

ANAMORPHIC SCAN LENS FOR LASER SCANNER

5 CROSS REFERENCE TO RELATED APPLICATION

This patent application claims the benefit of the filing date of U.S. provisional application Ser. No. 60/052,800, filed July 8, 1997.

BACKGROUND OF THE INVENTION

10 Field of the Invention

This invention relates to laser scanners and to optical systems for sweeping an image along a scan line, and more specifically, to flying spot (raster) scanners used for precise electronic imaging applications.

15 Description of Related Art

Photolithography is commonly employed to produce repeatable patterns on devices such as integrated circuits, flat panel displays, and printed circuit boards. A conventional photolithography process begins with coating a device with a layer of photoresist. An image projection system, for example, using an object reticle or
20 a sequential scanning, illuminates selected regions of the photoresist with light that changes the properties of the illuminated regions. Using the changed properties, the photoresist is developed by removing the illuminated or not-illuminated regions (depending on the type of photoresist) to create a patterned mask for processing of the device. A variety of different photolithography devices have
25 been developed for image projection.

A laser raster scanner (also known as a raster output scanner, flying spot scanner, or flat-bed scanner) is a photolithography device which scans one or more focused and spatially modulated laser beams in a series of scan lines covering a surface being patterned. The laser raster scanning systems can be used as a reticle
30 making tool or as a direct-imaging device, eliminating steps associated with

manufacture and use of reticles. Whether a laser raster scanner illuminates a region depends on the laser beam's intensity as the beam passes the region. Such laser raster scanners use imaging systems adapted for light having wavelengths at which a photoresist has high sensitivity. This generally occurs in the ultraviolet region of the spectrum.

A basic architecture for a laser raster scanner includes the f- θ lens system that may or may not include a rotating polygon mirror to sweep the beam and/or prepolygon optical system. Distinguishing features of scanner architectures are described below.

A first distinguishing feature is spectral performance, in particular the spectral center line and spectral bandwidth. Most laser scanners are designed for monochromatic light, but a few scanners are color corrected for 3-color visible applications. Achromatizing a refractive system for a raster scanner is complicated because such systems generally use high-index glasses to aid in aberration control. These glasses tend to limit the spectral range of the scanner to visible and near infra-red wavelengths. Designs that are useful in the ultraviolet are typically refractive, using all-fused silica optical elements and have very narrow spectral bandwidths. U.S. Pat. Ser. No. 4,832,429 describes scanner optics that uses three-spherical-mirrors after a polygon mirror. However, that system suffers from problems mentioned below that are typical of rotationally-symmetric, non-telecentric systems.

A second distinguishing feature of scanner optics is use of passive motion compensation (PMC). With PMC, a scan lens has an anamorphic architecture to re-image the polygon facet in the cross-scan (sagittal) direction. Most scanners for xerographic laser printers use PMC to remove facet wobble of low-cost ball-bearing polygon mirrors. Without PMC, scan lenses alternatively use rotationally symmetric optics, and the polygon mirror must be taller to accommodate the height of a four-fold symmetric input beam clear aperture (e.g., round or square). The polygon mirror is therefore more massive and requires more drive power for rotation. In addition, without PMC, removing facet signature requires costly

precision polygon mirrors with air bearing spindles, active component correction (acousto-optic or active mirror servo systems), or specialized, limited-use architectures involving multiple reflections from the polygon mirror, for example, as described in U.S. Pat. Ser. No. 4,662,709.

5 A third distinguishing feature is the method used to inject a beam onto a polygon mirror and into the scan lens. The predominant method is tangential injection in which an input beam is in the plane of the swept scan line. Figs. 1A and 1B respectively illustrate top and side views of a scan lens system 100 using tangential injection. In system 100, an input beam 105 reflects from a folding
10 mirror 110 so that input beam 105 and a reflected beam 115 are in a plane that is perpendicular to the rotation axis of a polygon mirror 120 and includes the optical axis of post-polygon lens elements 130 and 140. Non-PMC scan lenses use tangential injection unless specialized architectures are used (e.g., U.S. Pat. Ser. No. 4,682,842) since sagittal input places the scan line above or below the
15 tangential meridian of the polygon mirror, and introduces scan line bow with rotationally-symmetric optics due to the distortion present in the lens for f- θ linearity correction.

 Figs. 2A and 2B respectively illustrate top and side views of a scan lens system 200 using sagittal injection. In system 200, an input beam 205 reflects
20 from a folding mirror 210 so that input beam 205 and a reflected beam 215 are in a plane containing the rotation axis of a polygon mirror 220 and the optical axis of post-polygon lens elements 230 and 240. A sagittal injection makes scan line "bow" or deviation from a straight scan line difficult to control. The classical optical aberration referred to as distortion introduces bow in the scan line at an
25 image plane 250. Distortion is introduced to scan lenses to provide the f- θ correction, and is fundamentally non-zero for any scan line that does not lie on the tangential meridian of the image plane. This bow is inherent to sagittal injection in which the image plane is off-axis.

 Figs. 3A and 3B illustrate a fourth distinguishing feature, telecentricity. As
30 illustrated in Fig. 3A, a telecentric scanner 300 has the chief ray of a swept beam

305 substantially perpendicular in both meridians to an image plane 310 across the length of a scan line. Both anamorphic and rotationally symmetric telecentric designs exist are known and described, for example, in U.S. patents Ser. No. 4,056,307 and 4,527,858, respectively. Telecentricity is extremely important in high-precision, high-resolution scanning systems. A system may be considered "telecentric" if the chief ray is perpendicular within a third the subtended cone angle of the focused ray bundle to the final image plane in both meridians across all fields and scan positions.

