

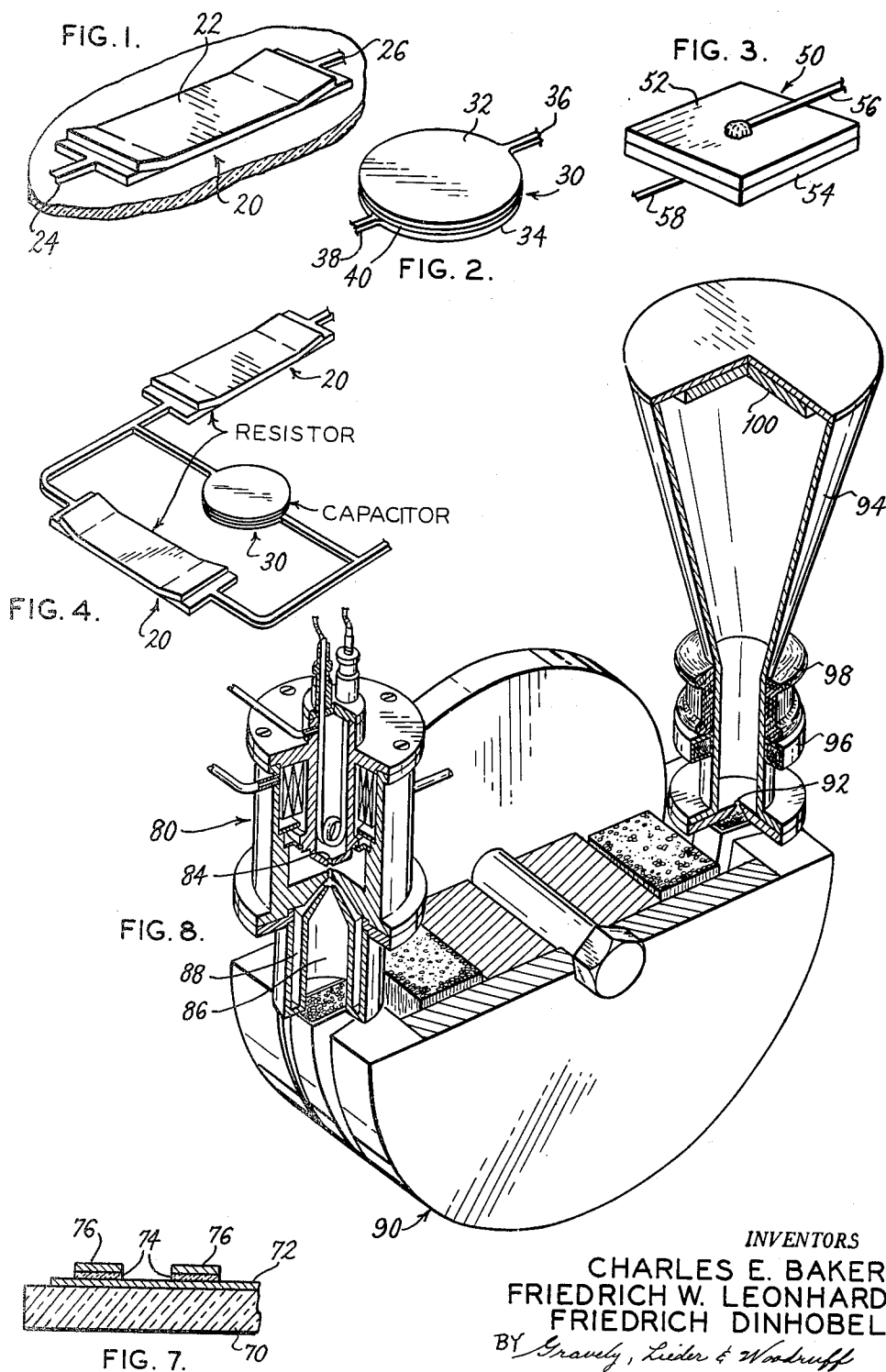
April 12, 1966

C. E. BAKER ETAL
ION BEAM DEPOSITION AS A MEANS OF MAKING
ELECTRIC CIRCUITS AND CIRCUIT ELEMENTS

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2 Sheets-Sheet 1



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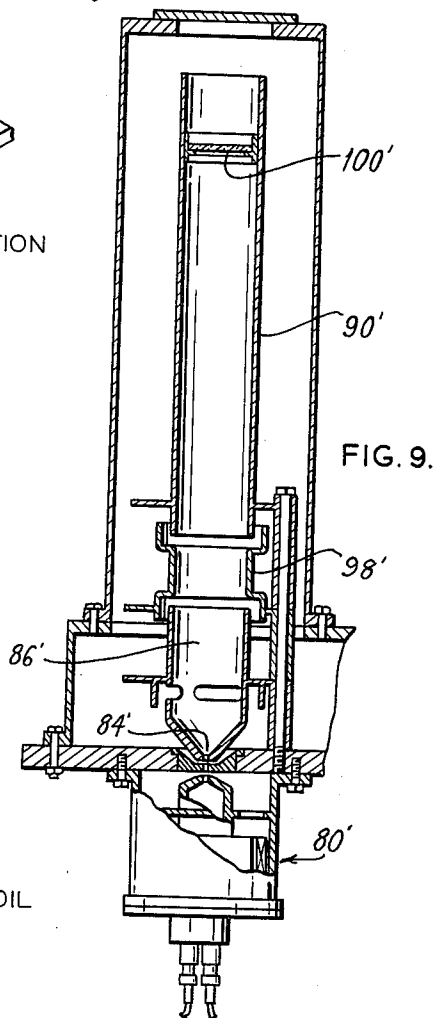
