WYNNE-DYSON PROJECTION LENS WITH REDUCED SUSCEPTIBILITY TO UV DAMAGE

FIELD

[0001] The present disclosure relates to projection lenses, and in particular to Wynne-Dyson projection lenses used in photolithography performed at ultraviolet (UV) and deep UV (DUV) wavelengths, and more particularly to such projection lens that have reduced susceptibility to damage from UV radiation.

[0002] The entire disclosure of any publication or patent document mentioned herein is incorporated by reference, including the following references: J. Dyson, "Unit Magnification Optical System without Seidel Aberrations," *Journal of the Optical Society of America*, July 1959; U.S. Patent No. 3,748,015; U.S. Patent No. 6,879,383; U.S. Patent No. 7,166,496; U.S. Patent No. 7,573,655; U.S. Pre-Grant Publication No. US2014/0049978; European Patent No. 0779558 A2; European Patent No. EP 206707 A2; and European Patent No. EP 0960074 A1.

BACKGROUND

[0003] Modern-day semiconductor manufacturing utilizes optical lithography projectors that image mask patterns onto semiconductor wafers as part of the process of making integrated circuits. The optical lithography projectors include illumination systems ("illuminators") that irradiate the mask with UV light because the smaller wavelength of UV light (as compared to visible light) allows for higher-resolution imaging. The optical lithography projectors utilize projection lenses (also called microlithographic lenses or optical lithography lenses), most of which include at least some glass lens elements. Because of the high demands placed on the imaging resolution over the image field, the projection lenses are designed for high performance.

[0004] A portion of the UV radiation (light) that passes through a given glass lens element interacts with the optical material. This includes light absorption whereby the absorbed light energy is converted to heat. The heat raises the local glass temperature, which changes the local index of refraction, thereby adversely changing the imaging performance of the projection lens. This effect is reversible, i.e., when the illumination terminates, the glass cools down and the imaging performance is restored. Thus, turning the illumination

on (or off) gives rise to a thermal transient effect whereby the projection lens heats up (or cools down) until the temperature stabilizes. During this time, there is a thermally induced variation in imaging performance.

[0005] A second type of interaction between the UV light and the glass material changes the glass atomic structure and makes the structure denser, thereby locally increasing the glass refractive index and degrading the projection lens imaging performance. This effect is called "radiation compaction." It is not reversible, and the attendant refractive index increase is proportional to the irradiance of the exposure light as well as the time-accumulated irradiance of the exposure light.

[0006] A third type of interaction is called solarization, which also changes the glass atomic structure and reduces the glass transmission. Like radiation compaction, solarization is not reversible and is also proportional to the light irradiance within the glass and the time-accumulated irradiance.

[0007] Consequently, when a projection lens is exposed to high irradiance UV light over an extended period of time, compaction and solarization effects can permanently damage the glass elements and result in significantly degraded imaging performance. These adverse effects are becoming more problematic as increasingly greater amounts of UV radiation and increasing large imaging fields are being employed, which lead to greater irradiance levels traveling through the glass elements. Further, increasingly higher degrees of imaging performance limit the amount of performance degradation that is acceptable.

SUMMARY

[0008] An aspect of the disclosure is a Wynne-Dyson projection lens for use in an ultraviolet optical lithography system, wherein the Wynne-Dyson projection lens is configured to have reduced susceptibility to damage from ultraviolet radiation is disclosed. The Wynne-Dyson projection lens utilizes lens elements that are made of optical glasses that are resistant to damage from ultraviolet radiation, but that also provide sufficient degrees of freedom to correct aberrations. The glass types used for the lens elements are selected from the group of optical glasses consisting of: fused silica, S-FPL51Y, S-FSL5Y, BSM51Y and BAL15Y.

[0009] Another aspect of the disclosure is a Wynne-Dyson projection lens having object and image planes and an image field, and that has reduced susceptibility to damage from ultraviolet radiation. The Wynne-Dyson lens includes along an optical axis: a concave mirror having a concave surface; a positive lens group spaced apart from the concave surface of the concave mirror; first and second prisms made of either fused silica or BSM51Y and disposed adjacent the positive lens group opposite the concave mirror and on respective sides of the optical axis, with the first and second prisms having respective surfaces that reside adjacent the object and image planes. The positive lens group consists of: a first lens group having a cemented doublet consisting of a plano-convex lens element made of either S-FPL51Y, S-FSL5Y or fused silica and having a planar surface in contact with the first and second prisms, and a negative meniscus lens made of either BAL15Y or BSM51Y; and a second lens group spaced apart from the first lens group and consisting of either one or two lens elements each made of either S-FSL5Y, S-FPL51Y or fused silica. The Wynne-Dyson projection lens has a numerical aperture NA in the range from 0.16 to 0.2, a substantially unit magnification, is substantially doubly telecentric and a Strehl ratio of > 0.95 over the image field for a spectral bandwidth that includes ghi radiation.

