(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
12 June 2008 (12.06.2008)

PCT

(10) **International Publication Number**
WO 2008/070559 A1

(51) **International Patent Classification:**
H01L 33/00 (2006.01)

(21) **International Application Number:**
PCT/US2007/086094

(22) **International Filing Date:**
30 November 2007 (30.11.2007)

(25) **Filing Language:** English

(26) **Publication Language:** English

(30) **Priority Data:**
0624453.7 6 December 2006 (06.12.2006) GB

(71) **Applicant** *(for all designated States except US)*: **SUN CHEMICAL CORPORATION** [US/US]; 35 Waterview Boulevard, Parsippany, NJ 07054 (US).

(72) **Inventors; and**
(75) **Inventors/Applicants** *(for US only)*: **CAIGER, Nigel, Anthony** [GB/GB]; 4 Eastside, Hurst Batch, Wookey Hole, Somerset BA5 1BE (GB). **SELMAN, Hartley, David** [GB/GB]; 10, The Avenue Keynsham, Bristol BS31, 2BU (GB). **HERLIHY, Shaun, Lawrence** [GB/GB]; 6 Fagus Close, Walderslade, Chatham, Kent ME5 9DD (GB).

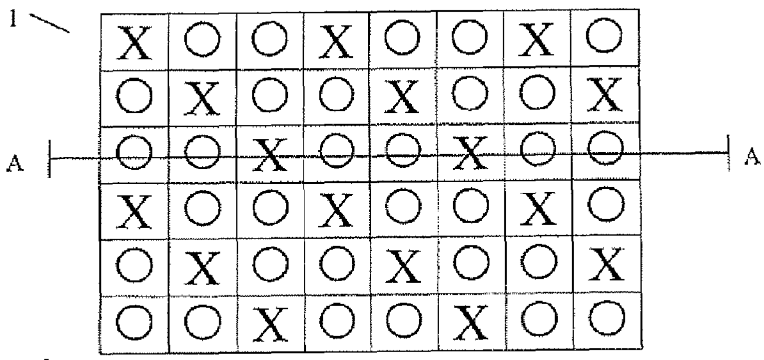
(74) **Agents: ACHKAR, Charles** et al.; Kramer Levin Naftalis & Frankel Llp, 1177 Avenue of the Americas, New York, NY 10036 (US).

(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM),

[Continued on next page]

(54) **Title:** A SOLID STATE RADIATION SOURCE ARRAY



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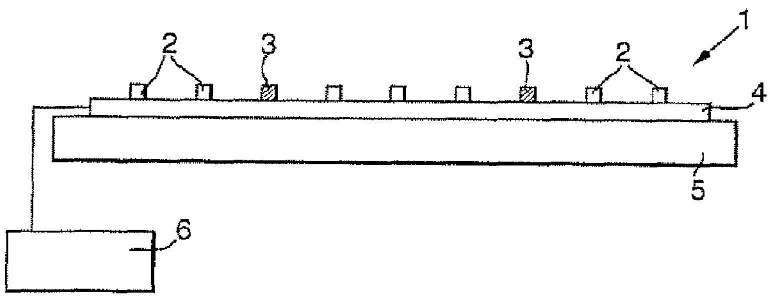

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(57) **Abstract:** A solid state radiation source array is provided, the array comprising at least one solid state ultraviolet radiation source and at least one solid state infrared radiation source.

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European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

A Solid State Radiation Source Array

The invention relates to a solid state radiation source array, especially to a solid state radiation source array for use in initiating the curing of an ultraviolet (UV) curable substance.

Traditionally, mercury vapour discharge lamps have been used to generate UV radiation for initiating the curing of UV curable substances such as inks, furniture coatings, lithography resists, adhesives and three-dimensional modelling materials. However, mercury lamps have a number of disadvantages. For instance, mercury lamps are inefficient in their use of energy, only a small percentage of the energy consumed being emitted as UV radiation. Mercury lamps also take time to heat up and cool down and if broken can release mercury which is highly toxic. Accordingly, there is a move away from mercury discharge lamps and toward solid state UV radiation sources such as UV light emitting diodes (LEDs). UV LEDs can be rapidly switched on and off, are more energy efficient than mercury lamps and are safer to use. They are also more compact and can be less expensive than mercury lamps. For example, the use of UV LEDs to cure UV curable ink jet inks is disclosed in US 2006/0119686A, US 2005/0128274A, US 2005/0099478A and US 2006/0050122A. The UV LEDs are generally used in the form of an array comprising a large number of individual LED chips. For some applications it is preferred that the array is a mixed array comprising LEDs having differing peak wavelengths in the UV region, thereby providing UV radiation having more than one peak wavelength.

