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Williamson

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

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[21] Appl. No.: 134,505

[22] Filed: Oct. 8, 1993

Related U.S. Application Data

[63]	Continuation-in-part of Ser. No. 9,284, Jan. 26, 199	3.

Int. Cl.⁶ G02B 17/00

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

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

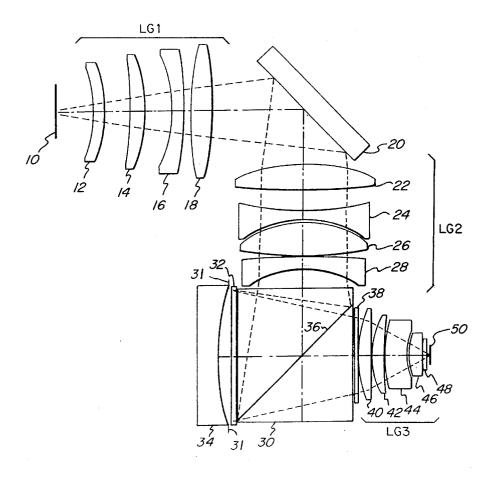
Primary Examiner—Georgia Y. Epps Assistant Examiner-Dawn-Marie Bey

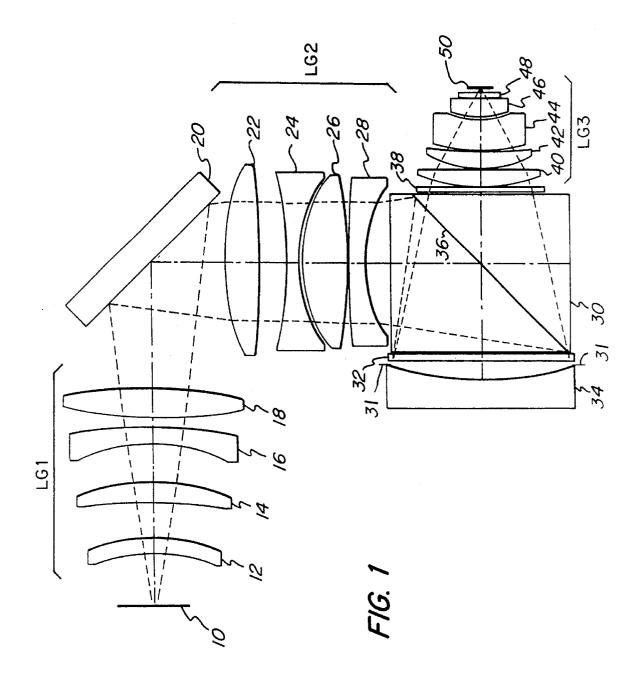
Attorney, Agent, or Firm-Fattibene and Fattibene; Paul A. Fattibene; Robert Moll

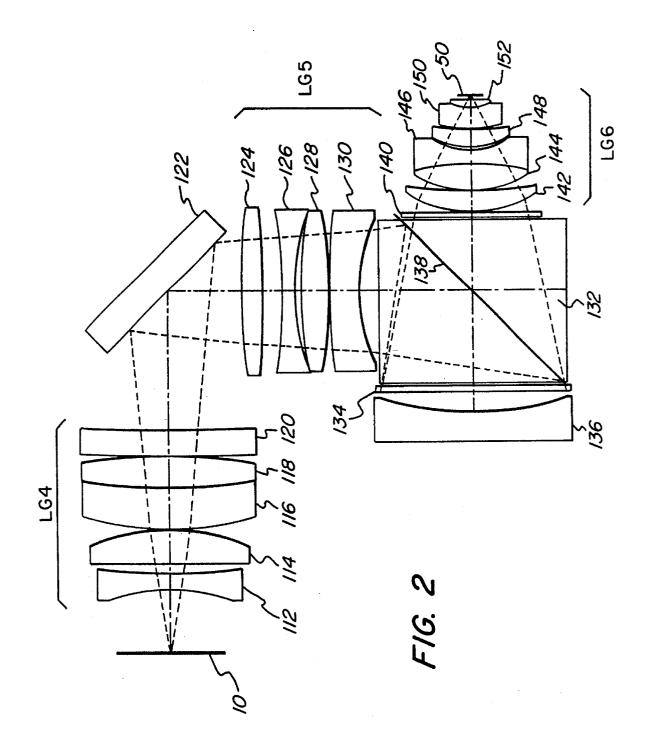
[57] ABSTRACT

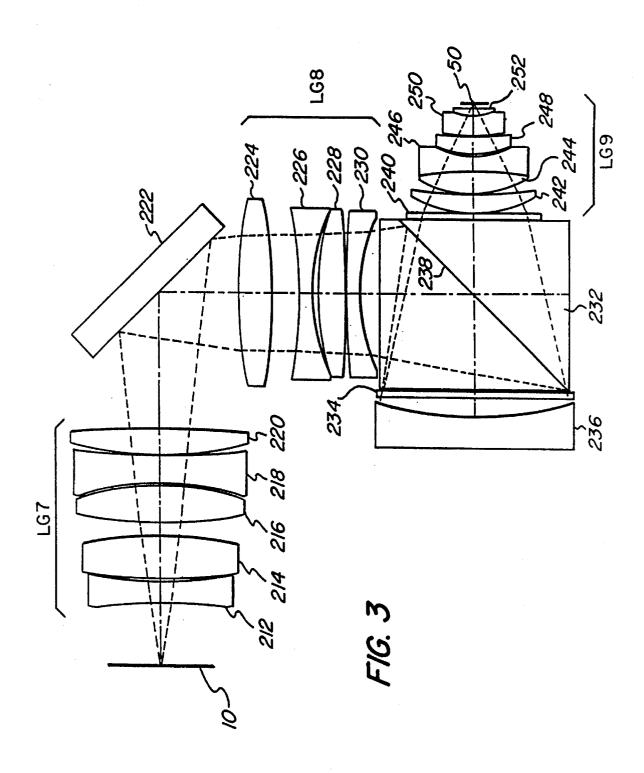
A catadioptric optical reduction system for use in the photolithographic manufacture of semiconductors having a concave mirror operating near unit magnification, or close to a concentric condition. A lens group before the mirror provides only enough power to image the entrance pupil at infinity to the 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.

