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(54) Title: LED LIGHTING MODULES

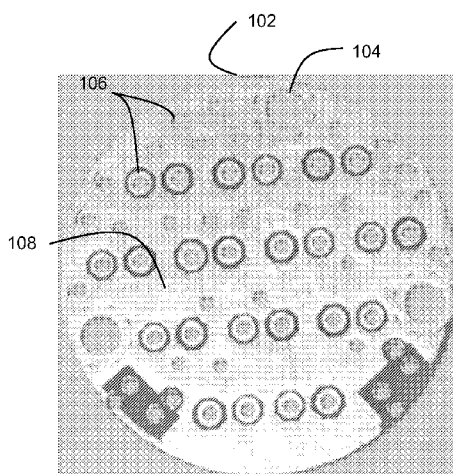


Fig. 1A

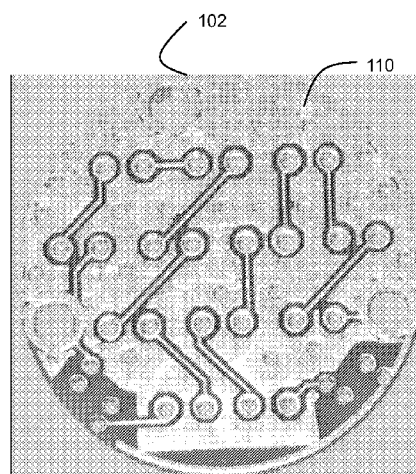


Fig. 1B

(57) Abstract: An LED module includes an LED circuit board that is substantially fully metallized on two opposing surfaces for a number of closely-packed, high-output LEDs, along with an adjacent, parallel circuit board to carry high-frequency drive circuitry for the LEDs. The improved LED light source can provide longer LED lifespan, better wavelength stability, and higher density packaging than convention LED modules. An improvement of 10°C in heat dissipation has been demonstrated over conventional printed circuit boards, and operation at frequencies above 2 MHz for 12 closely-packed, high-output, through-hole mounted LEDs. Continuous temperature monitoring is provided using an on-board calibrated integrated circuit thermistor. In one embodiment, 12 LED's are integrated into a 35 x 30.5 x 30.5 mm aluminum housing for a module that provides 100 mW of filtered light with full-depth AC modulation at 2+ MHz.

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LED LIGHTING MODULES

GOVERNMENT INTERESTS

[0001] The United States Government may have certain rights in this invention pursuant to National Institute of Health Grant # R01-CA-115296

CROSS-REFERENCE TO RELATED APPLICATIONS

[0002] This application claims priority to U.S. Provisional Patent Application No. 60/949,188, filed July 11, 2007, the entire contents of which are incorporated by reference herein.

BACKGROUND

[0003] Light emitting diodes (LEDs) are severely limited by over-heating, which reduces lifespan, changes output wavelength, and changes current-voltage characteristics. Thus, thermal management presents a continuing challenge for high-brightness LED applications, particularly where drive circuitry is placed in close proximity to the LEDs for high-frequency operation.

[0004] There remains a need for improved LED lighting systems.

SUMMARY

[0005] An LED module includes an LED circuit board that is substantially fully metallized on two opposing surfaces includes a number of closely-packed, high-output LEDs, along with an adjacent, parallel circuit board to carry high-frequency drive circuitry for the LEDs. The improved LED light source can provide longer LED lifespan, better wavelength stability, and higher density packaging than convention LED modules. An improvement of 10°C in heat dissipation has been demonstrated over conventional printed circuit boards, and operation at frequencies above 2 MHz for 12 closely-packed, high-output, through-hole mounted LEDs. Continuous temperature monitoring is provided using an on-board calibrated integrated circuit thermistor. In one embodiment, 12 LED's are integrated into a 35 x 30.5 x 30.5 mm aluminum housing for a module that provides 100 mW of filtered light with full-depth AC modulation at 2+ MHz.

[0006] In one aspect, an LED module that is disclosed herein includes a first printed circuit board, the first printed circuit board having a substantially fully metallized surface on a front side and a back side thereof; a plurality of light emitting diodes mounted to the front side of the first printed circuit board; a thermal layer formed of a thermally conductive, electrically insulating material, the thermal layer disposed on the back side of the first printed circuit board; a second printed circuit board having a front side abutting the thermal layer and a back side opposite the thermal layer; and a driver circuit mounted on the back side of the second printed circuit board, the driver circuit coupled to the plurality of light emitting diodes through the second printed circuit board, the thermal layer, and the first printed circuit board.

[0007] The LED module may include at least one temperature control integrated circuit on the second printed circuit board. The plurality of light emitting diodes may include at least twelve light emitting diodes. The LED module may include an aluminum housing for the first printed circuit board, the second printed circuit board, the thermal layer, the plurality of light emitting diodes, and the driver circuit. The LED module may include at least one filter for conditioning output from the plurality of light emitting diodes. The LED module may include a connector mounted to the housing, the connector electrically coupled to the driver circuit and including a plug receptacle for connecting the LED module to an external source. The external source may be at least one of a power source and a control source. The thermal layer may include a thermal pad. The thermal layer may include a thermal paste. The thermal layer may be a multi-layer material including an electrical insulation layer and a thermal conducting layer. The first printed circuit board may be at least 80% metallized on the front side and the back side thereof. The first printed circuit board may be at least 90% metallized on the front side and the back side thereof. The driver circuit may provide a drive signal to one or more of the plurality of light emitting diodes in response to a control signal. The plurality of light emitting diodes may include a plurality of through-hole light emitting diodes positioned in contact with one another. The first circuit board may be substantially circular. The first circuit board may include two or more mounting through-holes thermally coupled to a copper that forms the substantially fully metallized surface of at least one of the front side and the back side thereof.

[0008] In one aspect, an LED module that is disclosed herein includes a first circuit board, the first circuit board having a substantially fully metallized surface on a front side and a back side thereof; a plurality of light emitting diodes mounted to the front side of the first circuit board; a second circuit board having a driver circuit, the driver circuit electrically coupled to the plurality of light emitting diodes and adapted to receive a control signal and to generate a responsive drive signal to the plurality of light emitting diodes.

