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Stanek et al.

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(54) **OPTICAL SYSTEM FOR AN AUTOMATED LUMINAIRE**

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(58) **Field of Classification Search**
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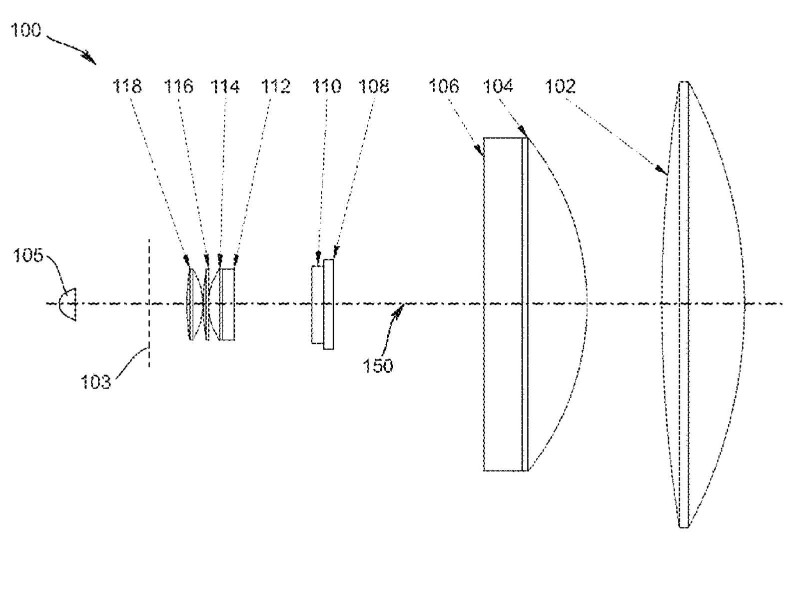
(57) **ABSTRACT**

A zoom optical system includes a light source and focus, zoom, and fixed lens groups. The light source illuminates an object in or adjacent to an object plane. The focus lens group has a first positive optical power and moves to focus an object. The focus lens group has four lenses of positive, positive, positive, and negative optical power. The zoom lens group has a negative optical power and moves relative to the object plane and the focus lens group to control a beam angle while the focus lens group remains fixed relative to the object plane. The zoom lens group comprises two negative power lenses. The fixed lens group has a second positive optical power, remains in a fixed position relative to the object plane, and projects an image of the object. The fixed lens group has three lenses, comprising negative, positive, and positive optical powers.

14 Claims, 9 Drawing Sheets



(51) **Int. Cl.**

F21V 5/04	(2006.01)
F21V 14/02	(2006.01)
F21V 14/06	(2006.01)
F21W 131/406	(2006.01)
F21Y 107/10	(2016.01)
F21Y 113/00	(2016.01)
F21Y 115/10	(2016.01)

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

CPC *F21W 2131/406* (2013.01); *F21Y 2107/10* (2016.08); *F21Y 2113/00* (2013.01); *F21Y 2115/10* (2016.08); *G02B 15/143105* (2019.08)

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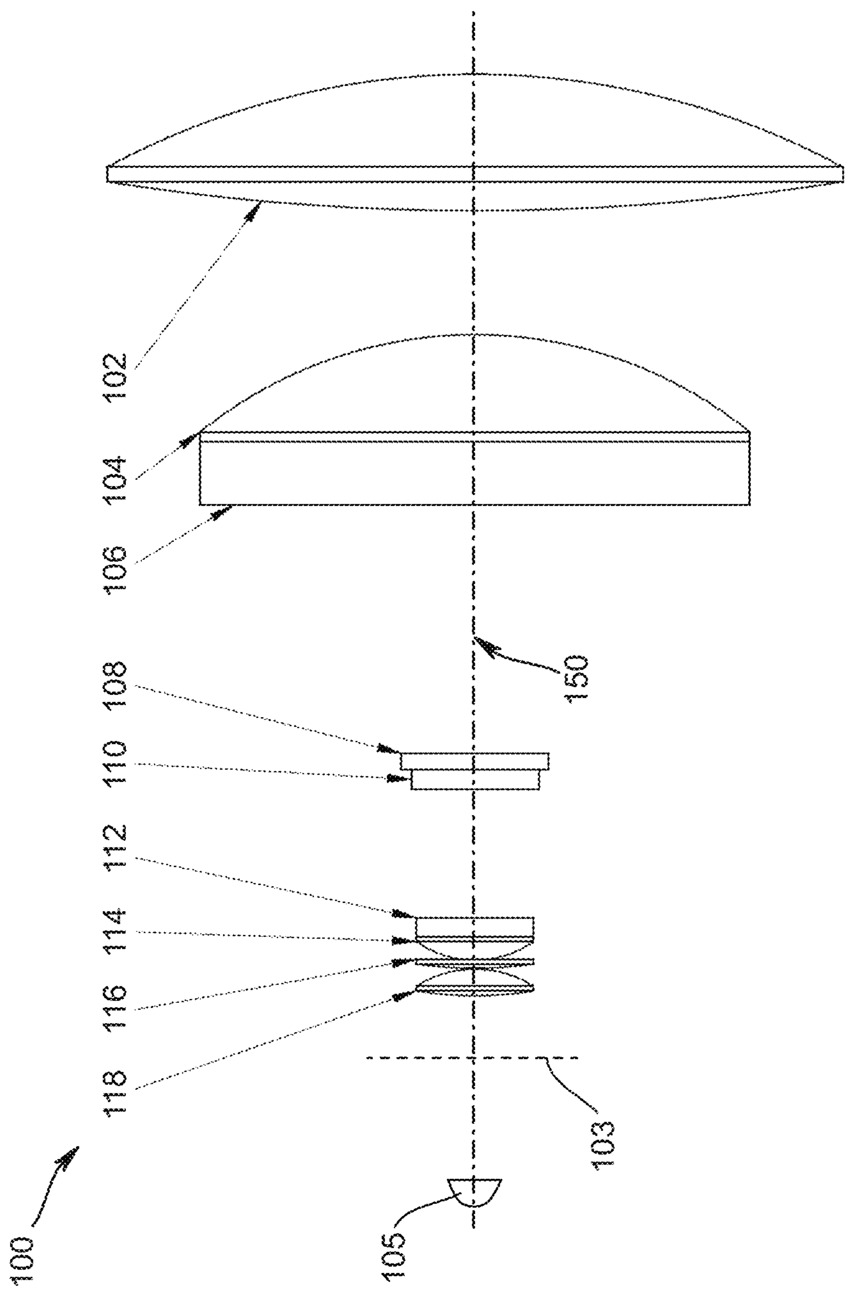