[0010] Another aspect of the disclosure is the Wynn-Dyson projection lens as described above, the image field is preferably 40 mm x 20 mm. The second lens group preferably consists of the one lens element made of S-FSL5Y.

[0011] Another aspect of the disclosure is the Wynn-Dyson projection lens as described above, the image field is preferably 68 mm x 28 mm. The NA is preferably equal to 0.16. The second lens group preferably consists of the two spaced-apart lens elements.

[0012] Another aspect of the disclosure is the Wynn-Dyson projection lens as described above, the most mirror-wise lens element of the second lens group preferably has a most mirror-wise concave surface.

[0013] Another aspect of the disclosure is the Wynn-Dyson projection lens as described above, the most mirror-wise lens element of the second lens group preferably has a most mirror-wise convex surface.

[0014] Another aspect of the disclosure is the Wynn-Dyson projection lens as described above, the first and second prisms are preferably each isosceles prisms.

[0015] Another aspect of the disclosure is an optical lithography system for imaging a reticle onto a wafer coated with photoresist. The optical lithography system includes the Wynne-Dyson projection lens as described above, wherein the reticle resides at the object plane and the wafer resides at the image plane. The optical lithography system also includes an illuminator arranged to operably illuminate the reticle with the ultraviolet radiation.

[0016] Another aspect of the disclosure is a Wynne-Dyson projection lens having object and image planes and an image field, and that has reduced susceptibility to damage from ultraviolet radiation. The Wynne-Dyson projection lens includes along an optical axis: a concave mirror having a concave surface; a positive lens group spaced apart from the concave surface of the concave mirror; first and second prisms made of either fused silica or BSM51Y and disposed adjacent the positive lens group opposite the concave mirror and on respective sides of the optical axis, with the first and second prisms having respective surfaces that reside adjacent the object and image planes. The positive lens group includes: a first lens element L1 made of S-FPL51Y, S-FSL5Y or fused silica; a second lens element L2 made of BSM51Y or BAL15Y; and a third lens element L3 made of S-FPL51Y, S-FSL5Y or fused silica. The Wynne-Dyson projection lens has: a numerical aperture NA in the range from 0.16 to 0.2; a substantially unit magnification; doubly telecentricity; and a Strehl ratio of > 0.95 over the image field for a spectral bandwidth that includes ghi radiation.

[0017] Another aspect of the disclosure is the Wynn-Dyson projection lens as described above, the positive lens group preferably further includes a fourth lens element L4 made of S-FPL51Y, S-FSL5Y or fused silica.

[0018] Another aspect of the disclosure is the Wynn-Dyson projection lens as described above, the first and second lens elements preferably define a cemented doublet. Additionally, the first lens element is preferably plano-convex and contacting the first and second prisms.

[0019] Another aspect of the disclosure is an optical lithography system for imaging a reticle onto a wafer coated with photoresist. The optical lithography system includes the Wynne-Dyson projection lens as described above, wherein the reticle resides at the object plane and the wafer resides at the image plane. The optical lithography system also includes an illuminator arranged to illuminate the reticle with the ultraviolet radiation.

[0020] Another aspect of the disclosure is a Wynne-Dyson projection lens having object and image planes and an image field, and that has reduced susceptibility to damage from ultraviolet radiation. The Wynne-Dyson projection lens includes along an optical axis: a concave mirror having a concave surface; a positive lens group spaced apart from the concave surface of the concave mirror; first and second prisms made of either fused silica or BSM51Y and disposed adjacent the positive lens group opposite the concave mirror and on respective sides of the optical axis, with the first and second prisms having respective surfaces that reside adjacent the object and image planes; first and second lens elements that define a cemented doublet, wherein the first lens element has a planar surface in contact with the first and second prisms and that is made of either S-FPL51Y or S-FSL5Y, and wherein the second lens element is made of either BAL15Y or BSM51Y; a third lens element spaced apart from the second lens element and made of either S-FSL5Y or S-FPL51Y. The Wynne-Dyson projection lens has: a numerical aperture NA of 0.16; the image field is 40x20mm; a substantially unit magnification; doubly telecentricity; and a Strehl ratio of > 0.95 over the image field for a spectral bandwidth that includes ghi radiation.

