

[54] **METHOD AND APPARATUS FOR
ELECTRON BEAM ALIGNMENT WITH A
MEMBER**

[75] Inventors: **Terence W. O'Keefe; Paul R.
Malmberg**, both of Pittsburgh, Pa.

[73] Assignee: **Westinghouse Electric Corporation**,
Pittsburgh, Pa.

[22] Filed: **Oct. 1, 1973**

[21] Appl. No.: **402,248**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 370,558, June 15,
1973, abandoned.

[52] U.S. Cl. **250/492 A; 250/397; 315/10;**
219/121 EM

[51] Int. Cl. **H01j 29/50; H01j 31/49**

[58] **Field of Search** 250/549, 561, 458, 459,
250/396, 397, 398, 400, 458, 459, 491, 492
A; 219/121 EB, 121 EM; 315/10

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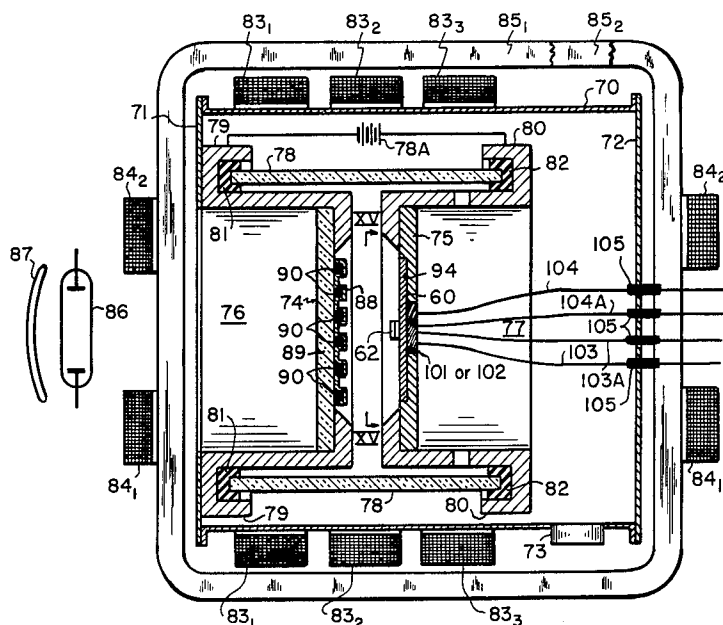
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Primary Examiner—Walter Stolwein
Attorney, Agent, or Firm—C. L. Menzemer

[57] **ABSTRACT**

A method and apparatus are provided for alignment of an electron beam with precisely located areas of a major surface of a member. Marks of predetermined shape are formed of cathodoluminescent material and are positioned adjacent the major surface of the member which is preferably substantially transparent to the cathodoluminescence generated by the marks. An electron beam to be aligned has at least one alignment beam portion of a predetermined cross-sectional shape and preferably corresponds in size to the alignment accuracy desired. The cathodoluminescence emissions detected by a detector means are preferably positioned adjacent the opposite surface of the member. The position of the electron beam is moved relative to the member while continuing said detection until the emissions detected indicate alignment of the alignment beam portion with a corresponding mark. Preferably, said alignment method is used in producing a very accurate component pattern in an electroresist layer supported by a member utilizing either a scanning electron beam or an electron image projection system for the electron radiation beam, and most preferably in the making of a novel photocathode source, which can itself be used in the alignment of a patterned electron beam with a member.

