

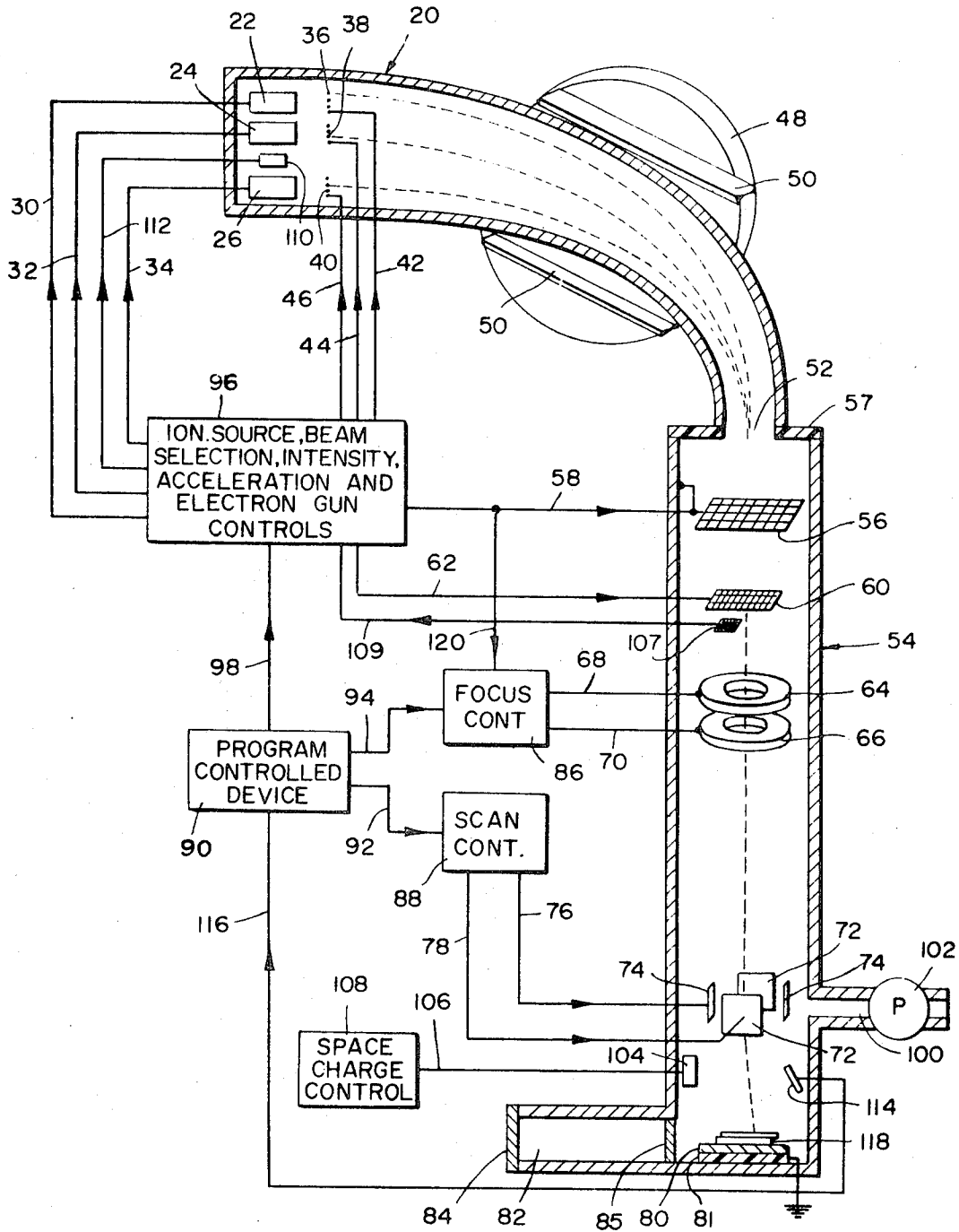
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METHOD OF FORMING MICROELEMENTS

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METHOD OF FORMING MICROELEMENTS

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8 Claims

ABSTRACT OF THE DISCLOSURE

A method of forming microelements of a given configuration by producing in vacuum a number of separate ion beams of materials, each beam being directed one at a time to a common path. Each beam is intensity controlled and is electrostatically focussed onto a common work piece. The focussed beam is deflected laterally to trace out a two-dimensional aspect of the configuration of the microelement, the ions being discharged along the trace to write-in the microelement, multiple layers being formed, if desired by depositing material on top of previously discharged ions. The method is preferably performed electronically in accordance with a sequence of instructions determining the parameters for a given type of microelement.