[0009] The second circuit board may be substantially parallel and adjacent to the first circuit board, the first circuit board and the second circuit board separated by a thermal layer. The substantially fully metallized surface of the front side of the first circuit board may include holes for a plurality of leads of the plurality of light emitting diodes. The substantially fully metallized surface of the back side of the first circuit board may include traces for coupling a plurality of leads of the plurality of light emitting diodes to the driver circuit. The driver circuit may drive the plurality of light emitting diodes at a frequency of at least 35 MHz. The driver circuit may drive the plurality of light emitting diodes concurrently at a full power producing at least nine milliWatts of usable optical power per light emitting diode. The driver circuit may drive the plurality of light emitting diodes concurrently at full power while modulating the plurality of light emitting diodes at at least 35 MHz.

[0010] These and other systems, methods, objects, features, and advantages of the present invention will be apparent to those skilled in the art from the following detailed description of the preferred embodiment and the drawings.

[0011] All documents mentioned herein are hereby incorporated in their entirety by reference. References to items in the singular should be understood to include items in the plural, and vice versa, unless explicitly stated otherwise or clear from the text. Grammatical conjunctions are intended to express any and all disjunctive and conjunctive combinations of conjoined clauses, sentences, words, and the like, unless otherwise stated or clear from the context.

BRIEF DESCRIPTION OF THE FIGURES

[0012] The invention and the following detailed description of certain embodiments thereof may be understood by reference to the following figures:

[0013] Figs. 1A-1B show a metallized printed circuit board.

[0014] Figs. 2A-2B show a conventional printed circuit board.

[0015] Figs. 3A and 3B show an LED driver board.

[0016] Fig. 4 shows an assembly of a metallized PCB and a driver PCB.

[0017] Fig. 5 is an exploded view of an LED module.

[0018] Fig. 6 shows a lighting system using a number of LED modules.

DETAILED DESCRIPTION

[0019] The LED systems described herein may be usefully employed in a wide range of lighting and imaging applications. For example, the systems described herein may be employed in multi-modal imaging systems such as an intraoperative imaging system that illuminates a field with visible white light and an excitation light source while capturing a corresponding visible light image and a diagnostic image from a fluorescent dye or the like. In such a surgical lighting applications, the surgical field may be relatively large, typically 15 cm in diameter = 176 cm². The fluence rate (light intensity) required for surgical imaging is in the range of 2-25 mW/cm², hence total light output of an illumination system must be at least 4.4 W. Actual lighting requirements may be greater when taking into consideration losses in filtration and splash shield. Two or more LED modules may be employed, for example, to alternate between visible light and excitation light at high frequency.

[0020] Five Watts of filtered light may be difficult to achieve. A laser of this size may be prohibitively expensive and dangerous. LEDs can provide such light output, but since each individual LED only produces approximately 9 mW of optical power, approximately 550 LEDs are required to generate adequate light. Since each LED produces 100 mW of electrical power consumption (but only 9 mW of usable optical power), the overall problem with LEDs is heat. In fact, the approximately 550 LEDs needed for surgical imaging will produce over 55 W of heat. Heat is deadly to LEDs, reducing light output, reducing lifespan, and shifting the wavelength emitted light.

[0021] In one aspect, the systems described herein provide heat dissipation for densely packed LEDs such as those described above. Typically, if one places a number of LEDs in close contact in a hexagonal array or the like, the LEDs in the middle will heat up significantly more than LEDs in the periphery, and all LEDs will be operated at temperatures that affect their function.

[0022] Fig. 1A and 1B show two sides of a metallized printed circuit board (“PCB”). On the circuit board 102, unmetallized surfaces may be used only as necessary to provide wire traces interconnecting LEDs on the circuit board. Any and all of the holes, such as mounting holes 104 or through-holes 106 for LEDs, may function as heat transfer holes (e.g., metallized through-holes) providing heat transfer between the metallization layers of a front side 108 and a back side 110 of the circuit board 102 (it being understood that front and back, as used herein, are relative terms used only to connote the opposing surfaces without expressing or implying a particular orientation with respect to an LED module or other hardware, except where such orientation is specifically stated or otherwise clear from the context). Heat may be drawn off of an LED’s package by the metallization on the front side 108. Similarly, heat may be drawn off of an LED’s leads by the coating on the back side 108. In any case, heat drawn off of an LED may be convected to mounting holes 104 (three of which are shown, but any number of which may be present in embodiments). Bolts mounted through the mounting holes 104 may act as radiators further dissipating heat to a housing that may be provided for LEDs and the circuit board 102 as generally described below.

[0023] In general, the term substantially metallized or substantially fully metallized are used to describe the over-metallization of surfaces of the PCB 102 as depicted by way of example in Figs. 1A and 1B. The circuit board 102 may have a two ounce pour of copper with solder coating (or any other suitable metal and/or metallization process) over the entire surface except as required for tracings. It will be understood that a substantially fully metallized circuit board 102 with a dense metal coating on both the front side 108 and back side 110 may achieve improved heat dissipation as compared with the conventional circuit board design illustrated in Figs. 1C and 1D. It will be understood that this characterization does not require a specific amount of metallization, and that some non-metallized areas are generally used to provide routing for electrical

signals on the circuit board 102 or other design purposes. Thus substantially fully metallized may include, for example, 99% metallized, 95% metallized, 90% metallized, 80% metallized, or some other percentage metallization of the circuit board 102 surface(s). While any amount of metallization that distinguishes this construction from conventional LED circuit boards is intended to fall within the scope of this disclosure, in certain embodiments the circuit board 102 may be at least 80% metallized on the front side 108 and back side 110 thereof. It should also be noted that metallization as described herein refers to metallization of an exterior layer of a circuit board, as distinguished from interior layers of a multi-layer circuit board which may include an internal ground plane or other highly metallized interior layer. At the same time, metallization of an exterior layer does not exclude masking or other protective or electrically insulating layers on top of the metallized surfaces; however in testing this extra layer has been demonstrated to reduce the thermal management benefits of substantially full metallization.

