United States Patent [19]

O'Keeffe et al.

[11] **3,840,749**

[45] **Oct. 8, 1974**

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

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

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

[21] Appl. No.: **402,250**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 371,447, June 19, 1973, abandoned.

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

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

[58] **Field of Search** .... 250/396, 397, 398, 400, 250/458, 459, 491, 492, 492 A; 219/121 EB, 121 EM; 315/10, 31 R

[56] **References Cited**

UNITED STATES PATENTS

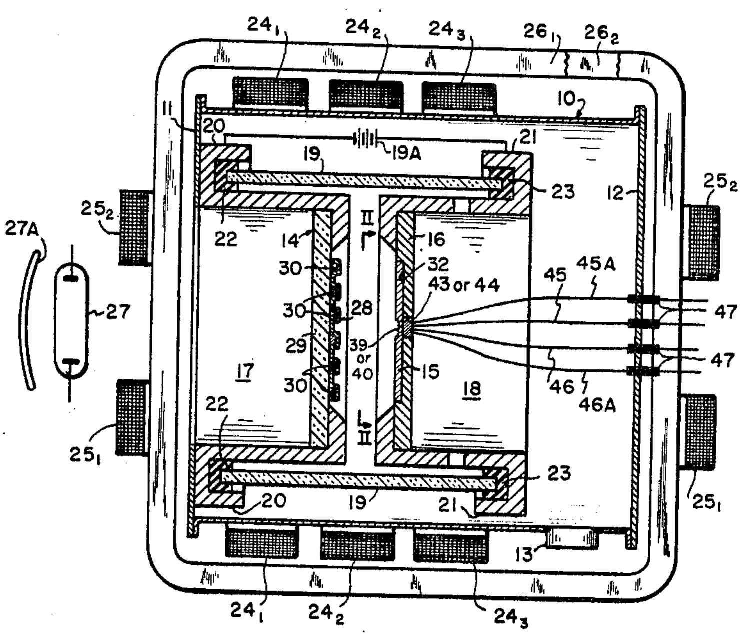
3,308,264	3/1967	Ullery, Jr.	219/121
3,679,497	7/1972	Handy et al.	250/492
3,710,101	1/1973	O'Keeffe et al.	250/492
3,745,358	7/1973	Firtz et al.	250/492

Primary Examiner—William F. Lindquist
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 semiconductor member. The semiconductor member generates cathodoluminecence of intensity corresponding to the thickness thereof. The semiconductor member has formed adjacent a major surface at least one and preferably at least two widely spaced detector marks of predetermined shape capable of providing a differential in cathodoluminescence generated by the member corresponding to the area of the mark irradiated by an electron beam. To align, an electron beam to be aligned has alignment beam portions corresponding to at least one detector mark and of predetermined cross-sectional shapes. The alignment beam portions are projected onto the major surface of the semiconductor member in the vicinity of the corresponding detector marks. And the cathodoluminescence generated by the member at least in the vicinity of the member is detected by detecting means. The electron beam is moved relative to the semiconductor member while continuing said detection until the detected cathodoluminescence indicates optimum alignment of each alignment portion thereof with a corresponding detector mark. Preferably, said alignment method is used in producing a very accurate component pattern in electroresist layer on the major surface of the semiconductor member with either a scanning electron beam or a patterned electron beam generated by a photocathode source.

