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Heynick et al.

[11] **3,924,136**
[45] **Dec. 2, 1975**

[54] **CHARGED PARTICLE APODIZED PATTERN IMAGING AND EXPOSURE SYSTEM**

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[21] Appl. No.: **550,642**

[52] **U.S. Cl.** .... **250/492 A;** 250/398
[51] **Int. Cl.^{2}** **H01J 37/12**
[58] **Field of Search** .... 250/492 A, 492 B, 491, 250/397, 398

[56] **References Cited**

UNITED STATES PATENTS

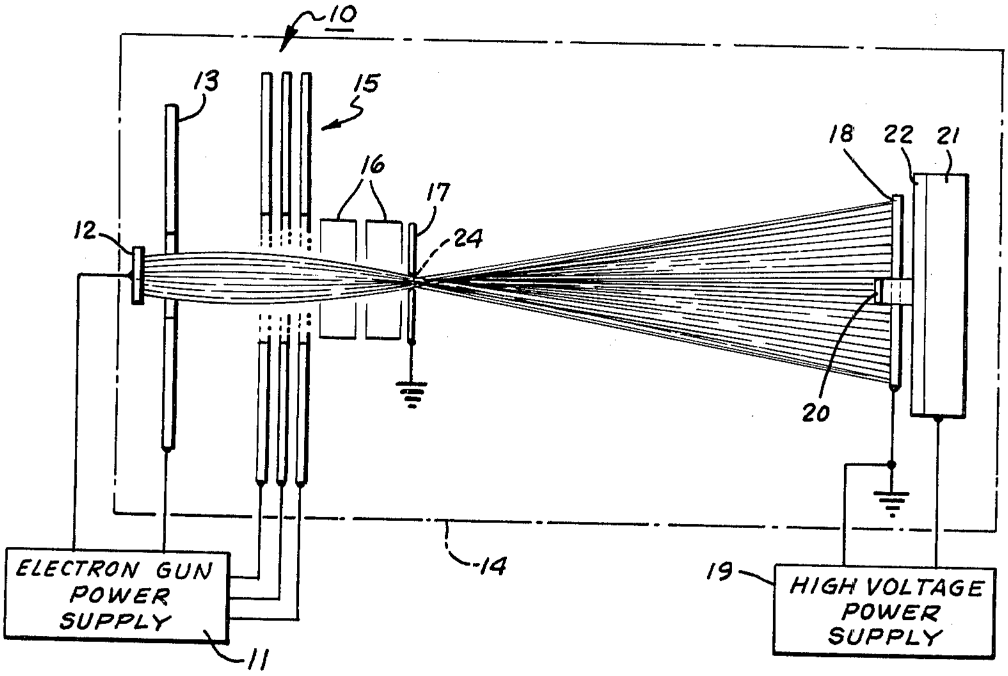
3,614,423	10/1971	Heynick et al.	250/492 A
3,619,608	11/1971	Westerberg	250/492 A

Primary Examiner—Archie R. Borchelt
Assistant Examiner—B. C. Anderson
Attorney, Agent, or Firm—Urban H. Faubion

[57] **ABSTRACT**

A charged particle beam pattern forming and imaging system for producing an apodized pattern is disclosed in which charged particles from one or more sources impinge upon an imaging plate. A high voltage electrical source is connected between the imaging plate and a target to produce a strong electrical field therebetween. The imaging plate contains one or more long and narrow slits. Each slit functions as a lens to yield one image of itself for each particle source, each image being converged only along the width of the slit (convergence in one dimension). A relatively narrow apodizing mask member is positioned between the particle source and the target (preferably between source and imaging plate) so that the mask divides the image of each slit lens at the target. The number of particle sources displaced in a direction transverse to the long dimension of the slit lenses determines the number of parallel slits imaged at the target, and their relative orthogonal displacement determines the distance between the parallel slit images at the target. Relative displacement of each particle source in a direction parallel with the length of the slit lenses determines the placement of each source relative to the apodizing mask and, consequently, the location of the division of the slit image formed by each source. The width (dimension orthogonal to the slit lens) of each slit image is proportional to the dimension transverse to the slit of the particle source used to produce that slit image, and the intensity of the particle stream used to produce that slit image is proportional to the length (dimension parallel with the slit lens) of the particle source, so slit images of varying widths but constant intensity are produced by corresponding variations of the transverse widths of the particle sources while utilizing particle sources of equal lengths.

