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(54) Title: IMAGING OPTICAL SYSTEM AND PROJECTION EXPOSURE INSTALLATION FOR MICRO-LITHOGRAPHY WITH AN IMAGING OPTICAL SYSTEM OF THIS TYPE

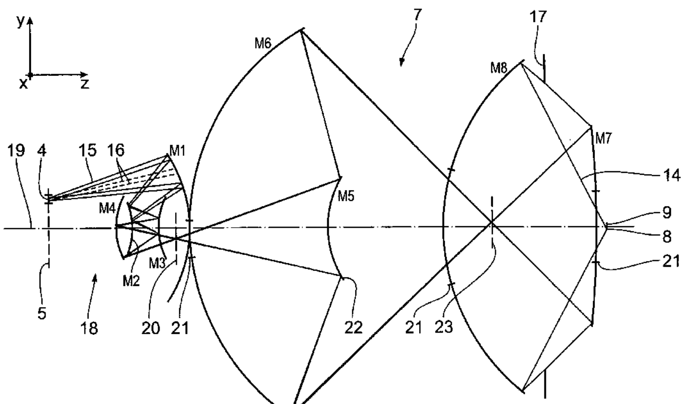

Fig. 2

(57) Abstract: An imaging optical system (7) comprises a plurality of mirrors (Ml to M8), which image an object field (4) in an object plane (5) into an image field (8) in an image plane (9). At least one of the mirrors (M6, M7, M8) is obscured, and thus has a through-opening (21) for imaging light (15) to pass through. The fourth-last mirror (M5) in the light path before the image field (8) is not obscured and provides, with an outer edge (22) of the optically effective reflection surface thereof, a central shadowing in a pupil plane (17) of the imaging optical system (7). The distance between the fourth-last mirror (M5) and the last mirror (M8) is at least 10 % of the distance between the object field (4) and the image field (8). An intermediate image plane (23), which is closest to the image plane (9), is arranged between the last mirror (M8) and the image plane (9). The imaging optical system (7) has a numerical aperture of 0.9. These measures, not all of which must be effected simultaneously, lead to an imaging optical system with improved imaging properties and/or reduced production costs.

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IMAGING OPTICAL SYSTEM AND PROJECTION EXPOSURE APPARATUS THEREWITH

The invention relates to an imaging optical system according to the preamble of claims 1, 5, 6, 7 and 10. Furthermore, the invention relates to a projection exposure installation comprising an imaging optical system of this type, a method for producing a microstructured component comprising a projection exposure installation of this type and a microstructured component produced with this method.

Imaging optical systems of the type mentioned at the outset are known from US 6,750,948 B2, US 2006/0232867 A1, EP 0 267 766 A2, US 7,209,286 B2 and WO 2006/069 725 A1.

In particular for use within a projection exposure installation for microlithography, in particular for the production of microstructured or nanostructured semiconductor components, there is a need for improved imaging properties, for example a greater numerical aperture or a better correction of imaging errors, in the imaging optical systems mentioned at the outset. Alternatively or additionally, there is a need for simpler manufacture of the mirror at pre-specified dimensions, or for a mirror arrangement which relaxes the requirements on the production of the mirror support in particular, at least for individual mirrors. In particular, the number of optical elements required for the imaging and for the correction of imaging errors should be kept as low as possible.

This object is achieved according to the invention by imaging optical systems with the features specified in the characterising parts of claims 1, 5, 6 and 8.

It has been found in accordance with the invention that a construction of an imaging optical system, according to claim 1 with a mirror which determines, with the outer edge thereof and not with a through-opening, the pupil obscuration of an obscured optical system, opens up entirely new constructional possibilities in comparison with the known imaging optical systems. This allows high-aperture objectives with well-corrected imaging errors. The outer edge of the fourth-last mirror which surrounds the optically effective reflection surface thereof, is either the outer edge of the optically effective reflection surface itself, or the outer edge of a substrate on which the reflection surface is provided, or the outer edge of a mechanical holding structure supporting the reflection surface or the substrate.

A convex fourth-last mirror according to claim 2 allows the imaging optical system to be constructed with relatively low pupil obscuration.

An arrangement of the fourth-last mirror according to claim 3 has equivalent advantages.

The arrangement of the fourth-last mirror according to claim 4 makes it possible to apply an aperture stop to this mirror.

The object stated at the outset is also solved by imaging optical systems according to claims 5 and 6. In these cases, an advantageously large space is present between the fourth-last and last mirrors. In other constructions with obscured mirrors and a high numerical aperture, the region between the fourth-last and the last mirror was a problematic region because either only very thin mirrors or a mirror which was very expensive to produce, comprising reflective coatings on both sides, could be used there.

The object stated at the outset is also solved by an imaging optical system according to claim 7. Moving the intermediate image plane in the direction of the image plane leads, by comparison with known constructions, to reduced requirements on the optical effect of the last two mirrors of the imaging optical system. In known obscured systems, the intermediate image plane is often spatially arranged at approximately the height of the last mirror in the light path. It has been found according to the invention that this is not a compulsory requirement because the last mirror in the light path is mostly not decisive as regards the pupil obscuration, in such a way that a relatively large central opening, and thus an intermediate plane separated from the reflection surface of the penultimate mirror, can be tolerated there.

A distance ratio according to claim 8 has proved to be particularly advantageous. The distance from the image plane of the last mirror in the light path is then defined as the distance from the image plane of the piercing point of an optical axis of the imaging optical system through the reflection surface of this mirror. In the case where the optical axis does not pass through the reflection surface of the mirror, i.e. in the case, for example, of an off-axis mirror, the piercing point of the optical axis through a surface which carries on continuously in accordance with the optical design input is selected instead of the piercing point of the optical axis through the reflection surface. If the mirror is rotationally symmetric about the optical axis, this piercing point coincides with the centre of the reflection surface of the mirror. In the case where this last mirror is obscured, the centre of the reflection surface may also lie in the obscuration through-opening, in which case it is assumed that the reflection surface carries on continuously within the obscuration through-opening in accordance with the optical design input. The distance of the intermediate image plane from the image plane may for example, be 0.7, 0.8 or 0.9 times the distance of the last mirror in the light path from the image plane.

Numerical apertures according to claim 9 are preferred for achieving a high local resolution of the imaging optical system.

The object stated above is also solved by an imaging optical system according to claims 10 and 11.

An imaging optical system according to claim 12 is useful in particular for a plurality of the solution methods described above. Accordingly, imaging optical systems result in which combinations of advantages are realised.

Imaging properties according to claims 13 and 14 are advantageous for achieving a high local resolution over the whole field. These imaging properties are independent of the wavelength of the imaging light. The wavelength of the imaging light can range from the EUV range to the visible spectrum. Wavefront errors are preferred which lead to a diffraction limited resolution and which are therefore, in particular, less than one fourteenth of the imaging light wavelength. For EUV wavelengths, a wavefront error which has a root mean square (rms) of less than 1 nm leads to a resolution which is, in practice, diffraction limited.

A low pupil obscuration, i.e. the proportion of the pupil surface which cannot be used because of the central pupil obscuration, according to claim 15 leads to an advantageously high light throughput for the imaging optical system. Additionally, an imaging optical system with a low pupil obscuration can be more widely used, because the lower the pupil obscuration, the greater the bandwidth of the available illumination means. Imaging optical systems with low pupil obscurations therefore provide high-contrast imaging substantially independently of the type of object structure to be imaged.

Field planes arranged parallel to one another according to claim 16 facilitate the integration of the imaging optical system into structural surroundings. This advantage is particularly significant when the imaging optical system is used in a scanning projection exposure installation, since the scan directions can then be guided parallel to one another.

Image field sizes according to claims 17 and 18 lead to a good throughput when the imaging optical system is used in a projection exposure installation. Other dimensions of the long and short image field sides are also possible. The short image field sides may also be less than 1 mm or greater than 1 mm. The long image field sides may, for example, also be 5 mm, 10 mm or 15 mm.

An imaging scale according to claim 19 allows a low angle of incidence on a reflection mask when using the imaging optical system in a projection exposure installation. In this type of application, the use of an imaging scale of this type does not lead to the requirement of unnecessarily large masks.

Constructions with an odd number of obscured mirrors according to claim 20 have also proved to be particularly suitable. For example, three mirrors could be obscured.

An arrangement according to claim 21 leads to the possibility, in a spatially restricted arrangement, of exerting influences both in a field plane and in a pupil plane of the imaging optical system. This can be particularly expedient for correction purposes.

One embodiment of the imaging optical system according to claim 22 leads to the possibility of supplying on the imaging optical system, directly and without the interposition of additional imaging elements, from a preceding illumination optical system via a pupil component which is the last element before the imaging optical system, it then being possible for this pupil component to be arranged in the pupil plane of the imaging optical system, which plane is disposed so as to precede said imaging optical system.

If there are a low number of mirrors, an imaging optical system according to claim 23 has two intermediate image planes, and this can be used on the one hand for compact beam guidance and also, on the other hand, for correction purposes.

