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Phillips, Jr. et al.

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[54] **IMAGING SYSTEM FOR DEEP ULTRAVIOLET LITHOGRAPHY**

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[52] **U.S. Cl.** **359/732**; 359/731

[58] **Field of Search** 359/732, 731, 359/730, 727, 726

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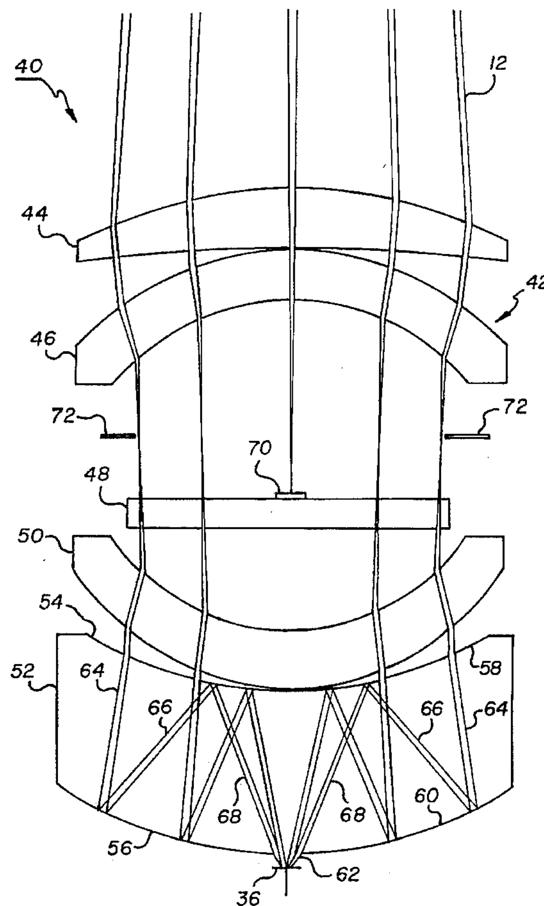
[57] **ABSTRACT**

A catadioptric reduction system operating in the deep ultraviolet range projects a reduced image of a mask on a substrate. A reducing optic made of a material transmissive to deep ultraviolet light has a concave front face covered by a partially reflective surface and a convex back face covered by a concave reflective surface surrounding a central aperture. The partially reflective surface transmits a portion of the light passing through the mask to the concave reflecting surface, which returns a portion of the transmitted light to the partially reflective surface. A portion of the returned light is reflected by the partially reflective surface on a converging path through said central aperture for producing a reduced image of the mask on the substrate.

