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[54] **CATADIOPTRIC OPTICAL REDUCTION SYSTEM WITH HIGH NUMERICAL APERTURE**

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Related U.S. Application Data

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[52] **U.S. Cl.** **359/727**; 359/631
[58] **Field of Search** 359/727, 728, 359/729, 730, 732, 631, 633, 639, 663

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,917,399	11/1975	Buzawa et al.	355/43
4,896,952	1/1990	Rosenbluth	359/638
4,953,960	9/1990	Williamson	359/663
5,089,913	2/1992	Singh et al.	359/727
5,212,593	5/1993	Williamson et al.	359/728
5,220,454	6/1993	Ichihara et al.	359/727

FOREIGN PATENT DOCUMENTS

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4110296A1	10/1991	Germany .
4203464	8/1992	Germany .
5088087	4/1993	Japan .

[57] **ABSTRACT**

A catadioptric optical reduction system for use in the photolithographic manufacture of semiconductors having a concave mirror operating near unit magnification, or close to a concentric condition. A lens group before the mirror provides only enough power to image the entrance pupil at infinity to the aperture stop at or near the concave mirror. A lens group after the mirror provides a larger proportion of reduction from object to image size, as well as projecting the aperture stop to an infinite exit pupil. An aspheric concave mirror is used to further reduce high order aberrations. The catadioptric optical reduction system provides a relatively high numerical aperture of 0.7 capable of patterning features smaller than 0.35 microns over a 26×5 millimeter field. The optical reduction system is thereby well adapted to a step and scan microlithographic exposure tool as used in semiconductor manufacturing. Several other embodiments combine glasses of different refracting power to widen the spectral bandwidth which can be achieved.
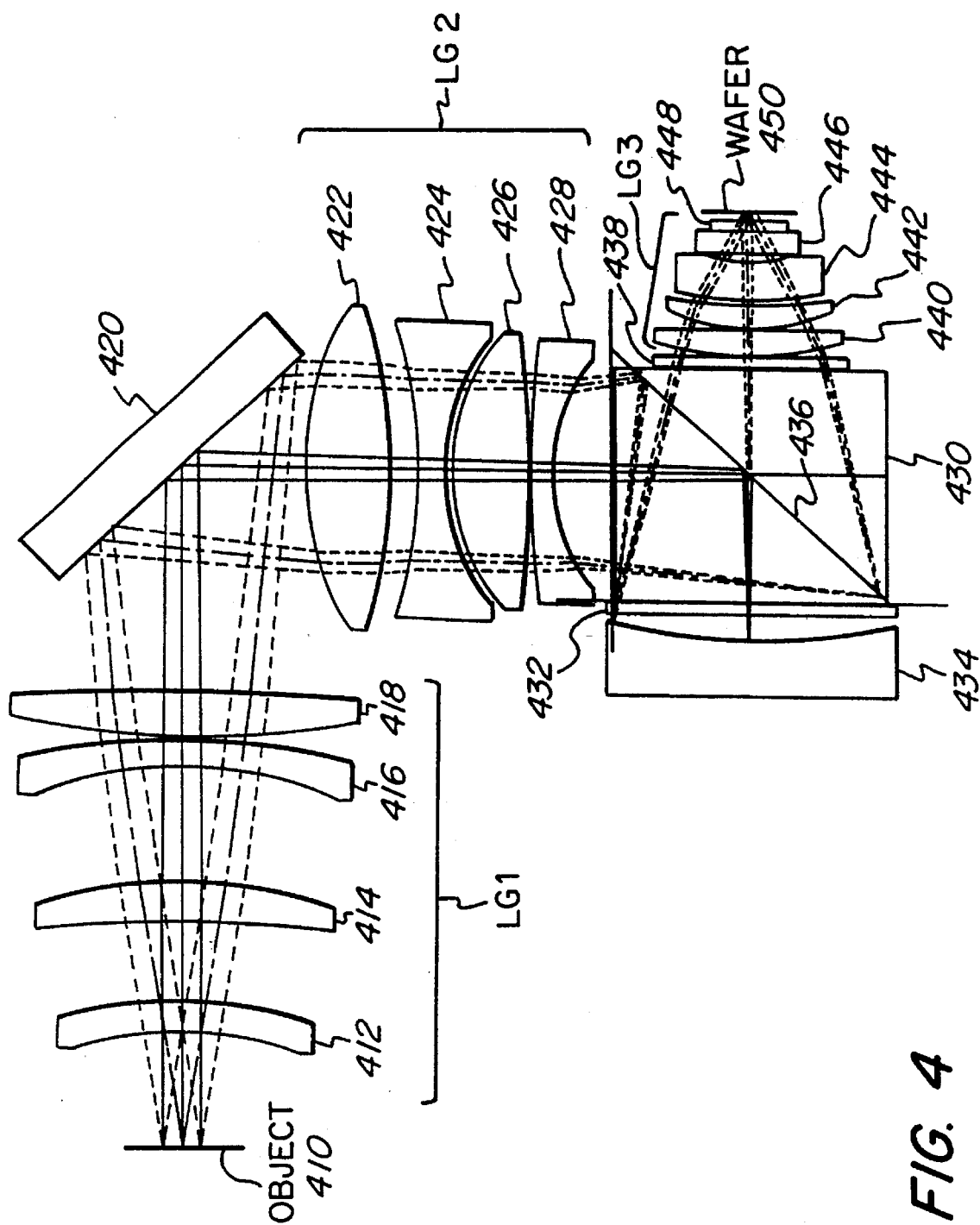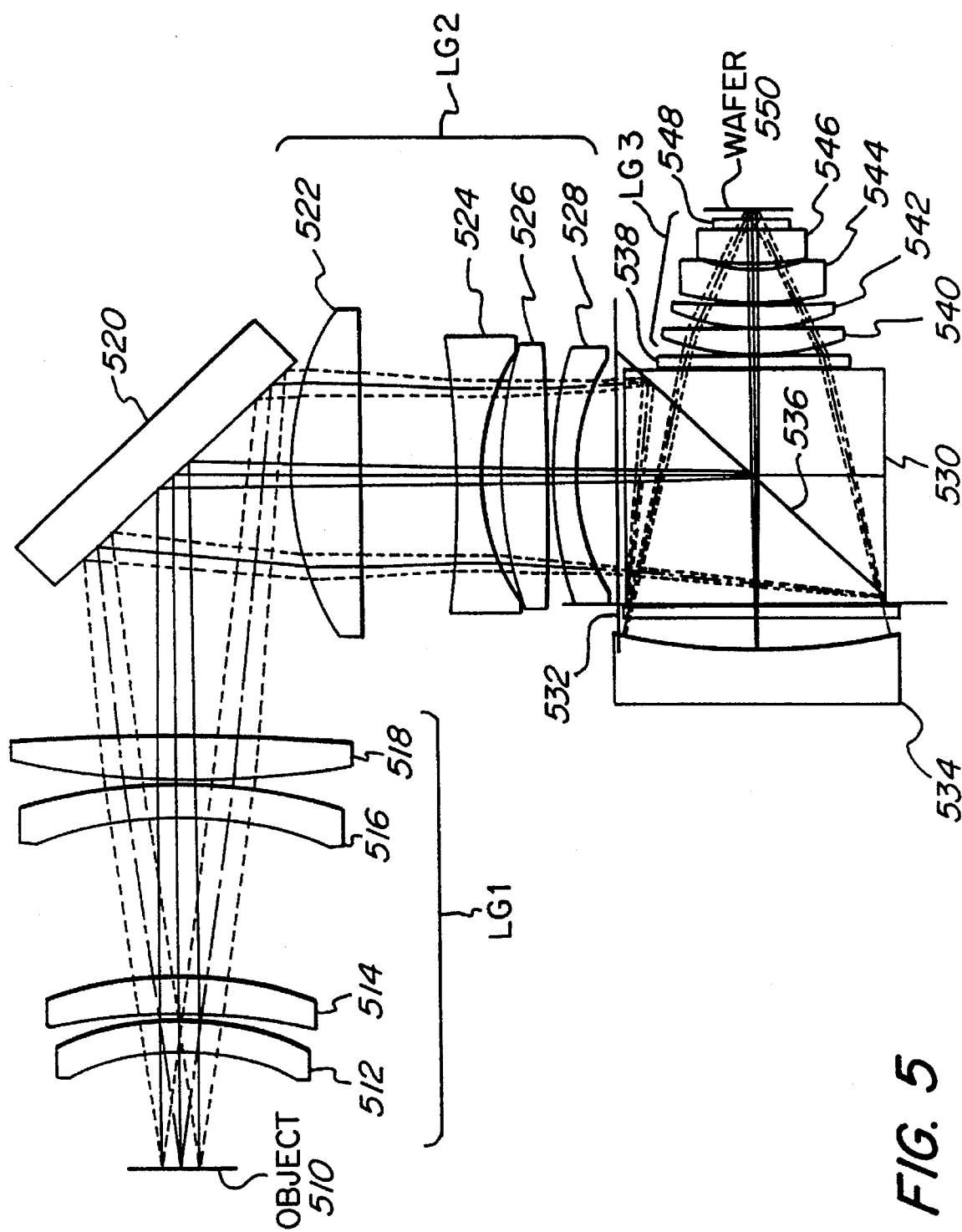
31 Claims, 5 Drawing Sheets

FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG. 5
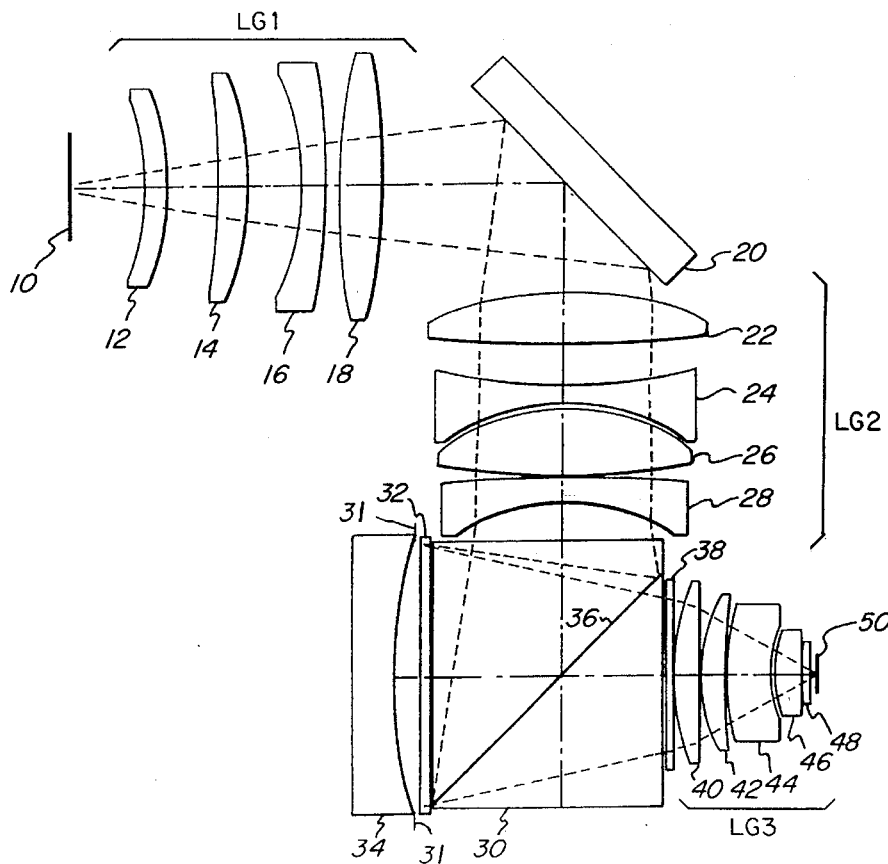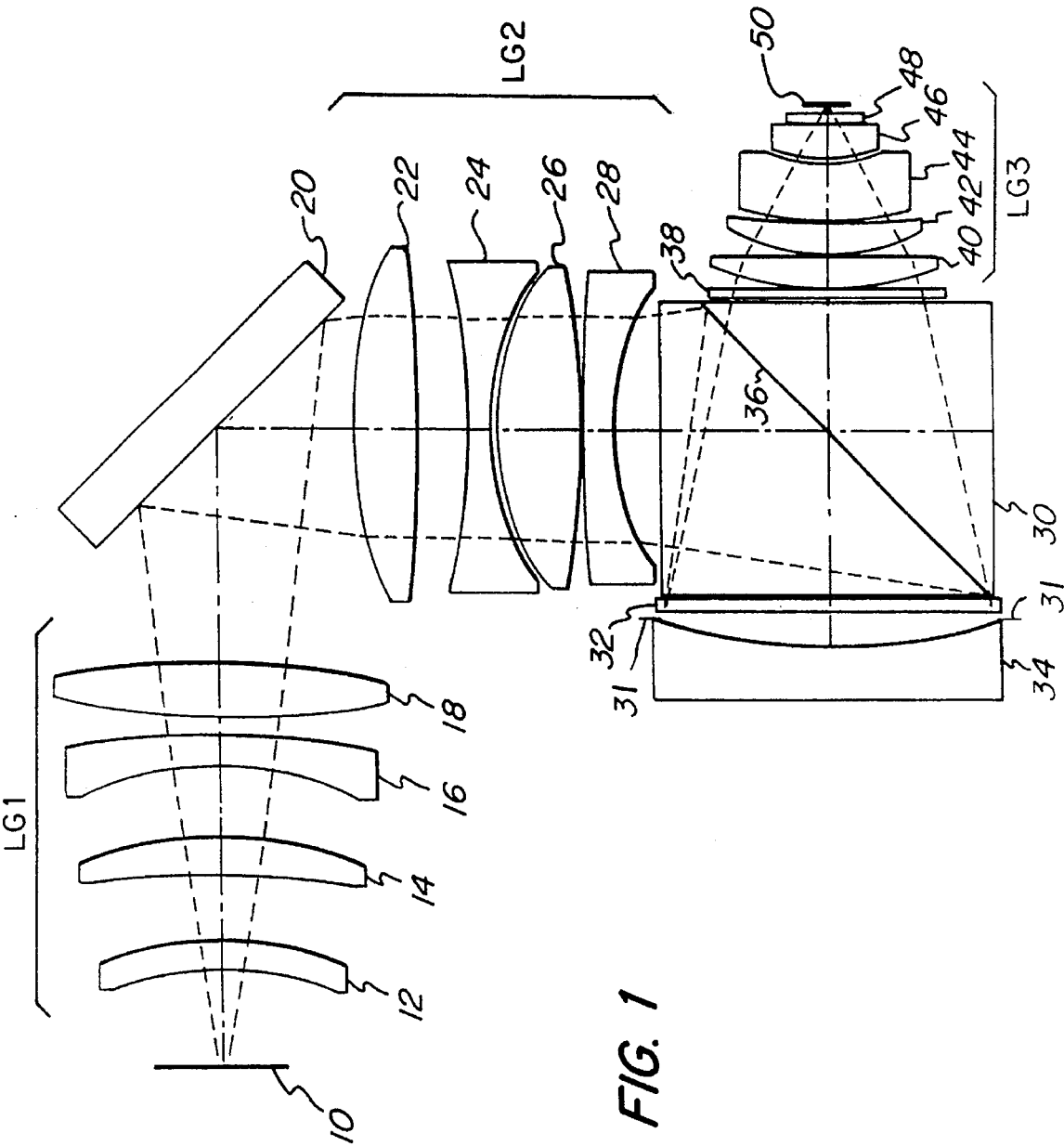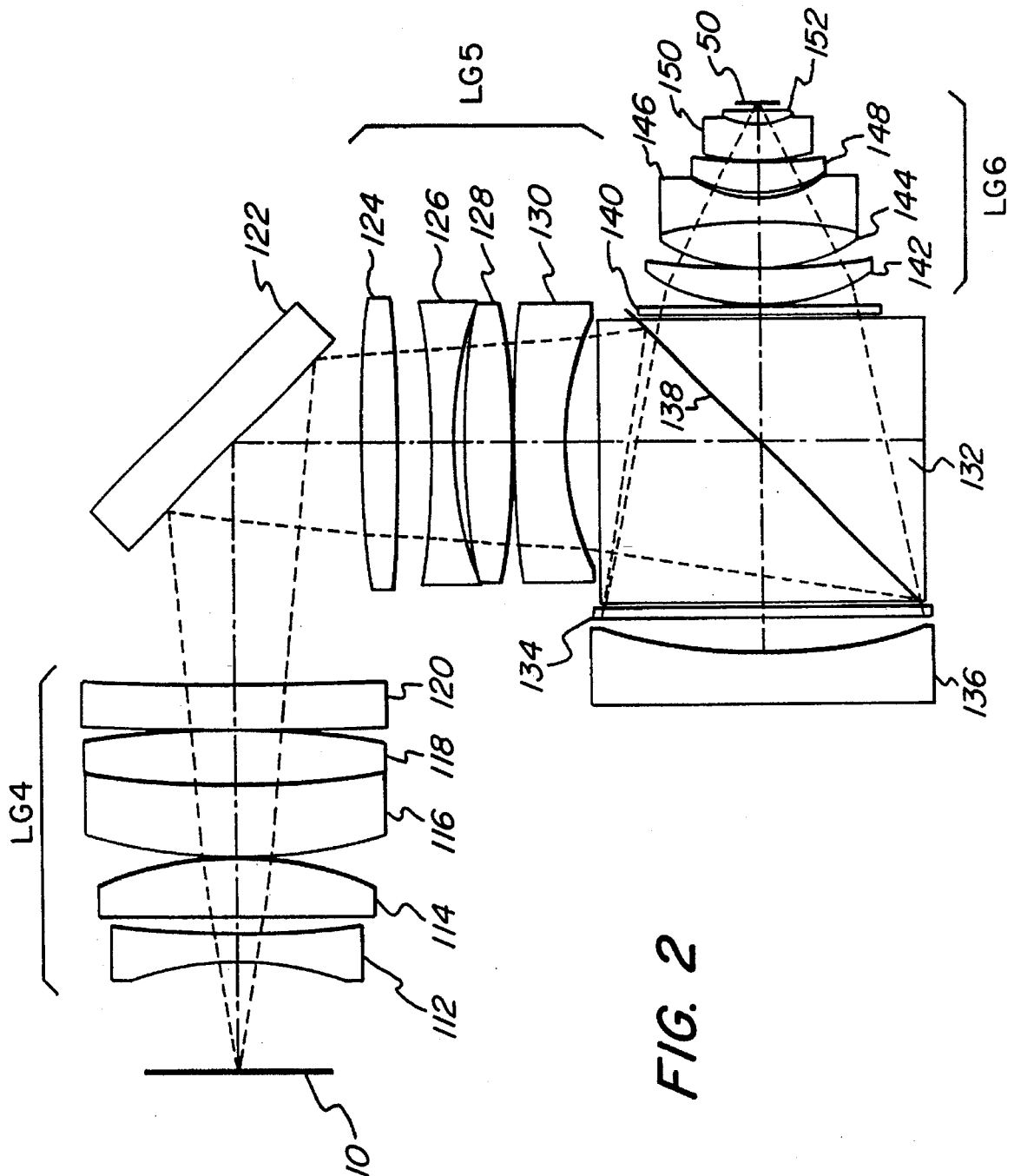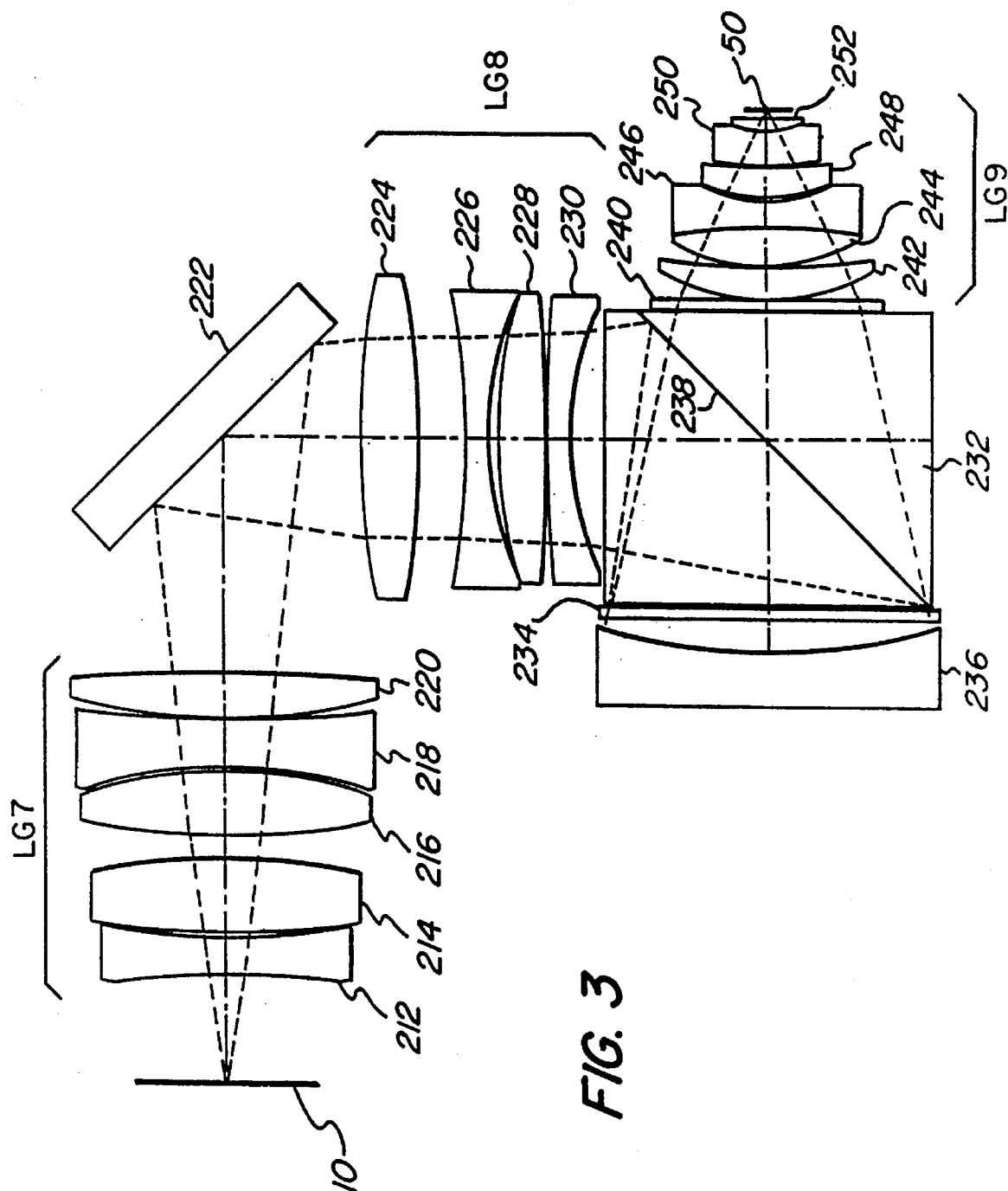
CATADIOPTRIC OPTICAL REDUCTION SYSTEM WITH HIGH NUMERICAL APERTURE