This application is a division of copending application Ser. No. 630,754 entitled Apparatus for Forming Microelements, filed Apr. 13, 1967, now U.S. Pat. No. 3,547,074.

This invention relates to microelements and particularly to a novel method of forming elements of microscopic dimensions.

In the last few decades, devices and techniques for effecting microminiaturization have become increasingly more important. In the field of optics, ruling engines and photographic methods are employed to provide even more precise optical devices, such as diffraction gratings, in which the grating period is typically of the order of several wave-lengths of visible radiation. In electronics, the entire field of microcircuits, including integrated and thin film circuitry, employs such well-known processes as thermal deposition or epitaxial growth through masks made by a photographic technique.

Typically, where photographic methods are used to reduce the desired arrangement of elements to miniature dimensions, several disadvantages are inherent, for example, the minimum lateral dimensions and the maximum precision of any lateral dimensions are fixed by the wavelength of light. Devices such as microcircuits formed of several layers, are generally produced in a series of separate, independent operations requiring considerable production time and frequently a series of changed conditions, each difficult to control. The set-up time for producing any particular type of circuit is quite long and small production runs or experimental tests of a number of different circuits become quite complex and expensive.

The problems of precision and speed become even more onerous where purely mechanical techniques are employed as in ruling of gratings. Clearly, wear and backlash sharply limit the precision obtainable in forming microelements mechanically. A fruitless attempt to avoid these problems was a broad proposal to form elements with a beam of ions and is described in the paper by W. E. Flynt in Proceedings—Third Symposium on Electron Beam Technology, Mar. 23–24, 1961, Boston, Mass., R. Bakish, Ed., Alloyd Electronics Corp., pp. 368–379, but no practical approach to implement the broad concept was provided.

A principal object of the present invention is to provide

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apparatus for forming microelements with extremely high precision and without recourse to photographic or purely mechanical techniques.

Other objects of the present invention are to provide a method of writing microelements with high accuracy; to provide a microcircuitry device wherein a beam of selected ions is focused and selectively deflected across a substrate to write-in a deposited microelement on the latter; to provide apparatus for writing microelements, and comprising a source of ions; means for forming a beam of such ions; means for focusing the beam to a focal spot; means for controlling intensity of the beam to a focal spot; means for controlling intensity of the beam; means for selectively deflecting the focal spot laterally; and means for discharging the ions at the focal spot so as to effect deposition on a substrate; to provide apparatus of the type described including a plurality of sources of different ions and means for sequentially depositing ions from a said source; to provide apparatus of the type described including means for testing microelements formed by such deposition; and to provide apparatus of the type described adapted for automatic programmed control of selection of ion source, beam intensity, focus, and deflection or any of them.

Generally, these and other objects of the present invention are achieved by apparatus including a hollow sealable elongated enclosure and pump means for maintaining the interior of the enclosure at a considerably reduced gas pressure, hereinafter generally called a vacuum. Adjacent one end of the enclosure are one or more sources for providing ions of materials that, when discharged, will plate out or deposit on a surface. Means are provided for forming a beam of ions and for focusing the beam to a focal spot. In order to write with the spot thus formed, i.e., to sweep the spot along a predetermined path wherein the ions are deposited, there is provided means for selectively laterally deflecting the focused beam. Means are further included for discharging the ions along the path or at the target after impact so that their deposition does not affect the trajectory of the beam by static buildup. Where more than one variety of material is to be deposited, means are provided for sequentially controlling the ion sources so that at any given time, the ion beam is homogeneous, i.e., is composed of the ions of but a single material.

In a desirable embodiment, means are included for producing and directing an electron beam at the deposited material so as to test and evaluate the microelement formed by the ion beam.

Several advantages are to be found in the invention over conventional microforming techniques. For example, not only conductive elements can be formed, but semiconductors, photoresponsive, capacitive, resistive and inductive elements can be included. Because the nature of the deposited or written material, speed of deposition, focal area, direction and speed of beam deflection can all be changed in microseconds, completed microelements can be formed in very short periods. The entire system, being electrically controlled, allows for programmed operation of the process either by direct computer interfacing or by a programmed memory. With internal test and evaluation, experimental design can be enhanced and improved programs prepared with high speed. The tooling process, for example, to prepare a circuit involves hereby loading the ion sources with appropriate materials and loading a program into a central unit. Thus, formulation of custom circuitry at reasonable prices becomes feasible.