FIG. 1

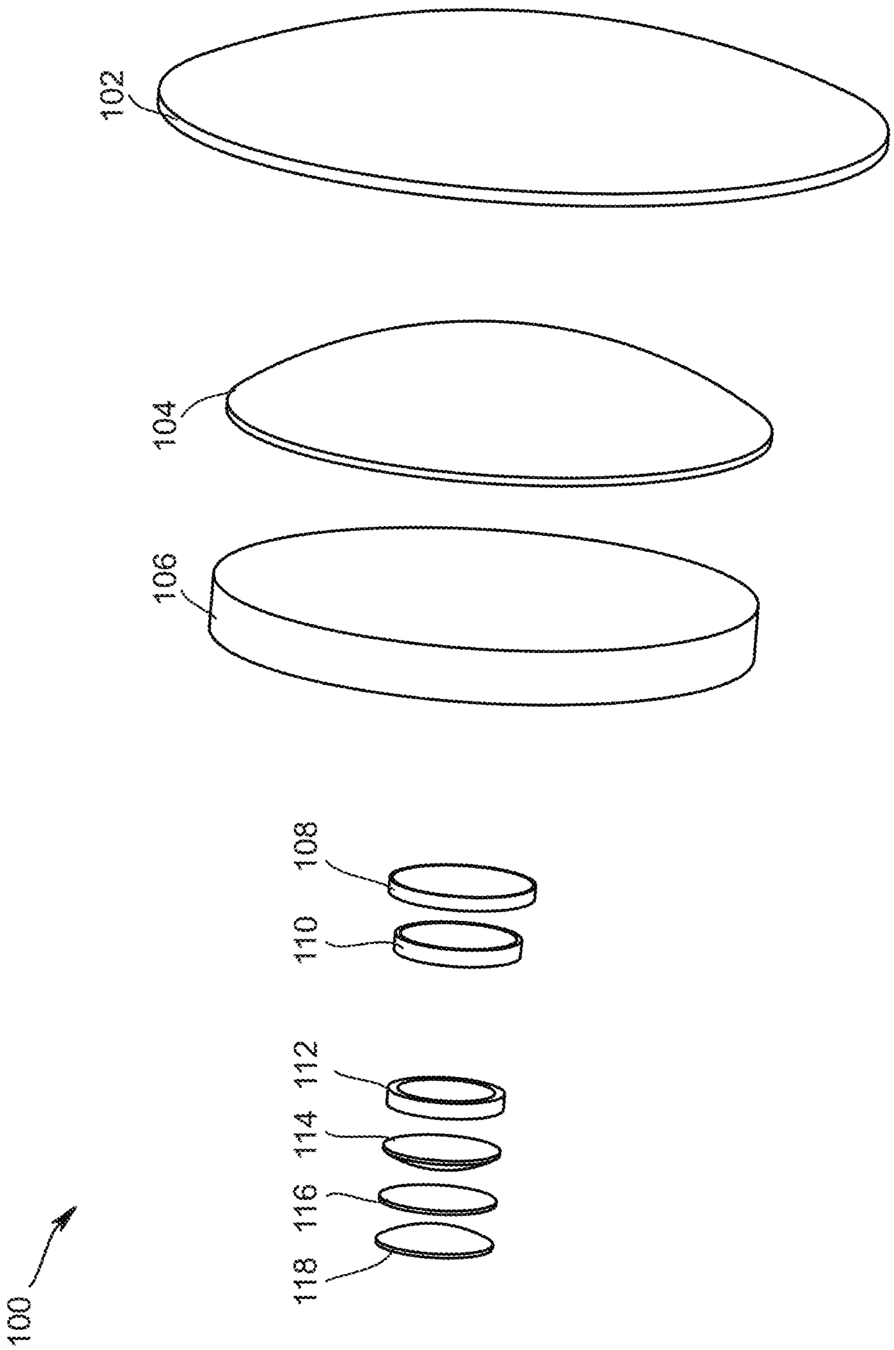
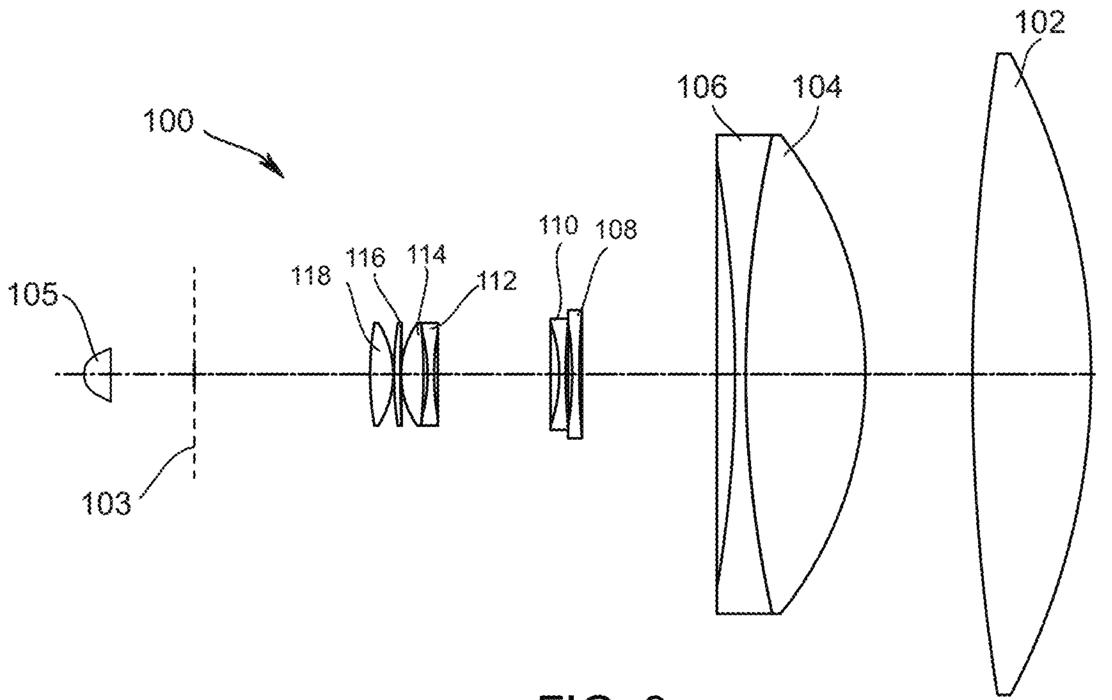