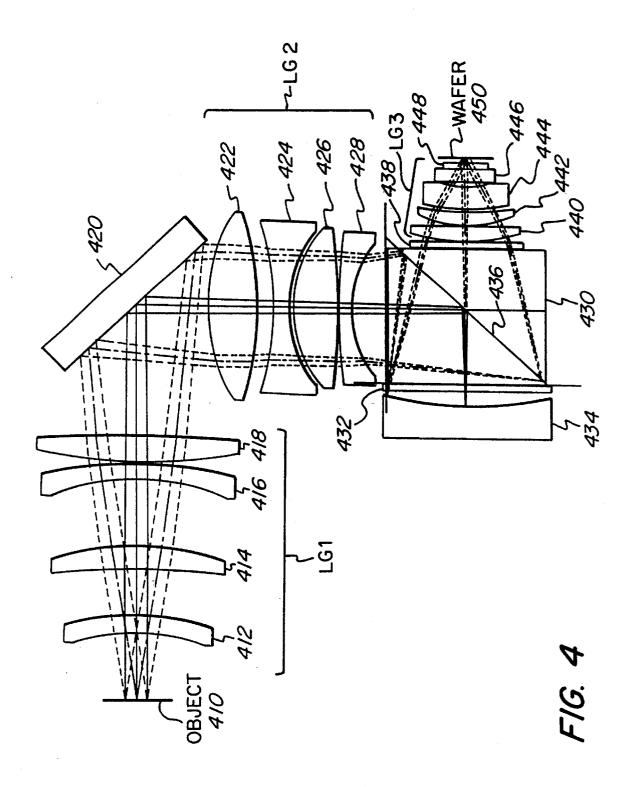
31 Claims, 5 Drawing Sheets

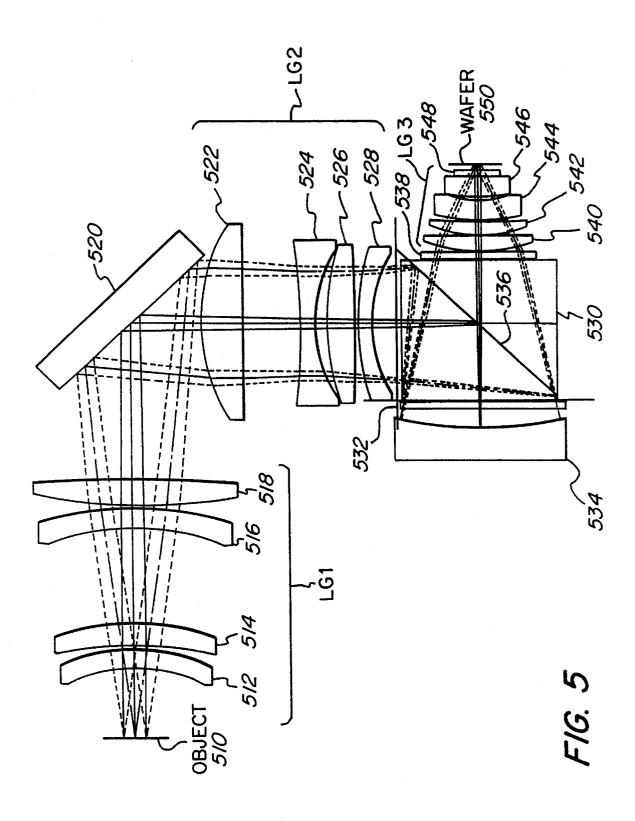












CATADIOPTRIC OPTICAL REDUCTION SYSTEM WITH HIGH NUMERICAL APERTURE

This application is a continuation-in-part, of application 5 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 20 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. 25 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 30 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. 60 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 65 pupil at infinity at the aperture stop at or near the concave mirror. The third lens group after the concave mirror pro-

2

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 500.

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 beam-splitter 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 quarterwaveplate 32 between the beamsplitter cube 30 and the 35 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,

4

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	Radius of Curvature (mm)		Thickness		Aperture Diameter (mm)		
Number	Front	Back	(mm)	Front	Back	Glass	
10	Infi	nite	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	Infi	nite	-74.0000	184.	6402	Reflection	

TABLE 1-continued

Element	Radi Curvatu	us of re (mm)	Thickness		Diameter m)	
Number	Front	Back	(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	Infi			253.		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				188.0	0655	
34	Aspl	neric	-17.9918	188.0	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	Infi	nite		26.5	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

 $A=6.08975\times10^{-11}$

 $B=2.64378\times10^{14}$

C=9.82237×10⁻¹⁹

D=7.98056×10⁻²³

 $E=-5.96805\times10^{-27}$

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

			IABLE 2			
Element	Radii Curvatu		Thickness		e Diameter nm)	
Number	Front	Back	(mm)	Front	Back	Glass
10	· Infi	nite	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	165,2126Ca	Fl
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		0.500	
122	Infi		-74.0000		.9590	Reflection
124	-761.9176	1088.9351	-19.2150	160.3165	159.2384	Silica
Space 126	648,8361	-202.5872	-19.9465 -12.0000	155.1711	153.0635	CaFl
Space	040.0301	-202.3672	-7.6304	133.1711	133,0033	Cari
128	-400.4276	458.5060	-7.0304 -25.8769	153.0635	153,8055	Silica
Space	-400.4270	430.3000	-2.0000	155.0055	133.0033	Sinca
130	-818.0922	-168.5034	-27.5927	152.6663	147,5200	CaFl
Space	010.0722	100.5051	-20.5014	152.0005	117.5200	Cia i
132	Infinite	Infinite	-91.7553	148.6158	252,7349	Silica
138	Infi				2.7349	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	Aspl		-18.1636		3.5681	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	7.6.	T. C	-2.0000	120 5600	101 2076	0.11.
140	Infinite	Infinite	-4.5000	132.5690	131.3876	Silica
Space 142	112.0665	507 6905	-0.5000	172 4006	110 2442	Silica
	-112.0665	-597.6805	21.4866 0.5000	123.4895	119,2442	Sinca
Space 144	-116.3137	282.3140	-0.5000 -24.0940	107.8451	101.2412	CaFl
144	282.3140	-66.5293	-13.7306	107.8431	72.6862	Silica
Space	202.3170	00.5295	-2.6346	101.2712	12.0002	Sinca
148	-77.2627	-374.4800	-17.9594	72.0749	62.7659	Silica
Space		57 1.1000	-0.5452	12.07 19	32.1007	- mou
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	Infi	nite		26	5.4992	
						<u></u>

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

 $B=-3.50840\times10^{-14}$

 $C=2.95934\times10^{-19}$

 $D=-1.10495\times10^{-22}$

E=9.03439×10⁻²⁷

 $F=-1.39494\times10^{-31}$

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 65 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 $_{50}$ 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