A non-telecentric scan lens 350 as shown in Fig. 3B has a scan beam 355 with a chief ray that meets an image plane 360 at a substantial angle to perpendicular. The variations in the chief ray angle across the scan field for a non-telecentric scanner causes two problems. First, the spot size on image plane 360 grows at the edges of a scan line, due to oblique projection of the focused spot onto the image plane. Second, small shifts in focal plane location cause absolute pixel placement errors. For a chief ray angle in the cross-scan direction, focal plane shifts result in pixel placement errors that mimic magnification errors. If the chief ray angle is in the cross scan direction, out-of-focus scan lines may appear bowed. (This type of bow is not to be confused with bow due to the optical aberration of distortion present in $f-\theta$ lenses.)

A fifth distinguishing feature is performance with multiple beam (data channel) input to the scan lens system. Multiple beams allow faster writing speeds with reasonable electronic data rates and polygon mirror rotational velocities. With a single beam system, distortion can be added to the design to provide $f-\theta$ linearization of the fast-scan beam position. With a multiple beam system, $f-\theta$ linearization is not necessarily sufficient to control the fixed channel-to-channel spacing across the scan line. Localized separation between first and last channels (i.e. fixed magnification in both slow and fast axes) must be maintained across the scan line to prevent pixel placement errors within the multiple beam field of view. The variation in beam magnification in the fast-scan direction is referred to as

differential distortion. Variation in magnification in the slow scan direction is referred to as differential bow.

A sixth distinguishing feature of laser scanner architecture is the number of resolvable spots in the scan line. Precision applications typically require spot diameters from 25 microns down to 2 microns, with absolute pixel placement accuracy down to a tenth of the spot diameter. A precision, refractive telecentric lens system may achieve up to 20,000 resolvable spots per scan line. In contrast, a typical non-telecentric xerographic scanners may have about 9,000 resolvable spots in a scan line, although more spots are achievable if significant spot size variation across the scan line is allowed.

A precision scan lens is sought which provides the features and performance desirable for a high resolution, radiometrically efficient scanner.

SUMMARY OF THE INVENTION

An embodiment of the invention provides an improved scanning system that incorporates the best of the above features within a performance range suitable for photolithographic applications. In particular, an optical system in accordance with an exemplary embodiment of the invention includes a telecentric scan lens having a sagittal injection and passive motion compensation (PMC) and achieves high radiometric efficiency for ultraviolet laser light, low differential distortion for multichannel beams, and up to 15,000 resolvable spots per scan line. Radiometric efficiency is important because ultraviolet laser power is expensive, and the speed of the scanning system is related to the power delivered to the image plane. The exemplary embodiment utilizes a catadioptric architecture that maximizes transmission efficiency by using a combination of reflective optics in conjunction with refractive elements that have high transmission of UV light. In addition, the exemplary system corrects aberrations over multiple UV wavelengths, thereby optimizing the use of available laser power.

In accordance with a further aspect of the invention, the optical system for a scanner incorporates anamorphic passive motion compensation. For high-end

scanning applications, PMC is useful because PMC reduces the heat load on the system since a polygon mirror for the system can be thinner to require less power for rotation at high speeds. In addition, PMC also reduces system cost because PMC permits use of less precise motor-polygon assemblies.

5 The projected size of the spot on the polygon mirror in the tangential (collimated input) plane is minimized with zero-degree tangential offset input to the polygon mirror. This allows use of a smaller polygon mirror, which in turn allows greater rotational velocities yielding faster imaging times. In addition, sagittal input combined with PMC creates a bi-laterally symmetric optical system
10 that allows aberrations to be corrected for greater numerical apertures and scan angles than tangential input systems, yielding more resolvable spots in a scan line. The invention provides for sagittal input in a unique manner that fundamentally minimizes cross-scan distortion.

15 The telecentricity (perpendicularity of the chief ray in both meridians to the image plane) of the scan lens removes variation in spot placement as a function of image defocus. This eases the requirement on work piece flatness and focal plane alignment with the exposed media.

20 In one embodiment to the invention, an optical path from a rotating polygon mirror of a scan lens encounters a spherical lens, a cylindrical lens element; a first sphero-cylindrical lens element; a concave spherical mirror; a convex cylindrical mirror; and a second sphero-cylindrical lens element. The scan lens also includes injection optics for a beam to the polygon mirror. The injection optics, like the post-polygon optics, can be anamorphic. In one embodiment of the invention the injection optics include a concave cylindrical mirror positioned to
25 receive a beam of collimated light at a non-zero angle with a radius of curvature of the concave cylindrical mirror; a cylindrical lens, and a folding mirror. The optical materials and coatings in the scanner are matched to the spectral sensitivity of the photo-sensitive media and for photoresist exposure, are suitable for ultraviolet light having wavelengths of about 340 to 390 nm.

One embodiment of an optical system in accordance with the invention includes: a cross-scan cylinder mirror, a cross-scan cylinder lens, a folding mirror that provides sagittal input of the beam to a rotating polygon mirror, a spherical meniscus lens, a plano-cylinder lens, a first sphero-cylinder lens, a primary
5 spherical mirror, a secondary cylindrical mirror, and a second sphero-cylinder lens.

BRIEF DESCRIPTION OF THE DRAWINGS

Figs. 1A and 1B show a scan lens with tangential injection of a beam to a polygon mirror.

10 Figs. 2A and 2B show a scan lens with sagittal injection of a beam to a polygon mirror.

Figs. 3A and 3B respectively show telecentric and non-telecentric scan lenses.

15 Figs. 4A and 4B show a top view and a side view of a laser scanner in accordance with an embodiment of the invention.

Figs. 5A and 5B respectively show a side view and a top view of scan optics in accordance with an embodiment of the invention.

Fig. 6 shows a schematic representation of sagittal input for an embodiment of the invention.