This application is a continuation-in-part, of application Ser. No. 08/009,284, filed Jan. 26, 1993.

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

This invention relates generally to optical systems used in semiconductor manufacturing, and more particularly to an unobscured catadioptric optical reduction system having a relatively high numerical aperture.

DESCRIPTION OF THE RELATED ART

Semiconductors are usually manufactured using various photolithographic techniques. The circuitry used in a semiconductor is reproduced from a reticle onto a semiconductor chip. This reproduction is often accomplished with the use of optical systems. The design of these optical systems is often complex, and it is difficult to obtain the desired resolution necessary for reproducing the ever-decreasing size of components being placed on a semiconductor chip. Therefore, there has been much effort expended to develop an optical reduction system capable of reproducing very fine component features, less than 0.35 microns. In addition to the need to develop an optical system capable of reproducing very fine component features, there is also the need to augment system performance by increasing numerical aperture. Increasing numerical aperture provides for a higher resolution optical system.

An optical system similar to that of the present invention is disclosed in U.S. Pat. No. 4,953,960 entitled "Optical Reduction System" issuing Sep. 4, 1990 to Williamson, which is herein incorporated by reference. Therein disclosed is an optical reduction system operating in the range of 248 nanometers and having a numerical aperture of 0.45. Another similar optical system is disclosed in U.S. Pat. No. 5,089,913 entitled "High Resolution Reduction Catadioptric Relay Lens" issuing Feb. 18, 1992 to Singh et al, which is herein incorporated by reference. Therein disclosed is an optical system having a restricted spectral waveband at 248 nanometers, and having a numerical aperture of 0.6.

While these prior optical systems perform adequately for their intended purpose, there is an ever increasing need to improve system performance by increasing numerical aperture. Therefore, there is a need for an optical system having a relatively high numerical aperture capable of acceptable system performance over a relatively large spectral waveband.

SUMMARY OF THE INVENTION

The present invention comprises a catadioptric reduction system having, from the object or long conjugate end to the reduced image or short conjugate end, a first lens group, a second lens group, a beamsplitter cube, a substantially or nearly concentric concave mirror, and a third lens group. The concave mirror operates substantially near unit magnification. This reduces the aberrations introduced by the mirror and the diameter of radiation entering the beamsplitter cube. The first and second lens groups before the concave mirror provide only enough power to image the entrance pupil at infinity at the aperture stop at or near the concave mirror. The third lens group after the concave mirror pro-

vides a substantial portion of the reduction from object to image of the optical system, as well as projecting the aperture stop to an infinite exit pupil. High-order aberrations are reduced by using an aspheric concave mirror.

Accordingly, it is an object of the present invention to provide an optical system having a relatively high numerical aperture.

It is another object of the present invention to provide an optical system having a spectral bandwidth substantially wider than could have previously been obtained at such a high numerical aperture.

It is an advantage of the present invention that the concave mirror operates substantially closer to unit magnification.

It is a feature of the present invention that the lens groups before the concave mirror provide only enough power to image the entrance pupil at infinity at the aperture stop at or near the concave mirror.

It is yet another feature of the present invention that the lens group after the concave mirror provides most of the reduction from object to image of the system.

These and other objects, advantages, and features will become readily apparent in view of the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic illustration of one embodiment of the present invention using a single refracting material.

FIG. 2 is another embodiment of the present invention using two different refracting materials.

FIG. 3 is yet another embodiment of the present invention using more than two different refracting materials.

FIG. 4 is another embodiment of the present invention.

FIG. 5 is yet a further embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 illustrates one embodiment of the optical reduction system of the present invention. From its long conjugant end, it comprises an object or reticle plane 10, a first lens group LG1, a folding mirror 20, a second lens group LG2, a beamsplitter cube 30, a first quarter-waveplate 32, a concave mirror 34, a second quarter-waveplate 38, and a third lens group LG3. The image is formed at image or wafer plane 50. The first lens group LG1 comprises a shell 12, a spaced doublet including positive lens 14 and negative lens 16, and positive lens 18. The shell 12 is an almost zero power lens. The second lens group LG2 comprises a positive lens 22, a spaced doublet including a negative lens 24 and a positive lens 26, and negative lens 28. The third lens group LG3 comprises two positive lenses 40 and 42, which are strongly positive, shell 44, and two positive lenses 46 and 48, which are weakly positive. The folding mirror 20 is not essential to the operation of the present invention. However, the folding mirror permits the object and image planes to be parallel which is convenient for the intended application of the optical system of the present invention, which is the manufacture of semiconductor devices using photolithography with a step and scan system.

Radiation enters the system at the reticle or long conjugate end and passes through the first lens group LG1, is reflected by the folding mirror 20, and passes through the second lens group LG2. The radiation enters the beamsplit-

ter cube **30** and is reflected from surface **36** passing through quarter-waveplate **32** and reflected by concave mirror **34**. The radiation then passes back through the quarter-waveplate **32**, the beamsplitter cube **30**, the quarter-waveplate **38**, lens group LG3, and is focused at the image or wafer plane **50**.

The lens groups before the mirror, LG1 and LG2, provide only enough power to image the entrance pupil at infinity to the aperture stop **31** at or near the concave mirror **34**. The combined power of lens groups LG1 and LG2 is slightly negative. The shell **12** and air spaced doublet **14** and **16** assist in aberration corrections including astigmatism, field curvature, and distortion. The lens group LG3, after the concave mirror **34**, provides most of the reduction from object to image size, as well as projecting the aperture stop to an infinite exit pupil. The two strongly positive lenses **40** and **42** provide a high numerical aperture at the image and exit pupils and infinity. The shell **44** has almost no power. The two weakly positive lenses **46** and **48** help correct high order aberrations. The concave mirror **34** may provide a reduction ratio of between 1.6 and 2.7 times that of the total system.

