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(54) **METHOD AND APPARATUS FOR GREYSCALE LITHOGRAPHY**

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***G03F 7/00*** (2006.01)

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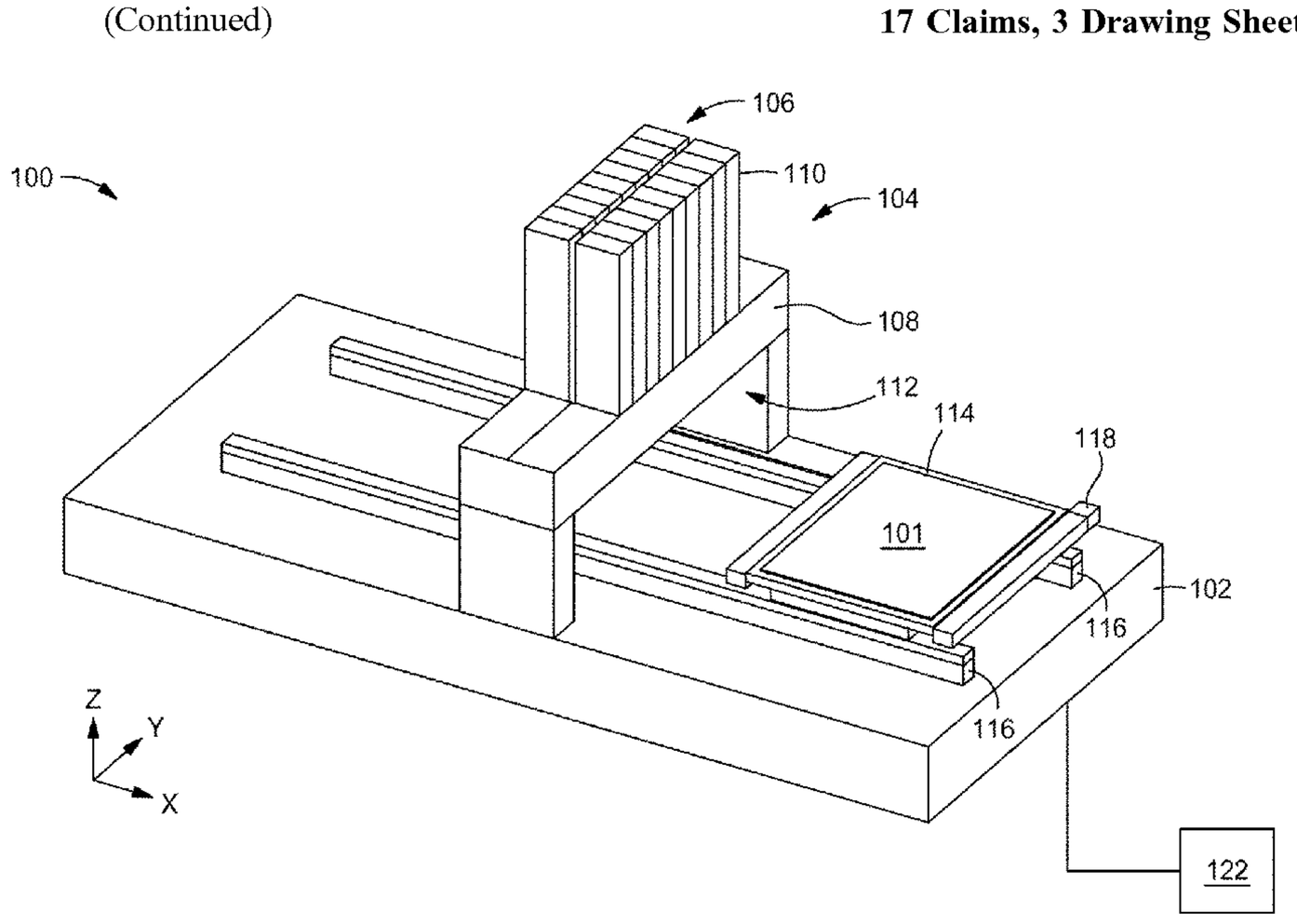
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(57) **ABSTRACT**

An image projection system is provided. The system can be used for performing lithography. The system includes a deuterium light source, a converging lens coupled to the deuterium light source. The system includes an aperture configured to provide image tiling disposed adjacent to the converging lens. The system includes a movable stage disposed adjacent to the aperture. A method of fabricating an optical device is provided. The method includes depositing a resist over a substrate and determining an exposure pattern for the optical device. The method includes exposing a portion of the resist with a light beam based on the determined exposure pattern. Exposing the portion of the resist includes directing the light beam from a deuterium light source to the substrate and developing the resist.