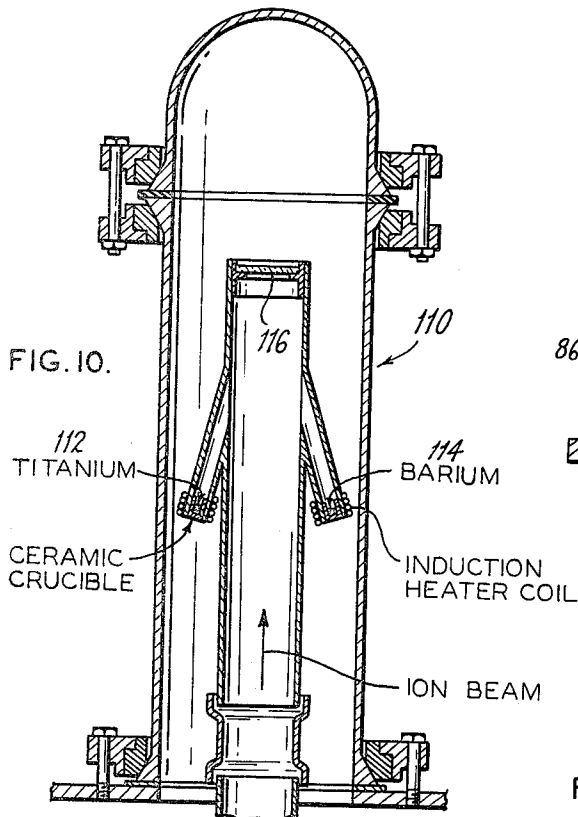
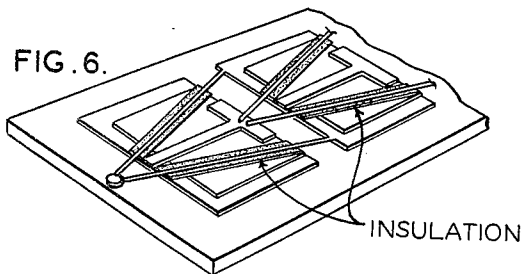
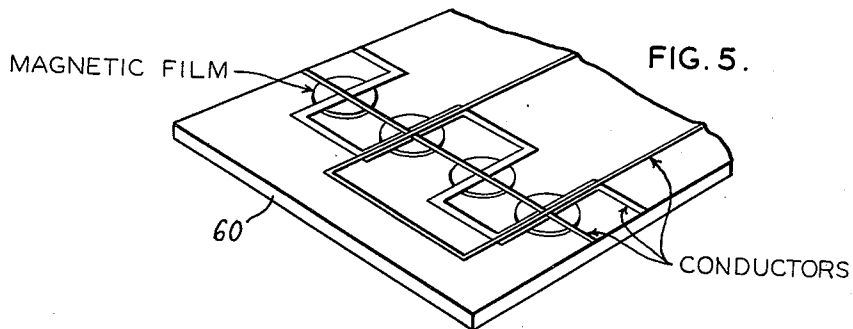
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ION BEAM DEPOSITION AS A MEANS OF MAKING ELECTRIC CIRCUITS AND CIRCUIT ELEMENTS