The negative lens **24** in the second lens group LG2 provides a strongly diverging beam directed at the beamsplitter cube **30** and concave mirror **34**. The strongly positive lens **22** provides lateral color correction. The air space doublet comprising lenses **24** and **26** helps to correct spherical aberrations and coma. Concave mirror **34** is preferably aspheric, therefore helping further reduce high order aberrations.

The transmission losses introduced by the beamsplitter cube **30** are minimized by illuminating the object or reticle with plane polarized light and including a true quarter-waveplate **32** between the beamsplitter cube **30** and the concave mirror **34**. By true quarter-waveplate is meant a thickness of birefringent material which introduces a quarter of a wave phase retardance between the S and P polarization states. This is in contrast to an integral number of half plus quarter waves or two thicknesses of material whose phase retardance differs by a quarter wave. The deleterious effects of large angle of incidence variations are thereby minimized at the high numerical aperture by the use of such true zero order waveplates, and by restricting the field size in the plane of incidence. Additionally, by increasing the numerical aperture in lens group LG3, after the concave mirror **34** and beamsplitter cube **30**, the greatest angular range is not seen in these elements.

However, the use of plane polarized light at numerical apertures greater than about 0.5 introduces small but noticeable asymmetries in the imaging. In the present invention,

this can effectively be removed by introducing a second quarter-waveplate **38** after the final passage through the beamsplitter cube **30**, thereby converting the plane polarized light into circularly polarized light. This circularly polarized light is indistinguishable from unpolarized light in its imaging behavior.

The optical system illustrated in FIG. **1** is designed to operate at a reduction ratio of 4 to 1. Therefore, the numerical aperture in the image space is reduced from 0.7 by a factor of 4 to 0.175 at the object or reticle. In other words, the object space numerical aperture is 0.175 and the image space numerical aperture is 0.7. Upon leaving the first lens group LG1 the numerical aperture is reduced to 0.12, a consequence of the positive power needed in lens group LG1 to image the entrance pupil at infinity to the aperture stop of the system close to the concave mirror **34**. The numerical aperture after leaving the second lens group LG2 and entering the beamsplitter is 0.19. Therefore, the emerging numerical aperture from the second lens group LG2, which is 0.19, is larger than the entering or object space numerical aperture of lens group LG1, which is 0.175. In other words, the second lens group LG2 has an emerging numerical aperture greater than the entering numerical aperture of the first lens group LG1. This is very similar to the object space numerical aperture, which is 0.175, due to the overall negative power of the second lens group LG2. This is contrary to prior art systems where the numerical aperture entering a beamsplitter cube is typically close to zero or almost collimated. The concave mirror **34** being almost concentric, the numerical aperture of the radiation reflected from it is increased only slightly from 0.19 to 0.35. The third lens group LG3 effectively doubles the numerical aperture to its final value of 0.7 at the wafer or image plane **50**.

The present invention achieves its relatively high numerical aperture without obstruction by the edges of the beamsplitter cube by means of the negative second group LG2 and the strongly positive third lens group LG3. The use of the beamsplitter cube **30** rather than a plate beamsplitter is important in the present invention because at numerical apertures greater than about 0.45 a beamsplitter cube will provide better performance. There is a reduction of the numerical aperture within the cube by the refractive index of the glass, as well as the absence of aberrations that would be introduced by a tilted plate beamsplitter in the non-collimated beam entering the beamsplitter. The construction data for the lens system illustrated in FIG. **1** according to the present invention is given in Table 1 below.

TABLE 1

Element Number	Radius of Curvature (mm)		Thickness (mm)	Aperture Diameter (mm)		Glass
	Front	Back		Front	Back	
10	Infinite		63.3853			
12	−158.7745	−177.8880	15.0000	124.0478	131.7725	Silica
Space			36.1130			
14	−556.6911	−202.0072	22.2126	148.3881	152.5669	Silica
Space			38.7188			
16	−183.7199	−558.8803	15.0000	156.5546	166.5750	Silica
Space			10.0674			
18	427.2527	−612.2450	28.8010	177.4010	179.0292	Silica
Space			132.3320			
20	Infinite		−74.0000	184.6402		Reflection

TABLE 1-continued

Element Number	Radius of Curvature (mm) Front	Back	Thickness (mm)	Aperture Diameter (mm) Front	Back	Glass
22	−240.4810	2050.9592	−33.3135	188.4055	185.3395	Silica
Space			−29.3434			
24	421.7829	−145.6176	−12.0000	175.5823	169.0234	Silica
Space			−4.2326			
26	−150.4759	472.0653	−46.5091	171.4244	169.9587	Silica
Space			−2.0000			
28	−1472.2790	−138.2223	−15.0000	165.3586	154.8084	Silica
Space			−27.2060			
30	Infinite	Infinite	−91.8186	155.6662	253.0917	Silica
36	Infinite			253.0917		Reflection
30	Infinite	Infinite	91.8186	253.0917	253.0917	Silica
Space			2.0000			
32	Infinite	Infinite	6.0000	185.8693	186.8401	Silica
Space			17.9918			
Stop				188.0655		
34	Aspheric		−17.9918	188.0655		Reflection
32	Infinite	Infinite	−6.0000	183.5471	180.1419	Silica
Space			−2.0000			
30	Infinite	Infinite	−91.8186	178.3346	149.2832	Silica
30	Infinite	Infinite	−70.000	149.2832	128.8604	Silica
Space			−2.0000			
38	Infinite	Infinite	−4.5000	127.9681	126.6552	Silica
Space			−0.7500			
40	−175.1330	1737.4442	−17.7754	121.4715	118.2689	Silica
Space			−0.7500			
42	−108.8178	−580.1370	−18.2407	104.5228	97.7967	Silica
Space			−0.7500			
44	−202.2637	−86.6025	−31.1216	91.7061	57.4968	Silica
Space			−2.3507			
46	−122.1235	−488.7122	−17.9476	56.4818	41.1675	Silica
Space			−0.2000			
48	−160.8506	−360.1907	−6.1500	39.4528	33.5764	Silica
Space			−4.000			
50	Infinite			26.5019		

Concave mirror 34 has an aspheric reflective surface according to the following equation.

$$Z = \frac{(CURV) \ Y^2}{1 + (1 - (1 + k) \ (CURV)^2 \ Y^2)^{1/2}} +$$

$$(A) \ Y^4 + (B) \ Y^6 + (D) \ Y^{10} + (E) \ Y^{12} + (F) \ Y^{14}$$

wherein the constants are as follows,

CURV=−0.00289051

K=0.000000

A=6.08975×10^{-11}

B=2.64378×10^{14}

C=9.82237×10^{-19}

D=7.98056×10^{-23}

E=−5.96805×10^{-27}

F=4.85179×10^{-31}

The lens according to the construction in Table 1 is optimized for radiation centered on 248.4 nanometers. The single refracting material of fused silica and the large portion of refracting power restricts the spectral bandwidth of the embodiment illustrated in FIG. 1 to about 10 picometers or 0.01 nanometers. This spectral bandwidth is more than adequate for a line narrowed krypton fluoride excimer laser light source. The embodiment illustrated in FIG. 1 can be optimized for any wavelength for which fused silica transmits adequately.

A wider spectral bandwidth can be achieved by the use of two optical materials with different dispersions. A second embodiment of the present invention is illustrated in FIG. 2. From its long conjugant end, it comprises an object or reticle plane 10, a lens group LG4, a folding mirror 122, a lens group LG5, a beamsplitter cube 132 having surface 138, a first quarter-waveplate 134, a concave mirror 136, a second quarter-waveplate 140, and lens group LG6. The image is formed at image or wafer plane 50. The lens group LG4 comprises a spaced doublet including negative lens 112 and positive lens 114, a weak positive lens 116, positive lens 118, and shell 120. The lens group LG5 comprises a positive lens 124, a negative lens 126, a positive lens 128, and a negative lens 130. The lens group LG6 comprises two positive lenses 142, 'cemented' doublet including positive lens 144 and negative lens 146, positive lens 148, and 'cemented' doublet including shell 150 and positive lens 152.

This second embodiment uses calcium fluoride in one of the individual positive lenses of the lens group LG4, negative lenses of the lens group LG5, and two of the positive lenses of the lens group LG6. The construction data of the second embodiment illustrated in FIG. 2 of the present invention is given in Table 2 below.

TABLE 2

Element Number	Radius of Curvature (mm) Front	Back	Thickness (mm)	Aperture Diameter (mm) Front	Back	Glass
10	Infinite		60.4852			
112	−205.5158	539.1791	15.2158	124.0926	137.3346	Silica
Space			8.8054			
114	2080.9700	−210.6539	32.4984	142.6149	151.7878	Silica
Space			1.2676			
116	310.4463	700.3748	40.7304	162.4908	165.2126	CaFl
Space			0.5000			
118	634.1820	−798.8523	27.5892	165.4595	166.4747	Silica
Space			0.5000			
120	1480.0597	1312.1247	25.4322	168.7516	164.7651	Silica
Space			136.2343			
122	Infinite		−74.0000	161.9590		Reflection
124	−761.9176	1088.9351	−19.2150	160.3165	159.2384	Silica
Space			−19.9465			
126	648.8361	−202.5872	−12.0000	155.1711	153.0635	CaFl
Space			−7.6304			
128	−400.4276	458.5060	−25.8769	153.0635	153.8055	Silica
Space			−2.0000			
130	−818.0922	−168.5034	−27.5927	152.6663	147.5200	CaFl
Space			−20.5014			
132	Infinite	Infinite	−91.7553	148.6158	252.7349	Silica
138	Infinite			252.7349		Reflection
132	Infinite	Infinite	91.7553	252.7349	252.7349	Silica
Space			2.0000			
134	Infinite	Infinite	6.0000	185.8070	187.0026	Silica
Space			18.1636			
Stop				188.5681		
136	Aspheric		−18.1636	188.5681		Reflection
134	Infinite	Infinite	−6.0000	184.2566	181.1084	Silica
Space			−2.0000			
132	Infinite	Infinite	−91.7553	179.3838	151.7747	Silica
132	Infinite	Infinite	−70.0000	151.7747	133.3985	Silica
Space			−2.0000			
140	Infinite	Infinite	−4.5000	132.5690	131.3876	Silica
Space			−0.5000			
142	−112.0665	−597.6805	−21.4866	123.4895	119.2442	Silica
Space			−0.5000			
144	−116.3137	282.3140	−24.0940	107.8451	101.2412	CaFl
146	282.3140	−66.5293	−13.7306	101.2412	72.6862	Silica
Space			−2.6346			
148	−77.2627	−374.4800	−17.9594	72.0749	62.7659	Silica
Space			−0.5452			
150	−130.1381	−57.1295	−20.8147	58.9696	37.4889	Silica
152	−57.1295	−7305.8777	−6.1425	37.4889	34.3156	CaFl
Space			−4.0000			
Image	Infinite			26.4992		

wherein the constants for the aspheric mirror **134** used in the equation after Table 1 are as follows,