18 Claims, 12 Drawing Figures



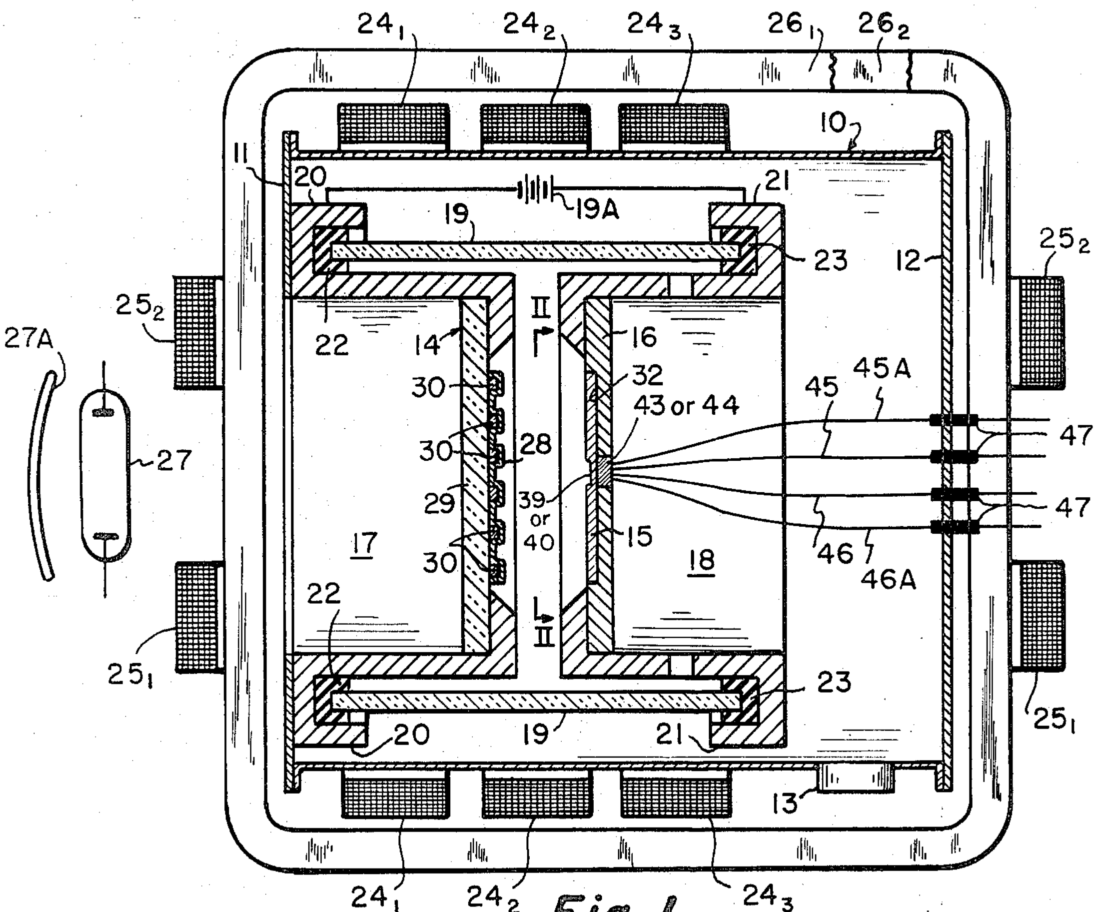


Fig. 1

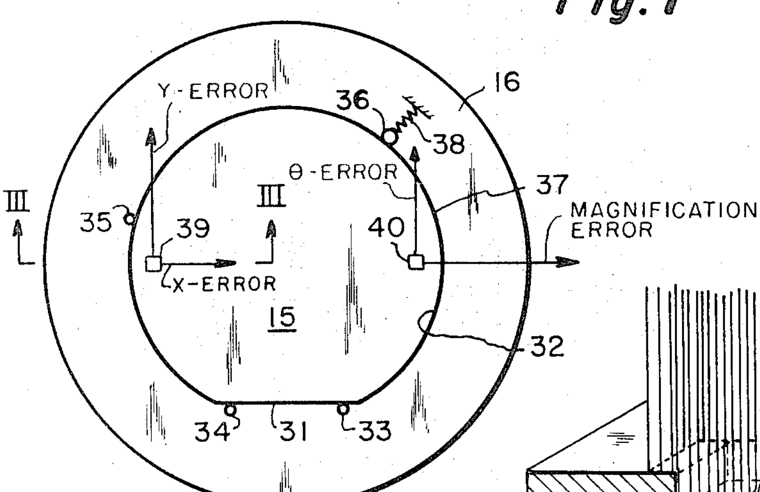


Fig. 2

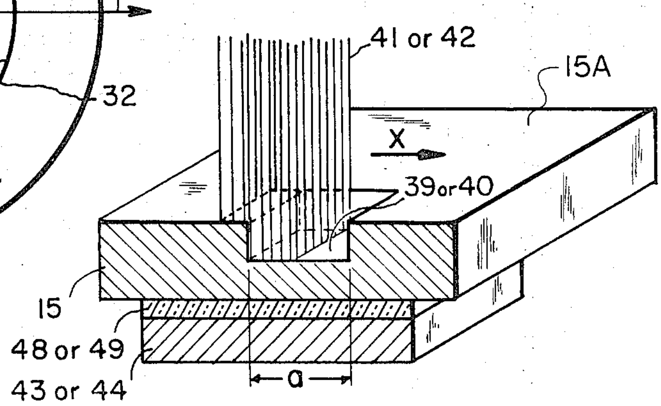


Fig. 3

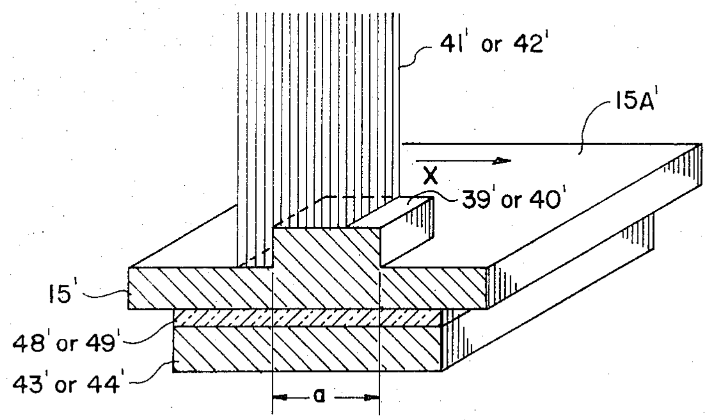


Fig. 4

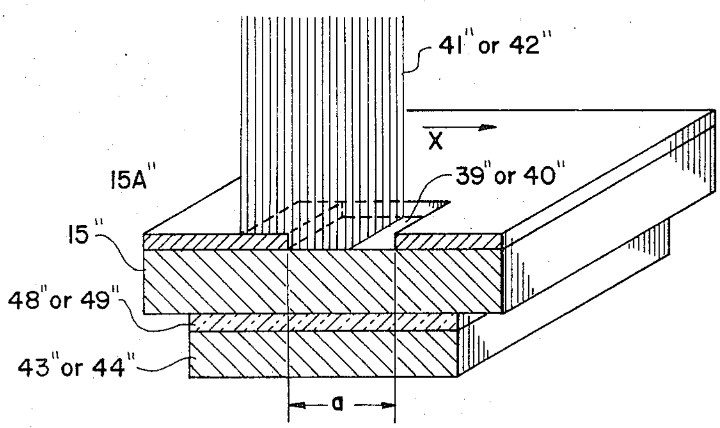


Fig. 5

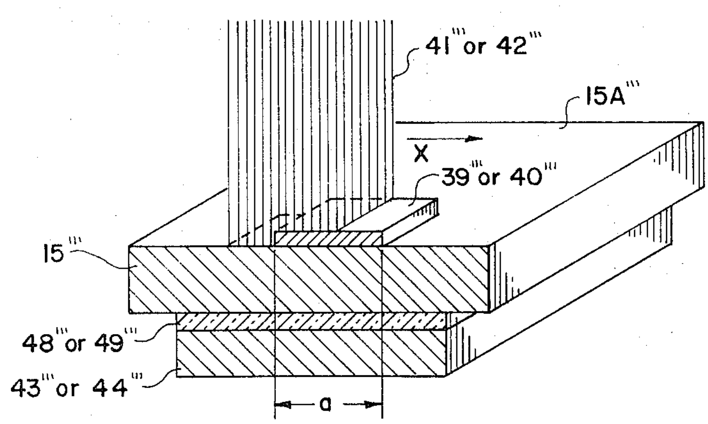


Fig. 6

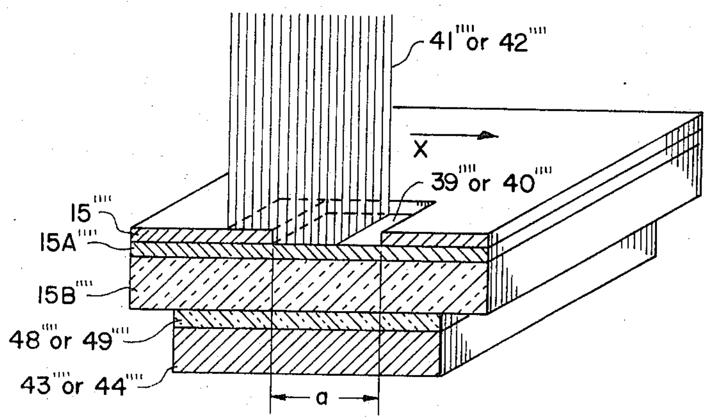

41'''' or 42''''
X
39'''' or 40''''
15''''
15A''''
15B''''
48'''' or 49''''
43'''' or 44''''
a

Fig. 7

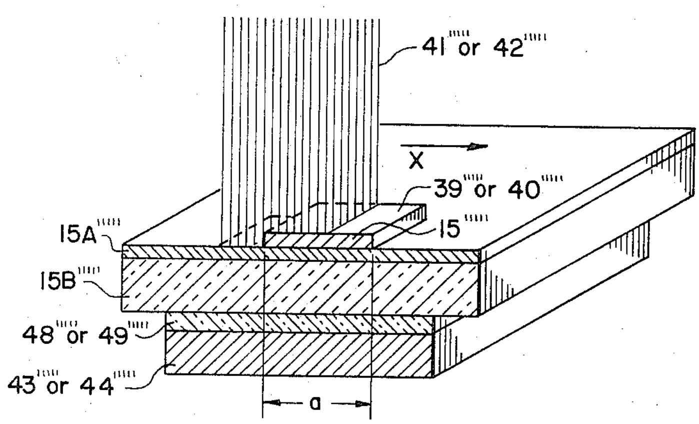

41''''' or 42'''''
X
39''''' or 40'''''
15'''''
15A'''''
15B'''''
48''''' or 49'''''
43''''' or 44'''''
a