15 Claims, 9 Drawing Figures



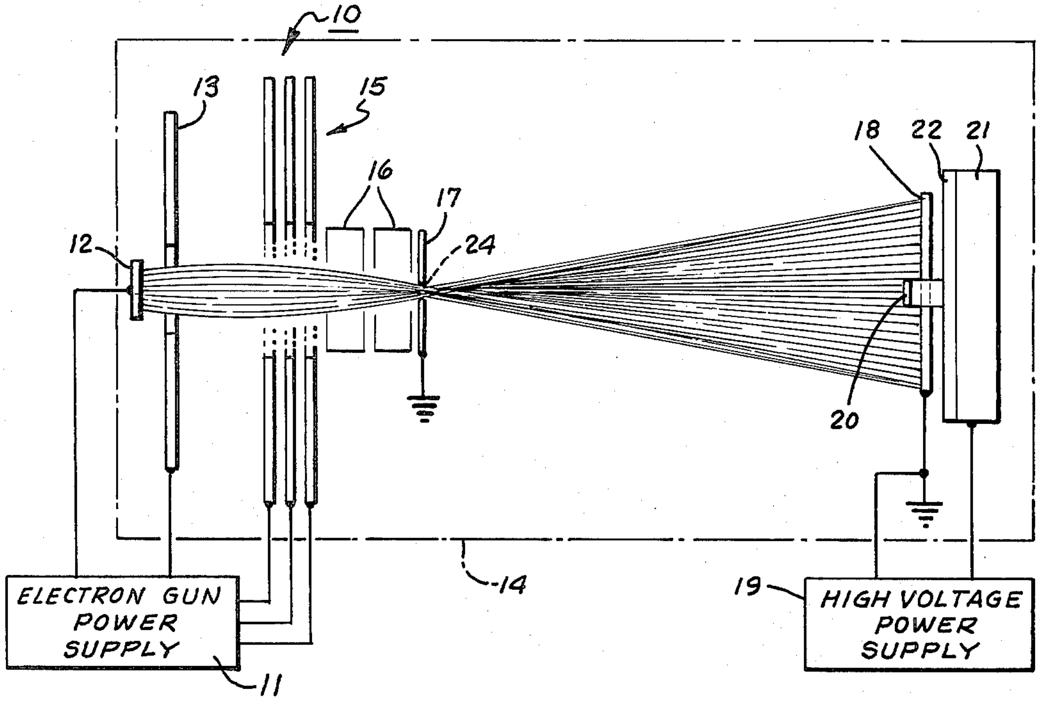


FIG. 1

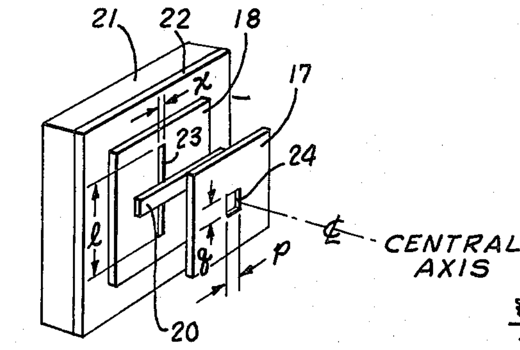


FIG. 2

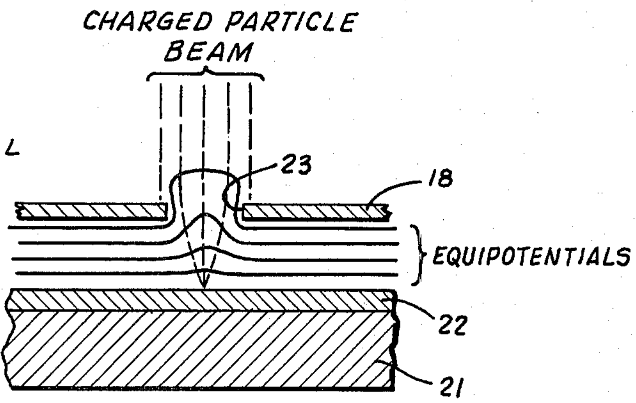


FIG. 3

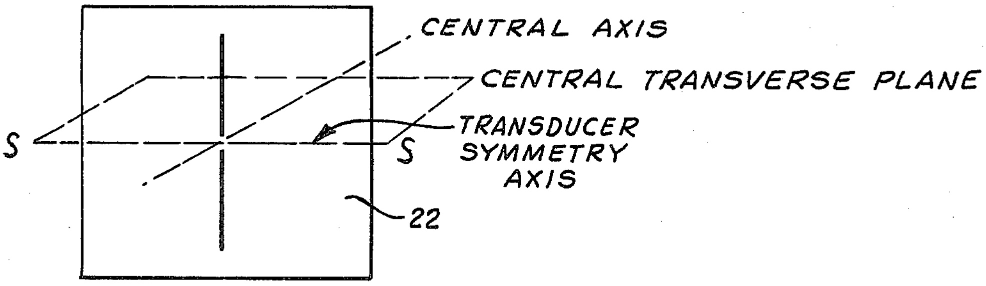


FIG. 4

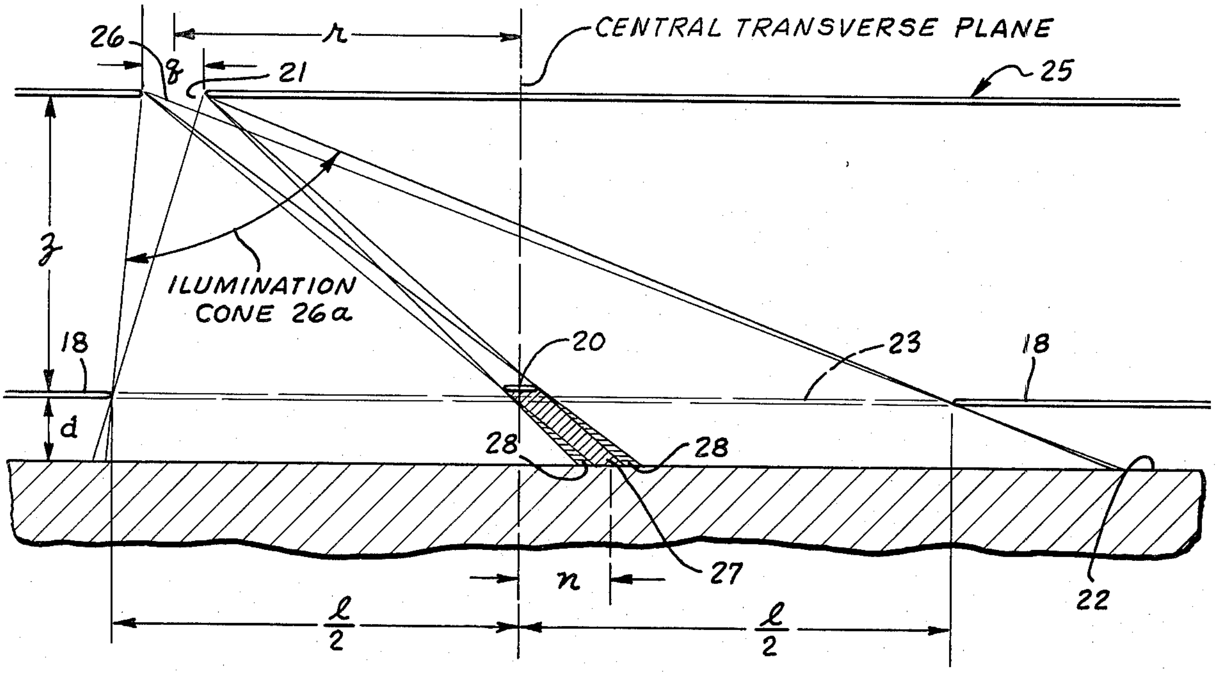


FIG. 5

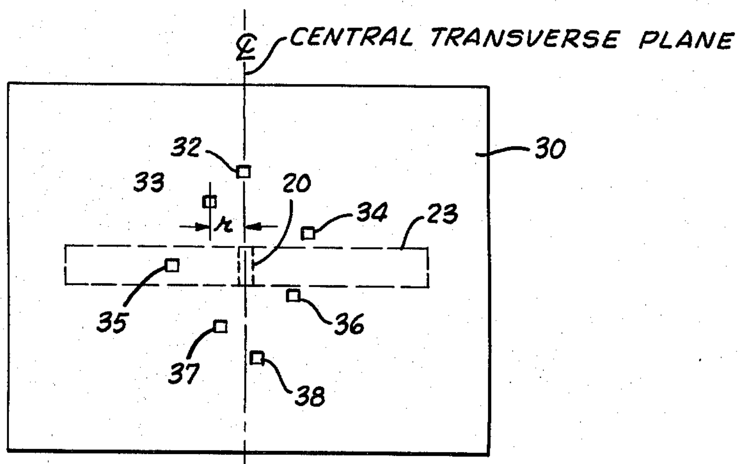


FIG. 6

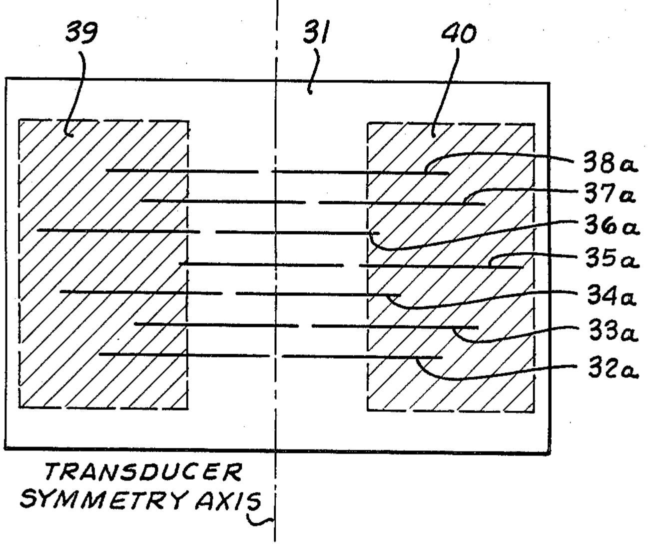
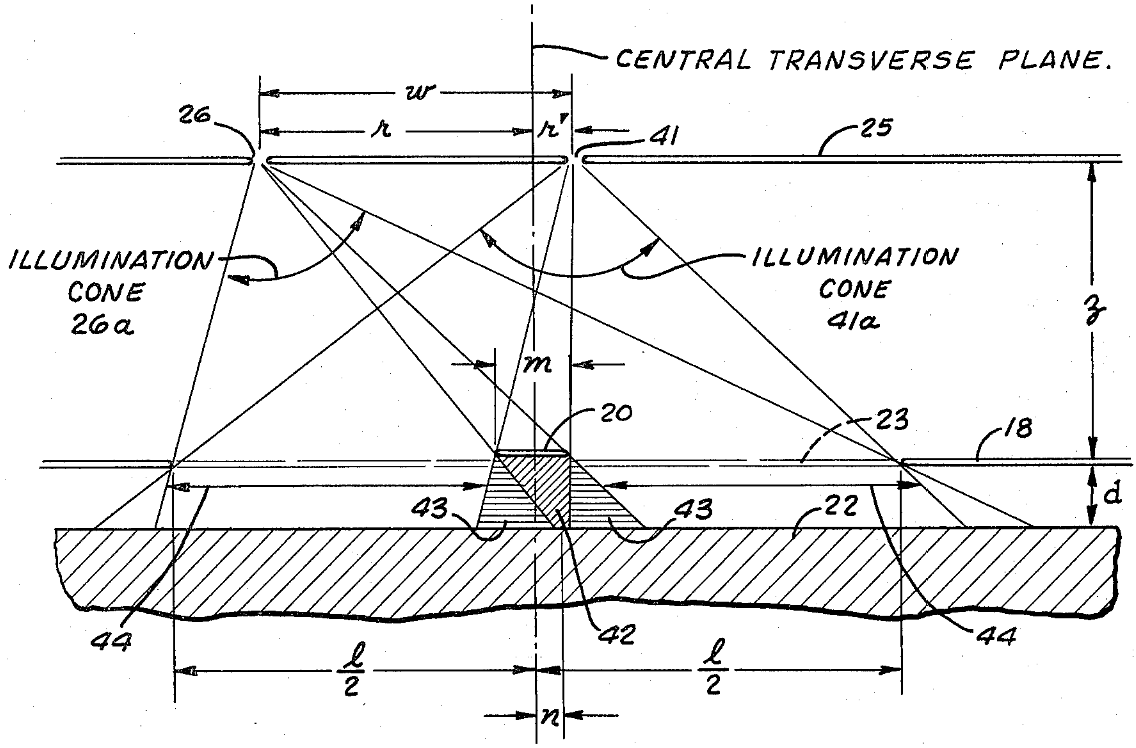


FIG. 7


CENTRAL TRANSVERSE PLANE.
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41
25
ILLUMINATION CONE 26a
ILLUMINATION CONE 41a