30 Claims, 2 Drawing Sheets



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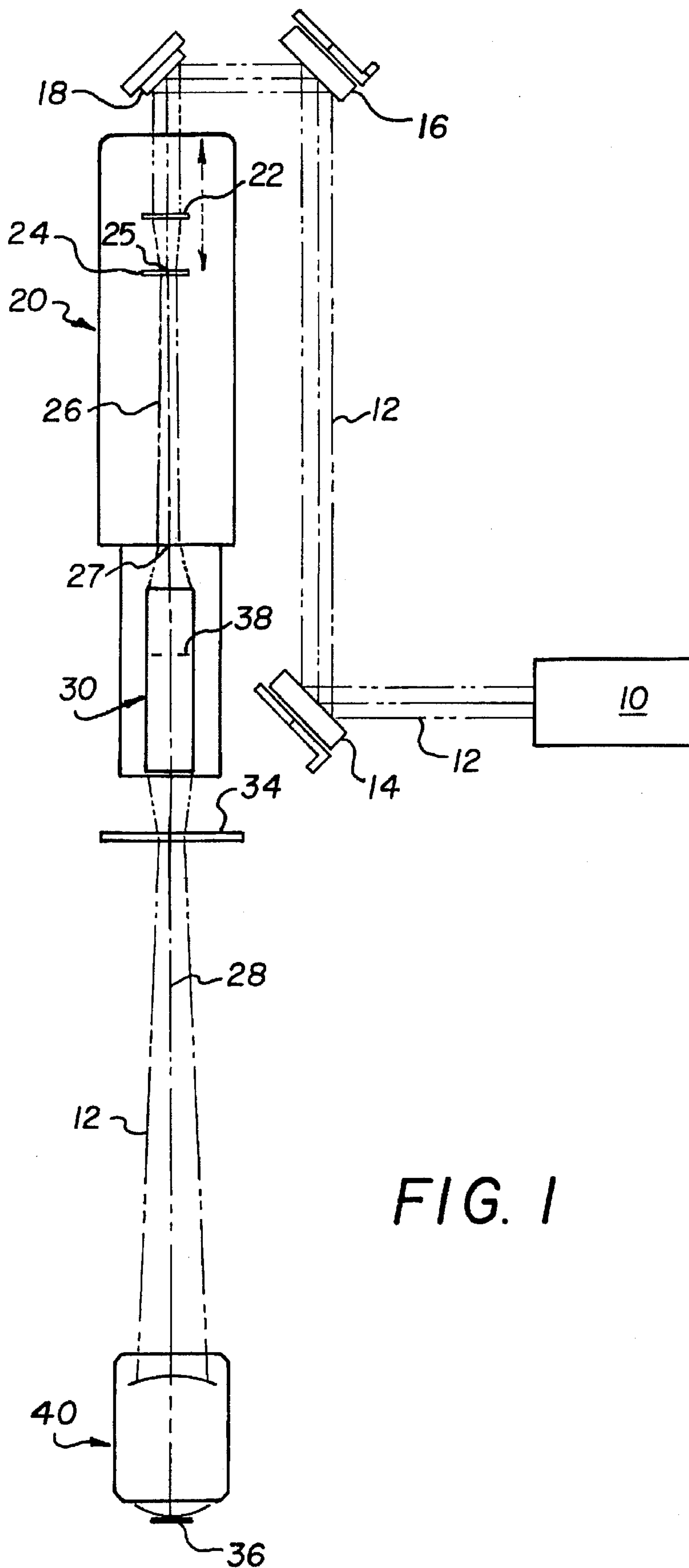

FIG. 1

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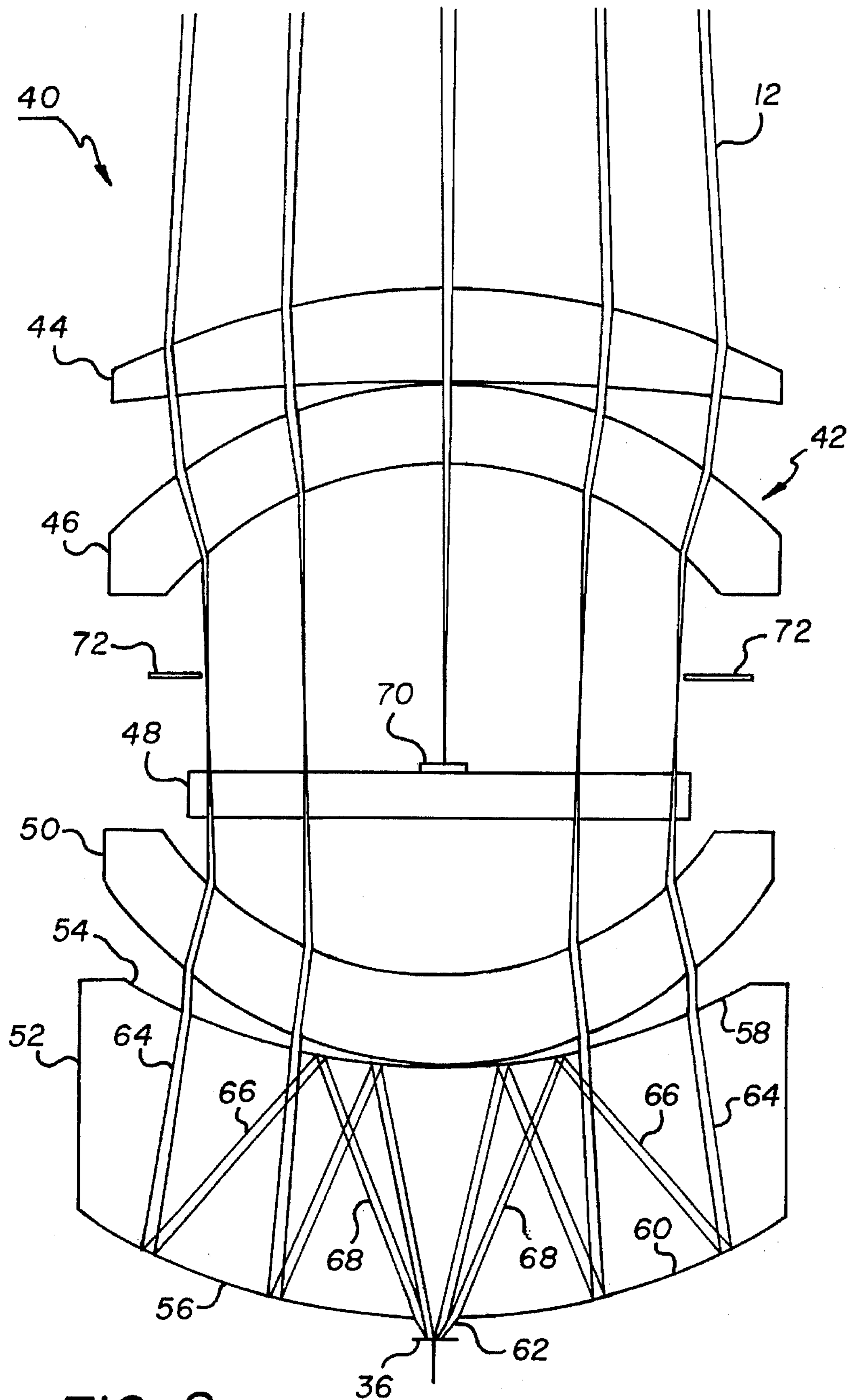

