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Jaffe et al.

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(54) **SOLID STATE LIGHT SOURCE FOR PHOTOCURING**

(71) Applicant: **LUMENCOR, INC.**, Beaverton, OR (US)

(72) Inventors: **Claudia B. Jaffe**, Portland, OR (US); **Steven M. Jaffe**, Portland, OR (US); **George S. Tylinski**, Portland, OR (US)

(73) Assignee: **LUMENCOR, INC.**, Beaverton, OR (US)

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F21V 11/00	(2015.01)
F21V 8/00	(2006.01)
G02B 27/10	(2006.01)

(Continued)

(52) **U.S. Cl.**

CPC ***F21V 29/004*** (2013.01); ***A61C 19/003*** (2013.01); ***F21V 11/00*** (2013.01); ***G02B 6/0008*** (2013.01); ***G02B 27/10*** (2013.01); ***G02B 27/141*** (2013.01); *G02B 6/3849* (2013.01); *G02B 6/4292* (2013.01); *G02B 2006/4297* (2013.01)

(58) **Field of Classification Search**

CPC A61B 19/004; A61B 19/003; A61N 2005/0652; F21W 2131/202

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See application file for complete search history.

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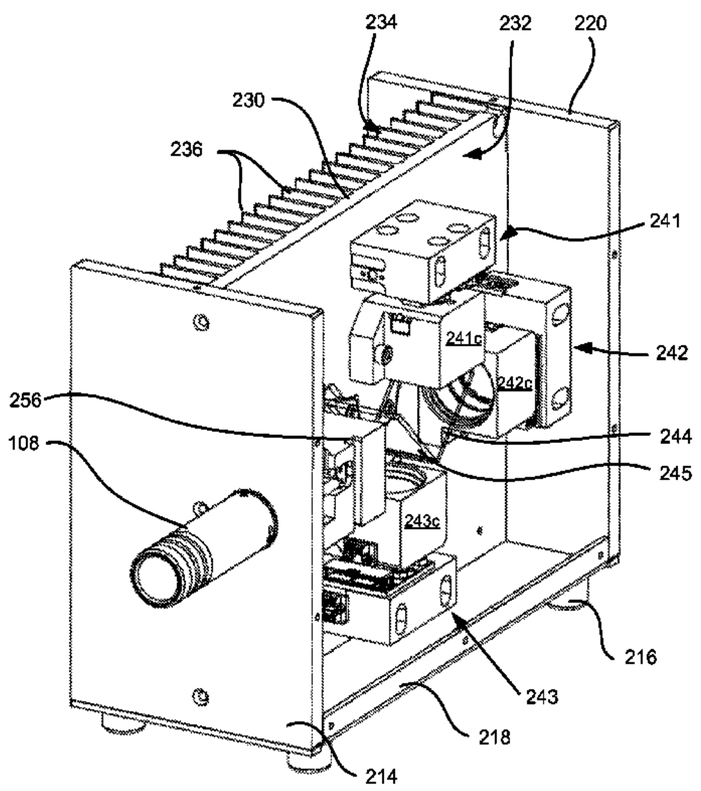
Primary Examiner — Peggy Neils

(74) *Attorney, Agent, or Firm* — Tucker Ellis LLP

(57) **ABSTRACT**

A compact passively-cooled solid state illumination system is provided as a replacement for conventional arc light, metal halide and Xenon white-light sources for photocuring applications. The solid state illumination system utilizes LED modules to generate high intensity light output suitable for photocuring. The light output is continuous in the visible spectrum from 380 nm to 530 nm and is suitable for photocuring using a wide range of photoinitiators. A touchscreen interface allows programming of spectral output, intensity and duration. Output can be initiated using the touchscreen interface and/or a foot pedal.

14 Claims, 9 Drawing Sheets



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FIG. 1A


110
100
108
104
102
106

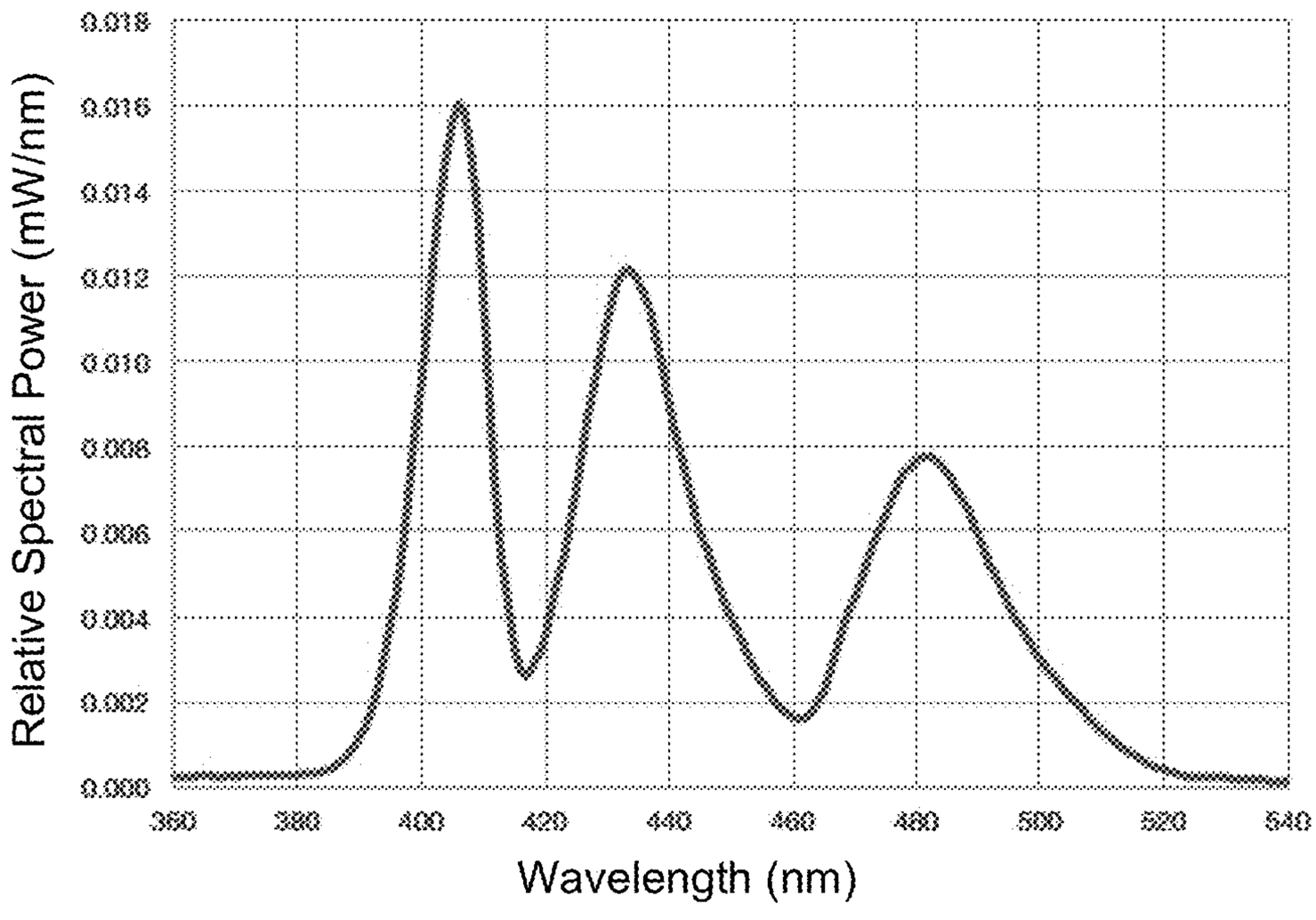
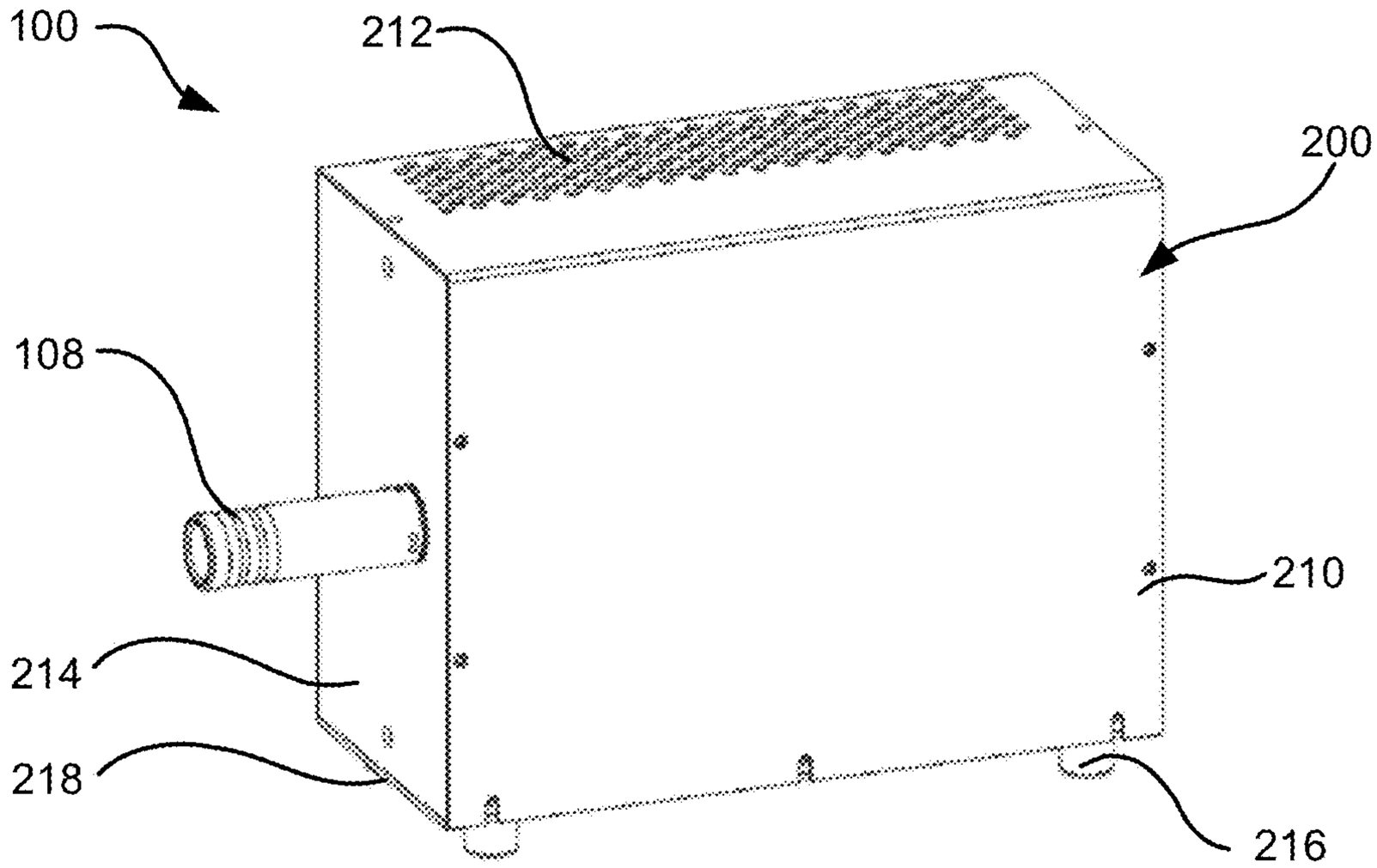

Relative Spectral Power (mW/nm)
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
360
380
400
420
440
460
480
500
520
540
Wavelength (nm)