**17 Claims, 3 Drawing Sheets**



(58) **Field of Classification Search**
CPC ..... G03F 7/70016; G03F 7/70275; G03F 7/70283; G03F 7/70558; G03F 7/7005; G03F 7/70391; G03F 7/70475; G03F 7/70425; G03F 7/704; G03F 7/70383; G03F 7/70375; G03F 7/70316; G03F 7/70291; G03F 7/70225; G03F 7/702; G03F 7/70208; G03F 7/70191; G03F 7/7015; G03F 7/70175; G03F 7/70058; G03F 7/70066; G03F 7/70083; G03F 7/70091
USPC ..... 355/18, 30, 52–55, 67–77, 133; 430/5, 430/22, 30; 362/230–231, 234, 235, 236, 362/241, 247, 257, 263, 268, 296.01, 297, 362/299, 311.06, 311.08, 311.11, 311.12; 250/492.1, 492.2, 492.22, 492.23, 493.1, 250/494.1, 503.1, 504 R, 505.1, 515.1
See application file for complete search history.

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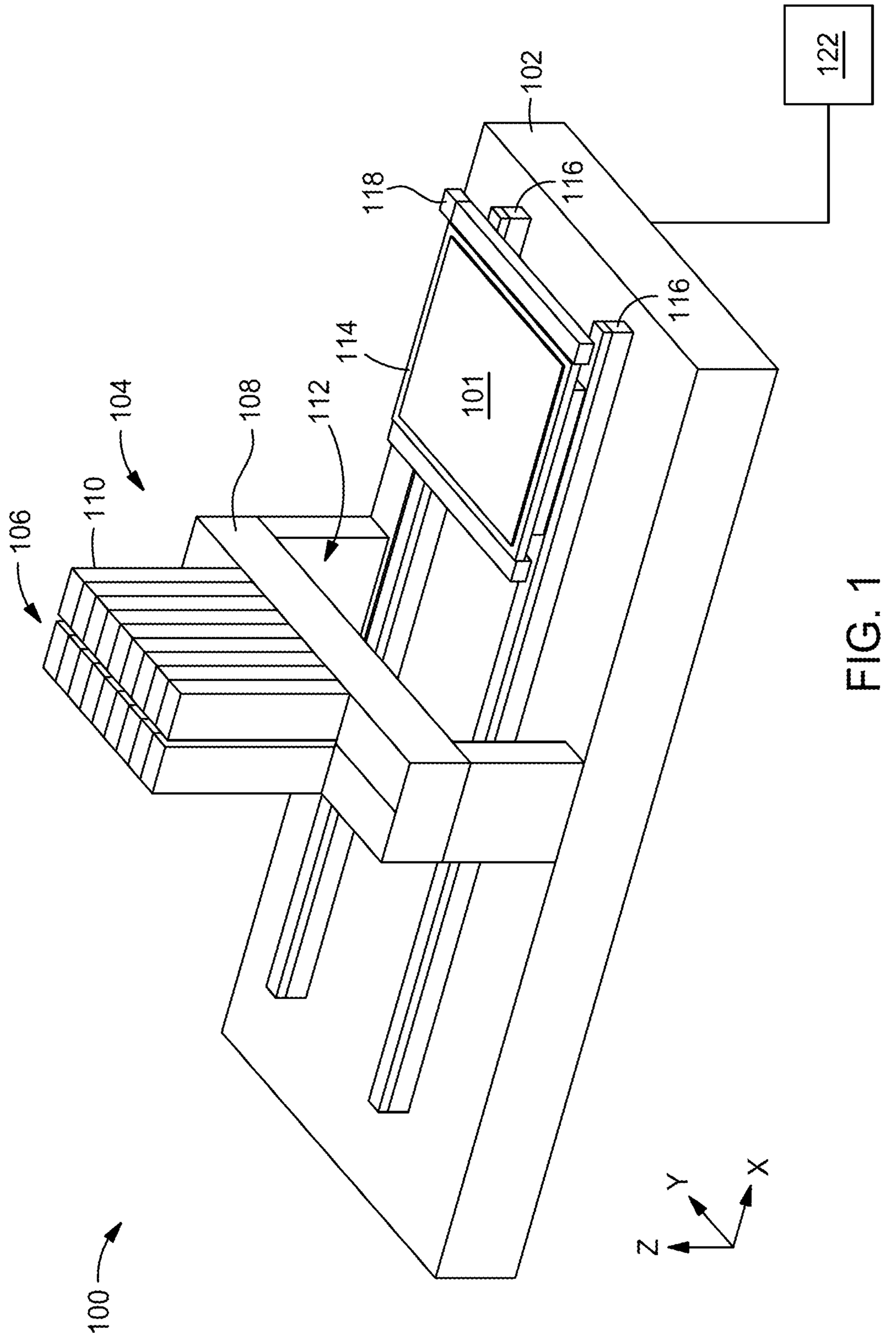