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22
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42
44
l/2
l/2
n

FIG. 8

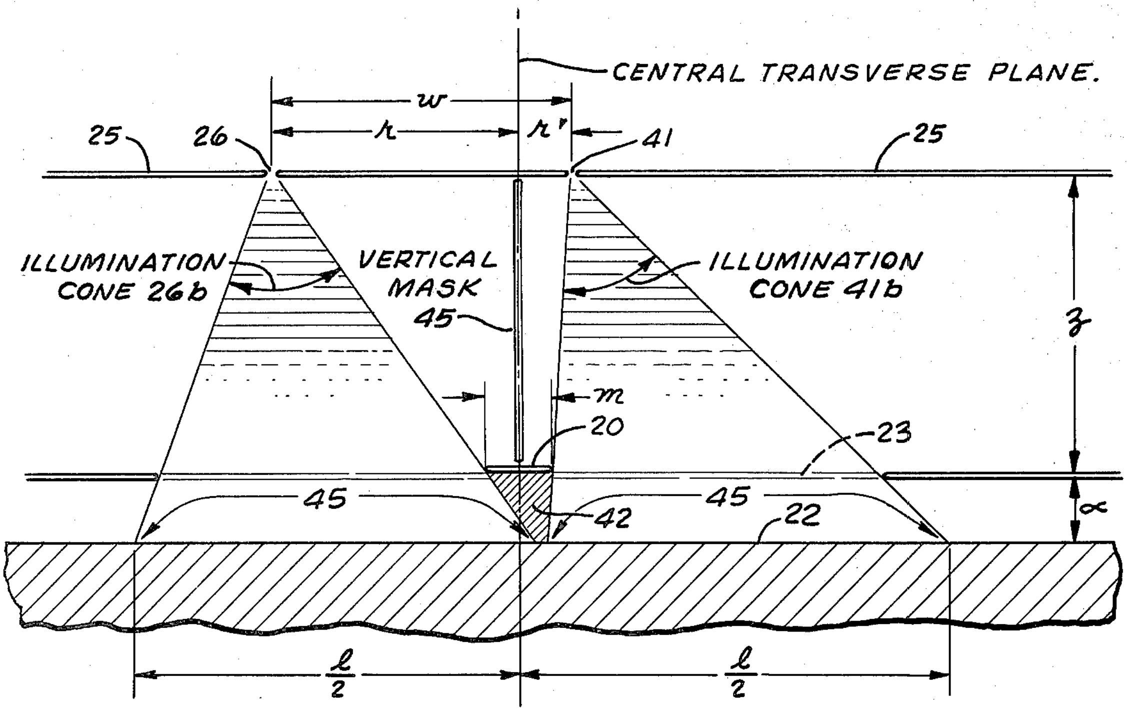
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FIG. 9

CHARGED PARTICLE APODIZED PATTERN IMAGING AND EXPOSURE SYSTEM

CROSS REFERENCES TO RELATED APPLICATIONS

The present invention involves a novel extension of inventions described in U.S. Pat. Nos. 3,619,608 (Nov. 9, 1971) and 3,614,423 (Oct. 19, 1971), respectively entitled "Multiple Imaging Exposure System" and "Charged Particle Pattern Imaging and Exposure System."

