Abstract: A backlight is provided for a direct-view display. The backlight comprises a plurality of discrete light sources (11), such as light emitting diodes, spaced from a diffuser (5). The light sources are arranged as sets cooperating with a mirror structure (101), which surrounds the set to form a region. The regions substantially tessellate the area of the backlight. Each mirror structure (101) comprises a plurality of mirror segments which are curved and concave in cross-section perpendicular to the diffuser (5). The mirror segments extend from around the light sources (11) towards the diffuser (5). The edges of adjacent mirror segments of adjacent regions meet at a meeting line such that all of the meeting lines are at the diffuser (5) or between the diffuser (5) and the light sources (11).
Published:

- with international search report
TECHNICAL FIELD

The present invention relates to a backlight, for example for use with an at least partially transmissive spatial light modulator. The present invention also relates to a display including such a backlight.

BACKGROUND ART

EP 01722267 (Samsung) describes a uniform direct-view backlight whereby a plurality of LED (light emitting diode) light sources is interspersed with vertical reflective barrier columns that extend across the horizontal width of the display. These columns support a diffusion plate that sits behind a liquid crystal display. The columns separate more than one LED in a row. Synchronous switching of the rows of LEDs between the columns with the display refresh rate allows reduced motion blur artifacts.

US 2006/ 0290840 (LG Philips) describes a uniform direct-view backlight whereby a regular array of LEDs is positioned on a circuit board behind a liquid crystal display (LCD). Each LED has a lens structure made into the LED to modify the emission profile. There also exist supports for an
optical diverter spaced between the LEDs and the display. The optical design of the diverter and LED lens structure is such as to give a uniform illumination of the display.

US 7072096 (Digital Optics International Corporation) describes a uniform direct-view backlight composed of an array of LEDs and one or more prism sheets to form a uniform directed illumination arrangement. One embodiment describes the use of vertically orientated triangular mirrors surrounding zones containing a plurality of LEDs. These mirrors recycle reflected light from the prism film and improve brightness.

WO 0507 1643 (Shanghai Sansi Technology Co.) describes a uniform direct-view backlight utilizing an array of LEDs placed a fixed distance behind an LCD. Each individual LED has a rounded square reflector extending vertically from the circuit board on which the LED is mounted. The reflector has a circular cross-section. The purpose of the patent is to improve brightness of the display by sending more high-angle light forward.

JP 2006/ 190847 (Citizen Electrical) describes a uniform direct-view backlight comprising an array of LEDs placed a fixed distance behind an LCD. Surrounding the whole array is a vertical mirror that extends from the LED plane to the LCD. The purpose of this patent is to improve colour uniformity towards the edges of the display as more light is
lost from these areas.

US 25128744 (Dialight Corporation) describes an LED array for directed light applications whereby one or more of the LEDs are surrounded by a circular reflector with a conic cross section. The reflectors are identical and arranged uniformly across the array. The purpose of this system is to replace lenses for illumination applications, for example in a traffic light.

Figure 1 of the accompanying drawings illustrates a typical display of known type that is used in large area devices such as large area televisions and display screens. The display, 1, comprises a flat transmissive spatial light modulator (SLM) in the form of a liquid crystal display (LCD) panel 4 having input and output polarisers 2 and 3. The panel 1 is provided with a backlight 9, whose main components are a diffuser 5, an array 6 of small point-like light sources 11 and a rear reflector plane 7. There may also be separation pillars 8 which may be transparent and are designed to maintain the separation between the diffuser 5 and the light source plane 6.

There is also driving electronics 12 for the light sources 11. Prism based brightness enhancement films and polarised reflectors (not shown) may also be used.

The light source array 6 and diffuser 5 have an area or "size" in a plane perpendicular to the plane of Figure 1 at least as big as the display area of the panel 4 with a
thickness typically much less than its other dimensions. The backlight unit 9 is placed behind the LCD 4 and is directed to illuminate the rear part of the LCD and through to the observer 10.

The backlight unit 9 comprises the diffuser 5, which that is placed nearer to the LCD 4. Behind the diffuser 5, parallel thereto and at a fixed distance therefrom, there is placed the light source array. Each element of the array is substantially identical and emits light in a parallel direction towards the diffuser. The reflector plate 7 sits surrounding the light source array and is used to recycle reflected light back through the system to improve brightness.

The small point-like light sources 11 may be Light Emitting Diodes (LEDs).

The light source array 6 may comprise individual LED structures 11 utilising blue or ultraviolet LEDs with phosphors, or integrated red, green and blue LEDs located close to each other as a single "point" in the array. LED driving electronics 12 are typically positioned behind the reflector plate.