[0024] Fig. 2A and 2B show two sides of a conventional printed circuit board 212 for purposes of comparison. In this conventional circuit board 212, most of the surface is an insulating material. Such a circuit board 212 may draw relatively little heat away from an LED's package and leads as compared with the metallized circuit board 102 described above.

[0025] Figs. 3A and 3B show a driver board 300 for use with the LED module described herein. The driver board 300 may provide a calibrated temperature integrated circuit 302 for direct measurement of temperature. The driver board may also include a header connector 304 for interfacing with other electronics such as a power supply, a controller, and/or a computer. The driver board 300 may employ long header pins that stick up through the LED PCB into a header receptacle, thus providing for a quick but durable contact point with the assembled LED module. Also, all driver board ICs may be placed on the back side of the driver board, thus providing an insulating barrier between the driver electronics and the LED board (with an exception for the temperature IC, which may face the LED board for more direct measurement of LED board temperature). In such embodiments, the driver board may advantageously be substantially non-metallized on at least one surface. A connection to the LED circuit board 102 may be

made through two 2-pin long header pins, and an interface to a computer system (e.g., to control operation of the LED module) may be through a 6-pin header mounted on the opposing surface. The driver board 300 may also contain a driver circuit (e.g., one or more integrated circuits 306, although no specific arrangement or packaging for the driver circuit is required, except as required for the desired speed and power of a particular LED module) including circuitry to permit modulation of LED output to up to 2 MHz at full depth of modulation. The metallized LED PCB and driver PCB may connect together through the header pins. A thin (1.5 mm) thermal conducting and/or electrically insulating pad (such as insulating pads available from 3M) may be used to separate the two circuit boards. This “sandwich” may then be mounted using three 2-56 bolt holes to an aluminum housing, or any other suitable mounting hardware.

[0026] Fig. 4 shows an assembly of a metallized circuit board 402 with a number of LEDs 404 coupled to a driver board 406. A first thermal pad 408 or other thermally conductive and/or electrically insulating layer may be positioned between the metallized circuit board 402 and the driver board 406. A second thermal pad 410 may be positioned on an opposing side of the driver board 406 to provide further thermal conduction and/or electrical insulation from a housing or other mounting surface. Bolts 412 (such as 2-56 bolts) or other mounting hardware may also provide thermal paths to dissipate heat from the LEDs 404 during operation and/or electrical grounding for the system.

[0027] Fig. 5 provides an exploded view of an LED module. In general, the module 500 may include a filter ring 502, a filter 504, a metallized circuit board 506 with a number of LEDs 508, a thermal pad 510, a driver circuit board 512 with at least one connector 514 for coupling to the metallized circuit board 506 and at least one connector 516 for external connections, a second thermal pad 518, and a housing 520.

[0028] The filter ring 502 and the filter 504 may be positioned on a light output side of the housing 520. The filter ring 502 may be threaded to the housing, or provide a twist lock, friction fit, or other means for securely engaging the housing and holding the filter 504 in position so that the filter 504 is securely retained and removable/replaceable on the housing 520. The filter 504 may provide any form of light conditioning desired for output from the module such as low-pass filtering, high-pass filtering, or band-pass

filtering. The filter may, for example, provide a narrow band pass centered on an excitation frequency, or attenuate light above and/or below visible light wavelengths. It will be understood that a number of alternative arrangements are possible. For example, the filter ring 502 and filter 504 may be omitted, or clear optical glass or other non-wavelength conditioning transparent or translucent material may be employed as the filter 504 in order to keep dust and other airborne particles off the LEDs 508. In other embodiments, the filter 504 may include a lens or other optics to focus, defocus, or otherwise condition light emitted from the module 500. In other embodiments, the filter 504 may be permanently affixed to the housing for a dedicated, single-purpose module 500.

[0029] The metallized circuit board 506 may be any of the metallized circuit boards described above. In general, the metallization on the metallized circuit board 506 provides thermal dissipation as described above, and provides electrical traces to couple the LEDs 508 to the driver circuit board 512. These traces may connect the LEDs to the driver board in parallel, in series, or some combination of these (e.g., two parallel groups of six LEDs in series). In one embodiment, the metallized circuit board 506 is substantially circular, although other shapes may be employed such as a cross-section corresponding to an interior of the housing 520, or any shape with additional surface area outside the LED mounting area to provide additional heat-dissipation surface area. As noted above, the metallized circuit board 506 may be at least 80% metallized on a front and back side thereof, at least 90% metallized on a front and back side thereof, or metallized some other amount consistent with the systems described herein.

[0030] The LEDs 508 may be any LEDs suitable for an intended use of the module 500. This may include narrow band, single wavelength LEDs, such as for an fluorescence excitation light source. Single wavelength LEDs may operate within the visible light spectrum or any suitable adjacent spectrum. The module 500 may also or instead include broadband white light LEDs, or some combination of different frequencies and/or white light. For illumination as discussed above, the LEDs may be high-brightness, through-hole mounted LEDs packed in close proximity to one another and/or in contact with one another. A hexagonal pattern provides a useful, high-density arrangement for generally circular groups of LEDs. The principles of the system

described herein may also be adapted to surface mounted LEDs or other packaging standards, although a surface mount package will necessarily reduce the amount of metallization that can be provided on one surface of the metallized circuit board 506.

[0031] The thermal pad 510 may be any thermally conducting and/or electrically insulating pad that can separate the metallized circuit board 506 from the driver circuit board 512. This may also or instead include a thermal paste, a thermal adhesive, a composite material including thermally conductive and electrically insulating layers, or any combination of these.

