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H01L 33/60 (2010.01) ***H01L 33/64*** (2010.01)

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(58) Field of Search:
INT CL **G02B, H01L**
Other: **ONLINE:EPODOC, WPI**

(54) Title of the Invention: **Illumination apparatus**
Abstract Title: **Illumination Apparatus**

(57) A light emitting element array 22, wherein the array of light-emitting elements 4 , 5 and an array of light directing optics 35 for example, catadioptric elements are provided between first and second attached mothersheet substrates 14, 34. The thermal resistance of at least one of the mothersheet substrates 14, is reduced, by reducing the substrate to a thickness of between 0.01 mm and 1.1 mm. by thickness reduction means for example, grinding, polishing, or chemical etching, so as to provide a reduced LED junction temperature. Heat spreading elememts 16, 17 may be present between the first substrate 14 and the light emitting elements 4, 5. The device may include a heat sink 50 and be used as a backlight to illuminate a known crystal display panel (Figure 33, 254)

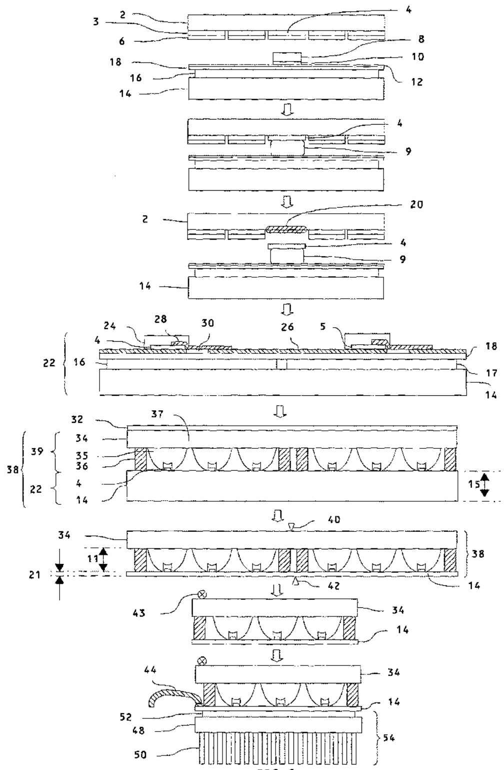

FIG.1

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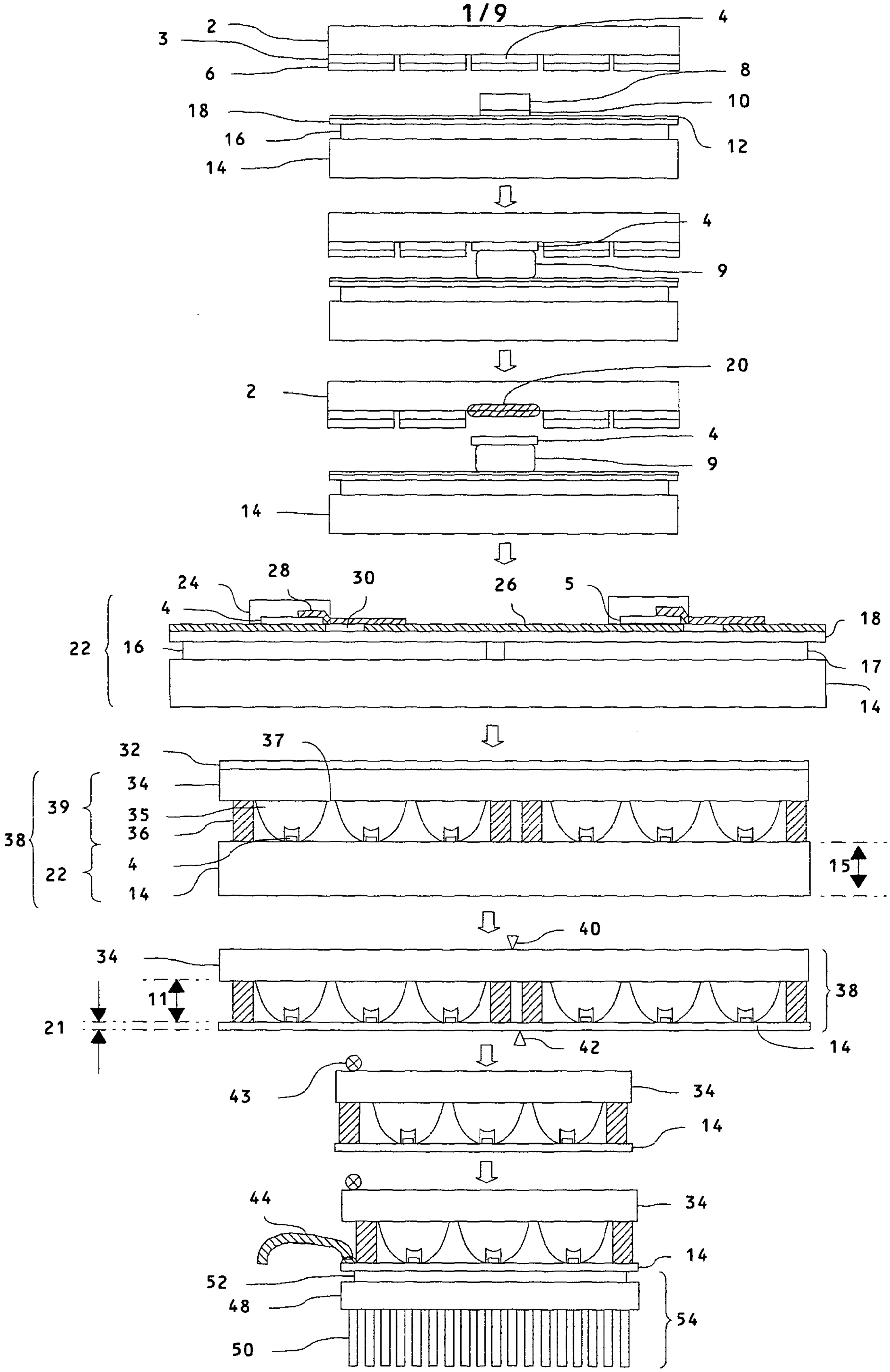
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FIG.1