There remains a need for improved devices for initiating the curing of UV curable substances and for improved methods of UV curing.

The invention provides a solid state radiation source array comprising at least one solid state infrared (IR) radiation source and at least one solid state ultraviolet (UV) radiation source. In use of the array of the invention the solid state IR radiation source generates infrared (IR) radiation which heats the UV curable material thereby increasing the temperature of that material and, in consequence, making possible an increase in the rate of the curing reaction and the solid state UV radiation source generates UV radiation which initiates the curing of the UV curable material. Accordingly, the invention aims to provide a simple and easy to use device for curing UV curable materials at an increased rate, thereby making possible an increase in productivity. The array of the invention is, of course, particularly suitable for curing those substances in which the rate of curing is increased at an elevated temperature. In certain applications, for example, the curing of UV curable free radical ink jet inks, the rate of curing is in general insensitive to the temperature of the substance to be cured and the invention is therefore less beneficial in respect of those limited applications. For applications involving cationic ink, however, the rate of curing will be increased with increasing temperature and therefore use of the array of the invention will help make possible an increase in productivity.

The word "array" as used herein refers broadly to any collection of solid state radiation sources. The phrase "solid state radiation source" as used herein refers to any device that generates electromagnetic radiation via the recombination of holes and electrons. The solid state radiation sources may be light emitting diodes, laser diodes, vertical cavity surface emitting lasers, polymer light emitting diodes (LEDs), electroluminescent devices, and any other suitable device which generates electromagnetic radiation via the recombination of holes and electrons. The array may comprise a mixture of different categories of solid state radiation source, for example, a mixture of UV LEDs and IR laser diodes. Optionally, however, all the solid state radiation sources will be of the same category. Semi-conductor devices such as LEDs, laser diodes and vertical cavity surface emitting lasers are preferred. LEDs are particularly preferred due to their commercial availability and good performance characteristics. Preferably, all the solid state radiation sources are LEDs.

The array may include a collection of individual LEDs arranged, for example, in a rectangular pattern. The individual LEDs may have a centre-to-centre separation in the range of from 2 to 5mm, preferably in the range of from 3 to 4mm. In a further embodiment, the array may comprise a dense array of LED chips on a common substrate as described further below.

Typically, the array will comprise a plurality of solid state UV radiation sources and a plurality of solid state IR radiation sources. For example, the array may include more than 20, optionally more than 50 solid state UV radiation sources. The array may comprise more than 20, optionally more than 50 solid state IR radiation sources. The array may comprise at least two types of solid state UV radiation source having different peak wavelengths such that the UV radiation emitted by the module has more than one peak wavelength. Using a mixture of solid state UV radiation sources, for example, a mixture of UV LEDs having different peak wavelengths makes possible more efficient curing of certain types of substance. For example, for UV curable ink jet inks it may be desirable to include solid state radiation sources that emit relatively short wave UV radiation to promote curing of the surface layer of the ink and also to include solid state radiation sources which emit a longer wavelength UV radiation which will be transmitted further into the depths of the ink layer. In that way, the array can more effectively cure varying thicknesses of ink layer and inks with varying pigmentation.

The term "solid state UV radiation source" and "UV LED" as used herein refer to solid state radiation sources and LEDs, respectively, having peak emission wavelengths in the UV region of the electromagnetic spectrum, for example, having a peak emission wavelength in the region of from 400nm to 50nm. Optionally, the solid state UV radiation source has a peak emission wavelength in the region of from 400nm to 200nm, especially preferably in the region of from 400nm to 300nm. Preferred solid state UV radiation sources include UV LEDs with peak emission wavelengths of 395nm and

365nm. LEDs having a wavelength of 395nm are widely available. 365nm LEDs are less common but produce UV radiation which is more closely centred on the absorbance peak of the photoinitiators used in certain cationic UV curable materials such as cationic ink jet inks.