18 Claims, 17 Drawing Figures



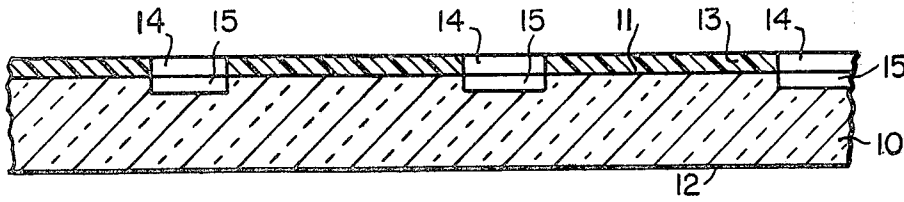


Fig. 1

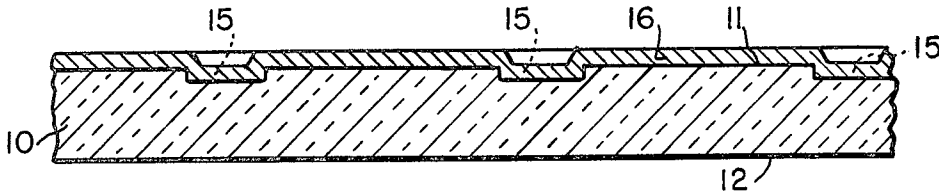


Fig. 2

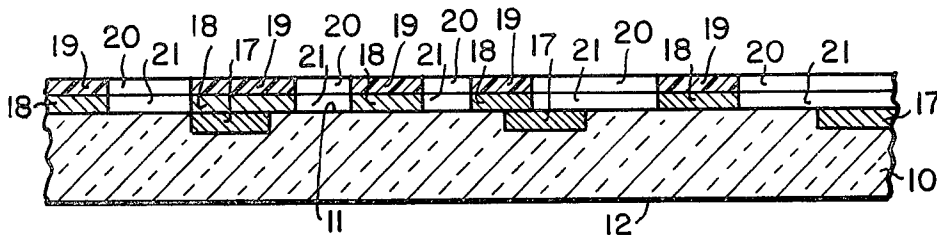


Fig. 6

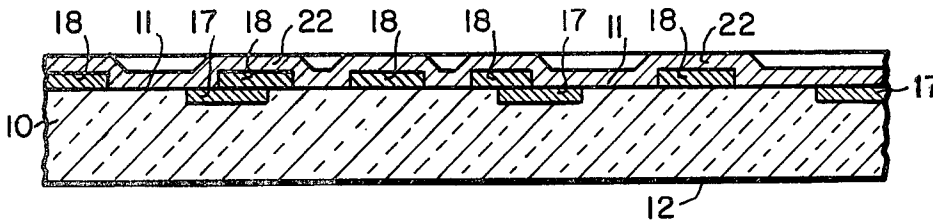


Fig. 7

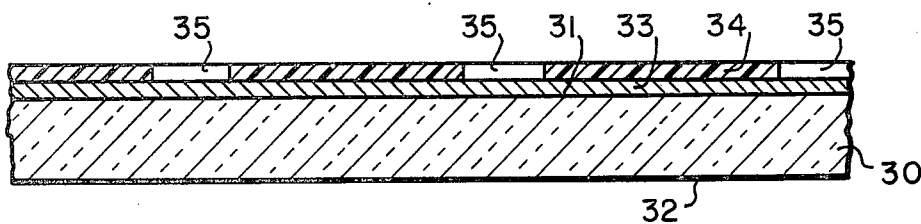


Fig. 8

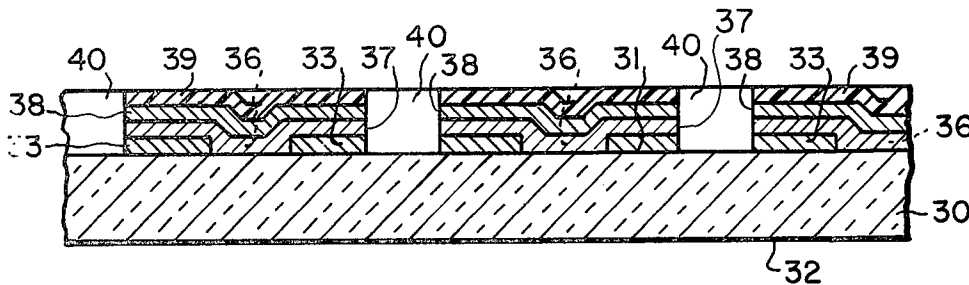


Fig. 9

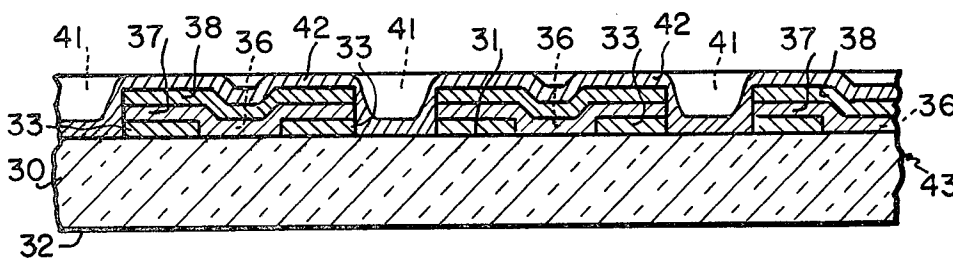
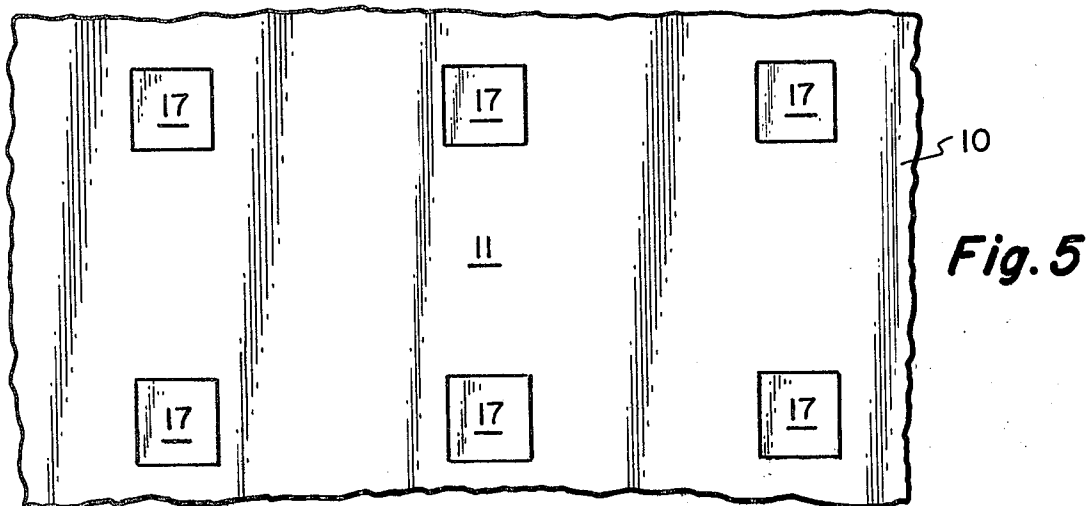
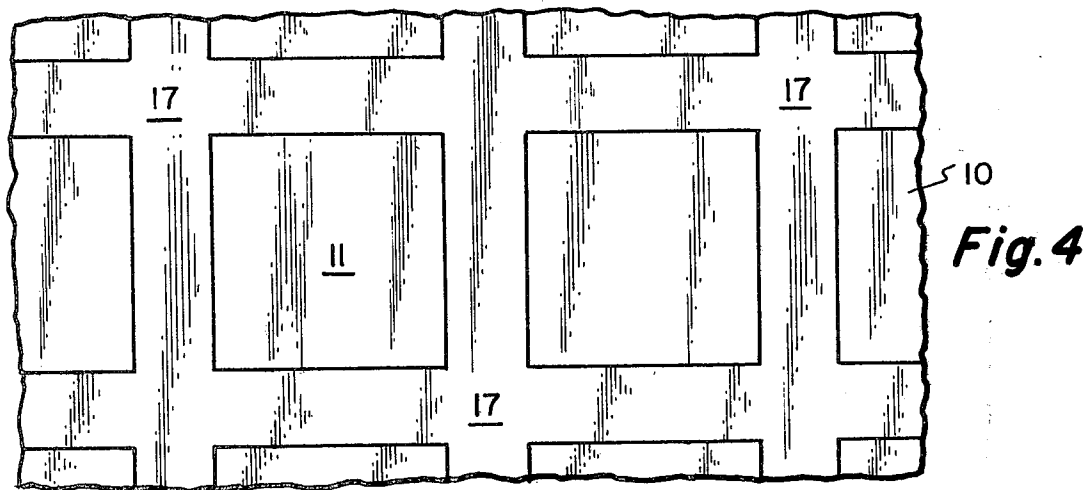
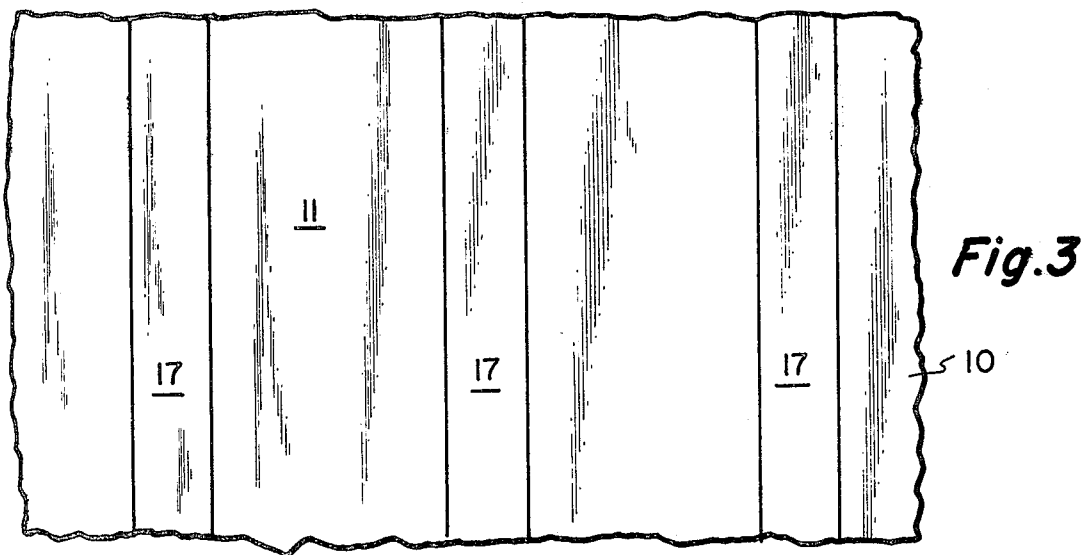