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The present invention relates generally to means and methods for making electric circuits and circuit elements and more particularly to means and methods employing ion beam deposition in the construction and formation thereof.

Many devices and methods have been developed and employed in the past for constructing circuits, circuit elements and other electrical and optical devices. So far as known, however, none of the known devices or methods have employed means in the form of a beam of charged particles, such as an ion beam, in the successful formation of circuits and circuit elements.

Prior attempts at making circuits and circuit elements from materials having certain desired characteristics have been unsatisfactory for a variety of reasons and have also been limited as to the number and kinds of materials that can be used. Furthermore, all prior attempts to make circuits and circuit elements from such materials have included as a step thereof, baking the materials at relatively high temperatures for relatively long periods of time. This has damaged the materials and has resulted in the production of inferior materials and elements, and has produced undesirable side effects, contamination, and structural and textural changes of the material being formed and of the materials adjacent thereto.

Furthermore, the equipment required for known means and methods have been relatively expensive and complicated to make, and have been inconvenient, inaccurate, cumbersome and difficult to operate, and for these and other reasons are unsatisfactory. The known equipment has also employed masking devices to outline the area of treatment or deposition and this has resulted in considerable waste and inefficiency.

Another disadvantage of the known means and methods is that the extreme temperatures that are required have prevented the materials being formed from remaining in contact with adjacent materials after cooling due to the differences in the coefficients of expansion and contraction of the several adjacent materials. This has also resulted in the production of inferior elements.

These and other disadvantages and shortcomings of the known means and methods for forming circuits and elements are overcome by the present invention, several embodiments of which are illustrated and described in this specification.

It is therefore a main object of the present invention to provide improved means and methods of forming circuits and circuit elements.

Another main object is to produce materials having desired electrical, optical or other characteristics by exposure to ionized particles which cause an ion reaction therewith.

Another object is to form circuits and circuit elements of materials which develop their desired electrical characteristics only after exposure to an ionized atmosphere.

Another object is to minimize the heat required to produce circuits and circuit elements.

Another object is to provide improved means for miniaturizing circuits and circuit elements.

Another object is to provide improved means and methods of producing objects such as electrical components

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in desired sizes and shapes and from materials having desired electrical characteristics.

Another object is to provide means for forming thin layers of materials such as ferromagnetic and ferroelectric materials.

Another object is to provide means for exposing substances to beam treatment to produce therefrom substances having predetermined electrical or optical characteristics.

Another object is to provide means for producing materials having predetermined characteristics by a process involving evaporation and condensation of one or more constituents in the presence of an ionizing atmosphere.

Another object is to increase the number of materials available for the construction of electrical, optical and photosensitive devices.

Another object is to provide means for making anisotropic substances and substances having relatively high dielectric properties.

Another object is to provide means for depositing a layer of an element on a surface.

Another object is to provide means to control the area of deposit of a substance without requiring masking devices.

Another object is to increase the efficiency and reduce waste in devices for transferring matter employing ion beams.

Another object is to provide means for oxidizing materials by exposure to ions of an inert gas in the presence of an oxygen atmosphere.

Yet another object is to provide relatively inexpensive yet versatile means for forming circuits and circuit elements in many different sizes and shapes using ion beam deposition and exposure.