The array may comprise at least two types of solid state IR radiation source having different peak wavelengths such that the IR radiation emitted by the array has more than one peak wavelength. For example, the array may comprise solid state radiation sources having peak wavelengths in the near-IR region and also solid state radiation sources having peak emission wavelengths in the mid-IR region.

The terms "solid state IR radiation source" and "IR LED" as used herein refer to solid state radiation sources and LEDs respectively, having peak emission wavelengths in the infrared (IR) region of the electromagnetic spectrum, for example, longer than 700nm. Optionally, the IR solid state radiation source or sources have peak emission wavelengths of from 700nm to 100,000nm, preferably from 700nm to 10,000nm and especially preferably in the range of from 700nm to 2000nm.

In a preferred embodiment, the array comprises at least one near-IR (NIR) solid state radiation source such as a NIR LED. NIR radiation is selectively absorbed by polar substances and therefore polar substances such as a polar ink applied to a non-polar substrate such as a polyethylene film will be selectively heated by NIR radiation in preference to the non-polar substrate. Accordingly, in this embodiment the array may be used to raise the temperature of a polar substance on a heat sensitive non-polar substrate whilst minimising the temperature rise of the sensitive substrate. NIR LED arrays have previously found application in the detection of errors in the manufacture of semi-conductor microcircuits. Optionally, the NIR solid state radiation source has a peak emission wavelength in the region of from 750nm to 1400nm.

In one embodiment the solid state IR radiation sources are substantially evenly dispersed across the array. In that embodiment, the solid state IR radiation sources may be randomly intermingled with the solid state UV radiation sources. Preferably, however, the arrangement of the solid state IR and UV radiation sources forms a repeat pattern. In an alternative embodiment, the solid state IR radiation sources are not evenly dispersed across the array and are instead concentrated in certain areas. The array may have at least first and second areas in which the ratio of solid state IR radiation sources to solid state UV radiation sources is higher in the first area than in the second area. Optionally, the first area comprises solely solid state IR radiation sources and the second area comprises solely solid state UV radiation sources. Such arrays having discrete areas of solid state IR radiation sources and discrete areas of solid state UV radiation sources may be easier to manufacture than arrays having an even distribution of UV and IR solid state radiation sources. It may be desirable for the array to be provided with a diffuser to help reduce unevenness in the nature of the radiation emitted from one area to another in the array.

As mentioned above, the array may comprise one or more dense LED arrays. Such dense LED arrays comprise a plurality of LEDs dispersed in a regular pattern across a common substrate and are described in, for example, WO 03/096387. The dense array may be a mixed dense array comprising both UV and IR LEDs. Alternatively, the array of the invention may comprise one or more dense arrays of UV LEDs and one or more dense arrays of IR LEDs. The array of the invention may comprise at least one solid state UV radiation source and at least one solid state IR radiation source mounted on a common substrate. The array may be provided with cooling means such as a heat sink, fan, or supply of cooling liquid. The array will also typically be provided with circuitry to enable the array to be connected to an external power source. The array may be present as part of a lighting module.

The invention also provides a lighting module comprising at least one solid state UV radiation source and at least one solid state IR radiation source together with the circuitry to provide power to the IR and UV solid state radiation sources. Desirably, the circuitry connects all of the solid state radiation sources of the array to an external power source via a single connector. The lighting module may also comprise control means to control the operation of the solid state radiation sources. For example, the control unit may enable the operator to choose between continuous emission or pulsed emission. Alternatively, the module may comprise connection means for connecting the array to an external control unit. The module may also comprise cooling means to maintain the solid state radiation sources at an acceptable temperature. The cooling means may include one or more of a heat sink, a cooling fan or a conduit for the circulation of cooling liquid. The module may also comprise a housing for the array and associated circuitry and any further optional components such as the cooling means.