Fig. 10



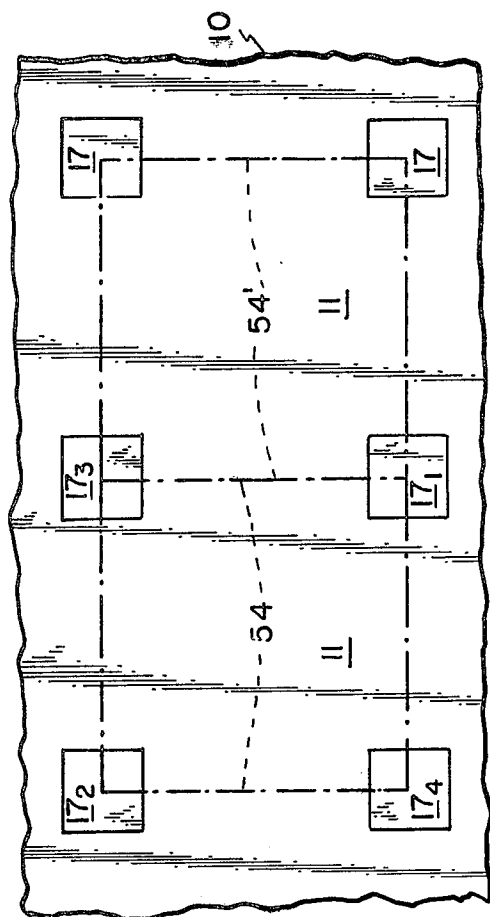


Fig. 12

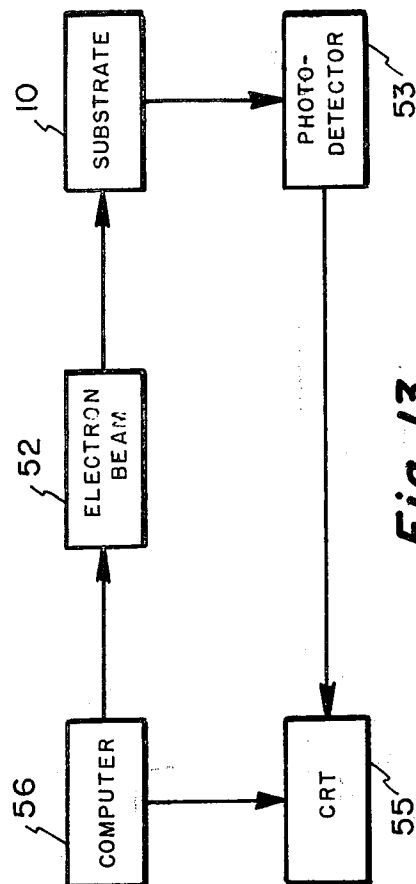


Fig. 13

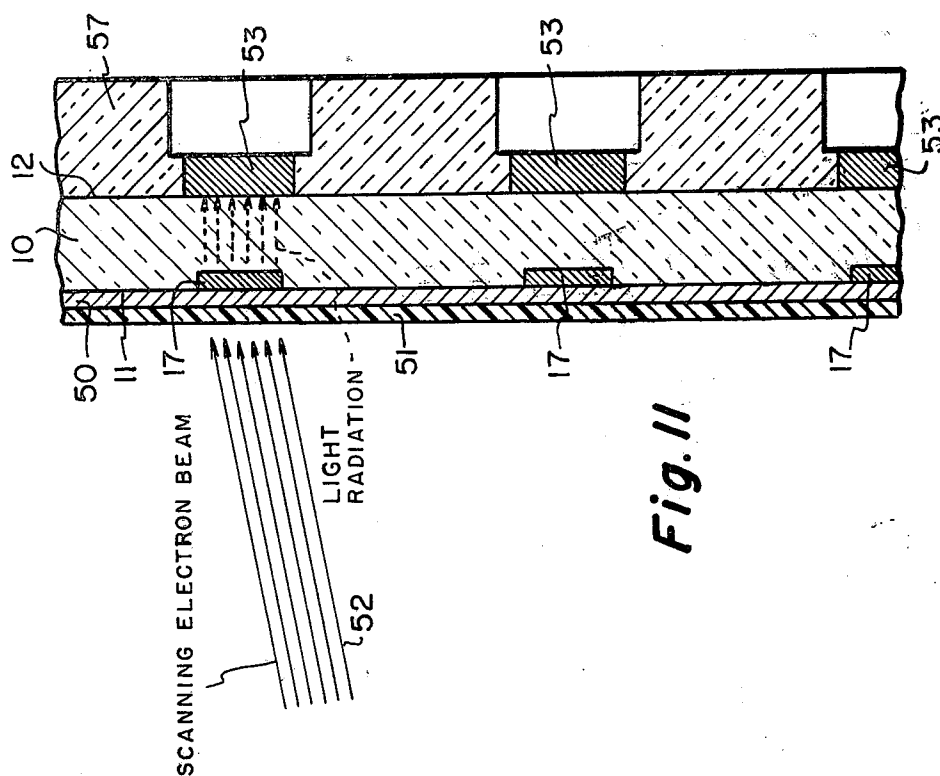


Fig. 11

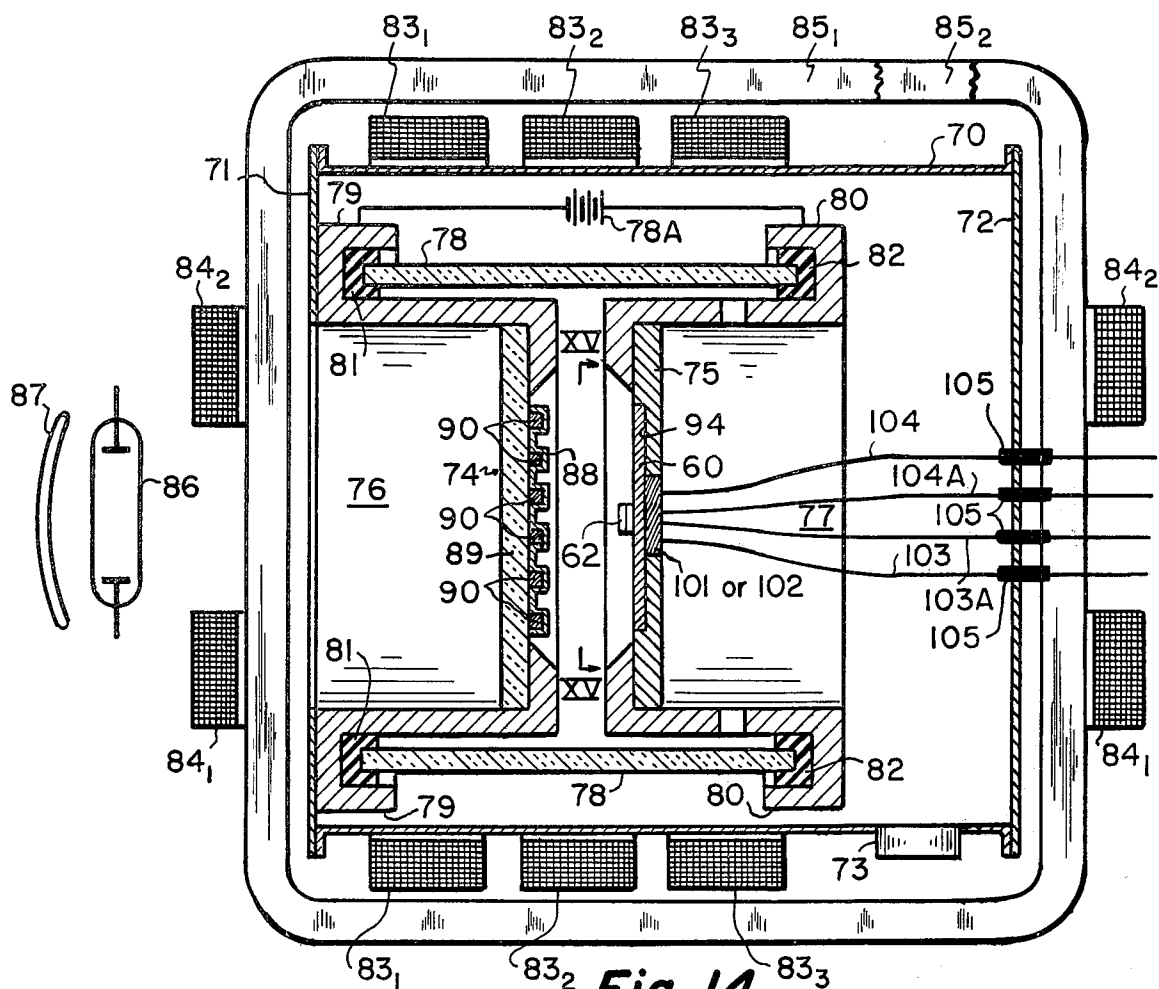


Fig. 14

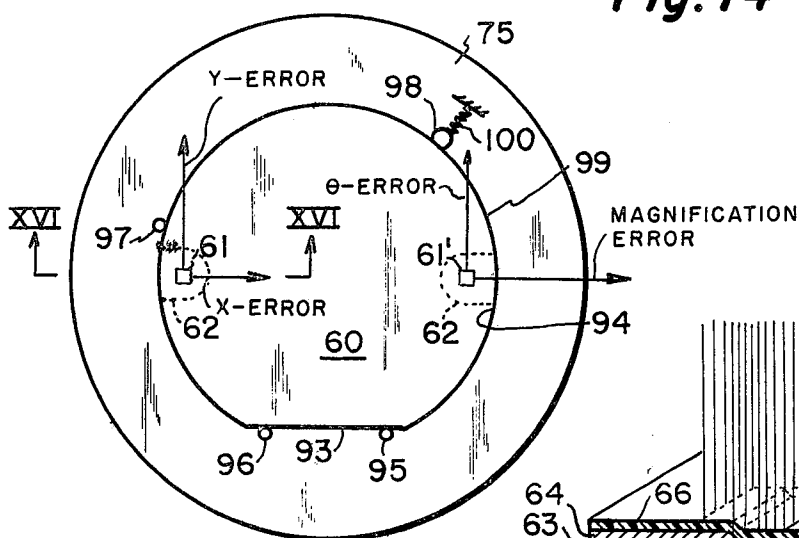


Fig. 15

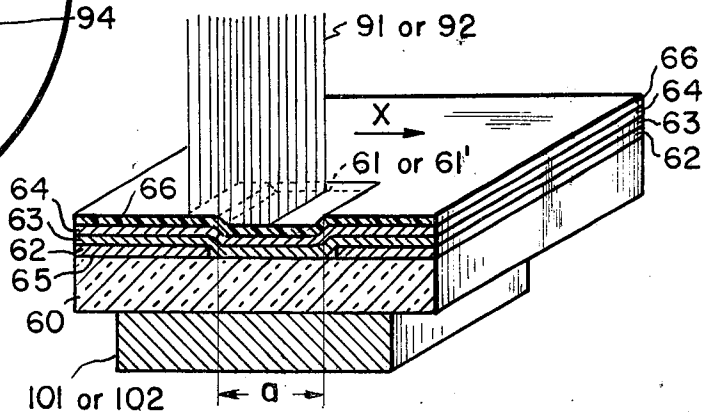


Fig. 16

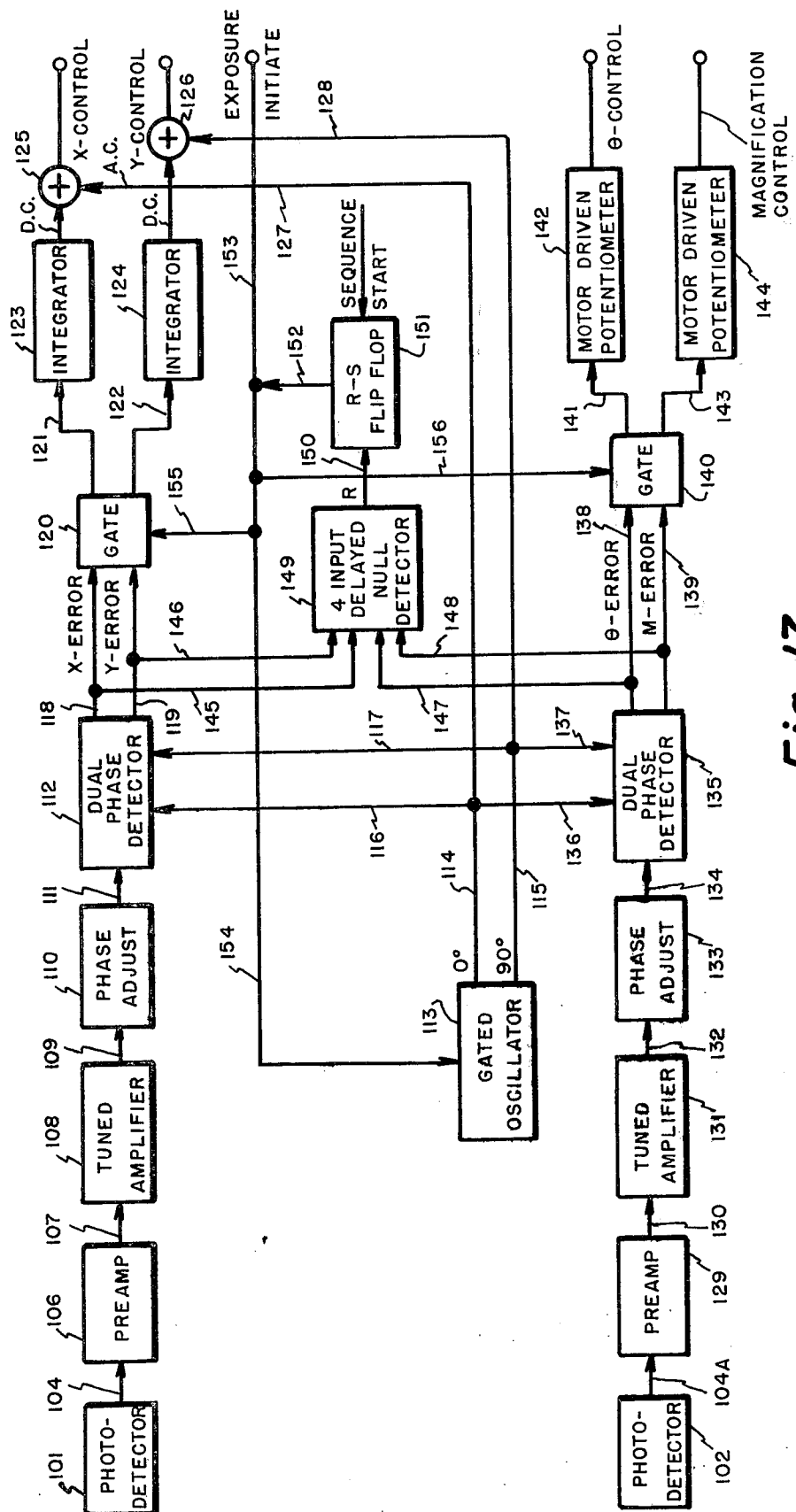


Fig. 17

METHOD AND APPARATUS FOR ELECTRON BEAM ALIGNMENT WITH A MEMBER

GOVERNMENT CONTRACT

This invention is made in the course of or under Government Contract F 30602-69-C-0280.

RELATED APPLICATION

This application is a continuation-in-part of copending application Ser. No. 370,558, filed June 15, 1973, now abandoned.

FIELD OF THE INVENTION

The invention relates to the making of integrated circuits and other micro-miniature electronic components with submicron accuracy.

BACKGROUND OF THE INVENTION

The present invention is an improvement on the electron beam fabrication system described in U.S. Pat. No. 3,679,497, issued July 25, 1972, and assigned to the assignee of the present invention.

The electron beam fabrication system employs a scanning electron microscope to produce a photocathode source or electromask. The photocathode source is adapted to project, on irradiation, typically by ultraviolet radiation, an electron beam in the desired pattern which impinges on an electroresist layer on a major surface of a member to implant in said resist layer a differential solubility between the irradiated and the unirradiated areas. Removing the more soluble portions of the electroresist layer after irradiation, selectively exposes the underlying member or layer on the member which can in turn be selectively altered through windows in the electroresist of the desired component pattern typically by etching, diffusion or deposition.

The electromask designates the pattern-bearing photocathode assembly which is analogous to the photomask in the well known photolithographic techniques. The electromask comprises a light transmissive substrate such as quartz by which the photocathode source is supported. The photocathode source is usually adapted to generate the patterned electron beam by overlaying the substrate with a layer such as titanium dioxide which is opaque to the radiation to which the photocathode material is sensitive. The negative of the desired component pattern is formed in the opaque layer over which a contiguous layer of a photocathodic material such as palladium is formed. The patterned electron beam thereafter is generated by irradiating the photocathode layer through the substrate and the opaque layer. See, e.g., U.S. Pat. Nos. 3,585,433, 3,588,570, 3,686,028 and 3,672,987.

The scanning electron microscope of such fabrication system involves the use of a finely focused electron beam to generate a planar component pattern having submicron accuracy in an electroresist layer or the like. The electron beam is automatically moved through the pattern matrix on command from a computer. The beam control information can be stored on a magnetic tape which is fed into the computer which is used to command the position and movement of the electron beam. While such as scanning electron beam system can be used to directly develop a high resolution pattern in an electroresist in making an integrated circuit, the electron beam fabrication system involves the

use of such a scanning electron beam to make the photocathode source for the electron image projection system.

The main problem in the use of such scanning electron beams is maintaining the accuracy over the entire pattern field. Resolution as such is not a problem in the use of the scanning electron beam. Lines less than 0.5 micron in width can be reliably reproduced in resist materials. However, the pattern field size of integrated circuits are typically as great as 2000×2000 microns and often as great as 4000×4000 microns. For electron optical reasons it is impractical to deflect the electron beam through more than a few degrees and still hold the high resolution of, for example, 0.5 micron. It is possible to increase the field size by increasing the distance between the cathode and the electroresist, but this also correspondingly increases the diameter of the focused electron beam and in turn sacrifices resolution. Thus, for a given resolution, the field size for the scanning electron beam is usually restricted to considerably less than the member size of the integrated circuit. For example, for an electron beam of 0.2 micron in diameter and a resolution of 0.5 micron, the throw of the electron beam is limited to 2 inches and field size is limited to about 2000 microns in diameter.