CURV=−0.00286744

K=0.000000

A=−1.92013×10^{-09}

B=−3.50840×10^{-14}

C=2.95934×10^{-19}

D=−1.10495×10^{-22}

E=9.03439×10^{-27}

F=−1.39494×10^{-31}

This second embodiment is optimized for radiation centered on 193.3 nanometers and has a spectral bandwidth of about 200 picometers or 0.2 nanometers. A slightly line narrowed argon fluoride excimer laser is an adequate light source. Additionally, the design can be optimized for any wavelength for which both refractive materials transmit adequately. The bandwidth will generally increase for longer wavelengths, as the material dispersions decrease. For example, around 248.4 nanometers such a two-material design will operate over at least a 400 picometers, 0.4 nanometers bandwidth.

At wavelengths longer than 360 nanometers, a wider range of optical glasses begin to have adequate transmission. A third embodiment illustrated in FIG. **3** takes advantage of this wider selection of glasses and further reduced dispersion. From its long conjugant end, it comprises an object or reticle plane **10**, a lens group LG7, a folding mirror **222**, a lens group LG8, a beamsplitter cube **232** having a surface **238**, a first quarter-waveplate **234**, a concave mirror **236**, a second quarter-waveplate **240**, and lens group LG9. The image is formed at image or wafer plane **50**. The lens group LG7 comprises a spaced doublet comprising negative lens **212** and positive lens **214**, spaced doublet including positive lens **216** and negative lens **218**, and positive lens **220**. The lens group LG8 comprises a positive lens **224**, a negative lens **226**, a positive lens **228**, and a negative lens **230**. The lens group LG9 comprises a positive lenses **242**, cemented doublet including positive lens **244** and negative lens **246**, positive lens **248**, and cemented doublet including shell **250** and positive lens **252**.

The construction data of the third embodiment illustrated in FIG. **3** is given in Table 3 below.

TABLE 3

Element Number	Radius of Curvature (mm) Front	Back	Thickness (mm)	Aperture Diameter (mm) Front	Back	Glass
10	Infinite		59.2960			
212	−620.7809	361.8305	20.2974	125.9406	134.7227	PBM2Y
Space			2.6174			
214	515.7935	−455.1015	39.8858	135.3384	145.6015	PBM2Y
Space			14.7197			
216	431.3189	−239.4002	36.9329	155.6269	157.3014	BSL7Y
Space			0.5000			
218	−259.6013	685.3286	26.3534	156.9363	162.2451	PBM2Y
Space			1.4303			
220	361.5709	−1853.2955	23.3934	168.7516	165.1801	BAL15Y
Space			131.8538			
222	Infinite		−77.8469	169.9390		Reflection
224	−429.2950	455.4247	−32.3086	173.0235	171.1102	PBL6Y
Space			−27.6206			
226	401.0363	−180.0031	−12.0000	159.3555	154.7155	BSL7Y
Space			−5.6227			
228	−258.4722	1301.3764	−26.1321	154.7155	154.1517	PBM8Y
Space			−2.0000			
230	−1282.8931	−180.2226	−12.0000	153.1461	149.4794	BSL7Y
Space			−19.7282			
232	Infinite	Infinite	−91.7349	150.4585	252.6772	Silica
238	Infinite			252.6772		Reflection
232	Infinite	Infinite	91.7349	252.6772	252.6772	Space
Space			2.0000			
234	Infinite	Infinite	6.0000	185.6435	186.7758	Silica
Space			18.2715			
Stop				188.1745		
236	Aspheric		−18.2715	188.1745		Reflection
234	Infinite	Infinite	−6.0000	183.6393	180.1377	Silica
Space			−2.0000			
232	Infinite	Infinite	−91.7349	178.3236	147.9888	Silica
232	Infinite	Infinite	−70.0000	147.9888	126.9282	Silica
Space			−2.0000			
240	Infinite	Infinite	−4.5000	126.0289	124.6750	Silica
Space			−0.5000			
242	−119.8912	−610.6840	−18.6508	117.5305	113.4233	BSM51Y
Space			−0.5000			
244	−114.1327	384.9135	−21.1139	102.6172	96.4137	BSL7Y
246	384.9135	−70.2077	−13.0576	96.4137	71.1691	PBL26Y
Space			−2.8552			
248	−85.7858	−400.3240	−16.9147	70.5182	61.2633	BSM51Y
Space			−0.8180			
250	−151.5235	−54.0114	−19.5810	57.6234	37.3909	BSM51Y
252	−54.0114	−2011.1057	−6.3947	37.3909	34.2119	PBL6Y
Space			−4.0000			
Image	Infinite			26.5002		

wherein the constants for the aspheric mirror **234** used in the equation after Table 1 as follows,

CURV=−0.00291648

K=0.000000

A=−1.27285×10⁻⁹

B=−1.92865×10⁻¹⁴

C=6.21813×10⁻¹⁹

D=−6.80975×10²³

E=6.04233×10⁻²⁷

F=3.64479×10⁻³²

This third embodiment operates over a spectral bandwidth of 8 nanometers centered on 365.5 nanometers. A radiation of this spectral bandwidth can be provided by a filtered mercury arc lamp at the I-line waveband. The optical glasses other than fused silica used in this third embodiment are commonly known as I-line glasses. These optical glasses have the least absorption or solarization effects at the mercury I-line wavelength. These glasses may be found in a commonly available glass catalog provided by O'Hara Corporation, 50 Columbia Road, Branchburg Township, Somerville, N.J. 08876-3519, USA.

FIG. **4** illustrates a fourth embodiment of the optical reduction system of the present invention. This embodiment has a numerical aperture of 0.63 and can operate at a spectral bandwidth of 300 picometers, and preferably of 100 picometers, centered on 248.4 nanometers. From the long conjugate end, it includes an object or reticle plane **410**, a first lens group LG1, a folding mirror **420**, a second lens group LG2, a beamsplitter cube **430**, a first quarter-waveplate **432**, a concave mirror **434**, a second quarter-waveplate **438**, and a third lens group LG3. The image is formed at the image or wafer plane **450**.

The first lens group LG1 comprises a shell **412**, a spaced doublet including a positive lens **414** and a negative lens **416**, and a positive lens **418**. The second lens group LG2 comprises a positive lens **422**, a spaced doublet including a negative lens **424** and a positive lens **426**, and a negative lens

428. The third lens group LG3 comprises two positive lenses **440** and **442**, a shell **444**, and two positive lenses **446** and **448**. Again, as in the embodiment illustrated in FIG. **1**, the folding mirror **420** of FIG. **4** is not essential to the operation of the invention, but nevertheless permits the object **410** and image plane **450** to be parallel to each other which is convenient for the manufacture of semiconductor devices using photolithography.

The construction data of the fourth embodiment illustrated in FIG. **4** is given in Table 4 below.

This fourth embodiment is optimized for radiation centered on 248.4 nm. The single refracting material of fused silica and the large portion of refracting power restricts the spectral bandwidth of the embodiment depicted in FIG. **4**. However, because the fourth embodiment has a maximum numerical aperture of 0.63 rather than of 0.7 as in the first three embodiments, the fourth embodiment provides acceptable imaging over a spectral full-width-half-maximum bandwidth of 300 picometers, or preferably of 100 picometers. Thus, in the former, an unnarrowed, or, in the latter, a

TABLE 4

Element Number	Radius of Curvature (mm) Front	Back	Thickness (mm)	Aperture Diameter (mm) Front	Back	Glass
410	Infinite		63.3853			
412	−183.5661CC	−215.7867CX	17.0000	122.8436	130.6579	Silica
Space			46.6205			
414	−601.1535CC	−230.9702CX	21.4839	149.1476	153.3103	Silica
Space			68.8075			
416	−195.1255CC	−345.4510CX	15.0000	161.6789	170.1025	Silica
Space			3.0000			
418	435.8058CX	−1045.1785CX	24.9351	177.4520	178.2672	Silica
Space			130.0000			
	Decenter (1)					
420	Infinite		−64.5000	180.3457		Reflection
422	−210.7910CX	380.1625CX	−43.1418	181.6672	178.0170	Silica
Space			−15.8065			
424	300.1724CC	−123.4555CC	−12.0000	166.7278	153.3103	Silica
Space			−3.8871			
426	−126.8951CX	972.6391CX	−41.3263	154.8530	151.8327	Silica
Space			−1.5000			
428	−626.4905CX	−116.6456CC	−12.0000	147.6711	136.1163	Silica
Space			−31.8384			
430	Infinite	Infinite	−74.0000	137.2448	200.1127	Silica
	Decenter (2)					
436	Infinite			200.1127		Reflection
430	Infinite	Infinite	74.0000	200.1127	200.1127	Silica
Space			2.0000			
432	Infinite	Infinite	6.0000	148.6188	149.0707	Silica
Space			14.4638			
Stop				149.6392		
434	Aspheric		−14.4638	149.6392		Reflection
432	Infinite	Infinite	−6.0000	144.8563	141.2737	Silica
Space			−2.0000			
430	Infinite	Infinite	−74.0000	139.3606	117.3979	Silica
	Decenter (3)					
430	Infinite	Infinite	−61.0000	117.3979	100.5074	Silica
Space			−2.0000			
438	Infinite	Infinite	−4.5000	99.6617	98.4157	Silica
Space			−1.2000			
440	−157.8776CX	2282.2178CX	−13.7501	94.8267	91.8775	Silica
Space			−1.2000			
442	−94.0059CX	−466.6659CC	−13.4850	82.8663	78.1418	Silica
Space			−1.2000			
444	−147.2485CX	−77.8924CC	−22.2075	72.7262	50.6555	Silica
Space			−3.2091			
446	−159.2880CX	−519.4850CC	−13.8321	49.5648	39.0473	Silica
Space			−0.2000			
448	−129.3683CX	−426.7350CC	−6.1500	37.3816	32.4880	Silica
Space	Image Distance =		−4.0000			
450	Image	Infinite				

