US011404610B2

(12) **United States Patent**
Wood et al.

(10) **Patent No.: US 11,404,610 B2**
(45) **Date of Patent: Aug. 2, 2022**

(54) **LIGHT FIXTURE WITH BROADBAND AND NARROW BAND EMITTERS**

(71) Applicant: **Electronic Theatre Controls, Inc.**, Middleton, WI (US)

(72) Inventors: **Michael Wood**, Austin, TX (US); **David J. Cahalane**, Dane, WI (US)

(73) Assignee: **Electronic Theatre Controls, Inc.**, Middleton, WI (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 296 days.

(21) Appl. No.: **16/419,265**

(22) Filed: **May 22, 2019**

(65) **Prior Publication Data**

US 2020/0373465 A1 Nov. 26, 2020

(51) **Int. Cl.**

H01L 33/50 (2010.01)
H05B 47/10 (2020.01)
(Continued)

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

CPC ***H01L 33/502*** (2013.01); ***C09K 11/7777*** (2013.01); ***F21K 9/20*** (2016.08);
(Continued)

(58) **Field of Classification Search**

CPC H01L 33/48; H01L 33/50; H01L 33/501; H01L 33/502; H05B 47/10; H05B 47/105; H05B 47/155; H05B 45/10; H05B 45/20
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,709,774 B2 5/2010 Schulz et al.
7,898,665 B2 3/2011 Brukilacchio et al.
(Continued)

FOREIGN PATENT DOCUMENTS

WO 2006031753 A2 3/2006
WO 2014054290 A1 4/2014
(Continued)

OTHER PUBLICATIONS

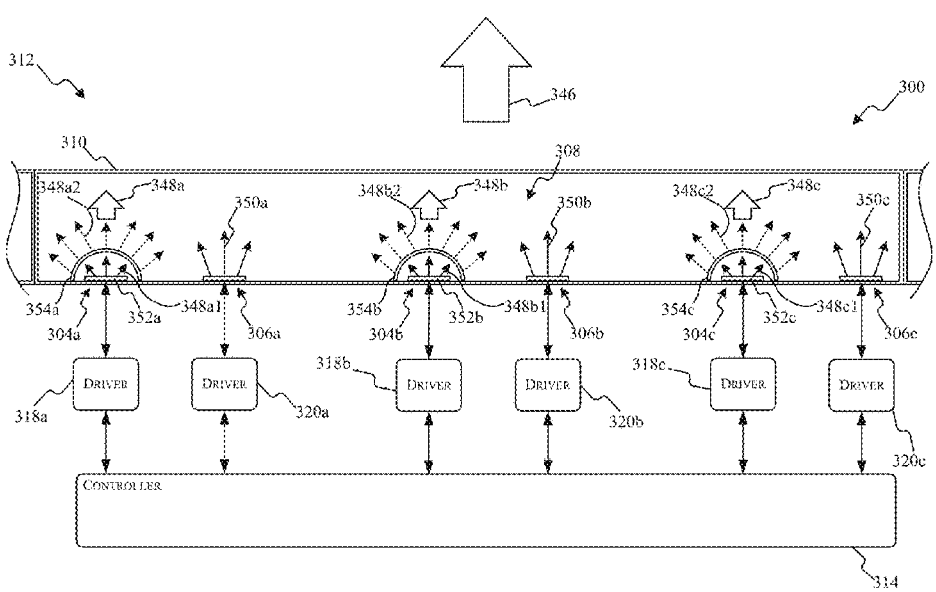
Search and Examination Report for related Application No. GB2004364.2 dated Aug. 7, 2020 (5 pages).
(Continued)

Primary Examiner — Jason Crawford
(74) *Attorney, Agent, or Firm* — Michael Best & Friedrich LLP

(57) **ABSTRACT**

A light fixture includes a first phosphor-converted light-emitting diode ("PCLED") emitting light in a first PCLED wavelength range having first PCLED upper and lower bounds, a first direct light-emitting diode ("DLED") emitting light in a first DLED wavelength range having first DLED upper and lower bounds, a second PCLED emitting light in a second PCLED wavelength range having second PCLED upper and lower bounds, and a second DLED emitting light in a second DLED wavelength range having second DLED upper and lower bounds. The first PCLED upper bound has a higher wavelength value than the first DLED upper bound. The first PCLED lower bound has a lower wavelength value than the first DLED lower bound. The second PCLED upper bound has a higher wavelength value than the second DLED upper bound. The second PCLED lower bound has a lower wavelength value than the second DLED lower bound.

20 Claims, 12 Drawing Sheets



(51) **Int. Cl.**
F21K 9/20 (2016.01)
C09K 11/77 (2006.01)
F21V 15/01 (2006.01)
F21V 19/00 (2006.01)

(52) **U.S. Cl.**
CPC ***F21V 15/01*** (2013.01); ***F21V 19/001*** (2013.01); ***H05B 47/10*** (2020.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,013,533	B2	9/2011	De Rijck et al.	
8,390,207	B2	3/2013	Dowling et al.	
8,403,523	B2 *	3/2013	Gerlach	H05B 47/10 362/249.02
8,508,127	B2	8/2013	Negley et al.	
8,921,875	B2	12/2014	LeToquin et al.	
9,022,598	B2	5/2015	Lee	
9,159,885	B2	10/2015	Ouderkirk et al.	
9,500,327	B2 *	11/2016	Oepts	F21K 9/64
10,077,886	B2	9/2018	Ouderkirk et al.	
10,109,773	B2	10/2018	Todorov et al.	
2006/0105482	A1	5/2006	Alferink et al.	
2007/0223219	A1 *	9/2007	Medendorp, Jr.	F21K 9/00 257/E33.001
2009/0108269	A1 *	4/2009	Negley	H01L 27/156 257/E33.061
2011/0037413	A1	2/2011	Negley et al.	
2011/0050125	A1 *	3/2011	Medendorp, Jr.	C09K 11/623 362/231
2012/0099303	A1 *	4/2012	Li	H01L 25/0753 362/231
2012/0300452	A1 *	11/2012	Harbers	F21K 9/64 362/231
2013/0114242	A1 *	5/2013	Pickard	F21K 9/232 362/84
2013/0264947	A1 *	10/2013	Ouderkirk	H01L 33/507 257/89
2014/0111985	A1 *	4/2014	Harbers	F21K 9/64 362/231
2014/0225137	A1 *	8/2014	Krames	F21V 9/08 257/89
2014/0240612	A1 *	8/2014	Gotou	F21K 9/90 362/613
2015/0131259	A1 *	5/2015	Ouderkirk	F21K 9/64 362/84
2015/0228868	A1 *	8/2015	Ouderkirck	F21V 7/00 362/84
2016/0076736	A1 *	3/2016	Van Bommel	F21V 9/40 362/276
2016/0290573	A1 *	10/2016	Allen	G02B 5/206
2019/0148605	A1 *	5/2019	Mu	H01L 33/50 257/98
2020/0373465	A1 *	11/2020	Wood	H01L 33/502

FOREIGN PATENT DOCUMENTS

WO	2014068440	A1	5/2014
WO	2018140727	A1	8/2018

OTHER PUBLICATIONS

Examination Report issued from the United Kingdom Patent Office for related Application No. GB2004364.2 dated Jan. 21, 2022 (3 Pages).

* cited by examiner

FIG. 1A

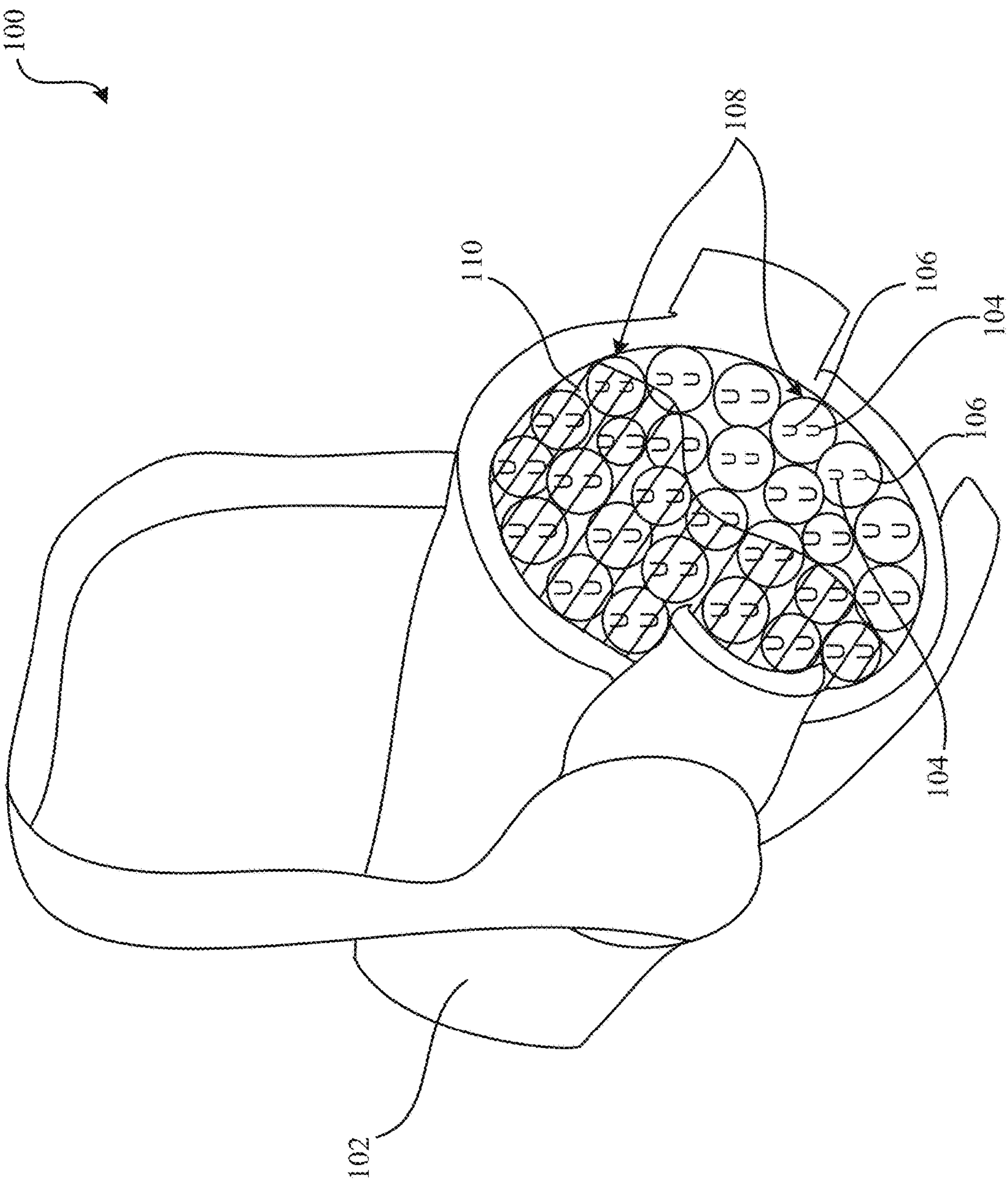


FIG. 1B

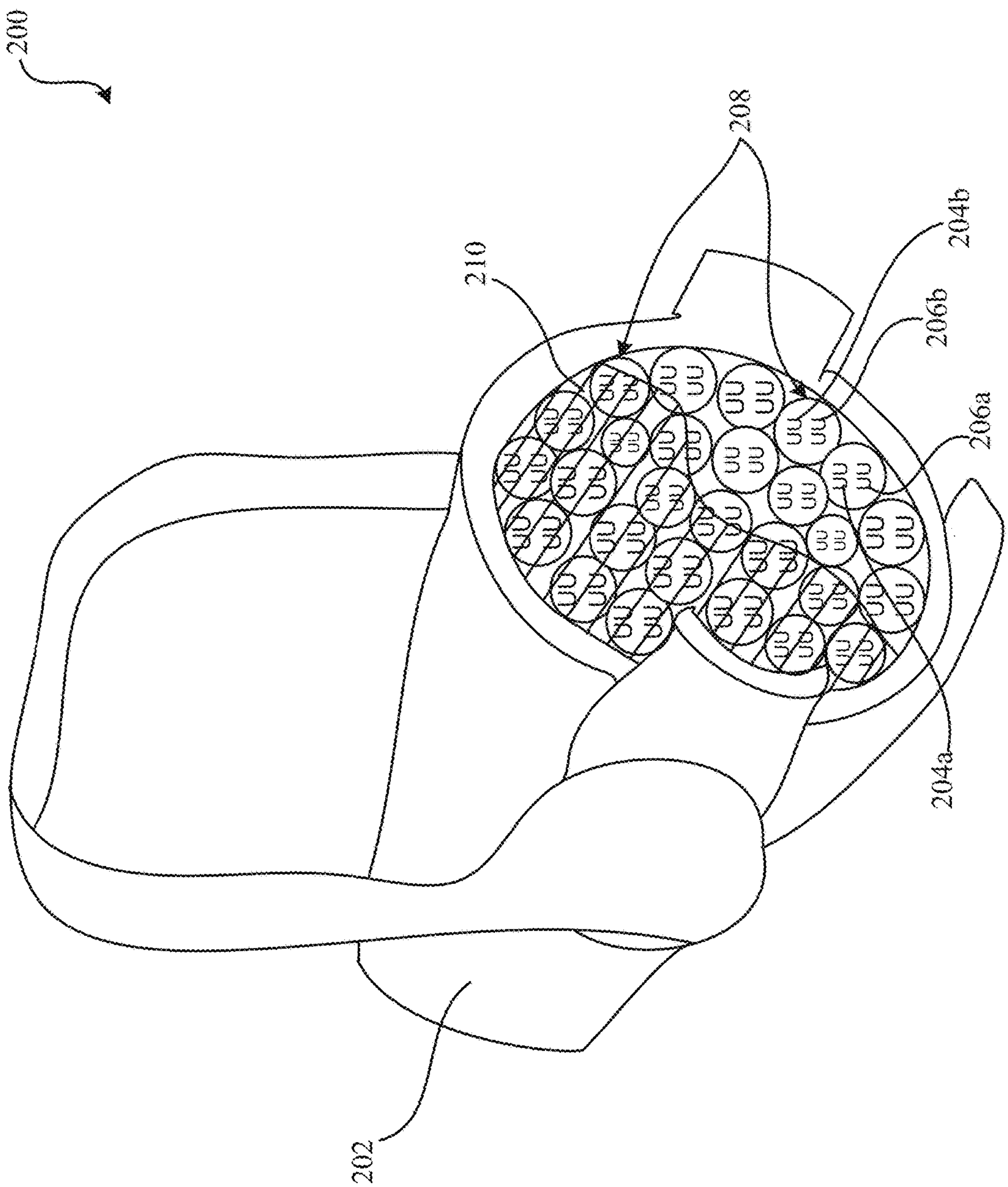
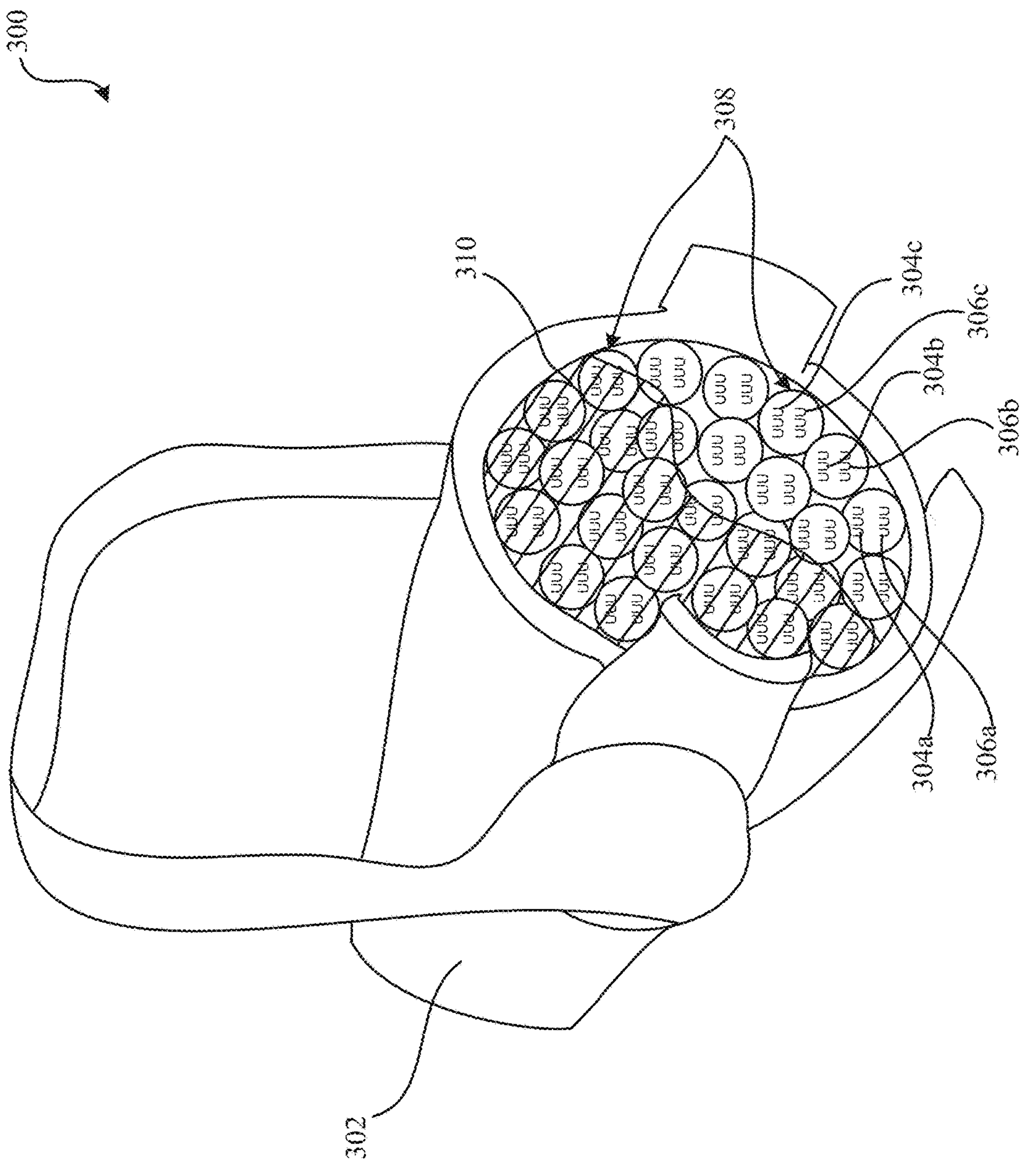