Briefly, the present invention comprises an ion source, and means for directing ions from said source in a preselected pattern and intensity onto a surface to form a layer thereof. Another form of the invention includes means for directing an ion beam of a non-metallic material onto a substance capable of reacting to said beam to change the electrical characteristics thereof. In some forms of the invention focusing and deflection means are also provided for controlling the movement and area distribution or pattern of the ion beam to thereby produce a deposit or reaction only with preselected portions of a surface or substance. These and other objects and advantages of the present invention will become apparent after considering the following detailed specification of several embodiments of the invention in conjunction with the accompanying drawings, wherein:

FIG. 1 is a perspective view of a resistor element constructed according to the present invention;

FIG. 2 is a perspective view of a capacitive element constructed according to the present invention;

FIG. 3 is a perspective view illustrating a semiconductor or transistor device constructed according to the present invention;

FIG. 4 is a perspective view of an electric circuit including circuit elements constructed according to the present invention;

FIG. 5 is a perspective view of another circuit constructed according to the present invention;

FIG. 6 is a perspective view of a circuit having insulation material therefor constructed according to the present invention;

FIG. 7 is an enlarged cross-sectional view showing the arrangement of parts in an electric device such as a capacitor constructed according to the present invention;

FIG. 8 is a perspective view, partly in cross-section, illustrating an ion beam unit used in the construction of

circuits and circuit elements such as those shown in FIGS. 1-7;

FIG. 9 is a perspective view showing another form of ion beam unit constructed according to the present invention; and

FIG. 10 is a cross-sectional view of an ion beam unit in combination with an evaporation unit for forming circuits and circuit elements according to a modified form of invention.

Referring to the drawings by reference numbers, the number 20 in FIG. 1 indicates a resistor element constructed according to the present invention. The element 20 is formed by a thin film of metal 22 deposited on a dielectric material or substrate. The opposite ends of the thin layer 22 are provided with connection leads 24 and 26 which can, if desired, also be formed by the method of the present invention as will be shown hereinafter.

In FIG. 2 a capacitor element 30 is shown formed by two spaced thin metal films 32 and 34 connected respectively to leads 36 and 38, and separated by a thin dielectric layer 40. All three layers of the capacitor 30 can be formed using the ion beam principles of the present invention.

In FIG. 3 there is shown a semiconductor device such as a semiconductor diode or transistor 50 which is formed as a wafer having an upper (p) layer 52, a lower (n) layer 54, connecting leads 56 and 58, and a junction formed between the layers 52 and 54. In this case the junction between layers is formed by bombarding with ions for the purpose of injecting impurities as a doping agent to produce the desired characteristics, in the manner of the present invention.

FIG. 4 shows a portion of an electric circuit including the wiring, the resistors 20 similar to the resistor shown in FIG. 1, and the capacitor 30 similar to the capacitor shown in FIG. 2. In this case, all or part of the circuit and circuit elements are formed by materials which are either deposited by an ion beam or develop their desired electrical properties after being exposed to an ion atmosphere or beam. In this case the different elements can be deposited or exposed individually or in some cases simultaneously, as desired.

FIG. 5 shows a block or template 60 having thereon a circuit including the circuit elements and connections therefor constructed according to the present invention.

FIG. 6 shows another circuit which can be formed entirely or in part according to the present invention. In this case, the circuit leads and elements are insulated by material which obtains its insulating character only after being exposed to an ion beam.

FIG. 7 is an enlarged cross-sectional view of an element formed of several different layers of material, one of which has been exposed to an ion beam. In this case, the element is formed of a non-conductor base, such as glass base 70, and includes a conductor member 72 attached to the glass, a pair of insulator members 74 formed on or attached to the member 72 and exposed to an ion beam to obtain the desired electrical insulating characteristics, and another layer of electrical conductive material 76 positioned on top of the insulator materials 74. The conductors 72 and 76 can be formed by ion deposition of an element such as aluminum, and the layer 74 can be formed of a ferroelectric substance which is exposed to a non-metallic ion beam such as an oxygen ion beam.

A great many substances can be selected for exposure to ion beams to develop desired properties. Some of these substances when exposed produce materials having a dielectric or insulating characteristic and others when exposed produce materials having desired conductive, resistive, or magnetic characteristics. In all cases, however, it is usually desirable that the material being exposed be in relatively thin film form so that exposure can penetrate the full thickness to obtain a final product that is uniform throughout. Ferromagnetic and ferroelec-

tric substances have demonstrated characteristics which are particularly well suited for this purpose.