The constants for the aspheric mirror **434** used in equation (1) located after Table 1 are as follows:

CURV=−0.00332614

K=0.000000

A=−4.32261E-10

B=3.50228E-14

C=7.13264E-19

D=2.73587E-22

narrowed excimer laser can be employed for the illumination source.

The fourth embodiment differs from the first three embodiments in that the net power of LG1 and LG2 of the fourth embodiment is weakly positive rather than weakly negative as in the first three embodiments. In addition, this illustrates that the overall focal power of LG1 plus LG2 can be either positive or negative and still permit an infinitely distant entrance pupil to be imaged at or near the concave mirror **434**.

FIG. 5 illustrates a fifth embodiment of the optical reduction system of the present invention. Preferably, this embodiment has a numerical aperture of 0.60 and operates at a spectral bandwidth of 300 picometers centered on 248.4

for the manufacture of semiconductor devices using photolithography.

The construction data of the fifth embodiment illustrated in FIG. 5 is given in Table 5 below.

TABLE 5

Element	Radius of Curvature (mm)		Thickness	Aperture Diameter (mm)		
Number	Front	Back	(mm)	Front	Back	Glass
510	Infinite		62.7514			
512	−136.1154 CC	−152.5295 CX	16.8300	120.7552	129.4354	Silica
Space			4.5206			
514	−270.1396 CC	−191.8742 CX	20.5341	132.9152	139.0377	Silica
Space			90.8476			
516	−188.9000 CC	−284.7476 CX	17.5000	156.1938	165.6567	Silica
Space			2.9700			
518	433.8174 CX	−841.5599 CX	25.8293	173.8279	174.8334	Silica
Space			149.4549			
		Decenter(1)				
520	Infinite		−61.0000	177.2183		Reflection
522	−190.3251 CX	−8413.4836 CC	−34.4584	178.5071	174.2260	Silica
Space			−51.5487			
524	690.5706 CC	−146.4997 CC	−11.8800	150.4109	141.8021	Silica
Space			−10.6267			
526	−265.9886 CX	1773.5314 CX	−24.1851	142.1592	141.2400	Silica
Space			−1.5000			
528	−244.9899 CX	−142.8558 CC	−11.8800	139.3290	133.8967	Silica
Space			−21.6411			
530	Infinite	Infinite	−71.2800	134.3115	189.7826	Silica
		Decenter(2)				
536	Infinite			189.7826		Reflection
530	Infinite	Infinite	71.2800	189.7826	189.7826	Silica
Space			1.9800			
532	Infinite	Infinite	5.9400	142.3429	142.6707	Silica
Space			18.5263			
Stop				143.5034		
534	Aspheric		−18.5263	143.5034		Reflection
532	Infinite	Infinite	−5.9400	134.2788	130.9398	Silica
Space			−1.9800			
530	Infinite	Infinite	−71.2800	130.1221	111.7247	Silica
		Decenter(3)				
530	Infinite	Infinite	−60.4000	111.7247	96.1353	Silica
Space			−1.9800			
538	Infinite	Infinite	−4.4550	95.3562	94.2064	Silica
Space			−1.1880			
540	−127.4561 CX	−1398.8019 CC	−13.0104	90.4737	87.7002	Silica
Space			−1.1880			
542	−98.8795 CX	−424.1302 CC	−12.2874	80.7016	76.3270	Silica
Space			−1.1880			
544	−132.0104 CX	−70.9574 CC	−17.8706	71.0789	53.4306	Silica
Space			−3.1246			
546	−123.1071 CX	−585.4471 CC	−19.9496	52.6417	38.2256	Silica
Space			−0.1980			
548	−137.8349 CX	−292.6179 CC	−6.0885	36.7251	31.8484	Silica
Space		Image Distance =	−4.0000			
550	Image	Infinite			26.5000	

nanometers. From the long conjugate end, it includes an object or reticle plane **510**, a first lens group LG1, a folding mirror **520**, a second lens group LG2, a beamsplitter cube **530**, a first quarter-waveplate **532**, a concave mirror **534**, a second quarter-waveplate **538**, and a third lens group LG3. The image is formed at the image or wafer plane.

The first lens group LG1 comprises a shell **512**, a spaced doublet including a positive lens **514** and a negative lens **516**, and a positive lens **518**. The second lens group LG2 comprises a positive lens **522**, a spaced doublet including a negative lens **524** and a positive lens **526**, and a negative lens **528**. The third lens group LG3 comprises two positive lenses **540** and **542**, a shell **544**, and two positive lenses **546** and **548**. Again, as in the embodiment illustrated in FIG. 1, the folding mirror **520** of FIG. 5 is not essential to the operation of the invention, but nevertheless permits the object and image planes to be parallel to each other which is convenient

The constants for the aspheric mirror **534** used in equation (1) located after Table 1 are as follows:

CURV=−0.00325995

K=0.000000

A=−6.91799E-10

B=5.26952E-15

C=6.10046E-19

D=1.59429E-22

This fifth embodiment is optimized for radiation centered on 248.4 nm. The single refracting material of fused silica and the large portion of refracting power restricts the spectral bandwidth of the embodiment depicted in FIG. 5. However, because the fifth embodiment has a maximum numerical aperture of 0.6 rather than of 0.7 as in the first three embodiments, the fifth embodiment provides acceptable imaging over a spectral full-width-half-maximum

bandwidth of 300 picometers. Thus, an unnarrowed excimer laser can be employed for an illumination source. The fifth embodiment differs from the first three embodiments in that the net power of LG1 and LG2 of the fifth embodiment is weakly positive rather than weakly negative as in the first three embodiments. In addition, this illustrates that the overall focal power of LG1 plus LG2 can be either positive or negative and still permit an infinitely distant entrance pupil to be imaged at or near the concave mirror 534.

Although the preferred embodiments have been illustrated and described, it will obvious to those skilled in the art that various modifications may be made without departing from the spirit and scope of thid invention.

What is claimed:

1. catadioptric optical reduction system having an object space numerical aperture, from the long conjugate end to the short conjugate end, comprising:

first lens means for providing a negative power having an emerging numerical aperture, the emerging numerical aperture being larger than the object space numerical aperture;

a beamsplitter;

a concave mirror; and

second lens means for providing a positive power, wherein the negative power of said first lens means provides only enough power to image an entrance pupil of the system at infinity to an aperture stop at or near said mirror, and the positive power of said second lens means provides substantially all of the power of the system and images the exit pupil of the system to infinity.

2. A catadioptric optical reduction system from the long conjugate end to the short conjugate end, comprising:

a first lens group of positive power, said first lens group having an entering numerical aperture;

a second lens group of negative power, said second lens group separated from said first lens group and having an emerging numerical aperture greater than the entering numerical aperture of said first lens group;

a beamsplitter;

a quarter waveplate;

a concave mirror;

a third lens group of positive power; and

wherein the positive power of said first lens group provides enough power to image an entrance pupil of the system at infinity through said second lens group to an aperture stop at or near said mirror, the negative power of said second lens group provides the necessary conjugates for said concave mirror, and the positive power of said third lens group provides the remainder of the total system power and images the exit pupil of the system to infinity.

3. An optical reduction system as in claim further comprising:

a first quarter-waveplate placed between said beamsplitter and said concave mirror.

4. An optical reduction system as in claim 3 further comprising:

a second quarter-waveplate placed between said beamsplitter and said second lens means.

5. An optical reduction system as in claim 2 wherein:

said first lens group includes refractive elements made from at least two different materials; and

said second lens group includes refractive elements made from at least two different materials.

6. An optical reduction system as in claim 2 wherein said first lens group comprises:

at least one lens of positive power;

a first lens of substantially zero power; and

a first doublet, whereby said at least one lens of positive power images an entrance pupil at infinity to an aperture stop near said mirror, and said first lens of substantially zero power and said first doublet help correct aberrations such as astigmatism, field curvature, and distortion.

7. An optical reduction system as in claim 6 wherein:

said first doublet is an air spaced doublet.

8. A catadioptric optical reduction system from the long conjugate end to the short conjugate end, comprising:

a first lens group of positive power;

a second lens group of negative power;

a beamsplitter;

a quarter waveplate;

a concave mirror;

a third lens group of positive power;

said first lens group including,

at least one lens of positive power;

a first lens of substantially zero power; and

a first doublet, whereby said first lens of substantially zero power and said first doublet help correct aberrations such as astigmatism, field curvature, and distortion,

said second lens group including,

at least one lens of negative power;

a positive lens; and

a second doublet, whereby said at least one lens of negative power provides a diverging beam for said beamsplitter and said mirror, said positive lens provides lateral color correction, and said second doublet helps to correct for spherical aberration and coma, and

wherein the positive power of said first lens group provides enough power to image the entrance pupil of the system at infinity through said second lens group to an aperture stop at or near said mirror, the negative power of said second lens group provides the necessary conjugates for said concave mirror, and the positive power of said third lens group provides the remainder of the total system power and images the exit pupil of the system to infinity.