20 Figs. 7A, 7B, 7C, and 7D shows performance curves for an exemplary embodiment of the invention.

Use of the same reference symbols in different figures indicates similar or identical items.

25 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A scan lens system in accordance with an exemplary embodiment of the invention is an unobscured catadioptric optical system incorporating anamorphic elements to implement passive motion compensation. In addition, all of the refractive optical elements have high transmission of UV light, and may be
30 modified to use other materials such as calcium fluoride for deep UV light or high-

index glasses for improved performance with the visible light. Furthermore, the system implements sagittal input in a manner that is consistent with but not limited to an unobscured catadioptric design. In addition, the system is telecentric at the image plane, and is color-corrected for multiple ultraviolet wavelengths.

- 5 Furthermore, the system implements f- θ correction. Finally, the system is capable of imaging up to 12 independent channels while maintaining stated performance criteria, and is capable of resolving over 15,000 pixels per line with pixel spacing equal to the full width at half maximum (fwhm) spot diameter.

A raster scanner 400 in accordance with an embodiment of the invention
10 shown in Figs. 4A and 4B includes a laser 410 with required beam shaping optics, a multi-channel modulator 420, scan optics 430, and a precision stage 490 for holding a workpiece. Laser 410 generates a collimated light beam 415 which modulator 420 converts into a modulated beam 425 containing separate collimated sub-beams. In an exemplary embodiment, laser 410 is a UV argon ion laser, and
15 beam 425 contains ultraviolet light of wavelengths 363.8 nm, 351.4 nm, and 351.1 nm and is split into two or more separate sub-beams. Modulation of beam 425 changes the intensities of the individual sub-beams typically turning sub-beams on and off, but gray scale intensity control can also be employed to provide an optimum irradiance profile to the beam eventually written to the photosensitive
20 media. A co-filed U.S. provisional patent application, entitled "ACOUSTO-OPTIC MODULATOR ARRAY WITH REDUCED RF CROSSTALK", Atty. Docket No. P-4296-US, describes a modulator for the exemplary embodiment of the invention.

Beam 425 from modulator 420 has a diameter that defines a stop size for
25 scan optics 430. Scan optics 430 forms an image of beam 425 and sweeps that image across a scan line in an image plane. An optional optical relay 480 reforms the image from scan optics 430 on a workpiece held by stage 490 so that a final image of the modulated beam sweeps along a scan direction at the surface of the workpiece. Precision stage 490 moves the workpiece perpendicular to the scan line
30 direction. Movement of the workpiece can be continuous during scanning or may

only occur each time scan optics 430 completes a scan line. As the image sweeps across the scan line, sub-beams in beam 425 are turned on and off to control which regions in the scan line at the surface of the workpiece are illuminated. In the exemplary embodiment, the sub-beams have a sub-beam line width of about 5 μ m.

5 Scan optic 430 includes receiving optics 440, folding mirror 450, a polygon mirror 460, and post-polygon optics 470. Receiving optics 440 performs initial shaping of beam 425 to generate a converging beam 445 which folding mirror 450 directs to polygon mirror 460. Receiving optics 440 and folding mirror 450 are sometimes referred to as injection optics since they inject the modulated beam onto
10 polygon mirror 460. To move the image along the scan direction, rotation of polygon mirror 460 changes the tangential incidence angle of a beam 455 from folding mirror 450 and the tangential reflection angle of a beam 465 reflected from polygon mirror 460. Scan lens 470 focuses beam 465 to reduce the separation between separate sub-beams and focus each sub-beam. Scan lens 470 has
15 anamorphic focusing which reduces or eliminates perpendicular offsets of an image from a desired scan line due to facet signature or wobble in rotating polygon mirror 460.

 Figs. 5A and 5B respectively show a side view and a top view of scan optics 430 in accordance with an embodiment of the invention. Referring to Fig.
20 5A, a collimated multi-channel light beam bundle enters scan lens 430 and is reflected by a folding mirror 510 into the pre-polygon optics consisting of a cylindrical mirror 520 and a bi-cylindrical refractive element 530. The purpose of the pre-polygon cylindrical optics provides motion compensation through use of a multi-element focusing system to accommodate the relatively large numerical
25 aperture. The focused beam bundle 535 then impinges a second folding mirror 450 sometimes referred to as the injection mirror, sending a beam bundle 455 into polygon mirror 460 at a sagittal angle. To minimize bow, system 430 uses an optical system with a polygon rotation axis 462 perpendicular to the scan lens' optical axis, centers the focused beam bundle on the optical axis through a polygon

facet, and re-images to the scan line such that the scan line is also centered on the optical axis.

A sagittal input system 600 of the class used in exemplary embodiment is schematically illustrated in Fig. 6. In system 600, pre-polygon optics 610 focuses
5 an input beam 605 which a folding mirror 620 directs onto a facet 630 of a polygon mirror. Post-polygon optics 640 re-images polygon facet 630 at the focal plane of the scanner as with tangential input systems. However, system 600 accomplishes injection and re-imaging using an off-axis section of the corrected clear aperture of the system rather than using laser beams that are symmetrically centered about the
10 optical axis. Let the focused light from the polygon mirror have a subtended angle of β . The aberration-corrected acceptance cone of the cross-scan optical system is designed to be $2\beta + 2\delta$, where δ is a displacement angle as required for beam 635 to clear folding mirror 620. Beam 625 can be injected into the polygon facet 630 using injection mirror 620 at an angle below the centerline by $\beta/2 + \delta$. The
15 converging beam is substantially focused on the optical centerline of post-polygon optics 640 at the polygon facet 630, and reflects at an angle $\beta/2 + \delta$ above the optical centerline, such that reflected beam 635 clears the top of injection mirror 620 and enters post-polygon scan optics 640.