FIG. 1B

FIG. 2A


100
212
200
108
210
214
218
216

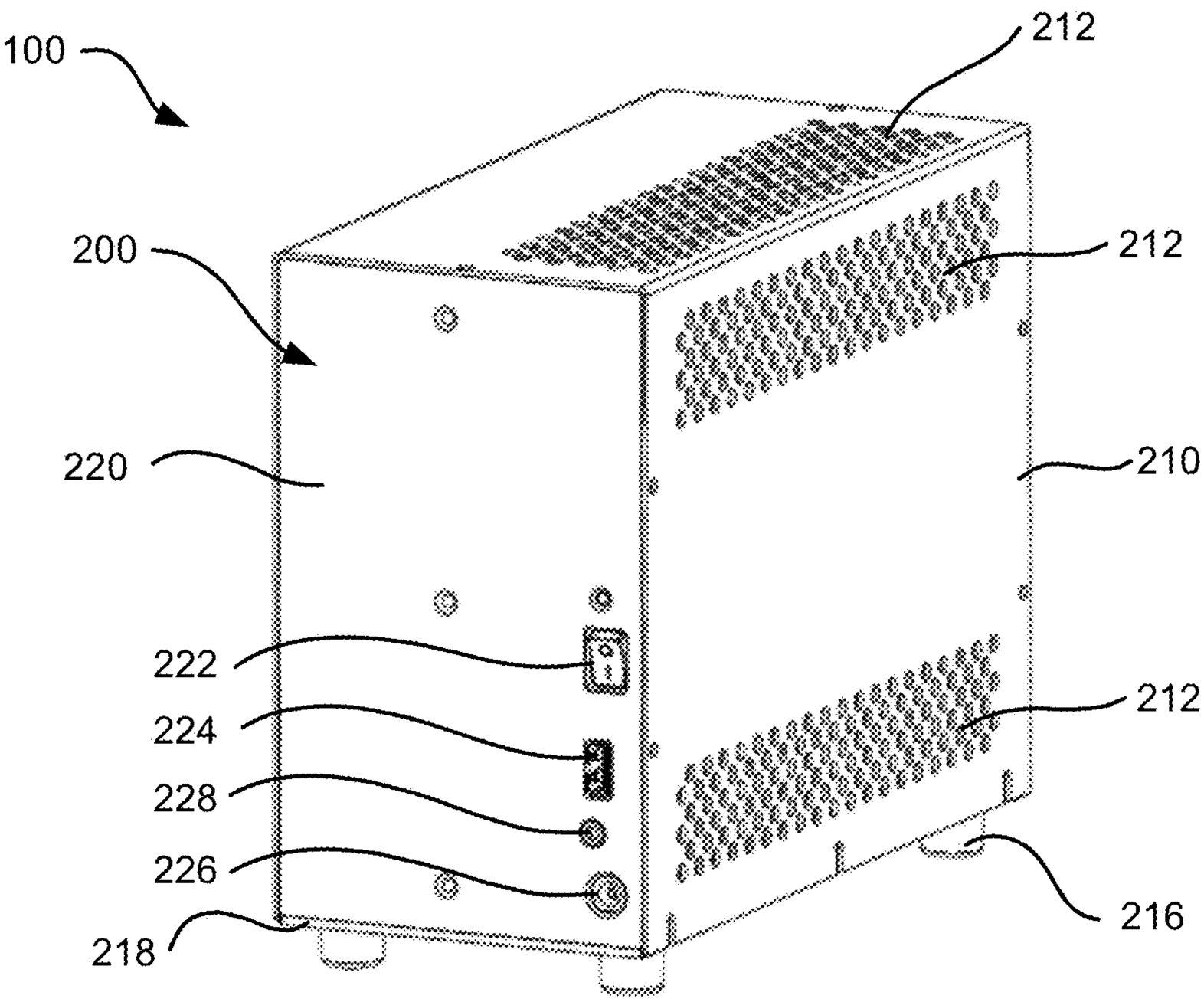
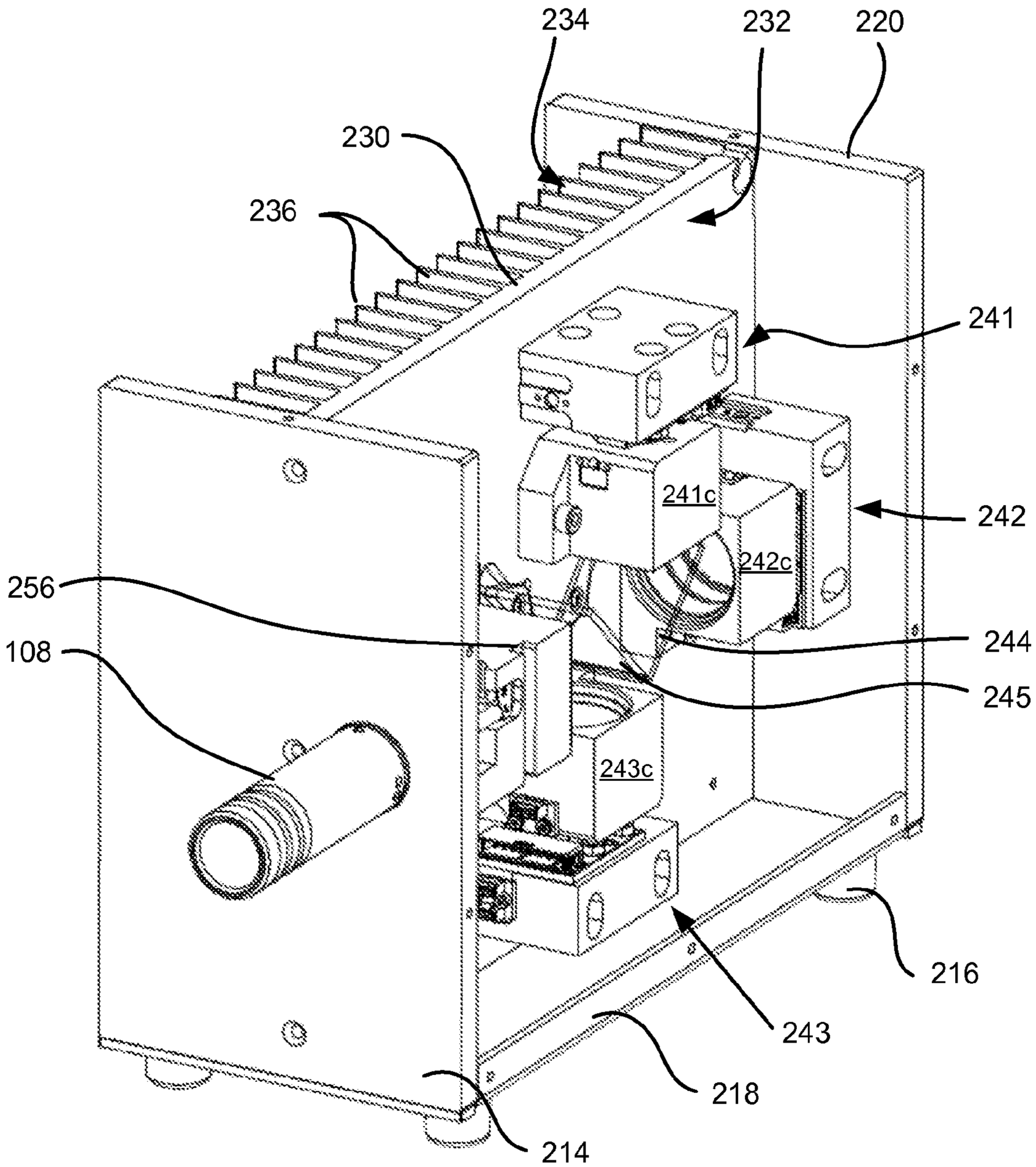