Preferably, the solid state radiation sources are LEDs and the lighting module is an LED module. The invention also provides a device for initiating the curing of a UV curable material, the device comprising at least one solid state IR radiation source and at least one solid state UV radiation source. The device may be, for example, a light bar. The light bar may comprise one or more of the lighting modules of the invention. Each lighting module may comprise an array of individual LEDS and/or one or more dense arrays. The device may be a device for curing inks in a printer or print line. For example, the curing device may be a curing station in an ink jet printer such as an ink jet printer for printing CDs and DVDs. The curing device may be a curing station in a flexographic or screen printer. The curing device may be a curing device for the curing of wood and furniture coatings. The curing device may a device for the curing of metal coatings and coil coatings. The curing device may be a curing device for curing three-dimensional prototypes, such as those prototypes which are built-up by ink jet printing successive layers of cationic UV curing ink. The curing device may be a curing device for curing adhesives.

The invention also provides a method of curing a UV curable material which includes the step of exposing the material to a mixture of IR and UV radiation generated by an array, module, or device according to the invention. The method may be a method of curing an ink or coating including metal, wood and furniture coatings, adhesives or it may be a method of three-dimensional modelling. In a preferred embodiment, the method is a method of curing a UV curable ink such as an ink jet ink and the array module or device is located in a printer or print line.

Embodiments of the invention will now be described for the purpose of illustration only with reference to the following drawings in which:

Figure 1a shows in schematic form an array according to the invention;

Figure 1b shows in schematic form a cross-section through the array of Figure 1a along line A to A;

Figure 2 shows a second array according to the invention;

Figure 3 shows a third array according to the invention;

Figure 4 shows a cross-section through a lighting module according to the invention; and

Figure 5 shows a device for curing a UV curable substance according to the invention.

Figure 1a shows a view from the front of a solid state radiation source array 1 according to the invention. The array comprises 40 LEDs arranged in a rectangular 8 x 6 grid. The LED chips are mounted on a common substrate as a dense LED array. The separation between each LED and its immediate neighbouring LEDs is 2mm and the array has a nominal length of 16mm and a nominal width of 12mm. In Figure 1a each X depicts a NIR LED chip and each O depicts a UV LED chip. As can be seen from Figure 1a, the IR chips are evenly spread across the surface of the array in a repeating pattern.

Figure 1b depicts a cross-section through the array of Figure 1a along the lines A to A. The UV LEDs 2 and the IR LEDs 3 are mounted on a common substrate 4 which is bonded with adhesive to a heat sink 5. The chip array 1 is connected via circuitry to a power source 6.

In an alternative embodiment, the array shown in Figure 1a could comprise individual LEDs such that each X would be an individual IR LED and each O would represent an individual UV LED. In that embodiment the distance between neighbouring LEDs may be of the order of 3mm and the length of the array may therefore be around 30mm and the width may be around 15mm. The individual LEDs would be connected by wiring circuitry to a common power source. Suitable IR LEDs including NIR LEDs are available from Epitex Inc of Japan. For example, high power NIR LEDs of peak emission wavelength of 870nm and 850nm are available from Epitex.

Figure 2 shows an alternative solid state radiation source array according to the invention in which the IR LEDs represented by X are located in two rows on one long side of the array and UV LEDs depicted with a O are located in the remaining three rows. In this embodiment, the IR LEDs are not evenly dispersed across the array but are instead confined in a certain area located along one long side of the array (the uppermost side as shown in Figure 2) which area comprises solely IR LEDs. The rest of the array defines a second area which comprises solely UV LEDs. When used for curing a coating applied to a substrate that is moving relative to the array in the direction shown by the arrows, the substrate and coating will pass first under the IR LEDs which will heat the coating to an elevated temperature and then pass under the UV LEDs which will initiate the curing of the coating.

In an alternative embodiment, the region of IR LEDs may comprise a small number of UV LEDs and/or the region of UV LEDs may comprise a small number of IR LEDs. It will furthermore be apparent to the skilled person that the arrays of the invention could comprise any number of LEDs arranged in any pattern and that the rectangular patterns shown in the Figures are for the purpose of illustration only.