FIG. 2



100
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FIG. 3

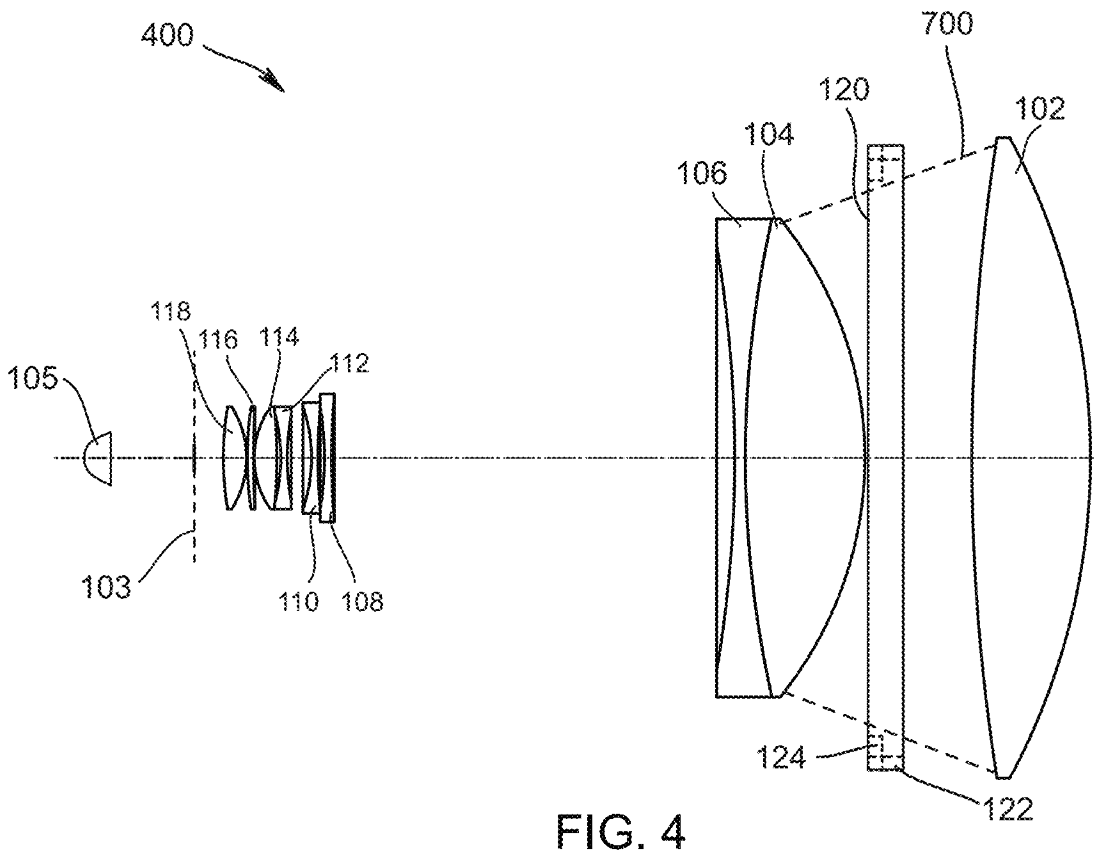

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FIG. 4

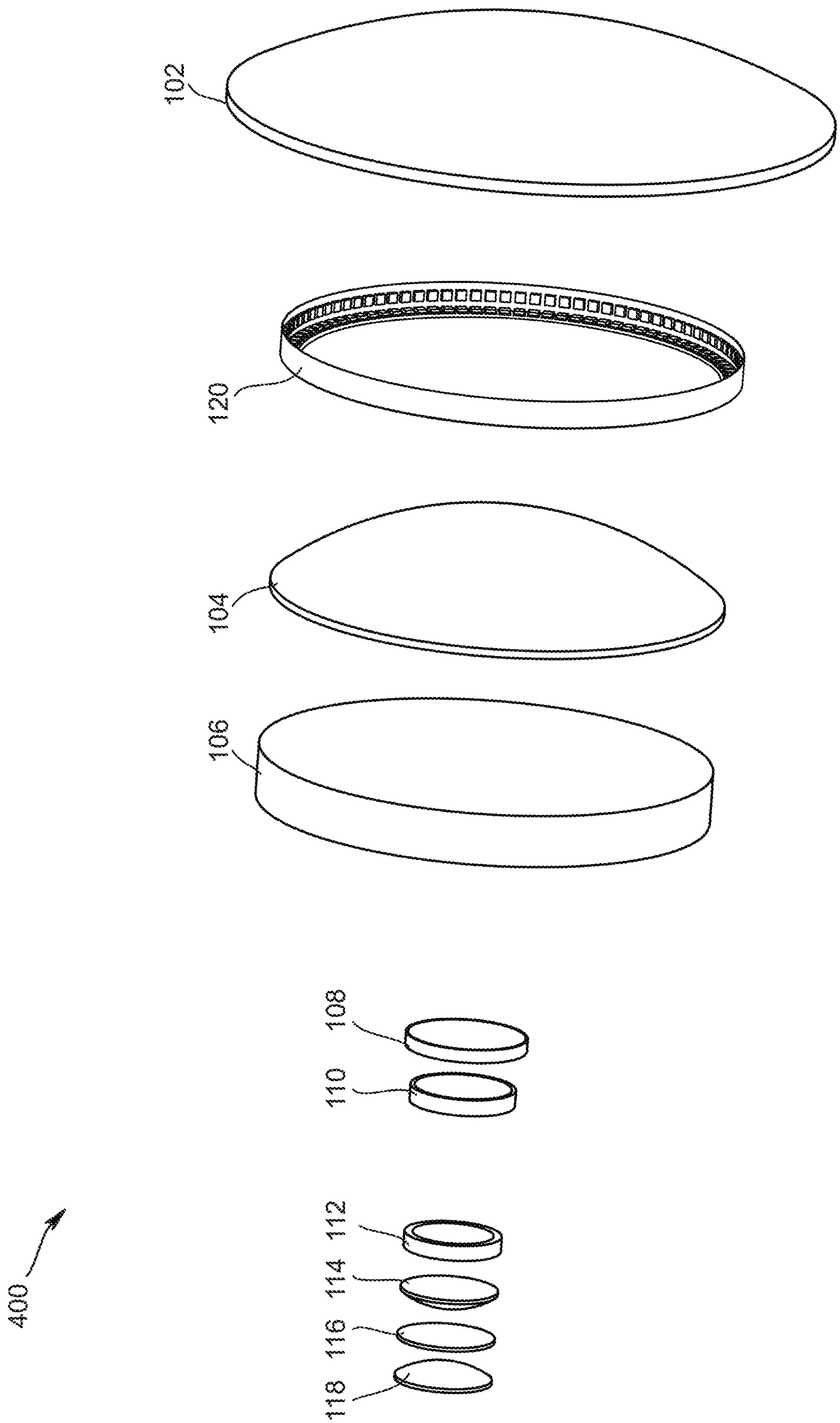

FIG. 5

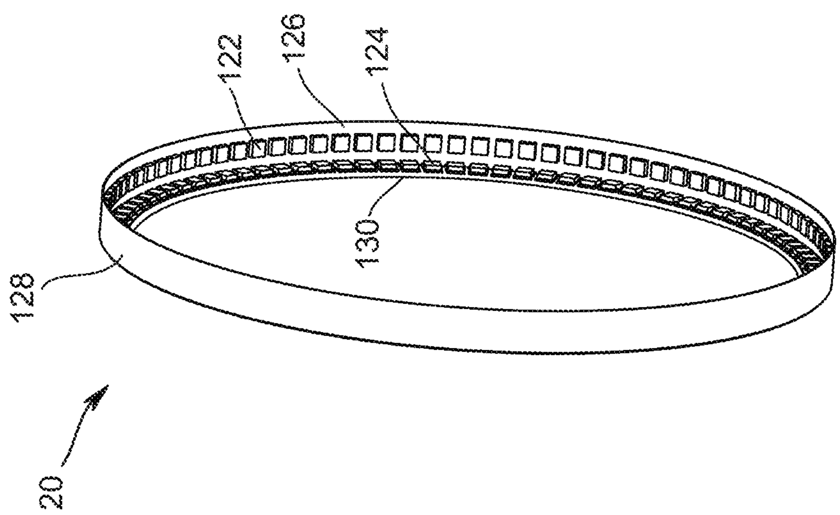

FIG. 6A

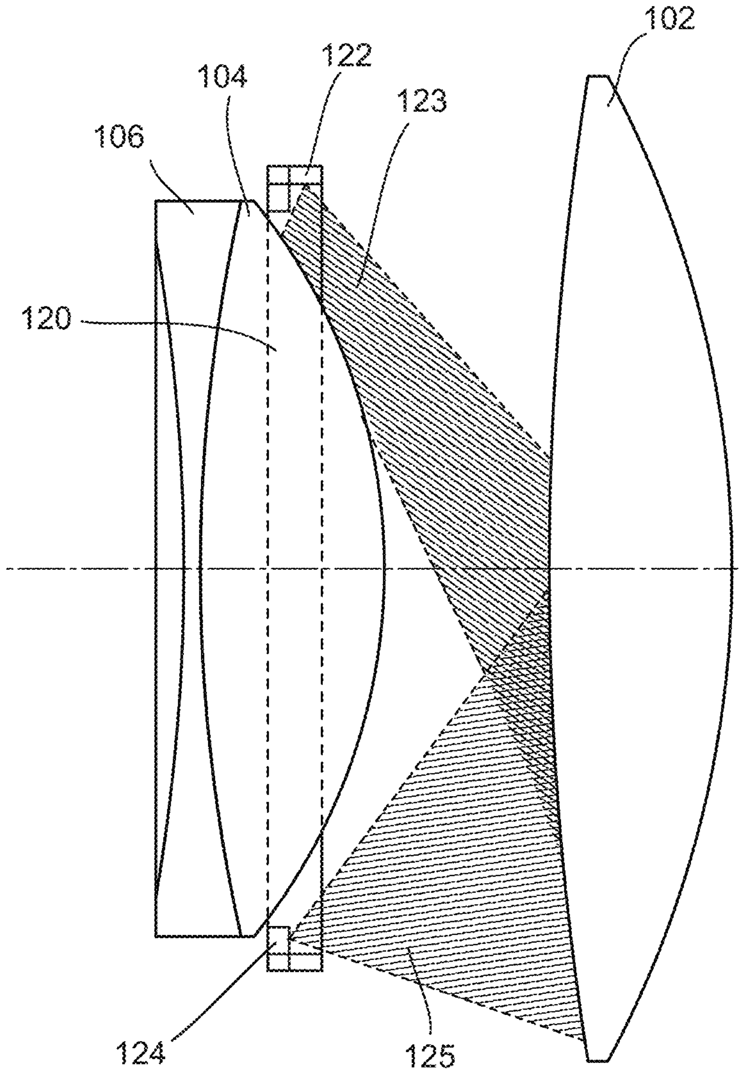