BACKGROUND OF THE INVENTION

This invention relates to electron or ion beam forming systems for producing patterns of long and very narrow, closely spaced parallel lines or grooves on appropriate substrates in nonserial fashion, analogous to photography but with higher resolution than can be obtained by photolithographic techniques. The systems contemplated are especially useful in producing such patterns wherein the relative length of adjacent lines or grooves are accurately controlled over a wide range.

A common method of producing sharply defined configurations on a substrate is to use light to expose the desired configuration to photosensitive resist material deposited on the substrate. The resist is then developed and the areas of the underlying material uncovered thereby are removed with an etchant that does not attack resist. The production of submicron patterns, however, requires the use of charged particles rather than light as an exposure means. For example, the useful range of visible wavelength spectrum limits practical resolution of photolithography to the order of a micron, whereas the wavelength of electrons used in resist exposure is several thousand times smaller, thus enabling higher resolution.

In principle, high resolution patterns can be produced serially on electron sensitive resists by using an appropriately driven scanning electron probe for exposure. In practice, however, the serial process is very slow in many cases because of beam current limitations at the required spot size and because of limitations in the sensitivities of resist materials. Also, instabilities of typical scanning electron probes can introduce spurious variations in the patterns produced.

In U.S. Pat. No. 3,619,608, supra, there is disclosed and claimed an exposure system which utilizes a mesh screen or a plate having a multitude of holes as an array of electron-optical lenses, one lens per hole screen or plate. More specifically, an electron source illuminates a pattern mask having a desired aperture pattern therein. Electrons passing through the pattern mask impinge upon a mesh screen. A high voltage electrical source is connected between the mesh screen and an electron sensitive resist coated substrate to produce a strong electrical field therebetween. Each hole in the mesh screen acts as a lens for producing an image of the pattern mask on the resist, resulting in an array of exposed images on the electron sensitive resist. A basic principle of this prior invention is that the converging electrical field at each screen hole has radial symmetry about the axis of the screen hole so that the image produced on the resist coated substrate is a uniformly demagnified replica of the object pattern.

In U.S. Pat. No. 3,614,423, supra, a plate having one or more long and narrow slits therethrough is used instead of a mesh screen, the principle being that the strong electrical field between the plate and the substrate produces convergence only in the direction corresponding to the narrow dimension of each slit at each location along its length. In other words, convergence is produced in only one dimension, as distinguished from the uniform convergence in all directions produced by each screen hole. The slits in the plate may be straight or curved segments, or of any desired combinations or configurations thereof. If such a plate is illuminated with a beam of electrons or a distant or small source of electrons, then the electron image produced on the substrate by the plate is of the same size and configuration as the slit pattern in the plate but the line width of the image pattern is smaller than the slit width by the one dimensional convergence factor. If two or more distant or small sources of electrons are used to illuminate the plate, then each such source will produced an image of the slit pattern. One convenient method for providing one or more such electron sources disclosed in U.S. Pat. No. 3,614,423 is to use a source of electrons (electron gun) properly to illuminate a plate having as many apertures therethrough as the number of sources desired, each such aperture thereby constituting an effective source. Combinations of electron sources and slit patterns are selected to produce image patterns, as exemplified therein. As explained in the patent, similar systems using ion sources can be used to expose ion sensitive resists, sputter images into targets directly (without resists), and implant ions directly.

A particularly useful transducer pattern incorporates two interdigitated sets of electrically conductive fingers on a piezoelectric substrate with two conductive contact pads each joining the outer ends of one set of the two interdigitated fingers. Electromagnetic energy of appropriate characteristics applied to the two contact pads is converted into acoustic waves that travel along the surface of the piezoelectric substrate. Conversely, acoustic waves arriving at such a transducer are converted into electromagnetic energy. The proportion of energy conversion occurring at each pair of adjacent fingers is dependent on the amount of finger length overlap. In the simple interdigital pattern all of the fingers have the same length and width, so that each pair of adjacent fingers contributes equally to the transduction process.

A much larger class of devices requires that the proportion of energy transduction very from finger pair to finger pair in accordance with prescribed formulas that are related to the specific applications intended. Such devices are called "apodized" transducers. In one form of apodized transducer, lengths of the fingers are varied to provide the requisite changes in relative overlap. In a variant of this apodizing pattern, interdigitated fingers of different lengths are used, but complementary finger segments connected to the opposing contact pads are also included. One way to visualize such patterns is to think in terms of a set of lines all connected to both contact pads and all of the same length contact pads, but having breaks or discontinuities at locations corresponding to the specific apodization scheme desired.

Another method for varying the proportion of energy transduction from finger pair to finger pair is to use fingers having widths that vary from finger to finger in accordance with prescribed formulas. Further, finger overlap and finger width apodizing patterns can be utilized in the same transducer.

At least theoretically, such apodized transducers as described above can be produced by serial scanning of a resist coated substrate. With lines and spacings of the order of a few microns, however, registration problems become so severe that serial scanning techniques are not practical.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an image projection system incorporating at least one slit lens for producing high resolution apodized transducer patterns of any of the forms described above.

It is another object of this invention to provide an image projection system incorporating at least one slit lens producing high resolution apodized transducer patterns of any of the forms described above wherein the interdigitated finger patterns are formed simultaneously (nonserially).

In carrying out the present invention there is provide a charged particle beam pattern forming and image projection system for producing apodized transducer patterns upon a target. Charged particles from one or more sources are projected through one or more long and narrow slits in an imaging plate onto the target and a high voltage electrical source is connected between the imaging plate and target, thereby producing a strong electrical field therebetween and causing each slit in the imaging plate to function as a lens to yield one image of itself for each particle source, with each such image being converged only along the width of the slit (not converged along the length).