[0021] Another aspect of the disclosure is the Wynne-Dyson projection lens as described above, wherein the positive lens group further includes a fourth lens element spaced apart from the third lens element towards the concave mirror and made of either S-FSL5Y or S-FPL51Y.

[0022] Another aspect of the disclosure is an optical lithography system for imaging a reticle onto a wafer coated with photoresist. The optical lithography system includes the Wynne-Dyson projection lens as described above, wherein the reticle resides at the object plane and the wafer resides at the image plane, and an illuminator arranged to illuminate the reticle with the ultraviolet radiation.

[0023] Additional features and advantages are set forth in the Detailed Description that follows, and in part will be readily apparent to those skilled in the art from the description or recognized by practicing the embodiments as described in the written description and claims hereof, as well as the appended drawings. It is to be understood that both the foregoing general description and the following Detailed Description are merely exemplary, and are intended to provide an overview or framework to understand the nature and character of the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] The accompanying drawings are included to provide a further understanding, and are incorporated in and constitute a part of this specification. The drawings illustrate one or more embodiment(s), and together with the Detailed Description serve to explain principles and operation of the various embodiments. As such, the disclosure will become more fully understood from the following Detailed Description, taken in conjunction with the accompanying Figures, in which:

[0025] FIGS. 1 through 4 are optical diagrams of first, second third and fourth examples, respectively, of a Wynne-Dyson projection lens configured to have reduced susceptibility to UV damage according to the disclosure;

[0026] FIG. 5 is a schematic diagram of an example optical lithography system that employs the Wynn-Dyson projections lens having reduced susceptibility to UV damage as disclosed herein;

[0027] FIG. 6A is a schematic front-on view of an example reticle showing the reticle pattern that defines the reticle field and also showing an example of a scanned illumination field;

[0028] FIG. 6B is a schematic diagram of an example scanning illumination field and an example exposure field associated with the scanned illumination field;

[0029] FIG. 6C is similar to FIG. 6A and illustrates an example of a full-field illumination field;

[0030] FIG. 6D is similar to FIG. 6B and illustrates an example of a full-field image field that corresponds in size to the corresponding exposure field; and

[0031] FIG. 7 is a plan view of a semiconductor wafer with exposure fields formed thereon by the photolithography system of FIG. 5.

DETAILED DESCRIPTION

[0032] Reference is now made in detail to various embodiments of the disclosure, examples of which are illustrated in the accompanying drawings. Whenever possible, the

same or like reference numbers and symbols are used throughout the drawings to refer to the same or like parts. The drawings are not necessarily to scale, and one skilled in the art will recognize where the drawings have been simplified to illustrate the key aspects of the disclosure.

[0033] The claims as set forth below are incorporated into and constitute part of this Detailed Description.

[0034] Cartesian coordinates are shown in some of the Figures for the sake of reference and are not intended to be limiting as to direction or orientation.

[0035] Reference is made below to the g, h and i lines of radiation, which nominally correspond to 365 nm, 405 nm, and 436 nm, respectively. UV light using these wavelengths is referred to below as "ghi light" or "ghi radiation," or just "ghi" for short. Optical lithography using these wavelengths is referred to as "ghi optical lithography." A projection lens designed for ghi optical lithography is referred to as a "ghi projection lens." In an example, the reduced susceptibility of the projection lens to UV radiation refers to ghi radiation.

Design considerations

[0036] Most of the standard optical glasses from the well-known commercial optical glass manufacturers are not suitable for high-quality projection lenses for semiconductor manufacturing because of their low transmission for ghi radiation, and especially for i-line radiation. Three optical glasses that have good transmission at ghi wavelengths and that have a low susceptibility to UV-induced damage are fused silica, S-FPL51Y and S-FSL5Y, which are available from Ohara Corporation, of Kanagawa, Japan.

[0037] For a Wynne-Dyson type unit magnification projection lens that operates over a relatively wide range of UV wavelengths such as the ghi wavelengths, chromatic aberrations need to be corrected. Because of the system's symmetry, lateral color is generally not a concern. On the other hand, axial color needs to be corrected, and this requires optical glass having a relatively high dispersion. However, the aforementioned S-FPL51Y, S-FSL5Y and fused silica optical glasses have relatively low dispersion. Thus, in example embodiments of the projection lenses disclosed herein, the optical glasses BSM51Y and

BAL15Y from Ohara Corporation are utilized because they have the necessary dispersion to correct axial color while also having a relatively low susceptibility to UV-induced damage.