Distortion-induced bow is introduced in a scan line when the scan line fails
20 to intercept the tangential meridian of the optics 640. Since the polygon facet is re-imaged at the scan line in the cross-scan plane to intercept the optical axis, and the polygon axis is perpendicular to said optical axis, there is no bow in the scan line due to distortion. For multi-channel systems, this is the minimum-bow configuration since the channels cannot be brought closer to the optical axis and
25 distortion-induced bow is minimized. Mention should be made at this point that the off-axis nature of the optimized aperture is critical in implementing a centered, catadioptric architecture. By increasing the incident angle to the polygon mirror still further, the ray bundle describing the used aperture of the laser beam moves farther away from the optical centerline, thus allowing clearance for a secondary
30 mirror typical to this construct.

Referring back to Figs. 5A and 5B, beam bundle 455 reflects off of rotating multi-facet polygon mirror 460. Beam bundle 455 in the tangential direction underfills a facet of polygon mirror 460. Since sagittal offset is used, the projected beam bundle size on the polygon face in the tangential direction is minimized, and the diameter of polygon mirror 460 can be reduced accordingly. In the exemplary embodiment, the polygon diameter is 5.33 inches in diameter, yielding a scan efficiency of 85% with a 12-facet polygon mirror. Note should be made that the sagittal input method of this invention can be used with active facet-tracking schemes as well, allowing further reduction in polygon diameter. Active facet tracking shifts the beam bundle to maintain the position of the beam bundle at the center of a polygon facet while the polygon mirror rotates.

In the exemplary embodiment, polygon mirror 460 has twelve facets which rotate about a rotation axis 462 at about 7500 rpm. Fig. 5B illustrates a facet 461 of polygon mirror 460 and a resulting direction for respective reflected beam bundle 465. When facet 461 is in the position show in Fig. 5B, an image is formed in image plane near a first end 596 of the a scan line. After polygon mirror 460 rotates so that beam bundle is reflected of 15 an opposite end of facet (i.e. rotates slightly less than 30° in the exemplary embodiment), the final image forms on an opposite end 597 of the scan line. Polygon mirror 460 may be mounted on precision air bearings to minimize wobble during rotation. However, the passive motion compensation reduces the effects from wobble and keeps an image from forming off the desired scan line. Accordingly, polygon mirror 460 can use roller bearings or other less expensive bearings and still achieve high performance. In addition, the passive motion compensation reduces the required facet height thus reducing air resistance and allowing use of a lower thermal load motor to drive the polygon mirror 460.

After passing over injection mirror 450, beam bundle 465 enters the post-polygon scan optics. All post-polygon optics are centered on the optical axis, thus creating a bilaterally symmetric architecture. This symmetry in the design is crucial to preventing unwanted bow in the final scan line. The first post-polygon

optical elements, spherical meniscus lens 540 and plano-cylinder lens 550, which form a doublet, and a sphero-cylinder lens 560 are refractive elements of fused silica or BK7, which both effectively transmit light having wavelengths down to 350 nm. For visible wavelengths, other glasses can be used with added
5 performance capability, especially if high-index glasses are used. System 400 can also work effectively at shorter wavelengths (at least down to 190 nm) if calcium fluoride is substituted for BK7.

Beam bundle 564 from lens 560 reflects off of a primary spherical mirror 570, while passing over a secondary cylindrical mirror 570. Beam bundle 575
10 from mirror 570 reflects off of cylinder mirror 570 so that a beam bundle 585 passes through a sphero-cylinder lens 590, which is designed such that its clear aperture does not encroach into beam bundle 575. Lens 590 focuses a beam bundle 595 at the scan lens' focal plane. Since an off-axis section of the centered lens 590 is used, the chief ray of the incident bundle 595 is not perpendicular to the optical
15 axis of the post-polygon lens elements. However, by redefining the focal plane to be normal to the chief ray of the bundle 595, the telecentricity requirement for the architecture is now met.

The appendix provides an optical listing of the exemplary embodiment of the invention. Figs. 7A, 7B, 7C, and 7D show performance curves for the
20 exemplary embodiment. In particular, Fig. 7A is a plot of the diameter at which the intensity of a spot falls to $1/e^2$ over a range of scan angles corresponding to a scan line. As indicated in Fig. 7A, the exemplary embodiment provides spots with a variation less than one tenth of the spot diameter. Fig. 7B indicates the ratio of the spots' major and minor axes for sub-beams 2, 3, 4, and 5 respectively in upper-
25 left, upper-right, lower-right, and lower-left corners of a beam bundle. For each sub-beam, the spot is nearly circular across the range of polygon angles. Fig. 7C indicates the differential distortion between sub-beams in the upper-left and lower-left and the differential distortion between sub-beams in the upper-right and lower-right of the beam bundle. As indicated, differential is less than about 0.5%. Fig.
30 7D indicates the cross-scan position of sub-beams 2, 3, 4, and 5 across the range of

5 polygon angles corresponding to a scan line. The position of diagonally located sub-beams 2 and 4 or 3 and 5 track each other to provide uniform spacing between scan lines formed by sub-beams if the sub-beams are oriented along a diagonal running from top-left to bottom-right (or from top-right to bottom left) of a square cross-section (i.e., aperture) for a beam bundle.

Although the present invention has been described with reference to particular embodiments, the description is only an example of the invention's application and should not be taken as a limitation. Various adaptations and combinations of features of the embodiments disclosed are within the scope of the
10 invention as defined by the following claims.

Appendix

This appendix contains an optical listing of the exemplary embodiment of the invention. The listing formatted and defines parameters as in the "Code V" optical design software available from Optical Research Associates.