FIG. 6B

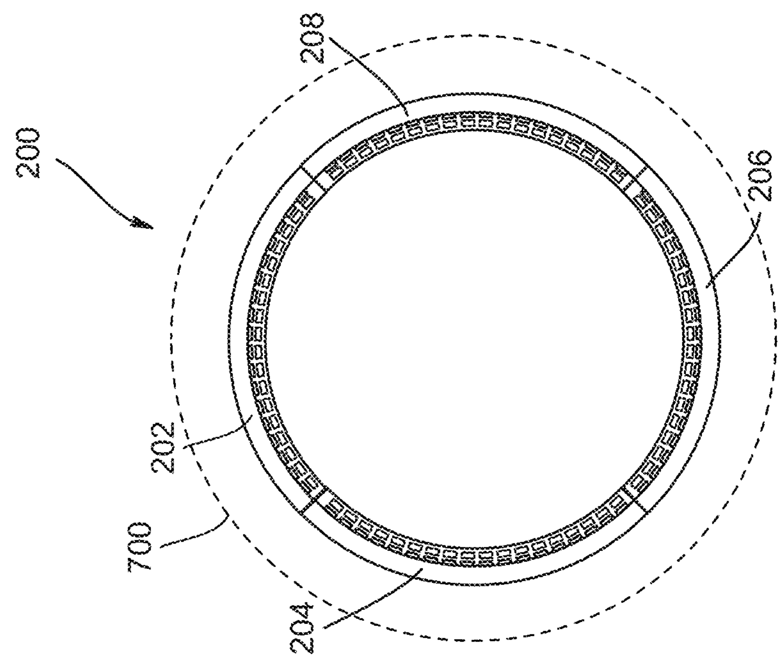

FIG. 8

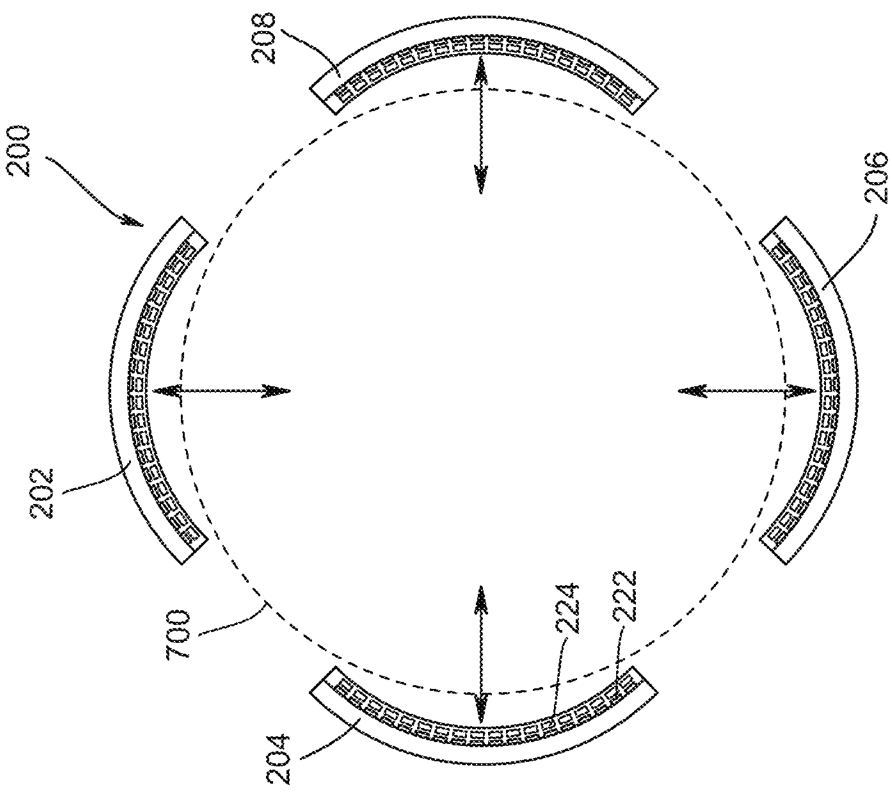

FIG. 7

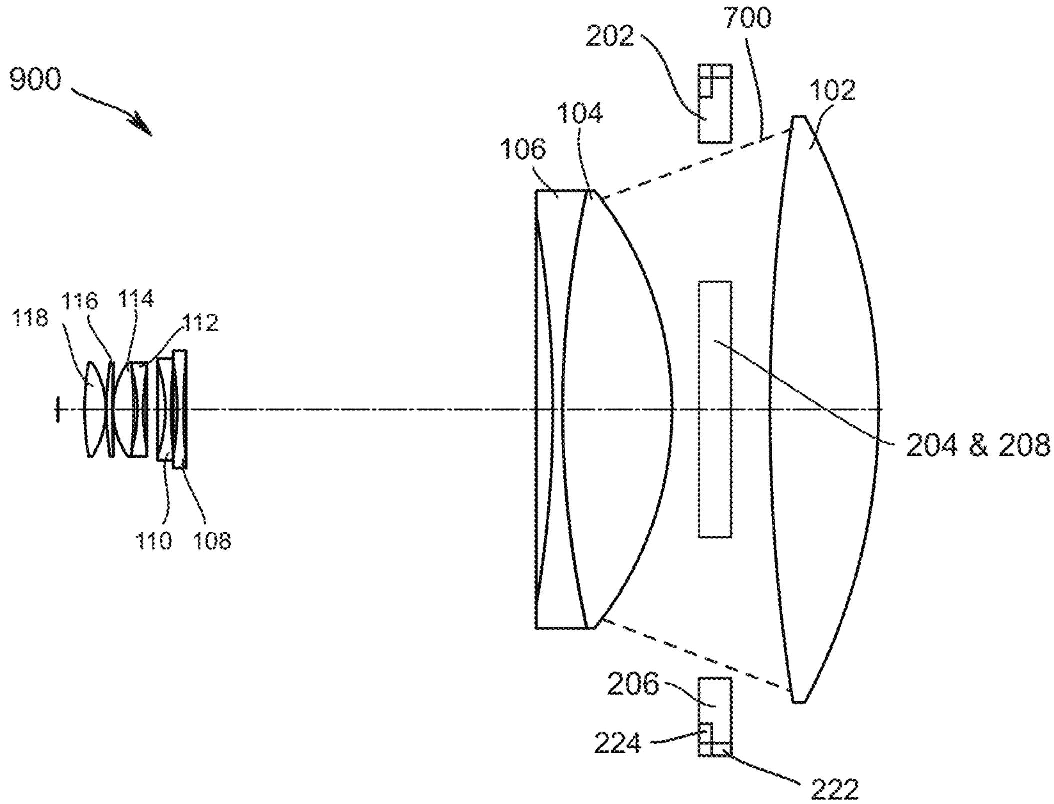
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FIG. 9

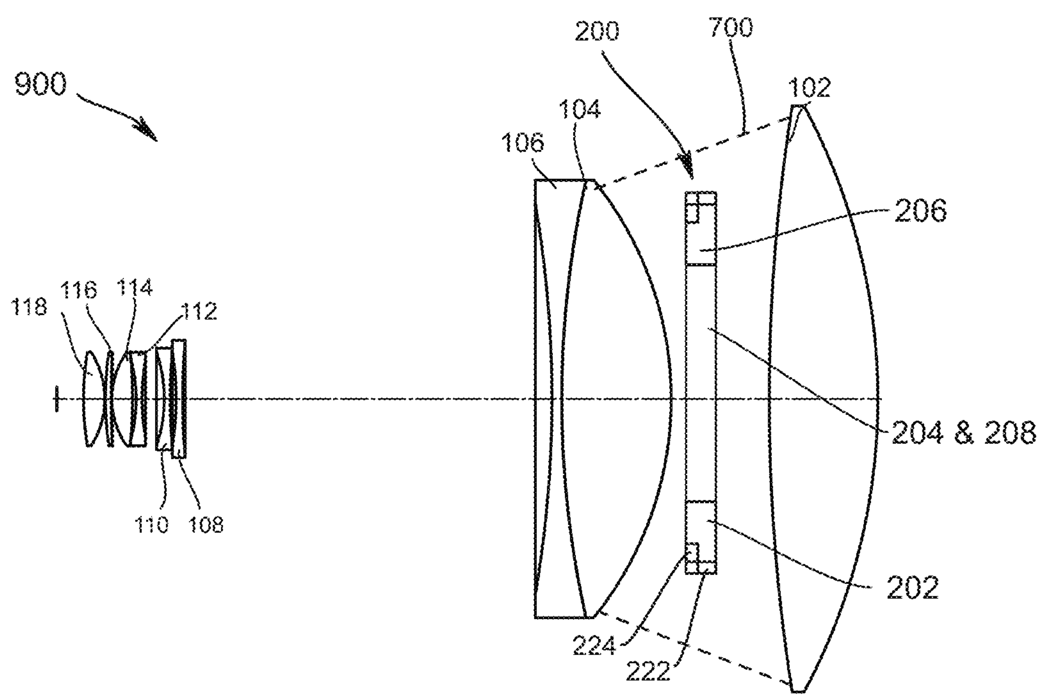
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FIG. 10