			1ABLE 3	'		
Element		us of re (mm)	Thickness		Diameter nm)	_
Number	Front	Back	(mm)	Front	Back	Glass
10	Infi	nite	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 <i>.</i> 7516	165.1801	BAL15Y
Space		_	131.8538			
222	Infi		-77.8469		9390	Reflection
224	-429.2950	455.4247	-32.3086	173.0235	171.1102	PBL6Y
Space	401 0060	100 0021	-27.6206	150 2555	1515155	Day av
226 Space	401.0363	-180.0031	-12.0000	159.3555	154.7155	BSL7Y
Space 228	-258.4722	1301.3764	-5.6227 -26.1321	154.7155	154 1517	DD3 rosz
Space	-230.4722	1301,3704	-20.1321 -2.0000	134.7133	154.1517	PBM8Y
230	-1282,8931	-180.2226	-2.0000 -12.0000	153.1461	149.4794	BSL7Y
Space	-1202.0931	-160.2220	-12.0000 -19.7282	133.1401	149.4794	DOL/I
232	Infinite	Infinite	-91.7349	150.4585	252.6772	Silica
238	Infi		-71.7547	252.		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	Asph		-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	T. C	T C '	-2.0000	106 0000	104 6750	0.1.
240	Infinite	Infinite	-4.5000	126.0289	124.6750	Silica
Space 242	110 0010	-610.6840	-0.5000	117 5205	112 4222	DCMCIN
Space	-119.8912	-010.0840	-18.6508 -0.5000	117.5305	113,4233	BSM51Y
244	-114.1327	384,9135	-0.3000 -21.1139	102.6172	96,4137	BSL7Y
244	384.9135	-70.2077	-13.0576	96.4137	71.1691	PBL26Y
Space	307.7133	10.2011	-2.8552	70.7137	/1.10/1	1 2020 1
248	-85.7858	-400.3240	-16.9147	70.5182	61,2633	BSM51Y
Space	05.7050	100.52 10	-0.8180	75.5102	01,2000	
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	Infi	nite		26.	5002	
			0.00			

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

CURV=-0.00291648

K=0.000000

 $A=-1.27285\times10^{-9}$

 $B=-1.92865\times10^{-14}$

 $C=6.21813\times10^{-19}$

 $D=-6.80975\times10^{23}$

E=6.04233×10⁻²⁷

 $F=3.64479\times10^{-32}$

This third embodiment operates over a spectral bandwidth 60 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 65 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

12

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	Radiu Curvatur		Thickness	Aperture (m	Diameter m)	<u>.</u> .
Number	Front	Back	(mm)	Front	Back	Glass
410	Infin	ite	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	Infir		-64.5000	180.		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 Decenter (2)	-74.0000	137.2448	200.1127	Silica
436	Infir			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	Asph	eric	-14.4638		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	,,,,,,,,,	2027	
440	-157.8776CX	2282.2178CX	-13.7501	94.8267	91.8775	Silica
Space	15.,5770011		-1.2000	,	, 1.0113	~
442	-94.0059CX	-466.6659CC	-13.4850	82.8663	78.1418	Silica
Space		.55.005,00	-1.2000	32.0000		
444	-147.2485CX	-77.8924CC	-22.2075	72.7262	50.6555	Silica
Space	111210501	77.072.00	-3.2091	, 2., 202	50,0555	
446	-159.2880CX	-519.4850CC	-13.8321	49.5648	39.0473	Silica
Space	ADJ.EUGOCA	517.4050CC	-0.2000	17.5010	37.0713	Simon
448	-129.3683CX	-426.7350CC	-6.1500	37.3816	32.4880	Silica
Space	Image Di		-4,0000	37.3010	32.4000	Sinca .
450	Image	Infinite	- 1 ,0000			
750	mage	mmic				