The accuracy and resolution with which lateral dimensions of a microelement can be delineated in the present invention, is substantially increased over the prior art techniques. The ion beams can be focused to spots as

small as 100 A. in diameter if required which, therefore, can be traversed to form lines of similar width; this is quite beyond the capability of thermal deposition techniques.

These and other objects of the invention will in part be obvious and will in part appear hereinafter. The invention accordingly comprises the apparatus possessing the construction, combination of elements, and arrangement of parts and the several steps and the relation of one or more of such steps with respect to each of the others all of which are exemplified in the following detailed disclosure and the scope of the application of which will be indicated in the claims.

For a fuller understanding of the nature and objects of the present invention, reference should be had to the following detailed description taken in connection with the accompanying drawing wherein:

The drawing is a schematic cross-sectional view, partly in block diagram, of apparatus embodying the principles of the present invention.

Referring now to the drawing there is shown a micro-writing device comprising elongated, hollow, evacuable chamber 20 having disposed therein adjacent one end, a plurality of ion sources 22, 24, and 26. Typically, the materials to be provided by the latter will include such diverse substances as metals (e.g. silver, copper, aluminum) gases (e.g., halogens, oxygen) semiconductors (e.g., germanium, silicon and the like). Where, for example, the material from which ions are to be formed are gases or can be vaporized at low temperatures, the material can be readily ionized by electron bombardment in which case the particular ion source would, as well known in the art, typically comprise a small enclosure having a leakage port through which gas, in the interior of the enclosure, could pass at a controllable rate as a stream into the interior of chamber 20. An electron source, typically a heated cathode located adjacent the leakage port would provide an electron stream for ionizing the gas molecules and suitable electrical fields should be supplied for accelerating the electron stream and for sorting the ions into streams of preferred charge. Means (not shown) are preferably provided giving access to chamber 20 for loading the ion sources with appropriate materials.

Where the materials to be ionized are not gaseous or readily vaporized at low temperatures, high temperature molecular ovens can be used in the ion sources. The usual oven includes a refractory crucible similar in material to those used in thermal deposition devices, usually electrically heated. The crucible has an aperture therein through which a molecular beam can issue from the heated material. While frequently a substantial proportion of the molecules emerging from the aperture will be ionized, electron bombardment of the molecular beam is desirable to enhance the percentage of ions formed. Alternatively, electric arc sources can be used to provide ions of normally solid materials.

Typically, the ion source is one which can produce positive ion beams from a broad range of elements, such as the source sold as Model 910 by the Physicon Company, Cohasset, Mass., manufactured by Danfysik Jylinge, Denmark.

In any event the intensity of emission from all of these ion sources is derived from an electrical power source. Ovens are electrically heated and the emission intensity is a function of vapor pressure, hence of temperature and ultimately electric current. The emission intensity of arc sources is also a function of electrical current, as is the intensity of the electron beam producing the ionization. Thus, electrical control leads 30, 32, and 34 are respectively connected to sources 22, 24, and 26 to provide power to the latter.

While the emission intensity from each ion source can be controlled by regulation of its power supply, in order to achieve high-speed control there are provided adjacent each ion source, gating means for controlling the intensity

of the ion streams emitted from each ion source. To this end, across the path of ion emission from sources 22, 24, and 26 are provided respective mesh electrodes 36, 38 and 40. Appropriate bias potentials can be placed on any of the mesh electrodes through corresponding electrical leads 42, 44, and 46. Preferably, the ion sources are spatially located or arranged so that ion streams therefrom are substantially parallel to one another.

Alternatively, one can employ a divergence system in which plates instead of grids are used. In such case, the control potential applied to the plates should bar the ions or deflect the ion beam so that the latter impinges on the wall of chamber 20. This is an on-off type of control as distinguished from a continuous type of control obtainable with a grid.