FIG. 1C



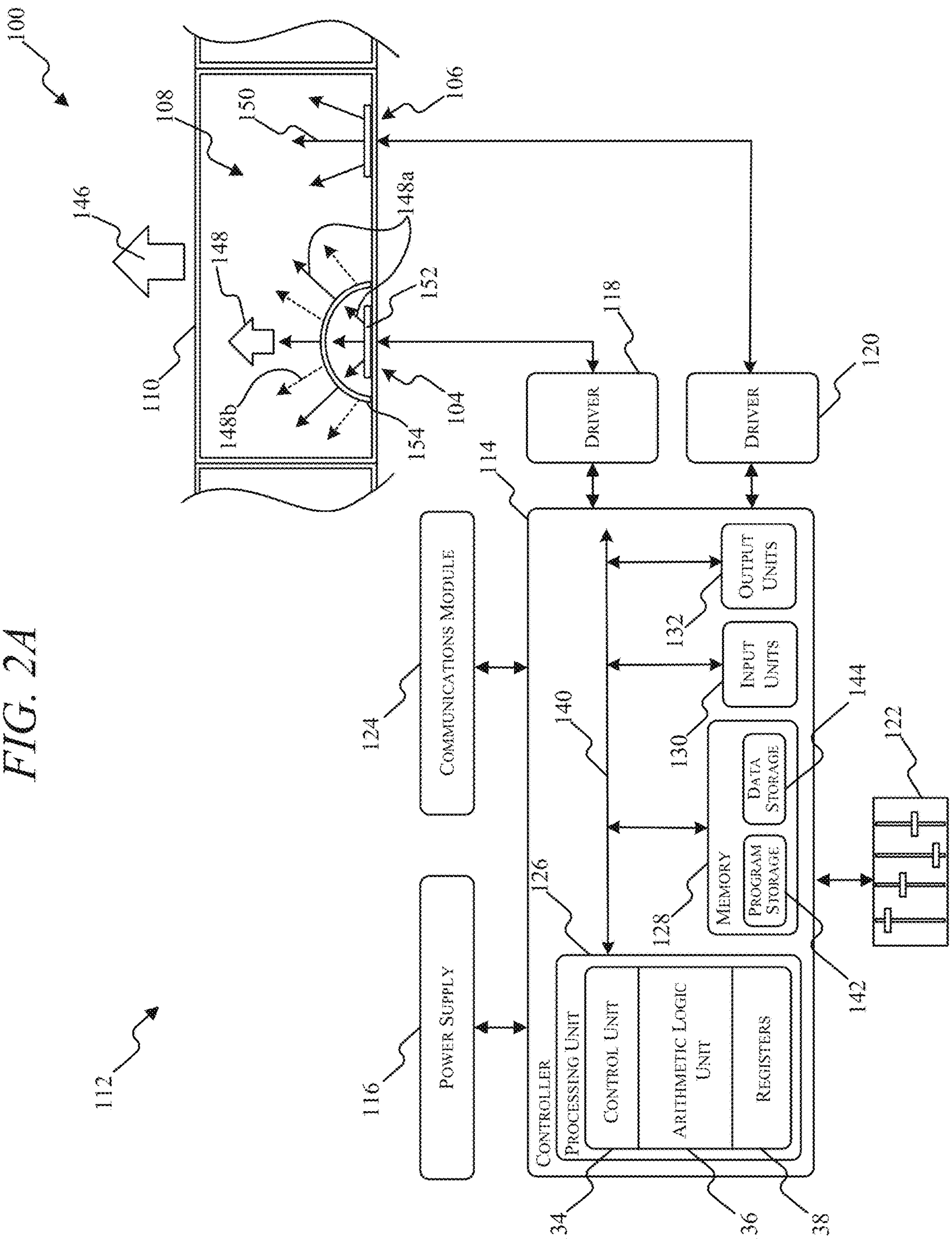

Driver
Driver
Communications Module
Power Supply
Controller
Processing Unit
Control Unit
Arithmetic Logic Unit
Registers
Memory
Program Storage
Data Storage
Input Units
Output Units

FIG. 2A

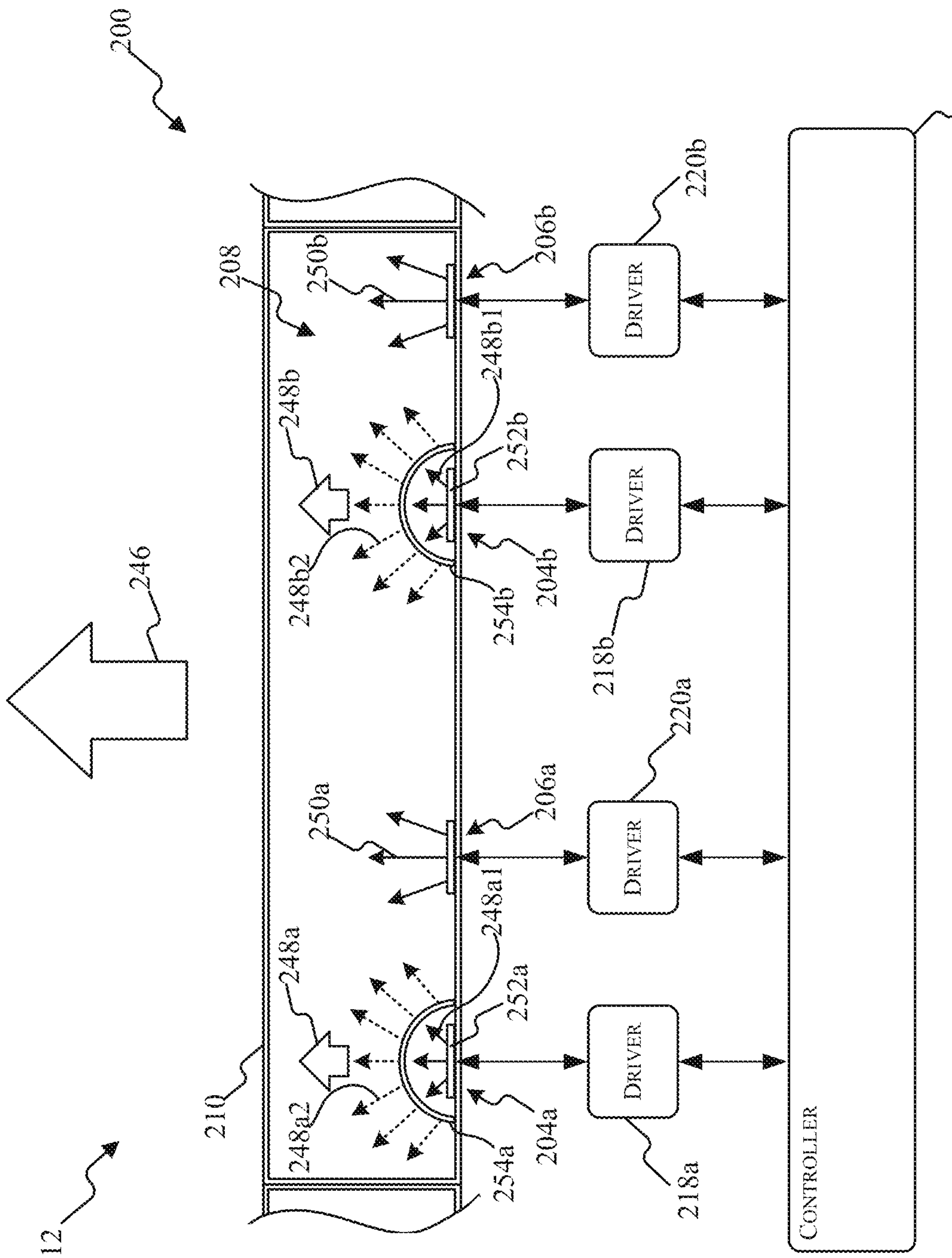

200
212
246
208
210
206b
250b
248b1
248b
252b
248b2
254b
204b
206a
250a
248a1
248a
252a
248a2
254a
204a
220b
218b
220a
218a
Driver
Driver
Driver
Driver
214
Controller

FIG. 2B

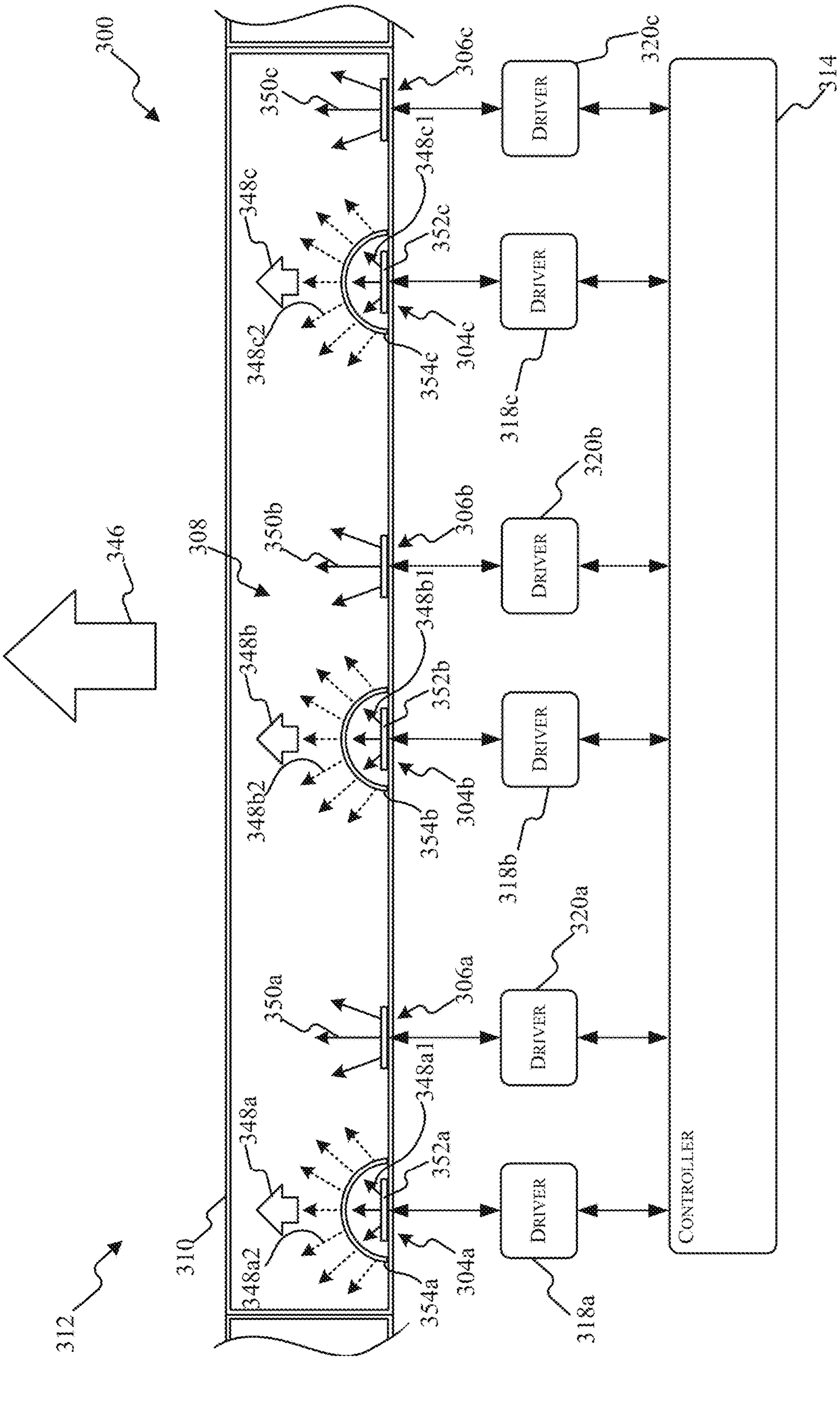

300
312
346
308
310
314
CONTROLLER
DRIVER
DRIVER
DRIVER
DRIVER
DRIVER
DRIVER
318a
318b
318c
320a
320b
320c
304a
304b
304c
306a
306b
306c
348a
348a1
348a2
348b
348b1
348b2
348c
348c1
348c2
350a
350b
350c
352a
352b
352c
354a
354b
354c