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

14

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

Number			T	ABLE 5			
Silica	Element	Radius of C	urvature (mm)	Thickness	Aperture D	iameter (mm)	
Size	Number	Front	Back	(mm)	Front	Back	Glass
Space Spac	510	In	finite	62.7514		_	
Space Spac	512	-136.1154 CC	-152,5295 CX	16.8300	120.7552	129.4354	Silica
Space Spac				4.5206			
Space Spac		-270.1396 CC	-191,8742 CX		132.9152	139.0377	Silica
Space Spac		100 0000 00	2015456 577		155 1000		
Silea		-188.9000 CC	-284.7476 CX		156.1938	165.6567	Silica
Space		122 0171 CV	941 5500 CV		172 0270	174 0224	Cilian
Decenter(1) S20		433,8174 CA	-641.3399 CA		173.8279	174.8334	Silica
S20	Space		Decenter(1)	147.4347	`		
Space	520	In		-61.0000	177	.2183	Reflection
Space Spac							
Space Spac							
526 -265.9886 CX 1773.5314 CX -24.1851 142.1592 141.2400 Silica Space -244.9899 CX -142.8558 CC -11.8800 139.3290 133.8967 Silica Space -21.6411 -21.6411 189.7826 Silica 530 Infinite Infinite 189.7826 Reflection 530 Infinite Infinite 1.9800 189.7826 189.7826 Silica Space 1.9800 189.7826 189.7826 Silica Space 1.9800 142.3429 142.6707 Silica Space 18.5263 143.5034 Reflection 532 Infinite Infinite -18.5263 143.5034 Reflection 532 Infinite Infinite -5.9400 134.2788 130.9398 Silica Space -1.9800 134.2788 130.9398 Silica 530 Infinite Infinite -71.2800 130.1221 111.7247 Silica Space -1.98	5 24	690.5706 CC	-146.4997 CC	-11.8800	150,4109	141.8021	Silica
Space -1.5000 -1.500	Space			-10.6267			
Space		-265.9886 CX	1773.5314 CX		142.1592	141.2400	Silica
Space							
Infinite		–244.9899 CX	-142.8558 CC		139.3290	133.8967	Silica
Decenter(2) 189.7826 Reflection 536 Infinite Infinite 71.2800 189.7826 189.7826 Silica 1.9800 1.		T 0 1	* 6 *		101011	100 500	G***
Table Tabl	530	Infinite		-71.2800	134.3115	189.7826	Silica
Space Infinite Infinite T1.2800 189.7826 189.7826 Silica	536	Infi			190	7826	Deflection
Space Infinite Infinite 5.9400 142.3429 142.6707 Silica				71 2800			
Space Infinite Infinite 5.9400 142.3429 142.6707 Silica		in in the second	minuc			105.7020	Since
Stop Aspheric -18.5263 143.5034 Reflection 532 Infinite Infinite -5.9400 134.2788 130.9398 Silica Space -1.9800 134.2788 130.9398 Silica Space -1.9800 130.1221 111.7247 Silica Space -1.9800 111.7247 96.1353 Silica Space -1.9800 538 Infinite Infinite -60.4000 111.7247 96.1353 Silica Space -1.9800 538 95.3562 94.2064 Silica Space -1.1880 -1.1880 540 -127.4561 CX -1398.8019 CC -13.0104 90.4737 87.7002 Silica Space -1.1880 -1.1880 -12.2874 80.7016 76.3270 Silica Space -1.1880 -1.1880 -1.1880 544 -132.0104 CX -70.9574 CC -17.8706 71.0789 53.4306 Silica Space <t< td=""><td></td><td>Infinite</td><td>Infinite</td><td></td><td></td><td>142.6707</td><td>Silica</td></t<>		Infinite	Infinite			142.6707	Silica
534 Aspheric -18.5263 143.5034 Reflection 532 Infinite Infinite -5.9400 134.2788 130.9398 Silica Space -1.9800 130.1221 111.7247 Silica 530 Infinite Infinite -60.4000 111.7247 96.1353 Silica Space -1.9800 -1.9800 -1.1824 95.3562 94.2064 Silica Space -1.1880 </td <td>Space</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>	Space						
Space Infinite Infinite -5.9400 134.2788 130.9398 Silica	Stop						
Space -1.9800 530 Infinite Infinite -71.2800 130.1221 111.7247 Silica 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 -1.1880 540 -127.4561 CX -1398.8019 CC -13.0104 90.4737 87.7002 Silica Space -1.1880 -1.1880 542 -98.8795 CX -424.1302 CC -12.2874 80.7016 76.3270 Silica Space -1.1880 -1.1880 544 -132.0104 CX -70.9574 CC -17.8706 71.0789 53.4306 Silica Space -3.1246 -3.1246 546 -123.1071 CX -585.4471 CC -19.9496 52.6417 38.2256 Silica Space -0.1980 -0.1980 548 -137.8349 CX -292.6179 CC -6.0885 36.7251 31.8484 Silica <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>							
530 Infinite Infinite -71.2800 130.1221 111.7247 Silica 530 Infinite Infinite -60.4000 111.7247 96.1353 Silica Space -1.9800 -1.9800 538 Infinite Infinite -4.4550 95.3562 94.2064 Silica Space -1.1880 -1.1880 -1.1880 -1.1880 -1.1880 -1.1880 Silica Space -1.1880 -1.1880 -1.1880 -1.1880 Silica Silica Space -1.1880 -1.1880 544 -132.0104 CX -70.9574 CC -17.8706 71.0789 53.4306 Silica Space -3.1246 -3.1246 546 -123.1071 CX -585.4471 CC -19.9496 52.6417 38.2256 Silica Space -0.1980 -0.1980 -0.1980 -0.1980 -0.1980 -0.1980 -0.1980 -0.1980 -0.1980 -0.1980 -0.1980 -0.1980 -0.1980 -0.1980 -0.1980 -0.1980 <t< td=""><td></td><td>Infinite</td><td>Infinite</td><td></td><td>134.2788</td><td>130.9398</td><td>Silica</td></t<>		Infinite	Infinite		134.2788	130.9398	Silica
Decenter(3) Silica Space -1.9800 Space -1.1880 Space -3.1246 Space					400 4004		a
530 Infinite Infinite -60.4000 111.7247 96.1353 Silica Space -1.9800 -1.9800 94.2064 Silica Space -1.1880 -1.1880 87.7002 Silica Space -1.1880 87.7002 Silica Space -1.1880 80.7016 76.3270 Silica Space -1.1880 71.0789 53.4306 Silica Space -3.1246 71.0789 53.4306 Silica Space -3.1246 52.6417 38.2256 Silica Space -0.1980 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 -4.0000 36.7251 31.8484 Silica	530	Infinite		~71.2800	130,1221	111.7247	Silica
Space -1.9800 538 Infinite Infinite -4.4550 95.3562 94.2064 Silica Space -1.1880 -1.1880 87.7002 Silica Space -1.1880 87.7002 Silica Space -1.1880 76.3270 Silica Space -1.1880 76.3270 Silica Space -1.1880 71.0789 53.4306 Silica Space -3.1246 71.0789 53.4306 Silica Space -3.1246 71.0789 52.6417 38.2256 Silica Space -0.1980 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 -4.0000 -4.0000 -4.0000	520	Infinito		60 4000	111 7047	06 1353	Pilion
538 Infinite Infinite -4.4550 95.3562 94.2064 Silica Space -1.1880 -1.1880 87.7002 Silica Space -1.1880 87.7002 Silica 542 -98.8795 CX -424.1302 CC -12.2874 80.7016 76.3270 Silica Space -1.1880 -1.1880 544 -132.0104 CX -70.9574 CC -17.8706 71.0789 53.4306 Silica Space -3.1246 -3.1246 546 -123.1071 CX -585.4471 CC -19.9496 52.6417 38.2256 Silica Space -0.1980 -0.1980 548 -137.8349 CX -292.6179 CC -6.0885 36.7251 31.8484 Silica Space Image Distance -4.0000 -4.0000 -4.0000		minne	minite		111./24/	90.1333	Sinca
Space -1.1880 540 -127.4561 CX -1398.8019 CC -13.0104 90.4737 87.7002 Silica Space -1.1880 -1.1880 -1.1880 542 -98.8795 CX -424.1302 CC -12.2874 80.7016 76.3270 Silica Space -1.1880 -1.1880 -1.1880 544 -132.0104 CX -70.9574 CC -17.8706 71.0789 53.4306 Silica Space -3.1246 -3.1246 52.6417 38.2256 Silica Space -0.1980 52.6417 38.2256 Silica Space -137.8349 CX -292.6179 CC -6.0885 36.7251 31.8484 Silica Space Image Distance -4.0000		Infinite	Infinite		95 3562	94 2064	Silica
540 -127.4561 CX -1398.8019 CC -13.0104 90.4737 87.7002 Silica Space -1.1880 <td< td=""><td></td><td>mmic</td><td>minic</td><td></td><td>75.5502</td><td>71.2001</td><td>Jinou</td></td<>		mmic	minic		75.5502	71.2001	Jinou
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 -3.1246 -3.1246 546 -123.1071 CX -585.4471 CC -19.9496 52.6417 38.2256 Silica Space -0.1980 -0.1980 548 -137.8349 CX -292.6179 CC -6.0885 36.7251 31.8484 Silica Space Image Distance = -4.0000		-127.4561 CX	-1398.8019 CC		90,4737	87,7002	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	Space						
\$44 -132.0104 CX -70.9574 CC -17.8706 71.0789 53.4306 Silica Space -3.1246 -3.1246 -3.1246 546 -123.1071 CX -585.4471 CC -19.9496 52.6417 38.2256 Silica Space -0.1980 -0.1980 -0.1980 548 -137.8349 CX -292.6179 CC -6.0885 36.7251 31.8484 Silica Space Image Distance -4.0000	542	-98.8795 CX	-424,1302 CC	-12,2874	80.7016	76.3270	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	Space						
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		-132.0104 CX	-70.9574 CC		71.0789	53.4306	Silica
Space -0.1980 548 -137.8349 CX -292.6179 CC -6.0885 36.7251 31.8484 Silica Space Image Distance = -4.0000							
548 -137.8349 CX -292.6179 CC -6.0885 36.7251 31.8484 Silica Space Image Distance = -4.0000		-123.1071 CX	-585.4471 CC		52.6417	38.2256	Silica
Space Image Distance = -4.0000		127 0240 CV	202 (170 (77		26 7251	21 0404	Cili
					30.7231	31.8484	Sinca
2000 Annage Annance 200000				-4.0000		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. 55 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 60 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 65 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 5 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 15 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 25 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 30 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 pro- 45 vides 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 50 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 com
 - 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.