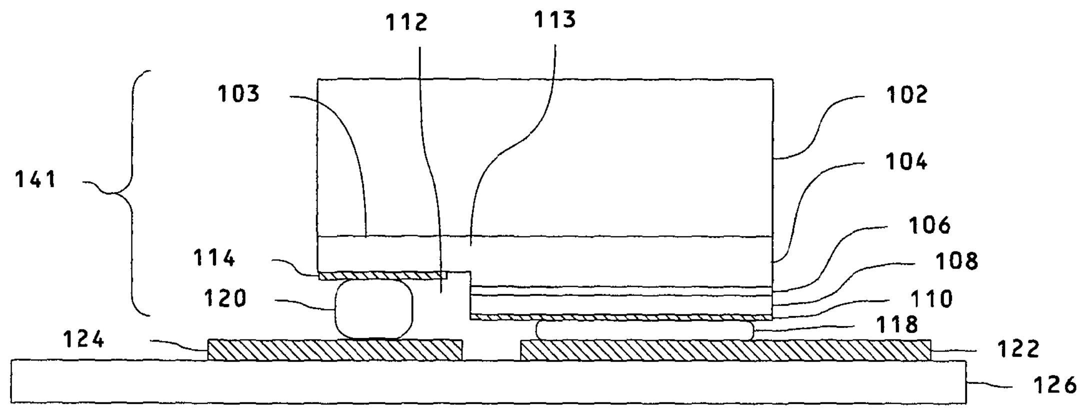

FIG.2

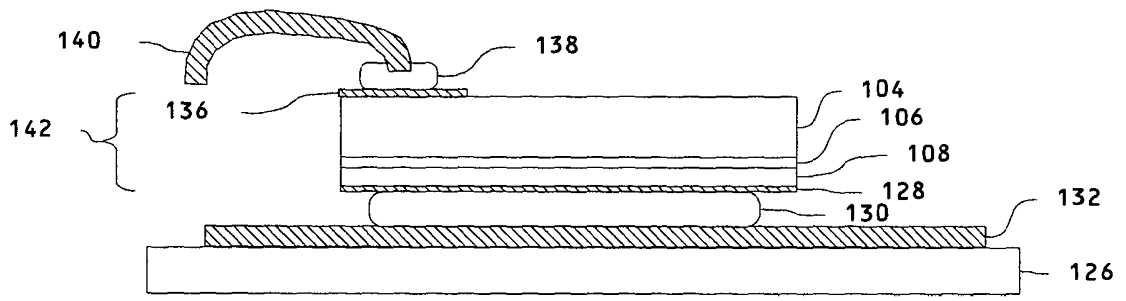

FIG.3

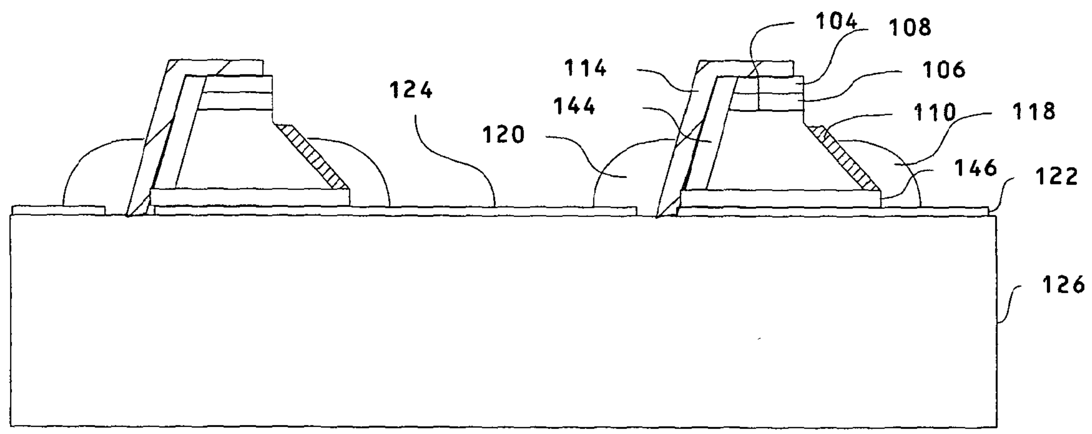

FIG.4

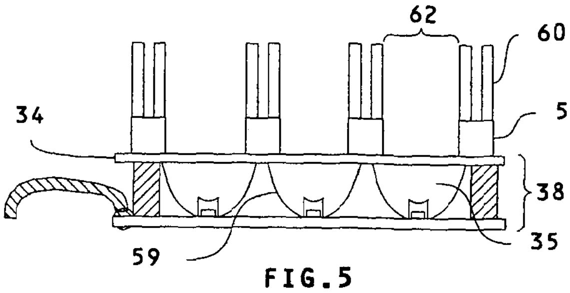

FIG.5

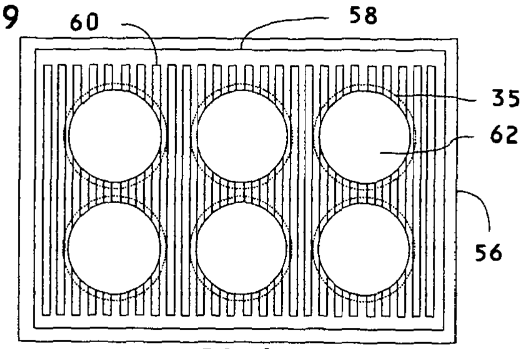

FIG.6

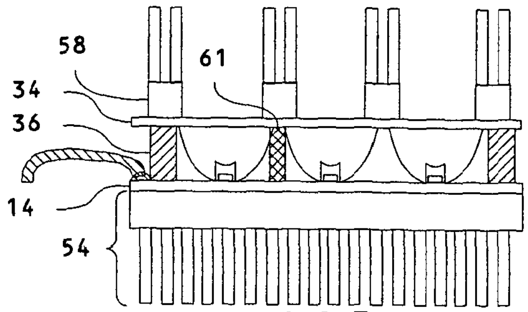

FIG.7

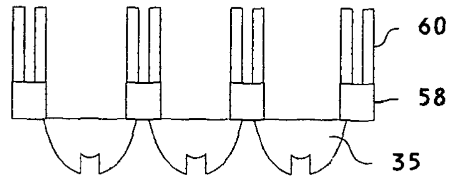

FIG.8

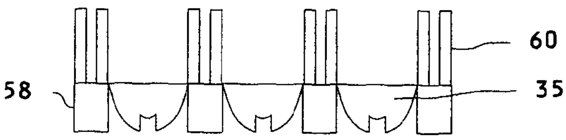

FIG.9

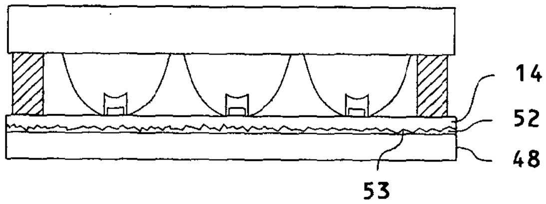

FIG.10

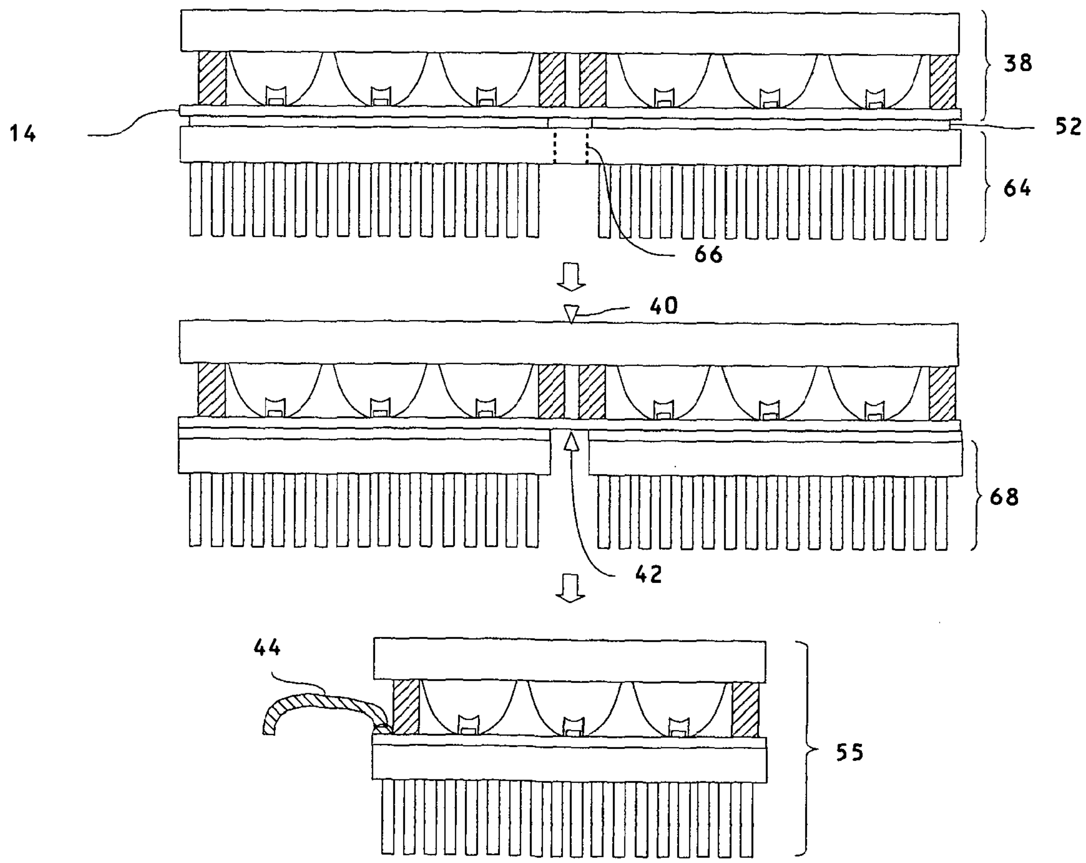

FIG.11

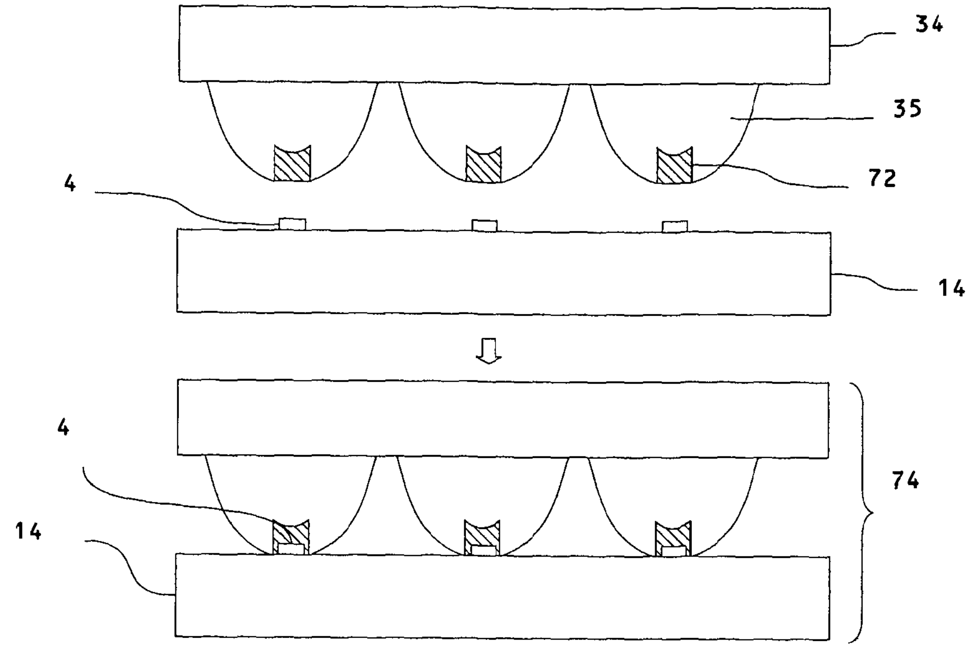

FIG.12a

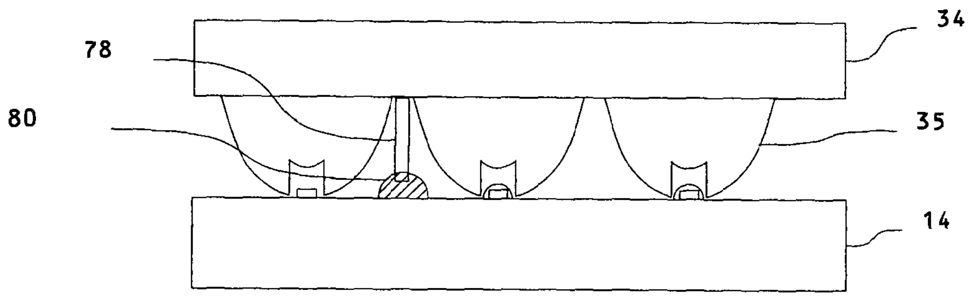

FIG.12b

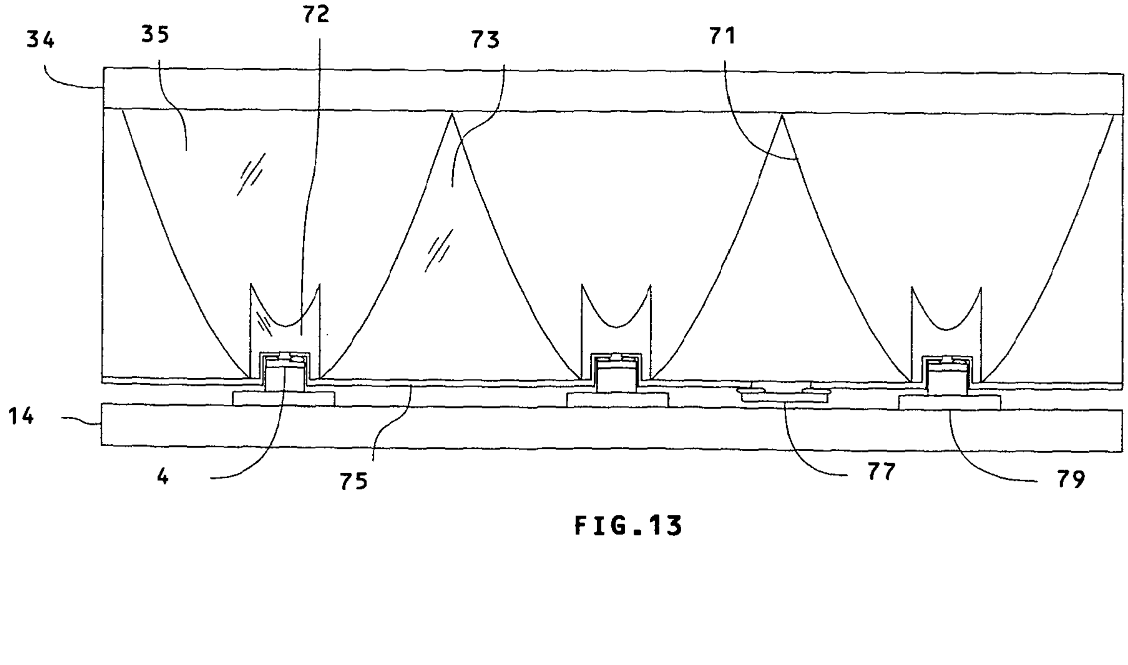

FIG.13

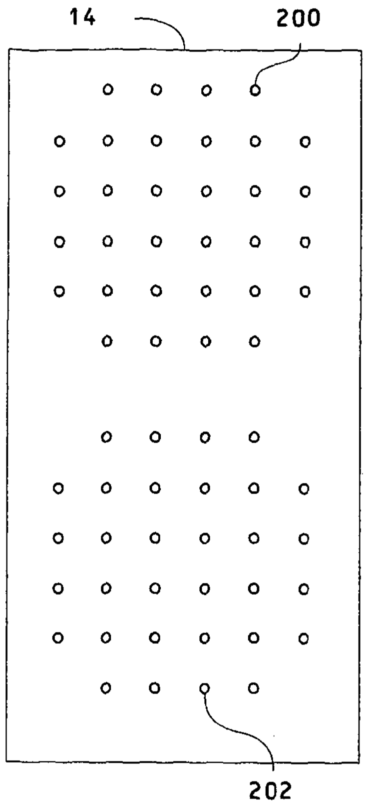

FIG.14

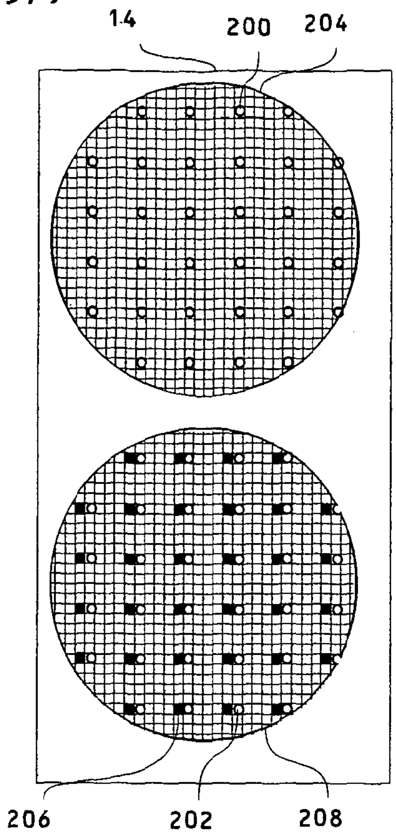

FIG.15

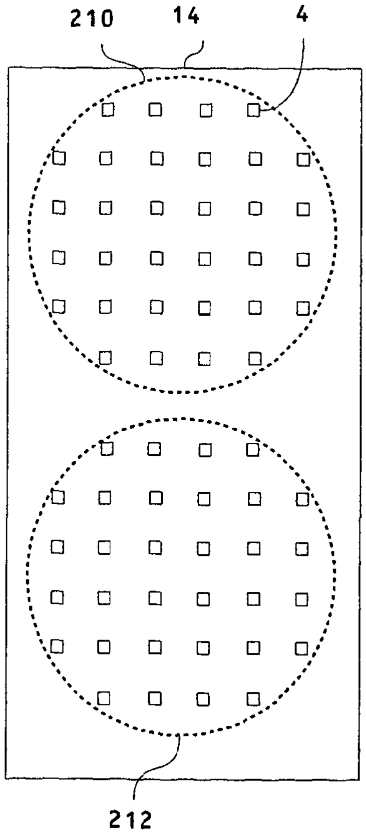

FIG.16

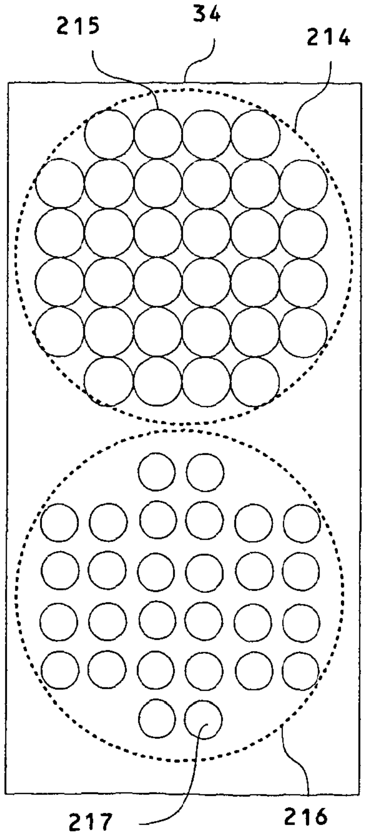

FIG.17

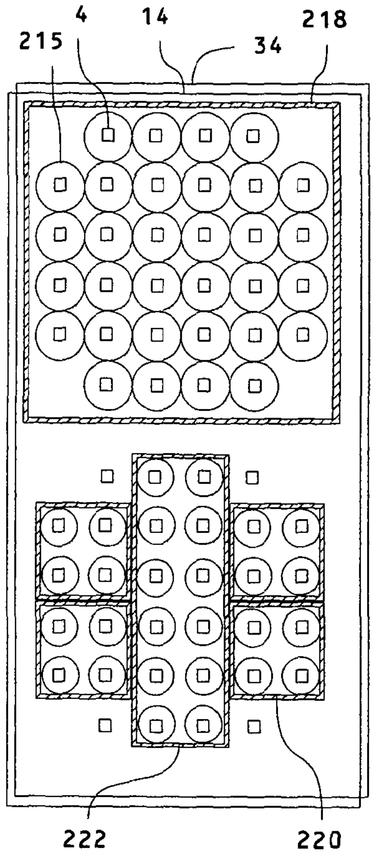

FIG.18

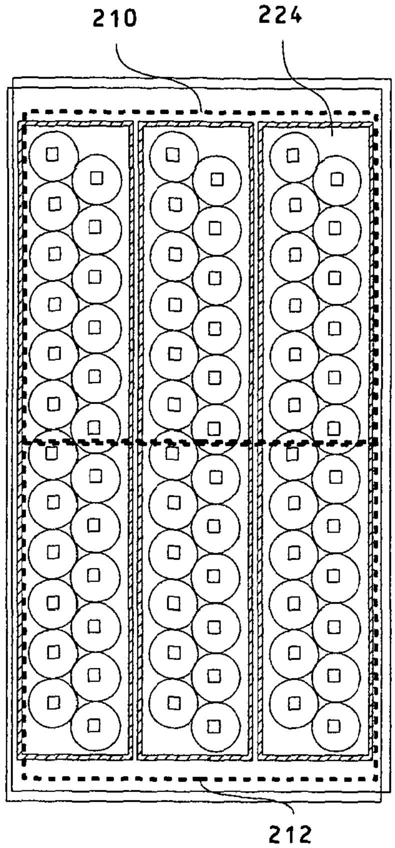

FIG.19

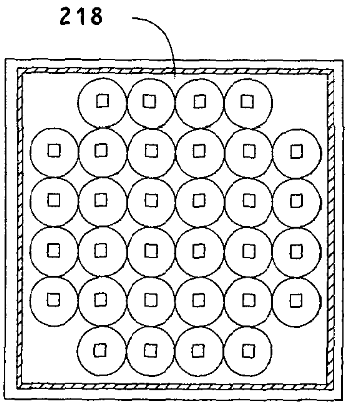

FIG.20

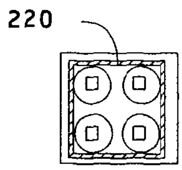

FIG.21

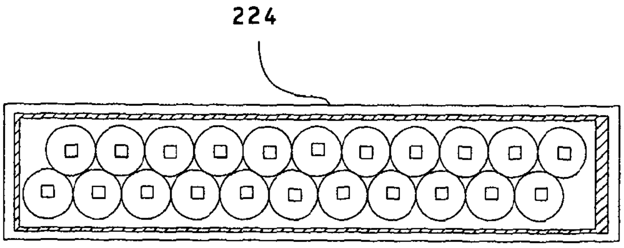

FIG.22

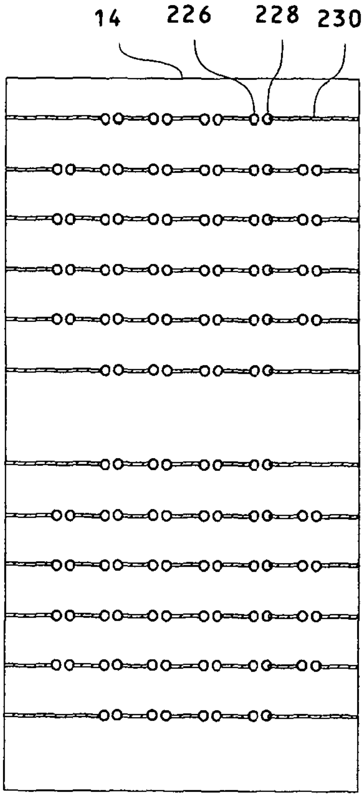

FIG.23

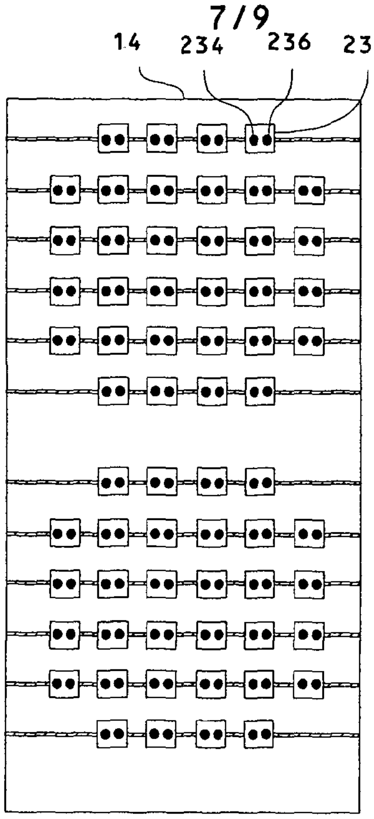

FIG.24

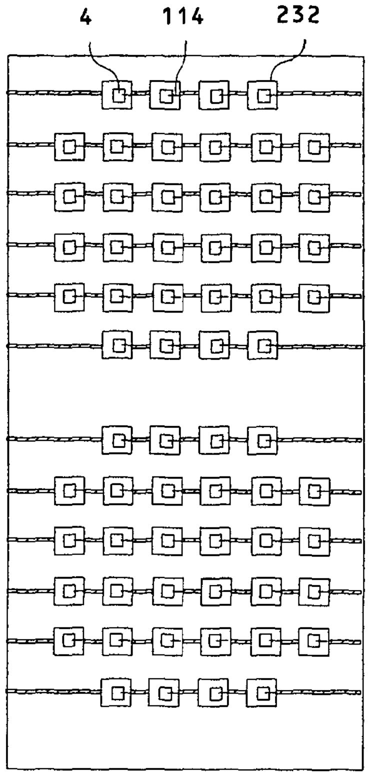

FIG.25

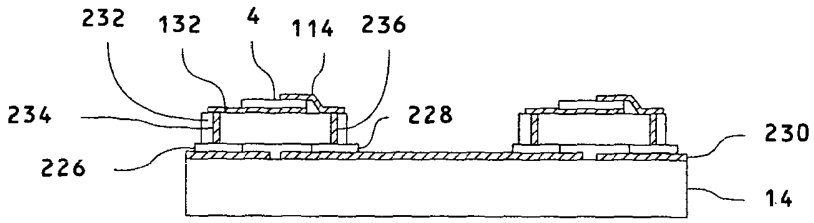

FIG.26

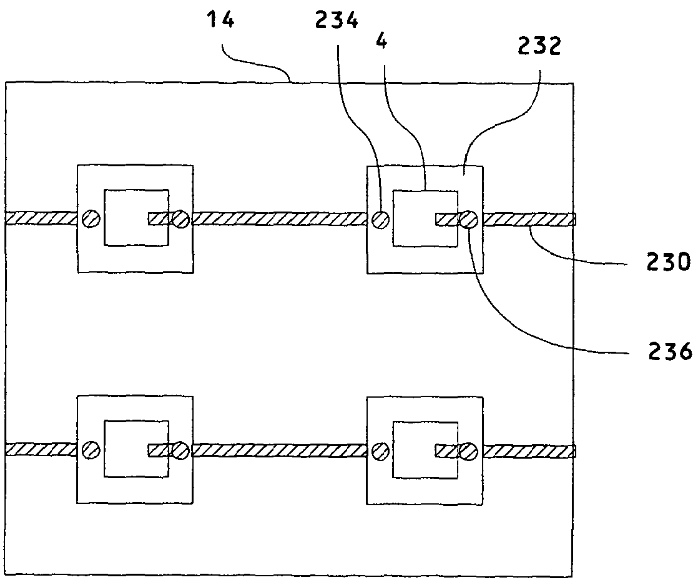

FIG.27

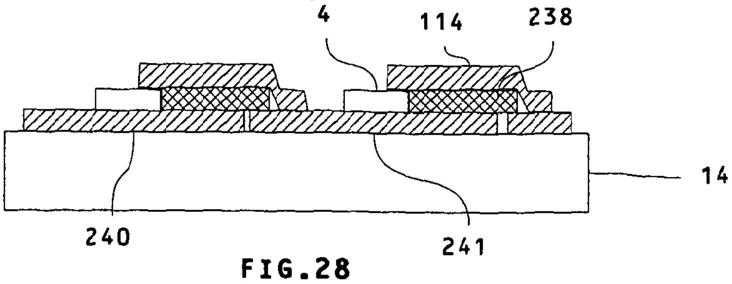

FIG.28

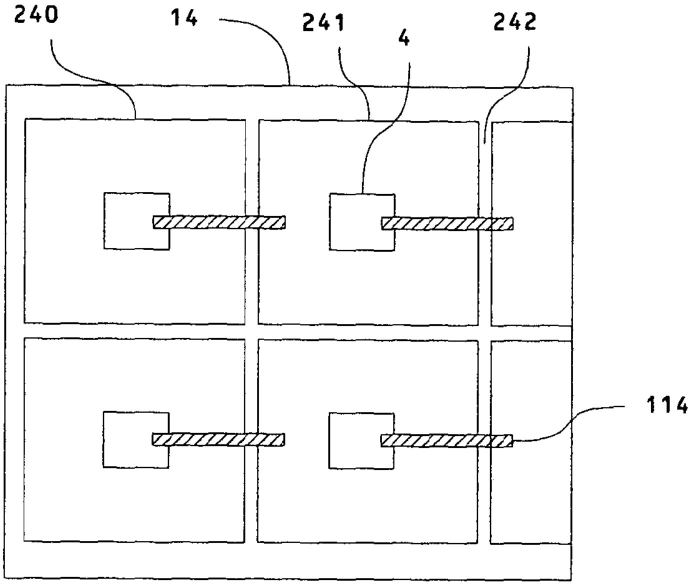

FIG.29

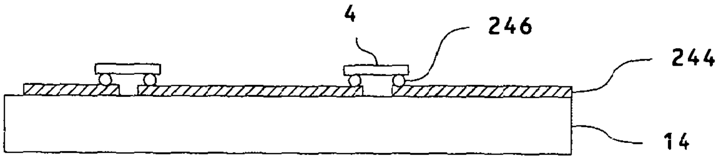

FIG.30

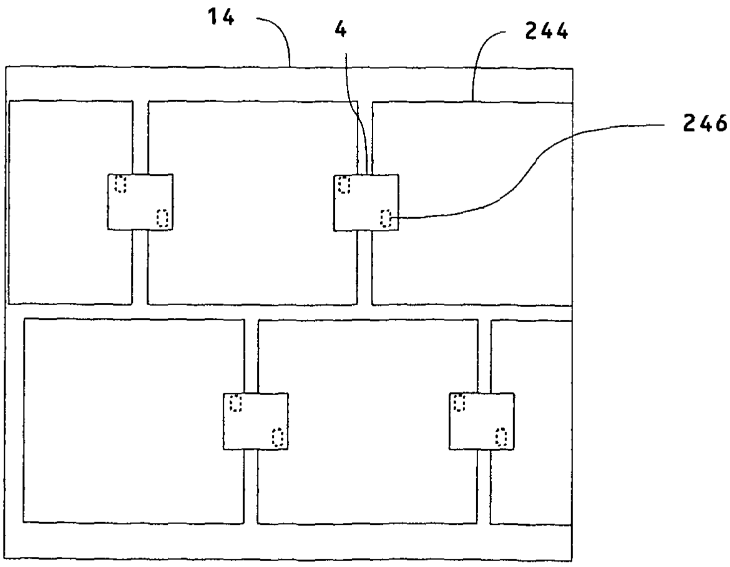

FIG.31

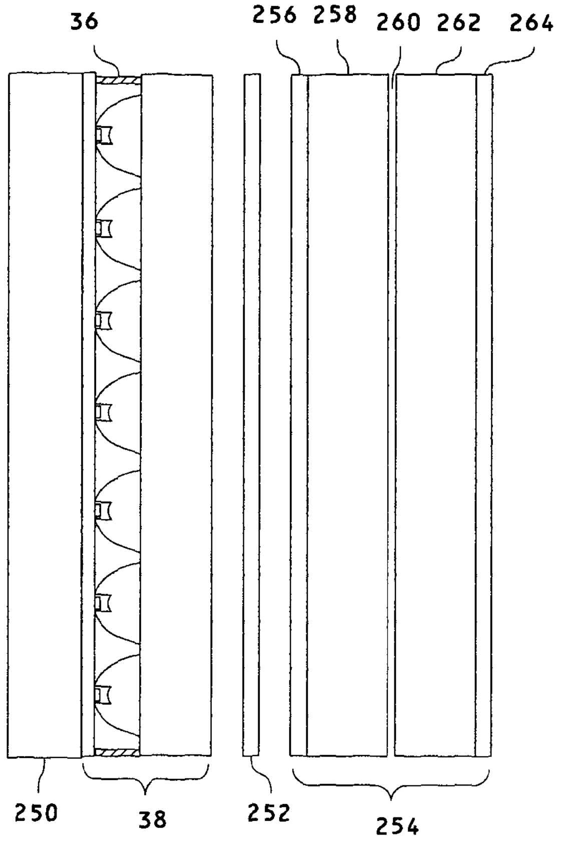

FIG.32

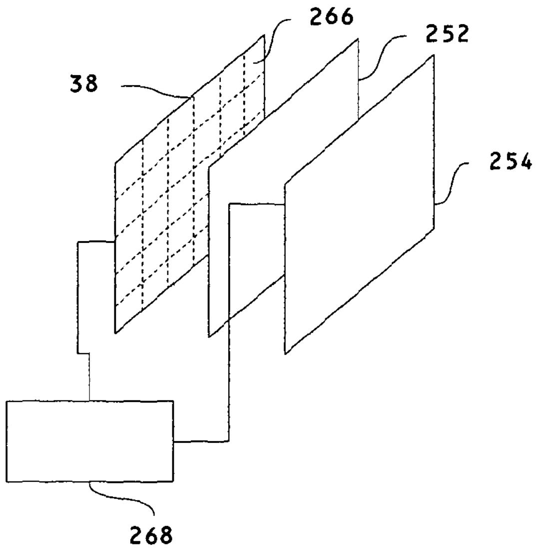

FIG.33

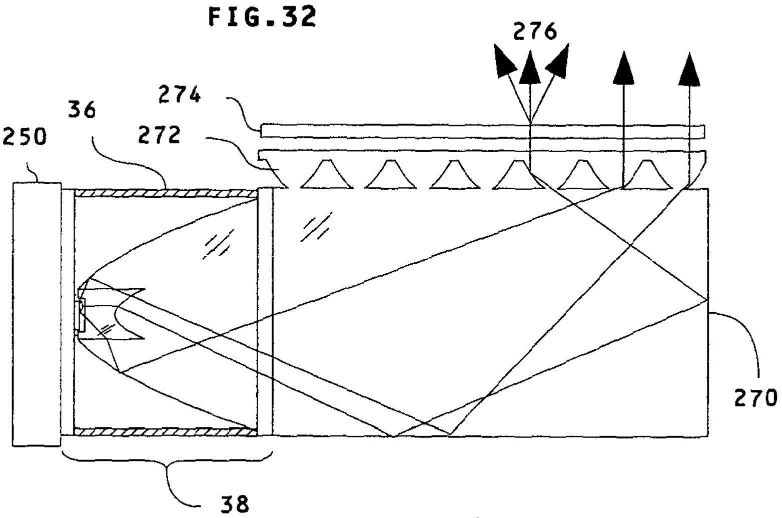

FIG.34a

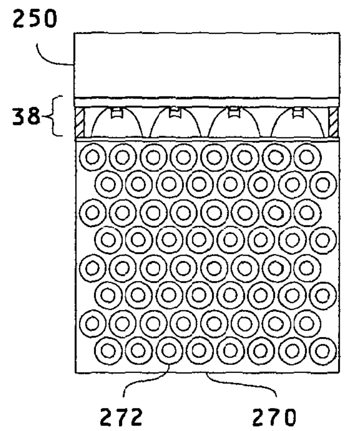

FIG.34b

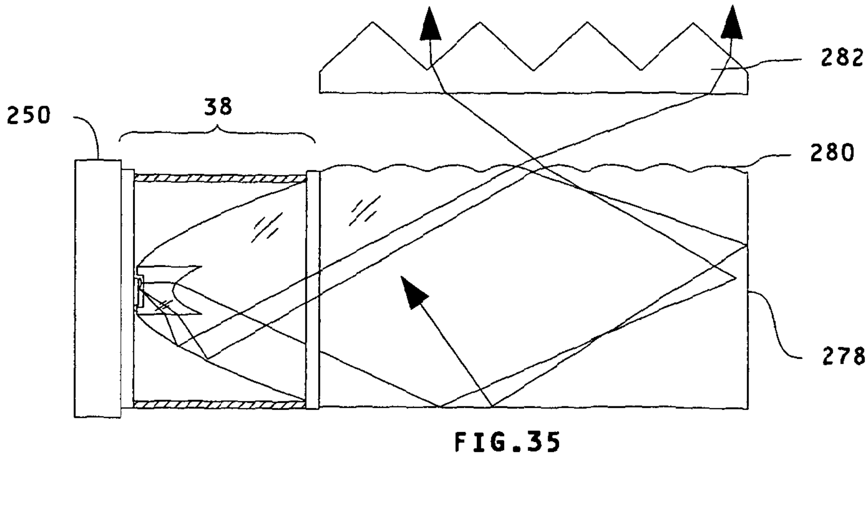

FIG.35

ILLUMINATION APPARATUS

The present invention relates to an illumination apparatus and a method for fabrication of the illumination apparatus. Such an apparatus may be used for domestic or professional lighting, for liquid crystal display backlights and for general illumination purposes.

Incandescent light sources are low cost but have low efficiency, and are relatively large requiring large light fittings. Fluorescent lamps in which a gas discharge generates ultraviolet wavelengths which pumps a fluorescent material to produce visible wavelengths, have improved efficiency compared to incandescent sources, but also have a large physical size. Heat generated by inefficiencies in these lamps is typically radiated into the illuminated environment, such that there is typically little need for additional heatsinking arrangements.

