes in such a row incidentally break down, the impact on the overall performance of the light emitting device is only minor, since the neighboring light emitting diodes providing light to the same receiving face as the broken light emitting diode still are functioning.

Further, light-emitting diodes of more than one color may be used to provide light to the same receiving face, in order to provide a color variable light-emitting device. For example, three or more independently addressable light emitting diodes of different colors, for example a red, a green and a blue LED, may form a color variable lighting unit (an RGB-unit).

In another embodiment of the present invention, as is illustrated in figure 2, the substrate 108 on which the LEDs are arranged, comprises a plurality of recesses 209 between mutually spaced apart light emitting diodes 107. The plurality of recesses 209 is preferably arranged in such a way that the protrusions 104 of the wave guide plate 101 extends at least partly into the recesses 209 of the substrate 108. Hence, the distance between two adjacent such recesses 209 corresponds to the distance between two adjacent protrusions 104 of the light guide plate 101. This improves and facilitates the alignment of the LEDs 107 with the receiving faces 105 of the protrusions 104 of the light guide plate. As will be apparent to those skilled in the art, the light from a light-emitting device as illustrated in figures 1 and 2 will typically exit the light guide plate via the front surface 102 thereof into the surroundings at an noticeable angle with respect to the normal of the front surface 102.

For instance, such a light-emitting device may be well suited for illuminating the ceiling when hung on a wall, or for illuminating a wall when arranged in the ceiling, but also for other purposes where light emission out of the normal of the front surface is desired.
However, in certain applications, it is desired to redirect the light exiting the light guide plate, for example to obtain light having a main direction at or close to the normal of the front surface of the light guide plate.

Thus, in embodiments of the present invention, as illustrated in figure 3, a redirection sheet 310 may be arranged at the front surface 102 to receive light that exits the light guide plate 101 via the front surface 102, in order to redirect the main direction of this light.

An example of such a redirection sheet 310 comprises a sheet of a translucent material (i.e. plastic, ceramic or glass), which has a prismatic surface 311 facing the front surface 102 of the light guide plate.

In an embodiment, the prismatic surface 311 comprises a second array of mutually parallel protrusions 312. For high efficiency, the protrusions 312 of the second array are advantageously essentially parallel to the protrusions 104 of the light guide plate 101.

Typically, the protrusions 312 of the second array have a triangularly shaped cross-section with an apex angle in the range of from 20 to 70°. The protrusions 312 of the second array are typically formed at a pitch (distance between two adjacent protrusions) that are markedly lower than the pitch of the protrusions 104 of the first array. Typically, the pitch of the protrusions 312 of the second array is in the range of about 50 to 300 μm.

The protrusions 312 of the second array may be symmetric or asymmetric with respect to the normal of the front surface 102 of the light guide plate, in the sense that the center line of the protrusions may be parallel (symmetric) or non-parallel (asymmetric) to the normal of the front surface 102.

The centerline of a protrusion having a triangularly shaped cross-section is a thought line that divides the apex angle into two equally large portions.

One way of quantifying the symmetry/asymmetry is to define a tilt angle γ as the angle between the centerline of a protrusion 312 and the normal to the front surface 102 of the light guide plate 101. Hence, γ = 0° refers to a symmetric protrusion, γ > 0° refers to an asymmetric protrusion tilted along the general direction of light emitted by the light emitting diodes, and γ < 0° refers to an asymmetric protrusion tilted against the general direction of light emitted by the light emitting diodes. Hence, if the general direction of light emitted by the light emitting diodes is to the right, γ > 0° refers to a protrusion tilted to the right, and γ < 0° refers to a protrusion tilted to the left as shown in Figure 3).
The tilt angle $\gamma$ of the protrusions 312 of the second array is typically in the range of from $-15^\circ$ to $15^\circ$, and may be constant or may vary along the array.

The apex and tilt angle of the protrusions 312 of the second array have been shown to affect the light exiting the redirection sheet into the surrounding.

One effect of a redirection sheet 310 is that the exiting light is given a tendency to show a plurality of intensity peaks at different angles relative to the normal of the redirection sheet.

At an apex angle value of about $40^\circ$, only one intensity peak appeared. Thus, in some embodiments of the present invention, about $40^\circ$ represent a preferred apex angle, since a single intensity peak is achieved.