16

- 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

said second lens group including,

- at least one lens of negative power;
- a positive lens; and

35

40

- 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 correc-
 - 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

			IMBLE			
Element	Radius of Cur	rvature (mm)	Thickness	Aperture Di	ameter (mm)	-
Number	Front	Back	(mm)	Front	Back	Glass
10	Infir	iite.	63.3853			
12	-158,7745	-177.8800	15.0000	124.0478	131.7725	Silica
Space	20011110		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	Infir		-74.0000		.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	150 4750	470 0 670	-4.2326	171 4044	160.0507	0'11'
26	-150.4759	472,0653	-46.5091	171.4244	169.9587	Silica
Space 28	-1472,2790	-138,2223	-2.0000 -15.0000	165.3586	154.8084	Silica
Space	-14/2.2/90	-136.2223	-27.2060	103.3360	134.6064	Sinca
30	Infinite	Infinite	-27.2000 -91.8186	155,6662	253.0917	Silica
36	Infir		71.0100		.0917	Reflection
30	Infinite	Infinite	91.8186	253.0917	253.0917	Silica
Space		211111111	2.0000			
32	Infinite	Infinite	6.0000	185.8693	186.8401	Silica
Space			17.9918			
Stop				188	.0655	
34	Asph	eric	-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		7.0.1	-2.0000	125 0601	106 6550	0.11
38	Infinite	Infinite	-4.5000	127.9681	126.6552	Silica
Space	125 1220	1727 4442	-0.7500	101 4715	110 2600	Silica
40	-175.1330	1737.4442	-17.7754 -0.7500	121.4715	118.2689	Sinca
Space 42	-108.8178	-580.1370	-0.7300 -18.2407	104.5228	97,7967	Silica
	-100.0170	-360.1370	-0.7500	104.3220	91.1901	Sinca
Space 44	-202,2637	-86.6025	-31.1216	91.7061	57.4968	Silica
Space	-202,2037	00.0025	-2.3507	71.7001	57.1700	Dinou
46	-222.1235	-488.7122	-17.9476	56.4818	41.1675	Silica
Space	222, 1233		-0.2000	201.013		
48	-160.8506	-360,1907	-6.1500	39.4528	33.5764	Silica
Space			-4.000			
50	Infi	nite		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

			IABLE 2	'		
Element	Radius of C	urvature (mm)	Thickness	Aperture Dia	meter (mm)	-
Number	Front	Back	(mm)	Front	Back	Glass
10	Ĭní	inite	60.4852			
112	-205.5158	539.1791	15.2158	124.0926	137.3346	Silica
Space	205.5150	337.1771	8.8054	124.0720	137.3340	Sinca
114	2080.9700	-210.6539	32.4984	142.6149	151.7878	Silica
Space	2000.7700	210.0555	1.2676	142.0147	131.7676	Sinca
116	310,4463	700,3748	40.7304	162,4908	165.2126	CaFl
Space	310.4403	100.5746	0.5000	102.4506	103.2120	Cari
118	634.1820	-798.8523	27.5892	165.4595	166.4747	Silica
Space	054.1020	-190.0323	0.5000	103.4393	100.4747	Sinca
120	1480.0597	1312,1247	25.4322	168.7516	164.7651	Silica
Space	1460.0377	1312.1247	136.2343	106.7310	104.7031	Sinca
122	Inf	inite	-74.0000	161.9	2500	Reflection
124	-761.9176	1088.9351		160.3165		
	-/61.91/6	1000.9331	-19.2150	100.5105	159.2384	Silica
Space 126	640 0261	202 5072	-19.9465	166 1911	152 0625	0.73
	648.8361	-202.5872	-12.0000	155.1711	153.0635	CaFl
Space 128	100 1076	450 5060	-7.6304	152 0625	150 0055	G.11
	-400.4276	458.5060	-25.8769	153.0635	153.8055	Silica
Space	010.0000	1.00 0004	-2.0000			~ ~~
130	-818.0922	-168.5034	-27.5927	152.6663	147.5200	CaFl
Space	7.6.1.	v a	-20.5014			
132	Infinite	Infinite	-91.7553	148.6158	252.7349	Silica
138		inite		252.7		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		heric	-18.1636	188.5		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	Inf	inite		26.4	992	