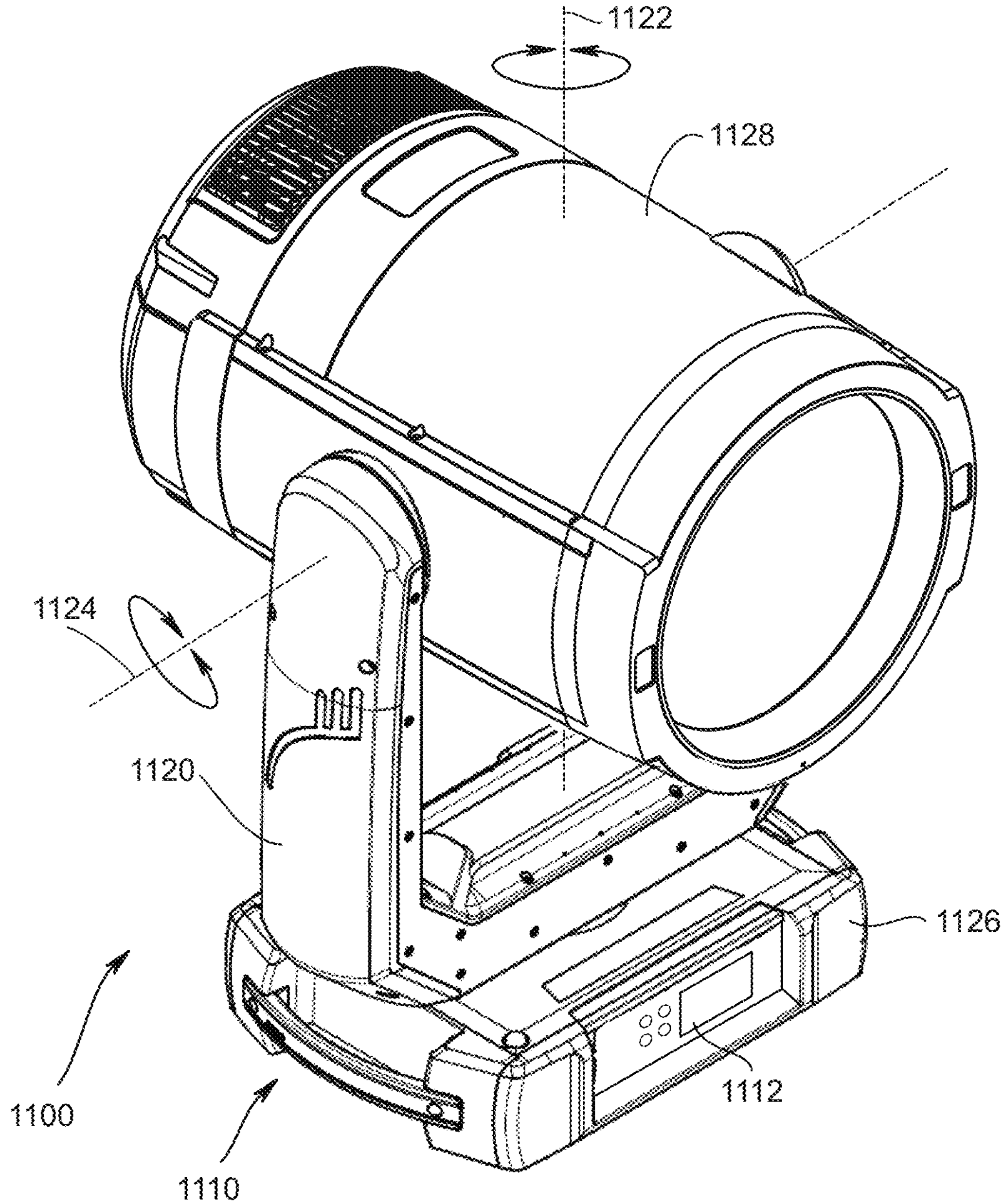

FIG. 11

OPTICAL SYSTEM FOR AN AUTOMATED LUMINAIRE

CROSS-REFERENCE TO RELATED APPLICATIONS

This patent application claims the benefit of U.S. Provisional Application No. 63/579,734, filed Aug. 30, 2023, entitled "OPTICAL SYSTEM FOR AN AUTOMATED LUMINAIRE" which is hereby incorporated by reference in its entirety.

TECHNICAL FIELD OF THE DISCLOSURE

The disclosure generally relates to luminaires, and more specifically to an optical system for an automated luminaire.

BACKGROUND

Some luminaires in the entertainment and architectural lighting markets include automated and remotely controllable functions. Such luminaires may be used in theatres, television studios, concerts, theme parks, night clubs and other venues. A luminaire may provide control over the pan and tilt functions of the luminaire, allowing the operator to control the direction the luminaire is pointing and thus the position of the light beam on the stage or in the studio. Such position control may be obtained via control of the luminaire's position in two orthogonal rotational axes, which may be referred to as pan and tilt. Some luminaires provide control over other parameters such as intensity, color, focus, beam size, beam shape, and/or beam pattern.

The optical systems of such automated luminaires may be designed to enable a user to control the beam size, from a very narrow output beam to a wide (or "wash") beam. Such control may allow such luminaires to be used with long throws to a target or for almost parallel-beam light effects as well as for wider, more traditional wash effects. Optical systems with the ability to produce narrow beams may be referred to as 'Beam' optics, while optical systems with the ability to produce wide beams may be referred to as 'Wash' optics.

SUMMARY

A zoom optical system includes a light source, a focus lens group, a zoom lens group, and a fixed lens group. The light source is configured to illuminate an object located in an object plane of the zoom optical system or in a plane adjacent to the object plane. The focus lens group is optically coupled to the object without intervening lenses, has a first positive optical power, and is configured to move relative to the object plane to control whether the object is in focus. The focus lens group includes four lenses, the four lenses comprising positive, positive, positive, and negative optical power lenses, listed in sequence beginning with a lens of the focus lens group closest to the object plane. The zoom lens group is optically coupled to the focus lens group without intervening lenses, has a negative optical power, and is configured to move relative to the object plane and the focus lens group. The zoom lens group is configured to move to control a beam angle while the focus lens group remains in a fixed position relative to the object plane. The zoom lens group comprises two lenses, both lenses comprising negative power lenses. The fixed lens group is optically coupled to the zoom lens group without intervening lenses, has a second positive optical power, and is configured to remain in a fixed position relative to the object plane and to project an image of the object. The fixed lens group comprises three lenses, the three lenses comprising negative, positive, and positive optical power lenses, listed in sequence beginning with a lens of the fixed lens group closest to the object plane.

An automated luminaire includes a light source, a zoom optical system, and a controller. The light source is configured to emit a first light beam and illuminate an object located in an object plane of the automated luminaire or in a plane adjacent to the object plane. The zoom optical system is optically coupled to the light source and includes a focus lens group, a zoom lens group, and a fixed lens group. The focus lens group has a first positive optical power and is configured to receive the first light beam as modified by the object, to emit a second light beam, and to move relative to the object to control whether the object is in focus. The focus lens group comprises four lenses, comprising positive, positive, positive, and negative optical power lenses, listed in sequence beginning with a lens of the focus lens group closest to the object plane. The zoom lens group has a negative optical power and is configured to receive the second light beam, to emit a third light beam, and to move to control a beam angle while the focus lens group remains in a fixed position relative to the object. The zoom lens group comprises two lenses, both lenses comprising negative power lenses. The fixed lens group has a second positive optical power and is configured to receive the third light beam, to project an image of the object, and to remain in a fixed position relative to the object. The fixed lens group comprises three lenses, the three lenses comprising negative, positive, and positive optical power lenses, listed in sequence beginning with a lens of the fixed lens group closest to the object plane. The controller is coupled to the focus lens group and the zoom lens group and is configured to move the focus lens group and the zoom lens group independently along an optical axis of the zoom optical system.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of this disclosure, reference is now made to the following brief description, taken in conjunction with the accompanying drawings in which like reference numerals indicate like features.

FIG. **1** presents a side view of a zoom optical system according to the disclosure in a first configuration;

FIG. **2** presents an exploded isometric view of the zoom optical system of FIG. **1** with the elements of the lens groups separated from each other;

FIG. **3** presents a cross-section side view of the zoom optical system of FIG. **1**;

FIG. **4** presents a cross-section side view of a second zoom optical system according to the disclosure;

FIG. **5** presents an exploded isometric view of the second zoom optical system of FIG. **4**;

FIG. **6**A presents an isometric view of a first light effect ring according to the disclosure;

FIG. **6**B presents a cross-section side view of a portion of the second zoom optical system according to the disclosure;

FIG. **7** presents a front view of a second light effect ring according to the disclosure, in a first configuration;

FIG. **8** presents a front view of the second light effect ring in a second configuration;

FIG. **9** presents a side view of a third zoom optical system according to the disclosure;

FIG. **10** presents a side view of the zoom optical system of FIG. **9**; and

FIG. **11** presents an isometric view of a luminaire according to the disclosure.

DETAILED DESCRIPTION

Preferred embodiments are illustrated in the figures, like numerals being used to refer to like and corresponding parts of the various drawings.

Some zoom optical systems comprise a large number of lenses, which may make such zoom optical systems heavier, larger, and/or more costly to produce. Embodiments of zoom optical systems according to the disclosure comprise only nine lenses, making them potentially lighter, smaller, and less costly than such other zoom optical systems. Additionally, other zoom optical systems may comprise aspheric lenses, which may be more costly to fabricate. Embodiments of zoom optical systems according to the disclosure comprise only spherical lenses (where non-planar lens surfaces are used), making them potentially less costly than such other zoom optical systems.

Some luminaires in a lighting system may be visible to audience members, thereby becoming a part of the staging of the show. When the audience views the front of the head of a luminaire, they may see the fixed objective lens through which the light beam is emitted and may see something of the housing of the luminaire, depending on ambient illumination. The emitted beam may be narrow or wide and the lens may be slightly illuminated by the emitted beam.

In contrast to the control the operator may have over the appearance of other set pieces and truss elements that are equipped with, for example, color controllable strip lighting, such luminaires do not allow the operator independent control of the appearance of the front of the head of the luminaire. A light effect ring according to the disclosure provides the operator such control by enabling, if desired, one or more colors to be seen in the frontmost lens of the luminaire when the luminaire is viewed by the audience. The ring may present a solid color or a pattern of colors, the effect may be static or varying ("dynamic"), and may have a desired intensity, all under the control of the operator.

FIG. **1** presents a side view of a zoom optical system **100** according to the disclosure in a first configuration. The zoom optical system **100** comprises a light source **105** and an object plane **103**. The zoom optical system **100** includes an optical axis **150**. One or more objects to be imaged by the zoom optical system **100** are located in or adjacent to the object plane **103**. Examples of objects to be imaged include a static or rotating gobo mounted on a gobo wheel or other gobo carrier, and a variable iris, an aperture wheel, or other mechanism for producing a light beam of a selected size. Where more than one such object to be imaged is included in the zoom optical system **100**, it will be understood that the objects may be located in individual planes adjacent to the object plane **103**. As shown in FIG. **1**, the left end of the zoom optical system **100** may be referred to as the object end and the right end as the image end.

