

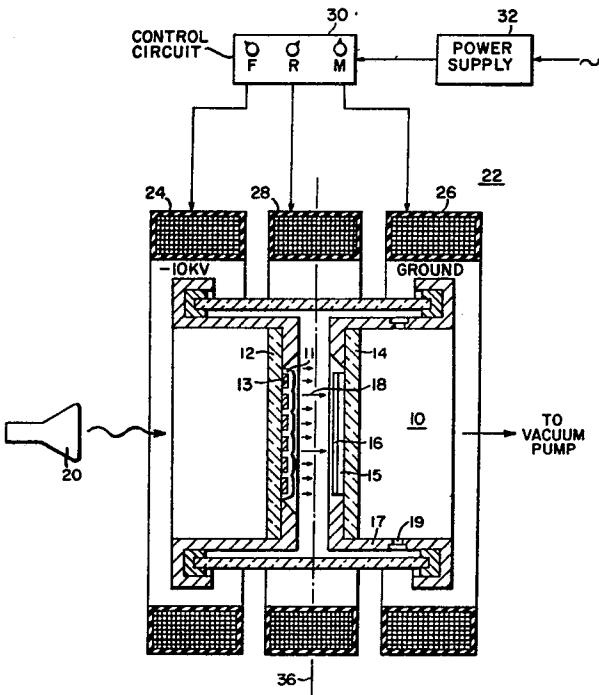
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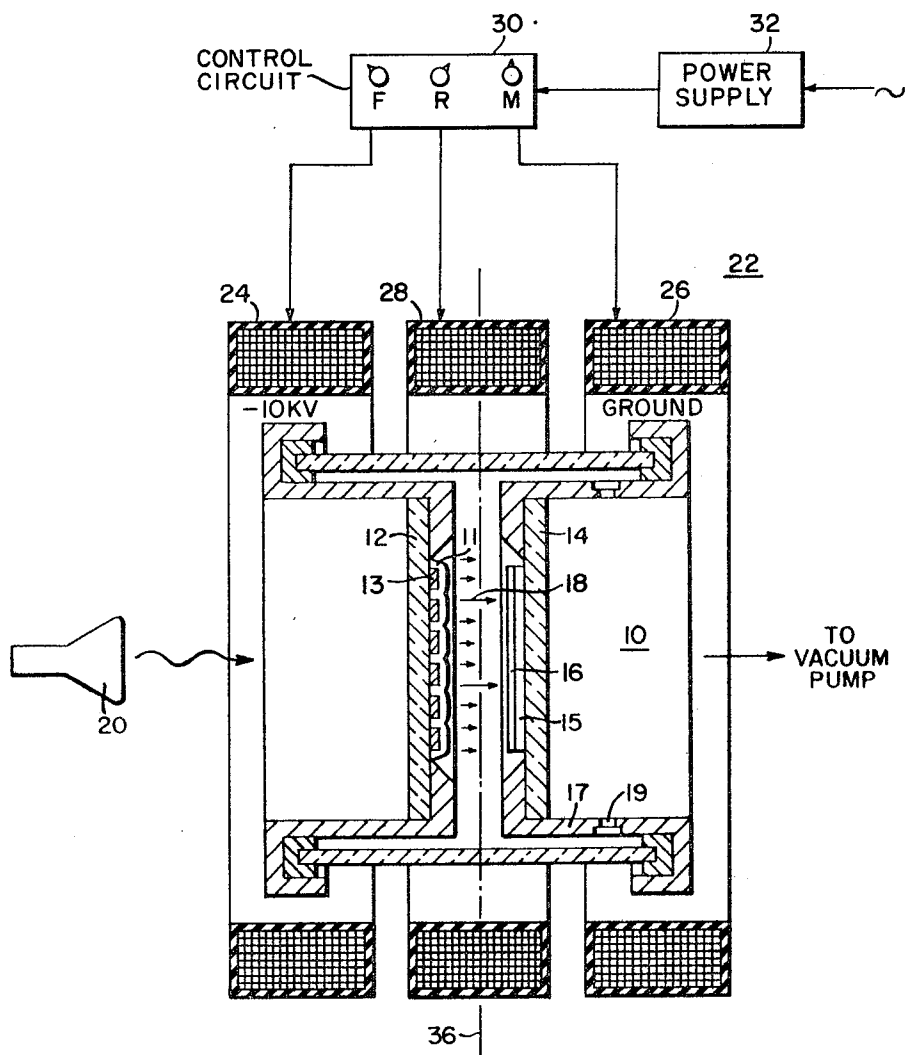
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[54] MULTI-COIL ELECTRON IMAGE CONTROL
APPARATUS
12 Claims, 1 Drawing Fig.