FIG. 1

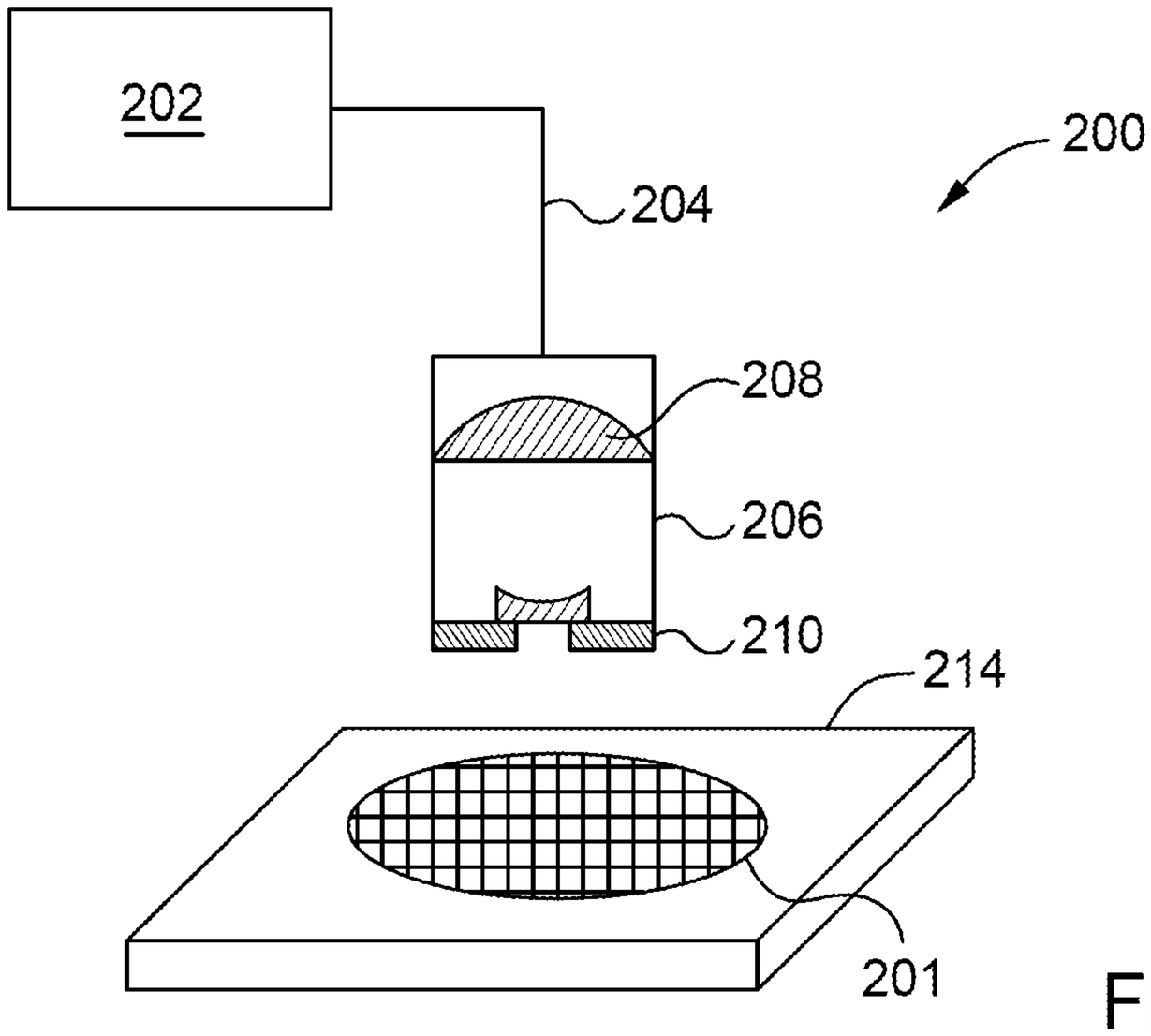

202
204
200
208
206
210
214
201

FIG. 2

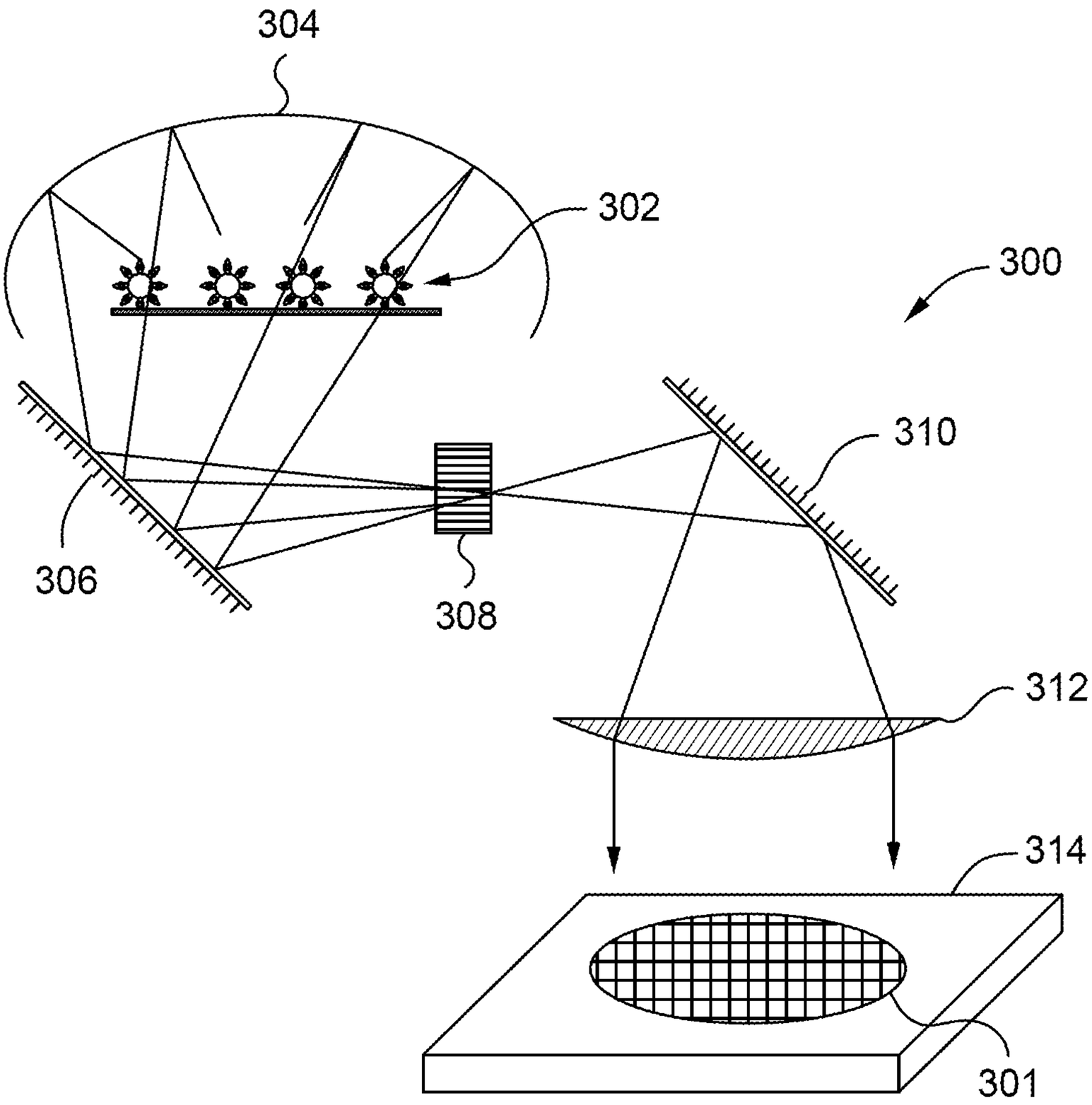

304
302
300
310
306
308
312
314
301

FIG. 3

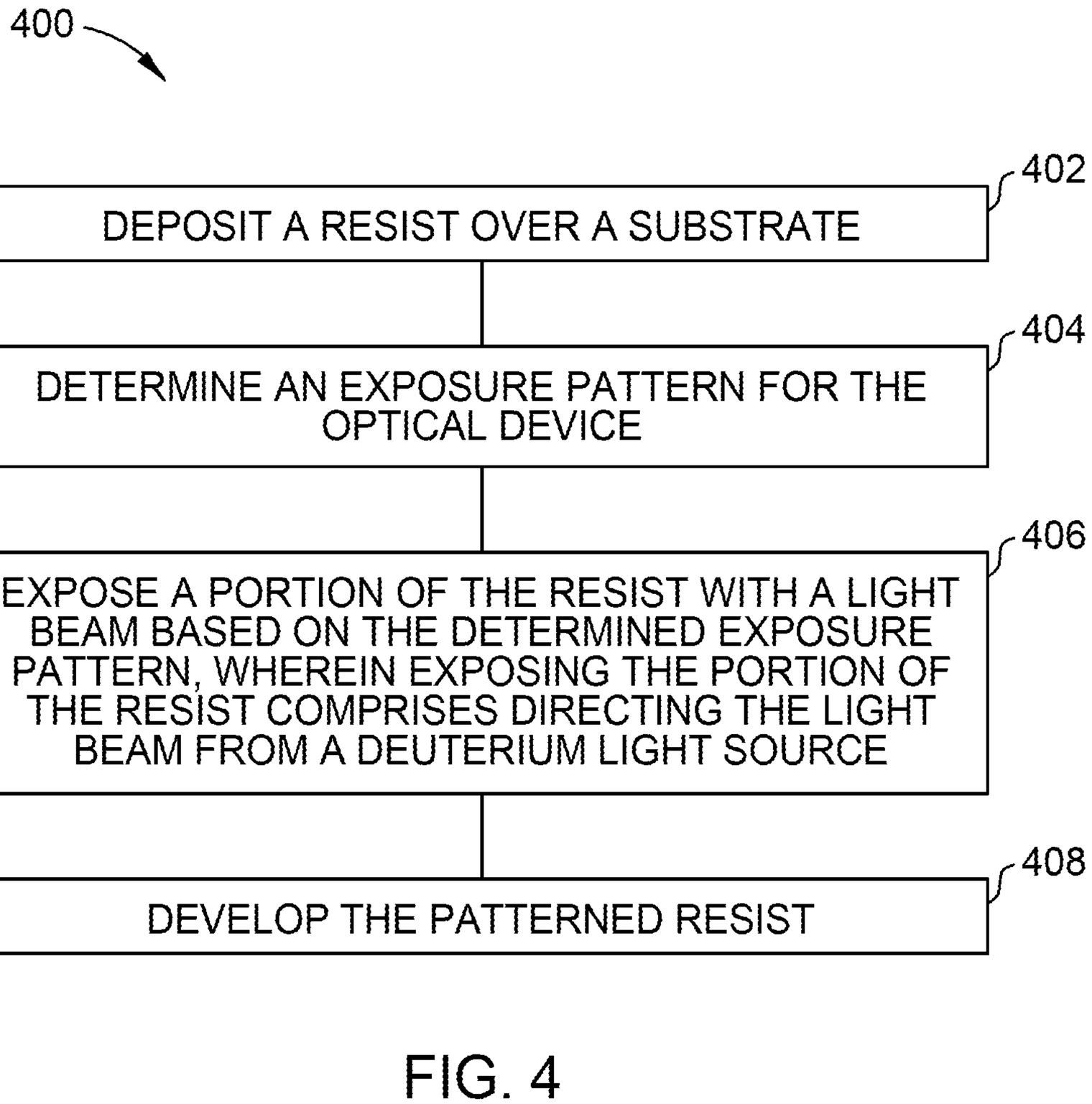

400
DEPOSIT A RESIST OVER A SUBSTRATE
402
DETERMINE AN EXPOSURE PATTERN FOR THE OPTICAL DEVICE
404
EXPOSE A PORTION OF THE RESIST WITH A LIGHT BEAM BASED ON THE DETERMINED EXPOSURE PATTERN, WHEREIN EXPOSING THE PORTION OF THE RESIST COMPRISES DIRECTING THE LIGHT BEAM FROM A DEUTERIUM LIGHT SOURCE
406
DEVELOP THE PATTERNED RESIST
408

FIG. 4

# METHOD AND APPARATUS FOR GREYSCALE LITHOGRAPHY

## CROSS-REFERENCE TO RELATED APPLICATIONS

This Application claims the benefit of U.S. Provisional Application 63/186,316 filed on May 10, 2021, which is incorporate herein by reference in its entirety.

## BACKGROUND

### Field

Embodiments of the present disclosure generally relate to optical devices for augmented, virtual, and mixed reality. More specifically, embodiments described herein provide systems and methods for greyscale lithography to fabricate optical devices.

### Description of the Related Art

Virtual reality is generally considered to be a computer-generated simulated environment in which a user has an apparent physical presence. A virtual reality experience can be generated in 3D and viewed with a head-mounted display (HMD), such as glasses or other wearable display devices that have near-eye display panels as lenses to display a virtual reality environment that replaces an actual environment.