The zoom optical system **100** further comprises nine lenses in three lens groups: lenses **102**, **104**, and **106** ("Objective" group); lenses **108** and **110** ("Variator" group); and lenses **112**, **114**, **116**, and **118** ("Compensator" group). The lens elements of the embodiment shown in FIG. **1** are described in Table 1. As described below, FIGS. **2-5** also show the lenses of the zoom optical system **100**. The column Group of Table 1 indicates the lens group of each lens element.

The columns Diameter, R1, and R2 present a prescription for the shape of each lens element, where "mm" indicates that the unit of measurement is millimeters (mm). R1 describes a curvature of an image side of the lens element (right-hand side in FIGS. **1**) and R2 describes a curvature of an object side of the lens element (left-hand side in FIG. **1**). As may be seen in FIG. **3**, a positive value of R1 indicates a convex image side surface of the lens element and a negative value of R1 indicates a concave image side surface of the lens element. As may also be seen in FIG. **3**, a positive value of R2 indicates a concave object side surface of the lens element and a negative value of R2 indicates a convex object side surface of the lens element. For the purposes of this disclosure, radii of curvature within 10% of the disclosed radii are considered substantially equal to the disclosed radii of curvature.

The column Spacing indicates the spacing of elements within that lens group, where the unit of measurement is millimeters. The column Glass Type specifies a type of glass material for each lens. Glass type values that include the letter "F" identify a lens made of flint glass. Glass type values that include the letter "K" identify a glass made of crown glass. The column Power indicates whether the lens element has a positive or negative optical power.

TABLE 1

Lens	Group	Diameter (mm)	Spacing (mm)	R1 (mm)	R2 (mm)	Glass Type	Power
102	Objective	300	50.1	316.6	−960.3	H-K9L	Positive
104	Objective	224	Cemented	178.0	−511.2	H-K9L	Positive
106	Objective	224	—	−511.2	591.2	H-ZFL7A	Negative
108	Variator	60	3.1	−331.7	146.5	H-ZK9A	Negative
110	Variator	60	—	−265.2	73.8	H-ZK9A	Negative
112	Compensator	48	2.2	−113.4	79.4	H-ZFL7A	Negative
114	Compensator	48	0.3	242.5	−41.7	H-K9L	Positive
116	Compensator	48	0.3	−487.8	−161.6	H-ZFL7A	Positive
118	Compensator	48	—	44.5	−144.1	H-K9L	Positive

In some embodiments, all of the objective, variator, and compensator lens groups are configured for motion along an optical axis **150** of the zoom optical system **100** relative to each other and to the object plane **103**. In other embodiments, the lens **102** of the objective lens group is fixed in place at an exit aperture of a luminaire **1100** (described in more detail with reference to FIG. **11**) comprising the zoom optical system **100**. In such embodiments, the objective lens group is not configured for motion and remains in a fixed position on the optical axis, while the variator, and compensator lens groups are configured for motion. As will be shown in more detail in subsequent figures, when the lens groups move relative to each other along the optical axis, the lenses within each lens group remain in the same position relative to each other.

The compensator group lenses form a converging (or positive power) group, the variator group lenses form a diverging (or negative power) group, and the objective group lenses form a converging group. The compensator, variator, and objective lens groups of the zoom optical system **100** have four, two, and three lenses, respectively. It will be recognized by a person of skill in the art that, in other embodiments, positive/negative/positive compensator/variator/objective lens groups may comprise lens groups of more or fewer than four/two/three lenses each, including lens ‘groups’ with only a single lens.

A first light beam emitted by the light source **105** converges and illuminates an object to be imaged, located in the object plane **103**, and then diverges as it approaches the compensator lens group. The compensator lens group receives the first light beam, as modified by any object placed in the first beam in the object plane **103**, and emits a second light beam. The variator lens group receives the second light beam and emits a third light beam. The objective lens group receives the third light beam and emits a fourth light beam, which is the light beam emitted by the zoom optical system **100**. As such, each of the compensator, variator, and objective lens groups may be said to be optically coupled to its preceding optical element in the zoom optical system **100** and the light beams received by each lens group may be said to have originated at the light source **105**.

In various embodiments, the objective lens group moves along the optical axis of the zoom optical system **100** or remains in a fixed location relative to the object plane **103**, as discussed above. Both the variator and compensator lens groups move independently along the optical axis. Movement of the variator lens group primarily controls the overall focal length (light output angle or beam angle) of the emitted light beam. For example, while the compensator lens group remains in a fixed position relative to the object plane, movement of the variator lens group changes the beam angle of the emitted light beam. Movement of the compensator lens group relative to the object plane primarily controls whether an object in the object plane **103** or in a plane adjacent to the object plane **103** is in focus. In combination, the positions of the compensator and variator lens groups determine a beam angle (or zoom) of the emitted beam and a distance from the objective lens group at which a projected image of the object plane is focused. As such, the compensator and variator lens groups may also be referred to respectively as a focus lens group and a zoom lens group. The objective lens group may be referred to as a fixed lens group in embodiments where it remains in a fixed location relative to the object plane **103**.

Moving both focus and zoom lens groups affects both zoom and focus, as does moving the objective lens group, although moving the objective lens group affects beam angle more than the distance from the objective lens group at which the projected image of the object plane is focused. Using a three lens group zoom optical system, a luminaire may be designed having any one of the lens groups in a fixed position and the other two lens groups configured to move relative to the fixed lens group.

Moving lens groups may be mechanically coupled to hand-operated manual controls or to motors, linear actuators, or other electromechanical mechanisms for motion. Such electromechanical mechanisms may be electrically coupled to a control system (or controller) **1110** of the luminaire **1100**, the control system **1110** configured to control a motion of the electromechanical mechanisms and thus the lens groups. In various embodiments, the control system **1110** comprises a microcontroller or other programmable processing system. In some embodiments, the control system **1110** may be coupled for local control to a user interface **1112** included in the luminaire **1100** and configured to receive therefrom signals relating to desired positions of the electromechanical mechanisms.

In other embodiments, the control system **1110** may be coupled for remote control by a data link (wired or wireless) to a remotely located control console and to receive signals therefrom indicating desired positions along the optical axis for the lens groups of the zoom optical system **100**. The data link may use DMX512 (Digital Multiplex) protocol or other suitable communication protocol, e.g., Art-Net, ACN (Architecture for Control Networks), and Streaming ACN. In such embodiments, the control system **1110** is configured to move the focus and/or zoom lens groups in response to signals received via the data link. In some such embodiments, the control system **1110** moves the compensator lens group in response to a control signal received on a first control channel of the data link and moves the variator lens group in response to a control signal received on a second control channel of the data link.

FIG. **2** presents an exploded isometric view of the zoom optical system **100** of FIG. **1**, with the elements of the lens groups separated from each other. As described above, the zoom optical system **100** is positioned coaxially with a light source that is located at the end of the zoom optical system **100** where the lens **118** is located. The zoom optical system **100** produces a light beam, emitted from lens **102**. The compensator lens group is optically coupled to one or more objects in the object plane **103** without intervening lenses. As may be seen in FIG. **2**, the variator lens group is coupled to the compensator lens group without intervening lenses and the objective lens group is coupled to the variator lens group without intervening lenses. The objective lens group projects an image of the one or more objects in the object plane without further intervening lenses.

FIG. **3** presents a cross-section side view of the zoom optical system **100** of FIG. **1**. In FIG. **3**, the lens groups are positioned in a first configuration that produces a wide angle beam. FIG. **4** presents a side view of a second zoom optical system **400**. The zoom optical system **400** comprises the lens groups of the zoom optical system **100** and a first light effect ring **120**. FIG. **4** presents a cross-section side view of the lens groups positioned in a second configuration that produces a narrow angle beam. The light effect ring **120** is discussed in more detail with reference to FIGS. **5-8**. In various embodiments, the light effect ring **120** may be configured for motion along the optical axis, the motion controllable to configure the zoom optical system **100** with the light effect ring **120** at any position between the lenses **104** and **102**.

FIG. **5** presents an exploded isometric view of the zoom optical system **400** of FIG. **4**. As discussed above, the zoom optical system **400** comprises the lens groups of the zoom optical system **100** and the light effect ring **120**. In the embodiment shown in FIG. **5**, the light effect ring **120** is positioned between lenses **102** and **104**. In other embodiments light effect ring **120** may be positioned at any point in the zoom optical system **400**.

FIG. **6**A presents an isometric view of the light effect ring **120** according to the disclosure. The light effect ring **120** comprises a cylinder having an axis, the cylinder having an inner face **126** and an outer face **128**. In the embodiment shown in FIG. **6**A, the axis of the light effect ring **120** is colinear with the optical axis **150**. In various embodiments, the axis of the light effect ring **120** may be parallel to and offset from the optical axis or may form an angle with the optical axis. A rim **130** extends toward the axis of the light effect ring **120** from an edge of the inner face **126** (the left edge as shown in FIG. **6**A).