[0032] The driver circuit board 512 holds circuitry to drive the LEDs 508 and to provide thermal management and the like. A driver circuit, which may be, for example, the integrated circuit 306 described above (along with supporting passive and/or active circuitry), may include any circuitry suitable for driving LEDs as described herein. The driver circuit may also include at least one temperature control integrated circuit such as the calibrated temperature integrated circuit 302 described above, or any combination of the foregoing. The driver circuit may receive a control signal through the connector(s) 516 on one side of the driver circuit board 512, and generate responsive drive signals to the plurality of LEDs 508 through the connector(s) 514 on the other side of the driver circuit board 512. It will be understood that a variety of suitable circuits are known for driving LEDs and may be employed with the module 500 described herein including dedicated LED drive chips as well as various combinations of general purpose discrete and active electronic components. The driver circuit may be designed to drive the LEDs 508 at a frequency of at least 35 MHz and/or at a full power producing at least nine milliWatts of usable optical power per LED. The driver circuit may be configured to drive the LEDs at full power while modulating at 35 MHz or greater.

[0033] One or more connectors 514 on one side of the driver circuit board 512 may provide electrical connections to the metallized circuit board 506 in order to electrically couple the circuitry of the driver circuit board 512 to the LEDs 508 of the metallized circuit board 506. On the other side of the driver circuit board 512, one or more connectors 516 may be provided for coupling the driver circuit board 512 to an external source of power and/or control. The connector(s) 516 may, for example, connect to a five-conductor ribbon cable or the like. While it is possible to provide drive signals

for the LEDs 508 from an external source as well, this configuration may make it more difficult to operate the module 500 at high frequency due to, e.g., wire capacitance and length. In general, the driver circuit board 512 may be positioned close to and generally parallel to the metallized circuit board 506, with only a thermal pad or other similar layer therebetween.

[0034] The housing 520 may provide a general protective exterior to the module 500, and may also be integrated into thermal management for the LEDs such as by thermally coupling the housing 520 to the metallized circuit board 506 using bolts or other thermal couplings. Silicone gel or the like may be injected into the housing 520 and/or around various components of the module to provide improved thermal conductance between the circuit boards 506, 512, LEDs 508, and the housing 520. The housing may be formed of aluminum or any other suitable material. The housing 520 may, for example, have exterior dimensions of 35 mm by 30.5 mm by 30.5 mm. It will be understood that housings composed of materials and having other dimensions may also suitably be employed, and all such housings consistent with the LED module 520 as described herein are intended to fall within the scope of this disclosure.

[0035] As a significant advantage, the module 500 described herein provides coupling through short leads between the drive circuit and the LEDs 508, which can mitigate stray capacitance and phase variations at high frequencies, as distinguished from conventional designs that position driver circuitry relatively far from the LEDs in order to avoid overheating. With the system described herein, the driver circuit board 512 may be placed substantially directly against the metallized circuit board 506 that carries the LEDs 508, with only a thin thermal pad or the like between them.

[0036] Fig. 6 shows a lighting system using a number of LED modules. In general, the system 600 may include a number of lighting modules 602, which may be the module 500 described above, arranged in an enclosure 604. The enclosure 604 may provide a backplane that provides connectors for each of the lighting modules 602, and couples the lighting modules 602 to a power source 606 and a control source 608. The power source 606 may, for example, provide a 5 V DC power source with sufficient power to supply full power current to the LEDs and drive circuits within the enclosure 604. The control source 608 may, for example, be a general purpose computer with any

suitable input/output hardware to couple to the backplane of the enclosure, or a dedicated controller, or any other suitable source of control signals for the lighting modules 602.

As depicted, the system may operate to provide useful illumination at adequate frequencies (e.g., 30 MHz +) for frequency domain photon migration techniques and other applications requiring high-frequency, modulated light sources with one or more known frequencies or ranges of frequencies. Fully metallized circuit boards, as generally described herein (either with or without a thin mask), have been demonstrated to improve (i.e., reduce) operating temperature by over 10°C on the top surface and 8°C on the bottom surface relative to a conventional circuit board construction.

[0037] While particular embodiments of the present invention have been shown and described, it will be apparent to those skilled in the art that various changes and modifications in form and details may be made therein without departing from the spirit and scope of this disclosure and are intended to form a part of the invention as defined by the following claims, which are to be interpreted in the broadest sense allowable by law.

[0038] All documents mentioned herein are hereby incorporated in their entirety by reference. References to items in the singular should be understood to include items in the plural, and vice versa, unless explicitly stated otherwise or clear from the text. Grammatical conjunctions are intended to express any and all disjunctive and conjunctive combinations of conjoined clauses, sentences, words, and the like, unless otherwise stated or clear from the context.

CLAIMS

What is claimed is:

1. An LED module comprising:
 - a first printed circuit board, the first printed circuit board having a substantially fully metallized surface on a front side and a back side thereof;
 - a plurality of light emitting diodes mounted to the front side of the first printed circuit board;
 - a thermal layer formed of a thermally conductive, electrically insulating material, the thermal layer disposed on the back side of the first printed circuit board;
 - a second printed circuit board having a front side abutting the thermal layer and a back side opposite the thermal layer; and
 - a driver circuit mounted on the back side of the second printed circuit board, the driver circuit coupled to the plurality of light emitting diodes through the second printed circuit board, the thermal layer, and the first printed circuit board.
2. The LED module of claim 1 further comprising at least one temperature control integrated circuit on the second printed circuit board.
3. The LED module of claim 1 wherein the plurality of light emitting diodes includes at least twelve light emitting diodes.
4. The LED module of claim 1 further comprising an aluminum housing for the first printed circuit board, the second printed circuit board, the thermal layer, the plurality of light emitting diodes, and the driver circuit.
5. The LED module of claim 4 further comprising at least one filter for conditioning output from the plurality of light emitting diodes.