Augmented reality, however, enables an experience in which a user can still see through the display lenses of the glasses or other HMD device, or handheld device, to view the surrounding environment, yet also see images of virtual objects that are generated in the display and appear as part of the environment. Augmented reality can include any type of input, such as audio and haptic inputs, as well as virtual images, graphics, and video that enhances or augments the environment that the user experiences. As an emerging technology, there are many challenges and design constraints with augmented reality.

One such challenge is displaying a virtual image overlayed on an ambient environment. Optical devices are used to assist in overlaying images. Generated light is propagated through a waveguide until the light exits the waveguide and is overlayed on the ambient environment. Fabricating optical devices can be challenging as optical devices tend to have non-uniform properties. Accordingly, improved systems and method of fabricating optical devices are needed in the art.

## SUMMARY

In some embodiments, an image projection system is provided. The system can be used for performing lithography. The system includes a deuterium light source, a converging lens coupled to the deuterium light source. The system includes an aperture disposed adjacent to the converging lens. The system includes a movable stage disposed adjacent to the aperture.

In some embodiments, an image projection system for performing lithography is provided. The system includes a deuterium light source including an array of deuterium light sources. The system includes an elliptical reflector downstream of the deuterium light source along a beam path from the deuterium light source. The system includes an optical integrator disposed downstream of the elliptical reflector, a mirror disposed downstream of the optical integrator, and a collimating lens disposed downstream of the mirror. The system includes a stage disposed downstream of the collimating lens.

In some embodiments, a method of fabricating an optical device is provided. The method includes depositing a resist over a substrate and determining an exposure pattern for the optical device. The method includes exposing a portion of the resist with a light beam based on the determined exposure pattern. Exposing the portion of the resist includes directing the light beam from a deuterium light source to the substrate and developing the resist.



## BRIEF DESCRIPTION OF THE DRAWINGS

So that the manner in which the above recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only exemplary embodiments and are therefore not to be considered limiting of its scope, and may admit to other equally effective embodiments.

FIG. **1** is a schematic view of a lithography system, according to some embodiments.

FIG. **2** is a schematic view of an image projection system, according to some embodiments.

FIG. **3** is a schematic view of an image projection system, according to some embodiments.

FIG. **4** is a flow diagram depicting a method of forming a device, according to some embodiments.

To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is contemplated that elements and features of one embodiment may be beneficially incorporated in other embodiments without further recitation.