Now it will be appreciated that when an ion stream passes through a magnetic or electrical field it will be deflected. If the field is magnetic, the deflection varies with particle charge, mass, and velocity; if the field is electrostatic, the deflection varies with the charge on the ion, its sign, and the ion energy. There is thus provided means for deflecting any ion stream from any source to a single common path. This is accomplished by disposing a magnetic field source, such as pole pieces 48 (one shown), and an electrostatic field source, such as plates 50, so that their fields are substantially orthogonal to one another and perpendicular to the path of the ion streams from sources 22, 24, and 26. With appropriate selection of field intensities and careful placement of the ion sources according to the material to be ionized therein an ion stream from any of the sources will be directed by the crossed fields into a single common path without any further adjustment of the fields. It will be appreciated that if substantially all of the ions coming from the sources are of the same velocity, crossed fields are not necessary. If variation in ion velocity is desired, it can be achieved after the beams have been channelled to a single path, by using a variable additional acceleration. Alternatively, the fields can be so chosen as to improve the uniformity of the ion energy, by allowing only the fraction within a certain velocity to be directed towards the exit.

This permits one to rapidly change sources as by biasing of mesh electrodes 36, 38 and 40 to full open or to cut-off, yet permitting the ion stream, regardless of the source chosen, to be directed to the same path. Thus, chamber 20 as shown is curved to conform to the general path of ions from the various sources, an exit aperture 52, defining the final common path for the ion stream, being provided in chamber 20.

It will be seen that, in essence, the structure and function of chamber 20 and field sources 50 and 48 is akin to the well-known mass spectrograph in that the same basic principles are involved, although the present structure operates in the reverse to a mass spectrograph.

Aperture 52 is coupled to another elongated, hollow evacuable chamber 54. The axis of elongation of chamber 54 lies parallel to the mean path of ions passing through aperture 52.

Means are provided in chamber 54 adjacent aperture 52 for providing an accelerating or decelerating field to ions within chamber 20 and typically comprises mesh 56 connected to the cylindrical walls of chamber 54 and isolated, as by insulation 57, from those of chamber 20. A potential of appropriate polarity derived through lead 58 can be impressed on mesh 56 creating a constant field region within which other components are disposed. Of course, mesh 56 is disposed to not substantially obstruct the passage of ions into and through chamber 54.

Disposed in chamber 54, typically adjacent aperture 52, are means such as control grid 60, positioned to intercept the path of the ion stream, for providing fine control of the intensity of the ion stream. Grid 60 is connectable to a potential source through lead 62. Downstream from grid 60 are particle lens means such as apertured disks 64 and 66, for variably focusing the ion

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stream to a focal point in a beam of controllable cross-sectional characteristics. The structural details and operating parameters of particle lenses are well-known and need not be repeated here. However, such lenses should be of the electrostatic type rather than electromagnetic primarily because the focusing of electromagnetic lenses cannot be modulated as quickly as an electrostatic lens can be, and one can deflect or focus ions of different masses in the same manner with an electrostatic lens but not with an electromagnetic lens. This last consideration is highly pertinent here, because the microwriter is intended to employ sequentially a number of streams of ions of different weight, each of which would require a change in the magnetic field of a lens system to be focused to the same point. With the electrostatic lens, field changes are not required to maintain focus. Disks 64 and 66 are respectively connected to leads 68 and 70.

Located downstream, past the electrostatic lens means, are beam-scan or deflection means such as two sets 72 and 74 of plates for providing controllable two-dimensional scanning. The positioning of the deflection means is typical, but the deflection means can also be located upstream of the lens means or even between the elements of the latter. Thus, set 72 comprises two approximately parallel, spaced-apart plates electrically connected to one another as by lead 76 and disposed such that the focused ion beam can pass between the plates. Set 74 is similar to set 72 but the plates of set 74 are orthogonal to the plates of set 72 in the usual manner. The plates of set 74 are connected in common to lead 78.

Disposed adjacent the focal point of the beam of ions is movable support means such as block 80 which is preferably of a highly heat conductive material so as to serve as a heat sink. Block 80 is of electrically conductive material and is electrically insulated from contact with the walls of chamber 54 as by insulating layer 81. In order to insure discharge of ions incident thereat, block 80 is connected to ground or to some fixed potential with respect to the ions. Means may be provided, if desired, for refrigerating or cooling block 80. In order that block 80 can be selectively inserted into or removed from the interior of chamber 54, there is provided an air lock comprising enclosure 82 having movable partitions 84 and 85 at opposite ends, the latter partition forming a wall in common with chamber 54. Appropriate means (not shown) are preferably provided for pumping down enclosure 82.