Fig. 8

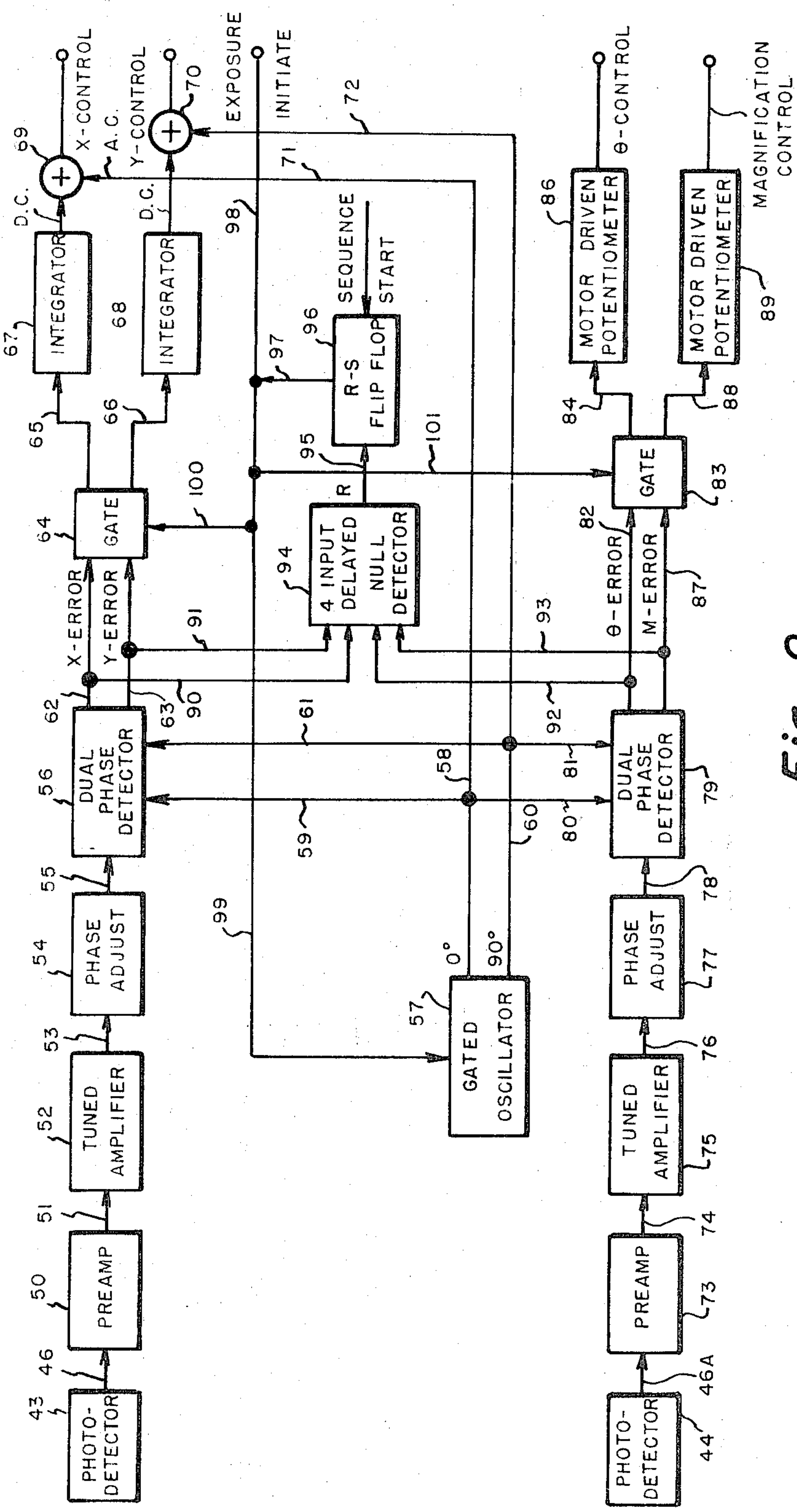


PHOTO-DETECTOR
PREAMP
TUNED AMPLIFIER
PHASE ADJUST
DUAL PHASE DETECTOR
X-ERROR
Y-ERROR
GATE
INTEGRATOR
D.C.
A.C.
X-CONTROL
Y-CONTROL
EXPOSURE
INITIATE
SEQUENCE START
R-S FLIP FLOP
R
4 INPUT DELAYED NULL DETECTOR
GATED OSCILLATOR
0°
90°
θ-ERROR
M-ERROR
MOTOR DRIVEN POTENTIOMETER
θ-CONTROL
MAGNIFICATION CONTROL