FIG. 2C

FIG. 3A

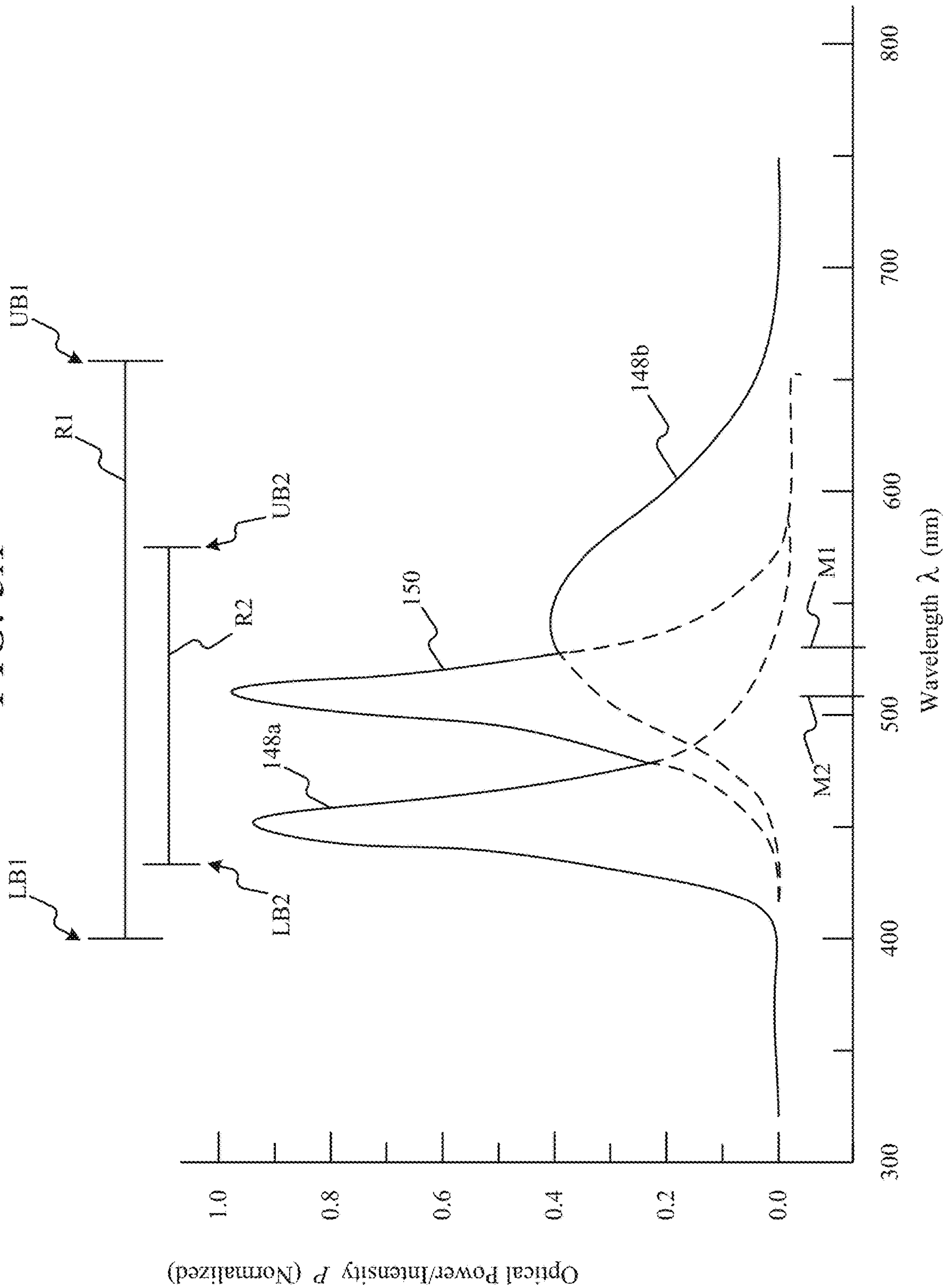
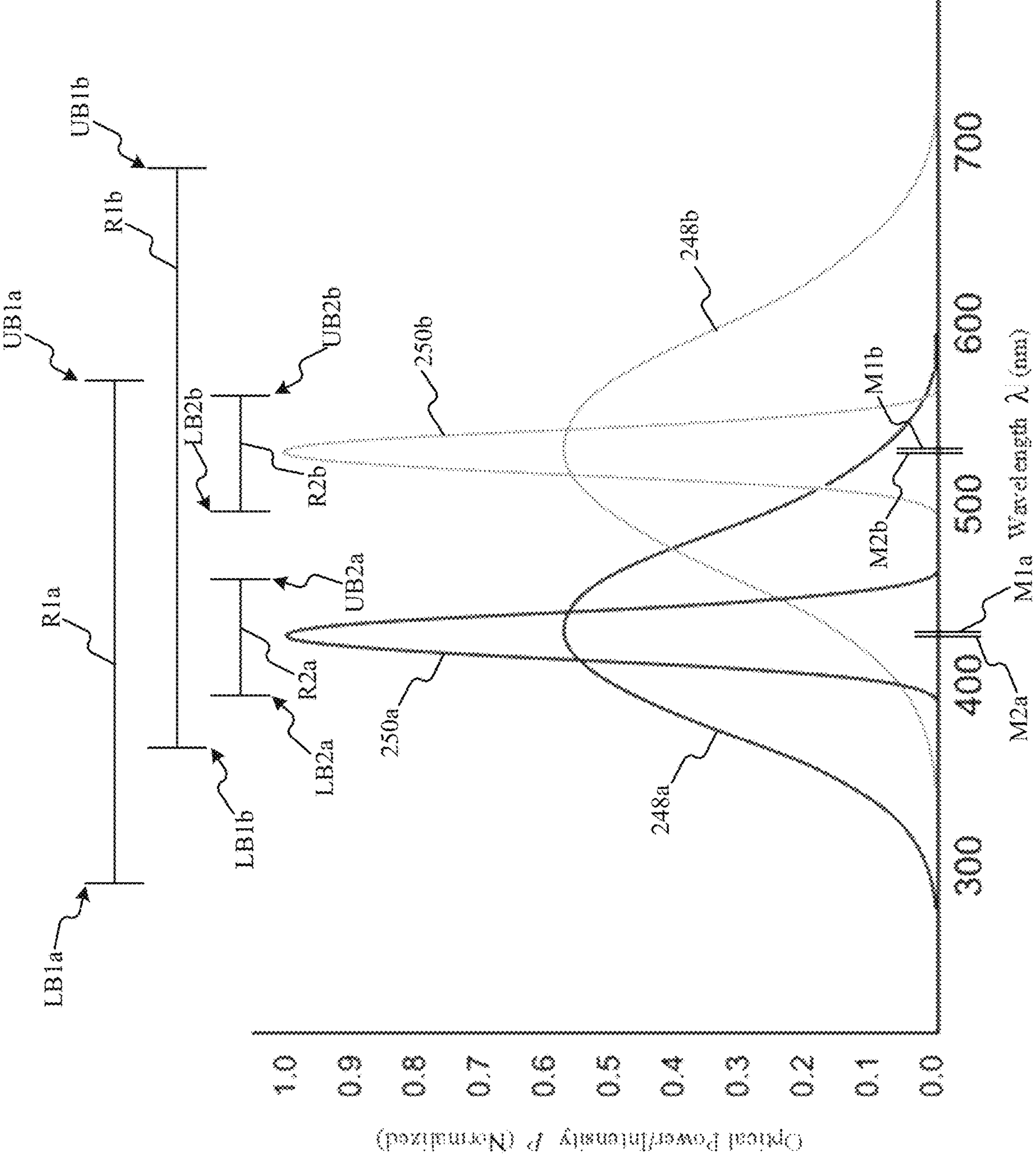

UB1
R1
UB2
R2
150
148b
148a
LB1
LB2
M1
M2
1.0
0.8
0.6
0.4
0.2
0.0
300
400
500
600
700
800
Wavelength λ (nm)
Optical Power/Intensity P (Normalized)

FIG. 3B


LB1a
R1a
UB1a
LB1b
R1b
UB1b
LB2a
R2a
UB2a
LB2b
R2b
UB2b
250a
248a
250b
248b
M1a
M2a
M1b
M2b
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
300
400
500
600
700
800
Wavelength λ (nm)
Optical Power/Intensity P (Normalized)

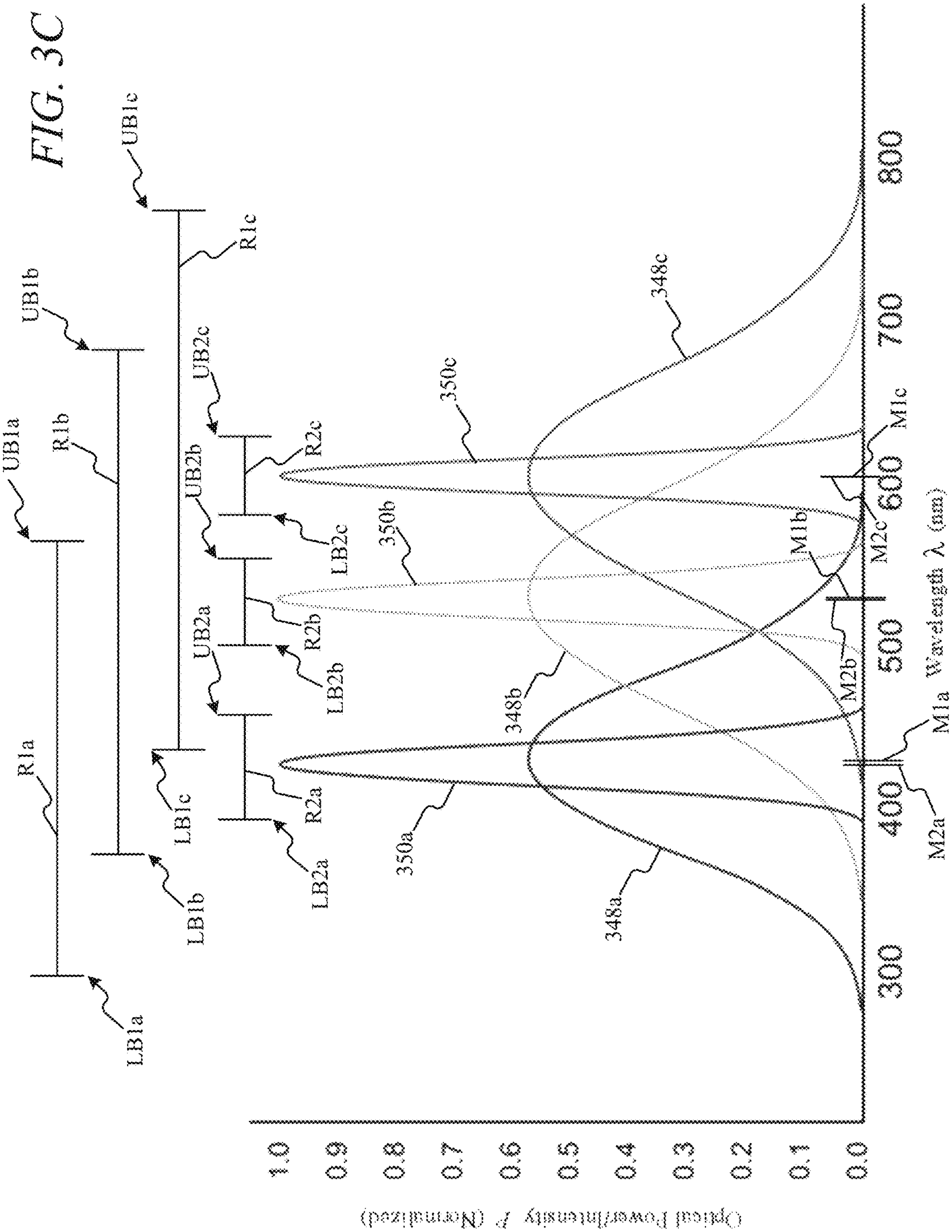

LB1a
R1a
UB1a
LB1b
R1b
UB1b
LB1c
R1c
UB1c
LB2a
R2a
UB2a
LB2b
R2b
UB2b
LB2c
R2c
UB2c
348a
348b
348c
350a
350b
350c
M1a
M2a
M1b
M2b
M1c
M2c
300
400
500
600
700
800
Wavelength λ (nm)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Optical Power/Intensity P (Normalized)