A first plurality of light emitters **122** are mounted to the inner face **126** and emit light toward the center of the light effect ring **120**. A second plurality of light emitters **124** are mounted to a face of the rim **130** facing toward the lens **102** and configured to emit light toward the lens **102**, i.e., toward a front edge of the light effect ring **120** (the right edge as shown in FIG. **6**A). Other embodiments may comprise more or fewer than two pluralities of light emitters and/or light emitters that emit light in more or fewer directions than toward the center and forward.

In various embodiments, the light emitters **122** and **124** may comprise one or more individual light emitting diodes (LEDs) or other light emitting devices. Where the light emitters **122** and **124** includes a plurality of LEDs, the LEDs may emit light in the same or in multiple colors. In some embodiments the LEDs are red, green, blue, and white. In other embodiments any combination of red, green, blue, amber, lime, dark blue, and cyan LEDs may be used. In yet other embodiments, any combination and number of colors or white LEDs may be used. Examples of such other embodiments include any combination of two or more red, green, blue, amber, warm white, cold white, or tunable white mix. The light emitters **122** and **124** may be electrically coupled to the control system **1110** for local or remote control of their brightness and/or color, as described with reference to motion control of the zoom optical system **100** of FIG. **1**. The brightness and/or color of the light emitters **122** and **124** may be controlled by the control system **1110** independently, in groups, or collectively.

FIG. **6**B presents a cross-section side view of a portion of the zoom optical system **400** according to the disclosure. The light effect ring **120** of FIG. **6**B is in a different position relative to lenses **102** and **104** than in the embodiment in FIG. **4**. In various embodiments, the light effect ring **120** may be positioned at any location between the lenses **102** and **104**—e.g., a position adjacent to the lens **104** (as shown in FIG. **6**B), a position intermediate between the lenses **104** and **102** (as shown in FIG. **4**), or a position adjacent to the lens **102**. As discussed above, the light effect ring **120** may be configured for motion along the optical axis to any location between the lenses **104** and **102**. In FIG. **4**, a portion of a light beam **700** is shown between lenses **104** and **102**, indicating the location of the light effect ring **120** relative to the light beam **700**. The light effect ring **120** may occlude an outer portion of the light beam **700**. Similarly, in the position shown in FIG. **6**B, the light effect ring **120** may occlude an outer portion of the light beam of the zoom optical system **400**.

Depending upon a position of the light effect ring **120** relative to the lenses **102** and **104**, the light emitters **122** and **124** illuminate one or both of the lenses **102** and **104** to produce an effect that is visible to a viewer outside of the luminaire **1100**. The light emitters **122** emit a light beam **123** that obliquely illuminates a surface of one or both of the lenses **102** and **104** (e.g., a portion of the front surface of the lens **104** and a portion of the back surface of the lens **102**). For the purposes of this application, the term "oblique" is defined as a light beam impinging a point on a surface at an angle greater than 30 degrees (30°) from a normal to the surface (i.e., from a vector perpendicular to the surface at the point). The light beam **123** represents only the light emitted by the light emitters **122** in the top portion (as depicted in FIG. **6**B) of the light effect ring **120**, but the light emitters **122** in other portions of the light effect ring **120** emit similar light beams **123** across the lenses **102** and **104** from other directions.

In the embodiment shown in FIG. **6**B, the light emitters **122** illuminate both of the lenses **102** and **104** with the oblique light beam **123**. In embodiments where the light effect ring **120** is positioned closer to the lens **102**, the light beam **123** may obliquely illuminate only the back side of the lens **102**.

The light emitters **124** emit a light beam **125** through the lens **102**. The light beams **123** and **125** illuminate the back surface of the lens **102**, as well as passing through the lens **102** to be emitted from the luminaire **1100**. The light beam **125** represents only the light emitted by the light emitters **124** in the bottom portion (as depicted in FIG. **6**B) of the light effect ring **120**, but the light emitters **124** in other portions of the light effect ring **120** emit similar light beams **125** through the lens **102** from other locations around the light effect ring **120**. In other embodiments, the light effect ring **120** may be used with other types of optical system (e.g., a fixed focus optical system) to produce a visible effect in an exit lens of such an optical system.

FIGS. **7** and **8** show front views of a second light effect ring **200** according to the disclosure, positioned in first and second configurations, respectively. The light effect ring **200** is configured to be moved within the luminaire **1100** into or out of position within the light beam **700**. The light effect ring **200** includes light emitters **222** and **224**, similar to the light emitters **122** and **124** of the light effect ring **120**. Movement of the light effect ring **200** into or out of position within the light beam **700** enables an operator to choose whether the light emitters **222** and **224** are visible in the light beam **700**.

To facilitate movement into and out of the light beam **700**, the light effect ring **200** comprises a plurality of physical segments configured for independent or collective motion toward and away from the optical axis of the zoom optical system **900** that is described with reference to FIGS. **9** and **10**. In some embodiments, the segments are configured for independent or collective motion parallel to the optical axis **150**. The light effect ring **200** is split into 4 physical segments: **202**, **204**, **206**, and **208**, each segment comprising a subset of the light emitters **222** and a subset of the light emitters **224**. Each segment **202**, **204**, **206**, **208** is configured to be moved into or out of the light beam **700**.

When all segments **202**, **204**, **206**, **208** are moved into the light beam **700**, the light effect ring **200** comprises a segmented cylinder having an axis, the cylinder segments having inner faces and outer faces. The axis of the light effect ring **200** is colinear with the optical axis **150**. A rim comprises rim segments extending toward the axis of the light effect ring **200** from an edge of each segment of the light effect ring. The light emitters **222** are mounted to the inner faces of the cylinder segments and the light emitters **224** are mounted to faces of the rim segments that face toward the lens **102**.

FIG. **7** shows the segments **202**, **204**, **206**, and **208** of the light effect ring **200** in a first configuration, in which they are outside the light beam **700**. FIG. **8** shows the segments **202**, **204**, **206**, and **208** of the light effect ring **200** in a second configuration in which they have been assembled to form an unbroken light effect ring **200**, positioned within the light beam **700**. In some embodiments, the light effect ring **200** may be split into segments of different sizes. In other embodiments, the light effect ring **200** may be split into other numbers of segments than four. In various embodiments, each light effect ring segment may be controlled to move into or out of the optical path independently or in various groupings. For example, in a third configuration, the segments **202** and **206** may be moved into the beam **700** and the segments **204** and **208** moved outside the beam **700**.

The moving segments **202**, **204**, **206**, **208** may be mechanically coupled to hand-operated manual controls or to motors, linear actuators, or other electromechanical mechanisms for motion. As discussed above with reference to moving lens groups, the electromechanical mechanisms physically coupled to the moving segments **202**, **204**, **206**, **208** may be electrically coupled to a control system (or controller) **1110** of the luminaire **1100**, where the control system **1110** is configured to control motion of the electromechanical mechanisms and thus motion of the moving segments **202**, **204**, **206**, **208** into and out of the beam **700**. In various embodiments, the control system **1110** may be coupled for local control via a user interface **1112** or for remote control via a data link. In various such embodiments, the control system **1110** is configured to move the moving segments **202**, **204**, **206**, **208** independently, in groups, or collectively in response to signals received via the data link on one or more control channels.

FIG. **9** presents a side view of a third zoom optical system **900** according to the disclosure. The third zoom optical system **900** comprises the lens groups of the zoom optical system **100** and the light effect ring **200**. The lens groups of the zoom optical system **100** are shown in the second configuration (described with reference to FIG. **4**) and the light effect ring **200** is shown in the first configuration (described with reference to FIG. **7**), where the light ring segments are moved out of the light beam **700**. It may be seen that the segment **202** has been moved above the light beam **700** and the segment **206** has been moved below the light beam **700**. The segments **204** and **208** have also been moved out of the light beam **700**, in directions out of and into the page, respectively. FIG. **10** presents a side view of the zoom optical system **900** of FIG. **9**. In FIG. **10** the lens groups of the zoom optical system **100** are shown in the second configuration and the second light effect ring **200** in the second configuration (described with reference to FIG. **7**), moved into the light beam **700**.

As described for the lens groups of the zoom optical system **100**, the light effect ring segments **202**, **204**, **206**, and **208** may be coupled to motors, linear actuators, or other electromechanical mechanisms for motion. Such electromechanical mechanisms may be electrically coupled (for local or remote control) to the control system of the luminaire **1100**, as described with reference to the zoom optical system **100** of FIG. **1**.

While the light effect rings **120** and **200** are circular or circular segments, in other embodiments a light effect according to the disclosure may have other shapes or other segment shapes. In various embodiments, the light effect ring or assembled segments may be square, triangular, hexagonal, oval, lobed, or any combination of such rectilinear and/or rounded shapes.