## DETAILED DESCRIPTION

Embodiments described herein provide a system, a software application, and a method of a lithography process, such as a digital lithography process, to write grey tone portions. One embodiment of the system includes a controller configured to provide mask pattern data to a lithography system. The mask pattern data has a plurality of grey tone exposure polygons. The lithography system has a processing unit with a plurality of image projection systems that receive the mask pattern data. Each image projection system includes a spatial light modulator with a plurality of spatial light modulator pixels to project a multiplicity of shots. The controller is configured to divide the plurality of spatial light modulator pixels temporally by grey tone shots of the multiplicity of shots, and the controller is configured to vary an intensity of a light beam generated by a deuterium light source of each image projection system at the grey tone shots.

FIG. **1** is a perspective view of a system **100**, such as a digital lithography system, that may benefit from embodiments described herein. The system **100** includes a stage **114** and a processing apparatus **104**. In some embodiments, the stage **114** is supported by a pair of tracks **116** disposed on a slab **102**. A substrate **101** is supported by the stage **114**. The stage **114** is supported by a pair of tracks **116** disposed on the slab **102**. The stage **114** moves along the pair of tracks **116** in the X direction as indicated by the coordinate system

shown in FIG. **1**. In one embodiment, which can be combined with other embodiments described herein, the pair of tracks **116** is a pair of parallel magnetic channels. As shown, each track of the pair of tracks **116** extends in a straight line path. An encoder **118** is coupled to the stage **114** in order to provide information of the location of the stage **114** to a controller **122**. In some embodiments, the stage **114** is coupled to an actuator and is movable in an x, y, and z direction. In some embodiments, the stage **114** is movable using magnetic levitation without the use of tracks (not shown).

The controller **122** is generally designed to facilitate the control and automation of the processing techniques described herein. The controller **122** may be coupled to or in communication with the processing apparatus **104**, the stage **114**, and the encoder **118**. The processing apparatus **104** and the encoder **118** may provide information to the controller **122** regarding the substrate processing and the substrate aligning. For example, the processing apparatus **104** may provide information to the controller **122** to alert the controller **122** that substrate processing has been completed. The controller **122** facilitates the control and automation of methods of performing a grayscale lithography. A program (or computer instructions), which may be referred to as an imaging program, readable by the controller **122**, determines which tasks are performable on a substrate **101**. The program includes a mask pattern data and code to monitor and control the processing time and substrate position. The mask pattern data corresponding to a pattern to be written into the photoresist using the electromagnetic radiation.

The substrate **101** comprises any suitable material, for example, glass, which is used as part of a wearable display device. In other embodiments, which can be combined with other embodiments described herein, the substrate **101** is made of other materials capable of being used as a part of the wearable display device. The substrate **101** has a film layer to be patterned formed thereon, such as by pattern etching thereof, and a photoresist layer formed on the film layer to be patterned, which is sensitive to electromagnetic radiation, for example UV or deep UV "light". A positive photoresist includes portions of the photoresist, when exposed to radiation, are respectively soluble to a photoresist developer applied to the photoresist after the pattern is written into the photoresist using the electromagnetic radiation. A negative photoresist includes portions of the photoresist, when exposed to radiation, will be respectively insoluble to photoresist developer applied to the photoresist after the pattern is written into the photoresist using the electromagnetic radiation. The chemical composition of the photoresist determines whether the photoresist is a positive photoresist or negative photoresist. Examples of photoresists include, but are not limited to, at least one of diazonaphthoquinone, a phenol formaldehyde resin, poly(methyl methacrylate) (PMMA), poly(methyl glutarimide), and SU-8. After exposure of the photoresist to the electromagnetic radiation, the resist is developed to leave a patterned photoresist on the underlying film layer. Then, using the patterned photoresist, the underlying thin film is pattern etched through the openings in the photoresist to form a portion of the electronic circuitry of the display panel.

The processing apparatus **104** includes a support **108** and a processing unit **106**. The processing apparatus **104** straddles the pair of tracks **116** and is disposed on the slab **102**, and thereby includes an opening **112** for the pair of tracks **116** and the stage **114** to pass under the processing unit **106**. The processing unit **106** is supported over the slab **102** by a support **108**. In one embodiment, which can be combined with other embodiments described herein, the processing unit **106** is a pattern generator configured to expose photoresist in a photolithography process. In some embodiments, which can be combined with other embodiments described herein, the pattern generator is configured to perform a maskless lithography process. The processing unit **106** includes a plurality of image projection systems. Examples of image projection systems are shown in FIG. **2** and FIG. **3**. In some embodiments, each image projection system is disposed in a case **110**. Alternatively, the processing apparatus **104** includes a single image projection system. The processing unit **106** is useful to perform maskless direct pattern writing to photoresist or other electromagnetic radiation sensitive material.

FIG. **2** is a schematic view of an image projection system **200**. The system **200** is operable to perform grayscale lithography on a resist to fabricate optical devices. The system **200** includes a deuterium light source **202**, a housing **206**, and a stage **214**, such as the stage **114** depicted in FIG. **1**. The deuterium light source **202** is operable to produce light having a wavelength of about 120 nm to about 900 nm, such as about 180 nm to about 370 nm, such as about 200 nm to about 315nm. Without being bound by theory, it is believed that light of a wavelength of about 200 nm to about 240 nm produced by the deuterium light source **202** has a greater spatial irradiance than light of substantially the same wavelength produced by a mercury-vapor light source.