The action of the diffuser 5 is to spread the emitted light from the LEDs over a wide angle and to form the basis for a comfortable viewing plane for the observer 10. However, single diffusers are typically inefficient at improving the spatial uniformity of illumination passing through them.
Thus it is necessary to have reasonably uniform illumination onto them from the light plane 6.

DISCLOSURE OF INVENTION

According to a first aspect of the invention, there is provided a display backlight comprising a plurality of discrete light sources spaced from a diffuser, the sources being arranged as sets, each of at least some of which comprises a plurality of the sources, cooperating with a mirror structure which surrounds the set to form a region, the regions being arranged as a two dimensional array which substantially tessellates the area of the backlight, each mirror structure comprising a plurality of mirror segments, of curved concave cross-section in a plane substantially perpendicular to the diffuser, extending from around the sources of the set towards the diffuser, the edges of adjacent mirror segments of adjacent regions meeting at a meeting line with all of the meeting lines being at the diffuser or between the diffuser and the sources.

Each mirror segment may be arranged to reflect light incident thereon, at least from the sources adjacent the mirror segment, directly onto the diffuser.

Each of the at least some sets may comprise at least three sources.

The sources may all be of substantially the same type.
The sources may be substantially point-sources.
The sources may be of Lambertian type.
The sources may be light emitting diodes.
The light sources may be substantially white light sources.
The adjacent ends of adjacent mirror segments of each region may meet at curved lines.
The meeting lines may be straight lines. All of the meeting lines may be in a first common plane.
The diffuser may be a plane diffuser. The first common plane may be substantially at the diffuser plane.
Each plane, which intersects the mirror segments and which is parallel to the first common plane, may intersect each of the mirror segments at a straight line of intersection. Each mirror segment may be of substantially constant cross-sectional shape along each line of intersection. The cross-sectional shape may be substantially defined by the lateral distance with respect to an origin at the meeting line being proportional to distance perpendicularly from the first common plane raised to the power 1.2.
The sources may be disposed substantially in a second common plane. The second common plane may be substantially parallel to the diffuser plane. The mirror segments of each region may meet the second common plane at a polygon. The sources of each of the at least some sets may be arranged in a pattern having an outline which is
similar to the polygon.

The regions may all be of the same shape and may have the same number of sources. The regions may be one of triangular, square and hexagonal.

As an alternative, the regions may comprise a first set of regions, each of which is of a first shape and/or has a first number of sources, disposed in an inner area of the backlight and a second set of regions, each of which is of a second shape different from the first shape and/or has a second number of sources different from the first number of sources, disposed in an outer area of the backlight. The regions of the first and second sets may be triangular and square, respectively. The second number may be larger than the first number.

According to a second aspect of the invention, there is provided a display comprising a backlight according to the first aspect of the invention disposed behind a spatial light modulator.

The modulator may comprise a liquid crystal device.

It is thus possible to provide a backlight for a direct-view display which provides a high level of uniformity of illumination. For a fixed separation between the diffuser and the light sources, fewer light sources are required to achieve a desired level of uniformity of illumination. Also, conventional or standard light sources, such as light emitting
diodes, may be used. It is thus possible to provide a backlight of reduced cost requiring reduced complexity of drive circuitry for the light sources.

BRIEF DESCRIPTION OF DRAWINGS

Figure 1 is a cross-sectional view of a known type of direct-view display;

Figures 2 to 4 illustrate techniques for improving uniformity of illumination by a backlight;

Figure 5 illustrates diagrammatically desirable point light source emission profiles;

Figure 6 is a cross-sectional view of a backlight constituting an embodiment of the invention;

Figure 7 is a cross-sectional view and a plan view of a backlight constituting another embodiment of the invention;

Figure 8 is a plan view illustrating a detail of the backlight shown in Figure 7 to a larger scale;

Figure 9 is a cross-sectional view illustrating a mirror profile of the backlight of Figure 8;

Figure 10 is a plan view of a backlight constituting a further embodiment of the invention;

Figure 11 is a plan view to an enlarged scale of a detail of the backlight of Figure 10;

Figure 12 is a plan view of backlights constituting further embodiments of the invention; and
Figure 13 is a plan view of a backlight constituting yet another embodiment of the invention.

BEST MODE FOR CARRYING OUT THE INVENTION

Figures 2 to 4 illustrate three ways of controlling the illumination from the light source plane.