6. The LED module of claim 4 further comprising a connector mounted to the housing, the connector electrically coupled to the driver circuit and including a plug receptacle for connecting the LED module to an external source.
7. The LED module of claim 6 wherein the external source is at least one of a power source and a control source.
8. The LED module of claim 1 wherein the thermal layer includes a thermal pad.
9. The LED module of claim 1 wherein the thermal layer includes a thermal paste.
10. The LED module of claim 1 wherein the thermal layer is a multi-layer material including an electrical insulation layer and a thermal conducting layer.
11. The LED module of claim 1 wherein the first printed circuit board is at least 80% metallized on the front side and the back side thereof.
12. The LED module of claim 1 wherein the first printed circuit board is at least 90% metallized on the front side and the back side thereof.
13. The LED module of claim 1 wherein the driver circuit provides a drive signal to one or more of the plurality of light emitting diodes in response to a control signal.
14. The LED module of claim 1 wherein the plurality of light emitting diodes includes a plurality of through-hole light emitting diodes positioned in contact with one another.
15. The LED module of claim 1 wherein the first circuit board is substantially circular.

16. The LED module of claim 1 wherein the first circuit board includes two or more mounting through-holes thermally coupled to a copper that forms the substantially fully metallized surface of at least one of the front side and the back side thereof.

17. An LED module comprising:

a first circuit board, the first circuit board having a substantially fully metallized surface on a front side and a back side thereof;

a plurality of light emitting diodes mounted to the front side of the first circuit board;

a second circuit board having a driver circuit, the driver circuit electrically coupled to the plurality of light emitting diodes and adapted to receive a control signal and to generate a responsive drive signal to the plurality of light emitting diodes.

18. The LED module of claim 17 wherein the second circuit board is substantially parallel and adjacent to the first circuit board, the first circuit board and the second circuit board separated by a thermal layer.

19. The LED module of claim 17 wherein the substantially fully metallized surface of the front side of the first circuit board includes holes for a plurality of leads of the plurality of light emitting diodes.

20. The LED module of claim 17 wherein the substantially fully metallized surface of the back side of the first circuit board includes traces for coupling a plurality of leads of the plurality of light emitting diodes to the driver circuit.

21. The LED module of claim 17 wherein the driver circuit can drive the plurality of light emitting diodes at a frequency of at least 35 MHz.

22. The LED module of claim 17 wherein the driver circuit can drive the plurality of light emitting diodes concurrently at a full power producing at least nine milliWatts of usable optical power per light emitting diode.

23. The LED module of claim 22 wherein the driver circuit can drive the plurality of light emitting diodes concurrently at full power while modulating the plurality of light emitting diodes at at least 35 MHz.