In this specification, an illumination apparatus refers to an illumination apparatus whose primary purpose is illumination of an environment such as a room or street scene, or as a display backlight. An illumination apparatus is typically capable of significantly higher luminance than 1000 nits. This is opposed to for example displays, whose primary purpose is image display by providing light to a viewing observer's eyes so that an image can be seen. By way of comparison, if the luminance of a display is very high, for example greater than 1000 nits, then disadvantageously a display can be uncomfortably bright to view. Thus the considerations for an illumination apparatus with a primary illumination purpose and a display apparatus that provides a secondary illumination purpose are different.

If an illumination apparatus is used as a backlight in a display apparatus, losses in the spatial light modulator of the display apparatus will reduce the luminance to a level suitable for comfortable viewing. Thus such an arrangement has a secondary illumination function that is not generally suitable for the purpose of efficient and bright illumination of an environment.

Light-emitting diodes (LEDs) formed using semiconductor growth onto monolithic wafers can demonstrate significantly higher levels of efficiency compared to incandescent sources. In this specification LED refers to an unpackaged LED die (chip) extracted directly from a monolithic wafer, i.e. a semiconductor element. This is different from packaged LEDs which have been assembled into a package to facilitate subsequent assembly and may further incorporate optical elements such as a hemispherical structure which increases its size but increases light extraction efficiency. To optimise quantum efficiency, extraction efficiency and lifetime, it is desirable to minimise the junction temperature of the LED. This is typically achieved by positioning a heat dissipating structure (or heatsink) on the rear of the LED to provide extraction of heat from the chip into an ambient environment.

LED primary heatsinks typically comprise heat slugs (or heat spreaders), LED electrodes, and the dielectric layer of a metal core printed circuit board (MCPCB). LED secondary heat sinks typically comprise the metal layer of the MCPCB, MCPCB solder attachment points and formed fins in metal or thermally conductive plastic material attached to or formed on the primary heatsink arrangement. For illustrative purposes, in this specification, primary thermal resistance refers to the thermal resistance to heat generated in a light emitting element formed by the light emitting element itself, respective heat spreading elements, electrodes and electrically insulating support substrate (such as the dielectric layer of an MCPCB). The secondary thermal resistance is defined by the thermal resistance of subsequent elements, including the metal layer of an MCPCB, MCPCB solder attachment points and heatsink elements.