The advantages of a projection exposure installation according to claims 24 and 25 correspond to those previously discussed with regard to the imaging optical system according to the invention. The light source of the projection exposure installation may be in the form of a broadband light source and may have, for example, a bandwidth greater than 1 nm, greater than 10 nm or greater than 100 nm. In addition, the projection exposure installation may be constructed in such a way that it can be operated with light sources of different wavelengths. Light sources for other wavelengths, in particular wavelengths used for microlithography, can be used in conjunction with the imaging optical system according to the invention, for example light sources with wavelengths of 365 nm, 248 nm, 193 nm, 157 nm, 126 nm and 109 nm, and in particular also with wavelengths which are less than 100 nm.

Corresponding advantages also apply to the production method according to claim 26 and the microstructured component according to claim 27 produced thereby.

Embodiments of the invention will be described in the following in greater detail with reference to the drawings, in which:

Fig. 1	is a schematic view of a projection exposure installation for EUV microlithography;
Fig. 2 to 7	are embodiments of an imaging optical system, each in meridional section.

A projection exposure installation 1 for microlithography has a light source 2 for illumination light. The light source 2 is an EUV light source which produces light in a wavelength range in particular of between 10 nm and 30 nm. Other EUV wavelengths are also possible. In general, any desired wavelengths, for example visible wavelengths or any other wavelengths which are used, for example, in microlithography and are available for the appropriate laser light sources and/or LED light sources (for example 365 nm, 248 nm, 193 nm, 157 nm, 129 nm or 109 nm), are possible for the illumination light guided in the projection exposure installation 1. A light path of the illumination light 3 is shown extremely schematically in Fig. 1.

An illumination optical system 6 guides the illumination light 3 from the light source 2 to an object field 4 (cf. Fig. 2) in an object plane 5. The object field 4 is imaged into an image field 8 (cf. Fig. 2) in an image plane 9, at a pre-specified reduction scale, with a projection optical system 7. One of the embodiments shown in Fig. 2 to 7 may be used for the projection optical system 7. The projection optical system 7 of Fig. 2 has a reduction factor of 8. Other reduction scales are also possible, for example 4x, 5x, or even reduction scales that are greater than 8x. An imaging scale of 8x is particularly suitable for illumination light 3 with an EUV wavelength, since the object-side angle of incidence on a reflection mask 10 can thus remain small. An imaging scale of 8x also does not require the use of unnecessarily large masks. In the projection optical system 7 in the embodiments of Fig. 2 to 7, the image plane 9 is arranged parallel to the object plane 5. A portion of the reflective mask 10, also known as a reticle, coinciding with the object field 4 is hereby imaged.

The image field 8 is bent in an arc shape, the distance between the two arcs which delimit the image field 8 being 1 mm. 1 mm is also the side length of the straight side edges which delimit the image field 8 between the two arcs and which extend parallel to one another. These two straight side edges of the image field 8 are at a distance of 13 mm from one another. The surface of this curved image field corresponds to a rectangular image field with side lengths of 1 mm x 13 mm. A square image field 8 of this type is also possible.

Imaging takes place on the surface of a substrate 11 in the form of a wafer which is supported by a substrate holder 12. In Fig. 1, a light beam 13 of the illumination light 3 entering the projection optical system 7 is shown schematically between the reticle 10 and said projection optical system, and a light beam 14 of the illumination light 3 exiting from the projection optical system 7 is shown schematically between the projection optical system 7 and the substrate 11.

The image field-side numerical aperture of the projection optical system 7 in accordance with Fig. 2 is 0.9. This is not reproduced to scale in Fig. 1 for visual reasons.

In order to aid the description of the projection exposure installation 1 and the various embodiments of the projection optical system 7, an xyz Cartesian coordinate system is provided in the drawings and shows the respective locations of the components represented in the figures. In Fig. 1, the x direction extends perpendicular to and into the drawing plane. The y direction extends to the right and the z direction extends downwards.

The projection exposure installation 1 is a scanner-type device. Both the reticle 10 and the substrate 11 are scanned in the y direction during operation of the projection exposure installation 1.

Fig. 2 shows the optical construction of a first embodiment of the projection optical system 7. The light path of each of two individual rays 15, which proceed in each case from two object field points in Fig. 2 and are distanced from one another in the y direction, is shown. The two individual rays 15, which belong to one of these two object field points, are each associated with two different illumination directions for the two image field points. The individual rays 15, associated with the same illumination direction, of different field points extend divergently proceeding from the object plane 5. This is also referred to in the following as a negative input back focal length or a negative back focal length of the entrance pupil. An entrance pupil of the projection optical system 7 of Fig. 2 lies not inside the projection optical system 7, but before the object plane 5 in the light path. This makes it possible, for example, to arrange a pupil component of the illumination optical system 6 in the entrance pupil of the projection optical system 7, before the projection optical system 7 in the light path, without further imaging optical components having to be present between these pupil components and the object plane 5.

The projection optical system 7 of Fig. 2 has a total of eight mirrors, which are numbered in the sequence of the light path, proceeding from the object field 4, as M1 to M8. Fig. 2 shows only the calculated reflection surfaces of the mirrors M1 to M8.

The optical data for the projection optical system 7 of Fig. 2 are shown in the following by means of two tables. In the column "radius", the first table shows in each case the radius of curvature of the mirrors M1 to M8. The third column (thickness) describes the distance, proceeding from the object plane 5, to the following surface in each case.

The second table describes the precise surface form of the reflection surfaces of the mirrors M1 to M8, where the constants K and A to J are to be put into the following equation for the sagittal height:

$$z(h) = \frac{ch^2}{1 + SQRT\{1 - (1 + K)c^2h^2\}} + Ah^4 + Bh^6 + Ch^8 + Dh^{10} + Eh^{12} + Fh^{14} + Gh^{16} + Hh^{18} + Jh^{20}$$

In this case, h represents the distance from the optical axis 19. Therefore: $h^2 = x^2 + y^2$. The reciprocal of "radius" is used for c.

Surface	Radius (1/c)	Thickness	Operating mode
Object plane	infinity	517.466	
M1	-460.153	-217.028	REFL
M2	-380.618	101.780	REFL
M3	304.428	-158.351	REFL
M4	248.577	786.055	REFL
M5	320.928	-512.457	REFL
M6	826.181	1504.412	REFL
M7	-3221.704	-191.095	REFL
stop	infinity	-375.302	
M8	750.83	606.397	REFL
Image plane	infinity	0	

Surface	K	A	B	C	D
M1	0.000000E+00	-1.631597E-10	9.657530E-16	-6.306626E-20	1.072197E-24
M 2	-7.342117E+00	-3.247790E-08	1.007295E-13	-2.908653E-18	-6.581368E-21
M 3	-8.421287E+00	1.604616E-09	1.164266E-11	-7.638324E-15	2.158838E-18
M 4	5.504873E-02	-2.854695E-10	1.302845E-15	7.411326E-19	-1.319473E-22
M 5	-2.441303E-02	-4.072151E-09	-5.877441E-14	2.214912E-18	-8.175465E-23
M 6	3.411049E-03	-7.680740E-12	-7.621133E-18	-6.837917E-24	-8.305886E-30
M 7	-2.544754E+00	5.119174E-10	-8.412525E-16	8.746864E-21	-4.053738E-26
M 8	1.012485E-01	-6.355004E-11	-1.261118E-16	-6.586951E-24	-4.143278E-28
Surface	**E**	**F**	**G**	**H**	**J**
M1	-1.289213E-29	8.646860E-35	-2.746050E-40	0.000000E+00	1.075412E-51
M2	1.743214E-24	-2.256980E-28	1.288821E-32	0.000000E+00	-2.146208E-41
M3	2.665732E-25	1.001342E-24	-1.896580E-27	1.213404E-30	-2.772775E-34
M4	1.642304E-26	-1.185339E-30	4.697782E-35	-7.812489E-40	0.000000E+00
M5	1.783031E-27	-3.302179E-32	6.356237E-37	-8.439168E-42	3.970026E-47
M6	-1.193959E-35	3.014822E-41	-1.666695E-46	2.921935E-52	-2.589560E-58
M7	1.405577E-31	1.660762E-37	-4.750000E-42	2.390150E-47	-4.132019E-53
M8	3.396965E-35	3.588060E-40	-3.053788E-45	6.807302E-51	-1.109855E-56

The mirrors M1, M2 and M4 of a first mirror group 18, which comprises the mirrors M1 to M4, are shaped as ring segments and are used off-axis with respect to the optical axis 19 - completely in the case of the mirrors M1 and M2 and for the most part in the case of the mirror M4. The employed optical reflection surface of the mirrors M, M2 and - for the most part - M4 thus lies at a distance from the optical axis 19. The reflection surfaces of all the mirrors M1 to M8 are rotationally symmetric about the optical axis 19.

The employed reflection surface of the mirror M3 is approximately centred on the optical axis 19 (on-axis).

The mirrors M1, M4, M6, M7 and M8 are concave mirrors. The mirrors M2, M3 and M5 are convex mirrors.

An intermediate image plane 20 of the projection optical system 7 lies between the mirrors M4 and M5. As their course continues, the individual rays 15 pass through a through-opening 21 in the mirror M6. The mirror M6 is used around the through-opening 21. The mirror M6 is thus an obscured mirror. As well as the mirror M6, the mirrors M7 and M8 are also obscured and both likewise comprise a through-opening 21.