Connected to leads 68 and 72 is means, shown in block form at 86, for controlling the focus provided by disks 64 and 66, by variation of the electrical potential applied to the latter. Such focal control means are well known in the art, such as in electron microscopes, so need not be further detailed here. In similar manner, the deflection plates of sets 72 and 74 are connected by leads 76 and 78 to deflection or scan control means shown in block form at 88. The latter also is well known in the art, particularly in connection with cathode ray devices. While both the scan control means and focus control means can be individually and manually adjustable, it is preferred that their operation be subject to automatic control. Hence, program controlled device 90 is provided and connected with both the scan control means, as by lead 92, and the focus control means, as by lead 94, so as to adjust focus, scan or both in accordance with a predetermined program.

Device 90 can simply comprise an information storage readout system, such as a magnetic tape reader and a group of known analog controls, responsive to the information on a magnetic tape, typically for providing signals to means 86 and 88 respectively to govern the magnitudes of the potentials provided by the latter to the respective focusing elements 64, 66 or/and the deflection plate sets 72 and 74. Alternatively, device 90 can be an interface with a computer so that the information governing operation of the microwriter is derived directly from

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computation rather than from a storage medium. Device 90 is also intended to provide signals governing the other functions of elements of the microwriter such as ion activation, ion stream selection, fine intensity control and accelerating voltage. In order to simplify the description, a single control means is shown at 96 for controlling these functions as by being connected through leads 30, 32, and 34 respectively to ion-sources 22, 24, and 26 by leads 42, 44, and 46 respectively to electrodes 36, 38, and 40 by lead 58 to plates 56, and by lead 62 to grid 60. Hence, control means 96 is in turn under the control of program controlled device 90, being connected to the latter by multiple lead cable 98, over the leads of which, the particular signals can be transmitted to control each respective operation.

Chamber 54 includes an exhaust outlet or port 100 to which is coupled pump 102 for reducing the gas pressure inside chambers 54 and 20, i.e., evacuating them. Shown schematically is element 104 for reducing space charge effects due to the discharge of the ion stream upon discharge of the latter. Hence, element 104 is preferably located adjacent block 80. Element 104 is one of a number of different devices capable of preventing static buildup at block 80 by rendering conductive the very low pressure residual gases adjacent block 80. Typically, element 104 is a small microwave antenna intended to have sufficient microwave power applied thereto as to ionize the residual gases. Such ionization should be limited to gases as near to the surface of block 80 as possible in order to prevent the trajectory of the ion beam from being affected. Thus, element 104 is connected by lead 106 to a source 108 of microwave power which is preferably adjustable. Alternatively, of course, element 104 can be a gamma or beta ray source, an electron gun providing a large aperture electron beam for directly discharging the target, or the like.

Lastly, in one embodiment of the invention, positioned adjacent the ion sources, such as 22, is electron scanning beam source 110, typically an electron gun with beam deflection mechanisms. The latter is connected by lead 112 to control means 96 so that the intensity of the electron beam and its position can be controlled by the latter. Positioned adjacent block 80 is electron collector means 114 which is connected via lead 116 to feed back signals received by collector 114 into programmed controlled device 90.

In a typical mode of operation, ion sources 22, 24, and 26 are each loaded with a different one of the desired materials, and positioned according to the nature of the materials so that an ion stream from any of the ion sources will ultimately be deflected by the fields of the reversed mass spectrograph to a common path through aperture 52. A chip of substrate material 118 is inserted through air-lock 82 and emplaced on block 80. Preferably, chip 118 is bonded to block 80 with a low melting point solder so that there can be optimum heat transfer from the chip to the block. The chip itself can be a number of materials, preferably of high heat conductivity. Thus, where it is desired to use a dielectric substrate, the latter can typically be beryllia, alumina, or the like both of which are excellent heat conductive materials. Alternatively, the substrate can be an electrically conductive material most of which are good thermal conductors and the selection thereof is a matter of choice. If the microwriter is to be used to form a semiconductor circuit, the chip can be germanium, silicon or the like.