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5
di_f1ld:scan lens model
      RDY      THI      RMD      GLA      CCY      THC      GLC
> OBJ:      INFINITY      INFINITY      100      100
10  1:      INFINITY      0.000000      100      100
    STO:      INFINITY      6.698586      100      100
    3:      INFINITY      0.000000      100      100
      XDE:      0.000000      YDE:      0.000000      ZDE:      0.000000
      XDC:      100      YDC:      100      ZDC:      100
      ADE:      0.000000      BDE:      -45.000000      CDE:      0.000000
15  ADC:      100      BDC:      100      CDC:      100

      4:      INFINITY      0.000000      REFL      100      100
      CUM:      0.000000      THM:      0.250000      GLM:
20  5:      INFINITY      0.000000      100      100
      XDE:      0.000000      YDE:      0.000000      ZDE:      0.000000
      XDC:      100      YDC:      100      ZDC:      100
      ADE:      0.000000      BDE:      -45.000000      CDE:      0.000000
      ADC:      100      BDC:      100      CDC:      100

25  6:      INFINITY      -1.599090      100      100
      7:      INFINITY      0.000000      100      100
      XDE:      0.433726      YDE:      0.000000      ZDE:      0.000000
      XDC:      100      YDC:      100      ZDC:      100
      ADE:      0.000000      BDE:      0.000000      CDE:      0.000000
30  ADC:      100      BDC:      100      CDC:      100

      8:      INFINITY      0.000000      100      100
      9:      INFINITY      1.859901      REFL      100      0
35  CYL:
      RDX:      4.69080      CCX:      100
      XDE:      0.000000      YDE:      0.000000      ZDE:      0.000000      DAR
      XDC:      100      YDC:      100      ZDC:      100
      ADE:      0.000000      BDE:      0.000000      CDE:      0.000000
40  ADC:      100      BDC:      0      CDC:      0
      CUM:      0.000000      THM:      0.250000      GLM:

10:      INFINITY      0.000000      100      100
11:      INFINITY      0.215000      SILICA_SPECIAL      100      100
45  CYL:
      RDX:      -1.17400      CCX:      100
      XDE:      0.000000      YDE:      0.000000      ZDE:      0.000000
      XDC:      1      YDC:      100      ZDC:      100
      ADE:      0.000000      BDE:      0.000000      CDE:      0.000000
50  ADC:      100      BDC:      100      CDC:      2
      TRN:      0.99900      0.99900      0.99900

12:      INFINITY      1.178672      100      100
      CYL:
      RDX:      0.31352      CCX:      100
55  XDE:      0.000000      YDE:      0.000000      ZDE:      0.000000
      XDC:      1      YDC:      100      ZDC:      100
      ADE:      0.000000      BDE:      0.000000      CDE:      0.000000
      ADC:      100      BDC:      100      CDC:      2

60  13:      INFINITY      0.000000      100      100
      XDE:      0.000000      YDE:      0.000000      ZDE:      0.000000
      XDC:      100      YDC:      100      ZDC:      100

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	ADE:	0.000000	BDE:	-44.194664	CDE:	0.000000		
	ADC:	100	BDC:	3	CDC:	100		
5	14:	INFINITY	0.000000	REFL			100	100
	CUM:	0.000000	THM:	0.000000	GLM:			
	15:	INFINITY	0.000000				100	100
	XDE:	0.000000	YDE:	0.000000	ZDE:	0.000000		
	XDC:	100	YDC:	100	ZDC:	100		
10	ADE:	0.000000	BDE:	-44.194664	CDE:	0.000000		
	ADC:	100	BDC:	3	CDC:	100		
	16:	INFINITY	-0.365347				100	100
	17:	INFINITY	0.000000				100	100
15	XDE:	-0.025416	YDE:	0.000000	ZDE:	0.000000		
	XDC:	100	YDC:	100	ZDC:	100		
	ADE:	0.000000	BDE:	-1.610672	CDE:	0.000000		
	ADC:	100	BDC:	100	CDC:	100		
	18:	INFINITY	-2.690033				100	100
20	19:	INFINITY	2.690033				100	100
	XDE:	0.000000	YDE:	0.000000	ZDE:	0.000000		
	XDC:	100	YDC:	100	ZDC:	100		
	ADE:	0.000000	BDE:	0.000000	CDE:	0.000000		
25	ADC:	100	BDC:	100	CDC:	100		
	20:	INFINITY	-2.690033	REFL			100	100
	XDE:	0.000000	YDE:	0.000000	ZDE:	0.000000	DAR	
	XDC:	100	YDC:	100	ZDC:	100		
	ADE:	0.000000	BDE:	0.000000	CDE:	0.000000		
30	ADC:	100	BDC:	100	CDC:	100		
	CUM:	0.000000	THM:	2.872000	GLM:			
	21:	INFINITY	2.690033				100	100
35	XDE:	0.000000	YDE:	0.000000	ZDE:	0.000000		
	XDC:	100	YDC:	100	ZDC:	100		
	ADE:	0.000000	BDE:	0.000000	CDE:	0.000000		
	ADC:	100	BDC:	100	CDC:	100		
	22:	INFINITY	0.500000				100	100
40	23:	INFINITY	0.000000				100	100
	24:	-2.59900	0.175000	BK7_SCHOTT			100	100
	25:	-4.43700	0.767805				100	100
	26:	INFINITY	0.000000				100	100
	27:	INFINITY	0.000000				100	100
45	28:	INFINITY	0.175000	SILICA_SPECIAL			100	100
	CYL:							
	RDX:	INFINITY	CCX:	100				
	TRN:	0.99900	0.99900	0.99900				
50	29:	-5.36900	0.005002				100	100
	CYL:							
	RDX:	INFINITY	CCX:	100				
	30:	INFINITY	1.684027				100	100
55	31:	INFINITY	0.000000				100	100
	32:	-2.10100	0.450000	BK7_SCHOTT			100	100
	CYL:							
	RDX:	INFINITY	CCX:	100				
60	33:	-2.85500	0.743925				100	100
	34:	INFINITY	0.000000				100	100
	35:	INFINITY	0.782681				100	100
	36:	INFINITY	0.000000				100	100
	37:	INFINITY	2.348458				100	100
65	38:	-6.47950	-2.348458	REFL			100	100
	CUM:	0.000000	THM:	1.000000	GLM:			
	39:	INFINITY	0.000000				100	100
	40:	INFINITY	-0.782681				100	100