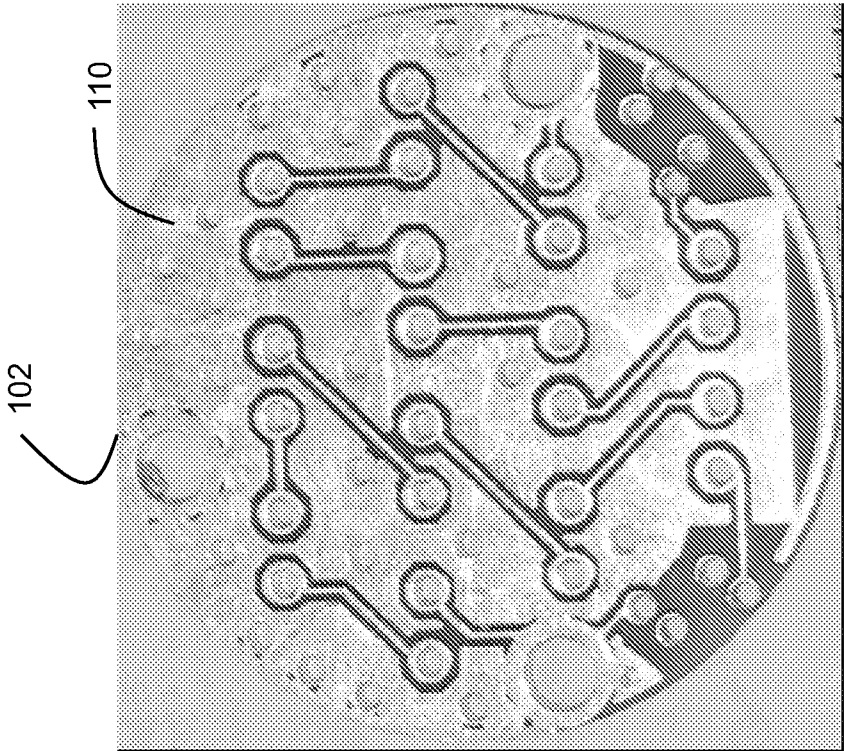


Fig. 1B

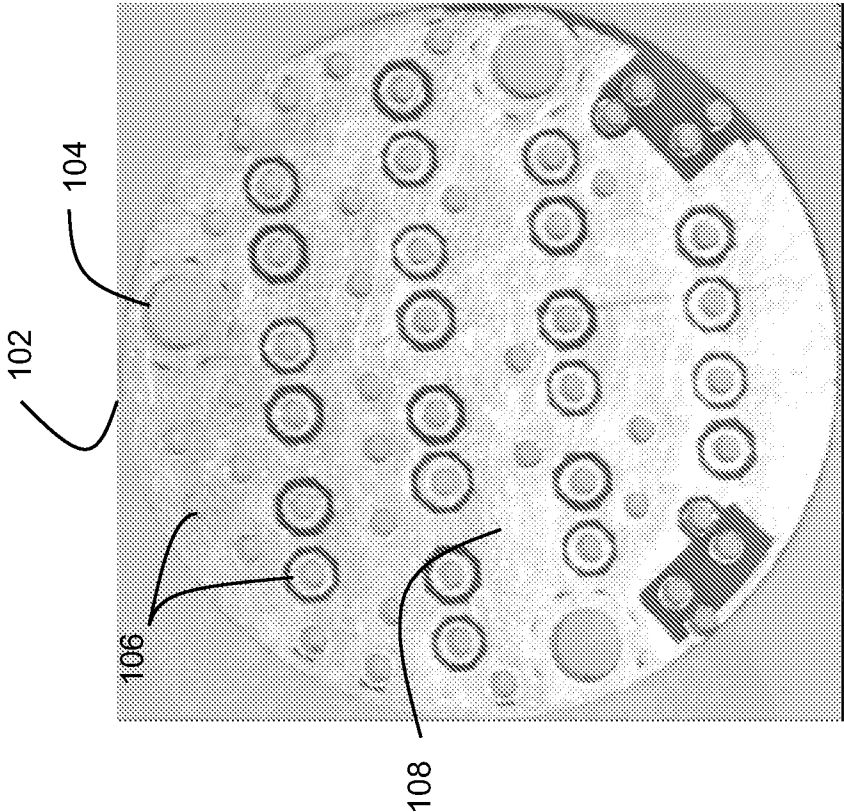


Fig. 1A

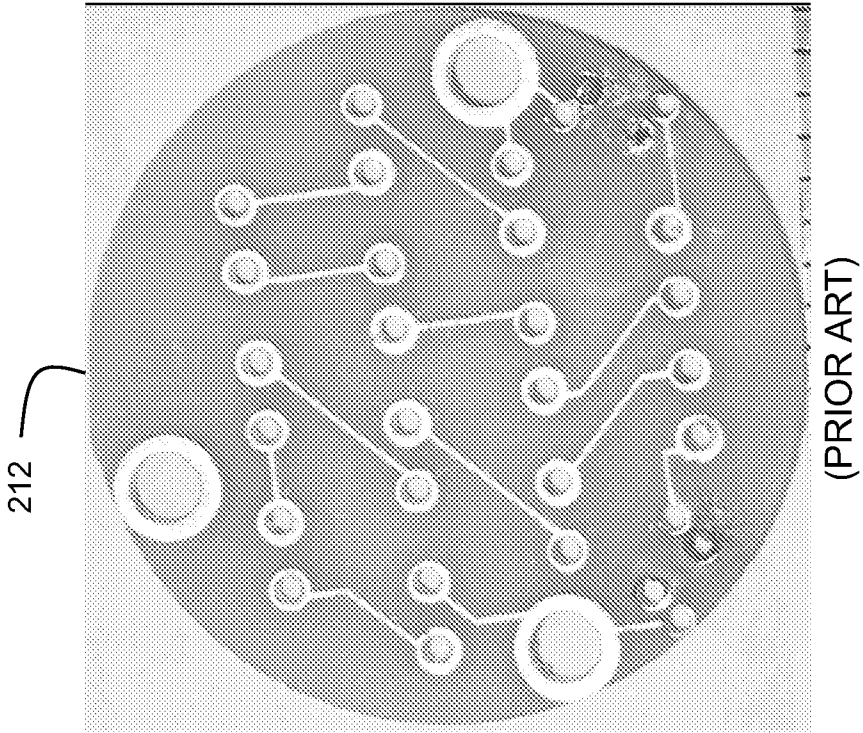


Fig. 2B