The mirror M5, i.e. the fourth-last mirror in the light path before the image field 8, is not obscured and thus has no through-opening for imaging light. An outer edge 22 of the optically effective reflection surface of the mirror M5 provides a central shadowing of the projection optical system 7, i.e. of the imaging optical system, in the pupil plane 17. The mirror M5 therefore shadows the light path between the mirrors M6 and M7.

The mirror M5 is arranged on the optical axis 19 and lies approximately centrally on said optical axis 19.

In the embodiment of Fig. 2, the distance between the mirror M5 and the last mirror M8, which are arranged back-to-back in terms of the reflective effect thereof, is approximately 20.6 % of the distance between the object plane 5 and the image plane 9 and, in particular, approximately 20 % of the marginally greater distance between the object field 4 and the image field 8. A substantially greater space is thus present in the optical system 7 between the mirrors M5 and M8.

A further intermediate plane 23 lies between the mirror M6 and the mirror M7 in the light path. This is the intermediate image plane which is closest to the image plane 9. This intermediate image plane 23 lies spatially between the last mirror M8 in the light path and the image plane 9. The distance of the intermediate image plane 23 from the image plane 9 is approximately 0.7 times the distance of the last mirror M6 in the light path from the image plane 9.

The projection optical system 7 of Fig. 2 has a maximum root mean square (rms) wavefront error of 0.9 nm. The distortion of the projection optical system 7 is at most 0.5 nm. The pupil obscuration, i.e. the ratio of a central shadowed surface portion in the pupil plane 17 to the whole surface within an illuminated edge contour in the pupil plane 17, is 11.6 %.

Fig. 3 shows a further embodiment of a projection optical system 7. Components and features which correspond to those which have previously been described with reference to Fig. 1 and 2 have the same reference numerals and will not be discussed in detail again.

The optical data for the projection optical system 7 of Fig. 3 are shown in the following by means of two tables, which correspond in layout to the tables for Fig. 2.

Surface	Radius (1/c)	Thickness	Operating mode
Object plane	infinity	240.357	
M1	306.212	-140.357	REFL
M2	472.863	1508.127	REFL
M3	-1214.568	-651.640	REFL
M4	371.570	1076.156	REFL
M5	210.825	-524.516	REFL
M6	793.298	1450.998	REFL
M	-3402.480	-176.337	REFL
stop	infinity	-366.873	
M8	734.006	584.084	REFL
Image plane	infinity	0.000	

Surface	K	A	B	C	D
M1	0.000000E+00	5.528998E-09	-4.968534E-13	1.659177E-17	-3.863442E-22
M2	-6.538633E-01	5.913642E-10	-2.068085E-15	1.843758E-20	-6.714355E-26
M3	0.000000E+00	9.809893E-10	1.757665E-15	6.252623E-20	-7.383824E-25
M4	2.740280E+00	-4.880461E-08	8.522603E-12	-1.221389E-15	1.142980E-19
M5	-5.973645E-02	-1.313275E-08	-1.603339E-13	2.016611E-18	-4.373542E-22
M6	4.517989E-02	-1.639817E-11	-1.843198E-17	-2.050197E-23	-3.219956E-29
M7	-1.286534E+01	4.603123E-10	-1.024577E-15	1.178213E-20	-7.426445E-26
M8	9.856773E-02	-8.505963E-11	-1.255661E-16	-1.224739E-22	-3.390517E-28

Surface	E	F	G	H	J
M1	5.540209E-27	-4.791768E-32	2.229758E-37	-4.553644E-43	0.000000E+00
M2	1.572034E-31	-1.728552E-37	1.501360E-43	0.000000E+00	0.000000E+00
M3	8.354870E-30	-3.768113E-35	0.000000E+00	4.020897E-45	0.000000E+00
M4	-6.828562E-24	2.234887E-28	-2.050695E-33	-5.185597E-38	0.000000E+00
M5	2.682717E-26	-1.836495E-30	8.559900E-35	-1.643140E-39	0.000000E+00
M6	2.845752E-35	-2.880170E-40	5.575425E-46	-7.139928E-52	0.000000E+00
M7	4.719915E-31	-2.246586E-36	6.923567E-42	-9.256971E-48	0.000000E+00
M8	5.071111E-34	-2.813625E-39	6.372889E-45	-9.981207E-51	0.000000E+00

The embodiment of Fig. 3 differs from that of Fig. 2 substantially by virtue of the arrangement of the first mirror group 18 comprising the mirrors M1 to M4. All four mirrors M1 to M4 of the first mirror group 18 of the projection optical system 7 of Fig. 3 are supplied off-axis via a light source. The mirror M1 is convex and the mirrors M2 to M4 are concave.

The projection optical system 7 of Fig. 3 has a negative back focal length of the entrance pupil.

The first intermediate image plane 20 is arranged in the region of the mirror M4 in the embodiment of Fig. 3. According to the precise configuration of the mirror construction, the associated intermediate image can be arranged before the mirror M4, on the mirror M4, or even after the mirror M4.

In the embodiment of Fig. 3, the mirror M3 lies not to the left of the mirror M6, as in the embodiment of Fig. 2, but at the level of the optical axis 19 to the right of the mirror M6. The rays 15 pass through the mirror M6 on the way from the mirror M2 to the mirror M3, exactly like the rays 15 on the way from the mirror M3 to the mirror M4 and on the way from the mirror M4 to the mirror M5. The through-opening 21 in the mirror M6 is thus passed through thrice by the individual rays 15.

In the projection optical system 7 of Fig. 3, the distance between the mirrors M5 and M8 is approximately 12.8 % of the distance between the object plane 5 and the image plane 9. The distance of the intermediate image plane 23 from the image plane 9 is approximately 0.8 times the distance of the last mirror M6 in the light path from the image plane 9.

The maximum (rms) wavefront error of the projection optical system 7 of Fig. 3 is 2.2 nm. The maximum distortion is 5 nm. The pupil obscuration is 8.4 %.

Fig. 4 shows a further embodiment of a projection optical system 7. Components and features which correspond to those which have previously been described with reference to Fig. 1 and 2 have the same reference numerals and will not be discussed in detail again.

The optical data for the projection optical system 7 of Fig. 4 are shown in the following by means of two tables, which correspond in layout to the tables for Fig. 2.

Surface	Radius (1/c)	Thickness	Operating mode
Object plane	infinity	390.160	
M1	5657.607	-290.160	REFL
M2	547.829	364.027	REFL
M3	150.329	-131.050	REFL
M4	182.077	674.854	REFL
M5	301.845	-517.671	REFL
M6	809.621	1464.069	REFL
M7	-3032.589	-177.803	REFL
stop	infinity	-377.065	
M8	753.606	600.638	REFL
Image plane	infinity	0.000	

Surface	K	A	B	C	D
M1	0.000000E+00	-2.662522E-10	-5.535133E-15	9.951400E-20	-1.728701E-24
M2	0.000000E+00	-7.758511E-11	-4.927920E-16	-2.380995E-21	1.771881E-27
M3	0.000000E+00	2.187978E-08	-4.324024E-12	-2.166837E-15	6.601874E-19
M4	0.000000E+00	1.844448E-09	6.801387E-14	2.528119E-17	-6.128096E-21
M5	1.156883E-04	-6.361997E-09	-4.599504E-14	1.885582E-18	-6.053781E-23
M6	3.259720E-02	-1.077005E-11	-1.049275E-17	-1.178590E-23	-1.688268E-30
M7	-8.103305E+00	3.958094E-10	-5.118462E-16	5.066772E-21	-1.825272E-26
M8	1.035316E-01	-7.996215E-11	-1.253165E-16	-7.448536E-23	-2.060928E-28
Surface	**E**	**F**	**G**	**H**	**J**
M1	1.574353E-29	-5.663846E-35	0.000000E+00	0.000000E+00	0.000000E+00
M2	-1.673915E-31	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
M3	-1.166941E-23	-9.288602E-26	5.378119E-29	0.000000E+00	0.000000E+00
M4	1.073882E-24	-9.788111E-29	3.783735E-33	0.000000E+00	0.000000E+00
M5	-4.369093E-28	5.123232E-32	-7.255963E-37	0.000000E+00	0.000000E+00
M6	-6.033318E-35	1.025297E-40	-1.418317E-46	0.000000E+00	0.000000E+00
M7	1.004654E-31	-5.423670E-37	2.038001E-42	-3.000000E-48	0.000000E+00
M8	-4.980960E-34	5.995233E-40	6.787033E-46	-4.632967E-51	0.000000E+00

The projection optical system 7 of Fig. 4 also differs from those of Fig. 2 and Fig. 3 substantially by virtue of the arrangement of the first mirror group 18 comprising the mirrors M1 to M4. The mirrors M1, M2 and M4 are supplied off-axis. The mirror M3 is convex. The mirrors M1, M2 and M4 are convex. The mirror M1 has such a low curvature that said mirror may not only be concave, but with a slight adaptation of the construction may also be planar or convex.

In the projection optical system 7 of Fig. 4, the first intermediate image plane 20 lies in the light path between the mirrors and M4 and M5, approximately at the level of the mirror M3.