- **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

55

TARLE 3

Number				TABLE 3			
Table Tabl	Element	Radius of C	urvature (mm)	Thickness	Aperture Dia	meter (mm)	
Space Spac	Number	Front	Back	(mm)	Front	Back	Glass
Space 2.6174 214 515.7935 -455.1015 39.8858 135.3384 145.6015 PBM2Y Space 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 168.7516 165.1801 BAL15Y Space 224 -429.2950 455.4247 -32.3086 173.0235 171.1102 PBL6Y PBM2Y 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 -12.0000 159.3555 154.7157 PBM8Y Space -12.0000 153.1461 149.4794 BSL7Y Space -19.7282 232 Infinite Infinite -91.7349 150.4585 252.6772 Silica Space 2.0000 234 Infinite Infinite 91.7349 252.6772 252.6772 Silica Space 18.2715 238 Infinite Infinite -6.0000 183.6393 180.1377 Silica Space -2.0000 232 Infinite Infinite -6.0000 183.6393 180.1377 Silica Space -2.0000 232 Infinite Infinite -70.0000 147.9888 126.9282 Silica Space -2.0000 242 -119.8912 -610.6840 -18.6508 117.5305 113.4233 BSM51Y Space -2.0000 244 -114.1327 384.9135 -70.2077 -13.0576 96.4137 MS.179 MS.17	10	Inf	inite	59.2960			
\$\frac{514}{\text{Space}} \	212	-620.7809	361.8305	20.2974	125.9406	134.7227	PBM2Y
Space Color							
\$\frac{1}{216}		515.7935	-455.1015		135.3384	145.6015	PBM2Y
Space							
\$\frac{1}{218}		431.3189	-239.4002		155.6269	157.3014	BSL7Y
Space 1.4303 168.7516 165.1801 BAL15Y		250 (010	40. 4.0. 0.4				
520 361.5709 -1853.2955 23.3934 168.7516 165.1801 BAL15Y Space 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 BSLTY Space -5.6227 -2.0000 -5.6227 -2.0000 153.1461 149.4794 BSLTY Space -2.0000 -12.0000 153.1461 149.4794 BSLTY Space -19.7282 -19.7282 Silica Reflection 232 Infinite Infinite -91.7349 150.4585 252.6772 Silica Space 2.0000 234 Infinite Infinite 91.7349 252.6772 252.6772 Silica Space 18.2715 188.1745 Reflection 18.2715 188.1745 Reflection 234 Infinite Infinite </td <td></td> <td>-259.6013</td> <td>685.3286</td> <td></td> <td>156.9363</td> <td>162.2451</td> <td>PBM2Y</td>		-259.6013	685.3286		156.9363	162.2451	PBM2Y
Space 1nfinite -77.8649 169.9390 Reflection 224 -429.2950 455.4247 -32.3086 173.0235 171.1102 PBL6Y Space -27.6206 -27.6206 -27.6206 -27.6206 -27.6206 -27.6206 -27.6206 -27.6206 -27.6206 -28.8722 1301.3764 -26.1321 154.7155 154.7155 BSL7Y Space -2.0000 -230 -1282.8931 -180.2226 -12.0000 153.1461 149.4794 BSL7Y Space -2.2000 -232 Infinite Infinite -91.7349 150.4585 252.6772 Silica Reflection 232 Infinite Infinite 91.7349 252.6772 252.6772 Silica Space -2.0000 18.2715 188.1745 Reflection 234 Infinite Infinite -6.0000 185.6435 186.7758 Silica Space -2.0000 232 Infinite Infinite -6.0000 183.6393 180.1377 Silica Space -2.0000 232 Infinite Infinite -91.7349 178.3236 147.9888 Silica Space -2.0000 232 Infinite Infinite -91.7349 178.3236 147.9888 Silica Space -2.0000 240 Infinite Infinite -70.0000 147.9888 126.9282 Silica Space -0.5000 240 Infinite Infinite -4.5000 126.0289 124.6750 Silica 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 -2.		261 5700	1052 2055		1/0.751/	165 1001	DAT 153/
5222 Infinite -77.8649 169.9390 Reflection 224 -429.2950 455.4247 -32.3086 173.0235 171.1102 PBL6Y Space 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 -2.0000 153.1461 149.4794 BSL7Y Space -19.7282 -19.7282 Silica Silica 232 Infinite Infinite -91.7349 150.4585 252.6772 Silica Space -2.0000 185.6435 186.7758 Silica Space 232 Infinite Infinite 91.7349 252.6772 252.6772 Silica Space -2.0000 185.6435 186.7758 Silica Space -18.2715 188.1745 Reflection 234 Infinite Infinite -6.0000 183.6393 180.1377		301.3709	-1800.2900		108.7510	165.1801	BALIST
\$\frac{224}{\sqrt{5pace}} = \frac{-429.2950}{\sqrt{276.206}} \text{455.4247} \text{276.206} \text{276.206} \text{276.206} \text{276.207} \text{276.206} \q		Inf	inite		160 0	390	Reflection
Space -27.6206 226 401.0363 -180.0031 -12.0000 159.3555 154.7155 BSL7Y Space -5.6227							
226 401.0363 -180.0031 -12.0000 159.3555 154.7155 BSL7Y Space -5.6227 -5.6227 -20000 154.7155 154.1517 PBM8Y Space -2.0000 -2.0000 153.1461 149.4794 BSL7Y Space -19.7282 -19.7282 -19.7282 -19.7249 150.4585 252.6772 Silica 238 Infinite Infinite 91.7349 252.6772 252.6772 Reflection 232 Infinite Infinite 91.7349 252.6772 252.6772 Silica Space 2.0000 185.6435 186.7758 Silica Space 18.2715 188.1745 Reflection 234 Infinite Infinite -6.0000 183.6393 180.1377 Silica Space -2.20000 183.6393 180.1377 Silica Space -2.20000 17.7349 178.3236 147.9888 Silica Space -2.20000 17.7349 178.2326		.25.250	.55,1217		173.0235	.,	12201
Space -5.6227		401.0363	-180.0031		159.3555	154.7155	BSL7Y
\$228 -258.4722 1301.3764 -26.1321 154.7155 154.1517 PBM8Y \$pace -2.0000 -2.0000 153.1461 149.4794 BSL7Y \$pace -19.7282 -19.7282 -19.7282 -19.7282 -19.7349 150.4585 252.6772 \$Silica 238 Infinite 1nfinite 91.7349 252.6772 252.6772 \$Silica \$pace 2.0000 252.6772 252.6772 \$Silica \$pace 2.0000 185.6435 186.7758 \$Silica \$pace 18.2715 188.1745 \$Silica \$pace 18.2715 188.1745 \$Reflection \$pace -2.0000 183.6393 180.1377 \$Silica \$pace -2.0000 183.6393 180.1377 \$Silica \$pace -2.0000 147.9888 126.9282 \$Silica \$pace -2.0000 147.9888 126.9282 \$Silica \$pace -0.5000 126.0289 124.6750 \$Silica							
230 -1282.8931 -180.2226 -12.0000 153.1461 149.4794 BSL7Y Space -19.7282 -19.7282 Silica -19.7282 Silica Silica -150.4585 252.6772 Silica Silica Silica -150.4585 252.6772 Silica Silica -150.4585 252.6772 Silica -150.4585 252.6772 Silica -150.4585 -150.		-258.4722	1301.3764	-26.1321	154.7155	154.1517	PBM8Y
Space Company							
Description		-1282.8931	-180.2226		153.1461	149.4794	BSL7Y
238 Infinite 1nfinite 91.7349 252.6772 252.6772 Reflection Space 2.0000 234 Infinite Infinite 6.0000 185.6435 186.7758 Silica Space 18.2715 188.1745 Silica Silica Stop Aspheric −18.2715 188.1745 Reflection 234 Infinite Infinite −6.0000 183.6393 180.1377 Silica Space −2.0000 183.6393 180.1377 Silica Silica 232 Infinite Infinite −91.7349 178.3236 147.9888 Silica Space −2.0000 147.9888 126.9282 Silica Space −2.0000 147.9888 126.9282 Silica Space −0.5000 126.0289 124.6750 Silica Space −0.5000 126.0289 124.6750 Silica Space −0.5000 126.0289 124.6750 Silica Space −2.885					4 # 0 4 # 0 #		a