[52] U.S. Cl. 315/31,
315/10
[51] Int. Cl. H01J 29/56
[50] Field of Search..... 315/31, 10;
313/84

ABSTRACT: The invention is an arrangement of three electromagnetic coils disposed in coaxial relationship about an image tube to control the magnetic field strength and magnetic field uniformity for the purpose of adjusting the image focus, rotation, and magnification.





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MULTI-COIL ELECTRON IMAGE CONTROL APPARATUS

GOVERNMENT CONTRACT

The invention herein described was made in the course of or under a contract with the U.S. Air Force.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates in general to electron beam control systems and more particularly to a system for electromagnetically controlling the focus, magnification and rotation of an electron pattern for imaging on a target.

2. Description of the Prior Art

The high degree of resolution required in the fabrication of complex planar integrated circuits and semiconductor devices has resulted in the application of electron beam devices for scanning a workpiece with the desired pattern.

The use of an image intensifier tube for imaging a pattern on a workpiece is subject of a copending application Ser. No. 753,373, filed Aug. 19, 1968, by T. W. O'Keeffe, now abandoned and R. M. Handy and assigned to the assignee of the present invention. The required circuit pattern is built into a photocathode and imaged onto a workpiece by the combined action of an accelerating electric field and a magnetic field.

In the fabrication of complex integrated circuits using the image tube, a series of successive workpiece exposures are required. After each exposure the workpiece is removed from the image tube, etched, processed and then returned to the tube for the exposure of a new pattern. In order to provide a high degree of registration between the successive patterns precise control of the image focusing, rotation and magnification by the magnetic field is required.

A conventional method of producing a highly uniform magnetic field is the use of a Helmholtz pair, a coaxial arrangement of two similar coils at a particular separation. The Helmholtz pair, while suitable for image tube applications where adjustment of the image magnification and rotation are not required, it is not suitable for fabrication of micron size-integrated circuits where control of the field uniformity is required for pattern alignment purposes.

SUMMARY

Precise image control heretofore not available in electron beam-integrated circuit fabrication devices is provided by a system of three magnetic coils disposed coaxially about an electron image tube.

Control of the current supplied to each of the coils provides the capability of altering the focus, magnification and rotation of the projected pattern.

Identical and simultaneous variation of the current supplied to the three coils will alter the magnitude of the magnetic field and thus the focus condition without affecting the magnification and rotation characteristics established.

Variation of the ratio of the currents flowing in the inner coil and outer coils will alter the uniformity of the magnetic field. This control of field nonuniformity provides control of image rotation and magnification.

DESCRIPTION OF THE DRAWING

The drawing is a cross-sectional view of an embodiment of apparatus in accordance with the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the drawing there is shown an image tube 10 having a cathode plate 12 and an anode target plate 14 that are essentially planar and parallel. On the cathode plate 12 is a photocathode 11 here shown as one incorporating a mask 13 so that incident light from a light source 20 illuminating the entire photocathode 11 produces response only from the unmasked areas. The electron response produces an electron image 18 which corresponds to a desired pattern to be etched

on the target plate 14. The target plate 14 contains one target plate more workpieces 15 that have a layer of an organic etch resistant material 16 thereon.

The cathode plate 12 includes a radiation transmissive support such as one of quartz that forms part of the enclosure of the space between the cathode and the target. The target plate 14 is mounted on a means such as frame 17 that permits the evacuation, by port 19, of the space between the cathode and the target.

A more complete description of the image tube structure and the photocathode materials may be found in the above identified application of O'Keeffe and Handy.

The electron image or pattern 18 generated by the masked photocathode 11 is accelerated to the target plate 14 by an accelerating potential, typically 10 KV. Electron image accelerated toward target plate 14 is magnified, focused and rotated by the magnetic fields established by the multicoin arrangements 22.

The multicoin arrangement 22 consists of magnetic coils 24, 26 and 28 which are positioned coaxially about the axis of the image tube 10 which extends perpendicular to the photocathode 11 and target 14.