[0038] More specifically, the optical glasses S-FPL51Y, S-FSL5Y, fused silica, BSM51Y and BAL15Y have respective Abbe numbers of 81.14, 70.35, 67.82, 60.65, and 58.68. Thus, S-FPL51Y can serve as the low dispersion glass, fused silica and/or S-FSL5Y can serve as the medium dispersion glass, and BAL15Y and/or BSM51Y serve as the high dispersion glass. Using these glasses provides enough degrees of freedoms to adequately correct for the secondary spectrum as well as other aberrations over the ghi wavelengths.

Example projection lenses

[0039] FIGS. 1 through 4 are optical system diagrams that respectively illustrate four different example embodiments of a Wynne-Dyson projection lens ("projection lens") 10. The projection lens 10 disclosed herein is substantially unit magnification, substantially doubly telecentric, and is designed for use with ghi radiation, i.e., it is well-corrected over a spectral bandwidth that includes ghi radiation.

[0040] The projection lens 10 includes an optical axis A1, a concave primary mirror M with a surface MS, and prisms PA and PB spaced apart from the concave primary mirror M and arranged on opposite sides of the optical axis A1. In an example, the prisms PA and PB are isosceles prisms. The prisms PA and PB have respective surfaces SR and SW that respectively reside adjacent a reticle plane RP and a wafer plane WP. The prisms PA and PB also each have surfaces S_{TIR} that serve at total-internal reflection surfaces, thereby allowing for the reticle and wafer planes RP and WP to be spatially separated. The reticle plane RP resides at an object plane while the wafer plane WP resides at an image plane.

[0041] The projection lens 10 includes a refractive lens group G with overall positive refractive power (i.e., a "positive" lens group) that resides between the primary mirror M and prisms PA and PB. The refractive lens group G can be divided into a first lens group G1 that includes a cemented doublet made up of a plano-convex lens element L1 and a (nominally) plano-concave lens element L2, and a second lens group G2 axially spaced apart from the first lens group G1 and that includes either one lens element L3 or two lens elements L3 and L4. In an example, the prisms PA and PB can be considered part of the first lens group G1. The primary mirror M defines an aperture stop AS for the projection lens 10.

[0042] Because the projection lens 10 is symmetric about the aperture stop AS, the distortion and lateral color are genereally well-corrected. The primary mirror M generates mainly astigmatism and field curvature without any color aberrations. So, the other refractive elements in the projection lens 10 are designed to compensate for the two types of aberrations generated by the primary mirror M, as well as aberrations that they would otherwise generate, such as spherical aberration and coma. The prisms PA and PB have no optical power, which allows for relatively loose mounting tolerances for these refractive elements.

[0043] In an example, even when the projection lens 10 is substantially defocused (e.g., by +/-5 microns for Examples 1 and 3, and by +/-2.5 microns for Example 2), its imaging performance (e.g., as reflected by the Strehl ratio) remains substantially diffraction limited everywhere across an image field IF. The ability to maintain imaging performance over a relatively large range of focus positions is important characteristic since the projection lens 10 is typically used to form images in photoresist, as described below in connection with an optical lithgraphy system 200 of FIG. 5.

[0044] For the example of projection lens 10 having three refractive lens elements L1 through L3, each lens elements L1 through L3 can be made of the following optical glasses:

Lens element L1: S-FPL51Y, S-FSL5Y or fused silica;

Lens element L2: BSM51Y or BAL15Y; and

Lens element L3: S-FPL51Y, S-FSL5Y or fused silica.

For the example of projection lens 10 having the additional lens element L4, the first three lens elements L1 through L3 can be made of the above optical glasses while the fourth lens element L4 can be made of S-FPL51Y, S-FSL5Y or fused silica.

Example 1

[0045] FIG. 1 is an optical diagram of Example 1 of projection lens 10. The projection lens 10 of Example 1 has a designed field radius of 50 mm, an usable field of view of 68 mm by 28 mm, a numerical aperture (NA) of 0.16, and an overall length of 800 mm. The prisms PA and PB are made of fused silica, while the lens elements L1, L2, L3 and L4 are respectively made of S-FPL51Y, BAL15Y, S-FSL5Y and fused silica. The optical glasses BSM51Y and

BAL15Y have very similar refractive indices at the ghi wavelengths (and hence have similar dispersion), and also have low susceptibility to UV-induced damage. Thus, the optical glass BAL15Y used in the design for the lens element L2 can be replaced by optical glass BSM51Y with minor modification of the design while still obtaining similar image performance.