100
212
200
212
220
210
222
224
212
228
226
218
216

FIG. 2B

FIG. 2C


234
232
220
230
236
241
241c
242
242c
256
244
108
245
243c
216
243
218
214

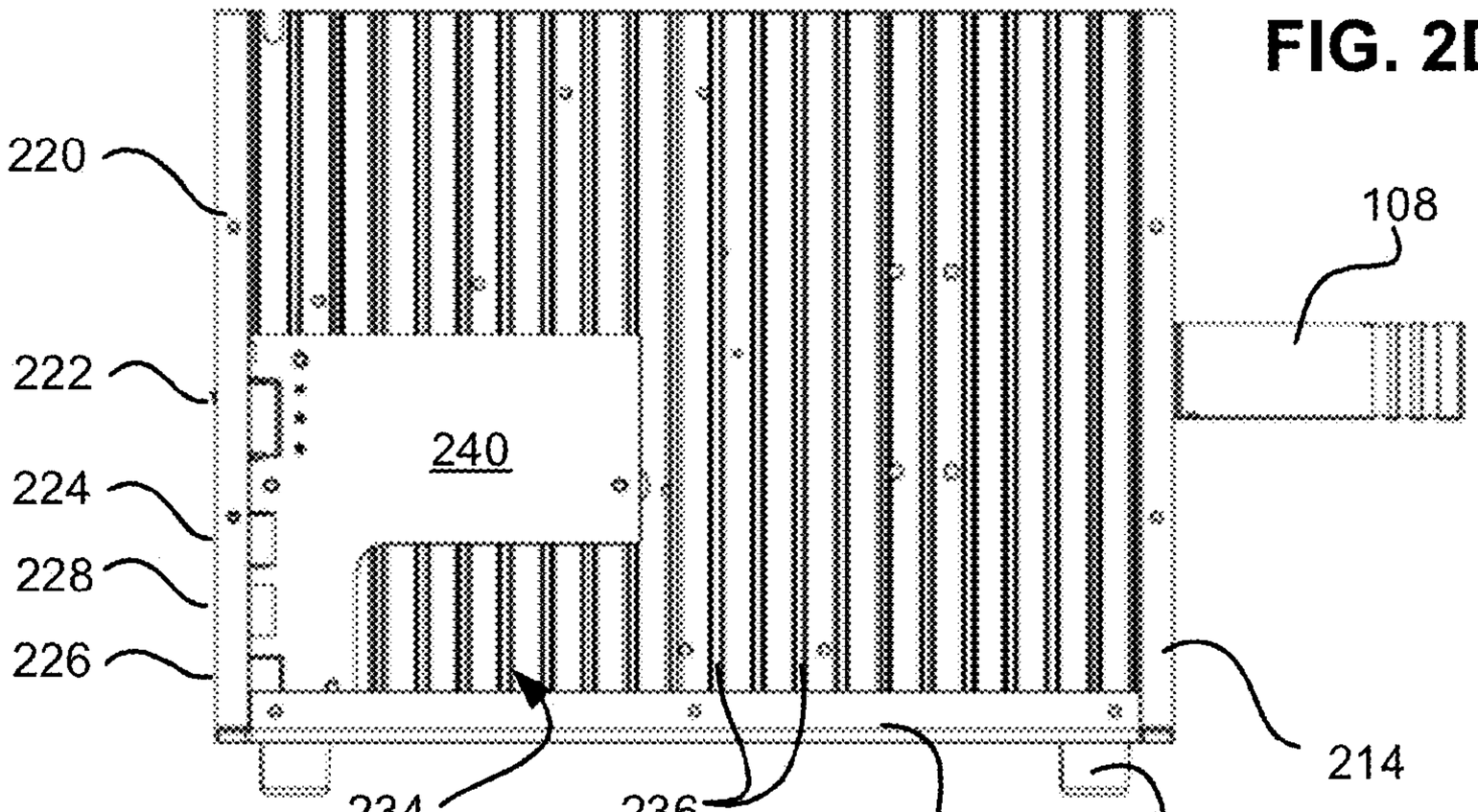


FIG. 2D

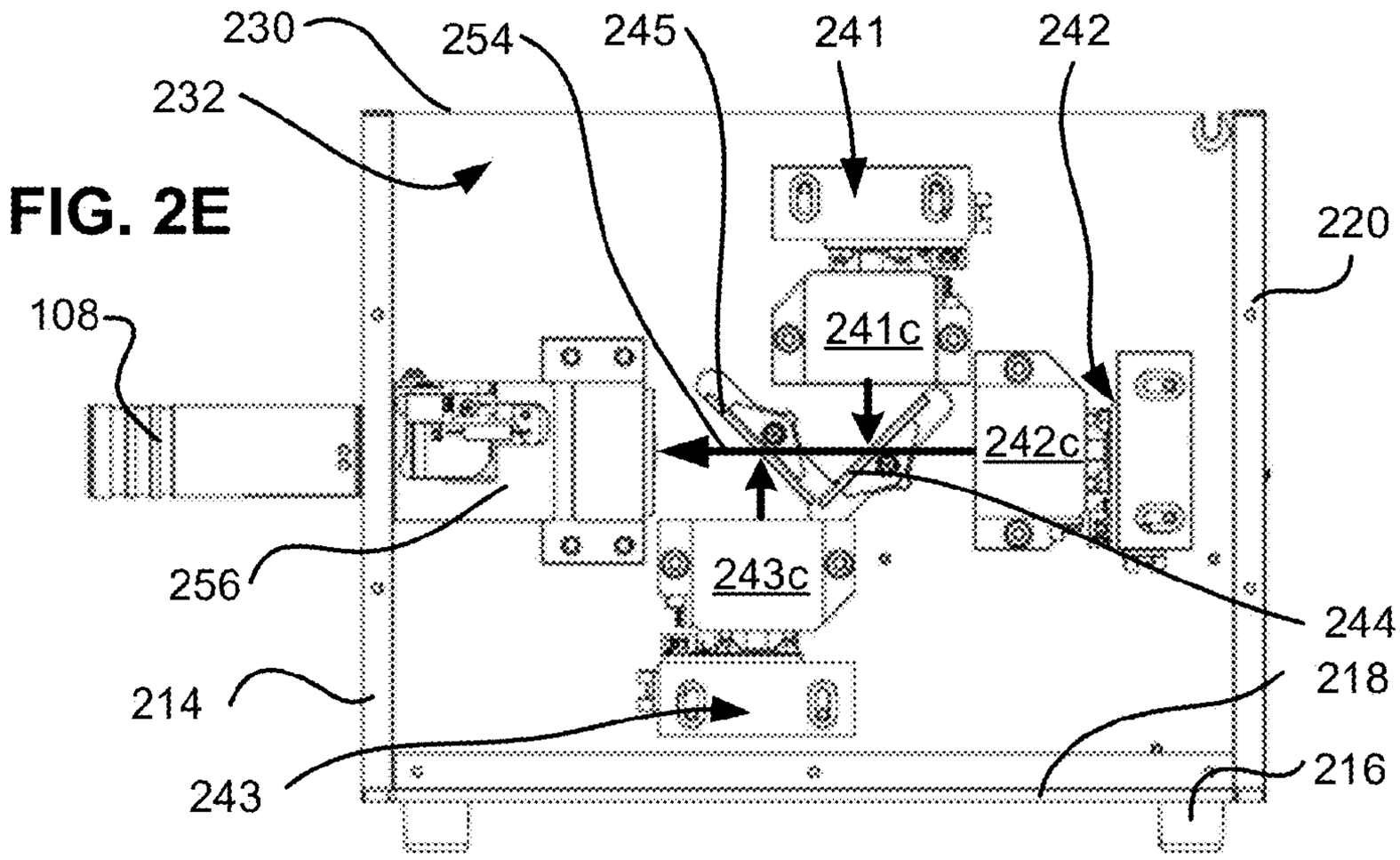


FIG. 2E

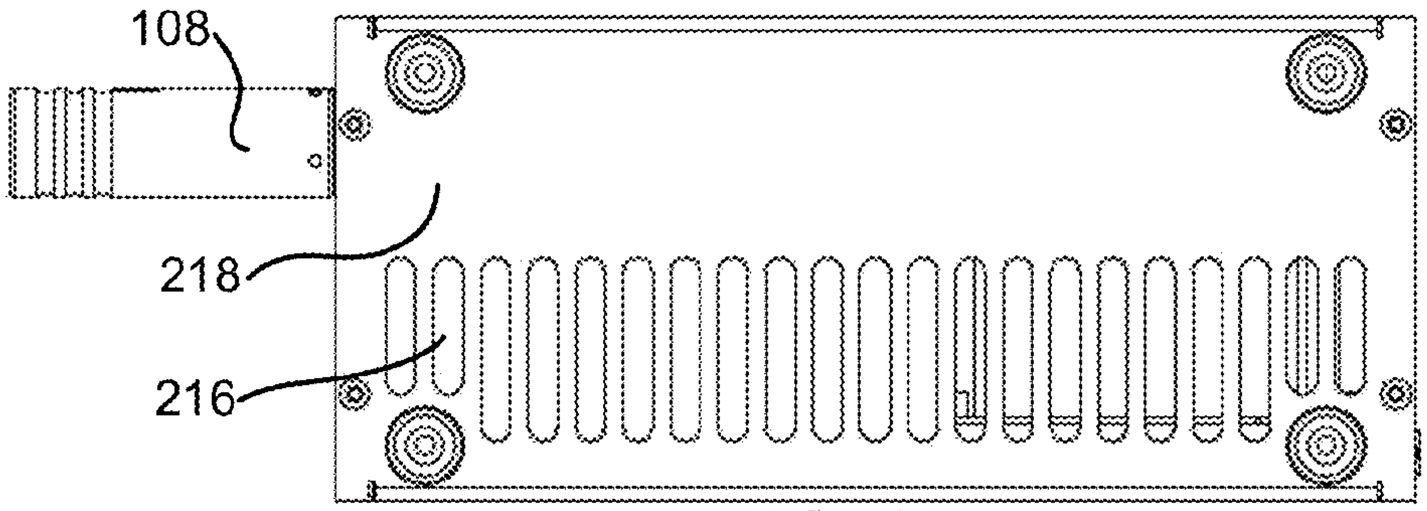


FIG. 2F

FIG. 2G

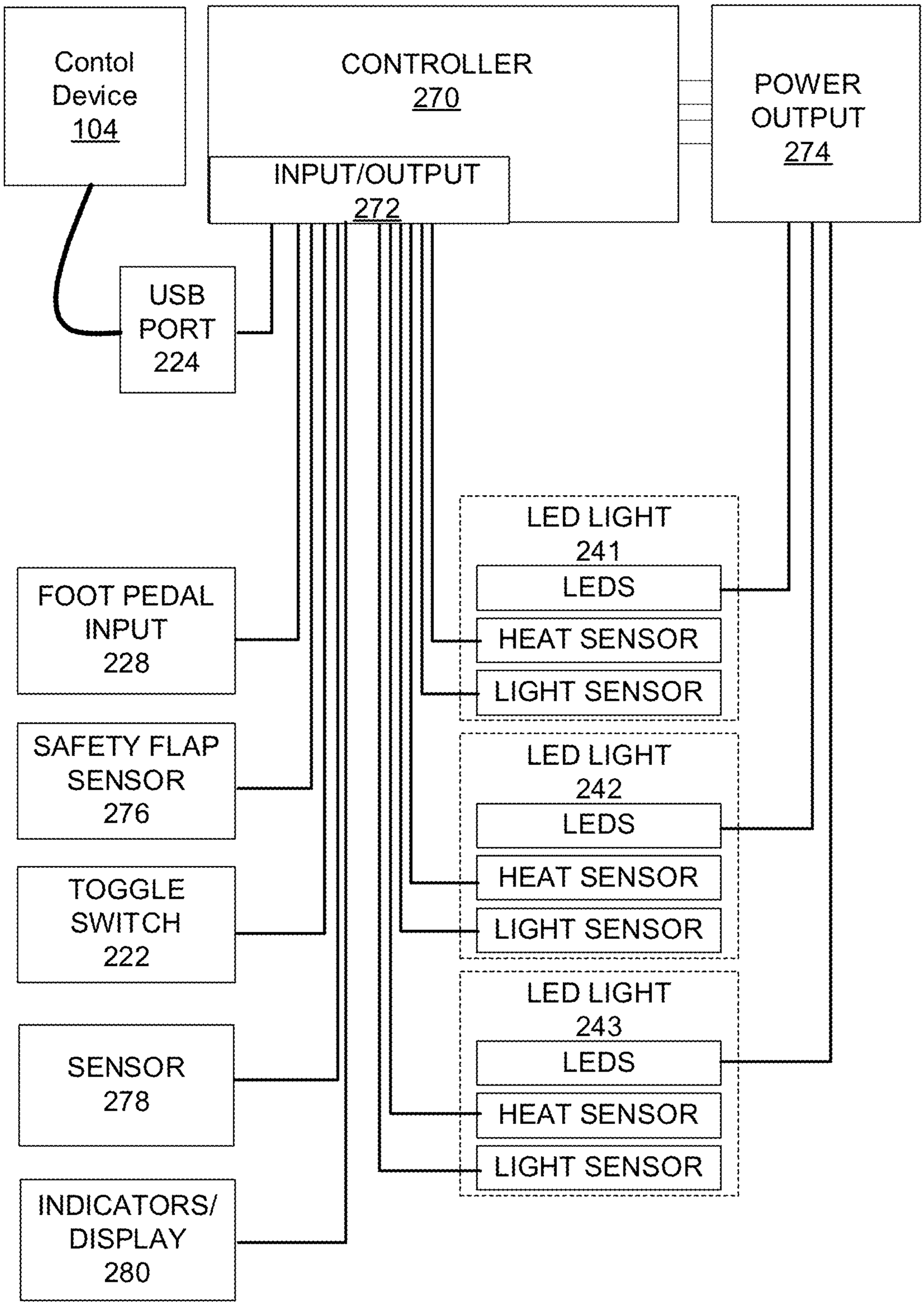
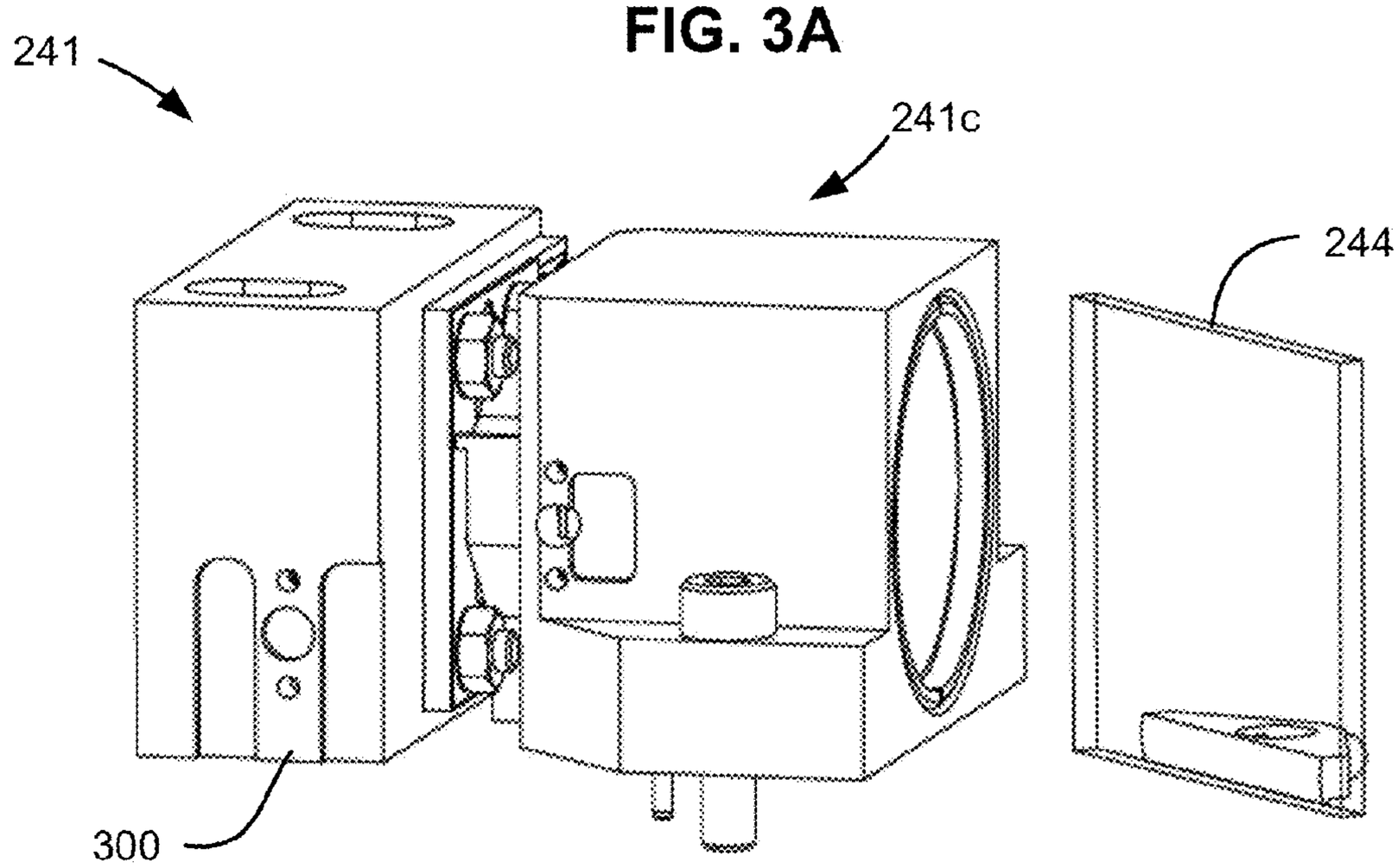