FIG. 3C

FIG. 4

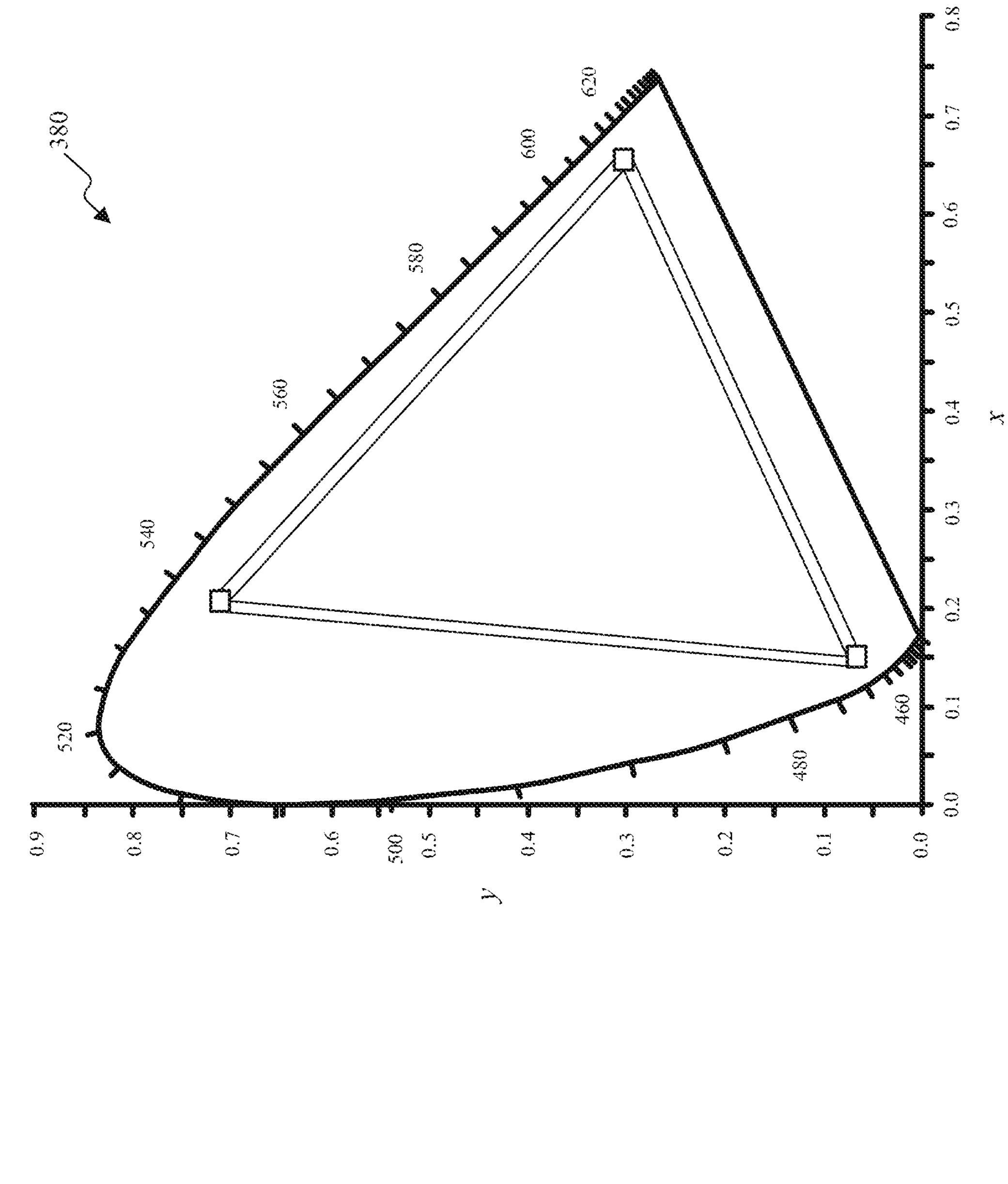
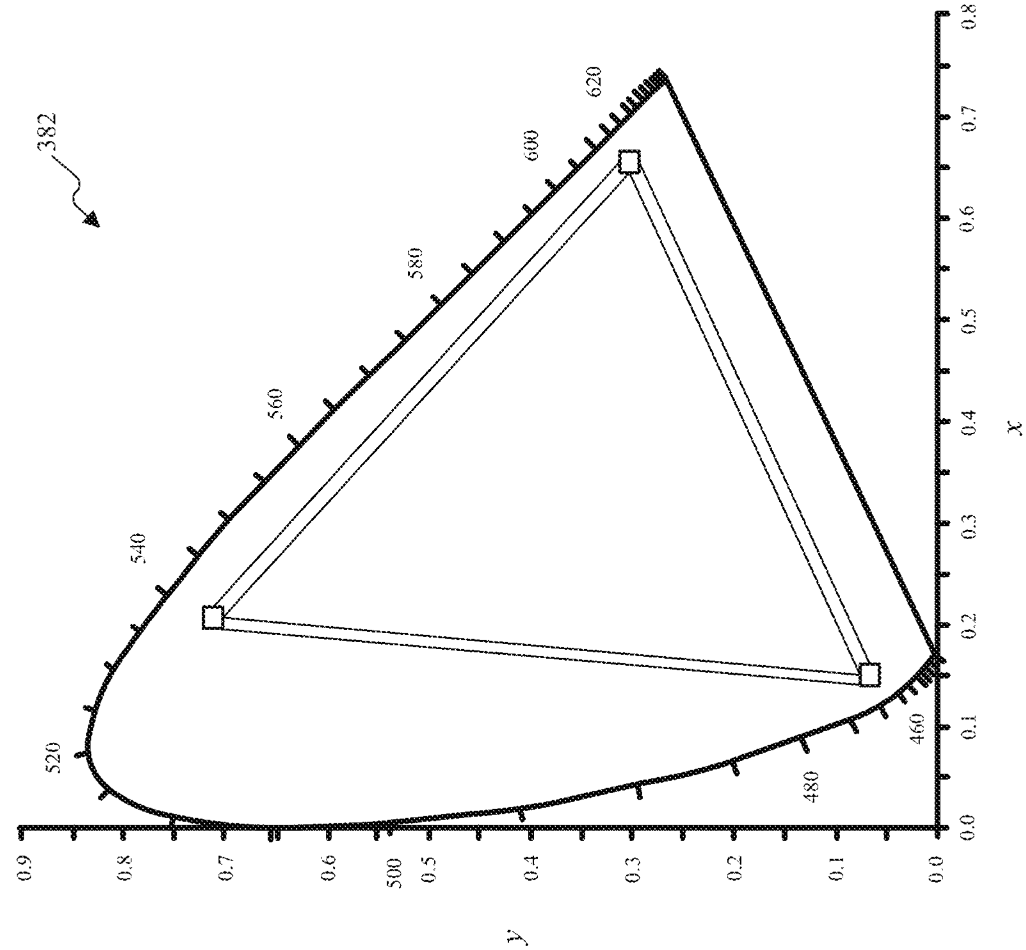
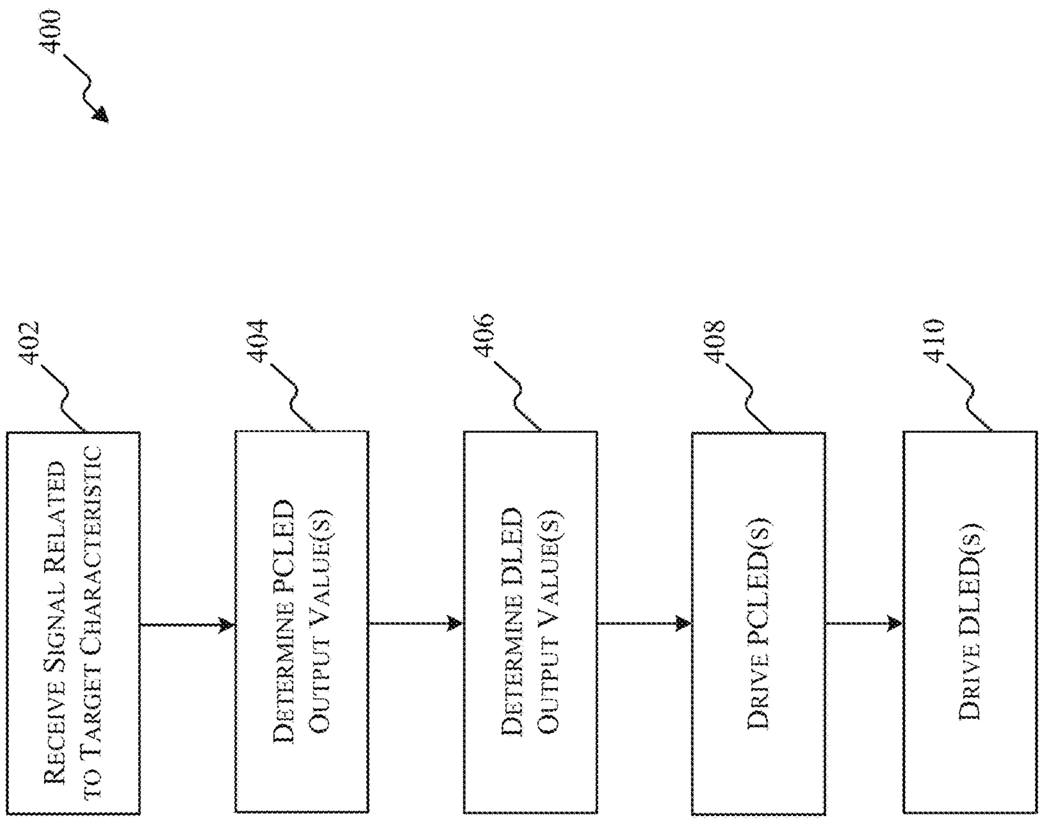

380
520
540
560
580
600
620
500
480
460
y
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
x
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

FIG. 5



382
620
600
580
560
540
520
500
480
460
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
x
y

FIG. 6


400
402
Receive Signal Related to Target Characteristic
404
Determine PCLED Output Value(s)
406
Determine DLED Output Value(s)
408
Drive PCLED(s)
410
Drive DLED(s)

LIGHT FIXTURE WITH BROADBAND AND NARROW BAND EMITTERS

FIELD

Embodiments described herein relate to controlling the spectral content of an output of a light fixture.

SUMMARY

Some light fixtures include phosphor-converted light-emitting diodes ("PCLEDs"). A PCLED includes a light-emitting diode ("LED") that emits light that can be blue, ultra-violet, or the like. A layer of phosphor material is applied onto a surface of the LED. Radiation emitted from the LED is absorbed by the phosphor material. Radiation energy absorbed by the phosphor material is then re-emitted as light having a longer wavelength in the visible range of the electromagnetic spectrum. The light produced by the phosphor material is often yellow. Some PCLEDs include the layer of phosphor material thin enough to allow some of the light from the LED, such as blue light, to leak through the layer of phosphor material. The combination of the blue light that leaks through the layer of phosphor material with, for example, yellow light produced by the phosphor material results in light that is perceived as white by the human eye.

Light fixtures including these PCLEDs typically produce light that is considered to be broadband (e.g., a range on the electromagnetic spectrum, where the light in the range has an intensity value of at least 1% of peak intensity, that is at least 100 nanometers [nm] wide). The broadband light produced by the PCLEDs may be distributed in a continuous band along the electromagnetic spectrum or may have peaks in the band. These PCLEDs are suitable for producing white light, which can be "warm" or "cool." However, PCLEDs are unsuitable for achieving saturated colors. Specifically, broadband light emitted from PCLEDs prevents light fixtures equipped with PCLEDs from producing light that falls on the electromagnetic spectrum in a relatively narrow band (i.e., not broadband).

Other light fixtures include direct LEDs ("DLEDs") that emit light in a relatively narrow range on the electromagnetic spectrum. These DLEDs do not include a phosphor material layer. Such light fixtures often include a mix of red, green, and blue LEDs and can be referred to as RGB LED fixtures. The combination of the red light, the green light, and the blue light results in light which is perceived as white by the human eye. RGB LED fixtures allow for control over the exact color of the light produced by controlling the light intensity from each of the colors of LEDs using, for instance, pulse width modulation ("PWM"). Although RGB LED fixtures are good for color saturation, white light produced by RGB LED fixtures is hardware-intensive when compared to PCLED fixtures. For example, to create white light, an RGB LED fixture requires at least three LEDs (one of each of red, green, and blue) to illuminate at a similar intensity and at the same time. Powering three LEDs to create white light with an RGB LED fixture requires more energy than powering a single LED in a PCLED fixture. Further, RGB LED fixtures tend to render pastel colors that appear relatively unnatural when compared to a natural light source or an ideal light source.

Embodiments described herein provide a light fixture that utilizes one or more PCLEDs to render white light and pastel light and one or more DLEDs to render specific saturated colors. With both PCLEDs and DLEDs, the light fixture is capable of good color rendering as well as good color saturation. The inclusion of PCLEDs further improves the overall efficacy of the light fixture without compromising color rendering. If at least one PCLED and at least one DLED in such a light fixture are illuminated simultaneously, the produced light can have a wavelength range with a different width on the electromagnetic spectrum than would be possible with either the PCLED or the DLED alone. Additionally or alternatively, the amount of color saturation can be tuned by having one or both of the PCLED and the DLED illuminated in a given instance. This variability allows for adjustment of the light fixture's wavelength range width on the electromagnetic spectrum and the intensity of individual color bands on the electromagnetic spectrum.

Embodiments described herein provide a light fixture that includes a housing, a first light-emitting diode ("LED") disposed in the housing, a first phosphor layer associated with the first light-emitting diode, a second LED disposed in the housing, a second phosphor layer associated with the second LED, a third LED disposed in the housing, and a fourth LED disposed in the housing. The first phosphor layer and the first LED form a first phosphor-converted light-emitting diode ("PCLED"). The second phosphor layer and the second LED form a second PCLED. The first PCLED emits light in a first PCLED wavelength range including a first PCLED upper bound and a first PCLED lower bound. The second PCLED emits light in a second PCLED wavelength range including a second PCLED upper bound and a second PCLED lower bound. The third LED emits light in a third LED wavelength range including a third LED upper bound and a third LED lower bound. The fourth LED emits light in a fourth LED wavelength range including a fourth LED upper bound and a fourth LED lower bound. The first PCLED upper bound of the first PCLED wavelength range is higher than the third LED upper bound of the third LED wavelength range. The first PCLED lower bound of the first PCLED wavelength range is lower than the third LED lower bound of the third LED wavelength range. The second PCLED upper bound of the second PCLED wavelength range is higher than the fourth LED upper bound of the fourth LED wavelength range. The second PCLED lower bound of the second PCLED wavelength range is lower than the fourth LED lower bound of the fourth LED wavelength range.

Embodiments described herein provide a lighting system. The lighting system includes a light fixture and a controller. The light fixture projects light therefrom. The light fixture includes a first PCLED that emits light in a first PCLED wavelength range. The light fixture also includes a first DLED that emits light in a first DLED wavelength range. The light fixture further includes a second PCLED that emits light in a second PCLED wavelength range. The light fixture also further includes a second DLED that emits light in a second DLED wavelength range. The first DLED wavelength range falls completely within the first PCLED wavelength range. The second DLED wavelength range falls completely within the second PCLED wavelength range. The controller receives a control signal corresponding to a target characteristic of the light projected by the light fixture, determines a first PCLED output value for the first PCLED based on the control signal, determines a first DLED output value for the first DLED based on the control signal, determines a second PCLED output value for the second PCLED based on the control signal, determines a second DLED output value for the second DLED based on the control signal, drives the first PCLED at the first PCLED output value, drives the first DLED at the first DLED output

value, drives the second PCLED at the second PCLED output value, and drives the second DLED at the second DLED output value.

Embodiments described herein provide a method for driving light-emitting diodes in a light fixture to project light therefrom. The light fixture includes a first PCLED that emits light in a first PCLED wavelength range, a first DLED that emits light in a first DLED wavelength range, a second PCLED that emits light in a second PCLED wavelength range, and a second DLED that emits light in a second DLED wavelength range. The first DLED wavelength range is within the first PCLED wavelength range. The second DLED wavelength range is within the second PCLED wavelength range. The method includes determining a first PCLED output value for the first PCLED based on a target characteristic of the light projected by the light fixture, determining a first DLED output value for the first DLED based on the target characteristic of the light projected by the light fixture, determining a second PCLED output value for the second PCLED based on the target characteristic of the light projected by the light fixture, determining a second DLED output value for the second DLED based on the target characteristic of the light projected by the light fixture, driving the first PCLED at the first PCLED output value, driving the first DLED at the first DLED output value, driving the second PCLED at the second PCLED output value, and driving the second DLED at the second DLED output value.

Before any embodiments are explained in detail, it is to be understood that the embodiments are not limited in its application to the details of the configuration and arrangement of components set forth in the following description or illustrated in the accompanying drawings. The embodiments are capable of being practiced or of being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein are for the purpose of description and should not be regarded as limiting. The use of "including," "comprising," or "having" and variations thereof are meant to encompass the items listed thereafter and equivalents thereof as well as additional items. Unless specified or limited otherwise, the terms "mounted," "connected," "supported," and "coupled" and variations thereof are used broadly and encompass both direct and indirect mountings, connections, supports, and couplings.

In addition, it should be understood that embodiments may include hardware, software, and electronic components or modules that, for purposes of discussion, may be illustrated and described as if the majority of the components were implemented solely in hardware. However, one of ordinary skill in the art, and based on a reading of this detailed description, would recognize that, in at least one embodiment, the electronic-based aspects may be implemented in software (e.g., stored on non-transitory computer-readable medium) executable by one or more processing units, such as a microprocessor and/or application specific integrated circuits ("ASICs"). As such, it should be noted that a plurality of hardware and software based devices, as well as a plurality of different structural components, may be utilized to implement the embodiments. For example, "servers" and "computing devices" described in the specification can include one or more processing units, one or more computer-readable medium modules, one or more input/output interfaces, and various connections (e.g., a system bus) connecting the components.

Other aspects of the embodiments will become apparent by consideration of the detailed description and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A illustrates a light fixture, according to embodiments described herein.

FIG. **1**B illustrates another light fixture, according to embodiments described herein.

FIG. **1**C illustrates yet another light fixture, according to embodiments described herein.