Chambers 54 and 20 are then sealed and pump 102 is operated until the two chambers are evacuated, typically to a pressure of about 1×10^{-7} mm. Hg. Ion sources 22, 24, and 26 are then operated to produce ion streams, only one of which at a given instant is allowed to traverse the magnetic and electrical fields provided by pole pieces 48 and plates 50. The ion stream passes through aperture 52 and through mesh 56 on which an acceleration or deceleration potential with respect to the ion

has been placed. The intensity of the accelerated ion stream is, of course, roughly controlled by the nature of the potential appearing at the respective one of the mesh electrodes 36, 38, or 40 and is fine controlled by the potential appearing at grid 60. A small sensor grid 107 picks up a signal proportional to the ion beam intensity which can be fed back to control means 96 along lead 109 to provide a feedback signal for adjusting the fine control potential as desired. The intensity of the ion stream, of course, determines, at least in part, the deposition rate of the ionized material on chip 118. but the beam should be of comparatively low energy so as to prevent deep penetration of the ions into the chip or undue heating of the latter as well as excessive sputtering. While this may make good focus somewhat more difficult to obtain, it is not a serious problem as the resolution obtainable is still excellent. Typically micron size spots can be had with ion currents of the order to 10^{-5} A. If more than simply deposition is desired, the energy of the ion stream can be controlled to yield some penetration, for example, to provide localized doping of semiconductor layers to a given depth, or to provide electrical contacts through a continuous layer of insulation. The intensity controlled ion stream is now focussed by disks 64 and 66. Depending upon the configuration of the disks the beam can be focused to a small circular spot or to an elongated ellipse as desired, depending upon the positions and the pattern which the beam is to lay down. Of course, the nature of the focus provided by disks 64 and 66 is under the control of focus control means 86 so that changes in focus can be achieved very rapidly and automatically depending upon the potential the disks have imposed thereon. Inasmuch as the potentials required for focus must be varied to accommodate for changes in beam energy, means are provided to adjust the focus control according to the potential on plates 50. Hence, the latter are connected to the focus control means by lead 120.

The now focused beam is moved laterally in direction and at speeds determined by variation in the potential on the plates of sets 72 and 74 as controlled by scan control means 88 in accordance with signals from programmed controlled device 90. The focused beam striking chip 118, deposits the ions on the latter, where they discharge and rapidly build up to form a layer of the material. Lateral deflection of the beam allows this layer to be laid down continuously as a strip, the width of which is determined by the cross-section of the beam. The tendency for a static charge to build up adjacent chip 118 due to ion discharge is reduced by the ionizing or neutralizing radiation provided by element 104.

The various operating parameters, of course, depend on the nature of the device being formed by the invention, and are largely under the control of the various control means. Typically, a number of the criteria upon which controls are based, and on the basis of which a program can readily be established either manually or by computer, are set forth in the following discussion.

Obviously, the larger the beam deflection rate becomes, the thinner the deposits produced and vice-versa. To achieve maximum production in minimum time, one should select the highest possible deposition rate and the lowest possible size of the element being formed. Generally, the deposition rate is proportional to the beam current which is in turn limited by the maximum power density which chip 118 will stand and the maximum space charge density that can be compensated by the focus system. Both of these latter parameters decrease as the focal spot size is decreased; thus for maximum production speed the spot size should always be the largest one allowed by the actual component being laid down or written. Deposition speed can be increased by making the spot elliptical, which increases the maximum allowable current for given allowable heating effects and space charge.

For a given temperature maximum to which the chip

can be brought, the allowable beam power increases as the spot size. If the spot size is increased, however, the current power increases as the square of the spot size and therefore spot size should be limited to only one value for each accelerating voltage and ion weight for a given substrate and focus system. For example, assuming a 5μ spot, and a substrate of high thermal conductivity beryllia, a total beam power of 0.5 watt would result in a temperature rise of about 107° C. Admissible temperature increases are limited to a few hundred degrees, thus placing a limit on the maximum power density. This is somewhat higher when the beam is being deflected, which spreads out the heating effect. Of course, higher temperature increases are possible if block 80 is cooled below ambient temperature.

One can calculate the amount of current that space charge limits will allow. For example, if one assumes a 5μ spot and assumes the tolerable power is 0.5 watt as the result of a 100 kev. beam with a current of 5μ a. and composed of Al^+ ions, one finds a space charge potential of about 15 kv., corresponding to a feasible beam half-angle of 0.15 radian. These values correspond to a deposition speed of about 265,000 A./sec. and are enormous in comparison with the present speeds in thermal evaporation techniques. The stated deposition rate corresponds to about $0.272 W_{at}^{1/2}$ μ g./sec. where W_{at} is the atomic weight for a singly charged ion, and g. is the weight in grams. Typically, for aluminum this amounts to 530 μ^3 /sec. if expressed in volume. While this appears small, it is in actuality an adequate quantity in view of the degree of miniaturization of the devices which the invention is capable of producing.