	41:	INFINITY	0.000000		100	100
	42:	-5.12300	0.278189	REFL	100	100
	CYL:					
5	RDX:	INFINITY	CCX: 100			
	CUM:	-0.254000	THM: 0.250000	GLM:		
	43:	INFINITY	0.000000		100	100
	44:	INFINITY	0.000000		100	100
10	45:	INFINITY	0.000000		100	100
	46:	INFINITY	0.005000		100	100
	XDE:	0.000000	YDE: 0.000000	ZDE: 0.000000		
	XDC:	100	YDC: 100	ZDC: 100		
	ADE:	0.000000	BDE: 0.464345	CDE: 0.000000		
15	ADC:	100	BDC: 100	CDC: 100		
	47:	INFINITY	0.165000	UBK7_SCHOTT	100	100
	CYL:					
	RDX:	0.31352	CCX: 100			
20	48:	-33.41100	0.222961		100	100
	49:	INFINITY	0.000000		100	100
	XDE:	-0.006000	YDE: 0.000000	ZDE: 0.000000		
	XDC:	100	YDC: 100	ZDC: 100		
25	ADE:	0.000000	BDE: 10.221860	CDE: 0.000000		
	ADC:	100	BDC: 100	CDC: 100		
	50:	INFINITY	0.000000		100	100
	51:	INFINITY	0.000000		100	100
30	52:	INFINITY	0.001147		100	100
	IMG:	INFINITY	0.000000		100	100
SPECIFICATION DATA						
	EPD	0.27500				
35	PUX	0.75000				
	PUY	0.75000				
	PUI	0.13500				
	DIM	IN				
	WL	363.80	351.40	351.10		
	REF	2				
40	WTW	100	100	100		
	XAN	0.00000	0.01220	-0.01220	0.01220	-0.01220
	YAN	0.00000	-0.07700	-0.07700	0.07700	0.07700
	VUX	0.00000	0.00000	0.00000	0.00000	0.00000
45	VLX	0.00000	0.00000	0.00000	0.00000	0.00000
	VUY	0.00000	0.00000	0.00000	0.00000	0.00000
	VLY	0.00000	0.00000	0.00000	0.00000	0.00000
	PFR	1.0000	0.0000	0.0000	0.0000	0.0000
	PTP	0.0000	0.0000	0.0000	0.0000	0.0000
	PCR	0.0000	0.0000	0.0000	0.0000	0.0000
50	PRO	LIN	LIN	LIN	LIN	LIN
APERTURE DATA/EDGE DEFINITIONS						
	CA					
55	REX S20	0.224872				
	REY S20	0.769500				
	CIR S24	0.500000				
	CIR S25	0.750000				
	REX S28	0.500000				
	REY S28	1.000000				
60	REX S29	0.500000				
	REY S29	1.000000				
	REX S32	0.500000				
	REY S32	1.425000				
	REX S33	0.500000				
65	REY S33	1.688000				
	REX S38	0.500000				
	REY S38	3.700000				
	REX S42	0.350000				

5 REY S42 1.650000
 REK S47 0.080000
 REY S47 1.700000
 REK S48 0.080000
 REY S48 1.700000

10 REFRACTIVE INDICES
 GLASS CODE 363.80 351.40 351.10
 SILICA_SPECIAL 1.474723 1.476662 1.476712
 BK7_SCHOTT 1.536487 1.538878 1.538940
 UBK7_SCHOTT 1.536443 1.538826 1.538887

No solves defined in system

15 No pickups defined in system

20 ZOOM DATA
 POS 1 POS 2 POS 3 POS 4 POS 5 POS 6 POS 7
 ADE S19 0.00000 3.00000 5.00000 7.00000 9.00000 11.00000 12.75000
 ADC S19 100 100 100 100 100 100 100
 ADE S21 0.00000 -3.00000 -5.00000 -7.00000 -9.00000 -11.00000 -12.75000
 ADC S21 100 100 100 100 100 100 100

25 This is a decentered system. If elements with power are decentered or tilted, the first order properties are probably inadequate in describing the system characteristics.

30 POS 1 POS 2 POS 3 POS 4 POS 5 POS 6 POS 7
 INFINITE CONJUGATES
 EFL 3.4075 3.4075 3.4075 3.4075 3.4075 3.4075 3.4075
 BFL 0.0071 0.0071 0.0071 0.0071 0.0071 0.0071 0.0071
 FFL 11.9020 11.9020 11.9020 11.9020 11.9020 11.9020 11.9020
 35 FNO 12.3909 12.3909 12.3909 12.3909 12.3909 12.3909 12.3909
 IMG DIS 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011 0.0011
 OAL 13.1596 13.1596 13.1596 13.1596 13.1596 13.1596 13.1596
 PARAXIAL IMAGE
 HT 0.0046 0.0046 0.0046 0.0046 0.0046 0.0046 0.0046
 40 ANG 0.0770 0.0770 0.0770 0.0770 0.0770 0.0770 0.0770
 ENTRANCE PUPIL
 DIA 0.2750 0.2750 0.2750 0.2750 0.2750 0.2750 0.2750
 THI 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
 EXIT PUPIL
 45 DIA 0.0787 0.0787 0.0787 0.0787 0.0787 0.0787 0.0787
 THI 0.9827 0.9827 0.9827 0.9827 0.9827 0.9827 0.9827
 STO DIA 0.2750 0.2750 0.2750 0.2750 0.2750 0.2750 0.2750