9. An optical reduction system as in claim 8 wherein said third lens group comprises:

a first subgroup of at least two positive lenses;

a second lens of substantially zero power; and

a second subgroup of at least two positive lenses,

whereby said first subgroup of at lease two positive lenses provides a high numerical aperture at an image and exit pupil and infinity, and said second lens of substantially zero power and said second subgroup of at least two positive lenses provide high-order aberration correction.

10. An optical reduction system as in claim 9 wherein:

said second doublet is a cemented doublet.

11. An optical reduction system as in claim 2 further comprising:

a folding placed between said first lens group and said second lens group.

12. An optical reduction system as in claim 2 wherein:

said mirror is aspheric.

13. An optical reduction system as in claim 1 wherein:

said first lens means and said second lens means include refractive elements made of at least two different materials.

14. An optical reduction system comprising:

a construction according to the following construction data

a second quarter-wave plate;

a fifth positive lens;

a second doublet;

a sixth positive lens; and

a third doublet,

TABLE 1

Element Number	Radius of Curvature (mm) Front	Back	Thickness (mm)	Aperture Diameter (mm) Front	Back	Glass
10	Infinite		63.3853			
12	−158.7745	−177.8800	15.0000	124.0478	131.7725	Silica
Space			36.1130			
14	−556.6911	−202.0072	22.2126	148.3881	152.5669	Silica
Space			38.7188			
16	−183.7199	−558.8803	15.0000	156.5546	166.5750	Silica
Space			10.0674			
18	427.2527	−612.2450	28.8010	177.4010	179.0292	Silica
Space			132.3320			
20	Infinite		−74.0000	184.6402		Reflection
22	−240.4810	2050.9592	−33.3135	188.4055	185.3395	Silica
Space			−29.3434			
24	421.7829	−145.6176	−12.0000	175.5823	169.0234	Silica
Space			−4.2326			
26	−150.4759	472.0653	−46.5091	171.4244	169.9587	Silica
Space			−2.0000			
28	−1472.2790	−138.2223	−15.0000	165.3586	154.8084	Silica
Space			−27.2060			
30	Infinite	Infinite	−91.8186	155.6662	253.0917	Silica
36	Infinite			253.0917		Reflection
30	Infinite	Infinite	91.8186	253.0917	253.0917	Silica
Space			2.0000			
32	Infinite	Infinite	6.0000	185.8693	186.8401	Silica
Space			17.9918			
Stop				188.0655		
34	Aspheric		−17.9918	188.0655		Reflection
32	Infinite	Infinite	−6.0000	183.5471	180.1419	Silica
Space			−2.0000			
30	Infinite	Infinite	−91.8186	178.3346	149.2832	Silica
30	Infinite	Infinite	−70.000	149.2832	128.8604	Silica
Space			−2.0000			
38	Infinite	Infinite	−4.5000	127.9681	126.6552	Silica
Space			−0.7500			
40	−175.1330	1737.4442	−17.7754	121.4715	118.2689	Silica
Space			−0.7500			
42	−108.8178	−580.1370	−18.2407	104.5228	97.7967	Silica
Space			−0.7500			
44	−202.2637	−86.6025	−31.1216	91.7061	57.4968	Silica
Space			−2.3507			
46	−222.1235	−488.7122	−17.9476	56.4818	41.1675	Silica
Space			−0.2000			
48	−160.8506	−360.1907	−6.1500	39.4528	33.5764	Silica
Space			−4.000			
50	Infinite			26.5019		

15. A catadioptric optical reduction system having a relatively high numerical aperture, from the long conjugate end to the short conjugate end, comprising:

a first doublet;

a first positive lens;

a second positive lens;

a shell;

a third positive lens;

a first negative lens;

a forth positive lens;

a second negative lens;

a beamsplitter cube;

a first quarter-wave plate;

a concave mirror;

arranged such that radiation entering the system passes through said first doublet, said first positive lens, said second positive lens, said shell, said third positive lens, said first negative lens, said second negative lens; said beamsplitter cube, said first quarter-wave plate, and is reflected by said concave mirror back through said first quarter-wave plate and said beamsplitter cube, and through said second quarter-wave plate, said fifth positive lens, said second doublet; said sixth positive lens, and said third doublet.

16. An optical reduction system as in claim 15 further comprising:

a folding mirror placed between said shell and said third positive lens.

17. An optical reduction system as in claim 16 having:

a construction according to the following construction data

a shell; and

TABLE 2

Element Number	Radius of Curvature (mm) Front	Back	Thickness (mm)	Aperture Diameter (mm) Front	Back	Glass
10	Infinite		60.4852			
112	−205.5158	539.1791	15.2158	124.0926	137.3346	Silica
Space			8.8054			
114	2080.9700	−210.6539	32.4984	142.6149	151.7878	Silica
Space			1.2676			
116	310.4463	700.3748	40.7304	162.4908	165.2126	CaFl
Space			0.5000			
118	634.1820	−798.8523	27.5892	165.4595	166.4747	Silica
Space			0.5000			
120	1480.0597	1312.1247	25.4322	168.7516	164.7651	Silica
Space			136.2343			
122	Infinite		−74.0000	161.9590		Reflection
124	−761.9176	1088.9351	−19.2150	160.3165	159.2384	Silica
Space			−19.9465			
126	648.8361	−202.5872	−12.0000	155.1711	153.0635	CaFl
Space			−7.6304			
128	−400.4276	458.5060	−25.8769	153.0635	153.8055	Silica
Space			−2.0000			
130	−818.0922	−168.5034	−27.5927	152.6663	147.5200	CaFl
Space			−20.5014			
132	Infinite	Infinite	−91.7553	148.6158	252.7349	Silica
138	Infinite			252.7349		Reflection
132	Infinite	Infinite	91.7553	252.7349	252.7349	Silica
Space			2.0000			
134	Infinite	Infinite	6.0000	185.8070	187.0026	Silica
Space			18.1636			
Stop				188.5681		
136	Aspheric		−18.1636	188.5681		Reflection
134	Infinite	Infinite	−6.0000	184.2566	181.1084	Silica
Space			−2.0000			
132	Infinite	Infinite	−91.7553	179.3838	151.7747	Silica
132	Infinite	Infinite	−70.0000	151.7747	133.3985	Silica
Space			−2.0000			
140	Infinite	Infinite	−4.5000	132.5690	131.3876	Silica
Space			−0.5000			
142	−112.0665	−597.6805	−21.4866	123.4895	119.2442	Silica
Space			−0.5000			
144	−116.3137	282.3140	−24.0940	107.8451	101.2412	CaFl
146	282.3140	−66.5293	−13.7306	101.2412	72.6862	Silica
Space			−2.6346			
148	−77.2627	−374.4800	−17.9594	72.0749	62.7659	Silica
Space			−0.5452			
150	−130.1381	−57.1295	−20.8147	58.9696	37.4889	Silica
152	−57.1295	−7305.8777	−6.1425	37.4889	34.3156	CaFl
Space			−4.0000			
Image	Infinite			26.4992		

18. A catadioptric optical reduction system having a relatively high numerical aperture, from the long conjugate end to the short conjugate end, comprising:

a first doublet;

a second doublet;

a first positive lens;

a second positive lens;

a first negative lens;

a third positive lens;

a second negative lens;

a beamsplitter cube;

a first quarter-wave plate;

a concave mirror;

a second quarter-wave plate;

a fourth positive lens;

a third doublet;

a fifth positive lens;

a sixth positive lens,

arranged such that radiation entering the system passes through said first doublet, said second doublet, said first positive lens, said second positive lens, said first negative lens, said third positive lens, said second negative lens, said beamsplitter cube, said first quarter-wave plate, and is reflected by said concave mirror back through said first quarter-wave plate and said beamsplitter cube, and through said second quarter-wave plate, said fourth positive lens, said third doublet, said fifth positive lens, said shell, and said sixth positive lens.

19. An optical reduction system as in claim 18 further comprising:

a folding mirror placed between said first positive lens and said second positive lens.