[0046] Table 1 below sets forth the optical prescription for Example 1, wherein "S" stands for the surface number, "TH" is the thickness, and "CA/2" is half of the clear aperture, i.e., or semi-diameter of the given element. Also, "r" stands for radius, k is the conic constant, and c represents the aspheric coefficients that describe an aspheric surface using the standard equation for an aspheric surface as is known in the art.

TABLE 1 - EXAMPLE 1				
S	R (mm), k, c	TH (mm)	Material	CA/2 (mm)
S0	r= infinity	5.182 mm		
S1	r= infinity	55.5 mm	Fused Silica	
S2	r= infinity	0		
S3	r= infinity	0		56.45 mm
S4	r= infinity	26.372 mm	S-FPL51Y	57.15 mm
S5	r=- 92.4315	0		57.15 mm
S6	r =- 92.4315	35.011 mm	BAL15Y	64.44 mm
S7	r= infinity	25.766 mm		69.87 mm
S8	r=-6150	80.001	S-FSL5Y	79.28
S9	r= -212.6136	2.000		79.75
S10	r= 410.827	38.989	Fused Silica	
S11	r= 428.8633 k= -3.52295157 c_{4th}=6.4527E-9 c_{6th}= -5.8530E-14 c_{8th}= 6.0603E-18 c_{10th}= -3.52E-22	529.210		77.80
S12	r= -800			85.44

[0047] In Example, 1, the mirror-wise surface S11 of lens element L4 is aspheric and is the dominant contributor to compensating the astigmatism and field curvature from the primary mirror M. The lens element L4 has a meniscus shape and has very little power. Most of the optical power of projection lens 10 is controled by the primary mirror M and lens element L2. The asphere lens element L4 is mainly used to control overall length and chief ray aberrations, in addition to higher-order aberrations. It should be noted that the

aspheric lens element L4 is not limited to having its aspheric surface S9 bend towards the primary mirror M. This aspheric surface S9 could also bend away from the primary mirror M.

[0048] The example 1 of projection lens 10 includes the following two design considerations. The first involves locating aspheric surface S9 as far away from the reticle and the wafer planes RP and WP as possible. This is so that any high-frequency surface errors, which can occur during fabrication of the aspheric surface S9, have less effect on telecentricity and distortion. The second consideration is to avoid making the surface MS of primary mirror M an aspheric surface since any surface errors are multiplied by a factor of two due to the reflective nature of the surface MS, and because testing of aspheric mirror surfaces tends to be more difficult and costly.

Example 2

[0049] FIG. 2 is an optical diagram of an Example 2 of the projection lens 10 as disclosed herein. The projection lens 10 of Example 2 has four lens elements L1 through L4 of the same glass type as in Example 1. The Example 2 design has a field radius of 50mm, an usable field of view of 68 mm by 28 mm, a NA of 0.2, and an overall length of 805 mm. As in Example 1, the surface S11 of lens element L4 is aspheric and is the dominant contributor to correcting astigmatism and field curvature introduced by the primary mirror M. The lens element L4 has negative overall optical power, with its lens surfaces S8 and S9 bending away from the primary mirror M. The lens element L4 has the same main function as in Example 1, namely to finely control the overall length and telecentricity.

[0050] In this Example 2 design, the lens elements L3 and L4 are significantly thinner than those used in Exampe 1. This serves to reduce the amount of glass in the optical path, which reduces absorption and thus the aforementioned adverse thermal transient effects.

[0051] Table 1 below sets forth the optical prescription for Example 2.