In the embodiment of Fig. 4, the mirror M3 is again arranged to the left of the mirror M6, in such a way that the through-opening 21 of the mirror M6 is only passed through once by the rays 15. With a slight adaptation of the construction, the mirror M3 may also be moved into the opening of the mirror M6.

In the projection optical system 7 of Fig. 4, the distance between the mirrors M5 and M8 is approximately 19.6 % of the distance between the object plane 5 and the image plane 9. The distance of the intermediate image plane 23 from the image plane 9 is approximately 0.76 times the distance of the last mirror M6 in the light path from the image plane 9.

The maximum (rms) wavefront error of the projection optical system 7 of Fig. 4 is 1.4 nm. The maximum distortion is 1.5 nm. The pupil obscuration is 10.9 %.

Fig. 5 shows a further embodiment of a projection optical system 7. Components and features which correspond to those which have previously been described with reference to Fig. 1 and 2 have the same reference numerals and will not be discussed in detail again.

The optical data for the projection optical system 7 of Fig. 5 are shown in the following by means of two tables, which correspond in layout to the tables for Fig. 2.

Surface	Radius (1/c)	Thickness	Operating mode
Object plane	infinity	591.532	
M1	-6782.876	-530.662	REFL
M2	702.707	1026.755	REFL
stop	infinity	0.000	
M3	217.303	-507.993	REFL
M4	776.996	1490.702	REFL
M5	-2014.188	-533.319	REFL
M6	791.740	603.252	REFL
Image plane	infinity	0.000	

Surface	K	A	B	C
M1	0.000000E+00	8.899437E-09	-1.356259E-12	2.954130E-15
M2	-3.639089E+00	1.110645E-09	-2.542191E-15	2.297600E-20
M3	1.390154E-01	-1.972567E-08	3.444974E-13	-7.400803E-17
M4	-2.088645E-02	-1.996767E-11	-3.060841E-17	-4.632700E-23
M5	-1.390893E+01	1.114680E-09	1.108176E-15	5.215888E-20
M6	1.112425E-01	6.540015E-11	8.340321E-17	2.310935E-22
Surface	D	E	F	G
M1	-2.165883E-18	0.000000E+00	6.325365E-25	-1.919429E-28
M2	-1.439457E-24	9.400607E-29	-3.212860E-33	4.384528E-38
M3	9.862318E-21	-2.518066E-24	3.734400E-28	-2.241749E-32
M4	-5.236534E-29	-6.140963E-35	-6.134373E-40	8.521628E-46
M5	-1.658708E-24	7.482784E-29	-1.911769E-33	1.936176E-38
M6	-2.192695E-27	6.492849E-33	1.784557E-37	-1.082995E-42

The projection optical system 7 of Fig. 5 has a total of six mirrors, which are numbered in the sequence of the light path, proceeding from the object field 5, as M1 to M6.

In the projection optical system 7 of Fig. 5, a first mirror group 24 comprises only two mirrors, namely the mirrors M1 and M2. The mirror M1 is supplied approximately on-axis and the mirror M2 is supplied off-axis. The following mirrors M3 to M6 correspond in arrangement and function to the mirrors M5 to M8 of the embodiments of Fig. 2 to 4.

The projection optical system 7 of Fig. 5 has a numerical aperture of 0.4.

The projection optical system 7 according to Fig. 5 has a positive back focal length for the entrance pupil, i.e. principal rays 16 extending initially convergently from the object field 4. The mirror M1 lies in the region of an entrance pupil plane 25 of the projection optical system 7. The first intermediate image plane 20 also lies between the mirrors M2 and M3, likewise approximately at the level of the mirror M1.

The mirror M1 is arranged in the through-opening 21 of the mirror M4. The through-opening 21 of the mirror M4 is again passed through thrice, similarly to the mirror M6 in the embodiment of Fig. 3.

The fourth-last mirror M3, the outer edge 22 of which again provides the pupil obscuration of the projection optical system 7 of Fig. 5, lies in the region of a further pupil plane 26 of the projection optical system 7 of Fig. 5. An aperture stop of the projection optical system 7 according to Fig. 5 can therefore be applied to the mirror M3.

The distance between the fourth-last mirror M3 and the last mirror M6 is equal to approximately 21.0 % of the distance between the object plane 5 and the image plane 9 in the embodiment of Fig. 5. The distance of the intermediate image plane 23 from the image plane 9 is approximately 0.74 times the distance of the last mirror M6 in the light path from the image plane 9.

The projection optical system 7 of Fig. 5 has a maximum (rms) wavefront error of 0.4 nm. The maximum distortion is 0.3 nm. The pupil obscuration is 17.6 %.

Fig. 6 shows a further embodiment of a projection optical system 7. Components and features which correspond to those which have previously been described with reference to Fig. 1 to 5 have the same reference numerals and will not be discussed in detail again.

The optical data for the projection optical system 7 of Fig. 6 are shown in the following by means of two tables, which correspond in layout to the tables for Fig. 2.

Surface	Radius (1/c)	Thickness	Operating mode
Object plane	infinity	683.665	
M1	-694.834	-271.324	REFL
M2	-411.527	1372.036	REFL
M3	346.281	-1100.613	REFL
M4	1469.502	2005.780	REFL
M5	-722.731	-41.563	REFL
stop	infinity	-272.149	
M6	544.465	370.467	REFL
Image plane	infinity	0.000	

Surface	K	A	B	C
M1	7.396949E-03	-8.591818E-11	2.958631E-15	-1.515085E-19
M2	-4.696303E-01	-1.639186E-09	-1.894486E-14	-4.136066E-18
M3	-5.224549E-01	-2.010111E-09	-1.293006E-14	-2.918315E-20
M4	-3.021297E-02	9.250522E-14	5.057734E-20	4.887335E-28
M5	-3.126684E+00	2.153833E-09	1.799694E-14	-1.892202E-20
M6	6.984230E-01	-1.682769E-10	-1.422157E-15	1.234832E-20
Surface	**D**	**E**	**F**	**G**
M1	4.091038E-24	-5.790509E-29	3.296826E-34	8.178384E-41
M2	1.255234E-21	-1.379809E-25	5.435466E-30	-4.566966E-36
M3	1.475407E-23	-5.835055E-28	1.288505E-32	-3.671165E-37
M4	4.320243E-35	4.670696E-39	-4.109431E-45	2.963010E-51
M5	-6.296522E-25	2.964336E-29	6.191151E-34	-1.998284E-38
M6	-1.683381E-25	8.658821E-31	-3.676860E-36	-5.905802E-41

The projection optical system 7 of Fig. 6 is a six-mirror system, like that of Fig. 5. In this case, the first mirror group 24 also comprises only the mirrors M1 and M2. The two mirrors M1 and M2 are supplied off-axis.

The mirror M1 is arranged adjacent to the through-opening 21 of the mirror M4. This arrangement is such that the through-opening 21 of the mirror M4 is only passed through once for the ray between the mirrors M2 and M3.

The projection optical system 7 of Fig. 6 has only a single intermediate image plane 27, which is spatially arranged, like the intermediate image planes 23 in the embodiments of Fig. 2 to 5, between the last mirror in the light path, i.e. the mirror M6, and the image plane 9.

In the embodiment of Fig. 6, despite the fact that the through-opening 21 of the mirror M4 is passed though by a light beam which has no focus there and thus has a relatively large diameter, the fourth-last mirror M3 is still the mirror which, with the outer edge 22 thereof, provides the pupil obscuration of the projection optical system 7.

The projection optical system 7 of Fig. 6 has a numerical aperture of 0.55.

The distance between the fourth-last mirror M3 and the last mirror M6 is equal to approximately 22 % of the distance of the object plane 5 from the image plane 9 in the embodiment of the projection optical system 7 of Fig. 6. The distance of the intermediate image plane 23 from the image plane 9 is approximately 0.8 times the distance of the last mirror M6 in the light path from the image plane 9.

The projection optical system 7 of Fig. 6 has a maximum (rms) wavefront error of 1.4 nm. The maximum distortion is 1.4 nm. The pupil obscuration is 16.8 %.

Fig. 7 shows a further embodiment of a projection optical system 7. Components and features which correspond to those which have previously been described with reference to Fig. 1 to 5 have the same reference numerals and will not be discussed in detail again.

The optical data for the projection optical system 7 according to Fig. 7 are shown in the following by means of two tables, which correspond in layout to the tables for Fig. 2.