Figure 3 shows an array according to the invention comprising three dense arrays, each dense array being a rectangular pattern of 7 x 4 LEDs. The three dense arrays are arranged in a row with the outermost arrays 8 comprising only IR LEDs and the central dense array 9 comprising only UV LEDs. Typically, the substrate would move from left to right or vice versa relative to the arrays to allow for even coverage of UV and IR radiation over the substrate. The arrangement shown in Fig. 3 could be, for example, mounted on a print head which scans from side to side across the substrate. Once again, it will be apparent to the skilled person that the array shown in Figure 3 could comprise any number of dense arrays or indeed the dense arrays may be replaced by arrays of individual LEDs. Furthermore, each dense array or array of individual LEDs could comprise a mixture of UV and IR LEDs. However, the arrangement depicted in Figure 3 in which each dense array includes either IR LEDs or UV LEDs but not both may have the advantage of simplicity of manufacture.

Figure 4 shows a cross-section through a lighting module 10 according to the invention. The module 10 comprises an array 11 which is a mixed array of IR LEDs 12 and UV LEDs 13. At one side of the array is a power distribution bus 14. The array is mounted on a common substrate 15 which is bonded by a layer of thermally conductive adhesive 16 to a housing 17 which extends around the back and the sides of the array 11. The housing 17 is provided with an electrical connection unit 18 by which the power bus 14 is connected to an external power source (not shown in Figure 4). The external power source in not a part of the module shown in Figure 4. The module 10 is also provided with an optical window 19 which is mounted in the housing 17 such that the radiation generated by the array passes out through the window 19. The material of the window 19 is chosen to be substantially transparent to the UV and IR radiation emitted by the array. The optical window 19 could also incorporate a diffuser to ensure an even distribution of the radiation generated by the LEDs 12 and 13. Alternatively, the window 19 could incorporate lens optics to provide focusing of the radiation generated by the array. On the opposite side of the housing a heat sink 20 provided with cooling fans 21 is mounted.

The lighting module shown in Figure 4 comprises one dense array 11 of LEDs. In an alternative embodiment the lighting module could comprise an array having more than one dense array such as the arrangement shown in Figure 3 or alternatively could comprise one or more sub-arrays of individual LEDs.

Figure 5 shows a device for curing a UV curable substance according to the invention in the form of a light bar 22. The light bar 22 comprises three lighting modules 23 arranged side-by-side with the front window 24 of each lighting module 23 facing forwards from the same side of the light bar 22. The light bar 22 includes a housing 25 which contains the three lighting modules 23 and is provided at one end with ports 26 and 27 for the inflow and outflow respectively of a cooling fluid. The ports 26 and 27 are connected to conduits on the inside of the light bar (not shown in Figure 5) which carry the cooling fluid around the fins of the heat sinks of the individual lighting modules 23. At the same end of the light bar 22 the housing 25 is provided also with a connector 28 by which the light bar can be connected to an external power source. Connector 28 is connected on the interior of the light bar 22 to a wiring loom which distributes electrical power to the individual lighting modules 23. At the rear of the light bar 22 the housing 25 is provided with threaded studs (not shown in Figure 5) by which the light bar can be fixed in place, for example, at a curing station in a furniture coating line or on the end of a robotic arm at a curing station in an automotive paint shop.

It will be apparent to the skilled person that many variations of the invention are possible. For example, in place of the LEDs shown in Figures 1a to 5 laser diodes or polymer light emitting diodes may be used instead. For ascertaining the scope of the invention reference should be made to the appended claims.

Claims:

1. A solid state radiation source array comprising at least one solid state ultraviolet radiation source and at least one solid state infrared radiation source.

2. An array as claimed in claim 1 in which the solid state ultraviolet radiation sources and the solid state infrared radiation sources are light emitting diodes and the array is a light emitting diode array.

3. An array as claimed in claim 1 or claim 2 which comprises a plurality of solid state ultraviolet radiation sources and a plurality of solid state infrared radiation sources.

4. An array as claimed in any of claims 1 to 3 which comprises at least two types of solid state ultraviolet radiation source having different peak wavelengths such that the ultraviolet radiation emitted by the array has more than one peak wavelength.

5. An array as claimed in any of claims 1 to 4 in which the at least one solid state infrared radiation source is a solid state near-infrared radiation source.

6. An array as claimed in any of claims 1 to 5 which comprises at least two types of solid state infrared radiation source having different peak wavelengths such that the infrared radiation emitted by the array has more than one peak wavelength.

7. An array as claimed in any of claims 1 to 6 which comprises at least one solid state ultraviolet radiation source and at least one solid state infrared radiation source mounted on a common substrate.