A relatively narrow apodizing mask member is positioned between the particle source and the target so that it divides the image of the slit lens or lenses at the target. Preferably apodizing mask members are positioned between the imaging plate and the charged particle source. The number of particle sources displaced in a direction transverse (preferably orthogonal) to the long dimension of each slit lens determines the number of parallel images of each slit imaged at the target, and their relative orthogonal displacement determines the distance between the parallel images of each slit at the target. Relative displacement of each particle source in a direction parallel with the length of each slit lens determines the placement of each source relative to the apodizing mask and, consequently, the location of the division of the slit image formed by each source.

The novel features which are believed to be characteristic of the invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an overall system diagram of a pattern imaging and exposure system employing the invention;

FIG. **2** is an isometric view of a portion of the system of FIG. **1** showing the relationship between the target surface, imaging plate, apodizing mask and source mask;

FIG. **3** is a cross sectional view of the target surface and a slit in the imaging plate illustrating the electrical field therebetween;

FIG. **4** is an isometric view of a target as in FIG. **2** illustrating the image produced with the source mask (single source), slit lens and apodizing mask as shown in FIGS. **1** and **2**, and also showing, in phantom, planes through the target which are used in identifying various system axes;

FIG. **5** is a diagrammatic side view in cross section of a system, similar to that illustrated in FIG. **1**, showing how the image from the slit lens and apodizing mask is offset by displacing the source relative to the central transverse plane of the system;

FIG. **6** is a plan view of an illustrative source mask having multiple apertures used in producing an apodized image pattern;

FIG. **7** is a plan view of an illustrative apodized transducer (not to scale) produced utilizing the source mask illustrated in FIG. **6**;

FIG. **8** is a diagrammatic side view in cross section of a system similar to that of FIG. **5**, wherein a source mask having two apertures in a line parallel to the slit is utilized for each single line image from a slit lens; and

FIG. **9** is a diagrammatic side view of the system of FIG. **8**, wherein a vertical mask is added to eliminate cross illumination from the two source apertures in the source mask.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring now to FIG. **1**, there is shown one of the preferred embodiments of the invention in which the charged particles used are electrons. It is understood, of course, that the system works equally well with ions, but electrons are especially useful for making apodized transducers. Consequently, electron usage is emphasized here.

A power supply **11** is connected between a cathode **12**, a control electrode **13** and focusing electrodes **15** of a conventional electron gun **10** disposed within a vacuum chamber **14**. The vacuum chamber **14** may be any of the well known vacuum enclosures and the cathode may be of any conventional form, e.g., circular. The cathode **12** produces electrons electrons which pass through control electrode **13** and are collimated, condensed or formed into a beam by gun electrodes **15**, which constitute an electron lens (also referred to by the reference numeral **15**). The particular electron lens illustrated in FIG. **1** is a three electrode unipotential, or "einzel," lens. Einzel lenses and other suitable electron lenses are well known in the art. A source mask **17**, which contains one or more suitably located apertures, is placed in the path of the beam from the electron lens **15**. In order to make the distribution of the electrons at the source mask **17**, i.e., the illumination, as nearly constant as possible across the aperture **24**, pairs of deflection plates **16** are provided between the electron lens **15** and the source mask **17**.

A high voltage power supply **19** (on the order of 1 to 5 kV) is connected between the imaging plate **18** and a substrate **21**. The substrate **21** has, in a preferred embodiment, a target surface or coating **22** of electron sensitive resist, examples of which are well known in the art. As is explained in more detail below, the imaging plate **18** has one or more long and narrow slits. In a typical embodiment only one slit is required to produce one apodized transducer. Since two or more transducers spaced at appropriate distances on a single piezoelectric substrate comprise a class of surface acoustic wave signal processors, it will be appreciated that two or more slits spaced at corresponding distances in the image plate can be used to produced such processors. Also, the aperture pattern in the source mask can be such that each slit in the imaging plate produces a different transducer pattern. Because of the high electric field produced by power supply **19**, each slit acts as a one dimensionally convergent electron lens for forming images of the slit on the target surface **22**. If the source mask **17** has only one aperture, then only one image of the slit is formed on the target surface **22**. If the source mask **17** has two or more apertures displaced from each other in a direction orthogonal to the longitudinal axis of the slit lens, each aperture produces an image of the slit on the target surface **22**. The orthogonal width of each aperture in the source mask and their relative displacements are respectively represented on the target surface **22** by narrow line images and relative displacements determined by the demagnification factor of the slit lens, which factor is dependent on the relative distances from imaging plate **18** to source mask **16** and to target surface **22**.

Alternative arrangements are possible in the system of FIG. **1**. For example, if source **12** is made to be an ion rather than an electron source, then one dimensionally converted ion images of each slit in imaging plate **18** are produced on the coating **22**, one such image for each aperture in source mask **17**. Since the system of FIG. **1** is wholly electrostatic, the paths taken by the ions are identical to those traversed by the electrons; the ions merely traverse those trajectories at lower velocities. Positive ions, of course, require that the polarities of the voltages supplied by low voltage power supply **11** and high voltage power supply **19** be reversed.

If desired, patterns can be etched directly into the substrate material **21**, thereby eliminating the use of a resist layer **22** which requires exposure and development. This is done by using the slit patterns formed in the ion beam to sputter away or chemically remove the substrate material. In such chemical removal the ion beam chemically reacts with the substrate material to form a volatile compound. Hence, pattern micromachining of substrates or thin films can be done directly. Further, such an arrangement can be used for producing arrays of ion implanted solid state devices in semiconductor or insulator substrates by applying from high voltage power supply **19** a voltage on the order of 20 to 100 kV in order to obtain deep penetration of the ions in the substrate **21**. It should be understood that the following discussion is equally applicable to resist exposure, direct micromachining or ion implantation.

The system described thus far is substantially the same as that illustrated and described in U.S. Pat. No. 3,614,423, supra. In order to produce an apodized transducer on the target surface, an apodizing mask **20** (see FIGS. **1** and **2**) is positioned between the source mask **17** and the target surface **22**. The apodizing mask **20** is a relatively narrow member which extends across the slit lens **23** in the imaging plate **18** and thus is considered orthogonal to the longitudinal axis of the slit lens **23**. The purpose of the apodizing mask is to "break" the image of the slit lens **23** at the target surface **22**, as is illustrated by the "shadow" cast in the diagrammatic electron stream of FIG. **1**.

FIG. **2** is particularly useful in visualizing the relative positions of the source mask **17**, the apodizing mask **10**, the imaging plate **18**, and the target surface **22** and substrate **21**. In the simple embodiment illustrated here, the imaging plate **18** has a single long and very narrow slit **23** therein. The source mask **17** is spaced from the imaging plate **18** and in this embodiment may have a single aperture **24**, equivalent to a single source. The source aperture may be round, but preferably is rectangular, of width p orthogonal to the slit and length q parallel to the slit. In the preferred arrangement, the apodizing mask **20** is positioned (as shown) between the source mask **17** and imaging plate **18** and close to the imaging plate. Electron optics is such that the image of the slit **23** and the apodizing mask **20** at the target surface **22** is generally not well formed when the apodizing mask **20** is located in the plane of the imaging plate **18**.