Contol Device 104
CONTROLLER 270
INPUT/OUTPUT 272
POWER OUTPUT 274
USB PORT 224
FOOT PEDAL INPUT 228
SAFETY FLAP SENSOR 276
TOGGLE SWITCH 222
SENSOR 278
INDICATORS/ DISPLAY 280
LED LIGHT 241
LEDS
HEAT SENSOR
LIGHT SENSOR
LED LIGHT 242
LEDS
HEAT SENSOR
LIGHT SENSOR
LED LIGHT 243
LEDS
HEAT SENSOR
LIGHT SENSOR

FIG. 3A



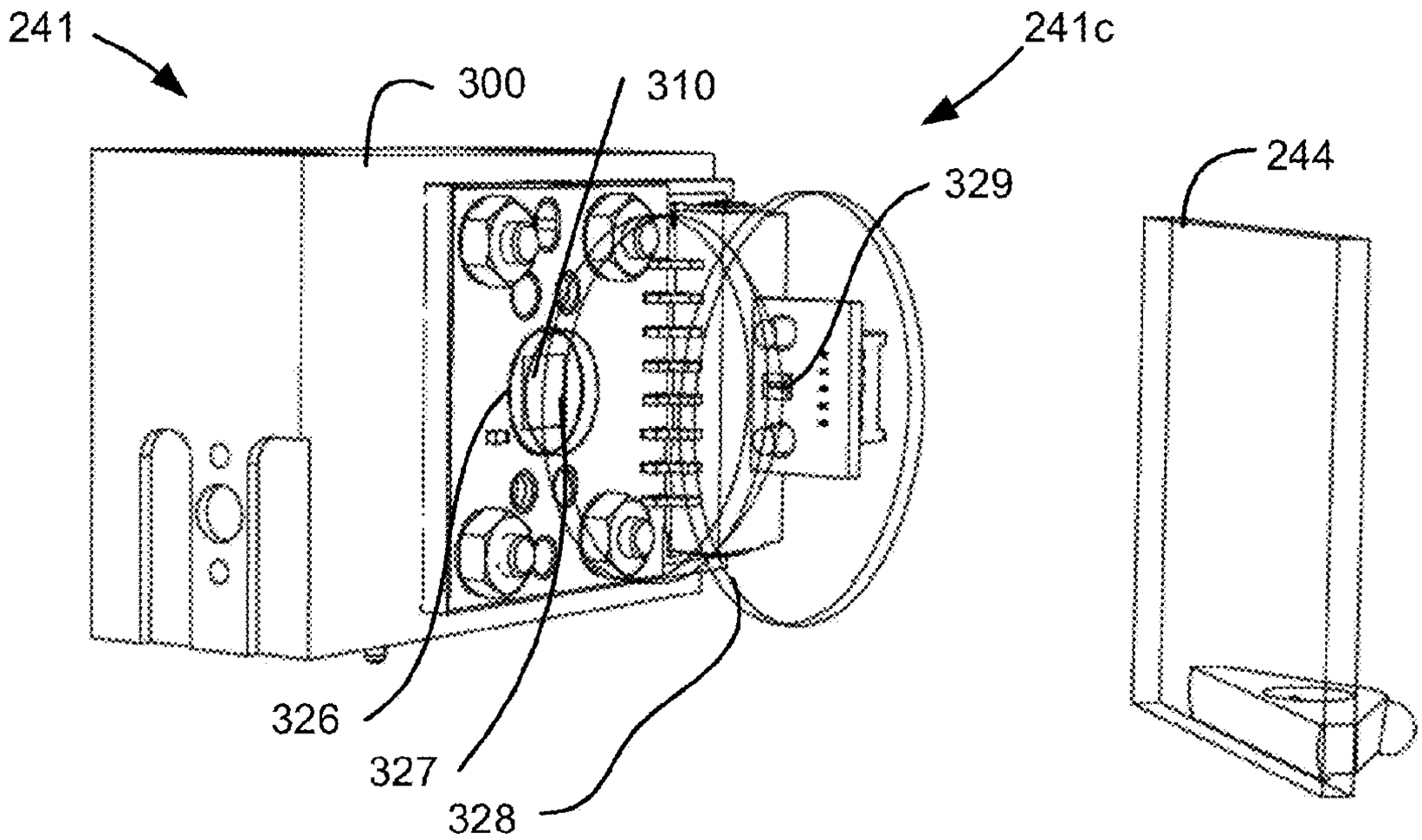


FIG. 3B

FIG. 3C

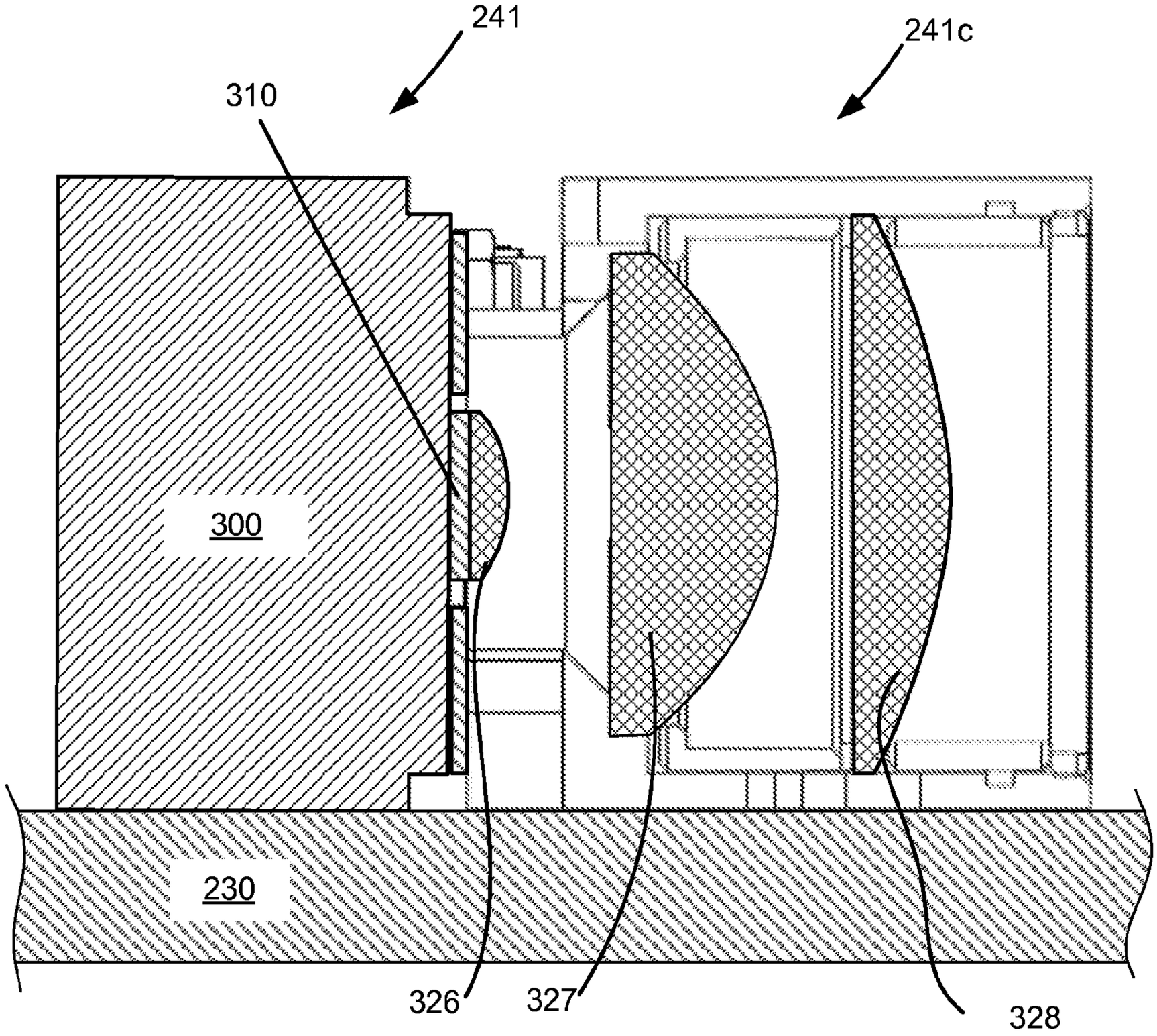
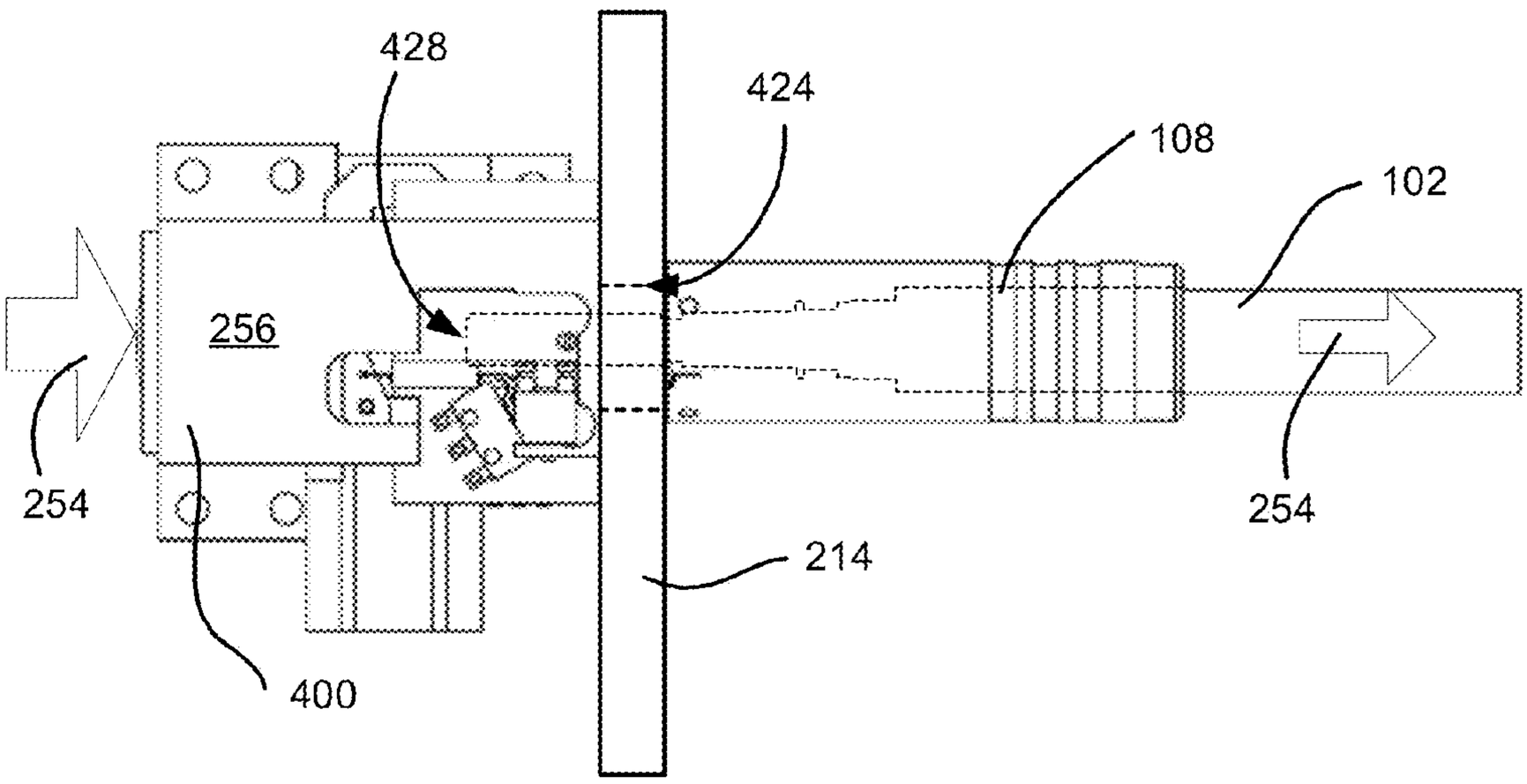