Assembly methods for known macroscopic LEDs typically of size 1x1mm comprise a pick-and-place assembly of each LED chip onto a conductive heat slug for example silicon. The heat slug is attached to a dielectric which is bonded on a metal layer, forming a metal core printed circuit board (MCPCB). Such a primary heatsink requires multiple pick-and-place operations and is bulky and costly to manufacture. It would thus be desirable to reduce primary heatsink complexity.

Secondary heatsinks can be heavy, bulky and expensive. It is thus desirable to minimise the thickness of the secondary heatsink by minimising the resistance of the thermal paths of the primary heatsink.

In lighting applications, the light from the emitter is typically directed using a luminaire structure to provide the output directionality. The angular variation of intensity is termed the directional distribution which in turn produces a light radiation pattern on surfaces in the illuminated environment and is defined by the particular application. Lambertian emitters provide light to the flood a room. Non-Lambertian, directional light sources use a relatively small source size lamp such as a tungsten halogen type in a reflector and/or reflective tube luminaire, in order to provide a more directed source. Such lamps efficiently use the light by directing it to areas of importance. These lamps also produce higher levels of visual sparkle, in which the small source provides specular reflection artefacts, giving a more attractive illumination environment. Further, such lights have low glare, in which the off-axis intensity is substantially lower than the on-axis intensity so that the lamp does not appear uncomfortably bright when viewed from most positions.

Directional LED illumination apparatuses can use reflective optics (including total internal reflective optics) or more typically catadioptric (or tulip) optic type reflectors, as described for example in US841423. Catadioptric elements employ both refraction and reflection, which may be total internal reflection or reflection from metallised surfaces.

PCT/GB2009/002340 describes an illumination apparatus and method of manufacture of the same in which an array of microscopic LEDs (of size for example 0.1x0.1mm) is aligned to an array of micro-optical elements to achieve a thin and efficient directional light source. GB1005309.8 describes an illumination apparatus, a method of manufacture of the same and a heat sink apparatus for use in said illumination apparatus in which an array of optical elements directs light from an array of light emitting elements through a heat dissipating structure to achieve a thin and efficient light source that provides directional illumination with efficient dissipation of generated heat into the illuminated environment.