8. An array as claimed in claim 7 which comprises a plurality of solid state infrared radiation sources and a plurality of solid state infrared radiation sources mounted on a common substrate.

9. An array as claimed in any of claims 1 to 8 in which the solid state infrared radiation sources are substantially evenly dispersed across the array.

10. An array as claimed in any of claims 1 to 8 in which the solid state infrared radiation sources are not evenly dispersed across the array.

11. An array as claimed in claim 10 which has at least first and second areas in which the ratio of solid state infrared radiation sources to solid state ultraviolet radiation sources is higher in the first area than in the second area.

12. An array as claimed in claim 11 in which the first area comprises solely solid state infrared radiation sources and the second area comprises solely solid state ultraviolet radiation sources.

13. A light emitting diode array comprising a plurality of ultraviolet light emitting diodes and a plurality of infrared light emitting diodes.

14. A lighting module comprising at least one solid state ultraviolet radiation source and at least one solid state infrared radiation source, together with circuitry to provide power to the infrared and ultraviolet solid state radiation sources.

15. A module as claimed in claim 14 in which the solid state radiation sources are light emitting diodes.

16. A light emitting diode module comprising a light emitting diode array including a plurality of ultraviolet light emitting diodes and a plurality of infrared light emitting diodes, a housing for the array and cooling means for carrying heat away from the light emitting diodes.

17. A device for initiating the curing of an ultraviolet curable material, the device comprising at least one solid state infrared radiation source and at least one solid state ultraviolet radiation source.

18. A device as claimed in claim 17 which comprises an array according to any of claims 1 to 12 or a module as claimed in any of claims 13 to 16.

19. A device as claimed in claim 17 or claim 18 which is a light bar.

20. A method of curing an ultraviolet curable material including the step of exposing the material to a mixture of infrared and ultraviolet radiation generated by an array according to any of claims 1 to 13, a module according to any of claims 14 to 16, or a device according to any of claims 17 to 19.

21. A method according claim 20 in which the material is an ultraviolet curable ink jet ink and the array, module or device is located in a curing station in a printer or print line.