The first way (Figure 2) is by controlling the distance 17 between the light source plane 6 and the diffuser 5. A plane 6 placed further away (19) will illuminate the diffuser 5 more uniformly than nearer (18). This is because the emission 20a from each source 11a has more space to merge into the illumination 20b from a neighbouring source 11b. However, there will be significantly more lost light and, at the extreme, the light source plane will need to be substantially bigger than the diffuser to maintain viewing angle properties of the display. These practical and also aesthetic considerations typically limit the maximum separation to a fixed value (normally not more than a few centimetres, depending on the display).

The second way (Figure 3) is to use a higher density array (22) of point emitters 11 (LEDs) than previously (21). There is clearly a limit to this, mainly with regard to cost. For a given display brightness, using a greater number of lower-power LEDs will substantially increase the costs, along with more complicated LED driving and control circuitry.
Cost is a significant negative factor of LED based backlights over other existing backlight technologies such as cold cathode fluorescent lamps (CCFLs), and so there is usually strong pressure to reduce costs. One possible way to do this is to use a lower number of higher-power LEDs.

The third way (Figure 4) to improve illumination is to modify the emission profile 13a (the brightness emitted at a particular angle) of the individual sources or introduce additional optical elements around the LEDs (24) over previously (23). A narrow emission profile 13a would give a low uniformity whereas a wide emission profile 13b would give a high uniformity. This can be done by refractive optical structures, sectioned light-guides or individual reflectors applied to the LEDs (not shown). Because the light sources illuminate a flat plane (diffuser 5), the required emission profile (14 in Figure 5) is quite different from the normal emission patterns of LEDs (near-Lambertian emission 15). Thus the individual modification requires complex designs. As with the number of LEDs in the backlight, this becomes a significant cost issue.

Embodiments of the invention seek to utilise light that is emitted from the sources at a large angle to the normal of the light source plane. Some LEDs are replaced by mirror structures in a regular manner across the light source plane. This large angle light is reflected by the mirror structures,
thus eliminating the non-uniformity caused by the loss of the LEDs.

The improvement is independent of the separation or the emission profile of the LEDs. There is a requirement that there is some emission at high angles but not such a high percentage as shown by 14 in Figure 5. For example, a more natural emission profile similar to 15 would be sufficient. Fewer LEDs are required than with equivalent known backlights. Conversely, for a given number of LEDs, the separation between the light sources and the diffuser can be reduced and/or the conditions on or requirements of the emission profile may be relaxed.

Figure 6 illustrates a display 100, which differs from that shown in Figure 1 in that there is a different arrangement of point-like light sources 11 and that there are curved mirror segments 101 that are regular and intersect the light source pattern arrangement in the same pattern. The segments are linear and extend from the light source plane substantially to the diffuser plane 5. The mirror structures surround and separate identical groups of light sources. The sources are then arranged in each separated group such that the interaction between light 115 from the sources and the reflections 116 from the mirror, which mimic the light emitted from 'missing' sources that would be where the mirrors are, produce a uniform illumination.
The light sources 11 are "discrete" in the sense that they are deliberately spaced apart in the plane 6. Although it is possible for the discrete light sources 11 to be of more than one colour, it is likely that each light source 11 in most embodiments will be arranged to emit substantially white light. White light sources may be of the types described hereinbefore with reference to Figure 1. For example, each source may be arranged to emit blue and ultraviolet light with the blue light contributing to the light output and the ultraviolet light being converted to red and green light by means suitable phosphors forming part of the device package.

As an alternative, each of the sources 11 may comprise a plurality of individual sources, such as red, green and blue sources, adjacent each other so as to be effectively non-discrete with their outputs blending together to provide substantially white light. However, any suitable arrangement may be used to provide a device which, in this application, acts as a single discrete light source.

The number of sources required in this arrangement is substantially less than that needed without the mirror segments.

Figure 7 illustrates an embodiment comprising a flat diffuser 5 and a light source plane 6 separated by a distance of 20mm (102). The light source plane is interspersed with a reflector layer 7 for light recycling.
The actual value of separation of 20mm in this case is for illustration purposes only and to serve as a relative marker. The system may be scaled in a linear fashion in a straightforward manner.

Curved mirrors 101 extend between the light source 6 and diffuser plane 5. The mirrors are in a square pattern and each open square between the mirrors contains nine light sources 103 also in a substantially square grid pattern. The ends of the mirrors 101 meet at curved lines such as 110, which appear straight in the plan views of the drawings.

This embodiment is not limited to nine light sources per group and may, for example, comprise a greater number per group. However, groups of nine are considered advantageous.

The light source points 11 are substantially identical and all lie substantially in the same plane 6. The light source points can be LEDs of very small emitting area. The sources are assumed to be Lambertian in their emission profile. Similarly, the exact emission profile is not important other than that there is small emission at high angles to the normal.