FIG. **11** presents an isometric view of the luminaire **1100** according to the disclosure. The luminaire **1100** is an automated luminaire comprising a head **1128** which comprises any of the zoom optical system **100** or either of the zoom optical systems **400** or **900** with light effect ring **120**, or **200**. The head **1128** is coupled by a tilt mechanism to a yoke **1120** and configured to rotate within the yoke **1120** about a tilt axis **1124**. The yoke **1120** is coupled by a pan mechanism to a fixed enclosure **1126** and configured to rotate relative to the fixed enclosure **1126** about a pan axis **1122**. The pan axis **1122** and the tilt axis **1124** are orthogonal to each other. The luminaire **1100** further comprises the control system **1110** and the user interface **1112** as described with reference to the zoom optical system **100** of FIG. **1**. The control system **1110** is located internal to the luminaire **1100** and is not visible in FIG. **11**.

One or both of the pan and tilt mechanisms are mechanically coupled to hand-operated manual controls or to motors, linear actuators, or other electromechanically controlled mechanisms. Such electromechanical mechanisms may be electrically coupled (for local or remote control) to the control system **1110**, as described with reference to the zoom optical system **100** of FIG. **1**.

While only some embodiments of the disclosure have been described herein, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments may be devised which do not depart from the scope of the disclosure herein. While the disclosure has been described in detail, it should be understood that various changes, substitutions, and alterations can be made hereto without departing from the spirit and scope of the disclosure.

What is claimed is:

1. A zoom optical system comprising:

a light source configured to illuminate an object located in an object plane of the zoom optical system or in a plane adjacent to the object plane;

a focus lens group optically coupled to the object without intervening lenses, the focus lens group having a first positive optical power and configured to move relative to the object plane to control whether the object is in focus, the focus lens group comprising four lenses, the four lenses comprising positive, positive, positive, and negative optical power lenses, listed in sequence beginning with a lens of the focus lens group closest to the object plane;

a zoom lens group optically coupled to the focus lens group without intervening lenses, the zoom lens group having a negative optical power and configured to move relative to the object plane and the focus lens group, the zoom lens group configured to move to control a beam angle while the focus lens group remains in a fixed position relative to the object plane, the zoom lens group comprising two lenses, both lenses comprising negative power lenses; and

a fixed lens group, optically coupled to the zoom lens group without intervening lenses, the fixed lens group having a second positive optical power, and configured to remain in a fixed position relative to the object plane and to project an image of the object, the fixed lens group comprising three lenses, the three lenses comprising negative, positive, and positive optical power lenses, listed in sequence beginning with a lens of the fixed lens group closest to the object plane.

2. The zoom optical system of claim **1**, wherein the focus lens group and the zoom lens group are further configured to be moved to selected positions relative to each other by an operator of the zoom optical system.

3. The zoom optical system of claim **1**, wherein the focus lens group and the zoom lens group are configured to be moved to selected positions relative to each other by a remotely located operator of the zoom optical system.

4. The zoom optical system of claim **1**, wherein:

the four lenses of the focus lens group comprise crown glass, flint glass, crown glass, and flint glass, listed in sequence beginning with the lens of the focus lens group closest to the object plane;

the two lenses of the zoom lens group both comprise crown glass; and the three lenses of the fixed lens group comprise flint glass, crown glass, and crown glass, listed in sequence beginning with the lens of the fixed lens group closest to the object plane.

5. The zoom optical system of claim **4**, wherein:

the four lenses of the focus lens group comprise glass of types H-K9L, H-ZFL7A, H-K9L, and H-ZFL7A, listed in sequence beginning with the lens of the focus lens group closest to the object plane;

the two lenses of the zoom lens group comprise glass of types H-ZK9A; and

the three lenses of the fixed lens group comprise glass of types H-ZFL7A, H-K9L, and H-K9L, listed in sequence beginning with the lens of the fixed lens group closest to the object plane.

6. The zoom optical system of claim **1**, wherein:

the lenses of the focus lens group, listed in sequence beginning with the lens of the focus lens group farthest from the object plane, have substantially the following radii of curvature:

R1	R2
−113.4	79.4
242.5	−41.7
−487.8	−161.6
44.5	−144.1;

the lenses of the zoom lens group, listed in sequence beginning with the lens of the zoom lens group farthest from the object plane, have substantially the following radii of curvature:

R1	R2
−331.7	146.5
−265.2	73.8;

and

the lenses of the fixed lens group, listed in sequence beginning with the lens of the fixed lens group farthest from the object plane, have substantially the following radii of curvature:

R1	R2
316.6	−960.3
178.0	−511.2
−511.2	591.2,

where R1 is a radius of curvature of an image side surface of the lens, a positive value of R1 indicating a convex image side surface, and a negative value of R1 indicating a concave image side surface; R2 is a radius of curvature of an object side of the lens, a positive value of R2 indicating a concave object side surface, and a negative value of R2 indicating a convex object side surface; and all radii are expressed in millimeters.

7. An automated luminaire, comprising:

a light source configured to emit a first light beam and illuminate an object located in an object plane of the automated luminaire or in a plane adjacent to the object plane;

a zoom optical system optically coupled to the light source, the zoom optical system comprising:

a focus lens group having a first positive optical power, the focus lens group configured to receive the first light beam as modified by the object, to emit a second light beam, and to move relative to the object to control whether the object is in focus, the focus lens group comprising four lenses, the four lenses comprising positive, positive, positive, and negative optical power lenses, listed in sequence beginning with a lens of the focus lens group closest to the object plane;

a zoom lens group having a negative optical power, the zoom lens group configured to receive the second light beam, to emit a third light beam, and to move to control a beam angle while the focus lens group remains in a fixed position relative to the object, the zoom lens group comprising two lenses, both lenses comprising negative power lenses; and

a fixed lens group having a second positive optical power, the fixed lens group configured to receive the third light beam, to project an image of the object, and to remain in a fixed position relative to the object, the fixed lens group comprising three lenses, the three lenses comprising negative, positive, and positive optical power lenses, listed in sequence beginning with a lens of the fixed lens group closest to the object plane; and

a controller coupled to the focus lens group and the zoom lens group and configured to move the focus lens group and the zoom lens group independently along an optical axis of the zoom optical system.

8. The automated luminaire of claim **7**, wherein:

the controller is electrically coupled to a first electromechanical mechanism mechanically coupled to the focus lens group and to a second electromechanical mechanism mechanically coupled to the zoom lens group; and

the controller is configured to actuate one or both of the first and second electromechanical mechanisms to move one of the focus lens group and the zoom lens group to a desired position relative to the object plane.

9. The automated luminaire of claim **8**, wherein the controller is coupled to a data link and configured to move the one of the focus lens group and the zoom lens group in response to a signal received via the data link.

10. The automated luminaire of claim **9**, wherein the data link uses a DMX512 protocol.

11. The automated luminaire of claim **9**, wherein the controller is configured to move the focus lens group in response to a first control signal received on a first control channel of the link and to move the zoom lens group in response to a second control signal received on a second control channel of the data link.

12. The automated luminaire of claim **7**, wherein:

the four lenses of the focus lens group comprise crown glass, flint glass, crown glass, and flint glass, listed in sequence beginning with the lens of the focus lens group closest to the object plane;

the two lenses of the zoom lens group both comprise crown glass; and

the three lenses of the fixed lens group comprise flint glass, crown glass, and crown glass, listed in sequence beginning with the lens of the fixed lens group closest to the object plane.

13. The automated luminaire of claim **12**, wherein:

the four lenses of the focus lens group comprise glass of types H-K9L, H-ZFL7A, H-K9L, and H-ZFL7A, listed in sequence beginning with the lens of the focus lens group closest to the object plane;

the two lenses of the zoom lens group comprise glass of types H-ZK9A; and

the three lenses of the fixed lens group comprise glass of types H-ZFL7A, H-K9L, and H-K9L, listed in sequence beginning with the lens of the fixed lens group closest to the object plane.

14. The automated luminaire of claim **7**, wherein:

the lenses of the focus lens group, listed in sequence beginning with the lens of the focus lens group farthest from the object plane, have substantially the following radii of curvature:

R1	R2
−113.4	79.4
242.5	−41.7
−487.8	−161.6
44.5	−144.1;

the lenses of the zoom lens group, listed in sequence beginning with the lens of the zoom lens group farthest from the object plane, have substantially the following radii of curvature:

R1	R2
−331.7	146.5
−265.2	73.8;

and

the lenses of the fixed lens group, listed in sequence beginning with the lens of the fixed lens group farthest from the object plane, have substantially the following radii of curvature:

R1	R2
316.6	−960.3
178.0	−511.2
−511.2	591.2,

where R1 is a radius of curvature of an image side surface of the lens, a positive value of R1indicating a convex surface, and a negative value of R1 indicating a concave surface; R2 is a radius of curvature of an object side of the lens, a positive value of R2 indicating a concave surface, and a negative value of R2 indicating a convex surface; and all radii are expressed in millimeters.

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