50 Position 1

Local surface coordinates with respect to surface 1

55 SURF XSC YSC ZSC ASC BSC CSC
 1 0.00000 0.00000 0.00000 0.0000 0.0000 0.0000
 STO 0.00000 0.00000 0.00000 0.0000 0.0000 0.0000
 3 0.00000 0.00000 6.69859 0.0000 -45.0000 0.0000
 4 0.00000 0.00000 6.69859 0.0000 -45.0000 0.0000
 5 0.00000 0.00000 6.69859 0.0000 -90.0000 0.0000
 60 6 0.00000 0.00000 6.69859 0.0000 -90.0000 0.0000
 7 -1.59909 0.00000 6.26486 0.0000 -90.0000 0.0000

	8	-1.59909	0.00000	6.26486	0.0000	-90.0000	0.0000
	9	-1.59909	0.00000	6.26486	0.0000	-90.0000	0.0000
	10	0.26081	0.00000	6.26486	0.0000	-90.0000	0.0000
	11	0.26081	0.00000	6.26486	0.0000	-90.0000	0.0000
5	12	0.47581	0.00000	6.26486	0.0000	-90.0000	0.0000
	13	1.65448	0.00000	6.26486	-180.0000	-45.8053	180.0000
	14	1.65448	0.00000	6.26486	-180.0000	-45.8053	180.0000
	15	1.65448	0.00000	6.26486	-180.0000	-1.6107	180.0000
	16	1.65448	0.00000	6.26486	-180.0000	-1.6107	180.0000
10	17	1.66962	0.00000	6.63078	-180.0000	0.0000	180.0000
	18	1.66962	0.00000	6.63078	-180.0000	0.0000	180.0000
	19	1.66962	0.00000	9.32081	-180.0000	0.0000	180.0000
	20	1.66962	0.00000	6.63078	-180.0000	0.0000	180.0000
	21	1.66962	0.00000	9.32081	-180.0000	0.0000	180.0000
15	22	1.66962	0.00000	6.63078	-180.0000	0.0000	180.0000
	23	1.66962	0.00000	6.13078	-180.0000	0.0000	180.0000
	24	1.66962	0.00000	6.13078	-180.0000	0.0000	180.0000
	25	1.66962	0.00000	5.95578	-180.0000	0.0000	180.0000
	26	1.66962	0.00000	5.18797	-180.0000	0.0000	180.0000
20	27	1.66962	0.00000	5.18797	-180.0000	0.0000	180.0000
	28	1.66962	0.00000	5.18797	-180.0000	0.0000	180.0000
	29	1.66962	0.00000	5.01297	-180.0000	0.0000	180.0000
	30	1.66962	0.00000	5.00797	-180.0000	0.0000	180.0000
	31	1.66962	0.00000	3.32394	-180.0000	0.0000	180.0000
25	32	1.66962	0.00000	3.32394	-180.0000	0.0000	180.0000
	33	1.66962	0.00000	2.87394	-180.0000	0.0000	180.0000
	34	1.66962	0.00000	2.13002	-180.0000	0.0000	180.0000
	35	1.66962	0.00000	2.13002	-180.0000	0.0000	180.0000
	36	1.66962	0.00000	1.34734	-180.0000	0.0000	180.0000
30	37	1.66962	0.00000	1.34734	-180.0000	0.0000	180.0000
	38	1.66962	0.00000	-1.00112	-180.0000	0.0000	180.0000
	39	1.66962	0.00000	1.34734	-180.0000	0.0000	180.0000
	40	1.66962	0.00000	1.34734	-180.0000	0.0000	180.0000
	41	1.66962	0.00000	2.13002	-180.0000	0.0000	180.0000
35	42	1.66962	0.00000	2.13002	-180.0000	0.0000	180.0000
	43	1.66962	0.00000	1.85183	-180.0000	0.0000	180.0000
	44	1.66962	0.00000	1.85183	-180.0000	0.0000	180.0000
	45	1.66962	0.00000	1.85183	-180.0000	0.0000	180.0000
	46	1.66962	0.00000	1.85183	-180.0000	-0.4643	180.0000
40	47	1.66966	0.00000	1.84683	-180.0000	-0.4643	180.0000
	48	1.67100	0.00000	1.68183	-180.0000	-0.4643	180.0000
	49	1.67880	0.00000	1.45893	-180.0000	-10.6862	180.0000
	50	2.57561	0.00000	-1.26583	-180.0000	0.0000	180.0000
	51	1.67880	0.00000	1.45893	-180.0000	-10.6862	180.0000
45	52	1.67880	0.00000	1.45893	-180.0000	-10.6862	180.0000
	IMG	1.67902	0.00000	1.45780	-180.0000	-10.6862	180.0000

I claim:

1. A method for sagittally injecting a modulated laser beam into a motion compensated scan lens, comprising:

5 cylindrically focussing the beam substantially on the optical centerline at a polygon surface in a sagittal plane;

 injecting the beam onto a polygon mirror having an axis of rotation perpendicular to an optical axis of post-polygon optics such that the reflected beam travels unobstructed through an off-axis aperture of centered scan lens elements;

10 and

 focussing the beam at the image plane in the cross-scan direction, where the image plane substantially intersects the optical axis.