The control circuit 30 can be considered as essentially comprising three separate variable power supplies, one connected to each of the three coils 24, 26 and 28. Adjustment of the current flow in the various coils provides control of the focus, rotation and magnification of the image. This simple independent control of the three currents would allow any combination of the degrees of freedom to be achieved. However, in general, each current would effect all three parameters thus rendering control inconvenient.

It will be assumed for the purpose of discussing the novel multicoin arrangement 22 that the variable power supplies of the control circuit 30 are interconnected through suitable feedback circuits such that a modification of one of the image control parameters by adjustment of the control knobs F, R or M, representing focus, rotation and magnification respectively, does not affect the remaining parameters except as noted in specific situations.

The focusing of image tube 10 is controlled by adjustment control knob F of control circuit 30. The focus parameter is determined by the magnitude of the magnetic field strength established by coils 24, 26 and 28. An adjustment of control knob F to increase or decrease the magnetic field strength produces a uniform change in the current supplied to the coils 24, 26 and 28.

Image rotation control differs from focus control in that the degree and direction of rotation is determined by the change in ratio of current supply between the outer coils 24 and 26 and the center coil 28. A change in the ratio of the current supply between the outer coils and the center coil introduces a change in the field uniformity resulting in a degree of field nonuniformity. This control of field nonuniformity provided by control knob R of the control circuit 30 establishes the desired direction and degree of image rotation. The regulation of image rotation by control knob R is accomplished without producing a net change in the field magnitude thus providing image rotation capability independent of image focus. The rotation of the image on either side of zero rotation, wherein zero corresponds to maximum field uniformity, is controlled by the regulation of the ratio of current supply between the outer coils 24 and 26 and the center coil 28.

The image magnification is determined in general by the position of the plane of symmetry of the magnetic field corresponding to the field nonuniformity established by the coils 24, 26 and 28. The plane of symmetry is defined as the plane normal to the coil axis passing through the point on the coil axis at the midpoint of the coil system at which the radial magnetic field is zero. The positioning of image tube 10 in a centered position with respect to the coil arrangement 22 will result in a magnetic field being established about a plane of symmetry 36 in response to controlled symmetrical current flow through the coils. For a symmetrical situation in which

the outer coils 24 and 26 are identical and are equally spaced about the center coil 28, the symmetry plane is positioned exactly at the midpoint of the coil system 22. The plane of symmetry of the total magnetic field can be considered a combination of the plane of symmetry of the magnetic field established by outer coils 24 and 26 and the plane of symmetry established by the center coil 28.

In a practical system, these ideal symmetry conditions cannot be realized. Adjustment of the current ratio between the coils 24, 26 and 28 can compensate for lack of geometrical symmetry of the two outer coils, noncoincidence of the symmetry plane of the outer coil pair and the symmetry plane of the center coil, and inaccuracy of the setting of the symmetry plane of the coil system 22 in relation to the center plane of the tube.

The spacing of the outer coils 24 and 26 exceeds the spacing defined by the well known Helmholtz relationship $2d = r$, where d is the spacing between the coils and r is the effective radius of the coils. While the Helmholtz relationship provides a desirable field uniformity for a two-coil system, the spacing defined by Helmholtz is not sufficient to permit bidirectional control of image rotation.

It has been determined theoretically that a coil spacing defined by the relationship $2d = 1.52r$ establishes sufficient field nonuniformity control to develop desired image rotation in either the clockwise or counterclockwise direction depending on the ratio of current supply between the outer coils 24 and 26 and the center coil 28. If zero rotation is desired the field uniformity established by the coil system 22 is superior to that available from the Helmholtz pair.

The application of the coil system 22 to the fabrication of integrated circuits represents a preferred embodiment. The current control circuit required in this application is quite simple inasmuch as the image magnification is maintained at unity.

In the applications of the coils system 22 requiring independent control of rotation and magnification, as well as focus, the complexity of the control circuit is far greater than that required under unity magnification conditions. This results from the fact that in a nonuniform field the image rotation and magnification are effected by both degree of field nonuniformity and the position of the symmetry plane of the magnetic field in relation to the position of the image tube electrodes. Thus a change in either rotation or magnification would result in a corresponding change in the other thus necessitating a compensating circuit response to maintain the unadjusted parameter at a preset value. The complexity of the interrelated current control is reduced when a unity magnification condition is established. Under unity magnification conditions the rotation of the focused image produced by varying the current flow in center coil 28 can be controlled totally independent of the focus and magnification parameter.