232 Infinite Infinite 91.7349 252.6772 252.6772 Silica Space 2.0000 185.6435 186.7758 Silica Space 182.715 188.1745 Silica Stop 188.1745 188.1745 Reflection 236 Aspheric -18.2715 188.1745 Reflection Space -2.0000 183.6393 180.1377 Silica Space -2.0000 183.6393 180.1377 Silica Space -2.0000 178.3236 147.9888 Silica Space -2.0000 147.9888 126.9282 Silica Space -2.0000 126.0289 124.6750 Silica Space -0.5000 126.0289 124.6750 Silica Space				-91.7349			
Space 234 Infinite Infinite 2.0000 (6.000) 185.6435 186.7758 Silica Space Stop Stop Stop 236 Aspheric Infinite Infinite -6.0000 188.1745 Reflection 234 Infinite Infinite Infinite -6.0000 183.6393 180.1377 Silica Space -2.0000 -2.0000 147.9888 Silica 232 Infinite Infinite Infinite -91.7349 178.3236 147.9888 Silica Space -2.0000 -2.0000 147.9888 126.9282 Silica Space -0.5000 -2.0000 126.0289 124.6750 Silica Space -0.5000 -0.5000 126.0289 124.6750 Silica Space -0.5000 -0.5000 17.5305 113.4233 BSM51Y Space -0.5000 -0.5000 10.6172 96.4137 BSL7Y 246 384.9135 -70.2077 -13.0576 96.4137 71.1691 PBL26Y Space -2.8852 -2.8852 -2.8852 248 -85.7858 -400.3240 -16.9147 70.5182 -61.2633 BSM51Y Space -54.0114 -2011.1057 -6.3947 37.3909 -34.2119 PBL6Y				04.5040			
Space Stop		Infinite	Infinite		252.6772	252.6772	Silica
Space Stop 18.2715 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		Infinite	In Guita		105 6125	106 7750	Cilian
Stop 236 Aspheric -18.2715 188.1745 188.1745 Reflection 234 Infinite Infinite -6.0000 183.6393 180.1377 Silica Space -2.0000 -2.0000 -2.0000 -2.0000 178.3236 147.9888 Silica 232 Infinite Infinite -70.0000 147.9888 126.9282 Silica Space -2.0000 126.0289 124.6750 Silica Space -0.5000 126.0289 124.6750 Silica		minue	minue		163.0433	160.7736	Sinca
236 Aspheric -18.2715 188.1745 Reflection 234 Infinite Infinite -6.0000 183.6393 180.1377 Silica Space -2.0000 -2.0000 -2.0000 178.3236 147.9888 Silica 232 Infinite Infinite -70.0000 147.9888 126.9282 Silica Space -2.0000 -2.0000 126.0289 124.6750 Silica Space -0.5000 -0.5000 10.26172 96.4137 BSL7Y 246 384.9135 -70.2077 -13.0576 96.4137 71.1691 PBL26Y Space -2.8852 -2.8852 -2.8852 -2.8852 -2.8852 -2.8652 -2.8652 -2.8652 -2.6000 -2.6000				10.2/15	188.1	745	
234 Infinite Infinite -6.0000 183.6393 180.1377 Silica Space -2.0000 -2.0000 178.3236 147.9888 Silica 232 Infinite Infinite -70.0000 147.9888 126.9282 Silica Space -2.0000 -2.0000 126.0289 124.6750 Silica Space -0.5000 126.0289 124.6750 Silica Space -21.1139 102.6172 96.4137 BSL7Y 246 384.9135 -70.2077 -13.0576 96.4137 71.1691 PBL26Y Space -2.8852 -2.8852 -2.8852 -2.8852 <td></td> <td>Asn</td> <td>heric</td> <td>-18.2715</td> <td></td> <td></td> <td>Reflection</td>		Asn	heric	-18.2715			Reflection
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 126.0289 124.6750 Silica Space -0.5000 126.0289 124.6750 Silica 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 -2.8852 -2.8852 -2.8852 -2.8852 -2.852 -2.852 -2.852 -2.852 -2.852 -2.852 -2.852 -2.852 -2.852 -2.852 -2.852 -2.852 -2.852 -2.852 </td <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>							
232 Infinite Infinite -91.7349 178.3236 147.9888 Silica 232 Infinite Infinite -70.0000 147.9888 126.9282 Silica Space -2.0000 126.0289 124.6750 Silica Space -0.5000 126.0289 124.6750 Silica Space -0.5000 17.5305 113.4233 BSM51Y Space -0.5000 17.5305 113.4233 BSM51Y 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 -2.8852 -2.8852 -2.8852 -2.8852 -2.8852 61.2633 BSM51Y Space -0.8180 -0.8180 -2.8852 -3.946 37.3909 BSM51Y 250 -151.5235 -54.014 -19.5810 57.6234 37.3909 BSM51Y 252 -54.0114 -2011.1057							
Space 240 Infinite Infinite -2.0000 -4.5000 -4.5000 -126.0289 124.6750 Silica Space 242 -119.8912 -610.6840 -18.6508 -0.5000 -126.0289 117.5305 -113.4233 BSM51Y Space 244 -114.1327 -384.9135 -21.1139 -0.5000 -2.1139 -0.5000 -2.246 -0.5000 -1.2007 -13.0576 -0.2077 -13.0576 -0.2077 -13.0576 -0.2077 -13.0576 -0.2077 -1.1691 -0.2077 -2.2077 -12.0576 -0.2077 -1.1691 -0.2077 -0.2077 -1.2077 -1.2077 -0.2077 -1.2077 -0.2077 -1.2077 -0.2077 -1.2077 -0.2077 -1.2077 -0		Infinite	Infinite		178.3236	147.9888	Silica
240 Infinite Infinite -4.5000 126.0289 124.6750 Silica Space -0.5000 -0.5000 113.4233 BSM51Y Space -0.5000 113.4233 BSM51Y Space -0.5000 113.4233 BSM51Y 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 -2.8852 -2.8852 -2.8852 -2.8852 -2.8852 -0.8180	232	Infinite	Infinite	-70.0000	147.9888	126.9282	Silica
Space 242 -0.5000 -119.8912 -0.5000 -610.6840 -18.6508 -18.6508 117.5305 113.4233 BSM51Y Space 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 248 -85.7858 -400.3240 -16.9147 70.5182 61.2633 BSM51Y Space 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				-2.0000			
242 -119.8912 -610.6840 -18.6508 117.5305 113.4233 BSM51Y Space -0.5000 -0.5000 -0.5000 -0.5000 -0.5000 -0.5000 -0.5000 -0.5000 -0.5000 -0.5000 -0.5000 -0.6172 96.4137 BSL7Y -0.624 -0.6172 96.4137 -0.1691 PBL26Y -0.8180<		Infinite	Infinite		126.0289	124.6750	Silica
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 -2.8852 -2.2852 -2.2852 -2.2852 -2.2852 -2.2852 -0.8180 -0.8180 -0.8180 -0.8180 -0.8180 -2.2852 -2.2852 -2.2852 -2.2852 -2.2852 -3.2862 -0.8180 <t< td=""><td></td><td></td><td></td><td></td><td></td><td></td><td></td></t<>							
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 -2.8852 -2.28852 -2.28852 -2.28852 -0.8180 -0.8180 -0.8180 -2.8180		-119.8912	-610.6840		117.5305	113.4233	BSM51Y
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252 -54.0114 -2011.1057 -6.3947 37.3909 34.2119 PBL6Y Space -4.0000		-151.5235	-54.0114		57.6234	37.3909	BSM51Y
Space4.0000							
*							- -
	•	Infir	nite		26.500	2	