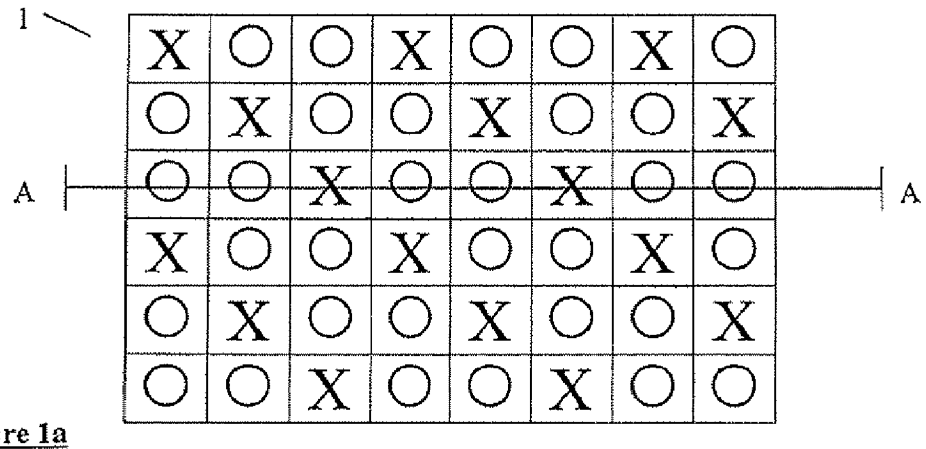

Figure 1a

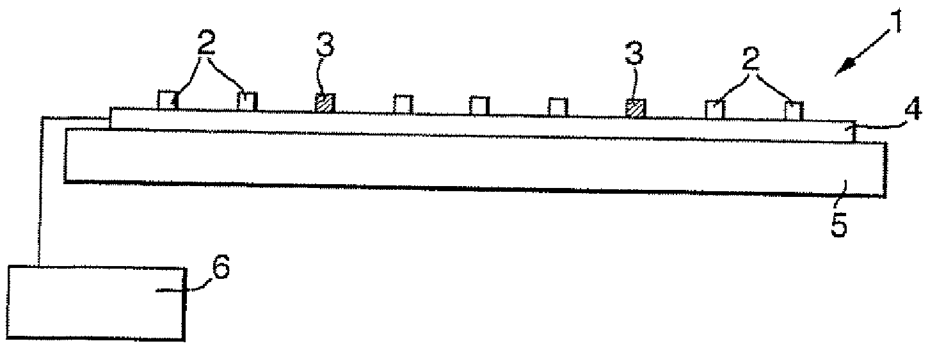

Figure 1b

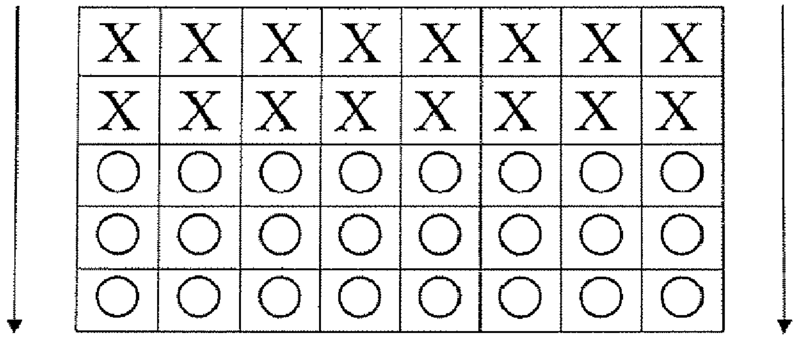

Figure 2

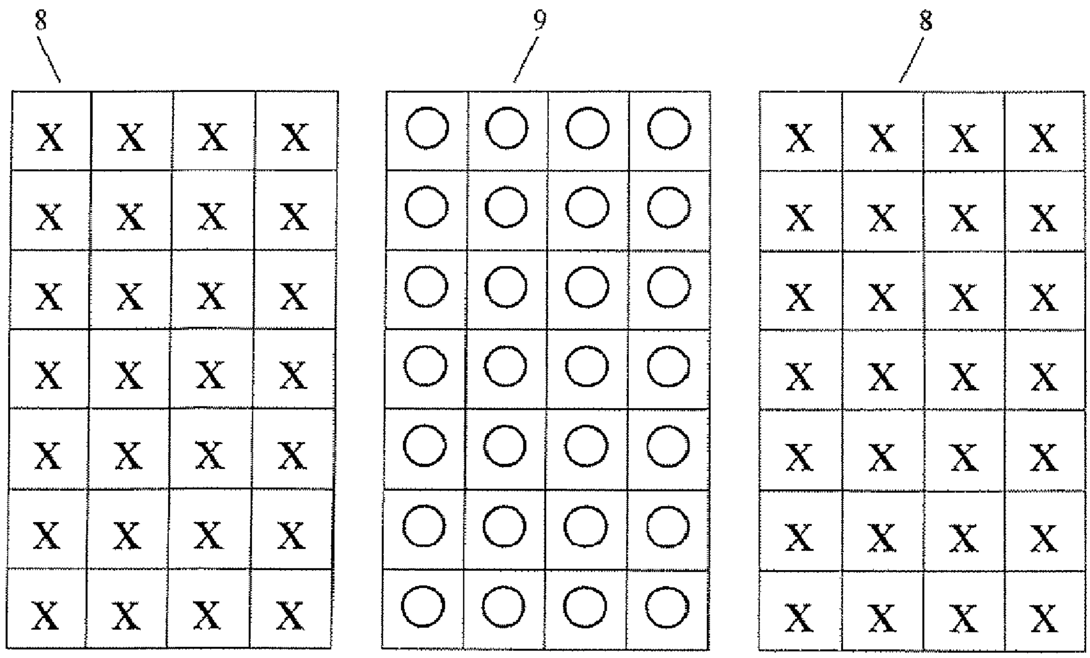

Figure 3

Fig.4.