2. An anamorphic catadioptric scan lens, comprising:

15 a polygon mirror mounted for rotation about a rotation axis;

 a cylindrical focussing pre-polygon optical system that conditions a beam for use with a motion-compensated post-polygon lens system;

 an injection mirror that injects the beam into the polygon mirror at a sagittal angle the rotation axis of the polygon mirror; and

20 a centered, bilaterally symmetric, anamorphic, catadioptric post-polygon optical system whose performance is optimized for off-axis aberration control such that the beam exiting the polygon mirror is unobscured and result in a scan line whose focus substantially intersects the optical centerline of the post-polygon optics.

25

3. The scan lens of claim 2, wherein whose focal plane is tilted to best fit the cross-scan telecentricity requirement.



4. The scan lens of claim 2, comprising of material suitable for total transmission greater than 70% in the spectral range suitable for use with applicable photosensitive materials.

5 5. The scan lens of claim 2 being designed to be achromatic over the spectral wavelength range equal to at least $1/10^{\text{th}}$ the center spectral wavelength.

6. The scan lens of claim 2, wherein differential distortion is corrected to yield absolute pixel registration errors less than $\frac{1}{2}$ pixel across the scan line for up to and including 12 channels, where each channel is spaced by at least 3 gaussian beam diameters from each other.

7. The scan lens of claim 2, in which the image quality produce by the scan optics are limited by diffraction with a Strehl ratio greater than 75% over all fields and scan positions.

8. A scan lens as in claim 2 in which the image resolution can resolve down to 6 micron fwhm gaussian spots

9. A complete photolithographic image scanner incorporating the anamorphic scan lens of any of claims 1 through 8.

10. A catadioptric, anamorphic scan optics comprising:
a concave cylindrical mirror positioned to receive a beam of collimated light at a non-zero angle with a radius of curvature of the concave cylindrical mirror;
a movably mounted mirror;
means for directing convergent light from the concave cylindrical mirror on to the movably mounted mirror;
a spherical lens element;
a cylindrical lens element;



a first sphero-cylindrical lens element;
a concave spherical mirror;
a convex cylindrical mirror; and
a second sphero-cylindrical lens element.

5

11. The scan lens of claim 10, wherein whose focal plane is tilted to best fit the cross-scan telecentricity requirement.

12. The scan lens of claim 10, comprising of material suitable for total
10 transmission greater than 70% in the spectral range suitable for use with applicable photosensitive materials.

13. The scan lens of claim 10 being designed to be achromatic over the spectral wavelength range equal to at least $1/10^{\text{th}}$ the center spectral wavelength.

15

14. The scan lens of claim 10, wherein differential distortion is corrected to yield absolute pixel registration errors less than $\frac{1}{2}$ pixel across the scan line for up to and including 12 channels, where each channel is spaced by at least 3 gaussian beam diameters from each other.

20

15. The scan lens of claim 10, in which the image quality produce by the scan optics are limited by diffraction with a Strehl ratio greater than 75% over all fields and scan positions.

25 16. A scan lens as in claim 10 in which the image resolution can resolve down to 6 micron fwhm gaussian spots.

17. An anamorphic scan lens comprising in order from object side to an image side:

30 a spherical lens element;



- a cylindrical lens element;
a first sphero-cylindrical lens element;
a concave spherical mirror;
a convex cylindrical mirror; and
5 a second sphero-cylindrical lens element.

18. The scan lens of claim 12, wherein each of the spherical lens element,
the cylindrical lens element, the first sphero-cylindrical lens element, and the
second sphero-cylindrical lens element consists of material suitable for
10 transmission in a spectral range suitable for use with photosensitive materials.

19. The scan lens of claim 18, wherein the scan lens is achromatic over the
spectral region.

15 20. The scan lens of claim 17, wherein the scan lens operates with a field of
view sufficient to permit simultaneous parallel scanning of multiple scan lines.

21. The scan lens of claim 20, wherein the scan lens operates with a field of
view sufficient to permit simultaneous parallel scanning more than three scan lines.

20

22. The scan lens of claim 20, wherein said scan lens corrects aberrations
which produce differential distortion in the multiple scan lines

23. The scan lens of claim 20, wherein the scan lens produces an image
25 quality limited by diffraction with a Strehl ratio greater than 75%.

24. The scan lens of claim 17, further comprising relay optics optically
coupled to second sphero-cylindrical lens element, wherein the relay optics
provides additional working distance between the scan lens and an image surface.

30



25. Catadioptric scan optics comprising:

a concave cylindrical mirror positioned to receive a beam of collimated light at a non-zero angle with a radius of curvature of the concave cylindrical mirror;

5 a movably mounted mirror;

means for directing convergent light from the concave cylindrical mirror on to the movably mounted mirror;

a spherical lens element;

a cylindrical lens element;

10 a first sphero-cylindrical lens element;

a concave spherical mirror;

a convex cylindrical mirror; and

a second sphero-cylindrical lens element.

15 26. The scan optics of claim 25, wherein the means for directing comprises:

a divergent cylindrical lens element; and

a folding mirror that directs the beam onto the movably mounted mirror below an optical axis of the scan lens but coplanar with an optical centerline of the scan lens.

20

27. The scan optics of claim 25, wherein the movably mounted mirror comprises a rotatably mounted mirror having mirror facets which are parallel to an axis of rotation of the rotatably mounted mirror. and

25 28. Scan optics comprising:

a polygon mirror mounted for rotation about an axis;

injection optics which direct a modulated beam onto the polygon mirror;

a catadioptric scan lens in an optical path from the polygon mirror, wherein the scan lens has an optical centerline is orthogonal to the axis of the polygon



mirror and is anamorphic to reduce movement of an image caused by wobble of the polygon mirror during rotation of the polygon mirror.