As shown in FIG. **3**, the electric field which is produced between the imaging plate **18** and the substrate **21** and the target surface **22** is convergent only in the direction parallel to the narrow dimension, or width x, of the slit **23**. This convergent electrical field is present along the entire "*length* of the slit **23**. Thus, if the source mask **17** has a single hole **24**, as shown in FIG. **2**, then the image produced on the target surface **22** is a line parallel to and approximately the same length l (actually slightly longer) as this slit **23**, and this line image has a width smaller than the orthogonal width p of the aperture **24** in the source mask **17**. The width of the line image is proportional to the orthogonal width p of the source aperture **24**, the proportion being defined as the demagnification factor, and the intensity of the line image is proportional to the length q of the source aperture **24**. The demagnification factor of the system is adjustable by varying the ratio of the spacing between the target surface **22** and the imaging plate **18** to the spacing between the imaging plate **18** and the source mask **17**.

The apodizing mask may be fixed at the same potential as the imaging plate **18** and does not affect image convergence. Thus, the width of the image of the apodizing mask **20** on the target surface **22**, i.e., the "break" in the image of the slit lens **23**, is a matter of "shadow" projection. Typically, the width of the image produced on the target surface **22** by the slit lens **23** is the orthogonal width p of the hole **24** demagnified by a factor of about **50**. Thus, very accurately defined submicron width lines may be produced or imaged on the target surface **22** and the lines so formed are "broken" by the apodizing mask **20**. A line image with the "break" located so as to provide two equal line segments, as illustrated in FIG. **4**, is obtained when the apodizing mask **20** is located midway between the ends of the slit **23**. With the center of the source aperture **24** on a line through the center of the slit **23** and perpendicular to the plane of imaging plate **18** (this line is defined as the central axis of the system), the location of the break in the line image on the target surface is also on the system's central axis. For descriptive purposes, it is convenient to define the plane perpendicular to the slit that incorporates the central axis as the "central transverse plane" and to define the line (s—s) representing the intersection of the central transverse plane with the plane of the target surface **22** (see FIG. **4**) as the "transducer symmetry axis."

In order to produce a full pattern having a given number (N) of "fingers" which overlap in varying amounts and thus produce an apodized transducer, it is necessary to use a source mask **17** having the same number (N) of apertures **24** disposed so as to shift the "breaks" or discontinuities in the individual line images of the pattern in corresponding proportional amounts from the transducer symmetry axis on the target surface **22**. In general, the locations of the N apertures **24** in the source mask **17** are selected to provide the desired locations of the corresponding line images and of the line breaks, and hence the desired amounts of finger overlaps.

The diagrammatic cross sectional side view of FIG. 5 illustrates the way in which the position of any aperture in the source mask relative to the central transverse plane determines the position of the line image with its break relative to the transducer symmetry axis. In this figure the target surface is again given the reference numeral **22**, the imaging plate given reference numeral **18**, the slit lens given reference numeral **23**, and the apodizing mask given reference numeral **20**. These reference numerals are the same as those given for the corresponding parts in previous figures (particularly see FIG. 2) because these elements are the same in structure and position as the corresponding elements in those figures. The source mask **25**, however, is different in that the source aperture **26** is shifted off the central transverse plane. As illustrated, the source aperture **26** (or length q parallel to the slit) is shifted to the left, parallel to the longitudinal axis of the slit a distance r from the central transverse plane.

Considering first the image produced by the slit lens **23**, it will be appreciated that this image again consists of a single line much narrower than the transverse dimension p of source aperture **26**, because of the transverse demagnifying action previously described, and of a length approximately equal to the slit length, since there is no demagnification in this direction. Actually, if the outer dimensions of the illumination cone produced by the aperture **26** in a source mask are considered, it is seen that charged particles are projected under the image plate **18** at both ends of the slit lens, so that the length of the line image on the target surface is somewhat longer than the length of the slit, a fact that is immaterial in the present application since the ends of the fingers are covered by contact pads described subsequently.

As discussed, the line image produced by the slit lens **23** from the source aperture has a discontinuity, break or shadow due to the presence of the narrow apodizing mask. With the apodizing mask disposed symmetrically with respect to the central transverse plane, this break is at the centrer of the line image. In the illustration of FIG. 5, the line image (together with the break in the center of the image) is displaced laterally to the right (along the longitudinal axis) from the central transverse plane of the system due to the leftward displacement of the source aperture **26** in source mask **25**. In order to illustrate the point, line projections are made from the outer periphery of the source aperture **26** in source mask **25** past the edges of the apodizing mask **20** to the surface of target **22**. An inspection of the figure shows that there is a region of no illumination or full shadow **27** projected by the apodizing mask **20** on target surface **22**, on the opposite side of the system's central transverse plane from the source aperture **26**.

On opposite sides of the area of full shadow **27** penumbrae **28** are produced, but they are of little practical consequence. Using simple geometry, the widths of the full shadow and of the penumbrae **28** are easily calculated from the size and vertical placement of the apodizing mask, the dimension q of the source aperture **26** parallel to the slit, and the other geometric parameters of the system. The center of the break or shadow **27** is laterally displaced from the central transverse plane of the system by an amount n which is proportional to the displacement r of the center of the source aperture **26**. Since the distance z from the source mask **25** to the imaging plate **18** is large relative to the distance d from the imaging plate **18** to the target surface **22** (to provide large demagnification), the proportionality factor is correspondingly small. The source and apodizing masks **25** and **20**, respectively, and their positions relative to each other and slit lens **23** can be designed to yield a line having a predetermined shadow width and displacement using the principles illustrated here.

Extension of the charged particle image projection arrangements just described to the formation of an entire apodizing pattern follows readily. The broken line image of FIG. 4 with the "break" in the center is produced using a single source of charged particles on the central axis of the system (system of FIGS. **1** and **2**), and the location of the broken line image is shifted to one side by shifting the source off axis in a direction perpendicular to the central transverse plane (i.e., parallel to the line forming slit lens). Thus, an apodizing line pattern is formed using the projection principle by utilizing a source mask which has an aperture for each line desired, each aperture being displaced in a direction perpendicular to the central transverse plane to obtain the desired location of its broken line image relative to the transducer symmetry axis. The source apertures are also displaced in a direction parallel to the central transverse plane by distance selected to provide the desired distances between the line images. In other words, the source mask **25** has an aperture for each line desired, each aperture being displaced both parallel and orthogonal to the central transverse plane by the respective distances required to locate the desired position of its broken line image along and transverse to the transducer symmetry axis.