Fig. 9

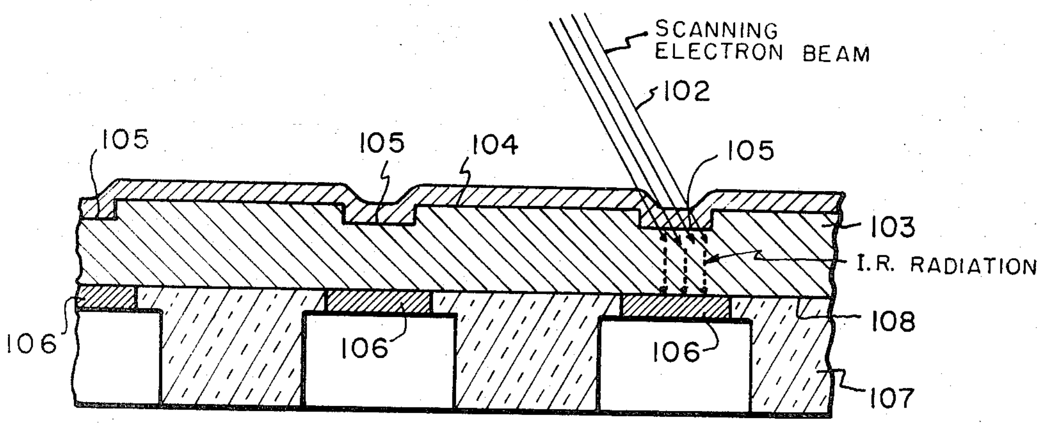


Fig. 10

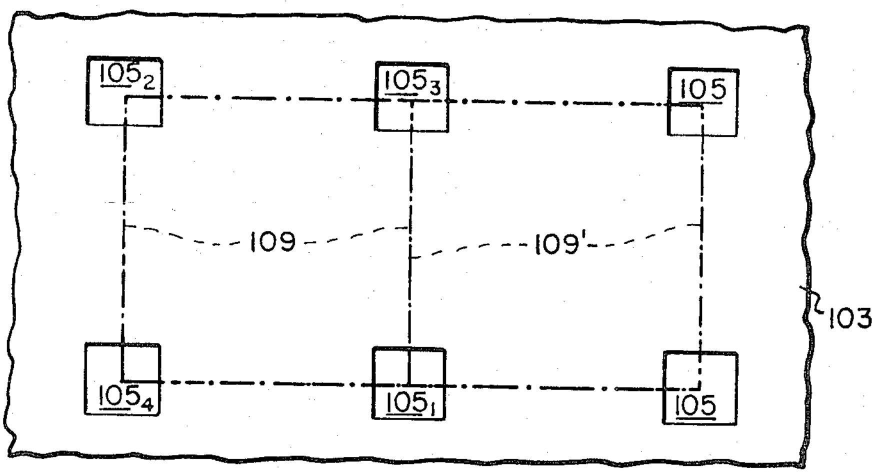


Fig. 11

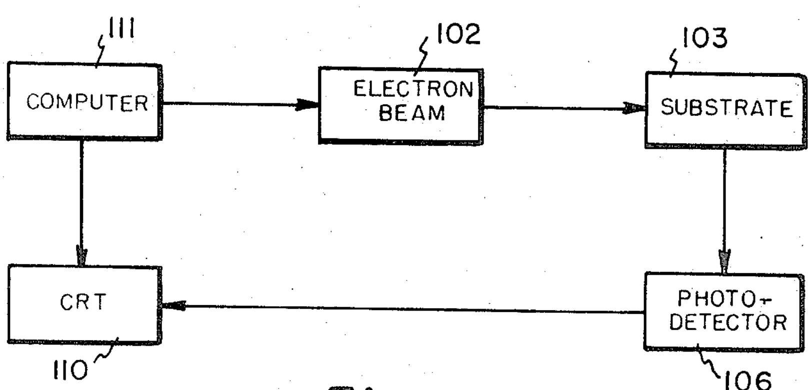


Fig. 12

METHOD AND APPARATUS FOR ELECTRON BEAM ALIGNMENT WITH A SEMICONDUCTOR MEMBER

RELATED APPLICATION

The present application is a continuation-in-part of copending application Ser. No. 371,447, filed June 19, 1973, now abandoned.

GOVERNMENT CONTRACT

This invention is made in the course of or under Government Contract F 33615-67-C-1335.

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 improved on the electron beam fabrication system and the alignment system therefor described in U.S. Pat. Nos. 3,679,497 3,710,101, granted July 25, 1972 and Jan. 9, 1973, respectively, both of which are assigned to the assignee of the present application. In the fabrication system, a planar photocathode source (called an "electromask") produces a patterned beam of electron radiation which is directed onto an electron sensitive layer (called an "electroresist") on a major surface of a substrate speced from the photocathode to cause a patterned differential in solubility between irradiated and unirradiated areas of the sensitive layer. The pattern in differential solubility is transferred to a pattern in a component layer or body by removing the less soluble portion of the electroresist layer to form a window pattern therein; and subsequently selectively etching or doping the component layer or body through the window pattern developed in the resist layer, or depositing a component layer, such as by evaporation, sputtering, oxidizing or epitaxially growing, through the window pattern in the electroresist layer.

The resolution of the electron image projection system, e.g. less than 0.5 micron, is however lost in the juxtaposition of component patterns unless the same resolution can be maintained in the alignment of successive electromasks. Making of an integrated circuit device requires, for example, registration and irradiation of at least 2 to 10 different component patterns in electroresist layers that are subsequently developed and transferred to a component layer by etching, doping or deposition. The electron radiation for each pattern must be aligned with precisely located areas of the major surface each time with a precision of 0.5 micron or less with respect to the first pattern. Otherwise, the precision and economies of the electron image projection system will not be obtained in the finished integrated circuit device.

Apparatus has been developed for precision juxtaposition of multiple component patterns by use of electron beam induced conductivity marks (EBIC). See U.S. Pat. No. 3,710,101, granted Jan. 9, 1973 and U.S. Pat. application Ser. No. 264,699, filed June 20, 1972, both of which are assigned to the same assignee as the present application. At least one and preferably two small spaced apart indexing electron beam patterns or marks of predetermined cross-sectional shapes are provided on the photocathode source to produce alignment beam portions; and corresponding detector marks of predetermined shape, preferably the same shape as the corresponding alignment beam portions, are formed in an oxide layer on a member and overlaid with a metal layer. At each detector mark, a DC potential is applied across the oxide layer between the metal layer and the member. The subsequent current flow between the terminals will vary in correspondence to the portion or area of the detector mark irradiated by the correspondingly alignment beam portion. Thus, the alignment beam portion can be precisely aligned with the detector mark by reading the electron induced current corresponding to the area of the detector mark irradiated. The electrical current flow may be processed through an amplifier to actuate a servomechanism to move the photocathode source or the member, or to change the magnetic field formed by focusing and deflecting electromagnetic coils surrounding the photocathode source and member to align and direct the electron beam pattern, and in turn provide automatic alignment of the alignment beam portions and corresponding detector marks.

A difficulty with this alignment system is that the detector marks must be fabricated on the member itself. Although this can be accomplished in some instances with negligible interferences, it may require additional fabrication steps to prepare the detector marks on the member for the alignment system. Further, the portions of the member on which the detector marks are formed are lost from use in the integrated circuit and therefore substantial waste of the member results. Moreover, the alignment system requires providing a circuit across the detector marks which is expensive and cumbersome; remote readings from the detector marks cannot be made.

SUMMARY OF THE INVENTION

The method and apparatus are provided for the alignment of an electron beam with a semiconductor member with a desired degree of accuracy of, for example, 0.5 micron or less. The invention eliminates fabrication steps previously necessary to the making of an alignment apparatus for the electron image projection system. Moreover, the areas of the major surface of the member where the detector marks are located are made available for use in the integrated circuit which is fabricated, and readings from the detector marks can be taken at remote portions from the marks.

A semiconductor member such as silicon, silicon carbide, germanium and gallium arsenide is provided which generates cathodoluminescence that corresponds in intensity to the thickness of the member. The member may be a single-crystal wafter made by any of the well-known techniques. Alternatively, the member may be an expitaxially grown layer on a suitable supporting substrate such as sapphire. In any case, the semiconductor member is prepared for use in the alignment system by forming at least one and preferably two widely spaced detector marks of predetermined shapes adjacent a major surface in or on which the integrated circuit or other electronic component is to be formed. Each detector mark of predetermined shape is capable of providing a differential in cathodoluminescence generated by the member corresponding to the area of the mark irradiated by an electron beam. The predetermined shapes of the detector marks are preferably all the same and are preferably of a regular geometric shape as a circle, rectangle triangle or the line.

The detector marks of predetermined shapes may be made in any number of suitable embodiments. For example each mark may be formed by simply providing a well in the semiconductor member in the predetermined shape so that the electron bam may penetrate the member and provide a differential in cathodoluminescence at the surface of the member opposite the major surface. Alternatively, a metal or insulating layer absorptive or reflective of the electron beam may be formed on the major surface to circumscribe an exposed portion of the major surface the exposed portion being in the predetermined shape. The negative of these embodiments may also provide the desired differential in cathodoluminescene. Specifically, a mesa of the predetermined shape may be provided instead of a well so that greater intensity cathodoluminescence is given off when the electron beam irradiates the area surrounding the mark than when the electron beam irradiates the area of the detector mark. Similarly, the opaque layer may be provided on the major surface in the predetermined shape rather than circumscribing an exposed surface portion in the shape of the desired detector mark.