- 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
- 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 $_{50}$ 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, 55 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 60 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;

10

- 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

		T	ABLE 4			
Element	Radius of Co	arvature (mm)	Thickness	Aperture Dia	meter (mm)	
Number	Front	Back	(mm)	Front	Back	Glass
410	Inf	inite	63.3853			
412	−183.5661 CC	-215.7867 CX	17.0000	122.8436	130.6579	Silica
Space	(01 1505 00	720 0700 OV	46.6205	140 1476	152 2102	631
414	−601.1535 CC	-230.9702 CX	21.4839	149.1476	153.3103	Silica
Space 416	-195.1255 CC	-345.4510 CC	68.8705 15.0000	161.6789	170.1025	Silica
Space	-193.1233 CC	-343.4310 CC	3.0000	101.0769	170.1023	Sinca
418	435.8058 CX	-1045.1785 CX	24,9351	177.4520	178.2672	Silica
Space	135.0050 011	10 15.17.05 011	130.0000	17111520	170.20.2	
		Decenter(1)				
420	Inf	inite	-64.5000	180.3	457	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	COC 4005 CW	116 6456 00	-1.5000	1 42 6211	126 1162	0:11:
428	-626.4905 CX	–116.6456 CC	-12.0000 -31.8384	147.6711	136.1163	Silica
Space 430	Infinite	Infinite	-31.8384 -74.0000	137.2448	200.1127	Silica
430	minite	Decenter(2)	-74.0000	137.2440	200.1127	Sinca
436	Int	inite		200.1	127	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				149.6	-	- ~ .
434		heric	-14.4638	149.6		Reflection
432	Infinite	Infinite	-6.0000 -2.0000	144.8563	141.2737	Silica
Space 430	Infinite	Infinite	-74.0000 -74.0000	139.3606	117.3979	Silica
430	minute	Decenter(3)	-74.0000	139.3000	117.5515	Sinca
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 444	147 2405 CV	77 9004 00	-1.2000	70 7060	E0 (555	Silica
	-147.2485 CX	-77.8924 CC	-22.2075 -3.2091	72.7262	50.6555	Silica
Space 446	-159.2880 CX	-519.4850 CC	-3.2091 -13.8321	49.5648	39.0473	Silica
Space	-139.2000 CA	-313.40JU CC	-0.2000	47.3040	33.0473	эшса
448	-129.3683 CX	-426.7350 CC	-6.1500	37.3816	32.4880	Silica
			-4.0000	5.,55.0		~~~~
Space	lmage I	Distance =	-4.0000			

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

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TABLE 5

			ADLE J			
Element	Radius of Curvature (mm)		Thickness	Aperture D	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		D(1)	149.4549			
520	Y	Decenter(1) finite	-61.0000	177.2183		Reflection
522	-190.3251 CX	-8413.4836 CC	-34.4584	178,5071	174.2260	Silica
Space	150.5251 CA	-0415.4650 CC	-51,5487	170.5071	174.2200	Sinca
524	690.5706 CC	-146.4997 CC	-11.8800	150.4109	141.8021	Silica
Space		- 10/17/1	-10.6267			5111011
5 26	-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
536	T C	Decenter(2)		100	7006	D. G:
530	Infi: Infinite		71 2000		.7826	Reflection
Space	immite	Infinite	71.2800 1.9	189.7826	189.7826	Silica
532	Infinite	Infinite	5.9400	142.3429	142.6707	Silica
Space	immic	minic	18.5263	142.3429	142.0707	Sinca
Stop			20.0200	143.5034		
53Â	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
520	T 6 1	Decenter(3)	60.4000	111 50 15	04.070	0111
530	Infinite	Infinite	-60.4000	111.7247	96.1353	Silica
Space 538	Infinite	Infinite	-1.9800 -4.4550	95.3562	94.2064	Silica
Space	minuc	mmue	-1.1880	93.3302	94.2004	Silica
540	-127.4561 CX	-1398.8019 CC	-13.0104	90.4737	87,7002	Silica
Space		***************************************	-1.1880	30.7707	5111.002	511104
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	100 00 10 577	202 (152 53	-0.1980	26 5251	21.2427	
548	-137.8349 CX	-292.6179 CC	-6.0885	36.7251	31.8484	Silica
Space 550		Distance =	-4.0000		26 6000	
330	Image	Infinite			26.5000	

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.

* * * * *