An example of a source mask **30** used in producing an apodizing image pattern is illustrated in FIG. **6**. For convenience of visualization a broken line image of a slit lens **23** and apodizing mask **20** is shown in position "under" the source mask **30**. FIG. **7** illustrates a target surface having an apodized transducer pattern (not to scale) produced by a source mask such as the one illustrated in FIG. **6**. In order to form a plurality of line images at the target surfaces **31** the source mask **30** utilizes a corresponding plurality of apertures which act as charged particle sources.

As illustrated, the source mask **30** has seven apertures displaced relative to one another in a direction parallel to the central transverse plane (vertical in FIG. **6**). Stated in another way, the apertures in source mask **30** are displaced relative to one another in a direction orthogonal to the longitudinal axis of the slit lens **23**. The apertures are numbered **32** through **38** consecutively (from top to bottom in the figure). Since the distances between each succeeding aperture in a direction parallel to the central transverse plane (direction orthogonal to the longitudinal axis of the slit lens) are equal, the distances between each corresponding line **32***a* through **38***a* inclusive produced on the target surface **31** by the corresponding apertures are equal.

Note that the projection of a given aperture in the source mask **30** results in an image at the transducer surface **31** which is on the opposite side of the central axis of the system. Thus, the line image **32***a* at the bottom of the target surface **31** is the projection of the source aperture **32** at the top of the source mask **30** and the line image **38***a* at the top of the target surface **31** is produced by the source aperture **38** at the bottom of the source mask **30**. Accordingly, the source apertures from top to bottom, numbered **32** through **38** inclusive, produce corresponging line images at the target surface in reverse order, that is, line images 32*a* through 38*a* inclusive from bottom to top.

As explained previously, the position of each line image and, consequently, its break relative to the transducer symmetry axis is determined by the displacement *r* of the source aperture forming that line in a direction perpendicular to the central transverse plane (a direction parallel to the longitudinal axis of the slit lens **23**). For example, the first source aperture **32** (top of figure) is directly at the central transverse plane ($r=0$). Projection of this source aperture then produces an image line (**32***a*, at bottom of FIG. 7) which is bisected by the transducer symmetry axis of the target surface **31**, and the discontinuity in the line so produced is directly on this axis.

Source apertures **33, 35** and **37** of source mask **30** are located to the left of the central transverse plane, just as source aperture **26** of the source mask **25** in FIG. **5**. Therefore, the corresponding line images and their discontinuities or breaks **33***a*, **35***a* and **37***a* (FIG. 7), respectively, are offset to the right of the transducer symmetry axis by amounts corresponding to the displacements *r* or their respective image forming sources **33, 35,** and **37.** Conversely, the source apertures **34, 36** and **38,** which are displaced to the right of the central transverse plane, project corresponding images and line breaks which are offset by amounts corresponding to the displacements *r* of the source apertures from the central transverse plane. Since each line image has a length corresponding approximately to the length of slit lens **23,** the lines are staggered relative to one another, either left or right, depending upon the direction of displacement of the forming source apertures (FIG. 7). This staggering is of little consequence since conductive contact pads **39** and **40** are formed on the target surface by conventional techniques in such a manner as to overlap the region of variable line length and thereby form an apodized transducer pattern effectively comprised of fingers, all of which have the same length, equal to the distance between conductive contact pads **39** and **40** and having breaks corresponding to the desired variation of overlap between adjacent finger pairs.

In the embodiments of the invention described thus far each line image is formed by a single source aperture and the width of the apodizing mask need be only slightly larger than the desired width of the discontinuity in the line image. Another embodiment is illustrated in FIG. **8**, a diagrammatic side view similar to that of FIG. **5**. In order to simplify the description and aid in understanding the embodiment, reference numerals for the elements of FIG. **8** which correspond to elements of FIG. **5** are given identical numbers. The difference between the systems resides in the fact that the source mask **25** of FIG. **8** is provided with two source apertures **26** and **41** instead of the single source aperture **26** utilized in the system of FIG. **5.** As in FIG. **5**, the source aperture **26** is displaced a distance *r* (to the left of the figure) from the central transverse plane. The additional source aperture **41** is displaced a distance *r'* to the right of the transverse plane. The source aperture **26** to the left side of the figure produces an illumination cone **26***a* precisely as described with respect to FIG. **5** and therefore provides an image at the target surface **22** as previously described, that is, a narrow line image with a discontinuity or break to the right of the central transverse plane (side opposite the source aperture **26**). Addition of the second source aperture **41** produces a second illumination cone **41***a*, which produces an image at the target surface **22** that overlaps or coincides in large measure with the image from the opposite source aperture **26.**

Consider first the image in the area of the target surface immediately under the apodizing mask **20.** The region of full break (full shadow region) **42** is determined by the spacing $w = r+r'$ between source apertures **26** and **41** and the width *m* of the apodizing mask, whereas in the system utilizing one source aperture per line image, as illustrated in FIG. **5**, the region of full shadow depends solely on the width of the apodizing mask. Thus the use of two source apertures provides an additional adjustment parameter *w*. For clarity in exposition, the penumbrae **28** in FIG. **5** produced by each source aperture **26** and **41** are not shown in FIG. **8.** The regions **43** on both sides of the shadow region **42** comprise illumination from only one source and therefore produce line segment images of the desired illumination on target surface **22.**

FIG. **8** also shows that use of the two source apertures **26** and **41** for each line results in illumination regions **44** on each side of regions **43** that produce line image segments on target surface **22** having about twice the illumination intensity as that produced in illumination regions **43.** (Note, again, that the penumbrae between regions **43** and **44** on each side are omitted.) These "double illumination" line segments are of little consequence since they are to be encompassed by proper placement of contact pads (such as contact pads **39** and **40** in FIG. 7). In other words, the effective line image analogous to that shown in FIG. **5** for a single source aperture is comprised of the images produced by illumination regions **43** and the full shadow region **42** directly under apodizing mask **20.**

Another embodiment that utilizes two source apertures without producing line image segments of double illumination is shown in FIG. **9.** The illustration of FIG. **9** contains all of the elements illustrated and described with respect to FIG. **8** and, therefore, corresponding elements are given identical reference numerals in the two figures. The embodiment illustrated in FIG. **9**, however, has a vertical mask (septum) **45** which is positioned immediately above the apodizing mask **20** and in the central transverse plane. A mask so positioned prevents cross illumination by source apertures **26** and **41** relative to the central transverse plane. This is particularly illustrated in the figure by the projections immediately under the two apertures between **26** and **41** respectively, showing the effective illumination cones **26***b* and **41***b*. It will be appreciated from the figure that the width of the discontinuity or break caused by the shadow area **42** at the target surface is controlled in the same manner as described with respect to the embodiment of FIG. **8**, so that the effective line image, comprised of the images produced by illumination regions **45** (that correspond in intensity to single illumination regions **43** in FIG. **8**) and the shadow region **42**, is produced by utilizing the full illumination cones **26***b* and **41***b*.