Exemplary volume deposition rates in μ^3 /sec. for a variety of other elemental materials are as follows:

C	420	Ni	230
Li	2110	Eu	240
Be	940	Zn	310
B	390	Ge	430
Na	1340	Ga	380
Mg	730	As	410
Si	600	Se	560
S	740	Ag	270
K	1930	Sn	410
Ca	1110	Sb	470
Ti	420	Te	470
Cr	270	Cs	1670
Mn	280	Ba	910
Fe	260	Ta	220
Co	230	W	190
Au	200	Pb	350

Mixed compounds also can be deposited by cycling two or more ion streams at a sufficient repetition rate so that layers of solid material, typically of 10 A. thickness are successively laid down. Thus, for example, a BeO strip can be produced by successively depositing very thin films of Be and each in turn being bombarded with a slight excess of O ions before the next layer of Be is deposited. Thus, neglecting the very minute switching time involved in changing the nature of the ion beam, typical volume deposition rates in μ^3 /sec. for mixed materials or compounds are as follows:

BeO	290	ZnS	470
MgO	320	GaAs	430
Al_2O_3	280	SiO	540
TiO_2	140	SiO_2	460

A number of unconventional components can readily be produced with the invention. For example, in integrated or thin film circuits it is difficult to produce really large capacitors, as multiple layer capacitors require too many fabrication steps and single layer ones will require unacceptably large lateral dimensions. The first limitation does not apply to the present invention. Typically, thin alternate layers of conductor and insulators can be

very easily deposited on top of one another, with a speed limited only by the heating of the substrate. Another factor which will decrease the area required for a given capacitor is that some of the best dielectric materials, such as the titanates, can be used here without the unacceptable charge leakage rate produced in the thermally deposited material as a result of chemical changes during exaporation. The latter are prevented here by the deposition of excess oxygen. Typical capacitors will then consist of a number of dielectric layers, as thin as may be allowed by tunnelling phenomena (typically several hundred angstroms), separated by thin metal layers.

The conductive layers can typically be formed of deposited aluminum because of its chemical resistivity and because outside layers can be easily insulated by bombardment with oxygen ions. Silver can also be used for conductive layers because of its high conductivity; to provide insulation of outside surface layers, the silver can be treated with sulfur ions. Calcium will also serve well as a conductor but it must be well protected at least on outside layers, typically with a surface layer of aluminum or aluminum oxide. An added advantage of calcium layers in capacitors is that if it partly reacts with a TiO_2 insulating layer, the reaction product, CaTiO_3 , is of even higher dielectric constant.

Typically, a calcium-calcium titanate capacitor can be made to the following specifications: assume that the capacitor has a $5 \times 50\mu$ elliptical shape with 10 layers, the Ca conductive layers being 100 A. thick and the dielectric layers of TiO_2 being 250 A. thick between the Ca layers and on the top and bottom of the capacitor. This can be produced in less than about 30 msec. Such a capacitor would have a series internal resistance of about 1 Ω and a capacitance of about 1770 pF.

Attempts to produce printed circuit inductors by thermal vapor deposition techniques have not been very successful as the highest inductances obtained are about 1 ΩH , and they have Ω 's below 20. The main reasons of this is that one cannot readily produce the most efficient shape, i.e. a coil, which requires two steps or mask changes for each turn of the coil and near perfect registration of successive masks between turns.

In the present invention these problems are not serious inasmuch as changes between steps are very quick and registration is much simpler in that no mask is required. In order to take advantage of the increase in deposition speed produced by an elliptical spot, a substantially square coil shape is preferred. The procedure involves depositing four elliptical spots of conductor with tips in contact to form a square and then overcoating all but one tip with an insulator. The next turn of the coil is started by depositing a fifth spot on top of the spot having the uncoated tip, and so on for as many turns as are desired.