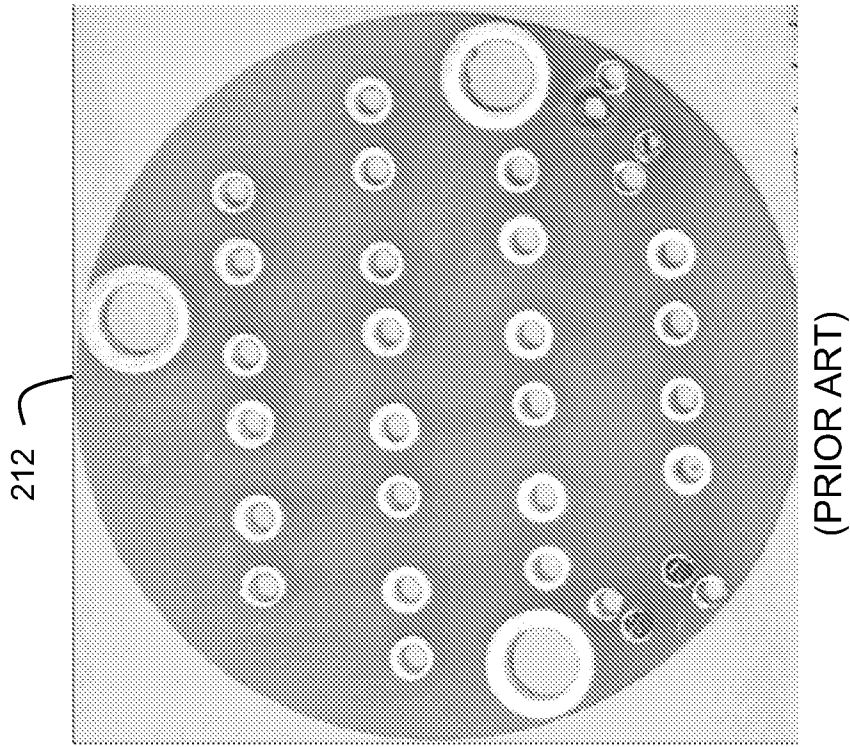


Fig. 2A

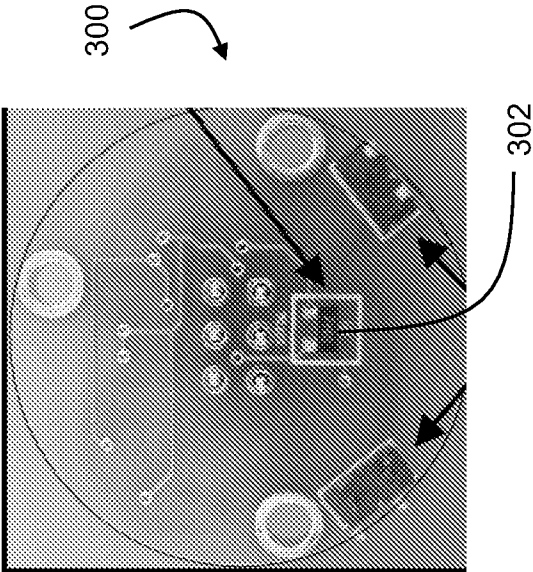


Fig. 3B

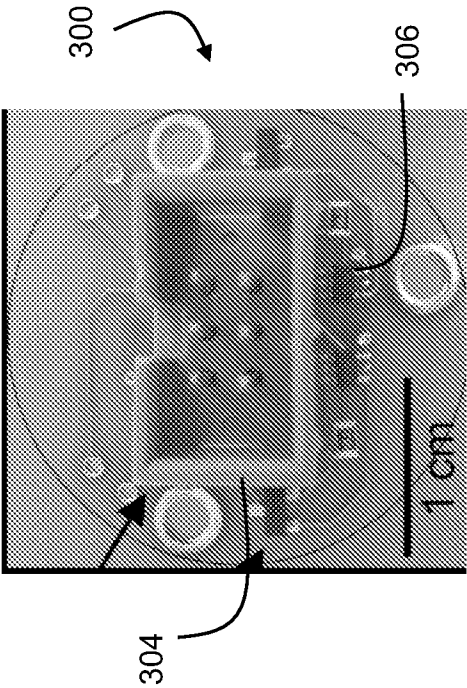


Fig. 3A