It has been discovered that the deuterium light source **202** efficiently develops deep-uv photoresists, such as PMMA photoresists. Increased efficiency leads to reduced exposure time and increased throughput of devices. In some embodiments, exposure time of a photoresist is about 10 minutes or less, such as about 8 minutes or less, such as about 6 minutes or less. In some embodiments, the deuterium light source **202** reduces an exposure time of processing a photoresist by about 50% or less, such as about 5% to about 40%, such as about 10% to about 30%, such as about 15% to about 25%, relative to other light sources, such as mercury-vapor light sources at the same power.

The deuterium light source **202** is capable of directing light to the housing **206** via an optical fiber **204**. The housing **206** includes a converging lens **208** and an aperture **210** through which the light from the deuterium light source **202** is directed. In some embodiments, the converging lens **208** increases the intensity of the light produced by the deuterium light source **202**. In some embodiments, the converging lens **208** is a double convex lens. In some embodiments, the aperture **210** is shaped to enable image tiling and exposes a photoresist disposed over a substrate **201** that is disposed on the stage **214**. In some embodiments, the aperture is shaped like a polygon, such as a square, or a rectangular (e.g., slits). In some embodiments, the aperture is sized to enable exposure of an entire surface area of a substrate. Alternatively, the aperture is sized to scan a portion of the surface area of a substrate, such as a "tile." As used herein, the term "image tiling" refers to scanning a plurality of portions of the surface of the substrate, e.g., tiles, and stitching the tiles together to form a large image.

The exposures, or write beams together form a plurality of pixels of the mask pattern. In some embodiments, each deuterium light source **202** has a power of about 50 W or greater, such as 100 W to about 5,000 W to increase light intensity. The image projection system **200** enables easy access and replacement of the deuterium light sources for maintenance purposes. Use of deuterium light sources instead of mercury based light sources provide environmental benefits. It has been discovered that using deuterium light

sources provide a cost benefit, a longer life, an increased intensity relative to other light sources operating at the same power, and a lower temperature at the same power relative to other light sources, such as mercury-vapor light sources. In some embodiments, the deuterium light source operates at a temperature of about 23° C. to 100° C., such as about 50° C. to about 80° C.

FIG. **3** is a schematic view of an image projection system **300**. The system **300** is operable to perform grayscale lithography on a resist to fabricate optical devices. The system **300** includes a deuterium light source array **302** that projects beams of light to an elliptical reflector **304**. The elliptical reflector **304** includes a convex side and a concave side. In some embodiments, the concave side of the elliptical reflector **304** is oriented downward toward a horizontally positioned deuterium light source array **302**. In some embodiments, the concave side of the elliptical reflector **304** is oriented at an angle relative to the horizontal axis, such as about 5° to about 180°, such as at 90° in which the elliptical reflector **304** is positioned vertically. The deuterium light source array **302** is similarly oriented in any of the angles described relative to the elliptical reflector **304** and substantially parallel to the elliptical reflector **304**. Each light source of the deuterium light source array **302** increases the intensity of light projected to the substrate **301** disposed on the stage **314**. In some embodiments, such as when the elliptical reflector **304** is positioned horizontally, the elliptical reflector **304** directs the beams to a dielectric mirror **306** that focuses the beams to an optical integrator **308**. In some embodiments, the dielectric mirror **306** includes a metal material. In some embodiments, the dielectric mirror **306** is composed of an oxide-containing material, a silicon-containing material, or combinations thereof. In some embodiments, the dielectric mirror **306** is a Fresnel dielectric mirror. Without being bound by theory, it is believed that the dielectric mirror **306** provides light uniformity to be directed to the substrate **101**. The elliptical reflector **304** includes a convex shape or other shapes. In some embodiments, such as when the elliptical reflector **304** and the deuterium light source array **302** are positioned vertically, the elliptical reflector **304** directs the beams directly to the optical integrator **308**. In some embodiments, the beam contacts a mirror **310** and is directed to a collimating lens **312**. The optical integrator **308** is operable to receive scattered light from the elliptical reflector **304** and consolidate the light into a single focused light. In some embodiments, the optical integrator **308** includes a plurality of lenses operable to focus light. In some embodiments, a mask may be disposed between the collimating lens **312** and the stage **314**. Alternatively, the system described herein is maskless. In some embodiments, the mirror **310** is an aluminum mirror. The image projection system **300** enables easy access and replacement of the deuterium light sources for maintenance purposes.

FIG. **4** is a flow diagram depicting a method **400** of forming a device, according to some embodiments. The method includes, at activity **402**, depositing a resist over a substrate, such as substrate **101** depicted in FIGS. **1**, **2**, and **3**. In some embodiments, the resist is deposited over an underlying film disposed below the resist and over the substrate. The underlying film can be the uppermost surface in a film stack disposed over the substrate.