TABLE 2 – EXAMPLE 2				
S	r (mm), k, c	TH (mm)	Material	CA/2 (mm)
S0	r= infinity	5.182		
S1	r= infinity	70.000	Fused Silica	

S2	r= infinity	0		
S3	r= infinity	0		
S4	r= infinity	24.185	S-FPL51Y	60.21
S5	r= -101.4781	0		60.75
S6	r= -101.4781	20.000	BAL15Y	60.75
S7	r= -559.7193	70.003		66.44
S8	r= -870.4049	25.000	S-FSL5Y	79.01
S9	r= -212.9743	24.381		80.99
S10	r= -322.6115	20.000	Fused Silica	81.68
S11	r= 484.4477 k=-1.59831712 c_{4th}=7.9861E-10 c_{6th}=-2.1783E-14 c_{8th}=-5.757E-20 c_{10th}=2.2703E-23	546.254		83.99
S12	r= -813.1166			120.04

Example 3

[0052] FIG. 3 is an optical system diagram of Example 3 of projection lens 10 as disclosed herein. The example 3 of projection lens 10 has a design field radius of 36 mm and usable field of view of 40 mm by 20 mm, and an NA of 0.16. The overal length of projection lens 10 is 691 mm. As the field size is substantially smaller than Examples 1 and 2, the number of refractive lens elements is reduced by one relative to Examples 1 and 2. The prisms PA and PB are made of fused silica. The lens elements L1, L2 and L3 are made from S-FPL51Y, BAL15Y and S-FSL5Y, respectively. Note that the lens element L2 can also be made from BSM51Y. The lens element L3 has an aspheric surface S9, and the surfaces S8 and S9 are configured to correct for astigmatism and field curvature introduced by the primary mirror M.

[0053] Table 3 sets for the optical prescription for Example 3 of projection lens 10.

TABLE 3 – EXAMPLE 3				
S	r (mm), k, c	TH (mm)	Material	CA/2 (mm)
S0	r= infinity	5.182		
S1	r= infinity	50.000	Fused Silica	
S2	r= infinity	0		
S3	r= infinity	0		
S4	r= infinity	25.000	S-FPL51Y	42.38

S5	r= -92.1029	0		43.87
S6	r= -92.1029	30.000	BAL15Y	43.87
S7	r= -311.7121	79.930		48.49
S8	r= -519.4889	30.000	S-FSL5Y	56.96
S11	r= -274.7936 k=1.075090621 c_{4th}=9.7906E-9 c_{6th}=2.0779E-13 c_{8th}=4.2347E-18	471.374		59.80
S12	r= -697.211955			84.06

Example 4

[0054] FIG. 4 is an optical system diagram of an Example 4 of projection lens 10 as disclosed herein. The example 4 of projection lens 10 has a design field radius of 50 mm, a usable field of view of 68 mm by 26 mm, and an NA of 0.16. The surface S11 is aspheric. Unlike the other examples, the prisms PA and PB are made of BSM51Y, while the lens element L1 is made of S-FPL51Y, the lens elements L2 and L4 are made of S-FSL5Y and the lens element L3 is made of fused silica. Thus, the prisms PA and PB need not be only made of fused silica.

[0055] Table 4 below sets for the optical prescription for Example 3 of projection lens 10.

TABLE 4 – EXAMPLE 4				
S	r (mm), k, c	TH (mm)	Material	CA/2 (mm)
S0	r=infinity	5.182mm		
S1	r=infinity	55.5mm	BSM51Y	
S2	r=infinity	0		
S3	r=infinity	0		56.45mm
S4	r=infinity	46.003mm	S-FPL5Y	57.15mm
S5	r=-84.18704mm	0		57.15mm
S6	r=-84.18704mm	60.001mm	S-FSL5Y	64.44mm
S7	r=930.18835	18.711mm		69.87mm
S8	r=274.1023mm	73.661mm	Fused Silica	79.28mm
S9	r=254.1152mm	7.377mm		79.75mm
S10	r=363.3433mm	55.539mm	S-FSL5Y	

S11	r=-452.3749mm k=9.230303384 c_{4th}=1.6900E-8 c_{6th}=3.6121E-13 c_{8th}=8.9935E-18 c_{10th}=6.5388E-22	480.041mm		77.80mm
S12	r=-800mm			86.00mm

Optical lithography system

[0056] FIG. 5 is a schematic diagram of an example optical lithography system 200 that employs the projection lens 10 as disclosed herein. The optical lithography system 200 includes, in order along an optical axis A0, an illuminator 202, a reticle 210 (e.g., a patterned mask) supported by a reticle stage 220 at a reticle plane RP, a projection imaging lens 230, and a wafer 240 supported by a wafer stage 250 at a wafer plane WP. The reticle 210 includes a patterned region 211 that includes pattern elements 212 and that defines a reticle field RF. The wafer 240 includes an outer edge 241 (see FIG. 7). Note that the reticle and wafer planes RP and WP are shown parallel and on the same axis for ease of illustration. FIG. 1A shows the actual orientation of the reticle plane RP and wafer plane WP.