FIG. 2

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IMAGING SYSTEM FOR DEEP ULTRAVIOLET LITHOGRAPHY

TECHNICAL FIELD

The invention relates to catadioptric reduction systems for projecting images with low aberrations and to exposure systems for microlithographic manufacture with deep ultraviolet light.

BACKGROUND

Microelectronics, including semiconductors, storage devices, and flat panel displays, are generally fabricated in successive layers using photolithographic techniques for patterning surface features. A reticle or mask having a predetermined pattern is evenly illuminated and projected onto a layer of photoresist on the surface of the microelectronic substrate. Exposed portions of the photoresist are chemically altered, rendering them more or less soluble to a developer that removes the soluble portions leaving a positive or negative image of the mask.

High resolution of the surface features is, of course, important; and improved resolution is continually sought for making the surface features smaller and more closely spaced so the resulting electronics can be made smaller, faster, and cheaper. A resolution dimension "R" representing minimum feature size is related to light wavelength "λ", numerical aperture "NA", and a process related constant "K_1" as follows:

$$R = K_1 \frac{\lambda}{NA}$$

Feature size "R" can be reduced by reducing the wavelength "λ" or the process constant "K_1" or by increasing the numerical aperture "NA". In production environments, process constants "K_1" equal to 0.7 to 0.8 are typical, whereas constants "K_1" as low as 0.5 can be achieved in laboratory settings. Numerical aperture "NA" and wavelength "λ" are also related to depth of focus "Df" as follows:

$$Df = \frac{\lambda}{NA^2}$$

A depth of focus "Df" of at least a fraction micron (e.g., 0.5 microns) is needed to accommodate flatness variations of the microelectronic substrates and their successive layers. Since numerical aperture "NA" is raised to a higher power than wavelength "λ" in the above expression for depth of focus "Df", resolution improvements achievable by enlarging numerical aperture "NA" are much more limited than those achievable by shortening the wavelength "λ".

Wavelengths less than 300 nanometers (NM) can be practically transmitted by only a few optical materials such as fused (synthetic) quartz and fluorite (calcium fluoride). The transmissivity of even these materials deteriorates at wavelengths in the deep ultraviolet range less than 200 NM so a minimum number of optical elements is desirable.

Although it is advantageous to minimize feature size of the images projected onto the microelectronic substrates, the feature size of the masks should remain large enough to manufacture efficiently and to avoid errors from mild levels of contamination. For example, it is important that small specks of contamination do not bridge features of the masks. Mask size can be maintained by optically reducing the projected image of the mask with respect to the mask itself.

Laser light sources operating within the ultraviolet and deep ultraviolet ranges emit light within narrow bands of wavelengths. However, even narrow bands of wavelength cause significant chromatic aberrations in single-material lenses with finite focal lengths. On the other hand, limiting laser output to a single wavelength is inefficient. Accordingly, catadioptric imaging systems have evolved which use reflective optics (mirrors) to reduce image size in combination with refractive optics (lenses) to compensate for symmetrical aberrations of the reflective optics.