Another restriction on the size of the field is the accuracy with which the electron beam can be deflected. This depends primarily on the electronics used to control the beam position. At present, the deflection accuracy of an electron beam of 0.2 micron diameter in a 2000 micron field is at best about 0.5 micron. Thus, a typically 2000×2000 micron field of an electron beam fabrication system is divided into 4000×4000 array of points each 0.5 micron apart; with the 4000 addresses on each axis provided by a 12 bit digital-analog converter. While memories are available with far greater numbers of addresses, larger fields and greater resolution within the same size fields cannot be obtained because of beam deflection limitations.

Ideally the problem can be remedied by sequentially developing the electroresist in multiple patterns of small fields. However, accurate registrations between contiguous fields is essential to the operability of such a technique. The high resolution, e.g. 0.5 micron, of the electron beam fabrication system is lost unless the same resolution can be maintained in alignment of the successive patterns. Thus, the electron radiation for each field must be aligned with respect to the adjoining field with a precision of 0.5 micron or less. Otherwise the precisions and economics of the electron beam fabrication system will not be attained in the integrated circuit device.

It has been proposed to simply accurately move the member on which the integrated circuit is to be formed from field to field by mechanical means, using a laser beam to maintain registration, see e.g., U.S. Pat. Nos. 3,632,205 and 3,719,780. However, such a system is not believed commercially practical. A change of only 0.01% in the physical alignment of the member can lead to an 0.2 micron error in the registration of adjacent fields. On a 2×2 inch member such an alignment error results from an 0.002 inch variation in dimension. Further, the deflection aberrations of the electron beam are such that an exactly regular rectangular array of fields is impossible to attain. Even with compensation, distortions remain that add to the mismatch between adjacent fields. Thus, a need exists for a multi-

ple sequential alignment system which will accurately and rapidly register adjacent fields of a desired electroresist pattern.

The need is particularly acute in Large Scale Integration (LSI) technology. LSI is the term applied to integrated circuits which provide high complexity electronic circuits (e.g. more than a thousand gates) in the same semiconductor wafer. Logically LSI technology requires larger and larger wafers. And LSI wafers measuring 2 and 3 inches on a side are now used. However, such large patterns can be generated with a scanning electron microscope only by combining several fields, where accurate registration between fields is essential. Moreover, LSI technology requires a greater density of electronic components and in turn better generation and alignment resolution. The quantitative yield of such integration corresponds directly to the size of the wafer. The probability of defects in the single crystal structure increases directly with the volume of the wafer. Thus, the higher the resolution, the greater the circuit density, the smaller the wafer, the greater the quantitative yield of the integration that results.

In the electron image projection system, there is also a need for precision registration and alignment of the patterned electron beam and the member. In order to attain high quantitative yields of consistent and reliable electronic performance in integrated circuits, it is necessary that the major surfaces of the member be altered in precisely located positions and areas. This precision is particularly important when a plurality of successive surface treatments and alternations are to be made to one member. In this connection, six or more successive treatments and alterations are commonly needed to produce a typical integrated circuit for a sophisticated electronic application. The high resolution of the electron image projection system is lost in the juxtaposition of planar component patterns unless the same high resolution of projection, e.g. 0.5 micron and less, can be maintained in alignment of the member with successive photocathode sources. Here again, LSI technology puts particular stress on this requirement.

SUMMARY OF THE INVENTION

A method and apparatus are provided for the alignment of an electron beam with selected areas of a major surface of a member with any desired degree of accuracy, example, 0.5 micron or less. The optical distortion and deflection inaccuracies of a scanning electron beam can all but be eliminated by permitting the scan to be done in smaller fields, e.g. 200 × 200 microns square, because of the precision alignment which the invention permits to be maintained between fields. The invention also permits precision alignment of a photocathode source or series of photocathode sources with selected areas of a major surface of a member in the electron image projection system as well as precision production of photocathode sources without detector marks which detract from the patterned electron beams projected by the sources.

Generally at least one and preferably at least two detector marks capable of generating cathodoluminescent radiation corresponding to the area of each mark irradiated by an electron beam are formed adjacent a major surface of a member. The marks are of a predetermined shape and preferably in accurate spatial relation relative to each other. At least one cathodoluminescent mark is irradiated with a corresponding

alignment beam portion of the electron beam to be aligned. The alignment beam portion is of a predetermined cross-sectional shape and preferably corresponds in size to the desired accuracy, e.g. 0.5 micron in diameter or width for 0.5 micron accuracy. The light radiation emissions from the irradiated cathodoluminescent mark or marks detected by a photodetector means preferably through the member. The electron beam is moved relative to the substrate until the cathodoluminescent radiation emissions detected from the irradiated marks indicates alignment of the alignment beam portion with a corresponding detector mark.

The alignment beam portions and the detector marks may be of any suitable relative size within practical limits provided the shapes of both are predetermined. Preferably, however, each alignment beam portion is of the same cross-sectional shape as the predetermined shape of the corresponding detector mark so that alignment can be determined simply by reading a maximum or a minimum in the electrical signal from the detector means. Otherwise, electrical processing of the electrical signals are needed, while the alignment beam portions are oscillated over the corresponding detector marks, to determine optimum alignment of the alignment beam portions with the corresponding detector marks.

The detector marks of cathodoluminescent material may in certain applications be directly formed on or in the major surface in the predetermined shape. In other applications it may be more appropriate that the cathodoluminescent marks be formed by forming adjacent a cathodoluminescent layer a layer of material opaque to light or electron radiation. The opaque layer causes a differential in cathodoluminescent radiation projected by the cathodoluminescent layer either by blocking the cathodoluminescence generated by the cathodoluminescent layer or by blocking the electron radiation irradiating the cathodoluminescent layer. To illustrate, an opaque layer capable of reducing the cathodoluminescent emissions of a cathodoluminescent layer is formed adjacent the major surface of the member. windows are then opened in the opaque layer corresponding to the desired cathodoluminescent marks, and contiguous layers of cathodoluminescent material are formed over the major surface at least at the windows so that the opaque layer circumscribes a portion of the cathodoluminescent layer in the predetermined shape.

Where the cathodoluminescent radiation is detected on reflection by a photodetector positioned on the same side of the member as the electron beam, the steps would be the same and the sequence altered; the relative positions of the opaque layer and the cathodoluminescent layer with respect to the member are reversed. In a similar embodiment, the opaque layer is positioned over the cathodoluminescent layer to circumscribe an exposed portion of the cathodoluminescent layer in the predetermined shape. The opaque layer substantially reduces the electron radiation irradiating the cathodoluminescent layer and in turn reduces the cathodoluminescent radiation generated by the cathodoluminescent layer rather than reducing the cathodoluminescent radiation projected.

Further, the negative of these various embodiments may be desired in certain applications. That is, the opaque layer may be in the predetermined shape either above or below the cathodoluminescent layer. Or, the

cathodoluminescent layer may simply circumscribe an exposed portion of the major surface, the exposed portion being in the predetermined shape for the cathodoluminescent marks.

Preferably, the alignment method is used in producing a very accurate component pattern in an electroresist layer supported by a member in making integrated circuits of high component density and high resolution. A scanning electron beam for an electron image projection system, such as are described in above-cited U.S. Pat. No. 3,679,497, is preferably utilized as the electron radiation beam. Where a scanning electron beam is used, the beam operates in its entirety as the alignment beam portion in the system, and the selective irradiation is preferably performed in contiguous fields, e.g. 200×200 microns. The electron beam is thereby aligned with the member at least between the irradiating of each field to register the member and the electron beam from field to field preferably by positioning the marks symmetrically along the boundaries of the fields.

Where an electron image projection system is used, the selective irradiation is usually performed simultaneously over the entire surface of the member and preferably at least two widely spaced apart cathodoluminescent marks of predetermined shape are simultaneously irradiated in performing the alignment. The patterned electron beam projected by the photocathode source includes alignment beam portions of predetermined cross-sectional shape which are preferably the same shape as corresponding cathodoluminescent mark or marks. Further, with an electron image projection system, the alignment method can be used in juxtaposition alignment of a set of component patterns in making an integrated circuit or other micro-miniature electronic component. A set of photocathode sources are prepared having as part of their patterned electron beam alignment beam portions of substantially identical cross-sectional shape and spatial position. The alignment steps can thus sequentially be repeated with the different photocathode sources of the prepared set in making a precision integrated circuit.

Preferably the present invention is utilized in making a novel photocathode source for use in the electron image projection system as described in above-cited U.S. Pat. No. 3,679,497. Such a photocathode source is adapted to project an electron beam in a predetermined component pattern on being irradiated with sensitizing light radiation such as ultraviolet light. The photocathode source of the present invention includes alignment marks of predetermined shape capable of generating cathodoluminescent radiation corresponding to the area of the mark irradiated and preferably substantially transparent to the light radiation to which the photocathode material is sensitive. Said cathodoluminescent marks are positioned adjacent a major surface of a substrate substantially transparent to the light radiation to which the photocathode material is sensitive and by which the photocathode material is supported. In certain instances, the cathodoluminescent marks of said photocathode source may be formed as above described with adjacent opaque layers which circumscribe portions of cathodoluminescent layers in the predetermined shape and cause a differential in cathodoluminescent radiation projected by the cathodoluminescent layers at said portions to form the desired cathodoluminescent marks.

Other details, objects and advantages of the invention will become apparent as the following description of the present preferred embodiments and present preferred methods of practicing the same proceeds.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings, the present preferred embodiments of the invention and present preferred methods of practicing the invention are illustrated in which:

FIGS. 1, 2, 6 and 7 are fragmentary cross-sectional views of a photocathode source of the present invention at various stages of its manufacture;

FIGS. 3, 4 and 5 are alternative fragmentary top views of the photocathode source of FIGS. 1, 2, 6 and 7 at a certain stage in its manufacture,

FIGS. 8, 9 and 10 are fragmentary cross-sectional views of an alternative photocathode source of the present invention at various stages of its manufacture; FIG. 11 is a schematic illustration of production of a highly accurate component pattern in an electroresist layer on a member utilizing a scanning electron beam in accordance with the present invention;

FIG. 12 is a partial top view of the member of FIG. 11 without the electroresist layer applied;

FIG. 13 is a flow diagram showing the interrelationship of functional component in utilizing the present invention to align the scanning electron beam as shown in FIG. 11;

FIG. 14 is a cross-sectional view in elevation of an electron image projection device employing the present invention;

FIG. 15 is a fragmentary cross-sectional view in elevation taken along line XV—XV of FIG. 14;

FIG. 16 is a fragmentary cross-sectional view in perspective taken along line XVI—XVI of FIG. 15; and

FIG. 17 is a block diagram of an electrical circuit for the electron image projection device shown in FIG. 14 to automatically align the electron beam pattern in accordance with the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1, substrate 10 having opposed major surfaces 11 and 12 is selected of a material transmissive to the radiation of interest. For making a photocathode source as hereinafter described, substrate 10 is typically quartz because it is substantially transparent to ultraviolet light radiation and relatively inexpensive. Wafers of sapphire or lithium fluoride may also be used in lieu of quartz for the substrate.