[0057] The wafer 240 includes a photosensitive coating 242 (e.g., photoresist) on the wafer surface that is activated by light (i.e., "actinic light") 320 generated by a light source 310 located in the illuminator 202. The actinic light 320 comprises ghi radiation. The Illuminator 202 is shown as included an aperture stop 330. In an example, the light source 310 includes an array 312 of light-emitting elements 314.

[0058] The optical lithography system 200 also includes a controller 260 operably connected to the illuminator 202, the reticle stage 220 and the wafer stage 250. The controller 260 is configured to control the operation of optical lithography system 200. An example controller 260 includes a computer such as a personal computer or workstation. In an example, the controller 260 includes apparatus-control software that includes instructions, embodied in a computer-readable medium, that control the various components of optical lithography system 200.

[0059] The illuminator 202 is configured to generate an illumination field ILF (see FIG. 5A) at the object plane, which corresponds to the reticle plane RP. The illumination field ILF

includes uniformized actinic light 320′ and illuminates at least a portion of the reticle field RF over a reticle field exposure time so that the projection lens 10 forms a corresponding image field IF at the wafer plane WP over a corresponding wafer exposure time. The wafer stage 250 is movable (e.g., via a control signal SCW from the controller 260) so that the image field IF can be placed at different parts of the wafer 240 to form various exposure fields EF on the wafer 240 and in particular in the photosensitive coating 242. In an example, the reticle stage 220 is movable via a control signal SCR from the controller 260.

[0060] Thus, the uniformized actinic light 320′ from the illuminator 202 is used to illuminate at least a portion of the patterned region 211 that defines the reticle field RF. The illuminated portion of reticle field RF is then imaged onto the photosensitive coating 242 of wafer 240 via the projection imaging lens 230. In an example embodiment, the reticle 210 and wafer 240 are moved together in a manner that scans the image field IF over the wafer 240 as the illumination field ILF scans over the reticle field RF, as illustrated by arrows AR in FIG. 1 and also as schematically illustrated in FIGS. 6A and 6B. This operation forms a scanned exposure field EF that is larger than either the illumination field ILF or the image field IF. This process is then repeated for a different (unexposed) region of the wafer 240. This printing approach is referred to in the art as "step and scan."

[0061] In another example, the illumination field ILF illuminates the entire reticle field RF at once, thereby forming, in a single exposure, one exposure field EF. The wafer 240 is then moved, and the single static exposure is repeated. This printing approach is called "step and repeat." FIG. 6C is similar to FIG. 5A and illustrates an example of a full-field illumination field ILF used for step-and-repeat printing. FIG. 6D is similar to FIG. 6B and illustrates an example of a full-field image field IF that corresponds in size to the corresponding exposure field EF as used in step-and-repeat printing.

[0062] With reference to FIG. 7, the exposure fields EF formed on the wafer 240 in the photosensitive coating 242 are in turn used to form integrated circuit chips via standard photolithographic and semiconductor processing techniques.

[0063] It is estimated that lower susceptibility to UV-induced damage for the projection lens 10 as disclosed herein should allow the projection lens 10 to last 7 to 10 times longer

than a conventional projection lens used in the same optical lithography system 200 under the same operating conditions.

[0064] It will be apparent to those skilled in the art that various modifications to the preferred embodiments of the disclosure as described herein can be made without departing from the spirit or scope of the disclosure as defined in the appended claims. Thus, the disclosure covers the modifications and variations provided they come within the scope of the appended claims and the equivalents thereto.

What is claimed is:

1. A Wynne-Dyson projection lens having object and image planes and an image field, and that has reduced susceptibility to compaction and solarization from ultraviolet radiation, the Wynne-Dyson projection lens comprising along an optical axis:

a concave mirror having a concave surface;

a positive lens group spaced apart from the concave surface of the concave mirror;

first and second prisms made of either fused silica or BSM51Y and disposed adjacent the positive lens group opposite the concave mirror and on respective sides of the optical axis, with the first and second prisms having respective surfaces that reside adjacent the object and image planes;

wherein the positive lens group consists of:

a first lens group having a cemented doublet consisting of a plano-convex lens element made of either S-FPL51Y, S-FSL5Y or fused silica and having a planar surface in contact with the first and second prisms, and a negative meniscus lens made of either BAL15Y or BSM51Y; and

a second lens group spaced apart from the first lens group and consisting of either one or two lens elements each made of either S-FSL5Y, S-FPL51Y or fused silica; and

wherein the Wynne-Dyson projection lens has a numerical aperture NA in the range from 0.16 to 0.2, a unit magnification, is doubly telecentric and a Strehl ratio of > 0.95 over the image field for a spectral bandwidth that includes ghi radiation.