Further, at tilt angle $\gamma$ of about $11^\circ$, the light exits the redirection sheet 310 approximately parallel to the normal of the redirection sheet. Thus, in some embodiments of the present invention, a tilt angle $\gamma$ of about $11^\circ$ is preferred since such a light-emitting device produces light perpendicular to the surface of the light-emitting device. At a lower tilt angle, for example $0^\circ$, light exits the redirection sheet 310 at a negative angle to the normal of the redirection sheet. At a higher tilt, such as $15^\circ$, light exits the redirection sheet 310 at a positive angle to the normal of the redirection sheet. In yet an embodiment of the present invention, the tilt angle $\gamma$ of the protrusions 312 of the second array varies along the extension of the second array in order to direct light from different portions of the device into different directions. For example, the tilt angle $\gamma$ may decrease, for example from about $15^\circ$ to $-5^\circ$, such as from $11^\circ$ to $0^\circ$, along the second array in the general direction of light emitted by the LEDs (i.e. if the LEDs are arranged to emit light generally to the right, the tilt angle $\gamma$ of the protrusions 312 of the second array is higher in a left portion of the second array then in a right portion of the array). This manner of varying the tilt angle will lead to a focusing of the light from the light-emitting device of the present invention.

The person skilled in the art realizes that the present invention by no means is limited to the preferred embodiments described above. On the contrary, many modifications and variations are possible within the scope of the appended claims.

For example, the redirection sheet 310 may be divided into two or more domains, where the tilt angle $\gamma$ of the protrusions 312 of the redirection sheet has a first value in a first such domain, and a second such value in a second domain. This may be used in order to achieve a light distribution with for example two intensity peaks at two different angles.
CLAIMS:

1. Light emitting device (100), comprising a plurality of light emitting diodes (107), arranged mutually spaced apart from each other on a substrate (108), said light emitting diodes (107) being arranged to emit light in a general direction along the surface of said substrate, wherein

   the light emitting device further comprises a light guide plate (101) of a translucent material having a back surface (103) facing said substrate (108) and an opposing front surface (102),

   said back surface (103) comprising a first array of protrusions (104) extending towards said substrate (108), and the light guide plate (101) being arranged such that the light emitting diodes (107) are located in spaces formed between adjacent protrusions (104), and

   said protrusions (104) providing a light receiving face (105) for transmitting light from the light emitting diodes (107) into said light guide plate, and a light reflection face (106) for reflecting light in said light guide plate (101), which light has a directional component along said general direction of light, towards said front surface (102).

2. A light emitting device according to claim 1 of the preceding claims, wherein more than one light emitting diode is located in a single space between two adjacent protrusions.

3. A light-emitting device according to claim 1 or 2, wherein said first array of protrusions (104) comprises extended protrusions arranged mutually parallel.

4. A light emitting device according to any of the preceding claims, wherein reflective layers (109) are arranged at the back surface side of the reflection face (106) of at least part of said protrusions (104).

5. A light emitting device according to any of the preceding claims, wherein the angle (α) between said light receiving face (105) and said front surface (102) is larger than the angle (β) between said light reflection face (106) and said front surface (102).
6. A light emitting device according to any of the preceding claims, wherein said protrusions (104) of said first array have triangularly shaped cross-section.

7. A light emitting device according to any of the preceding claims, wherein said substrate (208) comprises a plurality of mutually spaced apart recesses (209), and is arranged such that protrusions (104) of said first array are at least partly positioned in said recesses (209).

8. A light emitting device according to any of the preceding claims, wherein a redirection sheet (310) is arranged at said front side of said light guide plate, said redirection sheet having a prism-faced surface (311) facing said front side.

9. A light-emitting device according to claim 8, wherein said prism-faced surface (311) provides a second array of extended mutually parallel protrusions (312).

10. A light-emitting device according to claim 9, wherein said second array of protrusions (312) comprises protrusions having triangularly shaped cross-section.

11. A light emitting device according to claim 10, wherein said apex angle of said protrusions (312) of said second array is in the range of from 20 to 70°.

12. A light emitting device according to claim any of the claims 9 to 11, wherein said second array of protrusions (312) of is arranged parallel to said first array of protrusions (104).

13. A light emitting device according to claim 12, wherein the center line of the protrusions of said redirection sheet is tilted at an angle (γ) of from -15 to 15° along said general direction of light, in relation to the normal of said front side.

14. A light-emitting device according to claim 13, wherein said tilt angle (γ) varies along said second array of protrusions (312).
15. A light emitting device according to claim 14, wherein said redirection sheet is divided into at least a first domain and a second domain, and wherein the protrusions of said first domain has a first tilt angle, and the protrusions of said of said second domain has a second tilt angle.

16. A light-emitting device according to claim 14, wherein said tilt angle (γ) increases along said second array of protrusions (312) in said general direction of light.
### A. CLASSIFICATION OF SUBJECT MATTER

**INV. G02B6/00**

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

### B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical search terms used)

EPO-Internal, WPI Data

### C. DOCUMENTS CONSIDERED TO BE RELEVANT

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X Further documents are listed in the continuation of Box C

X 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

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**S** document member of the same patent family

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Kl oppenburg, Martin
## INTERNATIONAL SEARCH REPORT

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