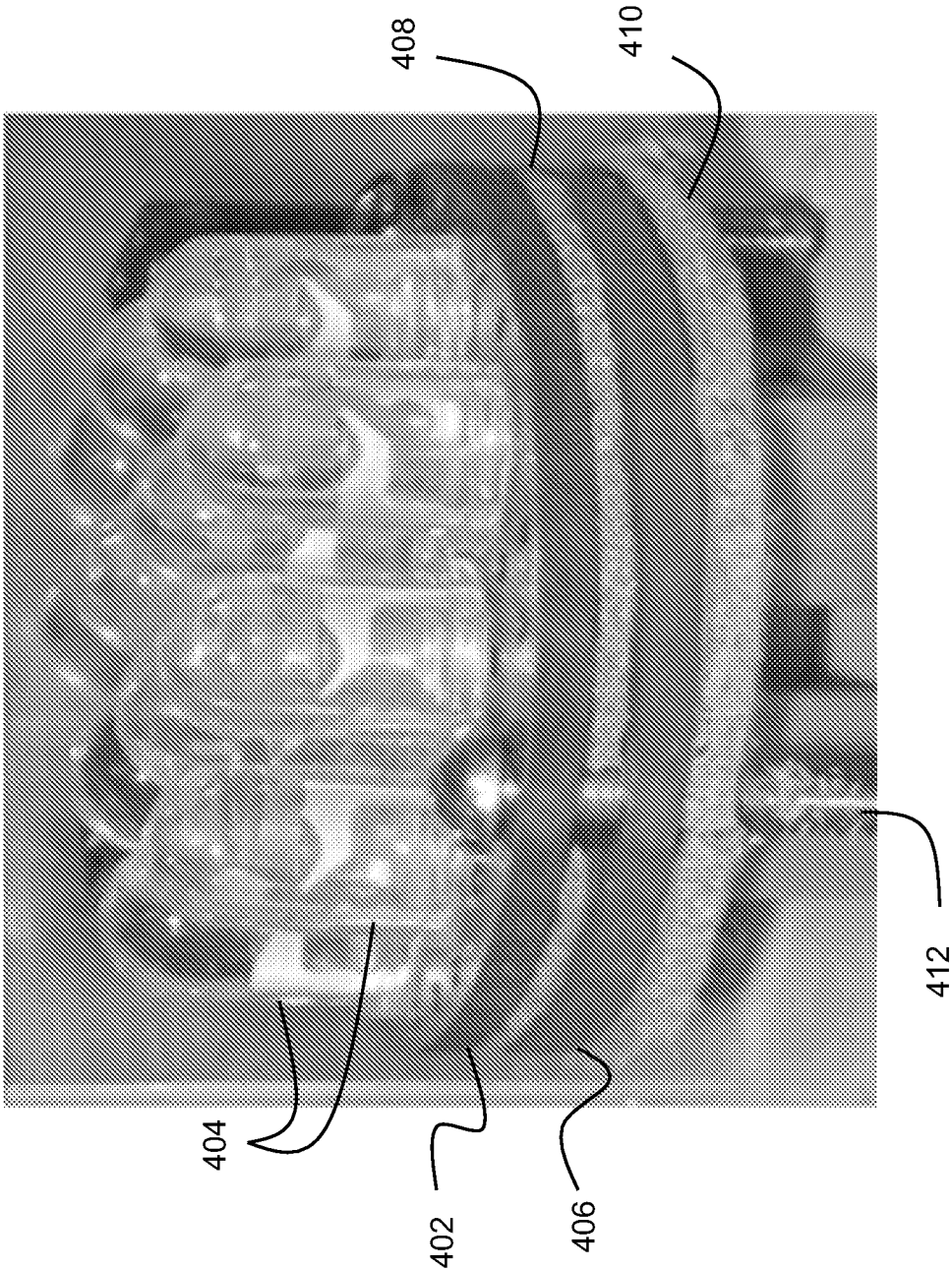


Fig. 4

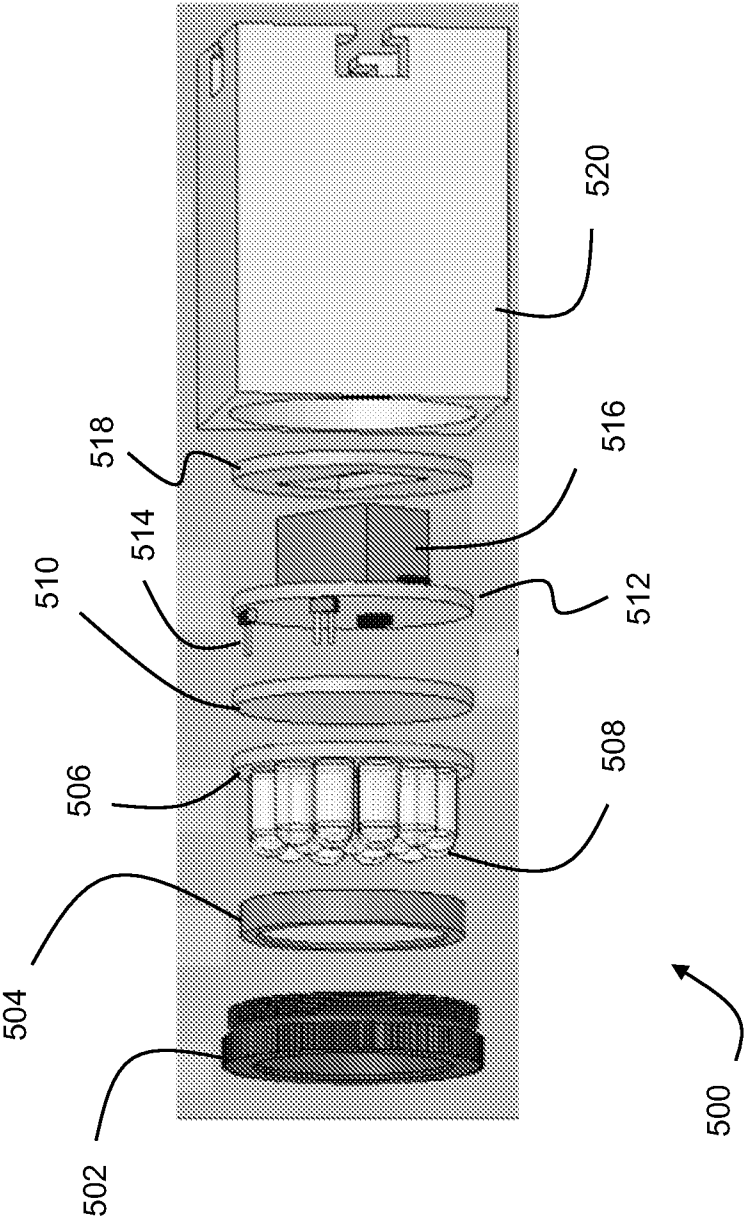


Fig. 5

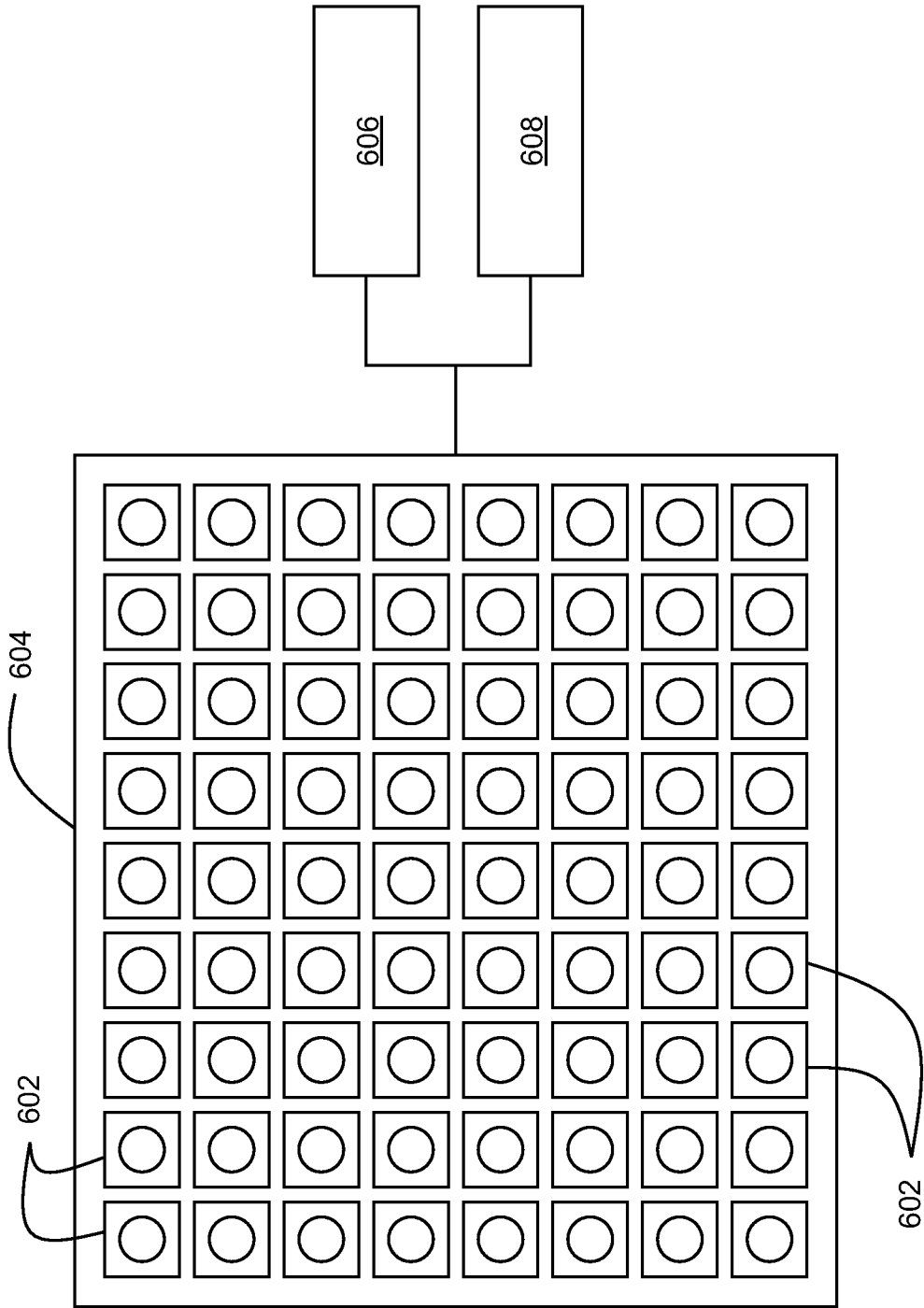


Fig. 6