According to a first aspect of the present invention, there is provided a method of manufacturing a light emitting element array for an illumination apparatus whose primary purpose is illumination as opposed to display; the method comprising the following steps performed in the following order: (i) providing a light emitting element array comprising a plurality of light emitting elements arrayed on a first side of a first substrate; and (ii) reducing the thickness of the light emitting element array by reducing the thickness of the first substrate by removing material from the direction of the second side of the first substrate. Prior to step (i), a plurality of heat spreading elements may be provided wherein in step (i) respective heat spreading elements are positioned between the first substrate and respective light emitting elements.

According to a second aspect of the present invention, there is provided a method of manufacturing an illumination apparatus whose primary purpose is illumination as opposed to display; the method comprising: providing a light emitting element array comprising a plurality of light emitting elements arrayed on a first side of a first substrate; providing an optical array comprising a plurality of directional optical elements arrayed on a first side of a second substrate; forming a structure comprising the light emitting element array and the optical array, with the first side of the first substrate facing the first side of the second substrate, and with respective light emitting elements aligned with respective optical elements; and thereafter, reducing the thickness of the structure by reducing the thickness of the first substrate by removing material from the direction of the second side of the first substrate. The thickness of the structure may be further reduced by reducing the thickness of the second substrate by removing material from the direction of the second side of the second substrate. Prior to providing the light emitting element array, a plurality of heat spreading elements may be provided wherein, in the step of providing the light emitting element array, respective heat spreading elements are positioned between the first substrate and respective light emitting elements.

According to a third aspect of the present invention, there is provided a method of manufacturing a light emitting element array for an illumination apparatus whose primary purpose is illumination as opposed to display; the method comprising the following steps performed in the following order: (i) providing a light emitting element array structure comprising a plurality of light emitting elements arrayed on a first side of first substrate; (ii) reducing the thickness of the light emitting element array structure by reducing the thickness of the first substrate by removing material from the direction of the second side of the first substrate; (iii) increasing the thickness of the light emitting element array structure by providing one or more heatsink structures at the second side of the first substrate. The thickness added to the light emitting element array structure by step (iii) may be greater than the thickness by which the thickness of the light emitting element structure was reduced by step (ii). The weight added to the light emitting element array structure by step (iii) may be greater than the weight by which the weight of the light emitting element structure was reduced by step (ii). Prior to providing the light emitting element array, a plurality of heat spreading elements may be provided wherein, in the step of providing the light emitting element array, respective heat spreading elements are positioned between the first substrate and respective light emitting elements.

According to first, second and third aspects of the present invention, the plurality of light emitting elements may be selectively removed from a monolithic wafer in a manner that preserves the relative spatial position of the selectively removed light-emitting elements. The material of at least the first substrate may comprise a ceramic material. The material of at least the first substrate may alternatively comprise a glass material. The material of at least the first substrate may comprise a conductive filler material. A mechanically compliant thermally conductive layer may be formed on the first substrate. A heat sink element may be attached to the second side of the first substrate. The heat spreading elements may comprise silicon. The heat spreading elements may be from a monolithic array of silicon heat spreading elements. The heat spreading elements may comprise via holes arranged to provide electrical connection paths between the first substrate and the plurality of light-emitting elements. The heat spreading elements may comprise metallic films formed on the first substrate. The metallic films may be of thickness greater than 10 nanometres and less than 10 micrometres and may be of thickness greater than 100 nanometres and less than 1 micrometre. The thickness of the first substrate after step (ii) may be between 0.01mm and 1.1mm thick, preferably between 0.02mm and 0.4mm thick and more preferably

between 0.05mm and 0.2mm thick. The thickness of the first substrate may be reduced by means of grinding, polishing, chemical etching or any combination thereof. Each light-emitting element may have a maximum width or diameter less than or equal to 300 micrometers, preferably a maximum width or diameter less than or equal to 200 micrometers and more preferably a maximum width or diameter less than or equal to 100 micrometers. Each optical element may have a maximum height less than or equal to 5 millimetres, preferably less than or equal to 2.5 millimetres and more preferably less than or equal to 1 millimetre. The second substrate may comprise an opaque layer provided with light transmitting apertures. At least two different regions of the light emitting element array may be separated. At least one seal may be formed between the first and second substrates.

According to a fourth aspect of the present invention there is provided a light emitting element array formed according to the first, second or third aspects of the present invention.

According to a fifth aspect of the present invention there is provided an illumination apparatus formed according to the first, second or third aspects of the present invention.

According to a sixth aspect of the present invention there is provided a light emitting element array for an illumination apparatus whose primary purpose is illumination as opposed to display; the light emitting element array comprising a plurality of light emitting elements arrayed on a substrate; wherein the substrate is of reduced thickness compared to what its thickness was when the plurality of light emitting elements were arrayed on the substrate.

According to a seventh aspect of the present invention there is provided an illumination apparatus whose primary purpose is illumination as opposed to display; the illumination apparatus comprising: a structure comprising a light emitting element array and an optical array, the light emitting element array comprising a plurality of light emitting elements arrayed on a first side of a first substrate; the optical array comprising a plurality of directional optical elements arrayed on a first side of a second substrate; the first side of the first substrate facing the first side of the second substrate, and respective light emitting elements aligned with respective optical elements; wherein the structure is of reduced thickness compared to what its thickness was when the light emitting element array and the optical array were placed together, by virtue of the light emitting element array being of reduced thickness compared to what its thickness was when the light emitting element array and the optical array were placed together.

According to an eighth aspect of the present invention there is provided a light emitting element array for an illumination apparatus whose primary purpose is illumination as opposed to display; the light emitting element array comprising: a plurality of light emitting elements arrayed on a first side of a first substrate; and one or more heatsink structures at the second side of the first substrate wherein the first substrate is of reduced thickness compared to what its thickness was when the plurality of light emitting elements were arrayed on the substrate. The one or more heatsink structures may be in combination thicker than the amount by which the substrate is of reduced thickness compared to what its thickness was when the plurality of light emitting elements were arrayed on the substrate. The one or more heatsink structures may be in combination of greater weight than the amount by which the substrate is of reduced weight due to the thickness reduction compared to what its weight was when the plurality of light emitting elements were arrayed on the substrate prior to the thickness reduction.

According to sixth, seventh and eighth aspects of the present invention there may be provided a plurality of heat spreading elements wherein respective heat spreading elements are positioned between the first substrate and respective light emitting elements. The material of at least the first substrate may comprise a ceramic material or a glass material. The material of at least the first substrate may comprise a conductive filler material. A mechanically compliant thermally conductive layer may be provided on the first substrate. A heat sink element may be attached to the second side of the first substrate. The heat spreading elements may comprise silicon. The heat spreading elements may comprise via holes arranged to provide electrical connection paths between the first substrate and the plurality of light-emitting elements. The heat spreading elements may comprise metallic films formed on the first substrate. The metallic films may be of thickness greater than 10 nanometres and less than 10 micrometres and preferably greater than 100 nanometres and less than 1 micrometre. The thickness of the first substrate may be between 0.01mm and 1.1mm thick, preferably between 0.02mm and 0.3mm thick and more preferably between 0.05mm and 0.2mm thick. Each light-emitting element may have a maximum width or diameter less than or equal to 500 micrometers, preferably less than or equal to 250 micrometers and more preferably less than or equal to 100 micrometers. Each optical element may have a maximum height less than or equal to 5 millimetres, preferably less than or equal to 2.5 millimetres and more preferably less than or equal to 1 millimetre. The second substrate may comprise an opaque layer provided with light transmitting apertures. At least one seal may be provided between the first and second substrates. At least one spacer may be provided between the first and second substrates. A plurality of electrically insulating element may be arranged on the plurality of heat spreading elements.

According to a ninth aspect of the present invention there is provided a backlight apparatus comprising the apparatus of the sixth, seventh or eighth aspects of the present invention further comprising a light guide plate and at least one output coupling optical element.

Further aspects of the invention are as claimed in the appended claims.

Compared to known illumination apparatuses, the present embodiments advantageously provide reduced thermal resistance to heat generated in an LED array, thus providing higher device efficiency, longer lifetime and greater reliability. Further, the cost of the apparatus is reduced as secondary heatsink cost is reduced. The substrates can advantageously be formed from glass and can thus be made with very large area using known methods and can undergo known large area masking processes. The method of the present embodiments advantageously provides many LED illumination devices with low thermal resistance to be processed in parallel, reducing cost. The step of reducing thermal resistance may be provided after forming the LED luminaire cell, thus providing greater reliability and strength of the luminaire during and after manufacture, further reducing cost. The thermal expansion of luminaire substrates can be matched, reducing thermal distortion effects and providing greater reliability. The illumination apparatus can be conveniently arranged to provide a thin and efficient backlight apparatus. Further an addressable backlight apparatus with high resolution and large area can conveniently be arranged, so as to improve display contrast.

Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Fig.1 shows a method to form a luminaire apparatus comprising heatsink structures;

Fig.2 shows a flip chip LED with lateral electrical connections;

Fig.3 shows a vertical thin film LED;

Fig.4 shows an LED array with lateral electrical connections;

Fig.5 shows in cross section a further heatsink apparatus;

Fig.6 shows in plan view the heat sink apparatus of Fig.5;

Fig.7 shows in cross section a further heatsink apparatus;

Fig.8 shows an optical substrate for a luminaire apparatus;

Fig.9 shows a further optical substrate for a luminaire apparatus;

Fig.10 shows a roughened substrate arranged to provide improved heat extraction from an LED array;

Fig.11 shows a method to form a heatsink structure with an optical array;

Fig.12a shows a method to attach an optical substrate with an LED substrate;

Fig.12b shows a further method to attach an optical substrate with an LED substrate;

Fig.13 shows an optical substrate further comprising electrodes and light emitting elements;

Fig.14 shows an LED substrate comprising an array of connection elements;

Fig.15 shows the alignment of monolithic LED wafers with the LED substrate of Fig.13;

Fig.16 shows the LED substrate following selective removal of LEDs from respective monolithic LED wafers;

Fig.17 shows an optical array substrate;

Fig.18 shows the alignment of the optical array substrate of Fig.16 with the LED substrate of Fig.15;

Fig.19 shows a further aligned optical array substrate and LED substrate;

Fig.20 shows a singulated substrate;

Fig.21 shows a further singulate substrate;

Fig.22 shows a further singulated substrate;

Fig.23 shows in plan view an LED substrate comprising an array of connection elements and an array of electrode elements;

Fig.24 shows the LED substrate of Fig.23 further comprising an array of heat spreading elements;

Fig.25 shows the LED substrate of Fig.24 further comprising an array of LEDs and electrode elements;

Fig.26 shows in cross section a detail of the arrangement of Fig.25;

Fig.27 shows in plan view a detail of the arrangement of Fig.25;

Fig.28 shows in cross section an LED substrate comprising electrode and heat spreading elements;

Fig.29 shows in plan view an LED substrate comprising electrode and heat spreading elements;

Fig.30 shows in cross section an alternative LED substrate comprising electrode and heat spreading elements;

Fig.31 shows in plan view an arrangement of Fig.30;

Fig.32 shows in cross section a display apparatus;

Fig.33 shows an arrangement of the display apparatus of Fig.32;

Fig.34a shows in cross section a back light apparatus;

Fig.34b shows in plan view the back light apparatus of Fig.34a; and

Fig.35 shows a further back light apparatus.

A method to form an illumination apparatus is shown in Fig.1. In a first step, a monolithic wafer comprises a substrate 2 which may be for example sapphire and a layer 3 of light emitting elements 4 formed on its surface, for example in Gallium Nitride. A first bonding layer 6 such as palladium is formed on the surface of layer 3 and the LED light emitting elements are singulated on the wafer, for example by etching, sawing or laser scribing. A glass substrate 14 (which may be termed a motherglass) has a heat spreading element 16 formed on its surface, a dielectric layer 18 (that may be patterned) and patterned electrode layer 12 formed thereon. On the surface of the electrode 10, a second bonding layer comprising a palladium layer 10 and indium layer 8 is formed. Other metal layers in substitution of or in addition to palladium and indium may be used, as is known in the art. The second bonding layer is patterned so that bonding regions are aligned with light emitting element 4.

In a second step, the first and second aligned bonding layers 6, 8, 10 are brought into contact and the sandwich is heated so as to provide an alloy bond layer 9 between the electrode layer 12 and the respective light emitting element 4. For example the layers 6, 8, 10 may be heated to for example 180 degrees Celsius to provide a rugged electrical and mechanical bond between the element 4 and electrode 12.