FIG. 4A



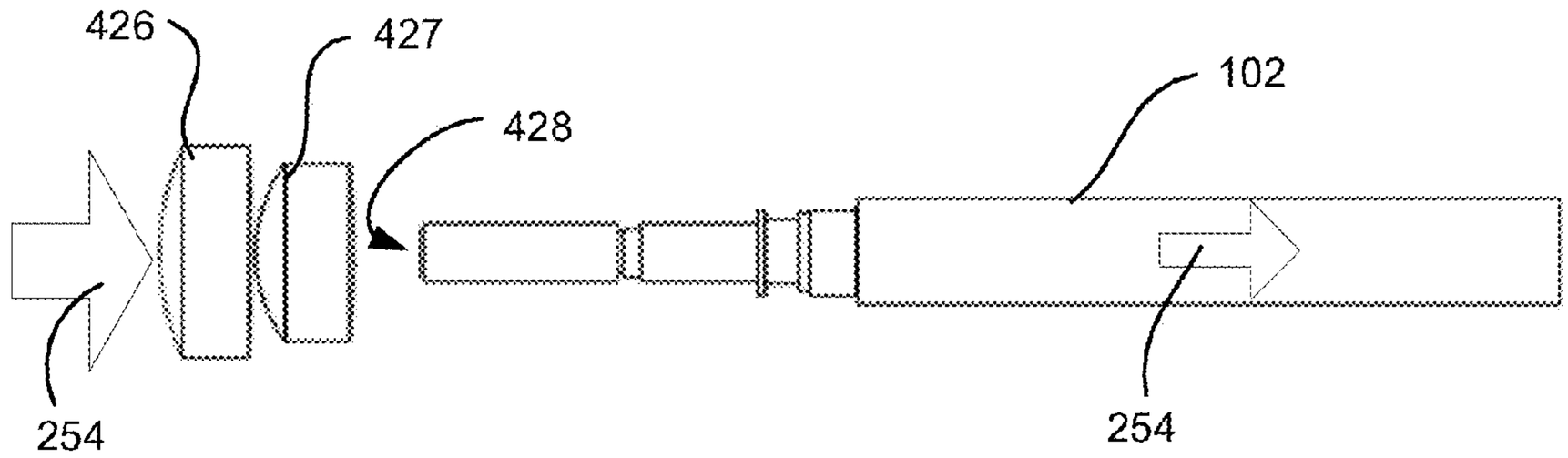
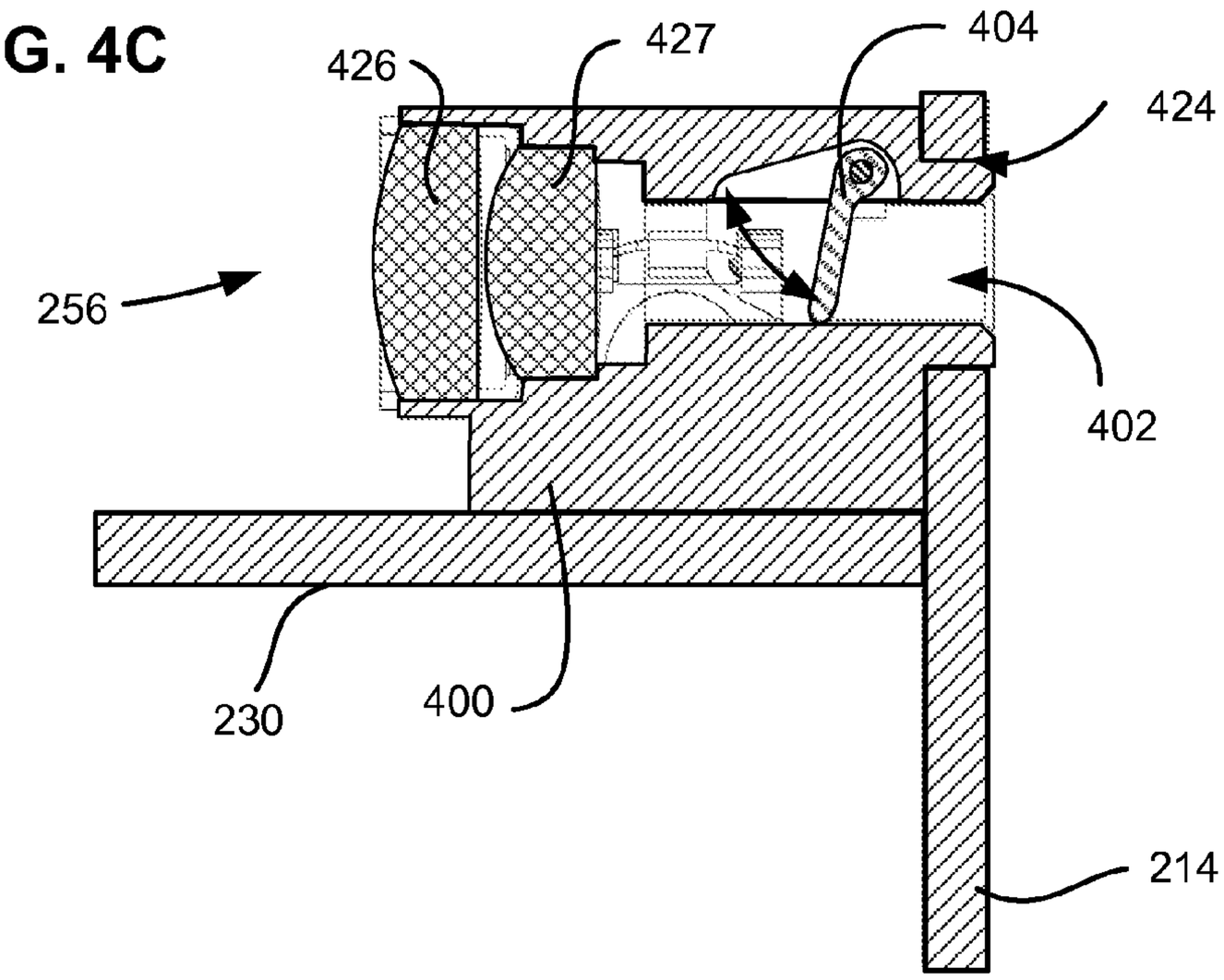


FIG. 4B

FIG. 4C


426
427
404
424
256
402
230
400
214

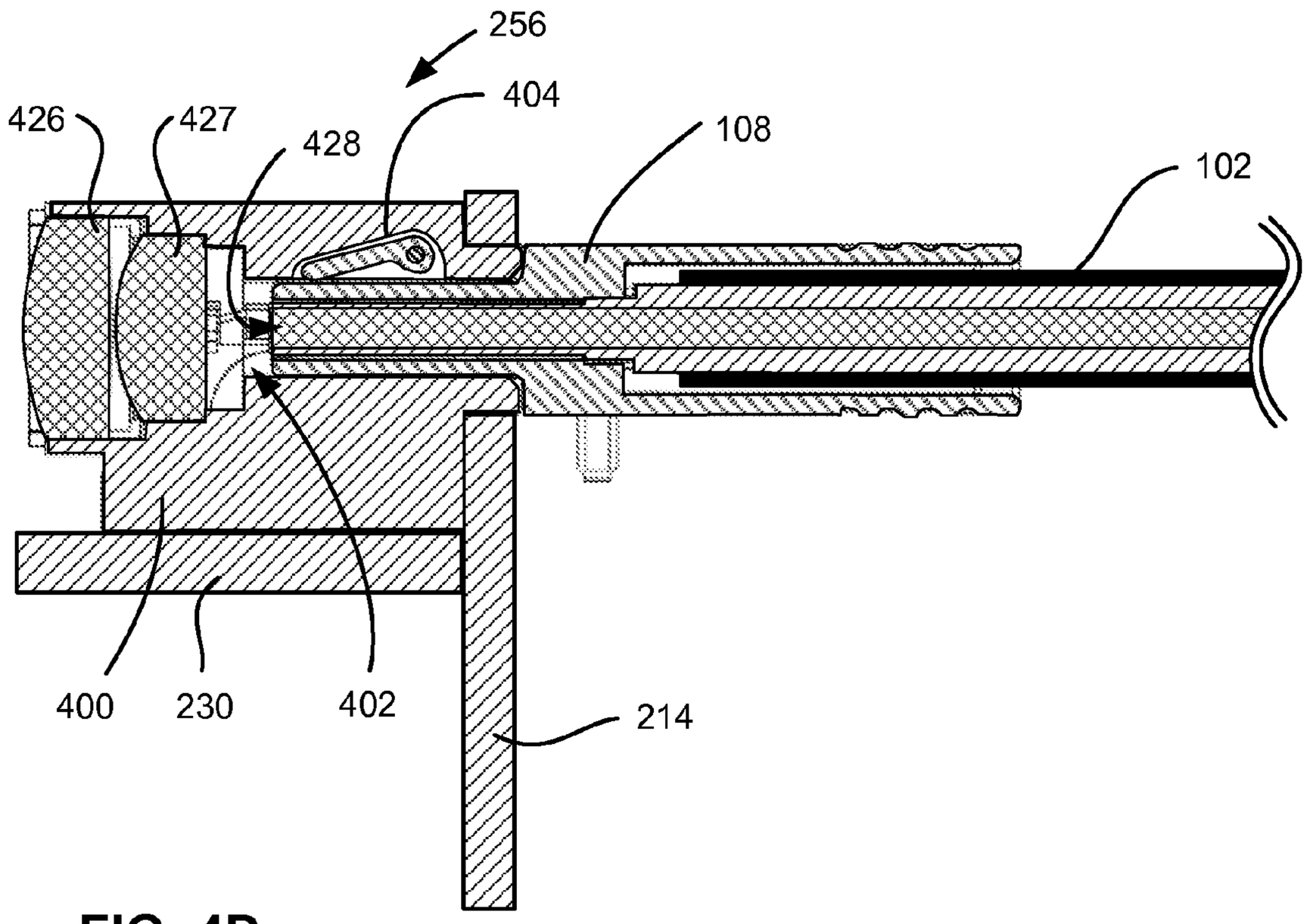

256
426
427
428
404
108
102
400
230
402
214

FIG. 4D

SOLID STATE LIGHT SOURCE FOR PHOTOCURING

CLAIM OF PRIORITY

The present application claims priority to U.S. Provisional Patent Application entitled "Solid State Light Source For Photocuring" Application No. 61/660,386, filed on Jun. 15, 2012 which application is incorporated herein by reference.

RELATED APPLICATIONS

The present application is related to the following patents and patent applications which are incorporated herein by reference in their entireties:

U.S. Pat. No. 7,846,391, granted Dec. 7, 2010, entitled "Bioanalytical Instrumentation Using A Light Source Subsystem," U.S. Publication No. 2007/0281322 filed May 21, 2007;

U.S. Pat. No. 7,709,811, granted May 4, 2010 entitled "Light Emitting Diode Illumination System," U.S. Publication No. 2009/0008573 filed Jul. 2, 2008;

U.S. Pat. No. 8,098,375, granted Jan. 17, 2012 entitled "Light Emitting Diode Illumination System," U.S. Publication No. 2009/0040523 filed Aug. 5, 2008;

U.S. patent application Ser. No. 13/012,658, filed Jan. 24, 2011 entitled "Light Emitting Diode Illumination System," U.S. Publication No. 2011/0116261; and

U.S. patent application Ser. No. 12/691,601, now U.S. Pat. No. 8,242,462, granted Aug. 14, 2012, entitled "Lighting Design of High Quality Biomedical Devices," U.S. Publication No. 2010/0187440 filed Jan. 21, 2010.

FIELD OF THE INVENTION

The present invention relates to systems for providing light to induce curing, hardening, and/or polymerization of monomeric, oligomeric or polymeric materials. Photocuring applications include, by way of example only, dentistry, coatings, imaging, inks, manufacturing, plastic, electronics, and packaging.

BACKGROUND OF THE INVENTION

Photocuring systems have been developed in which visible and/or ultraviolet light is used to induce curing, hardening, and/or polymerization of monomeric, oligomeric or polymeric materials. Generally speaking, a photocurable resin/adhesive includes a photoinitiator responsible for initiating free-radical polymerization of the resin. The resin remains in a liquid/workable condition until polymerization is initiated. In order to initiate polymerization, light source is used to provide light of a wavelength suitable for absorption by the photo initiator. The photoinitiator enters an excited state upon absorption of photons of the correct wavelength inducing the creation of free-radicals. The free-radicals induce curing, hardening, and/or polymerization of monomeric, oligomeric or polymeric resin/adhesive.

Light energy is typically provided by one of four types of curing lights: quartz-tungsten-halogen (QTH), arc lamps, light-emitting diode (LED), arc lamps, and argon laser. Both QTH and arc lamps have broad emission spectra suitable for initiating polymerization in a broad range of resins. However, QTH and arc lamps also emit a great deal of heat/infrared. The heat/infrared output is reduced utilizing filters which may also be used to select output wavelengths suitable for particular photoinitiators. The large heat output however requires the QTH and arc lamp systems to have substantial thermal management systems and also reduces the life span of the lamps such that costly replacement parts are required. Moreover, both QTH and arc lamps have significant warm-up periods before spectral output is stable. Thus, in practice the lamps must be kept running continuously while light output is controlled using a shutter. This further reduces the effective lifespan of the lights.