A regular array of marks of cathodoluminescent material is formed adjacent major surface by first applying to major surface 11 an electroresist layer 13. An electroresist is a material which is sensitive to electron radiation to form in a layer thereof a pattern of differential solubility. That is, the electron irradiated portion of the layer is made either more or less soluble to certain solvents than the non-irradiated portion of the layer. Preferably the electroresist layer is light insensitive and relatively stable and has a relatively long shelf life. Examples of negative resists are polystyrene, polyacrylamide, polyvinyl chloride and certain selected hydrocarbon silicones. Examples of positive resists are polyisobutylene, polymethylmethacrylates, and poly(alpha-methylstyrene).

A good positive resist is polymethylmethacrylate of an average molecular weight of over 100,000 containing a very low fraction of polymer having molecular weight of 50,000 or less to avoid pin holes during processing. It is rendered readily soluble in either 95% ethanol (5% water) or in a mixture of 30% by volume of methylethyl ketone and 70% isopropanol when subjected to an electron beam at 10 kilovolts to supply 5×10^{-5} coulombs per cm^2 . The portions so exposed are soluble in the previously mentioned solvent, whereas the remainder of the resist coating is not as soluble in such solvent.

Polyacrylamide is a good negative resist inasmuch as the electron beam at 10 kilovolts applying 3×10^{-6} coulombs per cm^2 will render it slowly soluble in deionized water, while the remainder of the coating will resist concentrated phosphoric acid, which renders it useful as a coating for aluminum. This electroresist is not removed by most organic solvents such as methanol. It forms an excellent mask for a sputtering-etch treatment of the substrate. The average molecular weight of a good polyacrylamide resist that has given good results is 4.5×10^7 .

The electroresist may also be provided by any of the various commercially available "photoresist" materials that are sensitive to electron bombardment to become more soluble or insoluble in specified solvents. Three such photoresists are AZ-1350 and AZ-1350H made by Shipley and Microline PR-102 made by GAF.

The electroresist may also be one of various inorganic compounds as well as organic compounds. For example, silicon dioxide and silicon nitride (Si_3N_4) coatings on a substrate when subjected to an electron beam are rendered more soluble in an etchant. Buffered hydrofluoric acid will dissolve more readily the electron beam treated portions of a silicon dioxide layer as compared to the portion of the layer not treated with the electron beam. This characteristic is known as the "BEER" effect (i.e. Bombardment Enhanced Etch Rate). Etch enhancement ratios of about 3 are obtained, so that the electron beam bombarded portions will be completely etched away while there will be only as little as a third of the unbombarded layer that will be etched away.

For example, silicon substrates with an oxide layer of a thickness of about 10,900 Å has areas electron irradiated to a total of 0.5 coulombs per cm^2 and then etched electrolytically with P etch at 6 volts with the silicon being anodic to yield etch rates of 142 Å per minute for the unirradiated areas and 416 Å per minute for the electron irradiated areas. When the same silicon substrate was made cathodic at 6 volts, all other procedures remaining the same, the etch rates were 134 Å per minute for the unirradiated portions and 391 Å per minute for the electron irradiated portions. Again, when the silicon substrate was made cathodic at 15 volts, the relative etch rates were 153 Å per minute for the unirradiated portions and 460 Å per minute for the electron irradiated portions. It should be noted for this example that the etchant employed was a buffered solution of hydrofluoric acid (pH 6.5) which is an aqueous solution 10 M in NH_4F and 2.62 M in HF. It was also found that the electron beam can be supplied as little as 0.25 to 1 coulomb per cm^2 to secure enhanced etching in silicon dioxide layers of 10,000 Å in thickness; the unirradiated portions were etched to 7000 to 8000 Å in thickness while the 0.5 and 1.0 coulomb per

cm^2 portions were completely etched through.

Irrespective of the composition, the thickness of electroresist layer 13 is also important to the definition of the pattern formed in it. The thickness of the resist layer 13 must be on the order of the resolution desired in the component pattern. Typically, the thickness will be between about 0.2 and 1.0 microns. If the desired resolution is 0.1 micron, then the electroresist layer need be on the order of 0.5 micron or less.

Still referring to FIG. 1, a predetermined pattern of windows or marks 14 of predetermined shapes corresponding to the desired array of cathodoluminescent marks are formed in electroresist layer 13. The electroresist layer 13 is irradiated by a scanning electron beam (not shown) of fine dimensions, e.g. 0.2 micron in diameter, to implant the mark pattern in differential solubility in layer 13. The position of the electron beam is sequentially moved on command from a computer over the electroresist layer to selectively irradiate and define the desired pattern in the electroresist, see above-cited U.S. Pat. No. 3,679,497 for further description. After irradiation, the electroresist layer 13 is developed to open windows 14 and expose selected portions of major surface 11 of substrate 10. The solvent used for this purpose will depend upon the composition of the electroresist layer as noted above.

After forming the predetermined pattern of marks in layer 13, the pattern corresponding to the desired array and predetermined shapes of the cathodoluminescent marks is transferred to a pattern in the substrate 10 by etching well pattern 15 in substrate 10 through windows 14. The etchant suitable for this purpose will depend upon the composition of the substrate 10. For quartz substrates a solution of hydrofluoric acid is a suitable etchant for this purpose. The depth of well pattern 15 is determined by the etching time for the particular etchant composition used. Typically the etching time is sufficient to form a well pattern of at least about 600 Å in depth in the substrate 10.

Referring to FIG. 2, the remainder of electroresist layer 12 is removed with a suitable solvent, and layer 16 of cathodoluminescent material is formed over surface 11 by standard RF sputtering or vapor deposition techniques, filling well pattern 15. The particular cathodoluminescent material will depend on the particular use of the invention. For use of the substrate 10 with the regular array of closely spaced cathodoluminescent marks of predetermined shapes, as shown, directly as a substrate for an integrated circuit, for example, any cathodoluminescent material can be used depending on the sensitivity of the electron beam and the photodetector as hereinafter described. For use in making a photocathode source, the cathodoluminescent material is preferably a material, such as calcium fluoride activated with manganese (i.e. $\text{CaF}_2:\text{Mn}$), which is substantially transparent to ultraviolet light and the like. No difficulty is thus encountered in having the cathodoluminescent marks reproduce as part of the patterned electron beam projected by the photocathode source.

Following disposition of layer 16, layer 16 is polished or possibly lap etched to remove the cathodoluminescent material of surface 11 while leaving the cathodoluminescent material in well pattern 15 forming cathodoluminescent marks 17 in a regular array and of predetermined shape (e.g. square as shown). A planar surface is thus provided with marks 17 in position. The substrate can in this form be used in accordance with

the present invention for making an integrated circuit or other microminiature electronic components as hereinafter described.

The pattern of cathodoluminescent marks 17 of predetermined shapes may be any regular array as desired. Preferably the pattern is symmetrical to facilitate alignment of a scanning electron beam from field to field as hereinafter described. Referring to FIGS. 3 through 5, some typical patterns of marks 17 are shown. The marks may form a single parallel-line pattern as shown in FIG. 3, a line-grid as shown in FIG. 4, or spaced rows as shown in FIG. 5. In any case, the shapes of marks 17 and spacing between marks 17 are selected to provide the desired alignment accuracy, and preferably the size, i.e. width or area, of marks 17 are selected to correspond to the desired alignment accuracy. Typically, the marks will have a width (or diameter) less than 0.5 micron and a spacing center-to-center of between 200 and 2000 microns. The alignment system resulting has a usual accuracy of 0.5 micron or less. In this connection, it should be noted that equivalent cathodoluminescent marks 17 can be obtained by forming the cathodoluminescent material in the negative of the marks 17. That is, cathodoluminescent layers are formed to circumscribe exposed portions of the surface of the members which are in the predetermined shape of the desired cathodoluminescent marks.

Referring to FIGS. 6 and 7, substrate 10 with cathodoluminescent marks 17 adjacent surface 11 is made into a photocathode source. A contiguous layer 18 opaque to ultraviolet light is deposited over major surface 11 and marks 17. Layer 18 may be either reflective or absorptive of ultraviolet light. For an absorptive layer, layer 18 can be a titanium ion containing material in the form of an oxide including titanium dioxide, or other materials such as Fe⁺³ containing materials. When an oxide of titanium is used, layer 18 may be made by reactively sputtering titanium in an oxidizing atmosphere or by RF sputtering of titanium dioxide itself. Alternatively, a layer of titanium may be vapor deposited and then wholly or partially oxidized in situ to provide opaque layer 18. For a reflective opaque layer 18, a layer of aluminum or chromium of thickness of about 800 Å may be deposited on exposed portions of surface 11 and marks 17 by standard sputtering techniques. In any case, a protective layer (not shown) of, for example, quartz or other glass having a thickness of about 1500 Å may be formed over layer 18 to prevent subsequent oxidation and/or permit periodic refitting of the photocathode source with a new photocathode material.

Overlayer 18 is then deposited a contiguous layer 19 of electroresist, and the positive or negative of a desired component pattern is implanted in electroresist layer 19 in differential solubility by irradiating the layer with a scanning electron beam or the electron image projection system, see U.S. Pat. No. 3,679,497. The desired component pattern is then formed in electroresist layer 19 to expose selected surface portions of opaque layer 18 by dissolving the more soluble portion of layer 19 in a suitable solvent. The desired component pattern is then transferred to the opaque layer 18 by etching or ion milling opaque layer 18 through window pattern 20 in electroresist 19. A suitable etchant for this purpose is dilute hydrofluoric acid.

Referring to FIG. 7, remaining portions of electroresist layer 19 are then removed with a suitable solvent

such as trichloroethylene or acetone and a contiguous layer 22 of photocathode material is then deposited over exposed surface portions of surface 11, cathodoluminescent marks 17 and opaque layer 18. Preferably the photocathode material is an air stable material such as palladium, gold, platinum, aluminum, barium, copper or cesium iodide. Typically such photocathode material is deposited by vacuum vaporization or RF sputtering. The resulting combination of layers 18 and 19 thus provided a photocathode source adapted to project an electron beam in the predetermined component pattern on irradiation by sensitizing light radiation such as ultraviolet light.

The result is a finished photocathode source shown in FIG. 7 which can be used in accordance with the invention as hereinafter described. Because of the recess of the cathodoluminescent marks into the substrate, a photocathode source embodying the present invention can be made without optical distortions arising from non-planar surfaces. In this connection, the importance of the cathodoluminescent marks 17 being substantially transparent to ultraviolet light is emphasized to avoid unnecessary difficulties in the design and manufacture of the photocathode source. It should also be noted that the resulting photocathode provides a negative projection. That is, it is designed to generate a patterned electron beam which is the negative of the desired component pattern. It is designed for use in the electron image projection system with negative electroresists.