Beamsplitters or partially reflective mirrors are used to separate light traveling to and from the reflective optics. Beamsplitters and partially reflective mirrors, particularly when subjected to angularly diverging beams, introduce additional aberrations requiring correction. The beamsplitters also add to the complexity of the imaging systems by misaligning the object and image planes.

A typical catadioptric optical reduction system used for microlithographic projections is disclosed in U.S. Pat. No. 5,241,423 to Chiu et al. A concave spherical mirror provides a four to five times reduction in the projected image size with respect to a mask, and a beam-splitting cube separates light beams traveling to and from the mirror. Groups of refractive optical elements located on opposite sides of the beam-splitting cube toward both the reticle (mask) and the substrate correct for aberrations of the mirror and beam-splitting cube.

Chiu et al.'s reduction system is intended for operation at wavelengths of about 248 NM produced by a KrF excimer laser. However, the large number of refractive elements and the bulky two prism construction of the beam-splitting cube limit usefulness of this system at shorter wavelengths. The transmission of light through fused quartz or fluorite diminishes with shortening wavelengths, so the number and bulk of refractive optics must be limited to utilize wavelengths within the deep ultraviolet spectrum at less than 200 NM length.

U.S. Pat. Nos. 5,251,070 and 5,289,312 to Hashimoto et al. also use a concave mirror to provide most of the reducing power but use a semi-transparent mirror on a plane parallel plate instead of a beam-splitting cube to separate light beams traveling to and from a concave mirror. The former patent of Hashimoto et al. incorporates plane parallel refracting plates to correct aberrations caused by the semi-transparent mirror. The latter patent of Hashimoto et al. uses high-power refractive optics to collimate the beam transmitted through the semi-transparent mirror. This reduces aberrations from the semi-transparent mirror but still requires other refractive optics to counteract aberrations introduced by the high-power refractive optics.

SUMMARY OF INVENTION

Our invention extends microlithographic manufacture into the deep ultraviolet spectrum (e.g., less than 200 NM wavelength) for further reducing the minimum feature size of projected images to less than 0.2 microns. A practical size reticle (mask) is maintained by achieving the feature size with a highly reduced image of the reticle. The number of corrective refractive optics is held to a minimum, and the configuration of optical elements is simplified by maintaining object and image planes of a reducing system both parallel to each other and aligned with a common optical axis.

A lens group conditions a beam of light after passing through the reticle. A reducing optic having specially configured front and back faces projects a reduced image of the

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reticle onto a substrate. Both the lens group and the reducing optic are made from materials that transmit deep ultraviolet light. The back face of the reducing optic has a central aperture surrounded by a concave reflective surface. The front face of the reducing optic has a partially reflective surface that transmits a portion of the light beam toward the concave reflecting surface and reflects a portion of the remaining light beam returned by the concave reflective surface on a converging path through the central aperture. The substrate is aligned with the aperture for receiving the reduced image of the reticle.

The reflective surfaces of the reducing optic provide the reducing power, which is preferably a 10-fold reduction in the mask size. The refractive elements of the lens group and reducing optic exhibit little or no combined reducing power to avoid chromatic aberrations. Instead, the lens group corrects at least some of the nonchromatic aberrations generated by the reducing optic. A substantially plane parallel plate is preferably incorporated into the lens group and modified to include an aspheric surface to correct spherical aberrations. The concave reflective surface of the reducing optic can also be modified to include an aspheric surface to correct spherical aberrations at an even higher rate.

A central obscuration blocks a portion of the beam of light, which would not be reflected by the concave reflective surface, from passing through the central aperture. Preferably, the central obscuration is limited in size to block no more than 15 percent of projected image. The central obscuration can be conveniently the beam diameter within the lens group. More than 15 percent blockage can cause significant degradation in contrast of the formed as a stop on the plane parallel plate.

DRAWINGS

FIG. **1** is a schematic layout of a microlithographic projection system arranged according to our invention.

FIG. **2** is an enlarged diagram of our new catadioptric reducing system for completing the projection of an illuminated mask on a substrate.

DETAILED DESCRIPTION

According to a preferred embodiment of our invention illustrated in the drawing figures, a laser light source **10** is an Argon-Fluoride excimer laser that produces a collimated beam **12** of ultraviolet light having a wavelength bandwidth between 192.6 and 194 NM. A series of three folding mirrors **14**, **16**, and **18** convey the collimated beam **12** to an illuminator **20**.