In the formation of the substances to be exposed to ion beams it is contemplated to produce the layers by an evaporation and condensation process. It is also possible to expose thin sheets or foils of the desired materials to an ion beam. These can then be attached to a suitable surface or members in a variety of ways such as by adhesive means to produce the desired element. Still further, it is also possible to use a thicker layer or object of a substance and to penetrate it to a specific depth to produce a surface portion or coating having the desired characteristics. The energy of the beam determines the depth of the penetration. In all of these cases the exposed substances develop their desired electric or optical characteristics only after being exposed to an ion beam.

All of the layers forming any given circuit or element can also be constructed in any desired size, shape or thickness depending upon the desired electrical and physical requirements.

Furthermore, the layers can be made extremely small, extremely thin, and extremely close together. This makes the present invention particularly well suited for circuit miniaturizing. For example, using the present means and method the conductor 72 of FIG. 7 can be spaced very close to the conductors 76 and the element 74 can be made to have a very high dielectric constant to form a capacitor element of relatively large capacitance for its size even though the overall size of the capacitor itself is extremely small. This is possible because the capacitance varies inversely with the spacing of its conductor members and also varies directly with the dielectric constant of the insulator material.

Devices made from ferromagnetic oxide components have been found to be particularly useful in the fields of information storage as for example in the construction of magnetic tapes and drums. They are also used in the construction of magneto-optical elements, and in many other electrical and optical devices. There are also many other applications for materials which can be produced in the manner taught by the present invention. These include applications requiring isotropic and anisotropic substances having metallic as well as non-metallic properties. These substances like those already mentioned, when exposed to ion bombardment, such as bombardment by non-metallic ions, such as oxygen ions, react by having their chemical structure changed, and in so doing produce materials having many desirable properties such as photosensitive properties which otherwise are difficult, if not impossible, to obtain.

In the forming of insulators, the exposed materials are usually selected from the group of metallic substances which react by forming insulating oxides thereof. The oxides of several such materials are known to have highly desirable electrical characteristics and are particularly well suited to the construction of certain kinds of electrical elements. Furthermore, by exposing certain metallic materials or objects to ion bombardment it is possible to form surface insulating layers or coatings thereon which are of relatively uniform thickness, and which are free of small pin holes or openings therethrough which could cause short circuits. Heretofore, it has not been possible using known evaporation and condensation processes to make such coatings which are free of pin holes and of uniform thickness. This, therefore is an important advantage obtained by the present invention and is particularly useful in the manufacture of certain kinds of devices such as tunnel effect devices. Furthermore, by means of the present device the penetration depth or thickness of the coating can be controlled by controlling the ion energy.

Some oxide compounds such as the ferroelectrics also offer promise. Three such oxide compounds which offer particular promise in the electrical field are barium titanite (BaTiO_3); strontium titanite (SrTiO_3) and lead tita-

nite (PbTiO_3). Many other dielectric and conductive materials are also being tested. Thin films of these oxide compounds are in great demand particularly in the field of miniaturization and micro-miniaturization of electrical components.

In the past it has been found that high vacuum evaporation of the ferroelectrics has not been feasible because of the thermal decomposition that takes place and also because of the high prolonged heat required in their formation. By means of the present invention, however, it is contemplated that the metallic constituents of the ferroelectrics or other material being produced may be deposited by an evaporation and condensation process in the proper proportions and exposed to a non-metallic ion beam to react therewith and form the desired compounds. The ferroelectrics or other materials to be exposed can also be provided in sheet form if desired.

When using the method of evaporation and condensation in the presence of ion beam exposure, the desired reaction usually takes place as the material condenses and forms on a substrate. A means and method for the simultaneous evaporation and ion exposure to produce the required elements will be described hereinafter in connection with FIG. 10. It should be noted, however, that it is important to maintain the proper ratio of the constituents, known as the stoichiometric ratio, during the evaporation and condensation of the constituents in order that the layer being deposited on the substrate be uniformly formed and have the desired electrical characteristics. By using this method, or in the alternative the method of exposing a thin film of the metallic constituents to ion radiation, the reaction takes place at a relatively low temperature and requires relatively short exposure periods. This is true because of the relatively high chemical affinity of ions as compared with neutral particles. This is extremely important to the satisfactory operation of the present invention because it enables the elements being formed to be securely attached to adjacent layers or substrates, without coming loose or being damaged by heat, and without damaging the adjacent layers of substrates. Furthermore, by being formed at a relatively low temperature, the differences in the coefficients of expansion and contraction of the adjacent materials has little or no effect to prevent a good bond between adjacent layers when the materials cool.