To align an electron beam with the semiconductor member, the electron beam to be aligned is disposed so that alignment portions thereof are projected onto the major surface of the member in the vicinity of corresponding detector marks. Each alignment beam portion is a predetermined cross-sectional shape and is typically of the same geometric shape. For convenience and accuracy of alignment in some embodiments, the cross-sectional shape of each alignment beam portion is of substantially the same shape as the predetermined shape of the corresponding detector mark or marks. In either embodiment, a photodetector is positioned, typically adjacent the opposite surface of the member, to detect the cathodoluminescence generated by irradiation of the substrate at least in the vicinity of the detector marks. The electron beam is moved relative to the semiconductor member while continuing the detection until the radiation indicates optimum alignment of the alignment beam portions with the corresponding detector marks.

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 present invention is particularly useful in producing a very accurate component pattern or patterns in an electroresist layer or series of electroresist layers on the major surface of the semiconductor members. Typically, the alignment is accomplished by selective irradiation of the electroresist layers either with a scanning electron beam or a patterned beam of electrons generated by a photocathode source.

When the scanning electron beam is used for selective irradiation, the major surface of the member is divided into contiguous fields with the detector marks of predetermined shapes preferably positioned symmetrically at the boundaries between the fields. In this way, the electron beam can be aligned with each field in turn and then the field be selectively irradiated. After each field is selectively irradiated, the member is moved to permit aligning and selective irradiation of another field with the scanning electron beam.

In aligning the photocathode source with precisely located areas of the major surface of the semiconductor member in an electron image projection system, preferably two detector marks are spaced apart preferably opposite each other along the periphery on the major surface of the integrated circuit, and corresponding alignment beam portions are provided as part of the patterned electron beam generated by the photocathode source. Photodetector means are positioned adjacent the detector marks preferably adjacent the opposite surface of the member. The radiation generated by impingement of the alignment beam portions at or adjacent the corresponding detector marks is detected by the corresponding detectors which output electrical signals corresponding to the intensity of the radiation. The patterned electron beam is then moved relative to the member, either manually or automatically, until the detected cathodoluminescence indicates the optimum alignment of the alignment beam portions with corresponding detector marks.

Preferably, the alignment is done automatically by an electrical means which moves the patterned beam of electrons relative to the member responsive to the electrical signal from the detector means. The electrical means preferably includes for this purpose a modulation means for oscillating the movement of each alignment beam portion over a detector mark; phase detection means, preferably synchronized with the modulation means, for detecting along orthogonal axis the error from alignment of the alignment beam portion and the detector mark and outputting an electrical signal corresponding thereto; and actuating means for changing the electrical input to electromagnetic means directing the patterned electron beam from the photocathode source onto the semiconductor member responsive to the electrical signal from the phase detector means. Preferably the electrical means also includes termination means for terminating the oscillation by actuating means at optimum alignment of the alignment beam portions and corresponding detector marks.

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

BRIEF DESCRIPTION OF THE DRAWINGS

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

FIG. 1 is a cross-sectional view in elevation of an electron image projection device employing the present invention;

FIG. 2 is a fragmentary cross-sectional view in elevation taken along line II—II of FIG. 1;

FIG. 3 is a fragmentary cross-sectional view in perspective taken along line III—III of FIG. 2;

FIG. 4 is an alternative fragmentary cross-sectional view in perspective taken along line III—III of FIG. 2;

FIG. 5 is a second alternative fragmentary cross-sectional view in perspective taken along III—III of FIG. 2;

FIG. 6 is a third alternative fragmentary cross-sectional view in perspective taken along III—III of FIG. 2;

FIG. 7 is a fourth alternative fragmentary cross-sectional view in perspective taken along III—III of FIG. 2;

FIG. 8 is a fifth alternative fragmentary cross-sectional view in perspective taken along III—IIII of FIG. 2;

FIG. 9 is a block diagram of an electrical circuit for the electrom image projection device shown in FIG. 1 to automatically align the electron beam pattern in accordance with the present invention;

FIG. 10 is a schematic illustration of production of a highly accurate component pattern in an electroresist layer on a semiconductor member utilizing a scanning electron beam in accordance with the present invention;

FIG. 11 is a partial top view of the substrate of FIG. 10 without the electroresist layer applied; and

FIG. 12 is a flow diagram showing the interrelationship of functional component in utilizing the present invention to manually align the scanning electron beam as shown in FIG. 10.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

An electron image projection device suitable to practice the present invention is described in U.S. Pat. Nos. 3,679,497 and 3,710,101 except for the alignment technique and apparatus therefor. For convenience and clarity of description the device is redescribed in part here.

Referring to FIG. 1, an electron image projection device is shown. A hermetically sealed chamber 10 of nonmagnetic material has removable end caps 11 and 12 to allow for disposition of apparatus into and removal of apparatus from the chamber. A vacuum port 13 is also provided in the sidewall of chamber 10 to enable a partial vacuum to be established in the chamber after the chamber is hermetically sealed.

Disposed within chamber 10 is cylindrical photocathode source or electromask 14 and alignable semiconductor member 15 in substantially parallel, spaced relation. Member 15 is a single-crystal semiconductor wafer such as silicon, or a semiconductor epitaxial layer capable of generating cathodoluminescence of intensity corresponding to the thickness thereof on a supporting substrate such as sapphire. Member 15 is supported in specimen holder 16 as more fully described hereinafter. Photocathode 14 and holder 16 are in turn positioned in parallel array by annular disk-shaped supports 17 and 18, respectively. Electromask 14 and holder 16 are spaced apart with precision by tubular spacer 19 which engages grooved flanges 20 and 21 via gaskets 22 and 23 around the periphery of supports 17 and 18. The entire assembly is supported from end cap 11 of chamber 10 at support 17 to allow for ease of disposition of the photocathode source and the semiconductor member within the chamber.

Photocathode 14 is made cathodic and semiconductor member 15 is made anodic to direct and accelerate electrons emitted from the photocathode to the member 15. To accomplish this, holder 16 and supports 17 and 18 are of highly conductive material and spacer 19 is of highly insulating material. A potential source 19A of, for example, −10 Kv is applied between supports 17 and 18. The difference in potential is conducted to and impressed on photocathode 14 and member 15 via supports 17 and 18 and holder 16.

Surrounding chamber 10 are three series of electromagnetic coils, positioned perpendicular to each other, to control and direct the impingement of the electron beam onto member 15. Cylindrical electromagnetic coils 24_1, 24_2 and 24_3 are positioned axially along the path of the electron beam from photocathode 14 to member 15 to cause electrons to spiral and move radially as they travel the distance from the photocathode to the member. These coils perimt control of the rotation (θ) and the magnification (M) of a patterned electron beam emitted from the electromask to provide for focusing of the electron beam. Rectangular electromagnetic coils 25_1 and 25_2, and 26_1 and 26_2 are symmetrically positioned perpendicular to each other in Helmholtz pairs, and to coils 24_1–24_3, to cause electrons to transversely deflect as they travel the distance from the photocathode to the semiconductor 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 27 such as a mercury vapor lamp backed by reflector 27A irradiates a photocathode layer 28 (e.g. gold or palladium) in the photocathode source or electromask 14. The photocathode layer is irradiated through a substantially transparent substrate 29 such as quartz overlaid with a layer 30 containing the negative of a desired component pattern. The layer 30 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. A part of the patterned electron beam emitted from the photocathode source 14 is at least one and preferably two relatively small alignment beam portions 41 and 42 of predetermined cross-sectional (shape (e.g. squares of 300 × 300 microns) which are widely spaced apart preferably oppositely positioned along the periphery of the patterned beam from the photocathode.