Surface	Radius (1/c)	Thickness	Operating mode
Object plane	infinity	379.207	
M1	-509.962	-179.207	REFL
M2	-318.440	1332.984	REFL
M3	343.817	-1093.195	REFL
M4	1475.059	2039.667	REFL
M5	-609.119	-28.006	REFL
stop	infinity	-281.138	
M6	562.495	354.144	REFL
Image plane	infinity	0.000	

Surface	K	A	B	C
M1	1.484533E-01	-5.739623E-10	9.023124E-14	-7.365787E-18
M2	5.827688E-01	3.542976E-09	1.241138E-13	-3.596600E-17
M3	-1.284995E+00	-4.653305E-09	1.019610E-13	-3.037140E-18
M4	-4.865988E-02	-1.091347E-13	-6.628260E-21	-4.841711E-28
M5	-4.572713E+00	2.517019E-09	7.268687E-16	6.794125E-19
M6	8.759896E-01	1.726609E-10	-2.501863E-15	1.688202E-20
Surface	D	E	F	G
M1	3.807256E-22	-1.215662E-26	2.193281E-31	-1.712891E-36
M2	9.673512E-21	-1.599535E-24	1.493641E-28	-5.987766E-33
M3	9.767861E-23	-2.436531E-27	3.766380E-32	-2.616614E-37
M4	-3.662658E-33	-1.445033E-38	1.208908E-44	-4.273745E-51
M5	-1.846769E-23	4.603723E-28	-6.890055E-33	4.664473E-38
M6	1.453398E-25	-6.794812E-30	8.060319E-35	-3.545269E-40

Like the embodiments of Fig. 5 and 6, the projection optical system 7 of Fig. 7 is also a six-mirror system. The construction of the first mirror group 24 comprising the mirrors M1 and M2 corresponds to that of the embodiment of Fig. 6. The embodiment according to Fig. 7 also has only one intermediate image plane, namely the intermediate image plane 27, which is arranged correspondingly to that of Fig. 6.

The projection optical system 7 of Fig. 7 has a numerical aperture of 0.60.

The distance between the fourth-last mirror M3 and the last mirror M6 is equal to approximately 25 % of the distance of the object plane 5 from the image plane 9 in the embodiment of the projection optical system 7 of Fig. 7. The distance of the intermediate image plane 23 from the image plane 9 is approximately 0.8 times the distance of the last mirror M6 in the light path from the image plane 9.

The maximum (rms) wavefront error of the projection optical system 7 of Fig. 7 is 0.7 nm. The maximum distortion is 0.3 nm. The pupil obscuration is 16.0 %.

To produce a microstructured or nanostructured component, the projection exposure installation 1 is used as follows: Initially, the reflection mask 10, or the reticle and the substrate, or the wafer 11 is prepared. Subsequently, a structure on the reticle 10 is projected onto a light-sensitive layer of the wafer 11 by means of the projection exposure installation 1. By developing the light-sensitive layer, a microstructure on the wafer 11, and thus the microstructured component, are then produced.

Claims

1. Imaging optical system (7) comprising a plurality of mirrors (M1 to M8; M1 to M6), which image an object field (4) in an object plane (5) into an image field (8) in an image plane (9), at least one of the mirrors (M6, M7, M8; M4, M5, M6) comprising a through-opening (21) for imaging light (15) to pass through,
characterised in that the imaging optical system (7) comprises at least six mirrors (M1 to M8; M1 to M6), a fourth-last mirror (M5; M3) before the image field (8), in the light path between the object field (4) and the image field (8), comprising no through-opening and providing, with an outer edge (22) surrounding the optically effective surface of the fourth-last mirror (M5; M3), a central shadowing in a pupil plane (17; 25, 26) of the imaging optical system (7).

2. Imaging optical system according to claim 1, **characterised in that** the fourth-last mirror (M5; M3) is a convex mirror.

3. Imaging optical system according to either claim 1 or claim 2, **characterised in that** the fourth-last mirror (M5; M3) lies on an optical axis (19) of the imaging optical system (7).

4. Imaging optical system according to any one of claims 1 to 3, **characterised in that** the fourth-last mirror (M3) is arranged in the region of a pupil plane (26) of the imaging optical system (7).

5. Imaging optical system (7) comprising a plurality of mirrors (M1 to M8; M1 to M6), which image an object field (4) in an object plane (5) into an image field (8) in an image plane (9), at least one of the mirrors

(M6, M7, M8; M4, M5, M6) comprising a through-opening (21) for imaging light (15) to pass through,
characterised in that the imaging optical system (7) comprises at least eight mirrors (M1 to M8; M1 to M6), the distance (M5 to M8, M3 to M6) between a fourth-last mirror (M5; M3), in the light path between the object field (4) and the image field (8), and a last mirror (M8; M6) in the light path being at least 10 % of the distance between the object field (4) and the image field (8).

6. Imaging optical system (7) comprising a plurality of mirrors (M1 to M8; M1 to M6), which image an object field (4) in an object plane (5) into an image field (8) in an image plane (9), at least one of the mirrors (M6, M7, M8; M4, M5, M6) comprising a through-opening (21) for imaging light (15) to pass through,
characterised in that the imaging optical system (7) comprises at least six mirrors (M1 to M8; M1 to M6), the distance (M5 to M8, M3 to M6) between a fourth-last mirror (M5; M3), in the light path between the object field (4) and the image field (8), and a last mirror (M8; M6) in the light path being at least 10 % of the distance between the object field (4) and the image field (8).

7. Imaging optical system (7) comprising a plurality of mirrors (M1 to M8; M1 to M6), which image an object field (4) in an object plane (5) into an image field (8) in an image plane (9), at least three of the mirrors (M6 to M8; M4 to M6) comprising a through-opening (21) for imaging light (15) to pass through,
at least one intermediate image plane (20, 23; 27) being present between the object plane (5) and the image plane (9),

characterised in that the intermediate image plane (23; 27) which is closest to the image plane (9), in the light path between the object field (4) and the image field (8), is spatially arranged between the last mirror (M8; M6) in the light path and the image plane (9).

8. Imaging optical system (7) according to claim 7, **characterised in that** the distance of the intermediate image plane (23; 27) from the image plane (9) is at most 0.95 times the distance, from the image plane (9), of the last mirror (M8; M6) in the light path .

9. Imaging optical system (7) according to any one of claims 1 to 8, **characterised by** a numerical aperture of at least 0.4, preferably at least 0.5, even more preferably at least 0.6, even more preferably at least 0.9.

10. Imaging catoptric optical system (7) comprising fewer than ten mirrors (M1 to M8), which image an object field (4) in an object plane (5) into an image field (8) in an image plane (9), **characterised by** a numerical aperture of ≥ 0.7.

11. Imaging optical system (7) according to claim 10, comprising precisely eight mirrors (M1 to M8) and having a numerical aperture of 0.9.

12. Imaging optical system (7) according to at least one of claims 1 to 11.

13. Imaging optical system according to any one of claims 1 to 12, **characterised by** a maximum root mean square (rms) wavefront error of less than 10 nm, preferably less than 5 nm, even more preferably less than 2

nm, even more preferably less than 1 nm, even more preferably less than 0.5 nm.

14. Imaging optical system according to any one of claims 1 to 13, **characterised by** a maximum distortion of 10 nm, preferably less than 5 nm, even more preferably less than 2 nm, even more preferably less than 1 nm, even more preferably less than 0.5 nm.

15. Imaging optical system according to any one of claims 1 to 14, **characterised by** a pupil obscuration of less than 20 %, preferably less than 15 %, even more preferably less than 10 %.

16. Imaging optical system according to any one of claims 1 to 15, **characterised in that** the image plane (9) is arranged parallel to the object plane (5).

17. Imaging optical system according to any one of claims 1 to 16, **characterised in that** the image field (8) is larger than 1 mm^2.

18. Imaging optical system according to claim 17, **characterised by** a rectangular or arc-shaped image field (8) with side-lengths of 1 mm and 13 mm.

19. Imaging optical system according to any one of claims 1 to 18, **characterised by** a reduction imaging scale of 8.

20. Imaging optical system according to any one of claims 1 to 19, **characterised by** an odd number of mirrors (M6 to M8; M4 to M6) having a through-opening (21) for imaging light (15) to pass through.

21. Imaging optical system according to any one of claims 1 to 20, **characterised in that** at least one intermediate image plane (20) is folded in the vicinity of a pupil plane (25) of the imaging optical system (7), in particular coinciding therewith.

22. Imaging optical system according to any one of claims 1 to 21, **characterised in that** principal rays (16) extend divergently to neighbouring field points in the light path from the object field (4) to the first mirror (M1).

23. Imaging optical system according to any one of claims 1 to 22, **characterised in that** the imaging optical system comprises precisely six mirrors (M1 to M6) and precisely two intermediate image planes (20, 23).

24. Projection exposure installation for microlithography
    - comprising an imaging optical system (7) according to any one of claims 1 to 23,
    - comprising a light source (2) for the illumination and imaging light (3),
    - comprising an illumination optical system (6) for guiding the illumination light (3) to the object field (4) of the imaging optical system (7).

25. Projection exposure installation according to claim 24, **characterised in that** the light source (2) for generating the illumination light (3) is formed with a wavelength of between 10 and 30 mm.

26. Method for producing a microstructured component comprising the following steps:
    - providing a reticle (10) and a wafer (11),
    - projecting a structure on the reticle (10) onto a light-sensitive layer of the wafer (11) by using the projection exposure installation according to claim 24 or claim 25,
    - producing a microstructure on the wafer (11).