In a third step, the interface of the layer 3 and substrate 2 is illuminated by short pulse ultraviolet radiation in region 20 so as to provide decomposition of the gallium and nitrogen close to the sapphire interface. On heating the sandwich to above the melting point of metallic gallium, for example to greater than about 40degC, the substrates 2, 14 can be separated as shown, with the element 4 attached to the substrate 14 and adjacent light emitting elements in layer 3 remain attached to the substrate 2.

The second bonding layer and ultraviolet illumination is patterned so that it can be further arranged in alignment with some others of the light emitting elements, for example light emitting element 5 to form a plurality of light emitting elements 4,5 arrayed on the first side of the substrate 14. Thus a light emitting element array 22 comprises a plurality of light emitting elements 4,5 arrayed on a first side of a first substrate 14. Advantageously, the patterning of the layers 8, 10 and of laser illumination in region 20 mean that elements 4,5 from the layer 3 may be selectively extracted with a pitch substantially the same as the pitch of the respective elements in the monolithic wafer. Thus the plurality of light emitting elements 4,5 are selectively removed from a monolithic wafer 2,3 in a manner that preserves the relative spatial position of the selectively removed light-emitting elements 4,5. Such an arrangement advantageously provides accurate location with a subsequent array of optical and electrical connection elements. Further a plurality of heat spreading elements 16 are provided on the substrate 14; wherein respective heat spreading elements are positioned between the first substrate 14 and respective light emitting elements 4,5.

In a fourth step (shown without bonding layers and for a pair of light emitting elements 4,5 on substrate 14), an LED array 22 is formed comprising substrate 14, heat spreading elements 16, 17, phosphor elements 24, bottom electrode 26, top electrode 28 and dielectric region 30. Other known wavelength conversion layers may be substituted for phosphor elements 24. In the current embodiments, each of the steps to form a particular feature can be performed in parallel for all of the light emitting elements 4 transferred onto the substrate 14. Advantageously, such a method can significantly reduce the processing cost of such a device. In this embodiment, the primary heatsink comprises the bottom electrode 26, dielectric layer 18, heat spreading element 17 and substrate 14.

In a fifth step, an optical substrate 34 is formed comprising an array of catadioptric directional optical elements 35 optionally separated by gaps 37. Alternatively, the directional optical elements may be for reflective or refractive. Advantageously, catadioptric optical elements provide efficient capture of LED light and a directional output light beam with relatively small thickness and width for a given cone angle compared to for example parabolic optical elements. The optical substrate 34 may be formed by moulding of an optically transparent polymer material onto a support glass substrate 34 using an appropriately shaped mould. The optical substrate 34 is aligned with the LED substrate array 22 and seal regions 26 are formed to provide an illuminator cell 38. The cell may be spaced by seal 36 and or optic array 35. The gaps 37 advantageously reduce the amount of bending of the substrate 34 due to differences in shrinkage during formation of the optical elements 35. Alternatively, the gap region 37 may comprise thin regions of the material used to form the elements 35.

The process steps described above require many different operations to be performed on the substrate 14. In manufacture, such a substrate must have sufficient ruggedness to be undamaged by handling and processing, but must have sufficient flatness and surface finish to be suitable for lithographic processing. Advantageously, substrate 14 may comprise a glass substrate, such as used in the manufacture of liquid crystal display devices. However, glass substrates have a low thermal conductivity, typically about 1 $WK^{-1}m^{-1}$ and glass substrates suitable for large area lithographic processing are typically of thickness 0.5mm or more. Such a substrate will result in a high primary thermal resistance to the flow of heat from the LED and increase LED junction temperature.

In a sixth step, the thickness 15 of the illuminator cell 38 is reduced by means known means such as grinding, polishing, chemical etching either singularly or in any combination. Thus the sixth step reduces the thickness of the light emitting element array 4,5,14 by reducing the thickness 15 of at least the substrate 14 by removing material from the direction of the second side of the first substrate 14 to provide a thickness 21. The thickness of the first substrate after the thickness reduction step may be between 0.01mm and 1.1mm thick; preferably between 0.02mm and 0.4 mm thick and more preferably between 0.05mm and 0.2mm thick. Advantageously the primary thermal resistance of the first substrate to heat produced in the light emitting element array is reduced. This increases the thermal resistance provided by the secondary heatsink, and thus reduces the cost of the system in comparison to the arrangement in which the substrate thickness has not been reduced. Glass of thickness less than 0.4mm and particularly glass of thickness less than 0.2mm can be susceptible to damage and surface distortion during handling unless adequately stabilised. Advantageously the attachment of substrate 14 to the substrate 34 provides mechanical stability such that after the thickness reduction step the substrate 14 has mechanical ruggedness during subsequent processing and handling steps.

Further, the thickness reduction step can be undertaken on the cell 38 to provide additional mechanical ruggedness during processing and after lithographic and other processing of the LED elements, thus enabling the substrate 14 to be formed from glass for example. Further the seals 36 protect the LEDs 5 and optics 35 from possible damage during the thickness reduction step and subsequent handling. The increased mechanical ruggedness of the assembled cell advantageously reduces the chance of breakage during handling and thus increases manufacturing yield and reduces device cost.

The substrates 34, 14 may have their thickness reduced by different or similar amounts depending on the thermal resistance required in each thermal path for heat generated in the light emitting elements.

The light emitting elements 4 may be microscopic LEDs; that is they have dimensions of less than 500 micrometres, preferably less than 250 micrometres and more preferably less than 100 micrometres. Microscopic LEDs of size 100micrometres advantageously use optical elements 35 that have a pitch of approximately 2mm or less and a height 11 of 5mm or less, preferably a height 11 or 2.5mm or less and more preferably a height of 1mm or less.. Thus, the total cell 38 thickness may be of thickness for example 2mm before the thickness reduction step. Such cells are conveniently handled using known substrate processing equipment, thus reducing cost of fabrication. Advantageously the thermal resistance of the substrate 14 is less than the thermal resistance of the substrate 34, thus providing a preferred path for heat dissipation from the rear of the LED substrate array 22.

Thus an illumination apparatus whose primary purpose is illumination as opposed to display is formed by providing a light emitting element array comprising a plurality of light emitting elements 4,5 arrayed on a first side of a first substrate 14; providing an optical array 39 comprising a plurality of directional optical elements 35 arrayed on a first side of a second substrate 34; forming a structure 38 comprising the light emitting element array 22 and the optical array 39, with the first side of the first substrate 14 facing the first side of the second substrate 34, and with respective light emitting elements 4 aligned with respective optical elements 35; and thereafter, reducing the thickness of the structure 38 by reducing the thickness 15 of at least the first substrate 14 by removing material from the direction of the second side of the substrate to provide a reduced thickness 21 of the substrate 14.

In a seventh step, regions of cell 38 may be scribed, for example by means of scribes 40, 42 or laser cutting (not shown) on each respective substrate between seal 36 regions, or as required. The cutting marks 40, 42 may be offset to facilitate breaking of the substrates 14, 34 to aid singulation of the devices. Thus at least two different regions of the light emitting element array 22 are separated. Advantageously, multiple light emitting element arrays can be produced from a single array 22. In this manner, highly parallel processing techniques can be used, significantly reducing device cost. The scribe points 40 and 42 may be slightly offset to aid singulation.

In an eighth step, the cell 38 may be separated (or singulated) for example by breaking the cell 38. Anti-reflection coating 43 may be applied, or alternatively coating 43 may be applied to the substrate 34 prior to formation of optical elements 35, or prior to singulation.

In a ninth step, further elements may be attached including electrodes 44 and heatsink 54 comprising a heat spreading plate 48 and fins 50, attached by means of a thermally transmitting interface 52. Interface 52 further provides a mechanically compliant thermally conductive layer on the first substrate 14 to provide an interface between the glass substrate 14 and heat spreading element plate 48 of the heatsink 54.

Thus a light emitting element array for an illumination apparatus whose primary purpose is illumination as opposed to display may be formed by providing a light emitting element array structure 38 comprising a plurality of light emitting elements 4 arrayed on a first side of first substrate 14; reducing the thickness of the light emitting element array structure 38 by reducing the thickness of the first substrate 14 by removing material from the direction of the second side of the first substrate14; and increasing the thickness of the light emitting element array structure 38 by providing one or more heatsink structures 52, 48, 50 at the second side of the first substrate 14. The thickness added to the light emitting element array structure 38 is greater than the thickness by which the thickness of the light emitting element structure 38 was reduced. Further, the weight added to the light emitting element array structure by providing the heatsink structures 52,48,50 is greater than the weight by which the weight of the light emitting element structure 38 was reduced. Advantageously such an arrangement provides a cheaper secondary heatsink in comparison to an apparatus in which the structure 38 is not reduced thickness, while providing mechanical ruggedness during processing and handling.

Advantageously, the step of reducing the thickness of the substrate 14 reduces the thermal resistance of the substrate 14 and thus the primary thermal resistance. Such a reduction in thermal resistance means that the thermal resistance of the secondary heatsink can be increased in order to achieve desired junction temperature for a certain ambient temperature. Higher thermal resistance heatsinks typically use less material and are cheaper, thus reducing illumination apparatus cost.

The substrate 14 may be formed from a ceramic material (an inorganic, non-metallic solid prepared by the action of heat and subsequent cooling with a crystalline or partly crystalline structure) such as aluminium oxide or aluminium nitride. Alternatively, the substrate material may be a glass material (an inorganic, non-metallic solid prepared by the action of heat and subsequent cooling with an amorphous structure) comprising for example sodalime or borosilicate compositions. Prior to the step of reducing its thickness, the glass substrate 14 may have a thickness of 1.1mm, 0.7mm, 0.5mm, 0.4mm or may alternatively be thin glass such as Corning 0211 microsheet. The glass thickness may be determined so as to provide rugged processing of large sheets prior to the thickness reduction process, at which stage a support structure such as substrate 34 and optical elements 36 is provided to prevent damage to the substrate 14 during processing.

Advantageously, glass materials have well characterised surface flatness and roughness together with bulk material properties that are appropriate for the accurate and repeatable deposition of electrodes, heat spreading elements, dielectrics, adhesives and solders. Such a substrate advantageously provides low cost and very large area substrates for the attachment of light emitting elements. Advantageously, glass substrates are compatible with known large area sheet (motherglass, or mothersheet) processes in which multiple lithographic and other processes can be performed across the sheet in parallel. Such sheets can be fabricated at low cost and very high area, such as greater than 1x1metre. The glass of the substrate 14 is not required to be transmissive and may further comprise conductive filler materials (which may be opaque) such as carbon, metals or ceramics with a thermal conductivity arranged to increase the thermal conductivity of the substrate 14, for example to greater than 1.5 $WK^{-1}m^{-1}$, preferably greater than 5 $WK^{-1}m^{-1}$ and more preferably greater than 10 $WK^{-1}m^{-1}$, reducing the primary thermal resistance.

By way of comparison, LED arrays are typically formed by means of pick-and-place methods rather than parallel methods of the present embodiments. Such methods do not benefit from parallel processing of many elements once they have been removed from the wafer.

A known type of flip chip lateral configuration LED 4 is shown with electrical connections in Fig.2. A substrate 102 such as sapphire has epitaxial layers formed on its surface 103. Typically a Gallium Nitride device comprises an n-doped layer 104, a multiple quantum well structure 106 and a p-doped layer 108 with a p-electrode 110. In the region 112, a portion of the p-layer 108 and structure 106 is removed to provide a contact electrode 114 to be formed in contact with the n-doped layer 104. This arrangement suffers from current crowding in the region 113, reducing the maximum light output that can be obtained from the device. Solder connections 118, 120 are formed on electrodes 122, 124 respectively, mounted on a support substrate 126.

In this specification, the term solder connections refers to known electrical connections including those formed by heating or by pressure or combination of heating and pressure applied to suitable electrically conductive materials.