It has been determined theoretically and confirmed experimentally that positioning the symmetrical plane 36 at a distance from the cathode 12 equal to $\frac{1}{2} - \frac{3}{2\pi^2}$ (or 0.348) of the spacing between the cathode 12 and the anode 14 establishes unity image magnification regardless of change in image focus and rotation.

In contrast to a fixed magnification setting, it may be desirable to control the degree of magnification of the image while reducing the image rotation to zero. A symmetry plane position corresponding to $1 - \frac{3}{2\pi^2}$ (or 0.848) of the electrode spacing in the image tube will establish zero image rotation and permit independent control of image focus and magnification.

The fabrication of integrated circuits often requires the exposure of numerous patterns on a workpiece to form a single composite pattern. In this situation it is essential that each succeeding pattern be properly aligned and registered with the previously exposed pattern. The coil arrangement 22 provides

the necessary pattern alignment through the control of pattern focus, rotation and magnification.

While the discussion has been directed to parallel electrode configurations and relatively uniform magnetic fields, it is noted that the coil system 22 can be applied to other configurations as well.

Furthermore the illustration of the multicoil system 22 as a three-coil system is not to be considered a limitation of the invention. Coil arrangements other than that illustrated may be utilized.

Various modifications may be made with the scope of the invention.

We claim:

1. Apparatus for registering high resolution electron beam patterns on an electron sensitive anode workpiece, comprising, in combination:

a photocathode means for generating an electron beam pattern in response to impinging radiation;

means for accelerating said electron beam pattern toward said anode workpiece; and

electromagnetic means for controlling the focus, rotation and magnification of said electron beam pattern.

2. Apparatus as claimed in claim 1 wherein said electromagnetic means is comprised of a multiple electromagnetic coil means for controlling the imaging of the electron beam pattern which is directed toward said anode workpiece, and an electrical excitation control circuit means electrically associated with said multiple coil means for controlling electron beam pattern focus, rotation and magnification by controlling the electrical excitations applied to the respective coils of said multiple electromagnetic coil means.

3. Apparatus as claimed in claim 2 wherein said multiple electromagnetic coil means is comprised of three electromagnetic coils.

4. Apparatus as claimed in claim 3 wherein said coils are disposed in coaxial relationship and positioned about said image tube to provide image control of said electron beam in response to controlled variations of the electrical excitation applied to said coils by said electrical excitation control circuit means.

5. Apparatus as claimed in claim 2 wherein the image focus is a function of the magnetic field strength established by the electromagnetic coils in response to electrical excitations, and image rotation and magnification is a function of controlled magnetic field nonuniformity produced by interrelated control of the electrical excitation of the respective electromagnetic coils; said electrical excitation control circuit means providing independent adjustment of image focus, rotation and magnification.

6. Apparatus as claimed in claim 4 wherein said multiple electromagnetic coil means establishes a magnetic field and associated therewith a magnetic field symmetry plane corresponding to a plane normal to the axis of the coil means and passing through a point on the axis at which the radial magnetic field is zero, said symmetry plane positioned between said photocathode and said anode.

7. Apparatus as claimed in claim 6 wherein the magnetic field symmetry plane is positioned between the photocathode and anode at a distance from the photocathode of approximately 0.348 of the spacing between the photocathode and the anode, said symmetry plane position establishing unity image magnification and permitting independent control of image focus and rotation.

8. Apparatus as claimed in claim 6 wherein the magnetic field symmetry plane is positioned between the photocathode and anode at a distance from the photocathode of approximately 0.848 of the spacing between the photocathode and the anode, said symmetry plane position establishing zero image rotation and permitting independent control of image focus and magnification.

9. A method for precisely registering a photocathode pattern of an image tube on an electron sensitive anode work-

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piece by electromagnetic means, comprising: exciting said photocathode with a suitable radiation source, accelerating the electron beam pattern emitted by said photocathode toward said anode workpiece, and adjusting the strength of the magnetic field produced by said electromagnetic means to control pattern focus.

10. A method as claimed in claim 9 including the step of altering the uniformity of the magnetic field produced by said

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electromagnetic means to impart desired pattern rotation and magnification.

11. A method as claimed in claim 10 including the steps of: maintaining unity pattern magnification; and adjusting pattern rotation.

12. A method as claimed in claim 10 including the steps of: maintaining zero pattern rotation, and adjusting pattern magnification.

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