FIG. **2**A schematically illustrates a lighting system including the light fixture of FIG. **1**A, according to embodiments described herein.

FIG. **2**B schematically illustrates a lighting system including the light fixture of FIG. **1**B, according to embodiments described herein.

FIG. **2**C schematically illustrates a lighting system including the light fixture of FIG. **1**C, according to embodiments described herein.

FIG. **3**A illustrates a graph of light emitted by the light fixture of FIG. **1**A comparing wavelength (in nanometers) to optical power (normalized).

FIG. **3**B illustrates a graph of light emitted by the light fixture of FIG. **1**B comparing wavelength (in nanometers) to optical power (normalized).

FIG. **3**C illustrates a graph of light emitted by the light fixture of FIG. **1**C comparing wavelength (in nanometers) to optical power (normalized).

FIG. **4** illustrates a gamut of the phosphor-converted light-emitting diodes of the light fixture of FIG. **1**C, according to embodiments described herein.

FIG. **5** illustrates a gamut of the direct light-emitting diodes of the light fixture of FIG. **1**C, according to embodiments described herein.

FIG. **6** illustrates a process for driving LEDs in any of the light fixtures of FIGS. **1**A-**1**C, according to embodiments described herein.

DETAILED DESCRIPTION

FIG. **1**A illustrates a light fixture **100**. The light fixture **100** includes a housing **102** with multiple light-emitting diodes ("LEDs") disposed therein. Particularly, the light fixture **100** includes phosphor-converted LEDs ("PCLEDs") **104** and direct LEDs ("DLEDs") **106**. In some embodiments, the DLEDs **106** are each multicolor LEDs (e.g., multicolor chip-on-board ["COB"] LEDs). The PCLEDs **104** and the DLEDs **106** are illustrated as being positioned adjacent each other in each of the LED reflector cells **108**, but other embodiments may include the PCLEDs **104** and the DLEDs **106** positioned in separate respective LED reflector cells **108**. The light fixture **100** is also illustrated with a light diffuser **110** positioned over the reflector cells **108**. In some embodiments, the light diffuser **110** may be omitted.

FIG. **1**B illustrates another light fixture **200**. The light fixture **200** is similar to the light fixture **100** above. The light fixture **200** includes a housing **202** with multiple LEDs disposed therein, including PCLEDs **204***a*, **204***b* and DLEDs **206***a*, **206***b*. The PCLEDs **204***a*, **204***b* and the DLEDs **206***a*, **206***b* are illustrated as being positioned adjacent each other in each of the LED reflector cells **208**, but they may be in separate LED reflector cells **208**. An optional light diffuser **210** is also illustrated as part of the light fixture **200**.

FIG. **1**C illustrates yet another light fixture **300**. The light fixture **300** is similar to the light fixture **100** above. The light fixture **300** includes a housing **302** with multiple LEDs disposed therein, including PCLEDs **304***a*, **304***b*, **304***c* and

DLEDs **306***a*, **306***b*, **306***c*. The PCLEDs **304***a*, **304***b*, **304***c* and the DLEDs **306***a*, **306***b*, **306***c* are illustrated as being positioned adjacent each other in each of the LED reflector cells **308**, but they may be in separate LED reflector cells **308**. An optional light diffuser **310** is also illustrated as part of the light fixture **300**.

With reference to FIG. **2**A, the light fixture **100** is shown schematically as part of a lighting system **112**. The lighting system **112** includes a controller **114** associated with the lighting system **112** and electrically and/or communicatively connected to a variety of modules or components of the lighting system **112**. For example, the illustrated controller **114** is connected to, among other things, the PCLEDs **104**, the DLEDs **106**, a power supply module **116**, a PCLED driver **118**, a DLED driver **120**, a user interface such as a lighting console **122**, and a communications module **124**. The controller **114** includes combinations of hardware and software that are operable to, among other things, control the operation of the lighting system **112**, an output of the PCLEDs **104** and the DLEDs **106**, information displayed in the lighting console **122**, or the like.

The controller **114** includes a plurality of electrical and electronic components that provide power, operational control, and protection to the components and modules within the controller **114** and/or the lighting system **112**. For example, the controller **114** includes, among other things, a processing unit **126** (e.g., a microprocessor, a microcontroller, or another suitable programmable device), a memory **128**, input units **130**, and output units **132**. The processing unit **126** includes, among other things, a control unit **134**, an arithmetic logic unit ("ALU") **136**, and a plurality of registers **138** (shown as a group of registers in FIG. **2**A), and is implemented using a known computer architecture, such as a modified Harvard architecture, a von Neumann architecture, etc. The processing unit **126**, the memory **128**, the input units **130**, and the output units **132**, as well as the various modules connected to the controller **114** are connected by one or more control and/or data buses (e.g., common bus **140**). The control and/or data buses are shown generally in FIG. **2**A for illustrative purposes. The use of one or more control and/or data buses for the interconnection between and communication among the various modules and components would be known to a person skilled in the art in view of the present disclosure.

The memory **128** is a non-transitory computer readable medium and includes, for example, a program storage area **142** and a data storage area **144**. The program storage area **142** and the data storage area **144** can include combinations of different types of memory, such as read-only memory ("ROM"), random access memory ("RAM") (e.g., dynamic RAM ["DRAM"], synchronous DRAM ["SDRAM"], etc.), electrically erasable programmable read-only memory ("EEPROM"), flash memory, a hard disk, an SD card, or other suitable magnetic, optical, physical, or electronic memory devices. The processing unit **126** is connected to the memory **128** and executes software instructions that are capable of being stored in a RAM of the memory **128** (e.g., during execution), a ROM of the memory **128** (e.g., on a generally permanent basis), or another non-transitory computer readable medium such as another memory or a disc. Software included in the implementation of the lighting system **112** can be stored in the memory **128** of the controller **114**. The software includes, for example, firmware, one or more applications, program data, filters, rules, one or more program modules, and other executable instructions. The controller **114** is configured to retrieve from memory and execute, among other things, instructions related to the control processes and methods described herein. In other embodiments, the controller **114** includes additional, fewer, or different components.

The power supply module **116** supplies a nominal AC or DC voltage to the controller **114** or other components or modules of the lighting system **112**. The power supply module **116** is powered by, for example, a power source having nominal line voltages between 100V and 240V AC and frequencies of approximately 50-60 Hz. The power supply module **116** is also configured to supply lower voltages to operate circuits and components within the controller **114** or lighting system **112**. In other embodiments, the controller **114** or other components and modules within the lighting system **112** are powered by one or more batteries or battery packs, or another grid-independent power source (e.g., a generator, a solar panel, etc.).

The lighting console **122** is used to control and/or monitor the lighting system **112**. For example, the lighting console **122** is operably coupled to the controller **114** to control the color output of the light fixture **100**. In some embodiments, the lighting console **122** includes a combination of digital and analog input or output devices required to achieve a desired level of control and/or monitoring for the lighting system **112**. For example, the lighting console **122** includes a display (e.g., a monitor) and input devices such as touch-screen displays, a plurality of knobs, dials, switches, buttons, etc. The display is, for example, a liquid crystal display ("LCD"), an LED display, an organic LED ("OLED") display, etc. The lighting console **122** can also be configured to display conditions or data associated with the lighting system **112** in real-time or substantially real-time. For example, the lighting console **122** is configured to display characteristics or properties of the lighting system **112**, the status of the lighting system **112**, the output of the light fixture **100**, etc. In some implementations, the lighting console **122** is controlled to provide visual or auditory indications of the status or conditions of the lighting system **112**. The lighting console **122** is further configured to generate a control signal corresponding to a target characteristic of the light **146** projected by the light fixture **100** (e.g., brightness, overall color, illumination duration, or the like). The controller **114** is configured to receive the control signal from the lighting console **122**, determine output values for the PCLED and the DLED respectively, and drive the PCLED and the DLED at the respective output values.

The PCLED driver **118** provides drive signals to the PCLED **104**, and the DLED driver **120** provides drive signals to the DLED **106**. In some embodiments, both the PCLED driver **118** and the DLED driver **120** are configured to generate multiple drive signals to drive multiple groups of LEDs.

With continued reference to FIG. **2**A, light **146** is projected from the light fixture **100**. The light **146** is a combination of the light **148** emitted from the PCLED **104** and the light **150** emitted from the DLED **106**. The light diffuser **110** promotes the combination of the light **148** from the PCLED **104** and the light **150** from the DLED **106**.

The PCLED **104** includes an LED **152**. The LED **152** is configured to emit light **148***a* in a narrow band relative to the light **148** emitted from the PCLED **104**. In some embodiments, the light **148***a* falls on the electromagnetic spectrum in a range associated with a blue LED. Other embodiments include the light **148***a* corresponding to ultraviolet light or a visible color other than blue.

The PCLED **104** further includes a phosphor layer **154**. The phosphor layer **154** covers the LED **152**. In some embodiments, the phosphor layer **154** is deposited directly on a surface of the LED **152**. In other embodiments, the phosphor layer **154** is formed as a structure connected to the housing **102** (shown in FIG. **1**A) or to the LED reflector cell **108** and at least partially surrounding the LED **152** with the housing **102** or the LED reflector cell **108** (such as, for instance, a remote phosphor). The phosphor layer **154** absorbs light **148***a* emitted from the LED **152**. The absorbed light is then emitted from the phosphor layer **154** in the form of light **148***b*. In some embodiments, the light **148***b* falls on the electromagnetic spectrum in a range associated with yellow light. Other embodiments include the light **148***b* corresponding to orange light, red light, green light, blue light, or the like.

In the illustrated embodiment, the phosphor layer **154** includes areas of light permeability such that not all of the light **148***a* emitted from the LED **152** is absorbed by the phosphor layer **154**. In such embodiments, the light **148***a* emitted from the LED **152** that passes through the phosphor layer **154** combines with the light **148***b* emitted from the phosphor layer **154**. This combination forms the light **148** output from the PCLED **104**. Other embodiments include all the light **148***a* from the LED **152** being absorbed by the phosphor layer **154** such that the light **148** emitted by the PCLED **104** beyond the phosphor layer **154** includes only the light **148***b* emitted from the phosphor layer **154**.

In some embodiments, the light **148** (a combination of **148***a* and **148***b*) emitted by the PCLED **104** is perceived by the human eye as white light due to the combination of the light **148***a* (e.g., as blue light) emitted by the LED **152** and the light **148***b* (e.g., as yellow light) emitted by the phosphor layer **154**. In other embodiments, the light **148** emitted by the PCLED **104** can have a broadband range on the electromagnetic spectrum that is centered on a wavelength that corresponds to a particular color of light. For instance, the light **148** emitted by the PCLED **104** can correspond to yellow light, orange light, red light, green light, blue light, or the like.

The light fixture **100** further includes the DLED **106** disposed in the housing **102**. The DLED **106** has no phosphor layer and instead emits light **150** directly outward toward the light diffuser **110**. The light **150** emitted from the DLED **106** falls on the electromagnetic spectrum in a relatively narrow band compared to the light **148** emitted from the PCLED **104**. The DLED **106** can be configured to emit light **150** in a narrow band on the electromagnetic spectrum corresponding to only one color, such as yellow, orange, red, green, blue, or the like.

With reference to FIG. **2**B, the light fixture **200** is shown schematically as part of another embodiment of a lighting system **212**. The lighting system **212** is similar to the lighting system **112** described above. Many of the components of the lighting system **212** are not shown, but reference can be made to FIG. **2**A for more detail regarding these components.

With continued reference to FIG. **2**B, the lighting system **212** includes two PCLEDs **204***a*, **204***b* of different colors and two DLEDs **206***a*, **206***b* of different colors. The lighting system **212** includes a controller **214** associated with the lighting system **212** and electrically and/or communicatively connected to a variety of modules or components of the lighting system **212** (not all of which are shown). For example, the illustrated controller **214** is connected to, among other things, the PCLEDs **204***a*, **204***b*, the DLEDs **206***a*, **206***b*, PCLED drivers **218***a*, **218***b*, and DLED drivers **220***a*, **220***b*. The controller **214** includes combinations of hardware and software that are operable to, among other things, control the operation of the lighting system **212**, an output of the PCLEDs **204***a*, **204***b* and the DLEDs **206***a*, **206***b*, or the like.

With continued reference to FIG. **2**B, light **246** is projected from the light fixture **200**. The light **246** is any combination of the light **248***a* emitted from the first PCLED **204***a*, the light **248***b* emitted from the second PCLED **204***b*, the light **250***a* emitted from the first DLED **206***a*, and the light **250***b* emitted from the second DLED **206***b*. The light diffuser **210** promotes the combination of the light **248***a*, **248***b*, **250***a*, **250***b*.

The first PCLED **204***a* projects light **248***a* of any color, such as blue light, for instance. The first PCLED **204***a* includes a first LED **252***a*. The first LED **252***a* is configured to emit light **248***a***1** in a narrow band relative to the light **248***a* emitted from the first PCLED **204***a*.

The first PCLED **204***a* further includes a first phosphor layer **254***a*. The first phosphor layer **254***a* covers the first LED **252***a*. In some embodiments, the first phosphor layer **254***a* is deposited directly on a surface of the first LED **252***a*. Other embodiments include the first phosphor layer **254***a* formed as a structure at least partially surrounding the first LED **252***a*. The first phosphor layer **254***a* absorbs light **248***a***1** emitted from the first LED **252***a*. The absorbed light is then emitted from the first phosphor layer **254***a* in the form of light **248***a***2**. In some embodiments, the light **248***a***2** falls on the electromagnetic spectrum in a range associated with blue light.

In the illustrated embodiment in FIG. **2**B, the first phosphor layer **254***a* absorbs a majority of the light **248***a***1** emitted from the first LED **252***a*. In some embodiments, the phosphor layer **254***a* allows none of the light **248***a***1**, or substantially none of the light **248***a***1**, to pass through the phosphor layer **254***a*. In such embodiments, the light **248***a***2** emitted by the phosphor layer **254***a* is the same light as the light **248***a* emitted generally by the PCLED **204***a*. Other embodiments may include the phosphor layer **254***a* having areas of light permeability such that not all of the light **248***a***1** emitted from the first LED **252***a* is absorbed by the phosphor layer **254***a*.

The second PCLED **204***b* projects light **248***b* of a color that is different from the color of the light **248***a* projected by the first PCLED **204***a*. The color of the light **248***b* projected by the second PCLED **204***b* may be green, for instance. The second PCLED **204***b* includes a second LED **252***b*. The second LED **252***b* is configured to emit light **248***b***1** in a narrow band relative to the light **248***b* emitted from the second PCLED **204***b*.

The second PCLED **204***b* is largely similar to the first PCLED **204***a*, aside from the color of the light **248***b* the second PCLED **204***b* is configured to project. The second PCLED **204***b* includes a phosphor layer **254***b* that absorbs light **248***b***1** emitted from the second LED **252***b* that is then emitted from the phosphor layer **254***b* in the form of light **248***b***2**. In some embodiments, the light **248***b***2** falls on the electromagnetic spectrum in a range associated with green light.

In the illustrated embodiment in FIG. **2**B, the phosphor layer **254***b* absorbs a majority of the light **248***b***1** emitted from the second LED **252***b*. In some embodiments, the phosphor layer **254***b* allows none of the light **248***b***1**, or substantially none of the light **248***b***1**, to pass through the phosphor layer **254***b*. In such embodiments, the light **248***b***2** emitted by the phosphor layer **254***b* is the same light as the light **248***b* emitted generally by the second PCLED **204***b*. Other embodiments may include the phosphor layer **254***b* having areas of light permeability such that not all of the light **248*b*1** emitted from the second LED **252*b*** is absorbed by the phosphor layer **254*b***.