Within the illuminator **20**, the collimated beam **12** is attenuated and dispersed by a pair of diffusers **22** and **24** before entering a square reflecting tunnel **26**. The diffuser **22** is adjustable along an optical axis **28** both to control the amount of light entering the reflecting tunnel **26** through the diffuser **24** and to more uniformly disperse the entering light over an area of the diffuser **24** in common with an entrance **25** of the reflecting tunnel **26**. The amount of separation between the diffuser **22** and the tunnel entrance **25** controls the amount of excess light that is scattered beyond the tunnel entrance **25**. Together, the two diffusers **22** and **24** produce a wider angle of uniformly dispersed light entering the reflecting tunnel **26**.

The reflecting tunnel **26** functions as a "uniformizer" by dividing the diffused beam **12** into segments and arranging the segments into a contiguous array. Unlike most uniformizers, which are made from solid optical materials

such as polyhedral rods or fly's eye lenses, the reflecting tunnel **26** is hollow with reflective sides to avoid excessive absorption of the deep ultraviolet light. Such excessive absorption limits control over the amount of light that can be transmitted through the illuminator **20** and reduces the useful life of the illuminator **20** by degrading the optical materials.

A lens group **30** magnifies and projects an image of a plane at an exit **27** of the reflecting tunnel **26** onto a plane of a reticle **34**, which functions as a mask for microlithographic manufacture of a substrate **36**. In addition, the lens group **30** images a plane at the entrance **25** of the reflecting tunnel **26** onto a plane at a variable aperture stop **38** within the lens group **30**. The tunnel entrance **25** is imaged at the variable aperture stop **38** as an array of closely knit reflections produced by the reflecting tunnel **26**. The variable aperture stop **38** functions as a mask by excluding portions of the beam **12** to enhance the diffractive effects of the reticle **34**. For example, the aperture stop **38** can take the form of an annular ring or a series of holes which transmit only selected portions of the beam **12**.

The combined effect of the diffusers **22** and **24**, which provide a wider angular dispersion of light entering the reflecting tunnel **26**, improves spatial uniformity of the distribution of light energy throughout the array of reflections within the aperture stop **38**. The dispersion of light produced by the adjustable diffuser **22** on the diffuser **24** also improves the spatial uniformity of the distribution of light within each reflection of the tunnel entrance **25** that comprises the array. The improved spatial uniformity of the beam **12** at the aperture stop **38** enhances the masking effect of the aperture stop **38**.

Although the uniformizing effects of the diffusers **22** and **24** are most evident at the aperture stop **38**, spatial uniformity is also improved at the tunnel exit **27**, which is imaged at the reticle **34**. Thus, the light beam **12** impinges on the reticle **34** with a uniform spatial distribution of light energy, while the angular distribution of the impinging light is controlled by the aperture stop **38** to enhance the contrast of the reticle's image on the substrate **36**.

Our catadioptric reducing system **40**, shown in more detail by FIG. **2**, projects a greatly reduced image of the illuminated reticle **34** onto a surface of the substrate **36**. The reticle **34** and the substrate **36** are oriented parallel to each other and are aligned together with our catadioptric reducing system **40** along the optical axis **28**.

A lens group **42**, comprising transmissive optical elements **44**, **46**, **48**, and **50**, conditions the beam **12** for entry into reducing optic **52** having a concave front face **54** and a convex back face **56**. The concave front face **54** of the reducing optic **52** is coated to form a partially reflective surface **58** that provides partial transmission uniformly throughout its aperture. The convex back face **56** is coated in an annular pattern to form a concave reflective surface **60** surrounding a central aperture **62**.

A portion **64** of the beam **12** is transmitted through the partially reflective surface **58** to the concave reflective surface **60**, which returns a converging beam **66**. A portion **68** of the returning beam **66** is reflected by the partially reflective surface **58** on a converging path through the central aperture **62** to a point of focus on the substrate **36**. The reducing optic **52** focuses a reduced image of the reticle **34** on the substrate **36**.

The lens groups **30** and **42**, along with the reducing optic **52**, are preferably made of fused silica for transmitting the beam **12** of deep ultraviolet light. However, fluorite could

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