Referring to FIG. 2, semiconductor member 15 is precision mounted within physically permissible limits in holder 16 and in turn with respect to photocathode 14. Member 15 has a flat peripheral portion 31; and holder 16 has depression 32 into which member 15 fits. Holder 16 has pins 33, 34, 35 and 36 positioned in respective quadrants around the periphery of depression 32. Member 15 is positioned by resting flat peripheral portion 31 of member 15 against pins 33 and 34 and curvilinear peripheral portion 37 of member 15 against pin 35. The member is thereby located with an accuracy of about 35 microns or less. Movable pin 36, which is fitted with a compression spring 38, is positioned and pushed against the curvilinear portion of member 15 to firmly retain member 15 and in turn, maintain member 15 precisely located.

Referring to FIG. 3, detector marks 39 and 40 of predetermined shapes are provided in semiconductor member 15 to provide a differential in cathodoluminescence generated by the member corresponding to the areas of the marks irradiated by an electron beam. Marks 39 and 40 of predetermined shapes are provided by forming preferably planar bottom wells in the member 15 of a predetermined planar shape. Detector marks 39 and 40 can be reasonably precisely formed by etching or ion milling the member through window patterns of the desired planar shape in a photo- or electroresist layer (not shown). As shown, marks 39 and 40 are preferably of substantially the same shape as the predetermined cross-sectional alignment beam portions 41 and 42. The cross-sectional shape of the alignment beam portions and detector marks are thus preferably about 10 × 10 mils in any suitable geometric shape, such as a square, rectangle or circle. The thickness of the member 15 particularly at marks 39 and 40 is important to the operation of the alignment system. The thickness at the marks must be small enough to permit penetration of the electron beam so that cathodoluminescence radiates from the opposite major surface of the member 15. The allowable thickness therefor depends on the energy level of the electron beam. For example, a 10 kilovolt electron beam requires a thickness at marks 39 and 40 0f about 1 micron or less, while a 30 kilovolt electron beam permits a thickness of about 5 microns or less. The major surface of member 15 is then overlaid with a layer of electroresist, as shown, in which the precision component pattern is to be formed.

Positioned behind detector marks 39 and 40 in holder 16 are photodetector means 43 and 44, respectively, with leads 45 and 46 and 45A and 46A, respectively, extending through vacuum seals in chamber 10 at 47. Photodectectors 43 and 44 are adapted for detecting the cathodoluminescence produced by the member, which is infrared radiation for a silicon member, and are substantially larger in size than and circumscribe marks 39 and 40 so that they can detect even dispersed and scattered infrared light or cathodoluminescence from member 15 close to or in the vicinity of the detector marks. For this reason, detector means 43 and 44 are also positioned in as close a proximity to marks 15 as the geometry will permit so that resolution of the light signal and in turn accuracy of alignment is not lost between the detector mark and the detector means. In this connection, it should be noted that in some embodiments it may be appropriate to position the detector means 43 and 44 on the same side of the member 15 as the photocathode source so that reflected cathodoluminescence is detected. However, it is much preferred that the detector means 43 and 44 be positioned opposite the member 15 from the photocathode source 14.

In operation, the alignment beam portions 41 and 42 of predetermined cross-sectional shape impinge on and overlap the detector marks 39 and 40, respectively. The electron beams produce typically an infrared cathodoluminescence which corresponds in intensity to the depth of penetration of the electron beam into the member 15. Alignment can be accurately recorded, therefore, simply by observing the intensity of the light at detector means 43 and 44. In this connection, it should be noted that light filters 48 and 49 are preferably interposed between member 15 and detector means 43 and 44, respectively, so that only light of the higher intensity provided by impingement of electron beams 41 and 42 on detector marks 39 and 40 register on the photodetectors. Where the alignment beam portions and corresponding detector marks are of the same predetermined shape, optimum alignment can be attained simply by detecting where the detected cathodoluminescence indicates the maximum intensity of the cathodoluminescence from the semiconductor member.

Referring to FIGS. 4, 5, 6, 7 and 8, alternative embodiments are shown for detector marks 39 and 40 of predetermined shapes. Specifically, detector marks 39′ and 40′ of predetermined shapes are provided by forming mesas on member 15 of the predetermined shape. Each mesa can be formed with a high degree of precision again by etching or ion milling the negative of the mesa in the member 15 through window patterns in suitable photo- or electromasks. This embodiment operates essentially the same as the embodiment as described in FIG. 3. However, here the important thickness is of the member at the portion surrounding the marks 39′ and 40′ rather than at the marks themselves, since what is detected is a lack of cathodoluminescence rather than a presence of cathodoluminescence. In turn, where the alignment beam portions and the corresponding detector marks are of the same predetermined shapes, the optimum alignment is attained where a minimum intensity of cathodoluminescence is sensed.

Referring to FIG. 5, detector marks 39″ and 40″ of predetermined shapes are provided by forming opaque layers over the major surface 15A″ of semiconductor member 15″ in the areas surrounding the detector marks. Detector marks 39″ and 40″ are thus provided by the exposed surface portions of major surface 15A″ being in the predetermined shape. The opaque layers can be readily made by standard techniques by forming an opque layer over the entire surface area and then etching or ion milling through the opaque layer to expose surface portions of surface 15″ in the form of the desired detector marks. The remainder of the alignment system is as above described with reference to FIGS. 1, 2 and 3. The composition of opaque layers may be any suitable material such as metal or oxide which absorbs or reflects the electron beam as desired. In this connection, it should be noted that "opaque" does not mean that the layer totally absorbs or reflects the electron beam. The "opaque" layer need only absorb or reflect sufficient electron energy 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 cathodoluminescence of the member 15″. The operation is again as described with reference to FIG. 3 where alignment is achieved by reading the maximum intensity cathodoluminescence at the detector means 43″ and 44″.

Referring to FIG. 6, detector marks 39‴ and 40‴ of predetermined shapes are provided by forming opaque layers over major surface 15A‴ of semiconductor member 15‴ in the area of the detector marks. The opaque layers are in the predetermined shape of the desired detector marks, are of the same composition as the opaque layer of FIG. 5, and are formed in the same way. Indeed, this embodiment is the negative of the embodiment shown in FIG. 5 and differs in operation only in that the minimum cathodoluminescence id detected to optimize alignment where the alignment beam portions 41'' and 42'' and the detector marks 39'' and 40'' are of the same predetermined shape.

Referring to FIG. 7, detector marks 39'''' and 40'''' of predetermined shapes are provided generally as above described with reference to FIG. 5. The composition and operation are precisely the same as there described except for the character of member 15. Semiconductor member 15'''' is, however, an epitaxial grown layer supported by a suitable substrate such as sapphire which is transparent to the cathodoluminescent radiation.