Fig.3 shows a VTF (vertical thin film) configuration LED 142 in which the n-doped layer 104 has been separated from the substrate 102, for example by means of laser lift off. An electrode 128 is applied to the p-doped layer 108 and attached by means of a solder element 130 to an electrode 132 formed on the substrate 126. The n-doped layer may have an electrode 136 to provide a solder 138 contact to an input electrode 140. Such a VTF configuration advantageously has reduced current crowding compared to the arrangement of Fig.2. However, the VTF configuration needs an electrode connection on the top surface, and so typically requires a wire bonding process. By way of comparison with the present embodiments, which employ large arrays of small LEDs, a large number of time consuming wire bonds would be needed. Further, wire bonding technology may have limited positional accuracy so that a large non-emitting bond pad 136 is required for reliable wire bonding. For example, the wire bond pad size may be 100 micrometers wide, comparable to the size of the

LED.

Fig.4 shows a detail of LED elements after extraction and further processing steps (not shown). As the array of LEDs is positioned with lithographic precision (with original wafer positions preserved), then the electrode connections can be made in parallel by metal deposition and precision photolithography (as opposed to wire bonding) process. The LEDs may incorporate inclined surfaces and dielectric layers 144 so as to provide convenient connection to the chip via solder contacts 118, 120. Advantageously this high accuracy process achieves many simultaneous connections and also reduces the size of the electrode connection pad.

Fig.5 shows an embodiment in which the substrate 34 is thinned in addition to the substrate 14. Advantageously the substrate 34 may be formed from the same material used to form the substrate 14. Such a sandwich has matched coefficients of thermal expansion and will thus have minimised bending over a temperature cycle, increasing device reliability. A secondary heatsink is attached to the surface of the substrate comprising a heat spreading element 58 and conductive fins 60. Apertures 62 are incorporated between the fins and heat spreading element so as to provide a path for light from the optical elements 35. Fig.6 shows in plan view the top secondary heatsink 56 of Fig.5. Thus the second substrate 34 comprises an opaque layer provided with light transmitting apertures 62. Advantageously such an arrangement reduces thermal resistance of the light output side of the illumination apparatus to heat generated in the light emitting elements.

Fig.7 shows an embodiment comprising front and rear secondary heatsinks. Thermal paths in the primary heatsink between top and bottom substrates may be provided for example within sealing pillars 36 or using spacers 61, such as metal spacers in the primary heatsink path, connected to the LED substrate 14. Thus a spacer may be provided between the first and second substrates. Fig.8 shows an alternative front substrate in which glass substrate 34 is not present, but replaced by a heatsink with aligned optical elements and thus may have a lower cost. Fig.9 shows a similar arrangement but the optical elements are within the heat spreading element 58. Advantageously, such an arrangement has a reduced thermal resistance between the LED substrate array 22(not shown) and heatsink 58.

Fig.10 shows an embodiment in which the thickness reduction step produces a rough surface 53 on the rear of the glass substrate 14. Such a surface may advantageously provide reduced thermal resistance compared to a smooth surface when combined with heatsink compound 52. Fig.11 shows a further embodiment in which a heatsink 64 of similar area to substrate 14 is attached to the cell 38 prior to the singulation step. Such a heatsink may be formed in metal such as aluminium or may be in a thermally conductive material such as carbon fibre or thermally conductive polymer for example that marketed with the trade name Stanyl. The heat spreading plate is cut at lines 66 and in a further step, the cell is singulated prior to separation of the devices. Advantageously, such an embodiment can further reduce the cost of assembly of the illumination apparatus.

Fig.12a shows a further embodiment in which the method of attachment of the substrate 34 and substrate 14 is by means of an optical adhesive 72 incorporated in the cavity of the catadioptric optic 35. After alignment, the adhesive 72 may be cured to provide both mechanical bonding and optical functions. Fig.12b shows an alternative embodiment incorporating pillars 78 of material which may be the same as the material used to form the optical elements 35. An adhesive 80 may be applied to the substrate 14 to provide attachment of the substrates and a rugged cell for subsequent processing and handling.

Fig.13 shows a further embodiment wherein reflective surfaces 71 are formed with a metallisation and a material 73 is incorporated between catadioptric optical elements 35 so as to provide a substantially plane surface between the light emitting elements on which electrodes 75 can be formed. In this manner, the optical element 35, 73, 34 can comprise a support substrate for electrode 75s, wavelength conversion layers and light emitting elements 4 as well as active electronic components 77 such as transistors and resistors. The heat spreading elements 79 can be attached to the light emitting elements and substrate 14. Advantageously such elements do not require electrodes to be formed thereon and so have low complexity and do not require precision alignment.

Fig.14 shows in plan view a glass substrate 14 comprising an array of connecting elements 200, which may comprise palladium and indium materials, or other known electrically and thermally conductive materials. Fig.15 shows alignment of monolithic wafer 204 such that connecting elements 200 are in alignment with some of the light emitting elements of the monolithic wafer 204. An additional wafer 208 is aligned with an array of connecting elements 202. The wafer 208 has regions 206 in which light emitting elements were removed in a previous alignment and bonding step. Fig.16 shows the substrate 14 after the light emitting elements 4 have been removed from the respective monolithic wafers 204, 208. The light emitting elements are arranged in regions 210, 212. Fig.17 shows in plan view an optical substrate 34 comprising a glass sheet with a first region 214 of optical elements 215 and a second region 216 of optical elements 217 different from elements 217.

Fig.18 shows the alignment of substrates 14 and 34 from Figs. 16 and 17 respectively. Seal regions 218, 220, 222 are arranged so that different areas of illuminator devices can be extracted from the same illuminator cell. Fig.19 shows an alternative arrangement of seal regions 224 arranged to provide elongate illuminators, for example for use in fluorescent tube and troffer replacements. Figs.20 and 21 show separated elements from Fig.18 and Fig.22 shows a separated element form Fig.19. Extra seal regions(not shown) may be included within the singulated devices to provide increased ruggedness.

In this manner, the light emitting elements from many wafer separation steps can be combined onto single substrates. The substrate may comprise all or some of the light emitting elements 4 from a single wafer, or may comprise light emitting elements 4 from different wafers. Advantageously the shape and size of the illumination device need not be determined by the size and shape of the monolithic wafer. Advantageously such a process provides motherglass processing so that many devices can be processed in parallel, reducing cost. Advantageously, the thickness reduction step means that the primary heatsink thermal resistance is minimised in devices that are formed on glass substrates.

Fig.23 shows in plan view an illustrative example of substrate 14 arranged to provide connection to a plurality of light emitting elements 4. Substrate 14 has electrical connection regions 226, 228 formed on its surface, connected by means of electrodes 230. The electrical connection regions further provide heat spreading elements arranged for reducing the primary thermal resistance to heat generated in the plurality of light emitting elements 4.

Fig.24 shows the alignment of an array of for example silicon heat spreading elements 232 to the electrical connection regions 226, 228. Further electrical connection regions 234, 236 are provided on the silicon heat spreading elements 232. The array of silicon heat spreading elements may be from a silicon wafer for example. The heat spreading elements 232 may be from a monolithic array of silicon heat spreading elements and may be extracted in parallel onto the substrate 14 with their separation preserved. Advantageously, such an arrangement provides for precise alignment of the array of silicon heat spreaders with the plurality of light emitting elements 4 extracted from a monolithic wafer with their separation preserved.

Alternatively, the heat spreading elements 232 may be provided by a known pick-and-place method. Fig.25 shows light emitting elements 4 and top connecting electrodes 114 mounted on the silicon heat spreading elements 232. Fig.26 shows in cross section a portion of the structure of Fig.25. Substrate 14 has electrodes 230 formed for example by lithographic processing. Connection regions 226, 228, such as solder are provided for connection to the heat spreading element 232. Via holes 234, 236 are metallised to provide connection regions for the light emitting element 4 bottom electrode 132 and top electrode 114 respectively. Thus the heat spreading elements 232 comprise via holes 234, 236 arranged to provide electrical connection paths between the first substrate 14 and the plurality of light-emitting elements 4. Fig.27 shows in further detail a plan view of the embodiment of Fig.26.

Advantageously the embodiment makes use of photolithographic parallel processing techniques and can be implemented over large areas, reducing cost. Such an embodiment advantageously provides enhanced primary heatsink arrangement compared to an embodiment in which the light emitting element 4 is mounted directly onto a dielectric. The silicon heat spreading element has a high thermal conductivity so that heat is distributed over a wider area than from the individual light emitting element 4. Thus, the primary thermal resistance is reduced. Advantageously the secondary thermal resistance may be increased, providing a lower cost and less bulky secondary heatsink.

The silicon heat spreading elements of Fig.27 are relatively thick and require mechanical handling technologies. It would be desirable to further reduce cost using lithographically defined metal and silicon deposition techniques. Fig.28 shows in cross section and Fig.29 shows in plan view an embodiment in which film heat spreading elements 240, 241, are formed as films on the substrate 14 using for example aluminium, tanatalum, copper or other thermally and electrically conductive materials. The films may be applied by means of known deposition techniques such as sputtering or alternatively may be printed, for example by means of screen, stencil or flexographic printing. The metallic films may have thickness greater than 10 nanometres and less than 10 micrometres and preferably greater than 100 nanometres and less than 1 micrometre. Advantageously such thicknesses provide a convenient deposition layer and provide a reduction in primary thermal resistance to heat generated by the light emitting elements 4. The deposited heat spreader layers may also comprise a thin electrically insulating layer such as an oxide,

Gap regions 242 may be provided for example by photoresist patterning and etch steps, or by laser ablation. The spreading elements 240, 241 may provide the bottom electrode for the light emitting elements 4. Additional dielectric layers 238 may be applied between the heat spreading elements 241 and top electrode 114 to provide electrical isolation. In this manner, strings of light emitting elements may be assembled. Thus an electrically insulating element 238 is formed on a heat spreading element 241.

In an alternative embodiment, a lateral configuration light emitting element may be provided between adjacent heat spreading elements 244 and connected by means of contact regions 246 as shown in cross section in Fig.30 and plan view in Fig.31. Such an arrangement reduces the complexity of patterning on the substrate 14.

Fig.32 shows a display embodiment wherein an illumination device 38 is attached to a secondary heat sink 250 and used as a backlight to illuminate a known liquid crystal display panel 254 comprising polarisers 256, 264, substrates 258, 262 and liquid crystal layer 260. An additional diffuser 252 may be inserted to provide increased uniformity of illumination across the panel. Advantageously such an arrangement provides very efficient coupling of light from the light emitting elements into the panel. The light source can be provided as a single element of the same size as the display panel using the methods of the present embodiments. Further, such illuminator devices can be singulated from glass the same size used to fabricate the panel 254, thus providing a common source of materials and cost reduction. To further improve display ruggedness and reduce thickness, such a backlight incorporating elements 250, 38, 252 may be bonded to the polariser 256 of the display. Advantageously the present embodiments can provide high uniformity and reducing losses in the diffuser 252 (as a weaker diffuser can be used than would otherwise be required to provide high uniformity). Such a backlight thus has reduced cost. Further such a backlight can be used to provide high resolution segmentation of the illumination to the LCD panel as shown in Fig.33. The backlight can be addressed as regions 266 to provide variable illumination functions by means of a controller 268 to adjust the illumination in cooperation with the image on the display panel 254 as well known in the display art. Advantageously the present embodiments can provide very high resolution display addressing at low cost.

Fig.34a shows an edge-lit backlight apparatus suitable for illuminating a transmissive or transflective display comprising the illumination cell 38, attached to the edge of a light guide plate 270. Light rays 276 from the cell 38 enter the light guide plate 270 and are guided through light redirecting elements 272 through an optional diffuser 274. Advantageously, the width of the optical elements 35 may be 2mm or less when used with microscopic LEDs of size of order 100 micrometres. By way of comparison with known edge lit backlights, such an arrangement provides for efficient coupling of light in a thin package. Fig.34b shows the embodiment of Fig.34a in plan view. Linear arrays of LEDs can conveniently be extracted from a mothersheet to provide sufficient input illumination power.

The optical elements 72 may for example comprise compound parabolic concentrators. Thus a backlight apparatus comprises a light guide plate 270 and output coupling optical element 272, 274.

A further embodiment of an edge lit backlight is shown in Fig.35. Patterned microlens elements 280 are formed on the output surface of the light guide plate 278 so that off-axis light is coupled towards a prism array 282 arranged to direct off-axis light in a forward direction. As for the embodiment of Fig.34a, the cell 38 provides a very thin and efficient source for coupling light into a thin waveguide.