Argon laser systems can be used to provide light for photocuring applications. The light output is coherent and can thus be used to generate high intensity illumination with photons of a selected wavelength. However, the emission spectra of the Argon laser is very narrow and may not be compatible with some photocurable resins. Moreover, Argon laser systems are expensive and have significant thermal regulation requirements

LEDs (light-emitting diodes) have matured significantly within the last decades. LEDs emit light in specific wavelengths and generate much less heat relative to arc and QTH lamps thereby providing for longer lifespan, easy switching, consistent output and lower power consumption. However LEDs presents trade-offs with respect to emission wavelength dependent intensity, broad emission spectrum (spectral half width on the order of 30 nm or more), poor spectral stability, and the wide angular range of emission. The narrow band emission may not be compatible with some photocurable resins. In addition, the process used to manufacture LED's cannot tightly control their spectral stability; anyone wishing to use LED's in applications requiring a good spectral stability typically works directly with a supplier to essentially hand-pick the LED's for the particular application. Moreover the spectral output of an LED varies with temperature. Also, LED's emit light over a wide angular range (50% of light intensity emitted at) 70°). While optics can narrow the emission band and focus the light output, the resulting loss in power and increase in thermal output further complicates the use of LEDs for photocuring. Thus, it can be difficult to provide sufficient light at a wavelength suitable for exciting a particular photoinitiator.

While lighting manufacturers cannot provide all things to all applications, it is precisely this breadth of demand for which a light engine can be designed. To that end, products are not simple sources, but rather light engines, sources and all the ancillary components required to provide pure, powerful, light to the sample or as close to it as mechanically possible. A qualitative comparison of light engine performance as a function of source technology is summarized in Table I.

TABLE I

A qualitative comparison of light source technology.

Source Technology	Useable Light	Uniformity	Temporal Response	Heat Generation	Durability	Cost
Arc Lamp	med	poor	none	high	low	high
Laser	high	poor	none	low	low	very high

TABLE I-continued

A qualitative comparison of light source technology.

Source Technology	Useable Light	Uniformity	Temporal Response	Heat Generation	Durability	Cost
LED	low	poor	fast	low	high	medium
QTH	low	poor	none	medium	low	medium
LED	high	high	fast	low	high	low

A wide range of photoinitiators are available. To initiate polymerization it is essential to provide sufficient light energy at a wavelength which can be absorbed by a selected photoinitiator. However, each photoinitiator has a particular absorption spectra. Additionally, the light energy may have to pass through the resin and other materials in order to reach the photoinitiator. Resins incorporating a photoinitiator can affect transmission and absorption of light in different ways. Accordingly, it may be difficult to ensure sufficient light energy is provided at a wavelength suitable for exciting the photoinitiator. Without proper absorption, free radical polymerization may not occur uniformly throughout the resin. Moreover, where narrow band light sources, such as LEDs, are used the wavelength provided will not be suitable for exciting all photoinitiators in all compositions and manufacturing environments.

Accordingly it would be desirable to provide an LED light source for photocuring that overcomes limitations of the prior art.

SUMMARY OF THE INVENTION

The present invention provides an LED light engine system suitable for photocuring. The LED light engine system is a compact, passively cooled, durable, inexpensive solid state lighting solution, uniquely well suited to the production of light for photocuring. In an embodiment of the invention, this light engine can provide powerful, stable, inexpensive light across a range of wavelengths suitable for photocuring. The LED light engine system is designed to directly replace the entire configuration of light management components with a single, simple unit. Power, spectral breadth and purity, stability and reliability data demonstrates the advantages of the LED light engine system for photocuring applications. Performance and cost analyses are superior to traditional optical subsystems based on QTH, arc lamps, and lasers. Moreover the LED light engine has relatively small footprint, and low heat output such that it has lower power requirements and no need for moving parts—such as a fan.

In an embodiment, the present invention provides a compact passively-cooled solid state illumination system usable as a replacement for conventional arc light, metal halide and Xenon white-light sources for photocuring applications. The solid state illumination system utilizes LED modules to generate high intensity light output suitable for photocuring. The light output is continuous in the visible spectrum from 380 nm to 530 nm and is suitable for photocuring using a wide range of photoinitiators. A touchscreen interface allows programming of spectral output, intensity and duration. Output can be initiated using the touchscreen interface and/or a foot pedal.

Embodiments of the present invention are directed to an LED light engine system suitable for use as a replacement for conventional QTH and arc light photocuring lamps. In particular embodiments, the LED light engine generates a broad band of wavelengths between 380 nm and 530 nm suitable for exciting a wide range of photoinitiators.

Another embodiment of the present invention relates to an improved system for cooling the LED modules of the LED light engine system which reduces contamination of the LED modules and optical pathway from cooling airflow. The system includes means for conductive transmission of heat away from LED modules to a remote heat sink which is passively cooled.

Other objects and advantages of the present invention will become apparent to those skilled in the art from the following description of the various embodiments, when read in light of the accompanying drawings.

BRIEF DESCRIPTION OF THE FIGURES

Various embodiments of the present invention can be described in detail based on the following figures.

FIG. **1**A shows a view of an LED light engine system according to an embodiment of the present invention.

FIG. **1**B shows the spectral power output of the LED light engine system of FIG. **1**A.

FIGS. **2**A and **2**B show exterior views of LED Light Engine according to an embodiment of the invention.

FIG. **2**C shows a perspective internal view of the LED Light Engine of FIGS. **2**A & **2**B.

FIGS. **2**D and **2**E show side internal views of the LED Light Engine of FIGS. **2**A & **2**B.

FIG. **2**F shows a bottom view of the LED Light Engine of FIGS. **2**A & **2**B.

FIG. **2**G illustrates a control system of the LED Light Engine of FIGS. **2**A & **2**B.

FIG. **3**A shows a perspective view of a LED module of the LED Light Engine of FIGS. **2**A & **2**B according to an embodiment of the invention.

FIG. **3**B shows a partial perspective view of the LED module of FIG. **3**A.

FIG. **3**C shows a sectional view of the LED module of FIG. **3**A.

FIG. **4**A shows a top view of an output optics subsystem of the LED Light Engine of FIGS. **2**A & **2**B according to an embodiment of the invention.

FIG. **4**B shows a top view of the optical components of the output optics subsystem of FIG. **4**A.

FIGS. **4**C and **4**D show different sectional views of the output optics subsystem of FIG. **4**A.

In the figures common reference numerals are used to indicate like elements throughout the drawings and detailed description; therefore, reference numerals used in a drawing may or may not be referenced in the detailed description specific to such drawing if the associated element is described elsewhere. The first digit in a three digit reference numeral indicates the series of figures in which the referenced item first appears. Likewise the first two digits in a four digit reference numeral.

DETAILED DESCRIPTION OF THE INVENTION

LED Light Engine System for Photocuring

While no one lighting solution can best satisfy all instrument architectures, an LED light engine according to an embodiment of the invention combines the best of solid state technologies to meet or outperform the traditional technologies listed in Table I on the basis of all figures of merit across

all wavelengths desired for photocuring. In an embodiment of the invention, an LED light engine can emit light exceeding 500 mW/color with intensifies up to 10 W/cm^2 at wavelength suitable for photocuring. The present invention offers a smart alternative for light generation. The capabilities of the LED light engine are highlighted in Table II. The high performance illumination provided by the LED light engine is embodied in a single compact unit designed to replace the entire ensemble of lighting components. The sources, excitation filters, multicolor switching capabilities and fast pulsing are contained within one box with a small footprint such that no external optics or mechanics are required.

TABLE II

Led Light Engine Metrics.

Key Metrics:	
Spectral Output	Three selected wavelengths suitable for photocuring >_ 100 mW/spectral band 1-10 W/cm
Peak Wavelength	Optimal for different floors, adjustable bandwidths
Power Stability	>99% over 24 hours
Spectral Width	10 to 50 nm
Spectral Drift	<1% in 24 hours
Color Dependence	None
Lifetime	>5000 hrs
Footprint	Amenable to portability
Maintenance	None, no consumable components for the light engine's lifetime

In various embodiments of the present invention, an LED light engine includes LED modules having light emitting diodes which emit wavelengths of light, which suitable for exciting a range of photoinitiators. The LEDs operate through the process of spontaneous emission, which results in a much larger selection of available wavelengths than is available for efficient stimulated emission (laser action). The outputs of LED modules each including LEDs which emit one or more color of light are combined using optics into a single output to produce multiple colors simultaneously or in sequence. The LED modules can be illuminated continuously, can be controlled in intensity, and can be pulsed on and off rapidly as necessary or desired to excite the photoinitiator in a particular application. The LED modules can be switched off between uses to eliminate the heat output. This can be contrasted with alternatives such as QTH lamps, arc lamps, and lasers which are unstable unless they are operated continuously.

Because of the solid state nature and independently operable designs of the LED modules, coupled to fast (approximately 10 ns) decay times of typical materials employed, an LED light engine outperforms any broad spectrum source in terms of support for switching control. QTH and arc lamp based sources are coupled to filters and/or shutters with mechanical supports that relegate them to 1 to 50 millisecond regimes and require continuous operation of the lamp. The LED light engine incorporates all that capability into its highly integrated design. Therefore switching times are limited today by the electronics of the boards controlling the sources. Rise times of less than 20 μs and fall times of less than 2 μs are can be achieved. Moreover each color can be switched independently and is compatible with triggering by TTL, RS232 and USB and intensity control by RS232, USB or manually.

Using an LED light engine, effectively instantaneous excitation of photointiators can be performed to achieve desired curing effects with no external hardware beyond the light engine itself. Moreover, because the LED light engine is based on solid state technologies, they are extremely stable both in short duration experiments and over long term use. The LED light engine is powered by 24 V power supplies operated in DC mode, therefore there is no 60 Hz noise. All colors perform similarly. In 24 hours of continuous operation, the output fluctuates on the order of 1%. Short term stability on the order of 1.0 ms is approximately 0.5%. Short term stability for 0.1 ms is diminished by a factor of ten to 0.05%.

FIG. **1**A shows a view of an LED light engine system **110** according to an embodiment of the present invention. As shown in FIG. **1**A, LED light engine system **110** includes, LED light engine **100**, light guide **102**, control device **104**, a foot pedal (not shown) is also provided with LED light engine system **110**. LED light engine **100** includes LED modules for each discrete output based on solid state technologies tailored to best satisfy that output requirement complete with collection and delivery optics. Light guide **102**, receives the light output from the LED light engine **100** and transmits it to the location and/or equipment where the light is to be used for Photocuring. Light guide **102**, may be, for example, a liquid light guide or fiber optic light guide. Light guide **102**, connects to an adapter **108** on the exterior of LED light engine **100**. Control device **104**, is in this embodiment a touchscreen tablet running software which allows the control device **104** to control operation of LED light engine **100**. The touchscreen tablet, enables the user to set intensity, a countdown timer and even program custom curing cycles. Initiation of such programmed outputs can be actuated by the touchscreen or a foot-pedal (not shown). Control device **104** is connected to LED light engine **100** by USB cable **106**, however, in alternative embodiments, a wireless or network connection can be used (Bluetooth, Wifi, NFC, Ethernet etc).

LED light engine **100** has a compact and novel fan-free design. The use of solid state light sources in combination with optimized thermal management allow for cool operation without the use of fans. LED light engine **100** has a long lifetime and is ideal for durable, reproducible, robust curing. A dual interlock system prevents light output from LED light engine **100** both mechanically and electronically when the light guide **102** is removed. The LED light engine **100** has no replaceable parts and no maintenance. Instant warm-up time and superior stability result in highly reproducible optical output power. LED light engine **100** is capable of fast on/off times that can be precisely controlled as well as intensity control. In an embodiment, LED light engine system **110** has the features shown Table III.

TABLE III

Photocuring LED Light Engine System Features.