Typically, such a coil is made using aluminum as a conductor and forming the insulating layers from beams of aluminum and of an excess of oxygen ions cycled at a rate sufficient to insure that the aluminum is fully oxidized after deposition. This method requires but two ion sources. If desired, another ion beam can be used to deposit a central core of ferrite material to increase the inductance. An exemplary coil formed of $\text{Al-Al}_2\text{O}_3$ used a spot which has an ellipticity of 10 and a minor diameter of about 100μ . This can be used to form a coil 1 mm. on each side width, for example, 200 turns of 500 A. thick aluminum to provide an inductance of about 96 μH , having a Ω of about 30 at 200 MHz. This coil can be produced in less than 1 sec.

Better results can be obtained using a three ion-source system to provide conductive layers of Ag and insulators of BeO . Because the higher thermal resistance and conductivity of the system allows an increase of the thermal load, a similar coil can be produced in less than 0.3 sec. with a Ω of about 50 at 200 MHz.

The presence of electron source 110 and collector 114 gives the invention even more flexibility. Essentially, then the device can be used alternatively as an electron scanning microscope. At any stage of writing, the ion beams are shut off, as by biasing electrodes 36, 38, and 40 and the electron source 110 turned on. The resulting electron beam is focused onto the surface of chip 118 and scanned across the written or deposited material. The potential difference between adjacent areas of the deposited material and substrate alter the intensity of the secondary electrons emitted or the primary electrons reflected, and is then detected by collector 114, creating a signal train that can, if desired, be converted in the usual manner into an image on a cathode ray tube screen. Preferably, this signal train is fed back through lead 116 to program controlled device 90 where the latter is computer controlled in order to adjust any program being computed to accord with the observations being made by the electron beam.

The attributes of the present invention make it particularly adapted for yet other unique applications. Because it can produce miniature components with an extremely high packing density, it can be used to produce very compact electronic memories and indeed, the electron beam aspect of the device can be used to read-out the memory whilst the ion beams can be used not only to write-in memory of elements but to erase them as by coating selected memory elements with an insulating layer. The device can also be used to produce very fine optical gratings and reticles, not only at much higher speed than can presently be achieved with ruling engines but of many materials that cannot readily be machined.

Since certain changes may be made in the above apparatus and processes without departing from the scope of the invention herein involved it is intended that all matter contained in the above description or shown in the accompanying drawing shall be interpreted in an illustrative and not in a limiting sense.

What is claimed is:

1. Method of forming a microelement of a given configuration on a work piece, comprising the steps of: substantially simultaneously producing a plurality of ion beams each of different deposition materials and each beam being directed along an individual path substantially in a vacuum; directing each of said beams along its individual path to a predetermined common path in said vacuum; controlling said beams so that only one of said beams at a time can traverse said common path; electrostatically focusing any beam traversing said common path onto said work piece; deflecting laterally in two dimensions any beam traversing said common path so as to trace out a predetermined path across said work piece; and discharging the charge on ions of any beam incident on said work piece so as to deposit said material along said predetermined path.

2. Method as defined in claim 1 wherein said beam is electrostatically focused to an elliptical spot onto said work piece.

3. Method of forming a reactance on a substrate and comprising the steps of:

- substantially simultaneously producing in vacuum a plurality of beams of ions each directed along an individual path, the ions of at least a first of said beams being of normally electrically conductive material, the ions of at least a second of said beams being of material capable of forming an insulating material upon bombardment of a layer of material from which the ions of one of said beams is formed; directing said beams, only one at a time according to a given sequence, through a common fixed path; focussing said beams in said sequence onto said substrate;

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deflecting each of said beams laterally across said substrate along a predetermined path covering a given area and discharging the ions of said beams so that said ions deposit onto said substrate; and

alternating said beams so that a sandwich of successive layers of conductive and insulating material are deposited on said substrate.

4. Method as defined in claim 3 wherein said plurality of beams includes only a beam of ions of said conductive material and a beam of ions of said material capable of forming an insulating material.

5. Method as defined in claim 3 wherein said plurality of beams includes at least three beams, the ions of two of which are of different normally electrically conductive materials.

6. Method as defined in claim 3 wherein said successive conductive layers are electrically insulated from one another, so as to form a capacitor.

7. Method as defined in claim 3 wherein adjacent ones of said successive conductive layers are in electrical contact with one another at minor portions staggered from layer to layer so as to form an inductive coil.

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8. Method as defined in claim 7 wherein said path defines a centrally apertured area and including the step of employing one of said beams to deposit a core of ferrite material in said central aperture of said area.

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