The light fixture **200** further includes a first DLED (or a third LED) **206*a*** and a second DLED (or a fourth LED) **206*b*** disposed in the housing **202**. The DLEDs **206*a***, **206*b*** have no phosphor layer and instead emit light **250*a***, **250*b*** (respectively) directly outward toward the light diffuser **210**. The light **250*a***, **250*b*** emitted from the respective DLED **206*a***, **206*b*** falls on the electromagnetic spectrum in a relatively narrow band compared to the light **248*a***, **248*b*** emitted from the respective PCLED **204*a***, **204*b***. The first DLED **206*a*** can be configured to emit light **250*a*** corresponding to the color blue, for instance, and the second DLED **206*b*** can be configured to emit light **250*b*** corresponding to another color, such as green, for instance.

With reference to FIG. **2**C, the light fixture **300** is shown schematically as part of yet another embodiment of a lighting system **312**. The lighting system **312** is similar to the lighting system **112** described above. Many of the components of the lighting system **312** are not shown, but reference can be made to FIG. **2**A for more detail regarding these components.

With continued reference to FIG. **2**C, the lighting system **312** includes three PCLEDs **304*a***, **304*b***, **304*c*** of different colors and three DLEDs **306*a***, **306*b***, **306*c*** of different colors. The lighting system **312** includes a controller **314** associated with the lighting system **312** and electrically and/or communicatively connected to a variety of modules or components of the lighting system **312** (not all of which are shown). For example, the illustrated controller **314** is connected to, among other things, the PCLEDs **304*a***, **304*b***, **304*c***, the DLEDs **306*a***, **306*b***, **306*c***, PCLED drivers **318*a***, **318*b***, **318*c***, and DLED drivers **320*a***, **320*b***, **320*c***. The controller **314** includes combinations of hardware and software that are operable to, among other things, control the operation of the lighting system **312**, an output of the PCLEDs **304*a***, **304*b***, **304*c*** and the DLEDs **306*a***, **306*b***, **306*c***, or the like.

With continued reference to FIG. **2**C, light **346** is projected from the light fixture **300**. The light **346** is any combination of the light **348*a*** emitted from the first PCLED **304*a***, the light **348*b*** emitted from the second PCLED **304*b***, the light **348*c*** emitted from the third PCLED **304*c***, the light **350*a*** emitted from the first DLED **306*a***, the light **350*b*** emitted from the second DLED **306*b***, and the light **350*c*** emitted from the third DLED **306*c***. The light diffuser **310** promotes the combination of the light **348*a***, **348*b***, **348*c***, **350*a***, **350*b***, **350*c***.

The first PCLED **304*a*** projects light **348*a*** of any color, such as blue light, for instance. The first PCLED **304*a*** includes a first LED **352*a***. The first LED **352*a*** is configured to emit light **348*a*1** in a narrow band relative to the light **348*a*** emitted from the first PCLED **304*a***.

The first PCLED **304*a*** further includes a phosphor layer **354*a*** covering the first LED **352*a*** as described above. The phosphor layer **354*a*** absorbs light **348*a*1** emitted from the first LED **352*a***. The absorbed light is then emitted from the phosphor layer **354*a*** in the form of light **348*a*2**. In some embodiments, the light **348*a*2** falls on the electromagnetic spectrum in a range associated with blue light.

In the illustrated embodiment in FIG. **2**C, the phosphor layer **354*a*** allows none of the light **348*a*1**, or substantially none of the light **348*a*1**, to pass through the phosphor layer **354*a***. In such embodiments, the light **348*a*2** emitted by the phosphor layer **354*a*** is the same light as the light **348*a*** emitted generally by the PCLED **304*a***. Other embodiments may include the phosphor layer **354*a*** having areas of light permeability such that not all of the light **348*a*1** emitted from the first LED **352*a*** is absorbed by the phosphor layer **354*a***.

The second PCLED **304*b*** projects light **348*b*** of a color that is different from the color of the light **348*a*** projected by the first PCLED **304*a***. The color of the light **348*b*** projected by the second PCLED **304*b*** may be green, for instance. The second PCLED **304*b*** includes a second LED **352*b***. The second LED **352*b*** is configured to emit light **348*b*1** in a narrow band relative to the light **348*b*** emitted from the second PCLED **304*b***.

The second PCLED **304*b*** is largely similar to the first PCLED **304*a***, aside from the color of the light **348*b*** the second PCLED **304*b*** is configured to project. The second PCLED **304*b*** includes a phosphor layer **354*b*** that absorbs light **348*b*1** emitted from the second LED **352*b*** that is then emitted from the phosphor layer **354*b*** in the form of light **348*b*2**. In some embodiments, the light **348*b*2** falls on the electromagnetic spectrum in a range associated with green light.

In the illustrated embodiment in FIG. **2**C, the phosphor layer **354*b*** allows none of the light **348*b*1**, or substantially none of the light **348*b*1**, to pass through the phosphor layer **354*b***. In such embodiments, the light **348*b*2** emitted by the phosphor layer **354*b*** is the same light as the light **348*b*** emitted generally by the second PCLED **304*b***. Other embodiments may include the phosphor layer **354*b*** having areas of light permeability such that not all of the light **348*b*1** emitted from the second LED **352*b*** is absorbed by the phosphor layer **354*b***.

The third PCLED **304*c*** projects light **348*c*** of a color that is different from the color of the light **348*a***, **348*b*** projected by the respective first PCLED **304*a*** and second PCLED **304*b***. The color of the light **348*c*** projected by the third PCLED **304*c*** may be red, for instance. The third PCLED **304*c*** includes a fifth LED **352*c***. The fifth LED **352*c*** is configured to emit light **348*c*1** in a narrow band relative to the light **348*c*** emitted from the third PCLED **304*c***.

The third PCLED **304*c*** is largely similar to the first PCLED **304*a*** and the second PCLED **304*b***, aside from the color of light **348*c*** the third PCLED **304*c*** is configured to project. The third PCLED **304*c*** includes a phosphor layer **354*c*** that absorbs light **348*c*1** emitted from the third LED **352*c*** that is then emitted from the phosphor layer **354*c*** in the form of light **348*c*2**. In some embodiments, the light **348*c*2** falls on the electromagnetic spectrum in a range associated with red light.

In the illustrated embodiment in FIG. **2**C, the phosphor layer **354*c*** allows none of the light **348*c*1**, or substantially none of the light **348*c*1**, to pass through the phosphor layer **354*c***. In such embodiments, the light **348*c*2** emitted by the phosphor layer **354*c*** is the same light as the light **348*c*** emitted generally by the third PCLED **304*c***. Other embodiments may include the phosphor layer **354*c*** having areas of light permeability such that not all of the light **348*c*1** emitted from the third LED **352*c*** is absorbed by the phosphor layer **354*c***.

The light fixture **300** further includes a first DLED (or third LED) **306*a***, a second DLED (or fourth LED) **306*b***, and a third DLED (or sixth LED) **306*c*** disposed in the housing **302**. The DLEDs **306*a***, **306*b***, **306*c*** have no phosphor layer and instead emit light **350*a***, **350*b***, **350*c*** (respectively) directly outward toward the light diffuser **310**. The light **350*a***, **350*b***, **350*c*** emitted from the respective DLED **306*a***, **306*b***, **306*c*** falls on the electromagnetic spectrum in a relatively narrow band compared to the light **348*a***, **348*b***, **348*c*** emitted from the respective PCLED **304*a***, **304*b***, **304*c***.

The first DLED **306***a* can be configured to emit light **350***a* corresponding to the color blue, for instance. The second DLED **306***b* can be configured to emit light **350***b* corresponding to another color, such as green, for instance. The third DLED **306***c* can be configured to emit light **350***c* corresponding to yet another color, such as red, for instance.

With reference to FIG. **3**A, a line graph representing an exemplary embodiment of the light **148***a* from the LED **152** of the PCLED **104**, the light **148***b* from the phosphor layer **154** of the PCLED **104**, and the light **150** from the DLED **106** on the electromagnetic spectrum is shown. In the illustrated embodiment, the light **148** emitted by the PCLED **104** includes blue light **148***a* emitted from the LED **152** that passes through the phosphor layer **154** and yellow light **148***b* emitted from the phosphor layer **154**. The light **150** emitted by the DLED **106** includes green light in the embodiment illustrated in FIG. **3**A.

As shown in FIG. **3**A, the light **148** (a combination of **148***a* and **148***b*) from the PCLED **104** is emitted in a first wavelength range (or a PCLED wavelength range) R**1**, and the light **150** from the DLED **106** is emitted in a second wavelength range (or a DLED wavelength range) R**2**. The first wavelength range R**1** includes a first upper bound UB**1** and a first lower bound LB**1**. The second wavelength range R**2** includes a second upper bound UB**2** and a second lower bound LB**2**. The first upper bound UB**1**, the first lower bound LB**1**, the second upper bound UB**2**, and the second lower bound LB**2** are not necessarily wavelength values on the electromagnetic spectrum beyond which no light is emitted from the respective LED **104**, **106**.

Instead, in some embodiments, the first upper bound UB**1** and the first lower bound LB**1** represent respective wavelength values beyond which lies only light **148** (**148***a* and **148***b*) that has an intensity value that is less than 10% of the peak intensity value of the light **148**. In other embodiments, the intensity value is less than 5% of the peak intensity value of the light **148**. In still other embodiments, the intensity value is less than 1% of the peak intensity value of the light **148**. Stated another way, some embodiments include the first wavelength range R**1** having only light **148** (**148***a* and **148***b*) that has an intensity value that is greater than 1% of the peak intensity value of the light **148**. Other embodiments include the first wavelength range R**1** having only light **148** that has an intensity value that is greater than 5% of the peak intensity value of the light **148**. Still other embodiments include the first wavelength range R**1** having only light **148** that has an intensity value that is greater than 10% of the peak intensity value of the light **148**.

Similarly, in some embodiments, the second upper bound UB**2** and the second lower bound LB**2** represent respective wavelength values beyond which lies only light **150** that has an intensity value that is less than 10% of the peak intensity value of the light **150**. In other embodiments, the intensity value is less than 5% of the peak intensity value of the light **150**. In still other embodiments, the intensity value is less than 1% of the peak intensity value of the light **150**. Stated another way, some embodiments include the second wavelength range R**2** having only light **150** that has an intensity value that is greater than 1% of the peak intensity value of the light **150**. Other embodiments include the second wavelength range R**2** having only light **150** that has an intensity value that is greater than 5% of the peak intensity value of the light **150**. Still other embodiments include the second wavelength range R**2** having only light **150** that has an intensity value that is greater than 10% of the peak intensity value of the light **150**.

In the illustrated embodiment in FIG. **3**A, the PCLED wavelength range R**1** has a PCLED upper bound UB**1** (e.g., approximately 660 nm) that has a wavelength of a higher value than the DLED upper bound UB**2** (e.g., approximately 575 nm) of the DLED wavelength range R**2**. The PCLED wavelength range R**1** also has a PCLED lower bound LB**1** (e.g., approximately 400 nm) that has a wavelength of a lower value than the DLED lower bound LB**2** (e.g., approximately 430 nm) of the DLED wavelength range R**2**. Stated another way, the DLED wavelength range R**2** falls along the electromagnetic spectrum completely within the PCLED wavelength range R**1**.

The light **148** from the PCLED **104** further includes a median PCLED wavelength M**1**, and the light **150** from the DLED **106** includes a median DLED wavelength M**2**. In some embodiments, the median PCLED wavelength M**1** and the median DLED wavelength M**2** are within 50 nanometers of each other. In other embodiments, the median PCLED wavelength M**1** and the median DLED wavelength M**2** are within 25 nanometers of each other. In still other embodiments, the median PCLED wavelength M**1** and the median DLED wavelength M**2** are within 10 nanometers of each other. In still other embodiments, the median PCLED wavelength M**1** and the median DLED wavelength M**2** are the same wavelength value. Even more embodiments include the median PCLED wavelength M**1** and the median DLED wavelength M**2** being within 50-100 nanometers of each other, within 100-200 nanometers of each other, and more than 200 nanometers away from each other.

In some embodiments, the target characteristic of the light **146** projected by the light fixture **100** includes a PCLED wavelength range intensity and a DLED wavelength range intensity combining at a target ratio. In the illustrated embodiment in FIG. **3**A, the yellow light **148***b* emitted from the phosphor layer **154** of the PCLED **104** combines with the green light **150** emitted from the DLED **106** at a target ratio. In some embodiments, the target ratio includes the DLED wavelength range intensity being at least two times greater than the PCLED wavelength range intensity. In FIG. **3**A, the green light **150** is more than two times greater in intensity (along the Y-axis labeled optical power) than the yellow light **148***b* (e.g., the green light **150** outputs 60 lumens while the yellow light **148***b* outputs 30 lumens). In some embodiments, the intensity of the light **150** emitted from the DLED **106** is at least three times greater than the intensity of the light **148***b* emitted from the phosphor layer **154** of the PCLED **104** (e.g., the green light **150** outputs 90 lumens while the yellow light **148***b* outputs 30 lumens). In some embodiments, the intensity of the light **150** emitted from the DLED **106** is at least four times greater than the intensity of the light **148***b* emitted from the phosphor layer **154** of the PCLED **104** (e.g., the green light **150** outputs 120 lumens while the yellow light **148***b* outputs 30 lumens).

In some embodiments, the target characteristic of the light **146** projected by the light fixture **100** includes a target wavelength range to correspond to a specific color or temperature of light (e.g., 400-660 nm, 430-660 nm, or the like). The light **146** projected by the light fixture **100** is limited to, for example, the target wavelength range under control of the lighting console **122**. Stated another way, the color of the light **146** can be controlled by illuminating the PCLED **104** and/or the DLED **106** at various intensities. For an example light color, only the DLED **106** is illuminated. For another example light color, only the PCLED **104** is illuminated. For still another example light color, the PCLED **104** and the DLED **106** are both illuminated at respective intensities.

With reference to FIG. **3**B, a line graph representing an exemplary embodiment of the light **248***a* from the first PCLED **204***a*, the light **248***b* from the second PCLED **204***b*, the light **250***a* from the first DLED **206***a*, and the light **250***b* from the second DLED **206***b* on the electromagnetic spectrum is shown. In the illustrated embodiment, the light **248***a* emitted by the first PCLED **204***a* includes generally blue light, the light **248***b* emitted by the second PCLED **204***b* includes generally green light, the light **250***a* emitted by the first DLED **206***a* includes blue light, and the light **250***b* emitted by the second DLED **206***b* includes green light.

As shown in FIG. **3**B, the light **248***a* from the first PCLED **204***a* is emitted in a first PCLED wavelength range R**1***a* that includes a first PCLED upper bound UB**1***a* and a first PCLED lower bound LB**1***a*. The light **248***b* from the second PCLED **204***b* is emitted in a second PCLED wavelength range R**1***b* that includes a second PCLED upper bound UB**1***b* and a second PCLED lower bound LB**1***b*. The light **250***a* from the first DLED **206***a* is emitted in a first DLED wavelength range R**2***a* that includes a first DLED upper bound UB**2***a* and a first DLED lower bound LB**2***a*. The light **250***b* from the second DLED **206***b* is emitted in a second DLED wavelength range R**2***b* that includes a second DLED upper bound UB**2***b* and a second DLED lower bound LB**2***b*. The bounds UB**1***a*, UB**1***b*, LB**1***a*, LB**1***b*, UB**2***a*, UB**2***b*, LB**2***a*, LB**2***b* are not necessarily wavelength values on the electromagnetic spectrum beyond which no light is emitted from the respective LED **204***a*, **204***b*, **206***a*, **206***b*.