Source	Multiple solid state sources operating simultaneously
Wavelength Range	380-530 nm (see FIG. 1A).
Power Intensity	13 W/cm2 with a 3 mm diameter liquid light guide
Switching Speed	5 kHz with turn on/off ~10 μs
Light Delivery	3 or 5 mm diameter light guide adapter (LLG sold separately)
Easy to install	Pre-aligned, simple to operate, no maintenance
Lifetime	~20,000 hours, 18 month warranty to end user
Safety Features	Dual electronic and mechanical safety interlock system
Interface	7-inch, 1280 × 600 resolution touchscreen LCD control pad
Power requirements	41 W, 24 V DC, 1.7 A power supply.
Dimensions (W × L × H)	110 mm × 230 mm × 190 mm (4.2 in × 9.1 in × 7.5 in)
Weight	3.6 kg (~8 lbs)
Shipment Contents	LED Light Engine, DC Power Supply, Touchscreen Control Pad, USB cable, foot pedal and cable, 3 mm diameter light guide adapter, Power supply for Touchscreen Control Pad.

FIG. **1**B shows the spectral power output of the LED light engine system **110** of FIG. **1**A. As illustrated by FIG. **1**B, and

LED light engine system **110** is powerful, intense and produces a broad spectral light output over the range of wavelengths from 380 nm to 530 nm light, suitable for activating common photoinitiators. LED light engine **100** provides an output well matched for photocuring adhesives designed for UVA and visible wavelength curing. LED light engine system **110** is a high-performance device which generates nearly one watt of optical output power.

As shown in FIG. **1**B, LED light engine system **110** produces high intensity visible light across a broad range of wavelengths suitable for photocuring LEDs (light-emitting diodes). The system exhibits good spectral stability, and focused emission. The wide emission band is compatible with most photocurable resins. Temperature is well controlled to maintain both lifespan and spectral stability. Thus, sufficient light is provided at wavelengths suitable for exciting particular photoinitiators. Moreover, the visible light generated by LED light engine system **110** has better penetration into photocurable resins than UV light, and the wide emission band means that the photoinitiator can be excited reliably across a wide range of compositions, environments, depths of resin etc thereby ensuring reliable and effective photocuring.

LED Light Engine For Photocuring

FIGS. **2**A-**2**G show views of LED light engine **100** of the LED light engine system **110** FIG. **1**A. FIGS. **2**A and **2**B show exterior views of LED light engine **100**. FIG. **2**C shows a perspective view of LED light engine **100** with the cover removed. FIGS. **2**D and **2**E show side views of LED light engine **100** with the cover removed. FIG. **2**F shows a bottom view of LED light engine **100**.

FIGS. **2**A and **2**B show exterior views of LED light engine **100**. As shown in FIGS. **2**A, **2**B, LED light engine **100** is a fully enclosed in a housing **200** having a small footprint suitable for bench top use. In an embodiment LED light engine **100** has dimensions of 110 mm×230 mm×190 mm (4.2 in×9.1 in×7.5 in). A three-sided cover **210** covers the top, left and right surfaces of LED light engine **100**. The cover **210** includes vents **212** to allow cooling air to flow through the right side of the LED light engine **100**. Adapter **108** is fitted to the front plate **214** of LED light engine **100**. Back plate **220**, includes a power switch **222**, USB port **224**, power connector **226** and foot pedal connector **228**. LED light engine **100** sits on four feet **216** mounted to base plate **218**. Housing **200** thus consists of three-sided cover **210**, front plate **214**, back plate **220**, and base plate **218**. Housing **200** protects the LED light engine **100** and substantially prevents the entry/exit of light, and air except as provided by vents through housing **200**.

FIG. **2**C shows a perspective view of LED light engine **100** with the three-sided cover **210** removed. As shown in FIG. **2**C, a platform **230** is mounted vertically between front plate **214** and back plate **220**. Platform **230** completely separates the left and right sides of the housing. The left side **232** of platform **230** is substantially planar for mounting and supporting the LED modules and optics. The right side **234** of platform **230** includes a large number of vertical fins **236** for cooling of platform **230**. Platform **230** is preferably machined from aluminum or another conductive metal or metal alloy.

As shown in FIG. **2**C, the interior of solid LED light engine **100** is divided by a platform **230**. The left side **732** of platform **730** is substantially flat and supports the solid state light sources and associated optics. The right side **234** of platform **230** bears a plurality of fins **236** which provided a large surface area for the cooling of platform **230**. The fins are arranged vertically parallel to the axis of the air flow rising from the bottom of the housing and escaping through the top of the housing. Platform **230**, maintains the cooling air flow in the right portion of the housing between the platform **230** and the three-sided cover. This reduces the possibility of contamination of the optical components.

As shown in FIG. **2**C, mounted to the left side **232** of platform **230** are three LED modules **241**, **242**, and **243** for generating light of selected wavelengths. Each of the LED modules **241**, **242**, and **243** includes a collimator **241***c*, **242***c*, and **243***c* which forms the light output from the module into a collimated beam. The light output of LED modules **241**, **242**, and **243** is combined into a single output beam using two dichroic mirrors **244**, **245** which are also mounted to the left side **232** of platform **230**. The single output beam of light is directed to output optics **256** which focuses the combined beam into a light guide (not shown) inserted in adapter **108**.

In an embodiment of the invention, LED light engine **100** includes three LED modules **241**, **242**, and **243** each generating light of a different peak wavelength (color). The two dichroic mirrors serve **244**, **245** color to create a single coaxial 3-color beam. In an embodiment the LED modules **241**, **242**, and **243** generate violet (405 nm), blue (440 nm), and cyan (485 nm) light. In a preferred embodiment, the output beam is substantially continuous over the spectrum of 380 nm-530 nm such that it is suitable for exciting a wide range of photoinitiators. Each individual LED light source is collimated so as to be efficiently combined by dichroic mirrors **244**, **245** and after combination, the single coaxial beam is refocused by output optics **256** into a light guide for transport to the device or system to be illuminated. Additional or different colors can be used by replacing one or more of LED modules **241**, **242**, and **243**. For example, UV light LED module including UV LEDS in place of or in addition to the violet LED module.

The cooling requirements for a solid state illumination system are substantially different than that for an incandescent light source. Incandescent lights typically release 90% or so of the heat they generate to their environment through radiation in the infrared and less than 10% through conduction. In comparison, LEDs typically release 90% or so of the heat they generate to their environment through conduction and less than 10% through conduction. Thermal dissipation is a key factor that limits the power output of an LED light source. Even though LEDs bulbs are considerably more efficient at converting electrical energy into light than incandescent light sources, but the LED components and the driver electronics can still create a considerable amount of heat. If this heat is not dissipated properly, the LED's quality of light, emission spectra, and life expectancy decrease dramatically. Thus, it is important in a solid state illumination system relying on LEDs to provide an effective solution for conductive cooling of the LEDs. Platform **230** provides both for mounting of LED modules **241**, **242**, and **243** as well as thermal regulation as described below.

As previously described cooling air is not circulated in the left portion of the housing. However, the LED modules **241**, **242**, and **243** generate heat during operation. This heat must be removed such that the temperature of the solid state light sources is maintained at a desired level. In prior devices, the individual solid state light sources were provided with individual finned heat sinks and air was passed over the heat sinks using a common or individual fan to remove heat—however, this cooling system allowed for the entry of dust and/or other contaminants into the light sources and onto the optical components. The dust and/or other contaminants could cause a number of problems including: reduction in optical efficiency, scattering of light within the housing, burning, and burning odor. In the LED light engine **100** shown in FIGS. **2**A-**2**F, each of the LED modules **241**, **242**, and **243** is in good thermal contact with platform **230**. The thermal contact is direct metal to metal contact or may be mediated by a thermal

paste between the LED modules and the platform **230**. Platform **230** is made from a conductive metal/metal alloy such that heat from the LED modules is rapidly conducted away towards fins **236** through which cooling air may circulate. Thus platform **230** serves both as an optical table for mounting and aligning the LED modules, dichroic mirrors and output optics as well as a common heat sink for the LED modules. The LED modules are suitably designed to efficiently transmit heat from their components to the platform **720** as described with respect to FIGS. **3**A-**3**C below. LED modules are arranged on the platform **230** based upon their heat output for example in an embodiment, LED modules **241**, **242**, **243** each put out 25 watts of heat each. Thus, the thermal output of the light sources is considered when arranging the light sources to ensure that each is adequately cooled by the cooling airflow on the finned side of platform **230**. Note, in FIG. **2**E, for example that the LED modules **241**, **242**, **243** are arranged so as to be horizontally displaced from each other such that each is effectively cooled. In a preferred embodiment passive cooling of fins **236** by air passing through the vents in housing **200** (see FIGS. **2**A, **2**B) is sufficient to maintain the temperature of LED modules **241**, **242**, and **243** without the use of a fan. Note also that platform **230** divides the internal volume of housing **200** such that cooling air only flows through the right side over fins **236**. The left side **230** of housing **200** is unvented such no external air passes around the optical components and LED modules **241**, **242**, and **243**. This reduces the possibility of contamination by dust and the like.

FIGS. **2**D and **2**E show side views of LED light engine **100** with the three-side cover **210** removed. FIG. **2**D shows the right side **234** of platform **230** showing fins **236** which are vertically mounted such that heated air can pass up through base plate **218** and out through vents **212** in three-sided cover **210** thus facilitating convective cooling of fins **236** without the use of a fan. A control board **240** is also housed adjacent the right side **234** of platform **230** and is connected to includes a power switch **222**, USB port **224**, power connector **226** and foot pedal connector **228** through back plate **220**. Control board **240** also receives cooling air flow. Control board **240** includes the circuitry for driving the solid state light sources and sensors of LED light engine **100**.

FIG. **2**F shows a bottom view of LED light engine **100**. Note that bottom plate **218** includes a plurality of slots **219** aligned with the gaps between fins **236** (not shown). Slots **219** are designed such that air can flow through slots **219** and between fins **236** thereby cooling platform **230** (not shown) by passive convection with requiring a fan.

The LED modules **241**, **242**, **243** are controlled by the controller board **240** either together or individually to control the spectral content of the output beam. In embodiments of the invention, three LED modules **241**, **242**, **243** produce spectral components centered on colors violet 405 nm, blue 425-460 nm, and cyan 460-500 nm. All the and three LED modules **241**, **242**, **243** can be turned on at the same time such that the different colors are combined to create a substantially continuous spectrum over the range 380 nm-530 nm.

FIG. **2**G illustrates a control system of the LED light engine **100**. As shown in FIG. **2**G, control board **240** includes a controller **270**. Controller **270** includes an input/output system **272** for receiving data from the various sensors, input port and input devices and sending data to the data output port and or any indicator/display devices. Controller **270** is coupled to power output system **274** which provides power to the electrical, optical and mechanical components of LED light engine **100**. Because of the solid state nature and independently operable designs of the light sources, coupled to fast (approximately 10 ns) decay times of typical materials employed, the solid state illumination system does not require a mechanical shutter and is capable of rise times of less than 20 μs and fall times of less than 2 μs under the control of controller **270** which is compatible with triggering by a control device **104** connected to USB port **224** and/or by a foot pedal connected to foot-pedal port **228**. Each light source is operated simultaneously to generate a continuous light output spectrum. Alternatively, each source can be switched independently to generate an output of the desired spectral power distribution and/or color.

In the control system embodiment shown in FIG. **2**G, controller **270** is coupled by input/output system **272** to USB port **224**, foot pedal input **228**, safety flap sensor **276**, toggle switch **222**, additional sensor(s) **278**, display/indicators **280**, as well as the heat and light sensors of LED modules **241**, **242**, **243**. Controller **270** is coupled to power output system **274** which provides electrical power to drive the LEDs and laser diodes of LED modules **241**, **242**, **243**. Additional sensors **278**, display/indicators **280** and inputs/switches and outputs may be added to LED light engine **100** as necessary to support desired functionality for the system, however, typically a control device **104** connected to USB port **224** is used to control and monitor LED light engine **100** and provides control and data display flexibility through a software application. For example, as shown in FIG. **1**A a control device **104**, in the form of a touchscreen tablet running software which allows the control device **104** to control operation of LED light engine **100**. The touchscreen tablet, enables the user to: set intensity for each LED module separately or as a group; set and initiate a countdown timer; and program custom curing cycles. Initiation of such programmed outputs can be actuated by the touchscreen or a foot-pedal (not shown). Control device **104** is connected to LED light engine **100** by USB cable **106**, however, in alternative embodiments, a wireless or network connection can be used (Bluetooth, Wifi, NFC, Ethernet etc).

LED Module For Photocuring System

FIGS. **3**A-**3**C shows views of LED module **241** and collimator **241***c*. LED modules **242** and **243** have the same design though each of LED modules **241**, **242** and **243** preferably includes LEDs which emit light of different wavelengths than the others of LED modules **241**, **242** and **243**. FIG. **3**A shows a perspective view of LED module **241**, collimator **241***c* and associated dichroic mirror **244**. As shown in FIG. **3**A, LED module **241** includes a base **300** adapted to be mounted to platform **230** (see FIGS. **7**C-**7**E). Collimator **241***c* is mounted to base **300**.