Referring to FIG. 8, detector marks 39''''' and 40''''' of predetermined shapes are provided generally as above described with reference to FIG. 6. The composition and operation are again precisely the same except for the character of member 15. In FIG. 8 semiconductor member 15''''' is epitaxially grown on a suitable supporting substrate such as sapphire which is transparent to the cathodoluminescent radiation.

Irrespective of the embodiment, the present invention provides a method of alignment of the patterned electron beam generated by the photocathode source 14 with precisely located areas of a major surface of the member 15. Further, the member may be similarly aligned with sucessive photocathode sources or electromasks by use of the same detector 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 detector marks and the photocathode layers emitting the corrresponding alignment beam portion can be shaped and spatially located, which presents no difficulty with the scanning electron microscope and electron image projection system.

Where the predetermined cross-sectional shapes of the alignment beam portions are different from the predetermined shapes of the corresponding detector marks, the reading of detector means 43 and 44 to determine optimum alignment is somewhat different than above described. Optimum alignment is no longer indicated by the maximum or minimum in the signal readings from the detector means. Rather, plateaus are reached in the signal readings, and optimum alignment is achieved by either selecting a certain point on each pleateau taking into consideration any difference in the geometric shapes between the alignment beam portions and detector marks, or selecting a certain point on the signal rise from the detector means as the alignment beam portions move into or out of the areas of the corresponding detector marks. The latter alignment sequence permits alignment with the edge of the detector mark. Any of these embodiments may be readily used in either a manual or automatic alignment system with electrical signal processing apparatus such as that hereinafter described. These alternative embodiments for the alignment system may be more useful, however, in alignment of the scanning electron beam system as hereinafter described than alignment of the elctron image projection as hereinbefore described.

The electric current flow from the detector means 43 and 44 may be processed through suitable electronic amplifiers and servomechanisms to automatically shift the entire patterned electron beam relative to the semi-

conductor member and precisely position the alignment beam portions 41 and 42 in alignment with the detector marks 29 and 40, respectively. For this purpose, suitable means such as a modulation means is preferably used to oscillate the electrical input to the electromagnetic coils and thereby cause the alignment beam portions 41 and 42 to oscillate or more typically in a circle over the detector marks 39 and 40 so that the electrical outputs from the detector means 43 and 44 are modulated.

Referring to FIG. 9, there is illustrated in a block diagram the electronics for adjusting the alignment beam portions 41 and 42 with respect to the detector marks 39 and 40 of the same predetermined shape, and in turn precisely aligning semiconductor member 15 with respect to the entire electron beam pattern from electromask 14. The modulated electrical signal from infrared detector means 43 is conveyed via lead 46 to a preamplifier 50 which amplified signal is then conveyed via lead 51 to a tuned amplifier 52. The output of amplifier 52 passes through lead 53 to a phase adjustor 54 and then through lead 55 to a dual phase detector 56. A gated oscillator 56 impresses reference signals, which are 90° out-of-phase, through conductors 58 and 59 and conductors 60 and 61, respectively, on the dual phase detector 56. The outputs of phase detector 56 thus comprise X-error signals via lead 62 and Y-error signals via lead 63, which pass through gate 64 via leads 65 and 66 to integrators 67 and 68, respectively. The integrators 67 and 68 have direct-current outputs to adders 69 and 70, respectively, where the outputs are modulated with alternating current from the oscillator 56 via leads 71 and 72, 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 Helmholtz pairs 25 and 26.

Similarly, the modulated signal from the infrared detector means 44 is conducted via lead 46A to preamplifier 73, and passed thereafter via lead 74 to the tuned amplifier 75 and then via lead 76 through phase adjustor 77 and lead 78 to dual phase detector 79. Oscillator 57 also impresses the two 90° out-of phase reference signals, above referred to, through leads 80 and 81 on dual phase detector 79. Two outputs from dual phase detector 79 are thus produced. The one output signal via conductor 82, which corresponds to a θ error signal, passes via leads 83 and 85 through gate 84 to control a motor-driven precision potentiometer 86 to effect the rotational control of the electron beam pattern by increasing or decreasing the current to the electromagnetic coils 24. The other output signal via leads 87 and 88 through gate 83 controls the size of the patterned electron beam through a motor-driven gang potentiometer 89 which adjusts the main focus field.

The error signals in conductors 62, 63, 82 and 87 are cross-fed electronically via leads 90, 91, 92 and 93, respectively, into a four input delayed null detector 94 whose output is conveyed by lead 95 to a set-reset flipflop 96. The operation of the flip-flop is initiated by actuation of a start sequence switch, whereupon current begins to flow via leads 97 and 98 to energize the ultraviolet source 27 to cause electron beams to be emitted from photocathode source 14, including the two alignment beam portions 41 and 42. Likewise, current from 97 passes through lead 99 to the gated oscillator 57, which in turn feeds sinusoidal signals in quadrature through lines 58''71 and 60–72 to the X and Y controls 69 and 70, respectively. The entire electron beam pattern, including the alignment beam portions 41 and 42, are thus caused to oscillate typically in a circle of, for example, 6 microns diameter at a frequency of 45 Hertz.

Once the alignment beam portions 41 and 42 are centered or aligned on detector marks 39 and 40, respectively, by operation on integrators 67 and 68, and potentiometers 86 and 89, the error signals passing through leads 90, 91, 92 and 93 reach a zero value which is detected by the null detector 94, The null detector thereupon produces an electrical signal which passes through lead 95 to the flip-flop 96, which terminates the operation of the gated oscillator 57 and closes gates 64 and 83 by signals through leads 100 and 101, respectively. The time sequence of the selective electron beam exposure of an electroresist layer on the full area of semiconductor member 15 is then begun and continued until the resist is fully exposed. A period of from 3 to 10 seconds is usually adequate to produce a sufficient electron beam treatment of the electron resist to cause it to be properly differentially soluble in selected solvents. The photocathode source 14 has been generating a patterned electron beam from all the emissive areas during the alignment period; however, the alignment period is so brief that the electron resist on all the areas of the member 15 has not been significantly exposed.

Referring to FIGS. 10 and 11 and 12, the invention is shown in use to align a scanning electron beam 102 with a semiconductor member 103. A scanning electron miscroscope for adoption to the present invention is shown in U.S. Pat. No. 3,679,497, assigned to the same assignee as the present apparatus. Preferably the detector marks 105 each have the same predetermined shape and are spaced over the major surface 104 in a uniformly spaced pattern as shown in FIG. 11, preferably dividing the surface 104 into contiguous symmetric fields suitable for selectively irradiating an electroresist layer over the member 103 with minimal distortion. Each detector mark 105 is of preferably the same or larger predetermined shape than the scanning electron beam which operates in toto as the alignment beam portion in the alignment system. An electroresist layer in which the precision component pattern is to be formed is then overlaid on major surface 104. A series of detector means 106 are positioned in holder 107 preferably adjacent the opposite surface 108 of the semiconductor member. Each detector means 106 is positioned adjacent a detector mark 105 to detect cathodoluminescence generated by irradiation of the semiconductor member 103 at and adjacent the detector marks 105.