Claims

1. A method of manufacturing a light emitting element array for an illumination apparatus whose primary purpose is illumination as opposed to display;

the method comprising the following steps performed in the following order:

(i) providing a light emitting element array comprising a plurality of light emitting elements arrayed on a first side of a first substrate; and

(ii) reducing the thickness of the light emitting element array by reducing the thickness of the first substrate by removing material from the direction of the second side of the first substrate.

2. A method according to claim 1, further comprising, prior to step (i), providing a plurality of heat spreading elements wherein in step (i) respective heat spreading elements are positioned between the first substrate and respective light emitting elements.

3. A method of manufacturing an illumination apparatus whose primary purpose is illumination as opposed to display;

the method comprising:

providing a light emitting element array comprising a plurality of light emitting elements arrayed on a first side of a first substrate;

providing an optical array comprising a plurality of directional optical elements arrayed on a first side of a second substrate;

forming a structure comprising the light emitting element array and the optical array, with the first side of the first substrate facing the first side of the second substrate, and with respective light emitting elements aligned with respective optical elements; and

thereafter, reducing the thickness of the structure by reducing the thickness of the first substrate by removing material from the direction of the second side of the first substrate.

4. A method according to claim 3, wherein the thickness of the structure is further reduced by reducing the thickness of the second substrate by removing material from the direction of the second side of the second substrate.

5. A method according to claim 3 or claim 4, further comprising, prior to providing the light emitting element array, providing a plurality of heat spreading elements wherein, in the step of providing the light emitting element array, respective heat spreading elements are positioned between the first substrate and respective light emitting elements.

6. A method of manufacturing a light emitting element array for an illumination apparatus whose primary purpose is illumination as opposed to display;

the method comprising the following steps performed in the following order:

(i) providing a light emitting element array structure comprising a plurality of light emitting elements arrayed on a first side of first substrate;

(ii) reducing the thickness of the light emitting element array structure by reducing the thickness of the first substrate by removing material from the direction of the second side of the first substrate;

(iii) increasing the thickness of the light emitting element array structure by providing one or more heatsink structures at the second side of the first substrate.

7. A method according to claim 6, wherein the thickness added to the light emitting element array structure by step (iii) is greater than the thickness by which the thickness of the light emitting element structure was reduced by step (ii).

8. A method according to claim 6 or claim 7, wherein the weight added to the light emitting element array structure by step (iii) is greater than the weight by which the weight of the light emitting element structure was reduced by step (ii).

9. A method according to any of claims 6 to 8, further comprising, prior to providing the light emitting element array, providing a plurality of heat spreading elements wherein, in the step of providing the light emitting element array, respective heat spreading elements are positioned between the first substrate and respective light emitting elements.

10. A method according to any of claims 1 to 9 wherein the plurality of light emitting elements are selectively removed from a monolithic wafer in a manner that preserves the relative spatial position of the selectively removed light-emitting elements.

11. A method according to any of claims 1 to 10 wherein the material of at least the first substrate comprises a ceramic material.

12. A method according to any of claims 1 to 10 wherein the material of at least the first substrate comprises a glass material.

13. A method according to any of claims 1 to 12wherein the material of at least the first substrate comprises a conductive filler material.

14. A method according to any of claims 1 to 13; the method further comprising: forming a mechanically compliant thermally conductive layer on the first substrate.

15. A method according to any of claims 1 to 14; the method further comprising: attaching a heat sink element to the second side of the first substrate.

16. A method according to any of claims 2 to 15; wherein the heat spreading elements comprise silicon.

17. A method according to claim 16; wherein the heat spreading elements are from a monolithic array of

silicon heat spreading elements.

18. A method according to claim 16 or claim 17 wherein the heat spreading elements comprise via holes arranged to provide electrical connection paths between the first substrate and the plurality of light-emitting elements.

19. A method according to any of claims 2 to 15 wherein the heat spreading elements comprise metallic films formed on the first substrate.

20. A method of according to claim 19 wherein the metallic films are of thickness greater than 10 nanometres and less than 10 micrometres.

21. A method of according to claim 20 wherein the metallic films are of thickness greater than 100 nanometres and less than 1 micrometre.

22. A method according to any of claims 1 to 21 wherein the thickness of the first substrate after step (ii) is between 0.01mm and 1.1mm thick.

23. A method according to claim 22 wherein the first substrate is between 0.02mm and 0.4mm thick.

24. A method according to claim 22 or claim 23 wherein the first substrate is between 0.05mm and 0.2mm thick.

25. A method according to any of claims 1 to 24 wherein the thickness of the first substrate is reduced by means of grinding, polishing, chemical etching or any combination thereof.

26. A method according to any of claims 1 to 25 wherein each light-emitting element has a maximum width or diameter less than or equal to 300 micrometers.

27. A method according to claim 26 wherein each light-emitting element has a maximum width or diameter less than or equal to 200 micrometers.

28. A method according to claim 26 or claim 27 wherein each light-emitting element has a maximum width or diameter less than or equal to 100 micrometers.

29. A method according to any of claims 1 to 28 wherein each optical element has a maximum height less than or equal to 5 millimetres.

30. A method according to claim 29 wherein each optical element has a maximum height less than or equal to 2.5 millimetres.

31. A method according to claim 29 or claim 30 wherein each optical element has a maximum height less than or equal to 1 millimetre.

32. A method according to any of claims 3 to 31 wherein the second substrate comprises an opaque layer provided with light transmitting apertures.

33. A method of manufacturing an illumination apparatus according to any of claims 1 to 32; the method further comprising: separating at least two different regions of the light emitting element array.

34. A method of manufacturing an illumination apparatus according to any of claims 3 to 33; the method further comprising: forming at least one seal between the first and second substrates.

35. A light emitting element array formed by the method of any of claims 1 to 34.

36. An illumination apparatus formed by the method of any of claims 1 to 34.

37. A light emitting element array for an illumination apparatus whose primary purpose is illumination as opposed to display;

the light emitting element array comprising a plurality of light emitting elements arrayed on a substrate; wherein the substrate is of reduced thickness compared to what its thickness was when the plurality of light emitting elements were arrayed on the substrate.

38. An illumination apparatus whose primary purpose is illumination as opposed to display;

the illumination apparatus comprising:

a structure comprising a light emitting element array and an optical array,

the light emitting element array comprising a plurality of light emitting elements arrayed on a first side of a first substrate;

the optical array comprising a plurality of directional optical elements arrayed on a first side of a second substrate;

the first side of the first substrate facing the first side of the second substrate, and respective light emitting elements aligned with respective optical elements; wherein

the structure is of reduced thickness compared to what its thickness was when the light emitting element array and the optical array were placed together, by virtue of the light emitting element array being of reduced thickness compared to what its thickness was when the light emitting element array and the optical array were placed together.

39. A light emitting element array for an illumination apparatus whose primary purpose is illumination as opposed to display;

the light emitting element array comprising:

a plurality of light emitting elements arrayed on a first side of a first substrate; and

one or more heatsink structures at the second side of the first substrate;

wherein the first substrate is of reduced thickness compared to what its thickness was when the plurality of light emitting elements were arrayed on the substrate.

40. A light emitting element array according to claim 39 wherein the one or more heatsink structures are in combination thicker than the amount by which the substrate is of reduced thickness compared to what its thickness was when the plurality of light emitting elements were arrayed on the substrate.

41. A light emitting element array according to claim 39 or claim 40 wherein the one or more heatsink structures are in combination of greater weight than the amount by which the substrate is of reduced weight due to the thickness reduction compared to what its weight was when the plurality of light emitting elements were arrayed on the substrate prior to the thickness reduction.

42. An apparatus according to any of claims 37 to 41, further comprising a plurality of heat spreading elements wherein respective heat spreading elements are positioned between the first substrate and respective light emitting elements.

43. An apparatus according to any of claims 37 to 42 wherein the material of at least the first substrate comprises a ceramic material.

44. An apparatus according to any of claims 37 to 42 wherein the material of at least the first substrate comprises a glass material.

45. An apparatus according to any of claims 37 to 44 wherein the material of at least the first substrate comprises a conductive filler material.

46. An apparatus according to any of claims 37 to 45 further comprising a mechanically compliant thermally conductive layer on the first substrate.

47. An apparatus according to any of claims 37 to 46 further comprising a heat sink element attached to the second side of the first substrate.

48. An apparatus according to any of claims 42 to 47 wherein the heat spreading elements comprise silicon.

49. An apparatus according to any of claims 42 to 48 wherein the heat spreading elements comprise via holes arranged to provide electrical connection paths between the first substrate and the plurality of light-emitting elements.

50. An apparatus according to any of claims 42 to 49 wherein the heat spreading elements comprise

metallic films formed on the first substrate.

51. An apparatus of according to claim 50 wherein the metallic films are of thickness greater than 10 nanometres and less than 10 micrometres.

52. An apparatus of according to claim 51 wherein the metallic films are of thickness greater than 100 nanometres and less than 1 micrometre.

53. An apparatus according to any of claims 37 to 52 wherein the thickness of the first substrate is between 0.01mm and 1.1mm thick.

54. An apparatus according to claim 53 wherein the first substrate is between 0.02mm and 0.3mm thick.

55. An apparatus according to claim 53 or claim 54 wherein the first substrate is between 0.05mm and 0.2mm thick.

56. An apparatus according to any of claims 37 to 55 wherein each light-emitting element has a maximum width or diameter less than or equal to 500 micrometers.

57. An apparatus according to claim 56 wherein each light-emitting element has a maximum width or diameter less than or equal to 250 micrometers.

58. An apparatus according to claim 57 wherein each light-emitting element has a maximum width or diameter less than or equal to 100 micrometers.

59. An apparatus according to any of claims 37 to 58 wherein each optical element has a maximum height less than or equal to 5 millimetres.

60. An apparatus according to claim 59 wherein each optical element has a maximum height less than or equal to 2.5 millimetres.

61. An apparatus according to claim 60 wherein each optical element has a maximum height less than or equal to 1 millimetre.

62. An apparatus according to any of claims 37 to 61 wherein the second substrate comprises an opaque layer provided with light transmitting apertures.

63. An apparatus according to any of claims 37 to 62 further comprising at least one seal between the first and second substrates.

64. An apparatus according to any of claims 37 to 63 further comprising at least one spacer between the first and second substrates.

65. An apparatus according to any of claims 37 to 64 further comprising a plurality of electrically insulating element arranged on the plurality of heat spreading elements.

66. A backlight apparatus comprising the apparatus of any of claims 37 to 65 further comprising a light guide plate and at least one output coupling optical element.

INTELLECTUAL PROPERTY OFFICE

Application No:	GB1017769.9	**Examiner:**	Claire Williams
Claims searched:	ALL	**Date of search:**	30 November 2010

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X,Y	X: 1, 14, 25, 33, 35, 36, 37, 46 Y: 3, 38	JP11126923 A (TOYODA GOSEI) see EPODOC English abstract and Figures 3 and 4
X,Y	X:1, 6, 15, 35, 36, 37, 39, 47 Y:3, 38	US2001/035580 A (KAWAI HIROJI) see paragraphs 0021 and 0022
X,Y	X: 1, 6, 15, 25,35, 36, 37, 39,47, 52 Y:3, 38	US2004/180470 A (ROMANO LINDA ET AL) see paragraph 0008
X,Y	X:1, 6, 15, 22, 23, 24, 25, 35, 36, 37, 39, 47, Y:3, 38	US6163557 A (XEROX CORP) see cols. 7 and 8 and Figures 5 and 6
Y	Y:3, 38	GB2371923 A (AGILENT) see Figure 5b and pages 6-9
Y	Y:3, 38	EP0796506 A (QUANTUM DEVICES) see paragraph 0027-0052
Y	Y:3, 38	EP0644443 A (HITACHI) see Figures 1 and 8 and col. 7 and col. 10, line 2, and col. 11, line 59
Y	Y:3, 38	EP1569467 A (LUMILEDS LIGHTING) see Figures 3 and 4 and paragraphs 0020, 0021, 0026 and 0028

Y	Y:3, 38	WO2009/130944 A (SHARP) see Figure 15a

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Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

G02B; H01L

The following online and other databases have been used in the preparation of this search report

EPODOC, WPI

International Classification:

Subclass	Subgroup	Valid From
H01L	0027/15	01/01/2006
G02B	0017/08	01/01/2006
H01L	0033/00	01/01/2010
H01L	0033/58	01/01/2010
H01L	0033/60	01/01/2010
H01L	0033/64	01/01/2010