Referring to FIGS. 8 through 10, an alternative procedure is shown for making a photocathode source embodying the invention. Substrate 30 having opposed major surfaces 31 and 32 is selected of a composition typically on the same considerations as substrate 10.

Over surface 31 is formed a contiguous layer 33 of material opaque to light radiation emitted by the cathodoluminescent material used in the photocathode source. Preferably opaque layer 33 is composed of a metal such as titanium.

Over opaque layer 33 is formed a contiguous layer 34 of electroresist. The desired pattern array of cathodoluminescent marks or the negative thereof, depending on whether the electroresist is positive or negative, is thereafter implanted in the electroresist layer as a pattern of differential solubility by use of a scanning electron beam or the electron image projection system as above described and referenced. The electroresist is then developed with a suitable solvent, depending on the resist composition, to form window pattern 35 corresponding to the desired array of cathodoluminescent marks to expose selected portions of opaque layer 33.

Window pattern 36 is then opened in opaque layer 33 corresponding to the desired array of cathodoluminescent marks by selectively etching or ion milling through the window pattern 35 in electroresist layer 34. Dilute hydrofluoric acid is a suitable etchant for this purpose where titanium is used for the opaque layer. The pattern corresponding to the desired array of cathodoluminescent marks of predetermined shapes is thus formed in opaque layer 33. The remainder of electroresist layer 34 is then removed with a suitable solvent such as trichloroethylene or acetone.

Over the exposed portions of surfaces 31 and opaque layer 33 is thereafter applied a contiguous layer 37 of cathodoluminescent material of interest to provide the cathodoluminescent mark of predetermined shape.

Preferably layer 37 is applied by standard RF sputtering or vacuum evaporation deposition techniques. The cathodoluminescent material is preferably of a material such as CaF_2Mn .

It should be noted at this point in connection with FIGS. 8 and 9 that equivalent cathodoluminescent marks of predetermined shapes so far as the alignment system is concerned can be formed by forming the opaque layer with the desired openings for the marks over the contiguous cathodoluminescent layer instead of under the cathodoluminescent layer. The opaque layer in this embodiment may either reduce the electron radiation reaching the cathodoluminescent layer or reduce the cathodoluminescent radiation projected by the cathodoluminescent layer to a detector means positioned above the major surface. Alternatively, the opaque layer may be in the predetermined shape above or below the cathodoluminescent layer to reduce the electron radiation reaching the cathodoluminescent layer or the cathodoluminescent radiation projected by the cathodoluminescent layer. It should also be observed that "opaque" does not mean that the layer totally absorbs or reflects the cathodoluminescent or electron radiation. The "opaque" layer need only absorb or reflect sufficient light or electron radiation to provide a discernible differential in cathodoluminescence produced. The opaque layer may even itself be cathodoluminescent provided it generates radiation which is discernibly different from the cathodoluminescent radiation projected by the cathodoluminescent marks.

Irrespective of the embodiment, the substrate 30 in this form, with layers 33 and 37 in place, can be used for the substrate directly in the making of an integrated circuit or other micro-miniature electronic components as hereinafter described. Preferably, however, the substrate is further processed to form a photocathode source by forming opaque layer 38 over layer 37. Opaque layer 38 is either absorptive or reflective to ultraviolet or other radiation to which the desired photocathode material is sensitive. Preferably opaque layer 38 is made of the same material and deposited in the same manner as opaque layer 18 above described.

Over opaque layer 38 is then applied electroresist layer 39. The desired component pattern or the negative thereof, depending on whether the resist is positive or negative, is thereafter implanted in the electroresist layer as a pattern in differential solubility by irradiating the layer with electron radiation. Preferably a scanning electron beam or the electron image projection system as above described and referenced is used to provide the electron radiation. The selectively irradiated electroresist is then developed with a suitable solvent, depending on the resist composition, to form window pattern 40 in layer 39 corresponding to the positive of the desired component pattern. Thereafter, the desired electronic component pattern is transferred to opaque layer 38 by selectively etching or ion milling window pattern 41 in layers 33, 37 and 38 through window pattern 40 to expose portions of surface 31. A suitable etchant for this purpose is dilute hydrofluoric acid.

Referring to FIG. 10, remaining portions of electroresist layer 39 are then removed with a suitable solvent such as trichloroethylene and a contiguous layer 42 of photocathode material is deposited over exposed portions of layers 38 and surface 31 to finish the photocathode source. Preferably the same photocathode ma-

terial deposition techniques are used for photocathode layer 42 as above described for photocathode layer 22. It should be noted that the finished photocathode source provides a positive projection. That is, the electron beam pattern generated by the source is the positive of the desired electronic component. The source is thus designed for use in the electron image projection system with positive electroresists.

Referring to FIGS. 11, 12 and 13, a method is shown for producing a highly accurate pattern in an electroresist on a substrate by aligning an adaptable beam relative to a member. A scanning electron microscope adaptable to the present invention is shown in above-cited U.S. Pat. No. 3,679,497, assigned to the same assignee as the present invention.

The member used is preferably a substrate prepared as shown in FIGS. 3, 4 or 5, or alternatively as shown in FIG. 9 without layers 38 and 39 applied. For convenience of explanation a member is prepared as shown and described in FIGS. 3, 4 or 5 is shown in FIG. 11 in use with a scanning electron beam. Alternatively the member may be a semiconductor wafer or a suitable insulator or semiconductor substrate with an epitaxially grown layer thereon.

Referring specifically to FIG. 11, substrate 10 is provided as above described with a closely spaced regular array of cathodoluminescent marks 17 of predetermined shape formed adjacent major surface 11. A layer 50 of a desired material such as a metal, an insulator or a semiconductor material in which a component pattern is desired is formed over exposed portions of surface 11 and marks 17 by sputtering, vapor deposition, epitaxial growth or any other suitable technique. Thereafter a contiguous electroresist layer 51 is overlaid on layer 50 over major surface 11 and marks 17. A series of photodetector means 53 are positioned in holder 57 adjacent the opposite surface 12 of the member to circumscribe the cathodoluminescent marks 17. That is, each photodetector 53 is positioned adjacent a mark 17 to detect cathodoluminescence generated by irradiation of said mark 17. This arrangement of course supposes that the member is substantially transparent to the cathodoluminescent emissions; if the member is not able to transmit the cathodoluminescence, the photodetectors may be positioned on the same side of the member as the electron beam and close to the marks as physically possible to avoid loss of resolution by radiation scattering.

Referring specifically to FIGS. 12 and 13, this arrangement can be used to align the scanning electron beam with the major surface 11 of the member 10 field by contiguous field for selective irradiation of precisely selected areas of the major surface of the substrate. As shown in FIG. 12, the member 10 is divided into contiguous fields preferably bounded symmetrically in quadrature by the marks 17, e.g. one at the intersection of each field, or one at the center along each side of each field. To align the beam 52 with, for example, field 54, the scanning electron beam 52 is modulated to overlap two opposite marks, for example marks 17₁ and 17₂ sequentially. The output signals from the detectors 53, positioned adjacent marks 17₁ and 17₂, respectively, are fed to a cathode-ray tube 55 which also has the intended locations of the marks for precise alignment inputted from the computer 56 controlling the scanning electron beam 52. The scanning beam 52 is thus moved relative to the member 10 until the signals from the two

detectors 53₁ and 53₂ indicate optimum alignment of beam and marks and also alignment of the superimposed input of the intended locations of the marks 17₁ and 17₂. The electron beam 52 is then modulated to overlap the other two opposite marks 17₃ and 17₄ sequentially until the outputs therefrom coincide on the CRT 55 with optimum alignment of the beam and marks and also alignment of the superimposed theoretical input for marks 17₃ and 17₄ from the computer 56. The electron beam 52 is then aligned and ready to selectively irradiate the field on command from the computer 56. At the end of the irradiation of the field 54, the member 10 is physically moved so that the scan field of the electron beam is concurrent with the next field 54' on the member 10 to be selectively irradiated. The aligning sequence is then repeated as described above. At each field 54, alignment is made by manually or automatically actuating means to move member 10 relative to beam 52 as described in above-cited U.S. Pat. No. 3,679,497, or to move beam 52 relative to member 10 by deflecting the electron beam electromagnetically. The alignment is accomplished by moving the beam or member relative to the other until the light radiation emissions detected by photodetector 53 indicates a predetermined alignment value for said radiation emissions.

It should be noted that said predetermined alignment value will vary with the relative relation of the predetermined shape of the cathodoluminescent marks 17 and the predetermined cross-sectional shape of the electron beam 52. Where the predetermined shapes are the same, it is simply a matter of reading the indication of maximum or minimum cathodoluminescence. Where the predetermined cross-sectional shape of the electron beam 52 is different from the predetermined shapes of the corresponding marks 17, the reading to determine alignment is somewhat different. Optimum alignment is no longer indicated by the maximum or minimum in the signal readings for cathodoluminescence. Rather, plateaus are reached in the signal readings, and optimum alignment is achieved by either selecting a certain point on each plateau taking into consideration any change in the geometric shapes of the electron beam and the marks, or selecting a certain point on the signal rise from the means as the electron beam moves into or out of the area of the corresponding mark. The latter alignment sequence permits alignment with the edge of the mark.

The alignment system shown in FIG. 13 is what one skilled in the art would connote a manual system because an operator makes the adjustments to align in accord with the read-out on the CRT. This is not a preferred system because of the relatively long length of time required to complete the alignment sequence. Thus, it is that the alignment sequence is preferably adapted to an automatic alignment system with electrical signal processing apparatus such as that hereinafter described.

After alignment, the electron beam 52 is moved at each field 54 through a predetermined matrix corresponding to a desired component pattern to be formed in or through layer 50, or the negative thereof. Whether beam 52 irradiates the positive or the negative of the desired component pattern is dependent on the type of electroresist used. If a positive resist is used, i.e. where the irradiation makes the resist layer more soluble in a given solvent, then the positive of the desired

electronic component pattern to be formed in layer 50 is irradiated in layer 51. Conversely, if a negative resist is used, i.e. where irradiation makes the resist less soluble to a given solvent, then the negative of the desired component pattern to be formed in layer 50 is irradiated in layer 51.

In either instance, the accuracy of the system is primarily based on the size of fields 54 in which layer 51 is irradiated and the sizing and spacing of the marks 17. For example, if the integrated circuit to be formed on the member is 0.080 inch $\times$ 0.080 inch and an accuracy of less than 1 micron is desired, the electron scan must be performed in four fields of 0.040 inch $\times$ 0.040 inch in size. Or, if an accuracy of less than 0.20 micron is desired, the same member is preferably scanned in 400 fields of 200 $\times$ 200 microns.