Referring to FIG. 12, this arrangement can be used to align the scanning electron beam with the major surface 104 of the semiconductor member 103 field by field for selective irradiation of precisely selected areas of the major surface of the member. The member 103 is divided into contiguous fields preferably bounded in quadrature by the detector marks 105, e.g. one at the intersection of each field, or one at the center along each side of each field with an infrared detector means 106 positioned adjacent each detector mark 105. To align the beam 102 with, for example, field 109, the scanning electron beam 102 is modulated to overlap two opposite detector marks, for example, marks 105_1

and 105_2 sequentially. The output signals from the detector means are fed to a cathode-ray tube 110 which also has the intended locations of the detector marks for precise alignment inputted from the computer 111 controlling the scanning electron beam 102. The scanning beam 102 is thus moved relative to the semiconductor member 103 until the signals from the two detector means adjacent detector marks 105_1 and 105_2, respectively, are centered in the superimposed input of the intended locations of the detector marks 105_1 and 105_2 and thus alignment. The electron beam 102 is then modulated to overlap the other two opposite detector marks 105_3 and 105_4 sequentially until the outputs therefrom coincide on the CRT 110 within the superimposed theoretical input for detector marks 105_3 and 105_4 from the computer 111. The electron beam 102 is then aligned and ready to selectively irradiate the field on command from the computer 111. At end of the irradiation of the field 109, the semiconductor member 103 is physically moved so that the scan field of the electron beam is concurrent with the next field 109' on the semiconductor member 103 to be selectively irradiated. The aligning sequence is then repeated as described above.

The alignment system shown in FIG. 12 is what one skilled in the art would connote a manual system because an operator makes the adjustment 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 preferred that the detector marks be of the same predetermined shapes as the scanning electron beam and that an automatic system similar to that described in reference to FIG. 9 be used in place of the CRT and manual adjustment to automatically align the scanning electron beam sequentially with the fields 109.

While the presently preferred embodiments of the invention have been specifically described, it is distinctly understood that the invention may be otherwise variously embodied and used within the scope of the following claims.

What is claimed is:

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

A. forming on a major surface of a semiconductor member capable of generating cathodoluminescence corresponding in intensity to the thickness of the member at least one detector mark of predetermined shape, each said detector mark being capable of providing a differential in cathodoluminescence generated by the member corresponding to the area of the mark irradiated by an electron beam;

B. causing at least one electron beam to be aligned to be projected onto the major surface of the member, said electron beam having at least one alignment beam portion corresponding to at least one detector mark and having a predetermined cross-sectional shape;

C. detecting cathodoluminescence generated by the member at and adjacent where each said alignment beam portion overlaps and irradiates a corresponding detector mark;

D. moving the aligning electron beam relative to the member while continuing step C to detect irradiation of corresponding detector marks by the alignment beam portions; and

E. positioning the electron beam relative to the semiconductor member where the detected cathodoluminescence indicates optimum alignment of the alignment beam portions and corresponding detector marks.

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

forming the detector mark includes providing a well in the member in the predetermined shape, and the cathodoluminescence generated is detected through the member.

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

forming the detector mark includes providing a mesa on the member in the predetermined shape, and the cathodoluminescence generated is detected through the member.

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

forming the detector mark includes positioning an opaque layer on the major surface of the semiconductor member in the predetermined shape.

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

forming the detector mark includes positioning an opaque layer on the major surface of the semiconductor member to circumscribe an exposed portion of the major surface wherein the exposed portion is of the predetermined shape.

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

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

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

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

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

the major surface of the member is divided into contiguous fields for selective irradiation, and the detector marks are positioned symmetrically along boundaries of said contiguous fields.

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

A. forming on a major surface of a semiconductor member capable of generating cathodoluminescence corresponding in intensity to the thickness of the member at least two widely spaced apart detector marks of predetermined shape, each said detector mark being capable of providing a differential in cathodoluminescence generated by the member corresponding to the area of the mark irradiated by an electron beam;

B. causing a patterned electron beam with alignment beam portions corresponding to the detector marks to be projected by a photocathode source onto the major surface of the member, each said alignment beam portion corresponding to a detector mark and having a predetermined cross-sectional shape;

C. detecting the cathodoluminescence generated by the member at least at and adjacent where the alignment beam portions overlap and irradiate the marks;

D. moving the patterned electron beam relative to the member while continuing step C to detect irradiation of the detector marks by the alignment beam portions; and

E. positioning the alignment beam portions relative to the detector marks where the detected cathodoluminescence indicates optimum alignment of the corresponding alignment beam portions and the detector 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 semiconductor member as set forth in claim 9 wherein:

forming each detector mark includes providing a well in the member in the predetermined shape, and the cathodoluminescence generated is detected through the member.

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

forming each detector mark includes providing a mesa on the member in the predetermined shape, and the cathodoluminescence generated is detected through the member.

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

forming each detector mark includes positioning an opaque layer on the major surface of the semiconductor member in the predetermined shape.

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

forming each detector mark includes positioning an opaque layer on the major surface of the semiconductor member to circumscribe an exposed portion of the major surface wherein the exposed portion is of the predetermined shape.

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

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

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

steps D and E are automatically performed by electrically processing the electrical signal output corresponding to the detected cathodoluminescence on modulation of the movement of the alignment beam portions over the corresponding detector marks, and steps D and E automatically are terminated at optimum alignment of the corresponding alignment beam portions and detector marks.

16. Apparatus for selectively irradiating precisely located areas of a major surface of a semiconductor member 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. a semiconductor member capable of generating cathodoluminescence of intensity corresponding to the thickness thereof and having adjacent a major surface thereof at least one detector mark corresponding to each said alignment beam portion, each said detector mark being of a predetermined shape and capable of providing a differential in cathodoluminescence generated by the member corresponding to the area of the mark irradiated by an electron beam;

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

D. means for applying a potential between the semiconductor member and the photocathode source whereby electrons from the photocathode source are directed to and selectively irradiate portions 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 precisely located areas and directing each alignment beam portion to irradiate selected portions of the surface portions of the major surface of the substrate close to a detector mark;

F. detector means for detecting the cathodoluminescence generated by the member at least at and adjacent the detector marks and producing an electrical signal corresponding to the area of the detector mark irradiated by the alignment beam portions; 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 substantially align with the respective detector marks, whereby the patterned beam of electrons from the photocathode is located and oriented relative to the semiconductor member so that precisely located areas of the major surface of the semiconductor member can be selectively irradiated with the patterned electron beam.

17. Apparatus for selectively irradiating precisely located areas of a major surface of a semiconductor 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 having predetermined cross-sectional shapes substantially the same as the predetermined shapes of the corresponding detector marks.

18. Apparatus for selectively irradiating precisely located areas of a major surface of a semiconductor 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 detector mark, phase detection means for detecting along orthogonal axis the error from alignment of the corresponding alignment beam portions and detector marks and outputting an 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 alignement beam portions and the detector marks into alignment.

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