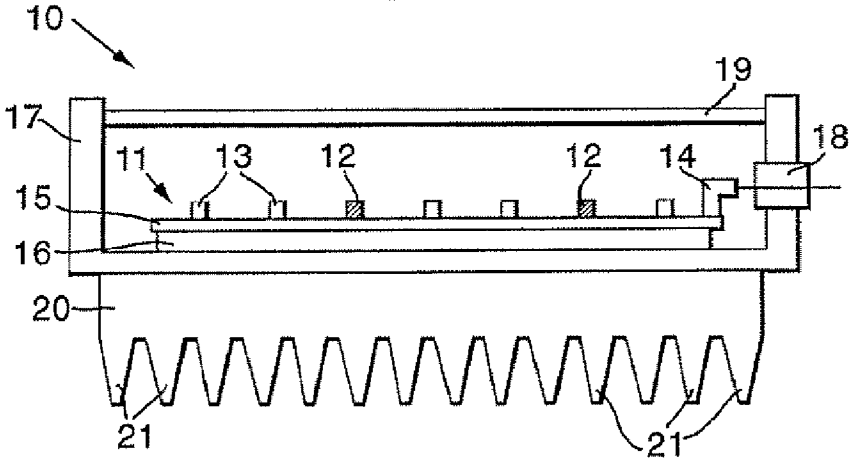
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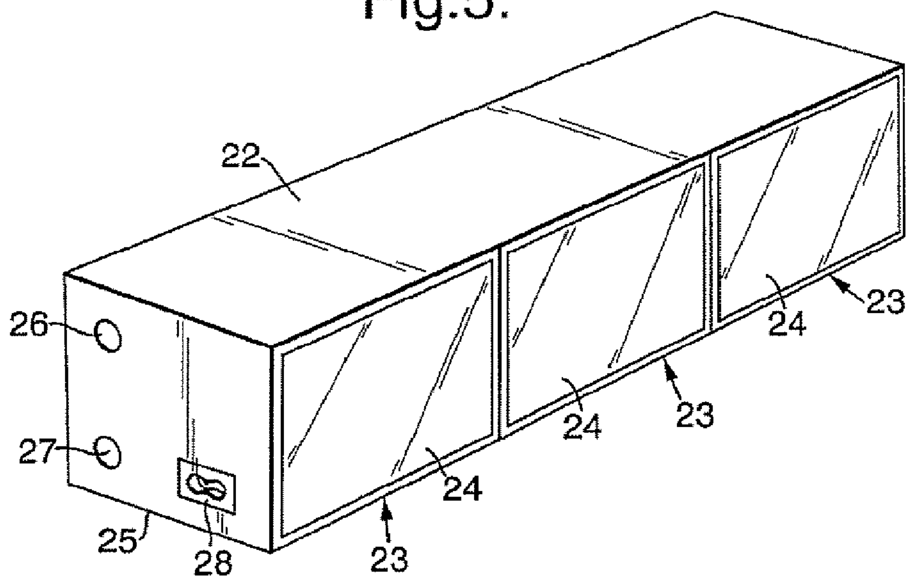
Fig.5.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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2007/086094

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 4-7, 9, 10, 18-20
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required addtional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2007/086094

A. CLASSIFICATION OF SUBJECT MATTER

H01L 33/00(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)
IPC 8 H01L, A61C, F21V, C08J, G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean Utility models and applictions for Utility models since 1975
Japanese Utility models and application for Utility models since 1975

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKIPASS(KIPO internal) "solid state ultraviolet radiation", "solid state infrared radiation"

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2005/0158687 A1 (DAHM) 21 Jul. 2005 See Abstract; Paragraph [0109]; Figure 10	1-3, 5, 7-10, 13-21
A	US 2004/0164325 A1 (SIEGEL) 26 Aug. 2004 See Abstract; Claim 13; Figure 2	1-21
A	JP 2005-015764 A (KEYENCE CO.) 20 Jan. 2005 See Abstract; Figure 1	1-21
A	US 2005/0116178 A1 (AGUIRRE et al.) 02 Jun. 2005 See Abstract; Figure 2	1-21

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

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

Date of the actual completion of the international search	Date of mailing of the international search report
29 APRIL 2008 (29.04.2008)	**29 APRIL 2008 (29.04.2008)**

Name and mailing address of the ISA/KR
Korean Intellectual Property Office
Government Complex-Daejeon, 139 Seonsa-ro, Seo-gu, Daejeon 302-701, Republic of Korea
Facsimile No. 82-42-472-7140

Authorized officer
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

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