2. The Wynne-Dyson projection lens of claim 1, wherein the image field is 40 mm x 20 mm, and wherein the second lens group consists of the one lens element made of S-FSL5Y.

3. The Wynne-Dyson projection lens of claim 1, wherein the image field is 68 mm x 28 mm, wherein the NA = 0.16, and wherein the second lens group consists of the two spaced-apart lens elements.

4. The Wynn-Dyson projection lens of claim 3, wherein the most mirror-wise lens element of the second lens group has a most mirror-wise concave surface.

5. The Wynn-Dyson projection lens of claim 3, wherein the most mirror-wise lens element of the second lens group has a most mirror-wise convex surface.

6. The Wynn-Dyson projection lens of claim 1, wherein the first and second prisms are each isosceles prisms.

7. An optical lithography system for imaging a reticle onto a wafer coated with photoresist, comprising:

the Wynne-Dyson projection lens of claim 1, wherein the reticle resides at the object plane and the wafer resides at the image plane; and

an illuminator arranged to operably illuminate the reticle with the ultraviolet radiation.

8. A Wynne-Dyson projection lens having object and image planes and an image field, and that has reduced susceptibility to compaction and solarization from ultraviolet radiation, the Wynne-Dyson projection lens comprising along an optical axis:

a concave mirror having a concave surface;

a positive lens group spaced apart from the concave surface of the concave mirror;

first and second prisms made of either fused silica or BSM51Y and disposed adjacent the positive lens group opposite the concave mirror and on respective sides of the optical axis, with the first and second prisms having respective surfaces that reside adjacent the object and image planes;

wherein the positive lens group includes: a first lens element L1 made of S-FPL51Y, S-FSL5Y or fused silica; a second lens element L2 made of BSM51Y or BAL15Y; and a third lens element L3 made of S-FPL51Y, S-FSL5Y or fused silica; and

wherein the Wynne-Dyson projection lens has: a numerical aperture NA in the range from 0.16 to 0.2; a unit magnification; doubly telecentricity; and a Strehl ratio of > 0.95 over the image field for a spectral bandwidth that includes ghi radiation.

9. The Wynne-Dyson projection lens of claim 8, wherein the positive lens group further includes a fourth lens element L4 made of S-FPL51Y, S-FSL5Y or fused silica.

10. The Wynne-Dyson projection lens of claim 8, wherein the first and second lens elements define a cemented doublet, with the first lens element being plano-convex and contacting the first and second prisms.

11. An optical lithography system for imaging a reticle onto a wafer coated with photoresist, comprising:

the Wynne-Dyson projection lens of claim 8, wherein the reticle resides at the object plane and the wafer resides at the image plane; and

an illuminator arranged to illuminate the reticle with the ultraviolet radiation.

12. A Wynne-Dyson projection lens having object and image planes and an image field, and that has reduced susceptibility to compaction and solarization from ultraviolet radiation, the Wynne-Dyson projection lens comprising along an optical axis:

a concave mirror having a concave surface;

a positive lens group spaced apart from the concave surface of the concave mirror;

first and second prisms made of either fused silica or BSM51Y and disposed adjacent the positive lens group opposite the concave mirror and on respective sides of the optical axis, with the first and second prisms having respective surfaces that reside adjacent the object and image planes;

first and second lens elements that define a cemented doublet, wherein the first lens element has a planar surface in contact with the first and second prisms and that is made of either S-FPL51Y or S-FSL5Y, and wherein the second lens element is made of either BAL15Y or BSM51Y;

a third lens element spaced apart from the second lens element and made of either S-FSL5Y or S-FPL51Y; and

wherein the Wynne-Dyson projection lens has: a numerical aperture NA of 0.16; the image field is 40x20mm; a unit magnification; doubly telecentricity; and a Strehl ratio of > 0.95 over the image field for a spectral bandwidth that includes ghi radiation.

13. An optical lithography system for imaging a reticle onto a wafer coated with photoresist, comprising:

the Wynne-Dyson projection lens of claim 12, wherein the reticle resides at the object plane and the wafer resides at the image plane; and

an illuminator arranged to illuminate the reticle with the ultraviolet radiation.