The marks 17 may be dimensioned so that the detection is totally qualitative. That is, the marks are sized, e.g. 0.5 $\times$ 0.5 microns or less (spaced, e.g. 200 $\pm$ 0.2 microns apart) so that whenever any light is detected by photodetector 53 the position of electron beam 52 relative to member 10 is known within a tolerance of 0.2 micron. Alternatively, marks 17 may be larger and the light emissions measured quantitatively so that the position of electron beam 52 relative to substrate 10 is accurately known. In any event, the marks 17 are of predetermined shapes preferably the same as the cross-sectional shape of the electron beam. The resolution errors rising from electron beam deflections and distortions are reduced to the desired accuracy with the alignment system. Scanning electron beam 52 can thus be aligned with a member with greater accuracy than in prior alignment systems, see above-cited U.S. Pat. No. 3,679,497.

Referring specifically to FIGS. 14, 15 and 16, the present invention is used to produce a highly accurate pattern in an electroresist layer on a member in an electron image projection system. The photocathode source 43 is as shown in FIG. 10 and described in connection therewith, except that the cathodoluminescent layer is localized and two cathodoluminescent marks 61 and 61' of predetermined shapes are provided diametrically opposite each other on the periphery of member 60. The patterned electron beam produced by the photocathode source including a set of alignment beam portions of predetermined cross-sectional shapes and corresponding substantially in spacing to cathodoluminescent marks 61 and 61' positioned on member 60. In this connection, it should be noted that marks 61 and 61' are in reality openings in layer 62 which are opaque to light emissions from contiguous localized layer 63 of cathodoluminescent material overlaying and adjoining layer 62. Thus, the pattern of light emissions from the cathodoluminescent layer 63 corresponds to the openings in opaque layer 62 and provide the equivalent of a closely regular array of cathodoluminescent marks as described above.

Member 60 with layers 62 and 63 in place is prepared for the electron image projection system by applying or epitaxially growing a layer 64 of suitable material such as a metal or semiconductor material in which or through which a portion of the integrated circuit is to be formed in or to major surface 65 of member 60. Thereafter, electroresist layer 66 in which the desired highly accurate component pattern is to be formed is applied over layer 64.

And with electroresist layer 66 applied, member 60 is inserted into the electron image projection system as shown and described in FIGS. 14, 15 and 16 and more fully described in above-cited U.S. Pat. No. 3,679,497 in substantially parallel relationship with photocathode source 43 also positioned in the system.

Referring to FIG. 14, an electron image projection device is shown. A hermetically sealed chamber 70 of nonmagnetic material has removable end caps 71 and 72 to allow for disposition of apparatus into and removal of apparatus from the chamber. A vacuum port 73 is also provided in the sidewall of chamber 70 to enable a partial vacuum to be established in the chamber after it is hermetically sealed.

Disposed within chamber 70 is cylindrical photocathode source or electromask 74 alignable with selected areas of the major surface of member 60 in substantially parallel, spaced relation. Member 60 is supported in specimen holder 75 as more fully described hereinafter. Photocathode 74 and holder 75 are in turn positioned in parallel array by annular disk-shaped supports 76 and 77, respectively. Photocathode source 74 and holder 75 are spaced apart with precision by tubular spacer 78 which engages grooved flanged 79 and 80 via gaskets 81 and 82 around the periphery of supports 76 and 77. The entire assembly is supported from end cap 71 of chamber 70 at support 76 to allow for ease of disposition of the photocathode source and the member within the chamber.

Photocathode 74 is made cathodic and member 60 is made anodic to direct and accelerate electrons projected from the photocathode to the member 60. To accomplish this, holder 75 and supports 76 and 77 are of highly conductive material and spacer 78 is of highly insulating material. A potential source 78A of, for example, -10Kv, is applied between supports 76 and 77. The difference in potential is conducted to and impressed on photocathode 74 and member 60 via supports 76 and 77 and holder 75.

Surrounding chamber 70 are three series of electromagnetic coils, positioned perpendicular to each other, to direct and focus the impingement of the electron beam onto member 60. Cylindrical electromagnetic coils 83₁, 83₂ and 83₃ are positioned axially along the path of the electron beam from photocathode 74 to member 60 to cause electrons to spiral and move radially as they travel the distance from the photocathode to the member. These coils permit control of the rotation (θ) and the magnification (M) of a patterned electron beam emitted from the photocathode source and in turn focusing of the patterned electron beam. Rectangular electromagnetic coils 84₁ and 84₂, and 85₁ and 85₂ are symmetrically positioned in Helmholtz pairs perpendicular to each other, and to coils 83₁-83₃, to cause electrons to transversely deflect as they travel the distance from the photocathode to the member. These electromagnets permit control of the direction (in X and Y coordinates) of a patterned electron beam emitted from the photocathode.

In operation, light source 86 such as a mercury vapor lamp backed by reflector 87 irradiates a photocathode layer 88 (e.g. gold or palladium) in the photocathode source or electromask 74. The photocathode layer is irradiated through a substantially transparent substrate 89 such as quartz overlaid with a layer 90 containing the negative of a desired component pattern. The layer 90 is of material (e.g. titanium dioxide) which is

opaque to the light radiation. The photocathode material is thus made electron emissive in a patterned electron beam corresponding to the desired component pattern to be formed in layer 64 or the negative thereof depending on whether the electroresist is positive or negative. A part of the patterned electron beam emitted from the photocathode source 74 is at least one and preferably two relatively small alignment beam portions 91 and 92 of predetermined cross-sectional shape (e.g. squares of 300 × 300 microns) which are spaced away preferably oppositely positioned along the periphery of the patterned beam from the photocathode.

Referring to FIG. 15, member 60 is precision mounted within physically permissible limits in holder 75 and in turn with respect to photocathode 74. Member 60 has a flat peripheral portion 93; and holder 75 has depression 94 into which substrate 60 fits. Holder 75 has pins 95, 96, 97 and 98 positioned in respective quadrants around the periphery of depression 94. Member 60 is positioned by resting flat peripheral portion 93 of member 60 against pins 95 and 96 and curvilinear peripheral portion 99 of member 60 against pin 97. The member is thereby located with an accuracy of about 25 microns or less. Movable pin 98, which is fitted with a compression spring 100, is positioned and pushed against the curvilinear portion of member 60 to firmly retain member 60 and in turn, maintain member 60 precisely located.

As shown by FIG. 14, cathodoluminescent marks 61 and 61' of predetermined shapes are formed on member 60 as above described. Preferably marks 61 and 61' are widely spaced apart along the periphery of the member, and preferably have predetermined shapes the same as the predetermined shape of alignment beam portions 91 and 92 (see FIG. 16), which form a part of the patterned electron beam emitted by the irradiated photocathode source 74. Marks 61 and 61' of predetermined shapes can be reasonably precisely formed by selectively etching or ion milling the member through window patterns of the desired cross-section in a photo- or electroresist layer (as above described in connection with FIGS. 8 through 10). The predetermined shapes of the alignment beam portions and marks are thus preferably about 10 × 10 mils in any suitable geometric shape, such as a square, rectangle or circle.

Positioned behind marks 61 and 61' of predetermined shapes in holder 75 are photodetector means 101 and 102, respectively, with leads 103 and 104 and 103A and 104A, respectively, extending through vacuum seals in chamber 70 at 105. Photodetectors 101 and 102 are adapted for detecting the cathodoluminescent radiation produced by the marks 61 and 61', which is usually light radiation, through member 60, and are substantially larger in size than and circumscribe marks 61 and 61' so that they can detect even dispersed and scattered cathodoluminescent radiation from member 60 close to or in the vicinity of the marks. For this reason, detector means 101 and 102 are also positioned in as close a proximity to member 60 as the geometry will permit. In this connection, it should be noted that in some embodiments, e.g. where member 60 is not transmissive of the cathodoluminescent radiation, it may be appropriate to position the detector means 101 and 102 on the same side of member 60 as the photocathode source so that cathodoluminescent radiation is detected. However, it is preferred that the

detector means are positioned in as close a proximity to marks 61 and 61' as the conditions will permit so that resolution of the light radiation and in turn accuracy of alignment is not lost between the cathodoluminescent marks and the detector means. It is preferred therefore that the detector means be positioned opposite member 60 from the photocathode source where possible so that resolution and accuracy are not lost.

In operation, the alignment beam portions 91 and 92 of predetermined cross-sectional shapes impinge on and overlap the marks 61 and 61' of predetermined shapes, respectively. The electron beams typically produce a cathodoluminescent radiation which corresponds to the degree of overlap between the alignment beam portions and the marks. Alignment can be accurately recorded therefore simply by observing the signals at detector means 101 and 102. The alignment beam portions and cathodoluminescent marks can thus be brought into precise alignment simply by detecting as the predetermined alignment value where the detected cathodoluminescence indicates the optimum alignment of the alignment beam portions with the marks.

The present invention thus provides a method of alignment of the patterned electron beam generated by the photocathode source 74 with precisely located areas of a major surface of the member 60. Further, the member may be similarly aligned with successive photocathode sources or electromasks by use of the same cathodoluminescent marks and like alignment beam portions on the successive photocathodes so that all of the patterned electron beams will selectively impinge on the member with the desired precision exactness, e.g. within a fraction of a micron. Error is reduced to the precision with which the marks and the photocathode sources emitting the corresponding alignment beam portion can be shaped and spatially located, which presents no difficulty with the scanning electron microscope and electron image projection system.

The electric current flow from the detector means 101 and 102 may be processed through suitable electronic amplifiers and servomechanisms to automatically shift the entire patterned electron beam relative to the member and precisely position the alignment beam portions 91 and 92 with the marks 61 and 61', respectively. For this purpose, suitable means such as a modulation means is preferably used to oscillate the electrical input to the electromagnetic means or coils and thereby cause the alignment beam portions 91 and 92 to oscillate or move in typically a circle over the marks 61 and 61' so that the electrical outputs from detectors 101 and 102 are modulated.

Referring to FIG. 17, there is illustrated in a block diagram the electronics for adjusting the alignment beam portions 91 and 92 with respect to the marks 61 and 61' of the same predetermined shapes and in turn precisely aligning selected areas of the major surface of member 60 with respect to the entire electron beam pattern from photocathode source 74. The modulated electrical signal from detector 101 is conveyed via lead 104 to a preamplifier 106, which amplified signal is then conveyed via lead 107 to a tuned amplifier 108. The output of amplifier 108 passes through lead 109 to a phase adjustor 110 and then through lead 111 to a dual phase detector 112. A gated oscillator 113 impresses reference signals, which are 90° out-of-phase,

through conductors 114 and 115 and conductors 116 and 117, respectively, on the dual phase detector 112. The outputs of phase detector 112 thus comprise X-error signals via lead 118 and Y-error signals via lead 119, which pass through gate 120 via leads 121 and 122 to integrators 123 and 124, respectively. The integrators 123 and 124 have direct-current outputs to adders 125 and 126, respectively, where the outputs are modulated with alternating current from the oscillator 113 via leads 127 and 128, respectively. The added modulated signals are then passed to and adjacent the controls in power units (not shown) of the type customarily used to power the electromagnetic coils, in this case the electromagnetic coils 84₁, 84₂, 85₁ and 85₂ in Helmholtz pairs.