FIG. **3**B shows a partial perspective view of LED module **241**, collimator **241***c* and associated dichroic mirror **244**. As shown in FIG. **3**B, LED module **241** includes an LED die **310**. LED die **310** includes a plurality of light-emitting diodes on the same substrate. The substrate is mounted in direct or indirect thermal contact with base **300** such that heat generated by the light-emitting diodes during operation is transmitted to base **300**. Base **300** is secured in thermal contact with platform **230** such that heat is rapidly transferred to platform **230** and then dissipated from fins **236**.

Referring again to FIG. **3**B, light emitted from LED die **310** is collected through plano-convex-lens **326** placed over die **310**. The light passes through plano-convex lens **326** and is collimated by plano-convex lenses **327**, **328** of collimator **241***c*. A light sensor **329** is placed adjacent plano-convex lens **327** where it receives scattered light in order to monitor the light output of LED die **310**. After passing plano-convex lenses **327**, **328** the collimated light beam is directed at dichroic mirror **244**. Dichroic mirror **244** is aligned such that the

collimated beam of light is directed along an optical axis towards output optics **256** (see FIG. **2**E).

FIG. **3**C shows a sectional view of LED module **241** and collimator **241***c*. As shown in FIG. **3**C, LED module **241** includes an LED die **310**. LED die **310** includes a plurality of light-emitting diodes on the same substrate. The substrate is mounted in direct or indirect thermal contact with base **300** such that heat generated by the light-emitting diodes of LED die **310** during operation is transmitted to base **300**. Base **300** is secured in thermal contact with platform **230** such that heat is rapidly transferred to platform **230** and then dissipated from fins **236** (not shown, but see FIG. **2**D). Referring again to FIG. **3**C, light emitted from LED die **310** is collected through plano-convex-lens **326** placed over die **310**. The light passes through plano-convex lens **326** and is collimated by plano-convex lenses **327**, **328** of collimator **241***c*.

Output Optics for Photocuring System

FIGS. **4**A-**4**D illustrate output optics **256** of LED light engine **100** (see FIGS. **2**C and **2**E). As shown in FIG. **4**A, output optics **256** receives the collimated combined beam of light **254** from all the light sources of LED light engine **100**, focuses the combined beam **254** and directs it into the aperture **428** of light guide **102**. An adapter **108** connects light guide **102** to output optics **256** and positions light guide **102** such that the aperture **428** of the light guide is correctly positioned to receive the focused combined beam of light **254**. Output optics **256** are positioned against front plate **214** such that light guide **102** can be connected to output optics **256** through an aperture in front plate **214**.

As shown in FIG. **4**B, output optics **256** includes two plano-convex lenses **426**, **427**. Plano-convex lenses **426**, **427** receive the collimated combined beam of light **254** from all the light sources of LED light engine **100**, focuses the combined beam **254** and directs it into the aperture **428** of light guide **102**. Light guide **102** transmits the combined beam to a location or instrument used to excite a photoinitiator.

FIGS. **4**C and **4**D are sectional views of output optics **256** illustrating attachment of a light guide **102**. FIG. **4**C shows output optics without light guide **102** in place. As shown in FIG. **4**C, light guide **102** includes a housing **400** which defines a lumen **402**. Housing **400** is mounted to platform **230**. Housing **400** projects through aperture **424** in front plate **214** such that lumen **402** is accessible from the exterior of solid state illumination system **700**. As shown in FIG. **4**C, a safety flap **404** occludes lumen **402** to prevent the exit of light or entry of contaminants through lumen **402** when light guide **102** is not connected. Safety flap **404** is spring loaded such that it occludes lumen **402** automatically upon removal of a light guide **102**. Safety flap **404** pivots out of the way when a light guide **102** is inserted. One or more limit sensors (not shown) are coupled to safety flap **404** to sense the position of safety flap **404** (and thus the presence or absence of a light guide) and provide such information to controller board **240**. The safety flap **404** and sensor operate as dual interlock system to prevent light output from LED light engine **100** both mechanically and electronically when the light guide **102** is removed.

As shown in FIG. **4**D, light guide **102** is received in an adapter **108** which connects light guide **102** to output optics **256** and positions light guide **102** such that the aperture **428** of the light guide **102** is correctly positioned to receive the focused combined beam of light **254**. When adapter **108** and light guide **102** are inserted into lumen **402** of housing **400**, safety flap **404** pivots out of the way. Aperture **428** is positioned coaxial with plano-convex lenses **426**, **427** such that the combined beam of light **254** is focused into aperture **428** of light guide **102**. Light guide **102** transmits the combined beam to a location or instrument used to excite a photoinitiator.

The foregoing description of the various embodiments of the present invention has been provided for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Many modifications and variations will be apparent to the practitioner skilled in the art. Embodiments were chosen and described in order to best describe the principles of the invention and its practical application, thereby enabling others skilled in the art to understand the invention, the various embodiments and with various modifications that are suited to the particular use contemplated. Other features, aspects and objects of the invention can be obtained from a review of the figures and the claims. It is to be understood that other embodiments of the invention can be developed and fall within the spirit and scope of the invention and claims.

What is claimed is:

1. A photocuring system comprising:

a housing enclosing a space;

a metal platform having a first substantially planar surface and a second surface;

the metal platform vertically dividing the enclosed space into a first volume defined by the first substantially planar surface and the housing, and a second volume defined by the second surface and the housing;

the metal platform having on the second surface a plurality of vertically oriented fins;

a first light source positioned within said first volume, the first light source having a first solid state light source, a collimator, and a first metal base, wherein the first solid state light source emits light of a first wavelength which is received by the collimator which generates a collimated first light beam;

a second light source positioned within said first volume, the second light source having a second solid state light source, a collimator, and a second metal base, wherein the second solid state light source emits light of a second wavelength which is received by the collimator which generates a collimated second light beam;

a third light source positioned within said first volume, the third light source having a third solid state light source, a collimator, and a third metal base, wherein the third solid state light source emits light of a third wavelength which is received by the collimator which generates a collimated third light beam;

a plurality of dichroic elements positioned in said first volume and mounted to said first substantially planar surface of said metal platform wherein the plurality of dichroic elements combine the collimated first light beam, collimated second light beam, and collimated third light beam into a combined light beam; and

an output optical stage, positioned in said first volume and mounted to said first substantially planar surface of said metal platform, the optical stage including a lumen for receiving a light guide and comprising a plurality of lenses positioned to receive the combined light beam and focus the combined light beam into an output beam of light suitable for illuminating the light guide;

wherein said first metal base is mounted to said first substantially planar surface of said metal platform such that it provides a heat conducting path between said first solid state light source and the metal platform through which heat generated by the first solid state light source is conducted to the metal platform;

wherein said second metal base is mounted to said first substantially planar surface of said metal platform such that it provides a heat conducting path between said second solid state light source and the metal platform through which heat generated by the second solid state light source is conducted to the metal platform;

wherein said third metal base is mounted to said first substantially planar surface of said metal platform such that it provides a heat conducting path between said third solid state light source and the metal platform through which heat generated by the third solid state light source is conducted to the metal platform;

wherein the housing has a top vent into said second volume and a bottom vent into said second volume whereby hot air can escape from the second volume through the top vent and cool air can be drawn into the second volume through the bottom vent to provide air flow through the second volume and between said vertically oriented fins to provide passive convective cooling of the metal platform and wherein the housing substantially seals the first volume to prevent contamination.

2. The photocuring system of claim **1**, further comprising:

a control board mounted within the second volume of the housing, the control board provides current to said plurality of light sources; and

a touchscreen control device external to said housing;

wherein the touchscreen control device is coupled to said control board and configured to control operation of said first light source, second light source and third light source.

3. The photocuring system of claim **2**, wherein said output optical stage, includes a spring-loaded mechanical flap within said housing that automatically obstructs said lumen of the output optical stage in the absence of a light guide.

4. The photocuring system of claim **3**, in combination with a light guide coupled to the output optical stage through an aperture in said housing, the light guide transmits the output beam of light from the photocuring system.

5. The photocuring system of claim **1**, further comprising a control board mounted within the second volume of the housing, the control board provides current to said first solid state light source, second solid state light source, and third solid state light source.

6. The photocuring system of claim **1**, wherein said output beam of light has an intensity of at least 10 W/cm^2 when used with a 3 mm diameter light guide.

7. The photocuring system of claim **1**, wherein said output beam of light has a spectral content which is substantially continuous between 380 nm and 530 nm.

8. A photocuring system comprising:

a housing having a top surface and a bottom surface and enclosing a space;

a metal platform having a first substantially planar surface and a second surface;

the metal platform dividing the enclosed space into a first volume defined by the first substantially planar surface and the housing, and a second volume defined by the second surface and the housing;

the metal platform having on the second surface a plurality of vertically oriented fins;

a first light source positioned within said first volume, the first light source having a first LED module, a collimator, and a first metal base, wherein the first LED module emits violet light which is received by the collimator which generates a collimated violet light beam;

a second light source positioned within said first volume, the second light source having a second LED module, a collimator, and a second metal base, wherein the second LED module emits blue light which is received by the collimator which generates a collimated blue light beam;

a third light source positioned within said first volume, the third light source having a third LED module, a collimator, and a third metal base, wherein the third LED module emits cyan light which is received by the collimator which generates a collimated cyan light beam;

a plurality of dichroic elements positioned in said first volume and mounted to said first substantially planar surface of said metal platform wherein the plurality of dichroic elements combine the collimated violet light beam, collimated blue light beam, and collimated cyan light beam into a combined light beam; and

an output optical stage, positioned in said first volume and mounted to said first substantially planar surface of said metal platform, the optical output stage comprising a lumen for receiving a light guide and a plurality of lenses configured to receive the combined light beam and focus the combined light beam into an output beam of light suitable for transmission into the light guide;

wherein said first metal base is mounted to said first substantially planar surface of said metal platform such that it provides a heat conducting path between said first solid state light source and the metal platform through which heat generated by the first solid state light source is conducted to the metal platform;

wherein said second metal base is mounted to said first substantially planar surface of said metal platform such that it provides a heat conducting path between said second solid state light source and the metal platform through which heat generated by the second solid state light source is conducted to the metal platform;

wherein said third metal base is mounted to said first substantially planar surface of said metal platform such that it provides a heat conducting path between said third solid state light source and the metal platform through which heat generated by the third solid state light source is conducted to the metal platform;

wherein the housing has a top vent through said top surface into said second volume and a bottom vent through said bottom surface into said second volume whereby air can escape from the second volume through the top vent and air can be drawn into the second volume through the bottom vent to provide air flow through the second volume and between said vertically oriented fins to provide passive convective cooling of the metal platform and wherein the housing substantially seals the first volume to prevent contamination.

9. The photocuring system of claim **8**, further comprising:

a control board mounted within the second volume of the housing, wherein the control board provides current to said first LED module, second LED module, and third LED module; and

a touchscreen control device external to said housing;

wherein the touchscreen control device is coupled to said control board and configured to control operation of said first LED module, second LED module and third LED module.

10. The photocuring system of claim **8** wherein said output optical stage includes a spring-loaded mechanical flap which automatically obstructs said lumen of the output optical stage unless a light guide is connected to the output optical stage.

11. The photocuring system of claim **8**, in combination with a light guide coupled through an aperture in said housing to said output optical stage.

12. The photocuring system of claim **8** comprising:

wherein the output beam is substantially continuous between 380 nm and 530 nm and has an intensity of at least 10 W/cm^2 when used with a 3 mm diameter light guide.

13. The photocuring system of claim **8** further comprising:

a control board mounted within the second volume of the housing, wherein the control board provides current to said first LED module, second LED module, and third LED module; and

a foot pedal external to said housing but coupled to said control board wherein the foot pedal is configured to control light output by the photocuring system.

14. The photocuring system of claim **8** further comprising:

a control board mounted within the second volume of the housing, wherein the control board provides current to said first LED module, second LED module, and third LED module; and

an electronic sensor in said optical output stage, wherein the electronic sensor is coupled to said control board and operative to turn off said first LED module, second LED module, and third LED module unless a light guide is connected to the optical output stage; and

a mechanical flap which automatically obstruct said lumen of the output optical stage unless a light guide is connected to the optical output stage.

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