In activity **404**, an exposure pattern is determined for forming the device. In activity **406**, a portion of the resist is exposed with a light beam based on the determined exposure pattern. The portion of the resist includes directing the light beam from a deuterium light source, such as the deuterium light source **202** depicted in FIG. **2** or the deuterium light source **302** depicted in FIG. **3**. The light beam can have a beam path from the deuterium light source **202**, as shown in FIG. **2** through an optical fiber **204**, to a converging lens **208** in a housing **206**. The light beam can be directed along the beam path from the converging lens **208** to an aperture **210** of the housing **206**. The light beam can be directed along the beam path from the aperture **210** to a portion of the substrate **101**.

Alternatively, the light beam can have a beam path from the deuterium light source **302** to a concave surface of an elliptical reflector **304**. In some embodiments, the elliptical reflector **304** can direct the light beam along the beam path directly to an optical integrator **308**. In some embodiments, the elliptical reflector **304** can direct the light beam along the beam path to one or more mirrors, such as dielectric mirror **306** prior to the optical integrator **308**. In some embodiments, the light beam can be directed along the beam path from the optical integrator **308** to one or mirrors, such as mirror **310**, such as an aluminum mirror. The light beam can be directed from the mirror **310** to a collimating lens **312**. The light beam can be directed from the collimating lens to the substrate **101**.

In activity **408**, the resist having portions that were exposed to light beams from the deuterium light source, is developed using a photoresist developer. The portions that are exposed are soluble to the photoresist developer such that developing the resist provides a patterned resist on an underlying film layer. The method can further include etching portions of the underlying film layer through openings in the developed resist.

The method and systems provided herein enable a lithography process that uses a deuterium light source. Using the deuterium light source in place of other light sources such as mercury-vapor light sources, provides a more efficient process with longer use life and increased device throughput.

While the foregoing is directed to embodiments of the present disclosure, other and further embodiments of the disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

What is claimed is:

**1**. A lithography system for performing lithography, comprising:

a plurality of image projection systems, each image projection system comprising:

a deuterium light source;

a housing, wherein the housing is directly coupled to the deuterium light source at a first end of the housing, the housing having a second end with an opening therein;

a converging lens disposed inside the housing in a path of an optical fiber; and

an aperture coupled to the second end of the housing with the opening of the housing in a path of the converging lens; and

a movable stage disposed immediately adjacent to the aperture, wherein the movable stage is configured to move along at least three axes and relative to at least one of the deuterium light source, the converging lens, and the aperture.

**2**. The lithography system of claim **1**, wherein the converging lens and the aperture are disposed in the housing.

**3**. An image projection system for performing lithography, comprising:

a deuterium light source comprising an array of deuterium light sources;

an elliptical reflector downstream of the deuterium light source along a beam path from the deuterium light source, wherein the array of deuterium light sources are substantially parallel to a major axis of the elliptical reflector;

an optical integrator disposed downstream of the elliptical reflector;

a mirror disposed immediately downstream of the optical integrator;

a collimating lens disposed downstream of the mirror; and

a stage disposed downstream of the collimating lens.

**4**. The image projection system of claim **3**, wherein the mirror is an aluminum mirror.

**5**. The image projection system of claim **3**, wherein the elliptical reflector is positioned with a concave side directed in a direction of a surface of the stage.

**6**. The image projection system of claim **3**, further comprising a dielectric mirror disposed between the elliptical reflector and the mirror along the beam path.

**7**. The image projection system of claim **3**, wherein the elliptical reflector is positioned with a concave side directed in a direction perpendicular to a surface of the stage.

**8**. A method of fabricating an optical device, the method comprising:

exposing a portion of a resist disposed over a substrate with light beams based on a determined exposure pattern using an image projection system comprising:

a deuterium light source comprising an array of deuterium light sources;

an elliptical reflector downstream of the deuterium light source along a beam path from the deuterium light source, wherein the array of deuterium light sources are substantially parallel to a major axis of the elliptical reflector;

an optical integrator disposed downstream of the elliptical reflector:

a mirror disposed immediately downstream of the optical integrator;

a collimating lens disposed downstream of the mirror; and

a stage disposed downstream of the collimating lens, wherein exposing the portion of the resist comprises directing the light beams from the array of deuterium light sources to the stage; and

developing the resist.

**9**. The method of claim **8**, wherein the resist is composed of poly (methyl methacrylate) (PMMA).

**10**. The method of claim **8**, wherein the developing the resist exposes portions of an underlying film layer.

**11**. The method of claim **10**, further comprising etching the underlying film layer through openings in the developed resist.

**12**. The method of claim **8**, wherein the deuterium light source operates at a temperature of about 23° C. to 100° C.

**13**. A non-transitory computer-readable medium storing instructions that, when executed by a processor, cause a computer system to perform the method of claim **8**.

**14**. The method of claim **8**, wherein the mirror is an aluminum mirror.

**15**. The method of claim **8**, wherein the elliptical reflector is positioned with a concave side directed in a direction of a surface of the stage.

**16**. The method of claim **8**, further comprising a dielectric mirror disposed between the elliptical reflector and the mirror along the beam path.

**17**. The method of claim **8**, wherein the elliptical reflector is positioned with a concave side directed in a direction perpendicular to a surface of the stage.

* * * * *