27. Microstructured component produced according to a method according to claim 26.

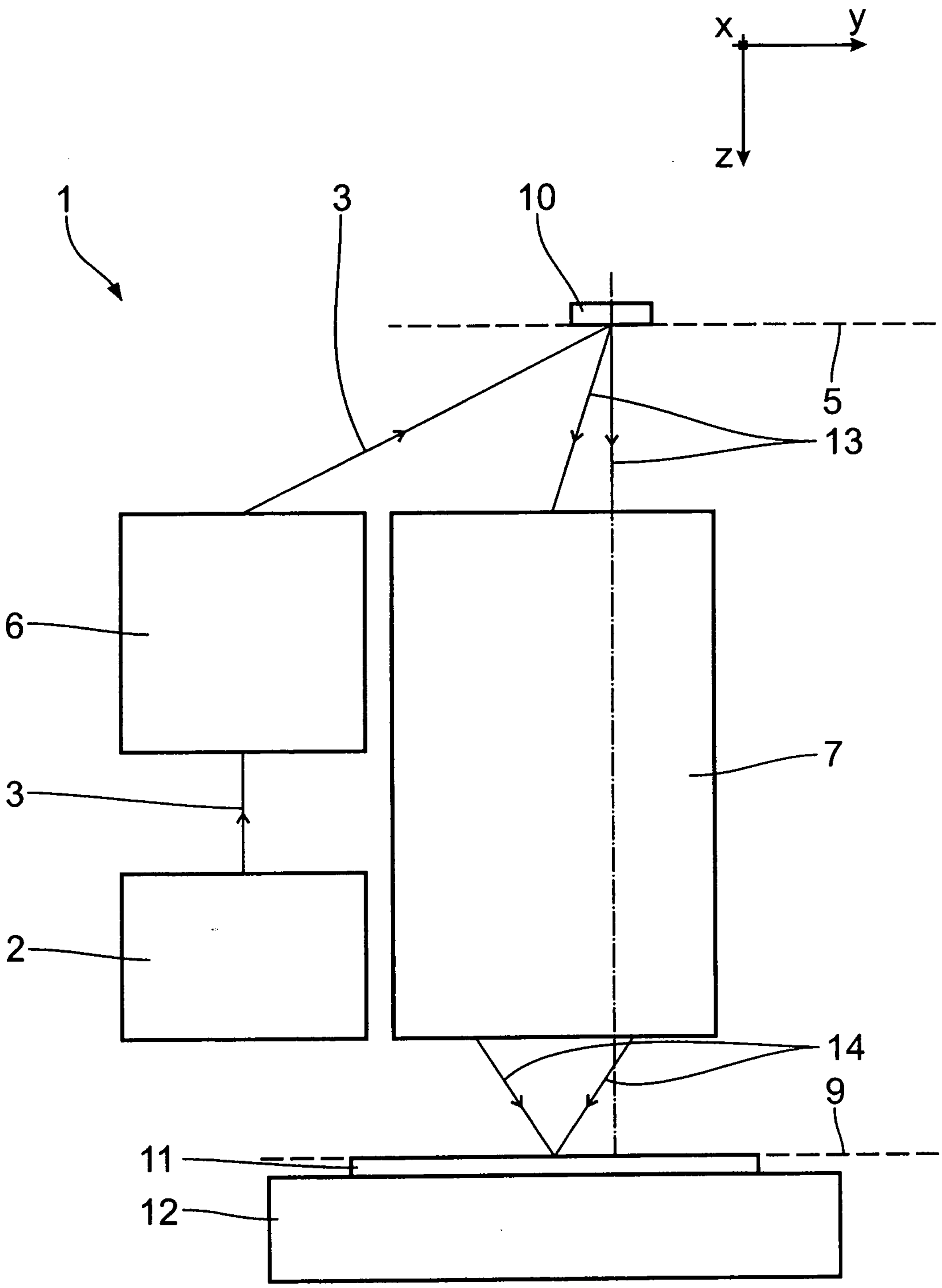

Fig. 1

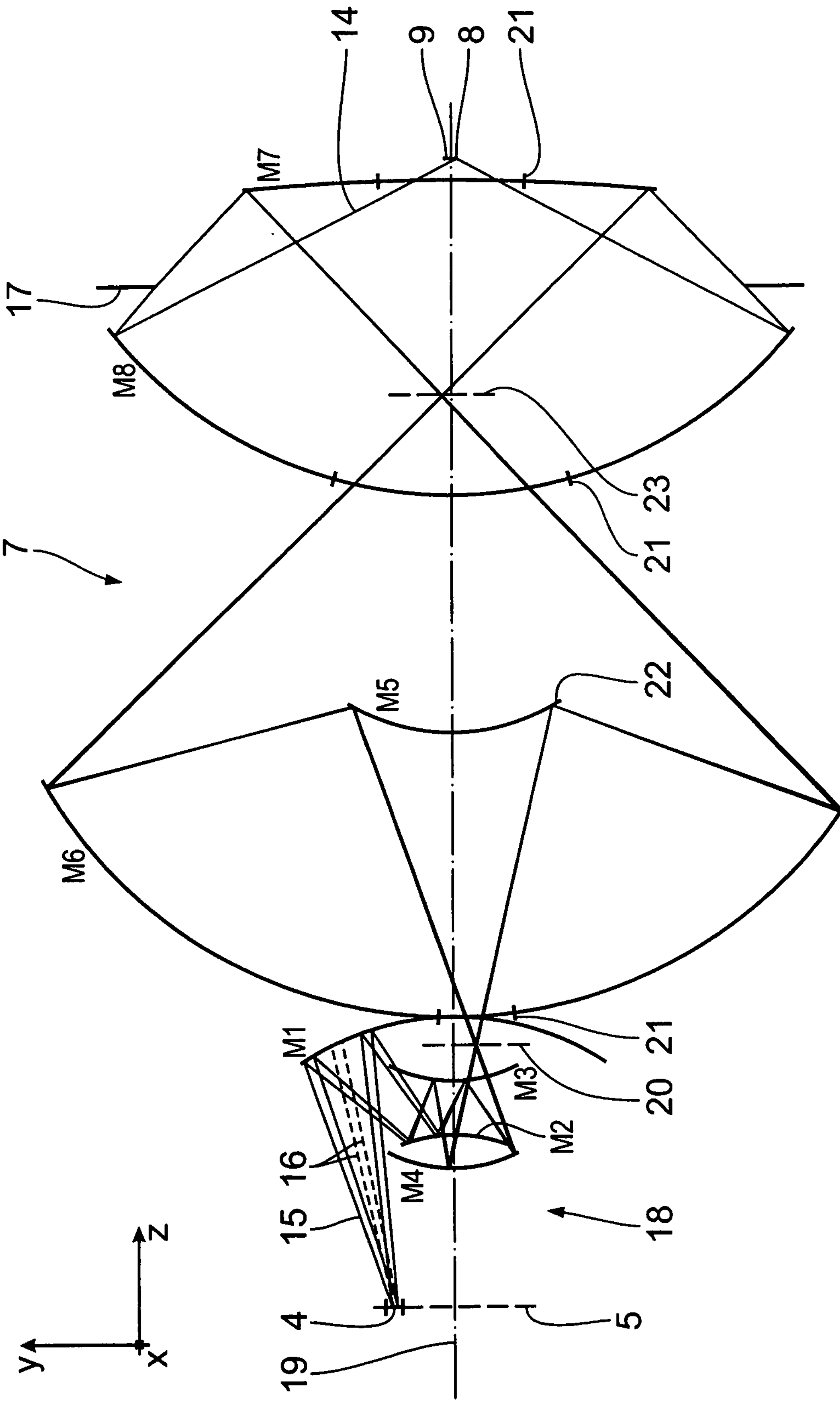

Fig. 2

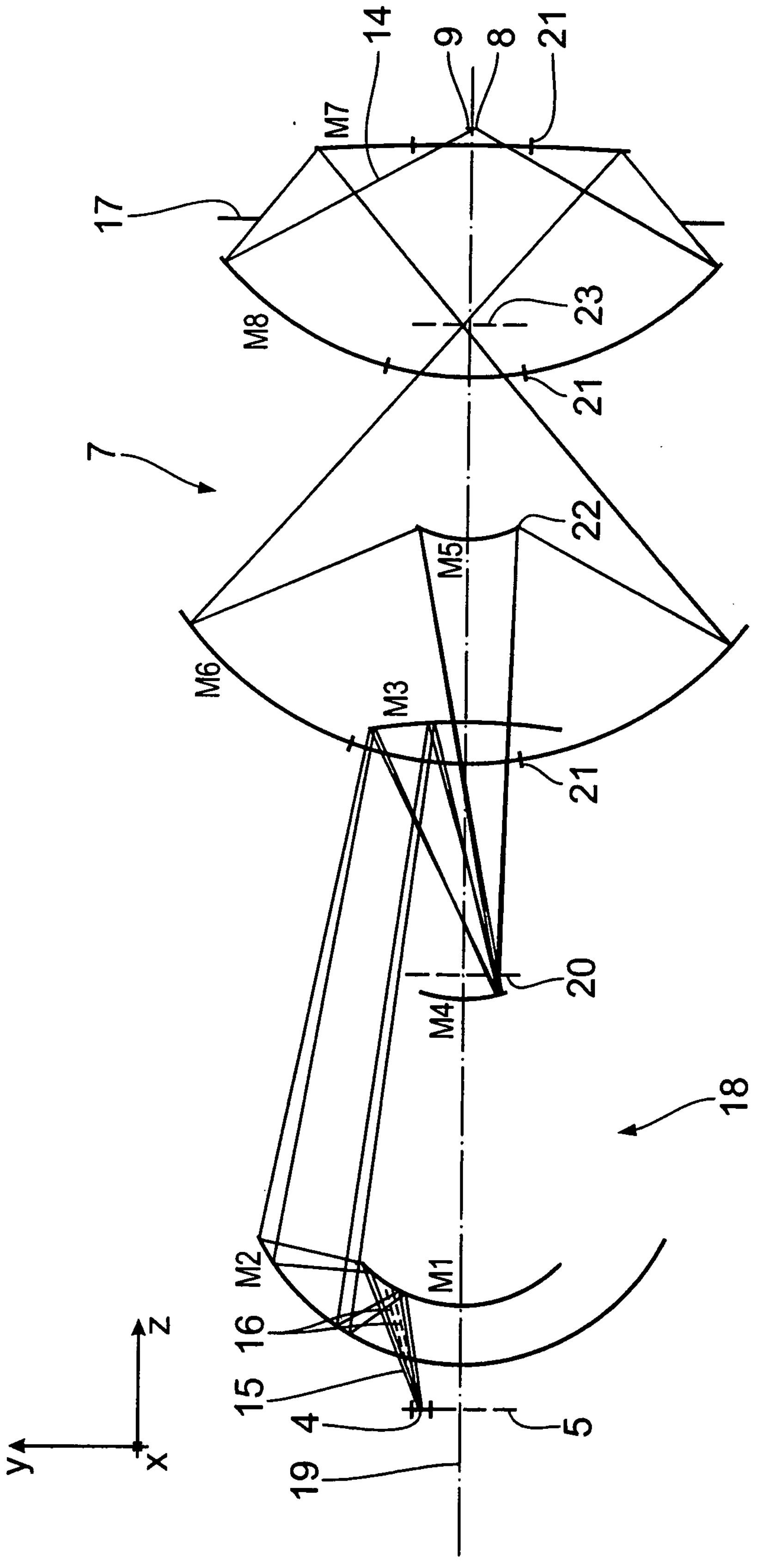

Fig. 3

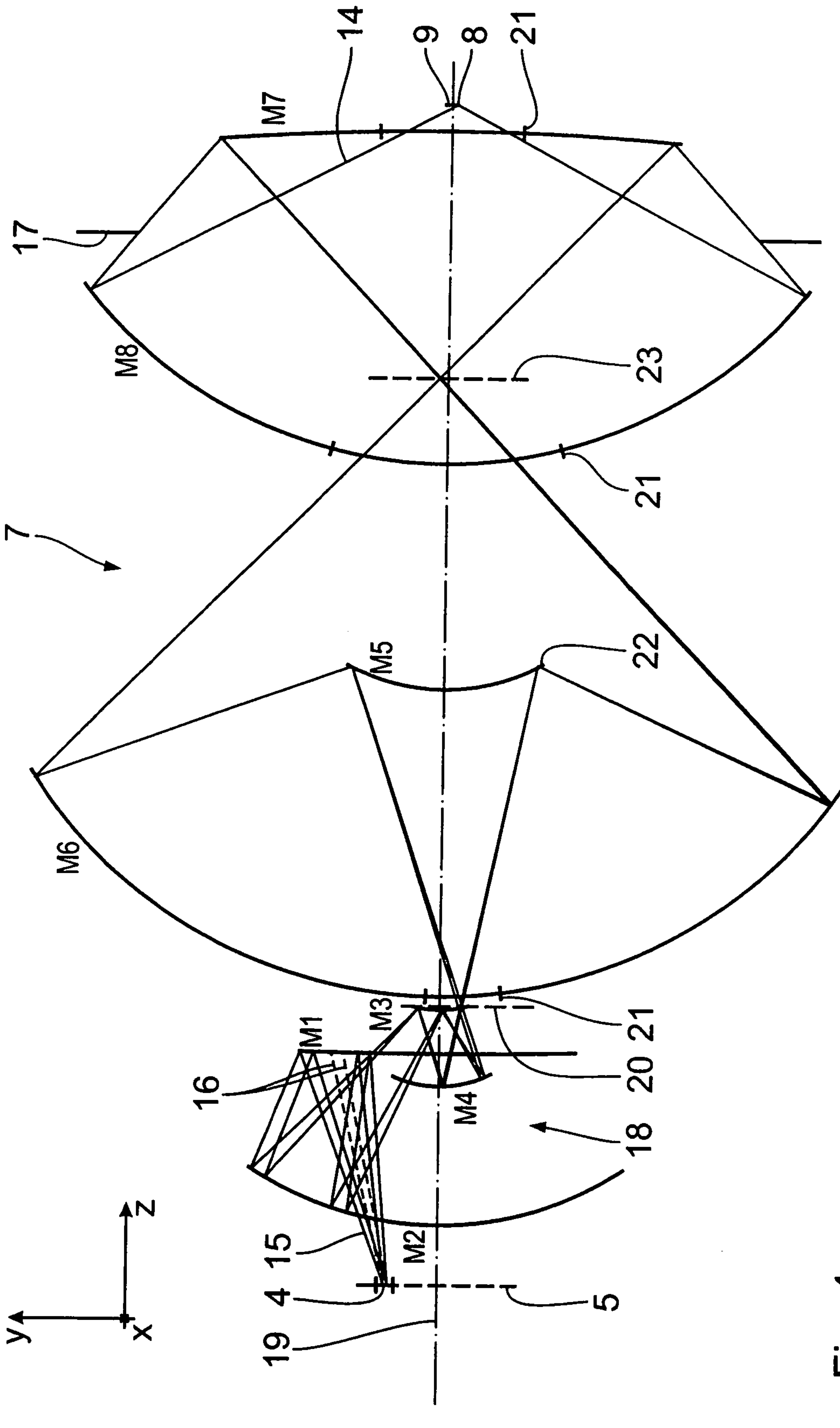

Fig. 4

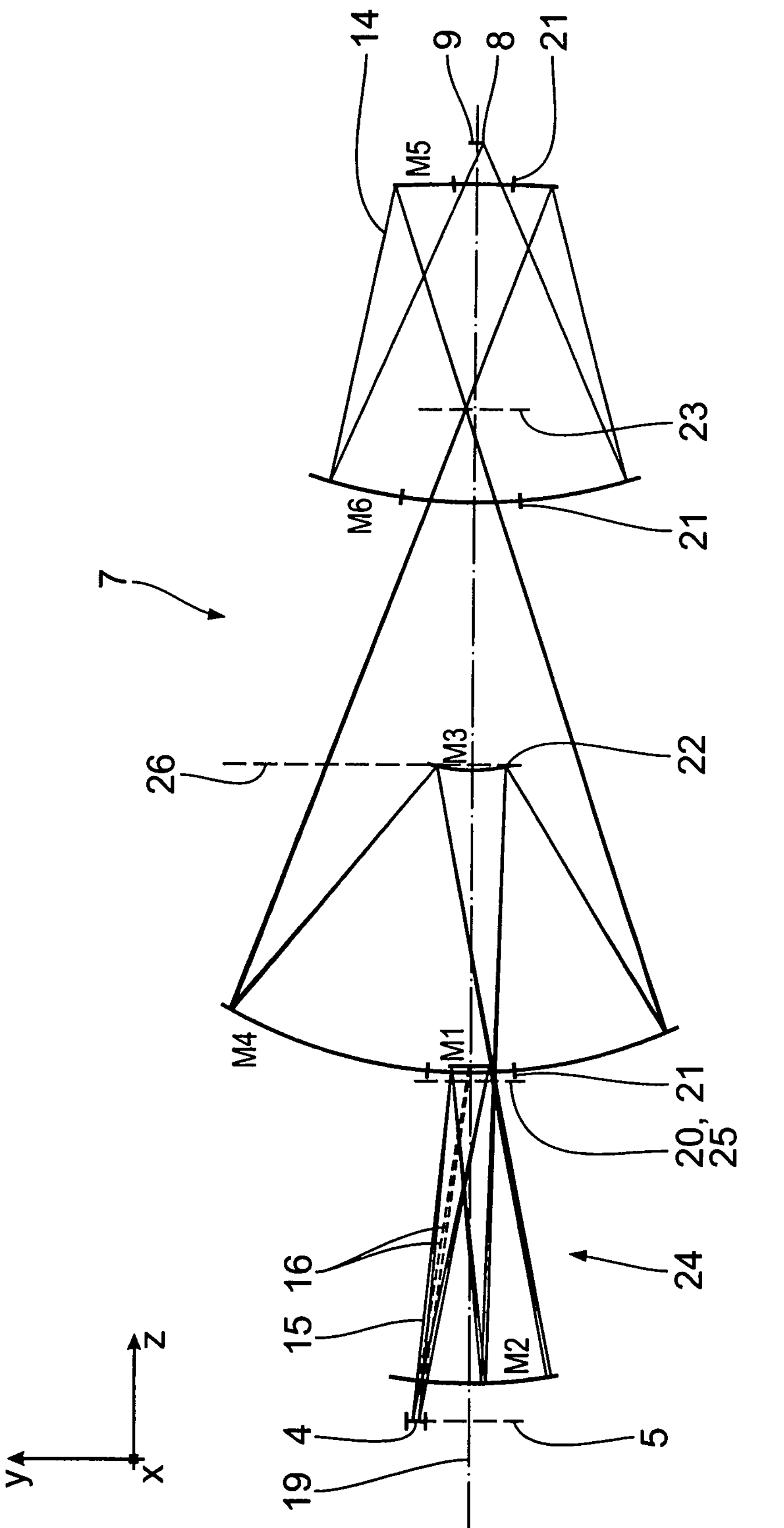

Fig. 5

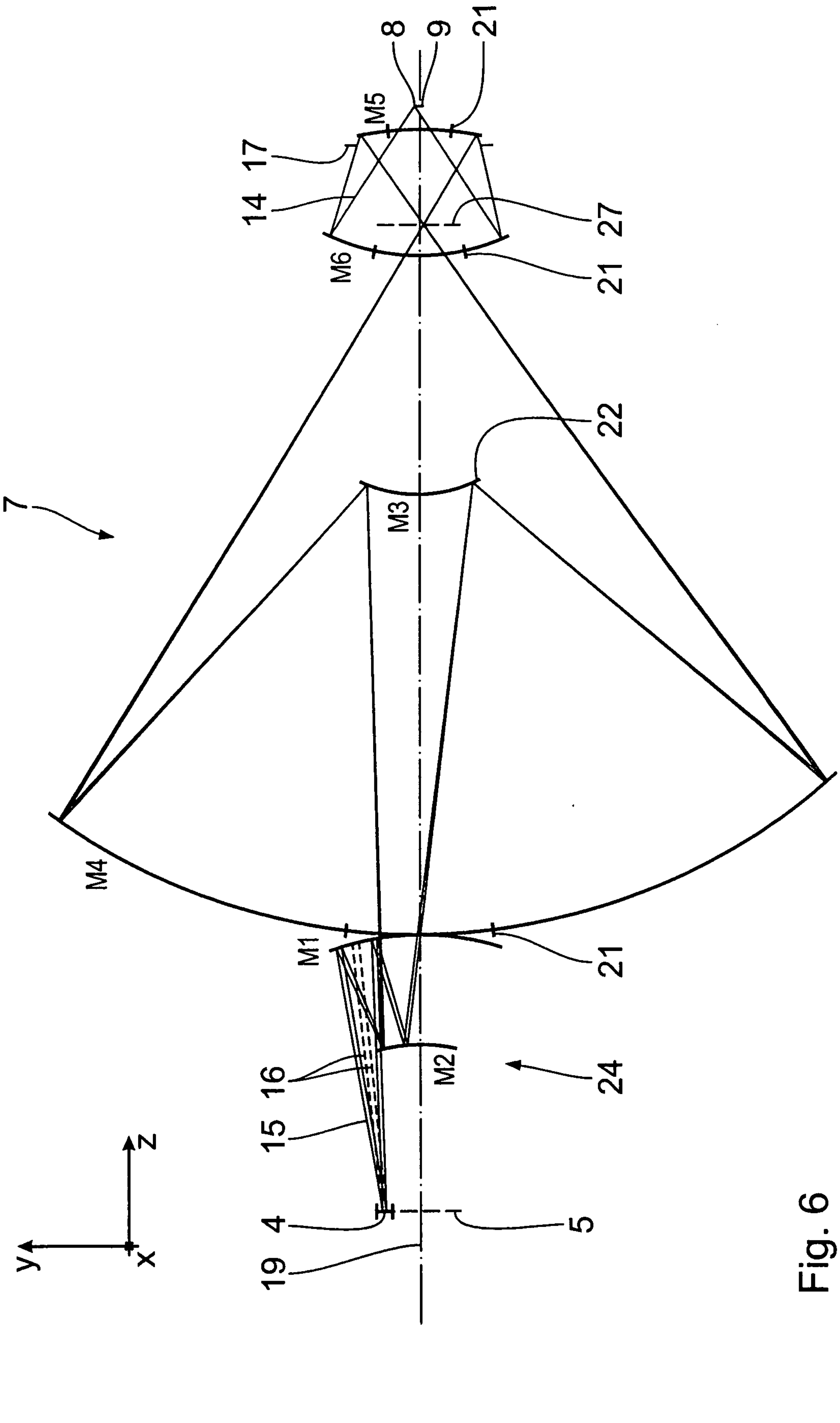

Fig. 6

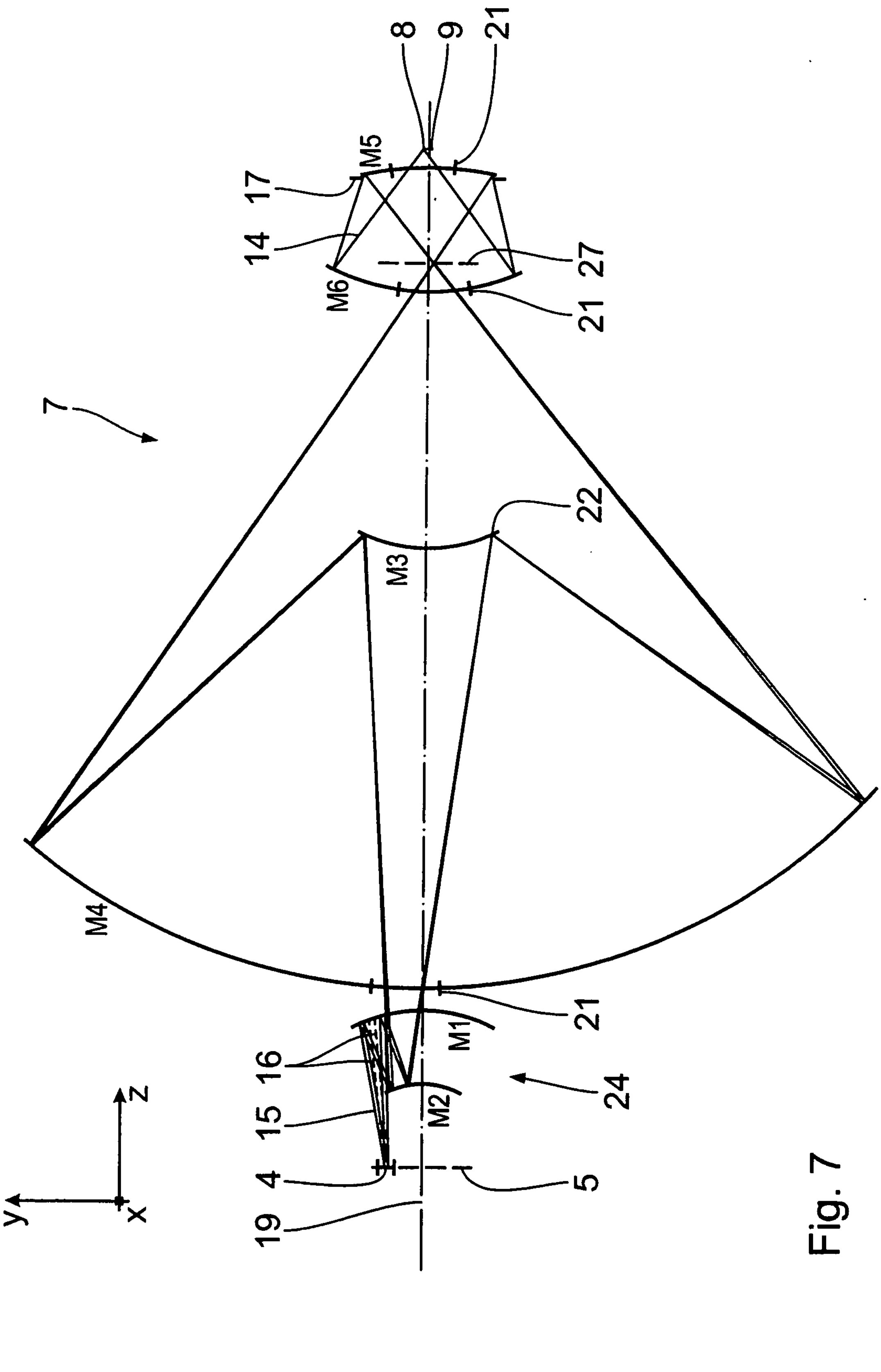

Fig. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2008/008381

A. CLASSIFICATION OF SUBJECT MATTER
INV. G03F7/20 G02B17/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G03F G02B H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1 434 093 A (CANON KK [JP]) 30 June 2004 (2004-06-30) abstract figure 1 table 1	5,6,12, 16,24-27
X	US 2002/056815 A1 (MANN HANS-JURGEN [DE] ET AL MANN HANS-JUERGEN [DE] ET AL) 16 May 2002 (2002-05-16) abstract figure 4	7-11,13, 14,17
A	US 2003/021026 A1 (ALLAN DOUGLAS C [US] ET AL) 30 January 2003 (2003-01-30) figure 2	1-27

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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"P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 December 2008	16/12/2008

Name and mailing address of the ISA/	Authorized officer
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