20. An optical reduction system as in claim 19 having:

a construction according to the following construction data

TABLE 3

Element Number	Radius of Curvature (mm) Front	Back	Thickness (mm)	Aperture Diameter (mm) Front	Back	Glass
10	Infinite		59.2960			
212	−620.7809	361.8305	20.2974	125.9406	134.7227	PBM2Y
Space			2.6174			
214	515.7935	−455.1015	39.8858	135.3384	145.6015	PBM2Y
Space			14.7197			
216	431.3189	−239.4002	36.9329	155.6269	157.3014	BSL7Y
Space			0.5000			
218	−259.6013	685.3286	26.3534	156.9363	162.2451	PBM2Y
Space			1.4303			
220	361.5709	−1853.2955	23.3934	168.7516	165.1801	BAL15Y
Space			311.8538			
222	Infinite		−77.8649	169.9390		Reflection
224	−429.2950	455.4247	−32.3086	173.0235	171.1102	PBL6Y
Space			−27.6206			
226	401.0363	−180.0031	−12.0000	159.3555	154.7155	BSL7Y
Space			−5.6227			
228	−258.4722	1301.3764	−26.1321	154.7155	154.1517	PBM8Y
Space			−2.0000			
230	−1282.8931	−180.2226	−12.0000	153.1461	149.4794	BSL7Y
Space			−19.7282			
232	Infinite	Infinite	−91.7349	150.4585	252.6772	Silica
238	Infinite			252.6772		Reflection
232	Infinite	Infinite	91.7349	252.6772	252.6772	Silica
Space			2.0000			
234	Infinite	Infinite	6.0000	185.6435	186.7758	Silica
Space			18.2715			
Stop				188.1745		
236	Aspheric		−18.2715	188.1745		Reflection
234	Infinite	Infinite	−6.0000	183.6393	180.1377	Silica
Space			−2.0000			
232	Infinite	Infinite	−91.7349	178.3236	147.9888	Silica
232	Infinite	Infinite	−70.0000	147.9888	126.9282	Silica
Space			−2.0000			
240	Infinite	Infinite	−4.5000	126.0289	124.6750	Silica
Space			−0.5000			
242	−119.8912	−610.6840	−18.6508	117.5305	113.4233	BSM51Y
Space			−0.5000			
244	−114.1327	384.9135	−21.1139	102.6172	96.4137	BSL7Y
246	384.9135	−70.2077	−13.0576	96.4137	71.1691	PBL26Y
Space			−2.8852			
248	−85.7858	−400.3240	−16.9147	70.5182	61.2633	BSM51Y
Space			−0.8180			
250	−151.5235	−54.0114	−19.5810	57.6234	37.3909	BSM51Y
252	−54.0114	−2011.1057	−6.3947	37.3909	34.2119	PBL6Y
Space			−4.0000			
Image	Infinite			26.5002		

21. An optical reductions system as in claim 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, or 14, wherein said beamsplitter is a cube.

22. An optical reduction system as in claim 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, or 14, wherein said aperture stop is between said beamsplitter and said concave mirror.

23. An optical reduction system as in claim 22, wherein a variable aperture is placed between said beamsplitter and said concave mirror.

24. An optical reduction system as in claim 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13 or 14, wherein said concave mirror includes a reduction ratio of between 1.6 and 2.7 times that of the total system reduction ratio.

25. A catadioptric optical reduction system having a relatively high numerical aperture, from the long conjugate end to the short conjugate end, comprising:

a first lens group of positive power;

a second lens group of negative power;

a beamsplitter;

a concave mirror;

a third lens group of positive power;

a first quarter-waveplate placed between said beamsplitter and said concave mirror;

a second quarter-waveplate placed between said beamsplitter and said third lens group; and

wherein the positive power of said first and second lens groups provide only enough power to image an entrance pupil of the system at infinity to an aperture stop at or near said mirror, the negative power of said second lens group provides the correct conjugates for said concave mirror, and the positive power of said third lens group provides the remainder of the total system power and images the exit pupil of the system to infinity.

26. An optical reduction system as in claim 25, wherein the first quarter-waveplate and/or second quarter-waveplate are true zero order quarter waveplates.

27. A catadioptric optical reduction system having a relatively high numerical aperture, from the long conjugate end to the short conjugate end, comprising:

a first lens group of positive power;

a second lens group of negative power, said first and second lens group having a net power;

a beamsplitter, the net power of said first and second lens
group resulting in a non-collimated beam entering said
beamsplitter from said first and second lens group;

a concave mirror,

the net power of said first and second lens group providing
only enough power to image the system entrance pupil
at infinity to an aperture stop at or near said concave
mirror; and

a third lens group of positive power;

arranged such that radiation entering said system passes
through said first lens group, said second lens group,
said beamsplitter, and is reflected by said concave
mirror back through said beamsplitter and through said
third lens group.

28. An optical reduction system as in claim 2 having a
construction according to the following data

TABLE 4

Element	Radius of Curvature (mm)		Thickness	Aperture Diameter (mm)		
Number	Front	Back	(mm)	Front	Back	Glass
410	Infinite		63.3853			
412	−183.5661 CC	−215.7867 CX	17.0000	122.8436	130.6579	Silica
Space			46.6205			
414	−601.1535 CC	−230.9702 CX	21.4839	149.1476	153.3103	Silica
Space			68.8705			
416	−195.1255 CC	−345.4510 CC	15.0000	161.6789	170.1025	Silica
Space			3.0000			
418	435.8058 CX	−1045.1785 CX	24.9351	177.4520	178.2672	Silica
Space			130.0000			
	Decenter(1)					
420	Infinite		−64.5000	180.3457		Reflection
422	−210.7910 CX	380.1625 CX	−43.1418	181.6672	178.0170	Silica
Space			−15.8065			
424	300.1724 CC	−123.4555 CC	−12.0000	166.7278	153.3103	Silica
Space			−3.8871			
426	−126.8951 CX	972.6391 CX	−41.3263	154.8530	151.8327	Silica
Space			−1.5000			
428	−626.4905 CX	−116.6456 CC	−12.0000	147.6711	136.1163	Silica
Space			−31.8384			
430	Infinite	Infinite	−74.0000	137.2448	200.1127	Silica
	Decenter(2)					
436	Infinite			200.1127		Reflection
430	Infinite	Infinite	74.0000	200.1127	200.1127	Silica
Space			2.0000			
432	Infinite	Infinite	6.0000	148.6188	149.0707	Silica
Space			14.4638			
Stop				149.6392		
434	Aspheric		−14.4638	149.6392		Reflection
432	Infinite	Infinite	−6.0000	144.8563	141.2737	Silica
Space			−2.0000			
430	Infinite	Infinite	−74.0000	139.3606	117.3979	Silica
	Decenter(3)					
430	Infinite	Infinite	−61.0000	117.3979	100.5074	Silica
Space			−2.0000			
438	Infinite	Infinite	−4.5000	99.6617	98.4157	Silica
Space			−1.2000			
440	−157.8776 CX	2282.2178 CX	−13.7501	94.8267	91.8775	Silica
Space			−1.2000			
442	−94.0059 CX	−466.6659 CC	−13.4850	82.8663	78.1418	Silica
Space			−1.2000			
444	−147.2485 CX	−77.8924 CC	−22.2075	72.7262	50.6555	Silica
Space			−3.2091			
446	−159.2880 CX	−519.4850 CC	−13.8321	49.5648	39.0473	Silica
Space			−0.2000			
448	−129.3683 CX	−426.7350 CC	−6.1500	37.3816	32.4880	Silica
Space	Image Distance =		−4.0000			
450	Image	Infinte			26.5003	

29. An optical reduction system as in claim 2 having a
construction according to the following data

TABLE 5

Element Number	Radius of Curvature (mm) Front	Back	Thickness (mm)	Aperture Diameter (mm) Front	Back	Glass
510	Infinite		62.7514			
512	−136.1154 CC	−152.5295 CX	16.8300	120.7552	129.4354	Silica
Space			4.5206			
514	−270.1396 CC	−191.8742 CX	20.5341	132.9152	139.0377	Silica
Space			90.8476			
516	−188.9000 CC	−284.7476 CX	17.5000	156.1938	165.6567	Silica
Space			2.9700			
518	433.8174 CX	−841.5599 CX	25.8293	173.8279	174.8334	Silica
Space			149.4549			
		Decenter(1)				
520	Infinite		−61.0000	177.2183		Reflection
522	−190.3251 CX	−8413.4836 CC	−34.4584	178.5071	174.2260	Silica
Space			−51.5487			
524	690.5706 CC	−146.4997 CC	−11.8800	150.4109	141.8021	Silica
Space			−10.6267			
526	−265.9886 CX	1773.5314 CX	−24.1851	142.1592	141.2400	Silica
Space			−1.5000			
528	−244.9899 CX	−142.8558 CC	−11.8800	139.3290	133.8967	Silica
Space			−21.6411			
530	Infinite	Infinite	−71.2800	134.3115	189.7826	Silica
		Decenter(2)				
536	Infinite			189.7826		Reflection
530	Infinite	Infinite	71.2800	189.7826	189.7826	Silica
Space			1.9800			
532	Infinite	Infinite	5.9400	142.3429	142.6707	Silica
Space			18.5263			
Stop				143.5034		
534	Aspheric		−18.5263	143.5034		Reflection
532	Infinite	Infinite	−5.9400	134.2788	130.9398	Silica
Space			−1.9800			
530	Infinite	Infinite	−71.2800	130.1221	111.7247	Silica
		Decenter(3)				
530	Infinite	Infinite	−60.4000	111.7247	96.1353	Silica
Space			−1.9800			
538	Infinite	Infinite	−4.4550	95.3562	94.2064	Silica
Space			−1.1880			
540	−127.4561 CX	−1398.8019 CC	−13.0104	90.4737	87.7002	Silica
Space			−1.1880			
542	−98.8795 CX	−424.1302 CC	−12.2874	80.7016	76.3270	Silica
Space			−1.1880			
544	−132.0104 CX	−70.9574 CC	−17.8706	71.0789	53.4306	Silica
Space			−3.1246			
546	−123.1071 CX	−585.4471 CC	−19.9496	52.6417	38.2256	Silica
Space			−0.1980			
548	−137.8349 CX	−292.6179 CC	−6.0885	36.7251	31.8484	Silica
Space	Image Distance =		−4.0000			
550	Image	Infinite			26.5000	

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30. A catadioptric optical reduction system having an image space numerical aperture and an object space numerical aperture, from the long conjugate end to the short conjugate end, comprising:

a first lens group of positive power;

a second lens group of negative power, said second lens group having an emerging numerical aperture, the emerging numerical aperture being substantially similar to the object space numerical aperture;

a beamsplitter;

a concave mirror; and

a third lens group of positive power;

arranged such that radiation entering said system passes through said first lens group, said second lens group, said beamsplitter, and is reflected by said concave mirror back through said beamsplitter and through said third lens group.

31. A catadioptric optical reduction system as in claim **30** wherein:

the emerging numerical aperture is slightly larger than the object space numerical aperture.

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