Instead, in some embodiments, each of the bounds UB**1***a* and LB**1***a*, UB**1***b* and LB**1***b*, UB**2***a* and LB**2***a*, UB**2***b* and LB**2***b* represents a respective wavelength value beyond which lies only light **248***a*, **248***b*, **250***a*, **250***b* (respectively) that has an intensity value that is less than 10% of the peak intensity value of the respective light. In other embodiments, the intensity value is less than 5% of the peak intensity value. In still other embodiments, the intensity value is less than 1% of the peak intensity value. Stated another way, some embodiments include each wavelength range R**1***a*, Rib, R**2***a*, R**2***b* having only light **248***a*, **248***b*, **250***a*, **250***b* (respectively) that has an intensity value that is greater than 1% of the peak intensity value of the respective light. Other embodiments include each wavelength range R**1***a*, Rib, R**2***a*, R**2***b* having only light **248***a*, **248***b*, **250***a*, **250***b* (respectively) that has an intensity value that is greater than 5% of the peak intensity value. Still other embodiments include each wavelength range R**1***a*, Rib, R**2***a*, R**2***b* having only light **248***a*, **248***b*, **250***a*, **250***b* (respectively) that has an intensity value that is greater than 10% of the peak intensity value.

In the illustrated embodiment in FIG. **3**B, the first PCLED wavelength range R**1***a* has a first PCLED upper bound UB**1***a* (e.g., approximately 570 nm) that has a wavelength of a higher value than the first DLED upper bound UB**2***a* (e.g., approximately 450 nm) of the first DLED wavelength range R**2***a*. The first PCLED wavelength range R**1***a* also has a first PCLED lower bound LB**1***a* (e.g., Approximately 300 nm) that has a Wavelength of a Lower Value than the First DLED lower bound LB**2***a* (e.g., approximately 390 nm) of the first DLED wavelength range R**2***a*. Stated another way, the first DLED wavelength range R**2***a* falls along the electromagnetic spectrum completely within the first PCLED wavelength range R**1***a*.

The second PCLED wavelength range R**1***b* has a second PCLED upper bound UB**1***b* (e.g., approximately 690 nm) that has a wavelength of a higher value than the second DLED upper bound UB**2***b* (e.g., approximately 560 nm) of the second DLED wavelength range R**2***b*. The second PCLED wavelength range R**1***b* also has a second PCLED lower bound LB**1***b* (e.g., approximately 350 nm) that has a wavelength of a lower value than the second DLED lower bound LB**2***b* (e.g., approximately 500 nm) of the second DLED wavelength range R**2***b*. Stated another way, the second DLED wavelength range R**2***b* falls along the electromagnetic spectrum completely within the second PCLED wavelength range R**1***b*.

The light **248***a* from the first PCLED **204***a* further includes a median first PCLED wavelength M**1***a*, and the light **250***a* from the first DLED **206***a* includes a median first DLED wavelength M**2***a*. The light **248***b* from the second PCLED **204***b* further includes a median second PCLED wavelength M**1***b*, and the light **250***b* from the second DLED **206***b* includes a median second DLED wavelength M**2***b*. In some embodiments, the median first PCLED wavelength M**1***a* and the median first DLED wavelength M**2***a* are within 50 nanometers of each other, and the median second PCLED wavelength M**1***b* and the median second DLED wavelength M**2***b* are within 50 nanometers of each other. In other embodiments, the median first PCLED wavelength M**1***a* and the median first DLED wavelength M**2***a* are within 25 nanometers of each other, and the median second PCLED wavelength M**1***b* and the median second DLED wavelength M**2***b* are within 25 nanometers of each other. In still other embodiments, the median first PCLED wavelength M**1***a* and the median first DLED wavelength M**2***a* are within 10 nanometers of each other, and the median second PCLED wavelength M**1***b* and the median second DLED wavelength M**2***b* are within 10 nanometers of each other. In still other embodiments, the median first PCLED wavelength M**1***a* and the median first DLED wavelength M**2***a* are the same wavelength value, and the median second PCLED wavelength M**1***b* and the median second DLED wavelength M**2***b* are the same value. Even more embodiments include the median first PCLED wavelength M**1***a* and the median first DLED wavelength M**2***a* being within 50-100 nanometers of each other, within 100-200 nanometers of each other, and more than 200 nanometers away from each other, and the embodiments include the median second PCLED wavelength M**1***b* and the median second DLED wavelength M**2***b* being within 50-100 nanometers away from each other, within 100-200 nanometers of each other, and more than 200 nanometers away from each other.

In some embodiments, the target characteristic of the light **246** projected by the light fixture **200** includes a first PCLED wavelength range intensity and a first DLED wavelength range intensity combining at a target ratio. In the illustrated embodiment in FIG. **3**B, the blue light **248***a* emitted from the first PCLED **204***a* combines with the blue light **250***a* emitted from the first DLED **206***a* at a target ratio and the green light **248***b* emitted from the second PCLED **204***b* combines with the green light **250***b* emitted from the second DLED **206***b* at a target ratio. In some embodiments, the target ratio includes each of the DLED wavelength range intensities being at least two times greater than the respective PCLED wavelength range intensity (e.g., each light **250***a*, **250***b* outputs 60 lumens while each light **248***a*, **248***b* outputs 30 lumens). In some embodiments, each DLED wavelength range intensity is at least three times greater in intensity (along the Y-axis labeled optical power) than the respective PCLED wavelength range intensity (e.g., each light **250***a*, **250***b* outputs 90 lumens while each light **248***a*, **248***b* outputs 30 lumens). In some embodiments, each DLED wavelength range intensity is at least four times greater in intensity than the respective PCLED wavelength range intensity (e.g., each light **250***a*, **250***b* outputs 120 lumens while each light **248***a*, **248***b* outputs 30 lumens).

In some embodiments, the target characteristic of the light **246** projected by the light fixture **200** includes a target wavelength range to correspond to a specific color or temperature of light (e.g., 400-660 nm, 430-660 nm, or the like). The light **246** projected by the light fixture **200** is limited to, for example, the target wavelength range. Stated another way, the color of the light **246** can be controlled by illuminating one or more of the PCLEDs **204***a*, **204***b* and/or one or more of the DLEDs **206***a*, **206***b* at various intensities.

With reference to FIG. **3**C, a line graph representing an exemplary embodiment of the light **348***a* from the first PCLED **304***a*, the light **348***b* from the second PCLED **304***b*, the light **348***c* from the third PCLED **304***b*, the light **350***a* from the first DLED **306***a*, the light **350***b* from the second DLED **306***b*, and the light **350***c* from the third DLED **306***c* on the electromagnetic spectrum is shown. In the illustrated embodiment, the light **348***a* emitted by the first PCLED **304***a* includes generally blue light, the light **348***b* emitted by the second PCLED **304***b* includes generally green light, the light **348***c* emitted by the third PCLED **304***c* includes generally red light, the light **350***a* emitted by the first DLED **306***a* includes blue light, the light **350***b* emitted by the second DLED **306***b* includes green light, and the light **350***c* emitted by the third DLED **306***c* includes red light.

The characteristics of the light **348***a* of the first PCLED **304***a* correspond to the characteristics of the light **248***a* of the first PCLED **204***a* discussed above. The characteristics of the light **350***a* of the first DLED **306***a* correspond to the characteristics of the light **250***a* of the first DLED **206***a* discussed above. The characteristics of the light **348***b* of the second PCLED **304***b* correspond to the characteristics of the light **248***b* of the second PCLED **204***b* discussed above. The characteristics of the light **350***b* of the second DLED **306***b* correspond to the characteristics of the light **250***b* of the second DLED **206***b* discussed above. These characteristics, therefore, will not be discussed with respect to these embodiments.

As shown in FIG. **3**C, the light **348***c* from the third PCLED **304***c* is emitted in a third PCLED wavelength range R**1***c* that includes a third PCLED upper bound UB**1***c* and a third PCLED lower bound LB**1***c*. The light **350***c* from the third DLED **306***c* is emitted in a third DLED wavelength range R**2***c* that includes a third DLED upper bound UB**2***c* and a third DLED lower bound LB**2***c*. The bounds UB**1***c*, LB**1***c*, UB**2***c*, LB**2***c*, are not necessarily wavelength values on the electromagnetic spectrum beyond which no light is emitted from the respective LED **304***c*, **306***c*.

Instead, in some embodiments, each of the bounds UB**1***c* and LB**1***c*, UB**2***c* and LB**2***c* represents a respective wavelength value beyond which lies only light **348***c*, **350***c* (respectively) that has an intensity value that is less than 10% of the peak intensity value of the respective light. In other embodiments, the intensity value is less than 5% of the peak intensity value. In still other embodiments, the intensity value is less than 1% of the peak intensity value. Stated another way, some embodiments include each wavelength range R**1***c*, R**2***c* having only light **348***c*, **350***c* (respectively) that has an intensity value that is greater than 1% of the peak intensity value of the respective light. Other embodiments include each wavelength range R**1***c*, R**2***c* having only light **348***c*, **350***c* (respectively) that has an intensity value that is greater than 5% of the peak intensity value. Still other embodiments include each wavelength range R**1***c*, R**2***c* having only light **348***c*, **350***c* (respectively) that has an intensity value that is greater than 10% of the peak intensity value.

In the illustrated embodiment in FIG. **3**C, the third PCLED wavelength range R**1***c* has a third PCLED upper bound UB**1***c* (e.g., approximately 770 nm) that has a wavelength of a higher value than the third DLED upper bound UB**2***c* (e.g., approximately 620 nm) of the third DLED wavelength range R**2***c*. The third PCLED wavelength range R**1***c* also has a third PCLED lower bound LB**1***c* (e.g., approximately 430 nm) that has a wavelength of a lower value than the third DLED lower bound LB**2***c* (e.g., approximately 580 nm) of the third DLED wavelength range R**2***c*. Stated another way, the third DLED wavelength range R**2***c* falls along the electromagnetic spectrum completely within the third PCLED wavelength range R**1***c*.

The light **348***c* from the third PCLED **304***c* further includes a median third PCLED wavelength M**1***c*, and the light **350***c* from the third DLED **306***c* includes a median third DLED wavelength M**2***c*. In some embodiments, the median third PCLED wavelength M**1***c* and the median third DLED wavelength M**2***c* are within 50 nanometers of each other. In other embodiments, the median third PCLED wavelength M**1***c* and the median third DLED wavelength M**2***c* are within 25 nanometers of each other. In still other embodiments, the median third PCLED wavelength M**1***c* and the median third DLED wavelength M**2***c* are within 10 nanometers of each other. In still other embodiments, the median third PCLED wavelength M**1***c* and the median third DLED wavelength M**2***c* are the same wavelength value. Even more embodiments include the median third PCLED wavelength M**1***c* and the median third DLED wavelength M**2***c* being within 50-100 nanometers of each other, within 100-200 nanometers of each other, and more than 200 nanometers away from each other.

In some embodiments, the target characteristic of the light **346** projected by the light fixture **300** includes a third PCLED wavelength range intensity and a third DLED wavelength range intensity combining at a target ratio. In the illustrated embodiment in FIG. **3**C, the blue light **348***a* emitted from the first PCLED **304***a* combines with the blue light **350***a* emitted from the first DLED **306***a* at a target ratio, the green light **348***b* emitted from the second PCLED **304***b* combines with the green light **350***b* emitted from the second DLED **306***b* at a target ratio, and the red light **348***c* emitted from the third PCLED **304***c* combines with the red light **350***c* emitted from the third DLED **306***c* at a target ratio. In some embodiments, the target ratio includes each of the DLED wavelength range intensities being at least two times greater than the respective PCLED wavelength range intensity (e.g., each light **350***a*, **350***b*, **350***c* outputs 60 lumens while each light **348***a*, **348***b*, **348***c* outputs 30 lumens). In some embodiments, each DLED wavelength range intensity is at least three times greater in intensity (along the Y-axis labeled optical power) than the respective PCLED wavelength range intensity (e.g., each light **350***a*, **350***b*, **350***c* outputs 90 lumens while each light **348***a*, **348***b*, **348***c* outputs 30 lumens). In some embodiments, each DLED wavelength range intensity is at least four times greater in intensity than the respective PCLED wavelength range intensity (e.g., each light **350***a*, **350***b*, **350***c* outputs 120 lumens while each light **348***a*, **348***b*, **348***c* outputs 30 lumens).

In some embodiments, the target characteristic of the light **346** projected by the light fixture **300** includes a target wavelength range to correspond to a specific color or temperature of light (e.g., 400-660 nm, 430-660 nm, or the like). The light **346** projected by the light fixture **300** is limited to, for example, the target wavelength range. Stated another way, the color of the light **346** can be controlled by illuminating one or more of the PCLEDs **304***a*, **304***b*, **304***c* and/or one or more of the DLEDs **306***a*, **306***b*, **306***c* at various intensities.

With reference to FIG. **4**, an example available color gamut **380** of the PCLEDs **304***a*, **304***b*, **304***c* of the light fixture **300** is shown. In some embodiments, only colors that fall within or on the illustrated color gamut polygon are reproducible by the PCLEDs **304***a*, **304***b*, **304***c* of the light fixture **300**. As discussed above, the output intensity of each of the PCLEDs **304***a*, **304***b*, **304***c* is adjusted until the light **346** is within a threshold or error value for the target ratio.

With reference to FIG. **5**, an example available color gamut **382** of the DLEDs **306***a*, **306***b*, **306***c* of the light fixture **300** is shown. In some embodiments, only colors that fall within or on the illustrated color gamut polygon are reproducible by the DLEDs **306***a*, **306***b*, **306***c* of the light fixture **300**. As discussed above, the output intensity of each of the DLEDs **306***a*, **306***b*, **306***c* is adjusted until the light **346** is within a threshold or error value for the target ratio. In some embodiments, the available color gamut **382** of the DLEDs **306***a*, **306***b*, **306***c* is substantially the same as the available color gamut **380** of the PCLEDs **304***a*, **304***b*, **304***c*. In some embodiments, the available color gamut **382** of the DLEDs **306***a*, **306***b*, **306***c* is the same as the available color gamut **380** of the PCLEDs **304***a*, **304***b*, **304***c*.

With reference to FIG. **6**, a process (or method) **400** of driving LEDs **104**, **106** in the light fixture **100**, driving LEDs **204***a*, **204***b*, **206***a*, **206***b* in the light fixture **200**, or driving LEDs **304***a*, **304***b*, **304***c*, **306***a*, **306***b*, **306***c* in the light fixture **300** is shown. The process **400** includes the light fixture **100**, **200**, **300** having PCLEDs **104**, **204***a*, **204***b*, **304***a*, **304***b*, **304***c* emitting light **148**, **248***a*, **248***b*, **348***a*, **348***b*, **348***c* in a PCLED wavelength range **R1**, **R1***a*, Rib, **R1***c* and DLEDs **106**, **206***a*, **206***b*, **306***a*, **306***b*, **306***c* emitting light **150**, **250***a*, **250***b*, **350***a*, **350***b*, **350***c* in a DLED wavelength range **R2**, **R2***a*, **R2***b*, **R2***c* that is within (e.g., completely within) the respective PCLED wavelength range **R1**, **R1***a*, Rib, **R1***c*.