This profile is used for illustrative purposes only.

Axes 104 on the diagram are defined as the z axis being normal to both the diffuser and light source planes. The origin 106 is at the diffuser plane and the positive direction is towards the light source plane (away from the display 4).
The x and y axes 105 are in the light-source/ diffuser planes and are parallel to the two mirror directions.

The mirrors 11 are identical and symmetric on all sides of the sectioned area.

The mirrors 101 are arranged to reflect light incident on them, from at least the adjacent light sources but preferably from all of the light sources surrounded by the mirrors, directly (i.e. without reflection) onto the diffuser 5. In particular, light at high angles, for example between 45° and 90° to the light source axes is reflected directly onto the diffuser and, after reflection, may travel paralleled or nearly paralleled to the light source axes, such as 120.

Consider a single section of this arrangement (Figure 8) containing mirrors on all sides and nine light sources. The square is 68mm each side 107 (using the same scale as above).

The corner (at the apex 117 at the diffuser plane 5) can be considered the origin in the x/y plane 104. One possible arrangement of the nine sources in a square array uses a single source in the centre of the square 111. The spacing of the other eight is 20mm horizontally 112a and vertically 112b.

The light source pattern 111 may not be in a perfect square grid. For example, the positions of one or more light sources may differ from the regular grid pattern to improve uniformity, even though in this embodiment they are shown in a regular
arrangement.

The mirror shape (Figure 9) follows equation 1:

\[ y = K \left( j - \frac{L}{z} \right)^R \] (Eq. 1)

where \( y \) is the \( y \) coordinate along the plane, \( z \) is the distance from the diffuser plane \( (z=0 \) at the diffuser plane, \( z=20\text{mm} \) at the light source plane), \( L=20\text{mm} \), the distance between the planes \( 102. \ K=4.352\text{mm} \) and \( R=1.2 \). The mirror curve is lenticular (does not change along one side) and is substantially the same on all four sides.

Such an arrangement will produce \( >95\% \) uniformity on the diffuser over a large area. Taking an example size of an approximately \( 28'' \) display, 432 light sources would be required in this area for \( >95\% \) uniformity.

Identical light sources without mirrors in a square arrangement would require 619 light sources for \( >95\% \) uniformity. This aspect thus provides a reduction of 30\% over the case without mirrors. Alternatively, a greater separation of \( 24\text{mm} \) would be required for such uniformity with 432 sources in a standard square arrangement.

In the embodiment shown in Figure 10, the mirrors 200 are in a tessellating equilateral triangular arrangement, each mirror segment containing three light sources 201. The light sources are in a triangular arrangement. This embodiment is not limited to triangular mirror arrangements 200 with only
three sources 201, as more can be enclosed. Also, the precise positioning of each source may not follow a precise triangular pattern.

In a specific example of this embodiment, the mirrors 200 are lenticular and substantially identical on the three sides and are defined by equation 1 above where $K=3.627\text{mm}$, $R=1.2$, $L=20\text{mm}$. The lenticular length of one edge along the apex of the mirror at the diffuser is 56.97mm.

If we define the origin 203 of the x/y plane 202 at the corner of one triangle at the apex at the diffuser 5, the three light sources in the triangle can be placed at the locations shown in Figure 11. The sources are placed at $x=0\text{mm}$, $y=17.8\text{mm}$ (204a); $x=11\text{mm}$, $y=36.86\text{mm}$ (204b); and $x=-11\text{mm}$, $y=36.86\text{mm}$ (204c).

Such an arrangement will produce $>95\%$ uniformity on the diffuser over a large area. Taking the example of the approximately 28" display, 480 light sources would be required in this area for $>95\%$ uniformity.

Identical light sources without mirrors in a triangular arrangement would require 622 light sources for $>95\%$ uniformity. Alternatively, a greater separation of 24mm would be required for such uniformity with 480 sources in a standard triangular arrangement.

Any tessellating structure may be used. For example, a hexagonal arrangement of mirrors and light sources is shown
in Figure 12. This can apply with or without triangular symmetry. The light source group 300 in the figure has triangular symmetry. In this case both the hexagonal and the triangular mirror arrangements can be applied. Note that the optimum source positions for good uniformity may not match the ideal grid position. The light source group 301 shows only hexagonal symmetry.