The apodized transducers described so far perform their apodizing function by variation of the amounts of overlap between adjacent fingers in accordance with prescribed formulas relating to the specific apodization requirements, and the fingers in any specific transducer have the same widths and the spacing is the same between adjacent fingers. Since the width of each finger in the target plane is directly proportional to the orthogonal width p of the one or two source apertures producing that finger and the spacing between fingers is proportional to the distance between corresponding source apertures in the direction parallel to the central transverse plane, it is appreciated that all of the embodiments above are capable of producing transducers having finger widths and spacings that vary in accordance with prescribed formulas by merely varying the orthogonal widths p of the source apertures and their spacings on the source masks. However, the intensity of a charged particle stream forming any single line image at the target is directly proportional to the length q (dimension parallel to slit lens **23**) of the source apertures producing that line image. Since it is frequently desirable that all the charged particle streams forming the line images at the target have the same intensity, e.g., for resist exposure, the source apertures are designed to be square (or round) for line images all having the same widths and are designed to be rectangular for line images having widths that vary in a prescribed pattern, with the parallel widths q of each source aperture the same.

While particular embodiments of the invention have been shown and described, it will, of course, be understood that the invention is not limited thereto since many modifications may be made without departing from the true spirit and scope of the invention. It is contemplated that the appended claims will cover such modifications.

What is claimed is:

1. A beam forming and imaging system comprising:

charged particle source means of directing charged particles along a path;

a source mask disposed in said path and having at least one aperture therein, whereby charged particles directed along said path pass through the said aperture in said source mask;

a target disposed in said path;

an imaging plate disposed in said path between said target and said source mask, comprising a member opaque to said charged particles and having at least one slit therein, said slit being substantially long in length and relatively narrow in width;

a voltage source connected between said imaging plate and said target and adapted to produce an electrical field therebetween, said electrical field convergent only in a direction parallel to said relatively narrow width, said convergent electrical field present along the substantially long length of said slit, whereby the charged particles in said path are focused by the convergent electrical field to form a one dimensionally converged image of said slit on said target for each aperture in said source mask; and

an apodizing mask comprising a member opaque to said charged particles and extending transversely across the said slit in said imaging plate, thereby to divide the said converged image of said slit on said target into at least two segments.

2. The beam forming and imaging system of claim **1**, wherein the said slit in said imaging plate is essentially rectangular and the said source mask has a plurality of apertures therein, each of the said apertures being displaced relative to each other in both a direction parallel to the longitudinal axis of the said slit in the said imaging plate and a direction orthogonal to the longitudinal axis of the said slit.

3. The beam forming and imaging system of claim **1**, wherein the slit in said imaging plate is essentially rectangular and the said source mask has a plurality of apertures therein displaced relative to each other in a direction orthogonal to the longitudinal axis of the said slit, at least some of said apertures in said source mask being displaced relative to each other in a direction parallel to the longitudinal axis of the said slit in the said source mask.

4. The beam forming and imaging system of claim **1**, wherein said charged particle source means comprises a source of electrons and wherein said target includes an electron sensitive resist in the path of said electrons.

5. The beam forming and imaging system of claim **2**, wherein said charged particle source means comprises a source of electrons and wherein said target comprises a substrate having a coating of electron sensitive resist thereon.

6. The beam forming and imaging system of claim **3**, wherein said charged particle source means comprises a source of ions and wherein said target comprises a substrate having electron sensitive resist thereon.

7. The beam forming and imaging system of claim **1**, wherein said charged particle source means comprises a material susceptible to ion sputtering.

8. The beam forming and imaging system of claim **1**, wherein said charged particle source means comprises a source of ions and wherein said target comprises a substrate having a coating of ion sensitive resist thereon.

9. The beam forming and imaging system of claim **1**, wherein the said slit in said imaging plate is essentially rectangular and the said source mask has a plurality of pairs of apertures therein, the apertures of each pair being displaced along a line parallel to the longitudinal axis of the said slit and displaced on opposite sides of the center of said longitudinal axis, each of said pairs of apertures being displaced relative to each in a direction orthogonal to the longitudinal axis of said slit.

10. The beam forming and imaging system of claim **9**, wherein a septum is provided between the said source mask and the said apodizing mask essentially perpendicular to the said source mask and imaging plates, whereby charged particles passing through apertures in the said source mask on opposite sides of said septum do not cross over the said apodizing mask and, consequently, do not pass through the said slit in the said imaging plate on opposite sides of the said apodizing mask.

11. The beam forming and imaging system of claim **1**, wherein the said aperture in said source mask is rectangular and the sides of said rectangle along its length and width are parallel to the corresponding sides of the said slit of said imaging plate, whereby the width of the said one dimensionally converged image of the said slit on said target is proportional to the width of the said aperture in the source mask and the intensity of the said image is proportional to the length of the aperture in the source mask.

12. The beam forming and imaging system of claim **2**, wherein the said plurality of apertures in said source mask is rectangular and the sides of each said rectangle along its length and width are parallel to the corresponding sides of the said slit of said imaging plate, whereby the width of the said one dimensionally converged image of the said slit on said target is proportional to the width of each said aperture in the source mask and the intensity of the said image is proportional to the length of each said aperture in the source mask.

13. The beam forming and imaging system of claim **3**, wherein the said plurality of apertures in said source mask is rectangular and the sides of each said rectangle along its length and width are parallel to the corresponding sides of the said slit of said imaging plate, whereby the width of the said one dimensionally converged image of the said slit on said target is proportional to the width of the said aperture in the source mask and the intensity of the said image is proportional to the length of the aperture in the source mask.

14. The beam forming and imaging system of claim **9**, wherein each of the said apertures of said plurality of pairs of apertures is rectangular, with the sides of each said rectangle along its length and width being parallel to the corresponding sides of the said rectangular slit in the said imaging plate.

15. The beam forming and imaging system of claim **10**, wherein each of the said apertures of said plurality of pairs of apertures is rectangular, with the sides of each said rectangle along its length and width being parallel to the corresponding sides of the said rectangular slit in the said imaging plate.

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