Similarly, the modulated signal from the detector 102 is conducted via lead 104A to preamplifier 129, and passed thereafter via lead 130 to the tuned amplifier 131 and then via lead 132 through phase adjustor 133 and lead 134 to dual phase detector 135. Oscillator 113 suppresses the two 90° out-of-phase reference signals, above referred to, through leads 136 and 137 on dual phase detector 135. Two outputs from dual phase detector 135 are thus produced. The one output signal via conductor 138, which corresponds to a θ error signal, passes through gate 140 and lead 141 to control a motor-driven precision potentiometer 142 to effect the rotational control of the electron beam pattern by increasing or decreasing the current to the electromagnetic coils 83₁, 83₂ and 83₃. The other output signal via lead 139, gate 140 and lead 143 to a motor driven gang potentiometer 144 which adjusts the main focus field controls the size of the patterned electron beam.

The error signals in conductors 118, 119, 138 and 139 are cross-fed electronically via leads 145, 146, 147 and 148, respectively, into a four input delayed null detector 149 whose output is conveyed by lead 150 to a set-reset flip-flop 151. The operation of the flip-flop is initiated by actuation of a start sequence switch, whereupon current begins to flow via leads 152 and 153 to energize the ultraviolet source 86 to cause electron beams to be emitted from photocathode source 74, including the two alignment beam portions 91 and 92 of predetermined cross-sectional shapes. Likewise, current from 152 passes through lead 154 to the gated oscillator 113, which in turn feeds sinusoidal signals in quadrature through lines 114-127 and 116-128 to the X and Y controls 125 and 126, respectively. The entire electron beam pattern, including the alignment portions 91 and 92, are thus caused to oscillate typically in a circle of, for example, 6 microns diameter at a frequency of 45 Hertz.

Once the alignment portions 91 and 92 are substantially aligned with marks 61 and 61', respectively, by operation of integrators 123 and 124, and potentiometers 142 and 144, the error signals passing through leads 145, 146, 147 and 148 reach a zero value which is detected by the null detector 149. The null detector thereupon produces an electrical signal which passes through lead 150 to the flip-flop 151, which terminates the operation of the gated oscillator 113 and closes gates 120 and 139 by signals through leads 155 and 156, respectively. The time sequence of the selective electron beam exposure of an electroresist layer on the full area of member 60 is then begun and continued until the resist is fully exposed.

The detection and alignment is accomplished in a time substantially less than the time period required to significantly irradiate the electroresist layer 66. A period of from 3 to 10 seconds is usually adequate to produce a sufficient electron beam treatment of the electroresist to cause it to be properly differentially soluble in selected solvents. In turn, the desired electronic component pattern of the electromask 43 is transferred to electroresist layer 66 without alignment distortions. Further, it should be noted that if the cathodoluminescent marks 61 are closely and regularly spaced the alignment can be accomplished with simply translational, i.e., *x* and *y*, corrections, without the need for rotational correction of previous alignment systems, see U.S. Pat. No. 3,710,101 and U.S. Pat. Application Ser. No. 264,699, filed June 20, 1972 and assigned to the same assignee as the present application.

Further, it should be noted that the alignment can be made by manually or automatically controlled by the physical movement of the member 60 and/or electromagnetic deflection of the electron beam pattern, see above-cited U.S. Pat. Nos. 3,679,497 and 3,710,101. In any case, the correction is continued until the light emissions from marks 61 detected at photodetector means 101 and 102 indicate a predetermined alignment value for said radiation emissions.

While the present invention is particularly suited and has been specifically described to align a scanning electron beam or an electron image projection system with a member in the accurate transfer of a desired electronic component pattern to an electroresist layer supported by a member, it is distinctly understood that the invention may be otherwise variously embodied and used within the scope of the following claims. For example, the invention may be used in the procedure for precision etching of selected areas of metal sheets to obtain desired shapes and patterns for various scientific and industrial applications.

What is claimed is:

1. A method of precision aligning an electron beam with selected areas of a major surface of a substrate member for electronic components comprising the steps of:

- A. forming adjacent a major surface of a member a plurality of marks of predetermined shape capable of generating cathodoluminescent radiation on irradiation by an electron beam corresponding to the area of the mark irradiated;
- B. irradiating at least one of the marks with a corresponding alignment beam portion of an electron beam to be aligned, said alignment beam portion having a predetermined cross-sectional shape;
- C. detecting cathodoluminescent radiation emissions from said irradiated mark;
- D. moving the electron beam relative to the member until the cathodoluminescent radiation emissions detected in accord with step C indicate alignment of the alignment beam portion with the corresponding mark.

2. A method of precision aligning an electron beam with selected areas of a major surface of a member as set forth in claim 1 wherein:

the predetermined cross-sectional shape of the alignment beam portion of the electron beam corresponds in size to the accuracy of alignment desired.

3. A method of precision aligning an electron beam with selected areas of a major surface of a member as set forth in claim 2 wherein:

the predetermined shape of the marks correspond in size to the accuracy of alignment desired.

4. A method of precision aligning an electron beam with selected areas of a major surface of a member as set forth in claim 1 wherein:

the predetermined shape of each mark is substantially the same as the predetermined cross-sectional shape of the corresponding alignment beam portion.

5. A method of precision aligning an electron beam with selected areas of a major surface of a member as set forth in claim 1 wherein:

forming the marks includes recessing the marks into the major surface to provide a substantially planar major surface with the marks position.

6. A method of precision aligning an electron beam with selected areas of a major surface of a member as set forth in claim 1 wherein:

forming each mark includes positioning an opaque layer adjacent a layer of cathodoluminescent material to circumscribe a portion of said layer in the predetermined shape and cause a differential in cathodoluminescent radiation projected by said layer at said portion on irradiation.

7. A method of precision aligning an electron beam with selected areas of a major surface of a member as set forth in claim 1 wherein:

the major surface of the member is divided into contiguous fields with the marks positioned symmetrically along boundaries between said contiguous fields.

8. A method of precision aligning an electron beam with selected areas of a major surface of a member as set forth in claim 7 wherein:

the electron beam to be aligned is a scanning electron beam for selectively irradiating an electroresist layer on the major surface of the member.

9. A method of precision aligning a patterned electron beam generated by a photocathode source with selected areas of a major surface of a substrate member for electronic components comprising the steps of:

A. forming adjacent a major surface of a member having at least two widely spaced marks of predetermined shape capable of generating cathodoluminescent radiation or irradiation by an electron beam corresponding to the area of the mark irradiated;

B. irradiating the marks with corresponding alignment beam portions of a patterned electron beam generated by a photocathode source, each said alignment beam portion having a predetermined cross-sectional shape;

C. detecting cathodoluminescent radiation emissions from said irradiated mark; and

D. moving the patterned electron beam relative to the member until the cathodoluminescent radiation emissions detected in accord with step C indicate alignment of the alignment beam portions with the corresponding marks.

10. A method of precision aligning a patterned electron beam generated by a photocathode source with selected areas of a major surface of a member as set forth in claim 9 wherein:

the predetermined cross-sectional shape of the alignment beam portions of the electron beam correspond in size to the accuracy of alignment desired.

11. A method of precision aligning a patterned electron beam generated by a photocathode source with selected areas of a major surface of a member as set forth in claim 10 wherein:

the predetermined shape of the marks correspond in size to the accuracy of alignment desired.

12. A method of precision aligning a patterned electron beam generated by a photocathode source with selected areas of a major surface of a member as set forth in claim 9 wherein:

the predetermined shape of each mark is substantially the same as predetermined cross-sectional shape of the corresponding alignment beam portion.

13. A method of precision aligning a patterned electron beam generated by a photocathode source with selected areas of a major surface of a member as set forth in claim 9 wherein:

forming the marks includes recessing the marks into the major surface to provide a substantially planar major surface with the marks positioned.

14. A method of precision aligning a patterned electron beam generated by a photocathode source with selected areas of a major surface of a member as set forth in claim 9 wherein:

forming each mark includes positioning an opaque layer adjacent a layer of cathodoluminescent material to circumscribe a portion of said layer in the predetermined shape and cause a differential in cathodoluminescent radiation projected by said layer at said portion on irradiation.

15. A method of precision aligning a patterned electron beam generated by a photocathode source with selected areas of a major surface of a member as set forth in claim 9 wherein:

step D is automatically performed by electrically processing the electrical signal output corresponding to the detected cathodoluminescent radiation on modulation of the movement of the alignment beam portions over the corresponding marks.

16. Apparatus for selectively irradiating precisely located areas of a major surface of a substrate member for electronic components comprising:

A. a photocathode source for generating a patterned beam of electrons including at least one alignment beam portion of predetermined cross-sectional shape;

B. at least one mark corresponding to each alignment beam portion and capable of generating cathodoluminescent radiation on irradiation with an electron beam corresponding to the area of the mark irradiated with the electron beam, each said mark being

supported adjacent a major surface of a member to be aligned with the patterned beam of electrons and having a predetermined shape;

C. means for positioning the member in a spaced relation to the photocathode source for the patterned beam;

D. means for applying a potential between the member and the photocathode source whereby electrons from the photocathode source are directed to and selectively irradiate selected areas of the major surface of the member;

E. electromagnetic means for directing the patterned beam of electrons from the photocathode source to irradiate selected portions of the major surface of the member close to the selected areas wherein each alignment beam portion irradiates selected portions of the surface portions of the major surface of the member close to a corresponding mark;

F. detector means for detecting the cathodoluminescent radiation projected by the corresponding mark and producing an electrical signal corresponding to the area thereof irradiated by the alignment beam portion; and

G. electrical means for moving the patterned beam of electrons relative to the member responsive to said electrical signal from the detector means to cause the alignment beam portions to align with corresponding marks, whereby the patterned beam of electrons from the photocathode source is located relative to the member so that precisely located areas of the major surface of the member can be selectively irradiated with the patterned electron beam.

17. Apparatus for selectively irradiating precisely located areas of a major surface of a member as set forth in claim 16 wherein:

the patterned beam of electrons generated by the photocathode source includes at least two spaced apart alignment beam portions of predetermined cross-sectional shape.

18. Apparatus for selectively irradiating precisely located areas of a major surface of a substrate as set forth in claim 17 wherein:

the electrical means includes modulation means for oscillating the movement of each alignment beam portion on a corresponding mark, phase detection means for detecting along orthogonal axes the error from coincidence of the alignment beam portions and the marks and outputting the electrical signal corresponding thereto, and actuating means for changing the electrical input to the electromagnetic means responsive to the electrical signal from the phase detector means to bring the alignment beam portions and the marks into alignment.

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