At step **402**, a signal related to a target characteristic of the light **146**, **246**, **346** is received. At step **404**, a PCLED output value is determined for at least one of the PCLEDs **104**, **204***a*, **204***b*, **304***a*, **304***b*, **304***c* based on the target characteristic of the light **146**, **246**, **346** to be projected by the light fixture **100**, **200**, **300**. At step **406** (which may occur after step **404**, during step **404**, or before step **404**), a DLED output value is determined for at least one of the DLEDs **106**, **206***a*, **206***b*, **306***a*, **306***b*, **306***c* based on the target characteristic of the light **146**, **246**, **346** to be projected by the light fixture **100**, **200**, **300**. At step **408**, the at least one of the PCLEDs **104**, **204***a*, **204***b*, **304***a*, **304***b*, **304***c* is driven at the PCLED output value. At step **410** (which may occur after step **408**, during step **408**, or before step **408**), the at least one of the DLEDs **106**, **206***a*, **206***b*, **306***a*, **306***b*, **306***c* is driven at the DLED output value.

In some embodiments, steps **404** and **406** include the respective output values of the PCLEDs **104**, **204***a*, **204***b*, **304***a*, **304***b*, **304***c* and the DLEDs **106**, **206***a*, **206***b*, **306***a*, **306***b*, **306***c* being determined based on a target color ratio made up of at least a first color wavelength range intensity and a second color wavelength range intensity. In some embodiments, the target color ratio includes the light **148**, **248***a*, **248***b*, **348***a*, **348***b*, **348***c* emitted from the respective PCLED **104**, **204***a*, **204***b*, **304***a*, **304***b*, **304***c* being at least two times greater, at least three times greater, or at least four times greater in intensity than the light **150**, **250***a*, **250***b*, **350***a*, **350***b*, **350***c* emitted from a corresponding DLED **106**. In other embodiments, the target color ratio includes the light **150**, **250***a*, **250***b*, **350***a*, **350***b*, **350***c* emitted from the respective DLED **106**, **206***a*, **206***b*, **306***a*, **306***b*, **306***c* being at least two times greater, at least three times greater, or at least four times greater in intensity than the light **148**, **248***a*, **248***b*, **348***a*, **348***b*, **348***c* emitted from a corresponding PCLED **104**, **204***a*, **204***b*, **304***a*, **304***b*, **304***c*.

In other embodiments, steps **404** and **406** include the respective output values of the PCLEDs **104**, **204***a*, **204***b*, **304***a*, **304***b*, **304***c* and the DLEDs **106**, **206***a*, **206***b*, **306***a*, **306***b*, **306***c* being determined based on a target wavelength range of the light **146**, **246**, **346** produced by the light fixture **100**, **200**, **300**. In such embodiments, steps **408** and **410** limit the light **146**, **246**, **346** produced by the light fixture **100**, **200**, **300** to the target wavelength range.

In some embodiments, at one setting of the light fixture **100**, **200**, **300**, step **404** includes determining a PCLED output value that illuminates one or more PCLEDs **104**, **204***a*, **204***b*, **304***a*, **304***b*, **304***c* to produce the target characteristic of the light **146**, **246**, **346** projected by the light fixture **100**, **200**, **300**. At this stetting, step **406** includes determining a DLED output value that does not illuminate the DLEDs **106**, **206***a*, **206***b*, **306***a*, **306***b*, **306***c*. Stated another way, only one or more of the PCLEDs **104**, **204***a*, **204***b*, **304***a*, **304***b*, **304***c* illuminates to produce the target characteristic of the light **146**, **246**, **346** projected by the light fixture **100**, **200**, **300**.

In some embodiments, at another setting of the light fixture **100**, **200**, **300**, step **404** includes determining a PCLED output value that does not illuminate the PCLEDs **104**, **204***a*, **204***b*, **304***a*, **304***b*, **304***c*. At this setting, step **406** includes determining a DLED output value that illuminates one or more DLEDs **106**, **206***a*, **206***b*, **306***a*, **306***b*, **306***c* to produce the target characteristic of the light **146**, **246**, **346** projected by the light fixture **100**, **200**, **300**. Stated another way, only one or more of the DLEDs **106**, **206***a*, **206***b*, **306***a*, **306***b*, **306***c* illuminates to produce the target characteristic of the light **146**, **246**, **346** projected by the light fixture **100**, **200**, **300**.

In addition to the embodiments disclosed above, some embodiments include narrow band PCLEDs instead of DLEDs. In such embodiments, these narrow band PCLEDs use a layer of phosphor material similar to the PCLEDs described above. The narrow band PCLEDs, however, emit light in a narrower band on the electromagnetic spectrum than the PCLEDs described above. In some embodiments, the narrow band PCLEDs emit light in a band on the electromagnetic spectrum that is the same as or substantially similar to light emitted from an equivalent DLED as explained above.

The definition of "broadband" can be considered in some embodiments to be a band of light on the electromagnetic spectrum that is wider than 70 nm. Other embodiments include the band of light being equal to or wider than 80 nm. Still other embodiments include the band of light being equal to or wider than 90 nm. Yet other embodiments include the band of light being equal to or wider than 100 nm.

The definition of "narrow band" can be considered in some embodiments to be a band of light on the electromagnetic spectrum that is narrower than 70 nm. Other embodiments include the band of light being equal to or narrower than 60 nm. Still other embodiments include the band of light being equal to or narrower than 50 nm. Yet other embodiments include the band of light being equal to or narrower than 40 nm.

Thus, the embodiments described herein provide, among other things, systems, methods, and devices for controlling the spectral content of an output of a light fixture. Various features and advantages of the embodiments described herein are set forth in the following claims.

What is claimed is:

1. A light fixture comprising:

a housing;

a first light-emitting diode disposed in the housing;

a first phosphor layer associated with the first light-emitting diode ("LED"), forming a first phosphor-converted light-emitting diode ("PCLED"), the first PCLED configured to emit light in a first PCLED wavelength range including a first PCLED upper bound and a first PCLED lower bound;

a second LED disposed in the housing;

a second phosphor layer associated with the second LED, forming a second PCLED, the second PCLED configured to emit light in a second PCLED wavelength range including a second PCLED upper bound and a second PCLED lower bound;

a third LED disposed in the housing, the third LED configured to emit light in a third LED wavelength range including a third LED upper bound and a third LED lower bound;

a fourth LED disposed in the housing, the fourth LED configured to emit light in a fourth LED wavelength range including a fourth LED upper bound and a fourth LED lower bound;

wherein the first PCLED upper bound of the first PCLED wavelength range has a higher wavelength value than the third LED upper bound of the third LED wavelength range;

wherein the first PCLED lower bound of the first PCLED wavelength range has a lower wavelength value than the third LED lower bound of the third LED wavelength range;

wherein the second PCLED upper bound of the second PCLED wavelength range has a higher wavelength value than the fourth LED upper bound of the fourth LED wavelength range; and

wherein the second PCLED lower bound of the second PCLED wavelength range has a lower wavelength value than the fourth LED lower bound of the fourth LED wavelength range.

2. The light fixture of claim **1**, further comprising

a third phosphor layer associated with the third LED, forming a third PCLED, the third PCLED configured to emit light in the third LED wavelength range;

a fourth phosphor layer associated with the fourth LED, forming a fourth PCLED, the fourth PCLED configured to emit light in the fourth LED wavelength range; and

wherein

the first PCLED and the second PCLED are broadband PCLEDs; and

the third LED and the fourth LED are narrow band PCLEDs.

3. The light fixture of claim **1**, wherein

the third LED is a first direct light-emitting diode ("DLED");

the third LED wavelength range is a first DLED wavelength range;

the third LED upper bound is a first DLED upper bound;

the third LED lower bound is a first DLED lower bound;

the fourth LED is a second DLED;

the fourth LED wavelength range is a second DLED wavelength range;

the fourth LED upper bound is a second DLED upper bound; and

the fourth LED lower bound is a second DLED lower bound.

4. The light fixture of claim **3**, wherein

the first phosphor layer absorbs light from the first light-emitting diode, and the first phosphor layer emits the absorbed light within the first PCLED wavelength range; and

the second phosphor layer absorbs light from the second light-emitting diode, and the second phosphor layer emits the absorbed light within the second PCLED wavelength range.

5. The light fixture of claim **3**, wherein

the light emitted in the first PCLED wavelength range includes a median first PCLED wavelength;

the light emitted in the first DLED wavelength range includes a median first DLED wavelength;

the median first PCLED wavelength and the median first DLED wavelength are within 25 nanometers of each other;

the light emitted in the second PCLED wavelength range includes a median second PCLED wavelength;

the light emitted in the second DLED wavelength range includes a median second DLED wavelength; and

the median second PCLED wavelength and the median second DLED wavelength are within 25 nanometers of each other.

6. The light fixture of claim **3**, further comprising

a fifth LED disposed in the housing;

a third phosphor layer associated with the fifth LED, forming a third PCLED, the third PCLED configured to emit light in a third PCLED wavelength range including a third PCLED upper bound and a third PCLED lower bound;

a sixth LED disposed in the housing, the sixth LED being a third DLED, the third DLED configured to emit light in a third DLED wavelength range including a third DLED upper bound and a third DLED lower bound;

wherein the third PCLED upper bound of the third PCLED wavelength range has a higher wavelength value than the third DLED upper bound of the third DLED wavelength range; and

wherein the third PCLED lower bound of the third PCLED wavelength range has a lower wavelength value than the third DLED lower bound of the third DLED wavelength range.

7. A lighting system comprising:

a light fixture including

a first phosphor-converted light-emitting diode ("PCLED") configured to emit light in a first PCLED wavelength range,

a first direct light-emitting diode ("DLED") configured to emit light in a first DLED wavelength range, the first DLED wavelength range falling completely within the first PCLED wavelength range,

a second PCLED configured to emit light in a second PCLED wavelength range, and

a second DLED configured to emit light in a second DLED wavelength range, the second DLED wavelength range falling completely within the second PCLED wavelength range; and

a controller configured to

receive a control signal corresponding to a target characteristic of light to be projected by the light fixture,

determine a first PCLED output value for the first PCLED based on the control signal,

determine a first DLED output value for the first DLED based on the control signal, determine a second PCLED output value for the second PCLED based on the control signal,

determine a second DLED output value for the second DLED based on the control signal,

drive the first PCLED at the first PCLED output value,

drive the first DLED at the first DLED output value,

drive the second PCLED at the second PCLED output value, and

drive the second DLED at the second DLED output value.

8. The lighting system of claim **7**, wherein

the target characteristic of the light to be projected by the light fixture includes a first DLED wavelength range intensity and a first PCLED wavelength range intensity combining at a target ratio; and

the color ratio includes the first DLED wavelength range intensity being at least two times greater than the first PCLED wavelength range intensity.

9. The lighting system of claim **7**, wherein

the target characteristic of the light to be projected by the light fixture includes a target wavelength range; and

the light to be projected by the light fixture is limited to the target wavelength range.

10. The lighting system of claim **7**, wherein the first DLED output value does not illuminate the first DLED and the first PCLED output value does illuminate the first PCLED to produce the target characteristic of the light to be projected by the light fixture.

11. The lighting system of claim **7**, wherein the first PCLED output value does not illuminate the first PCLED and the first DLED output value does illuminate the first DLED to produce the target characteristic of the light to be projected by the light fixture.

12. The lighting system of claim **7**, wherein

the light emitted in the first PCLED wavelength range includes a median first PCLED wavelength;

the light emitted in the first DLED wavelength range includes a median first DLED wavelength; and

the median first PCLED wavelength and the median first DLED wavelength are within 25 nanometers of each other.

13. The lighting system of claim **7**, wherein

the light fixture further includes

a third PCLED configured to emit light in a third PCLED wavelength range, and

a third DLED configured to emit light in a third DLED wavelength range, the third DLED wavelength range falling completely within the third PCLED wavelength range; and

the controller is further configured to

determine a third PCLED output value for the third PCLED based on the control signal,

determine a third DLED output value for the third DLED based on the control signal,

drive the third PCLED at the third PCLED output value, and

drive the third DLED at the third DLED output value.

14. A method for driving light-emitting diodes in a light fixture, the light fixture including at least a first phosphor-converted light-emitting diode ("PCLED") that emits light in a first PCLED wavelength range, a second PCLED that emits light in a second PCLED wavelength range, a first direct light-emitting diode ("DLED") that emits light in a first DLED wavelength range, and a second DLED that emits light in a second DLED wavelength range, the first DLED wavelength range being within the first PCLED wavelength range and the second DLED wavelength range being within the second PCLED wavelength range, the method comprising:

determining a first PCLED output value for the first PCLED based on a target characteristic of light to be projected by the light fixture;

determining a first DLED output value for the first DLED based on the target characteristic of light to be projected by the light fixture;

determining a second PCLED output value for the second PCLED based on the target characteristic of light to be projected by the light fixture;

determining a second DLED output value for the second DLED based on the target characteristic of the light to be projected by the light fixture;

driving the first PCLED at the PCLED output value;

driving the first DLED at the first DLED output value;

driving the second PCLED at the second PCLED output value; and

driving the second DLED at the second DLED output value.

15. The method of claim **14**, wherein

the target characteristic of the light to be projected by the light fixture includes a first DLED wavelength range intensity and a first PCLED wavelength range intensity combining at a target ratio; and

the target ratio includes the first DLED wavelength range intensity being at least two times greater than the first PCLED wavelength range intensity.

16. The method of claim **14**, wherein

the target characteristic of the light to be projected by the light fixture includes a target wavelength range.

17. The method of claim **14**, wherein

the first DLED output value does not illuminate the first DLED; and

the first PCLED output value does illuminate the first PCLED to produce the target characteristic of the light to be projected by the light fixture.

18. The method of claim **14**, wherein

the first PCLED output value does not illuminate the first PCLED; and

the first DLED output value does illuminate the first DLED to produce the target characteristic of the light to be projected by the light fixture.

19. The method of claim **14**, wherein

the light emitted in the first PCLED wavelength range includes a corresponding median first PCLED wavelength;

the light emitted in the first DLED wavelength range includes a corresponding median first DLED wavelength;

the light emitted in the second PCLED wavelength range includes a corresponding median second PCLED wavelength;

the light emitted in the second DLED wavelength range includes a corresponding median second DLED wavelength;

the median first PCLED wavelength and the median first DLED wavelength are within 25 nanometers of each other; and

the median second PCLED wavelength and the median second DLED wavelength are within 25 nanometers of each other.

20. The method of claim **14**, wherein the light fixture further includes a third PCLED that emits light in a third PCLED wavelength range and a third DLED that emits light in a third DLED wavelength range, the third DLED wavelength range being within the third PCLED wavelength range, the method further comprising

determining a third PCLED output value for the third PCLED based on the target characteristic of light to be projected by the light fixture;

determining a third DLED output value for the third DLED based on the target characteristic of the light to be projected by the light fixture;

driving the third PCLED at the third PCLED output value; and

driving the third DLED at the third DLED output value.

* * * * *