Regular tessellating structures and non-regular tessellating structures, where there are variations in shapes of the areas across the display (Figure 13), may be used. For example, an arrangement may have small groups of sources 400 with close mirrors 401 centrally in the display 1, where the uniformity is needed to be high. Towards the edges of the display, more sources 402 in larger mirror areas 403, which can be of a different pattern shape, can be placed where uniformity is less important. If a different pattern shape is used, then pattern 'fillers' 404, i.e. smaller areas of different shape that 'fill' the areas between the main patterns, can be used.
CLAIMS

1. A display backlight comprising a plurality of discrete light sources spaced from a diffuser, the sources being arranged as sets, each of at least some of which comprises a plurality of the sources, cooperating with a mirror structure which surrounds the set to form a region, the regions being arranged as a two-dimensional array which substantially tessellates the area of the backlight, each mirror structure comprising a plurality of mirror segments, of curved concave cross-section in a plane substantially perpendicular to the diffuser, extending from around the sources of the set towards the diffuser, the edges of adjacent mirror segments of adjacent regions meeting at a meeting line with all of the meeting lines being at the diffuser or between the diffuser and the sources.

2. A backlight as claimed in claim 1, in which each mirror segment is arranged to reflect light incident thereon, at least from the sources adjacent the mirror segment, directly onto the diffuser.

3. A backlight as claimed in claim 1 or 2, in which each of the at least some sets comprises at least three sources.
4. A backlight as claimed in any one of the preceding claims, in which the sources are all of substantially the same type.

5. A backlight as claimed in any one of the preceding claims, in which the sources are substantially point-sources.

6. A backlight as claimed in any one of the preceding claims, in which the sources are of Lambertian type.

7. A backlight as claimed in any one of the preceding claims, in which the sources are light emitting diodes.

8. A backlight as claimed in any one of the preceding claims, in which the light sources are substantially white light sources.

9. A backlight as claimed in any one of the preceding claims, in which the adjacent ends of adjacent mirror segments of each region meet at curved lines.

10. A backlight as claimed in any one of the preceding claims, in which the meeting lines are straight lines.

11. A backlight as claimed in claim 10, in which all of
the meeting lines are in a first common plane.

12. A backlight as claimed in any one of the preceding claims, in which the diffuser is a plane diffuser.

13. A backlight as claimed in claim 12 when dependent on claim 11, in which the first common plane is substantially at the diffuser plane.

14. A backlight as claimed in claim 11 or 13, in which each plane, which intersects the mirror segments and which is parallel to the first common plane, intersects each of the mirror segments at a straight line of intersection.

15. A backlight as claimed in claim 14, in which each mirror segment is of substantially constant cross-sectional shape along each line of intersection.

16. A backlight as claimed in claim 15, in which the cross-sectional shape is substantially defined by the lateral distance with respect to an origin at the meeting line being proportional to distance perpendicularly from the first common plane raised to the power 1.2.

17. A backlight as claimed in any one of the preceding
claims, in which the sources are disposed substantially in a second common plane.

18. A backlight as claimed in claim 17 when dependent directly or indirectly on claim 12, in which the second common plane is substantially parallel to the diffuser plane.

19. A backlight as claimed in claim 17 or 18, in which the mirror segments of each region meet the second common plane at a polygon.

20. A backlight as claimed in claim 19, in which the sources of each of the at least some sets are arranged in a pattern having an outline which is similar to the polygon.

21. A backlight as claimed in any one of the preceding claims, in which the regions are all of the same shape and have the same number of sources.

22. A backlight as claimed in claim 21, in which the regions are one of triangular, square and hexagonal.

23. A backlight as claimed in any one of claims 1 to 20, in which the regions comprise a first set of regions, each of which is of a first shape and/ or has a first number of sources,
disposed in an inner area of the backlight and a second set of regions, each of which is of a second shape different from the first shape and/or has a second number of sources different from the first number of sources, disposed in an outer area of the backlight.

24. A backlight as claimed in claim 23, in which the regions of the first and second sets are triangular and square, respectively.

25. A backlight as claimed in claim 23 or 24, in which the second number is larger than the first number.

26. A display comprising a backlight as claimed in any one of the preceding claims disposed behind a spatial light modulator.

27. A display as claimed in claim 26, in which the modulator comprises a liquid crystal device.
INTERNATIONAL SEARCH REPORT

International application No
PCT/JP2008/054238

A CLASSIFICATION OF SUBJECT MATTER
Int.Cl G02F1 / 13357 (2006.01)i, F21S2 / 00 (2006.01)i, F21V7 / 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)
Int.Cl G02F1 / 13357, F21S2 / 00, F21V7 / 00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Published examined utility model applications of Japan 1922 1996
Published unexamined utility model applications of Japan 1971 2008
Published registered utility model specifications of Japan 1996 2008

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Patent family annex

Special categories of cited documents:

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Date of the completion of the international search
31.03.2008

Date of mailing of the international search report
15.04.2008

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