One form 110 of the present device is shown in FIG. 10 and is used for exposing substances to ion treatment. In the construction of FIG. 10 provision is made for evaporating and condensing the metallic constituents 112 and 114 of the layer to be formed on a surface 116 while at the same time exposing the condensing layer to an ion beam so that a reaction takes place in which the desired material is produced. For illustrative purposes the constituents are identified as titanium and barium but it is to be understood that many other constituents can also be used. It is also necessary to provide suitable means to control the area distribution of the ion beam and the rate of evaporating and condensation of the constituents to produce uniform components. It is also expected that the reaction between the metallic constituents and the ion particles will usually take place at relatively low temperatures because of the relatively high chemical affinity of ions as compared to neutral particles and therefore the finished product will not be damaged by heat.

It is also contemplated in the several different forms of the invention shown and described herein that the same or similar result could also be achieved by positioning the substance to be exposed in an oxygen atmosphere and expose the substance or its constituents to a beam of ionized particles such as an ionized beam of some inert gas.

In FIGS. 8 and 9 there are shown two different forms of an ion beam unit for depositing a film of material on a surface. In FIG. 8 the device is shown constructed along the lines of a mass spectrometer having an ion

source or gun 80 for producing ions of desired characteristic and quantity. It has been found that a magnetically constrained arc source or duo plasmatron is suitable for this purpose although other ion source devices can also be used. An arc source has been found to be particularly desirable because it provides a relatively plentiful supply of ions and is also relatively more efficient than other types of ion sources.

The ions given off by the source pass through an opening 84 into a chamber 86 in an extraction electrode 88. From there they move along a semi-circular path through a magnetic unit 90. The opposite end of the magnetic unit 90 has an opening 92 through which the ions are directed into a tube 94. The tube 94 can be compared to a television picture tube. The entrance end of the tube 94 is equipped with a focusing coil 96 to focus the ions into a beam which is projected onto a surface where the deposit is to be made. A deflector mechanism, such as deflection coils 98, is also provided to form the beam into a desired beam pattern or shape depending upon the shape of the circuit or circuit elements being made. For illustrative purposes a substrate 100 on which a device or circuit is to be formed is positioned in the tube 94. The element which is to be deposited on the substrate is ionized by the source 80 and is caused to impinge on the substrate in a desired pattern by applying suitable currents to the deflection coils 98. Deflector plates can also be used for this purpose. Masking means which heretofore have been used to outline the circuit or circuit elements being made are not needed with the present device because the area distribution is controlled by the deflection mechanism. Also by using a mass spectrometer the purity of the element being deposited is maintained.

A modified form of the structure of FIG. 8 is shown in FIG. 9. The principal difference between the modified structure of FIG. 9 and that shown in FIG. 8 is that the beam in the modified structure moves along a linear path instead of a semi-circular path and therefore the element being deposited is apt to be less pure. For convenience, the members making up the structure of FIG. 9 are numbered similarly to the corresponding members of the structure of FIG. 8, but primed.

Thus, there has been shown and described several embodiments of novel means employing an ion beam for forming electrical devices including circuits, circuit elements, semiconductor devices and many other devices which fulfills all of the objects and advantages sought therefor. Many changes, modifications, variations and adaptations of the present device, however, will become apparent to those skilled in the art after considering this specification and the accompanying drawings. All such changes, modifications, variations and adaptations which do not depart from the spirit and scope of the invention are deemed to be covered by the present invention which is limited only by the claims which follow.

What is claimed is:

1. Means for making components of electrical circuits comprising means for securing a relatively thin layer of a substance, means for producing a source of ionized particles capable of reacting with said layer to produce therefrom material having preselected electrical characteristics, and means for forming said particles in a collimated and geometrically defined beam and means for focusing said beam on said layer.

2. Means for making components of electrical circuits comprising means for securing a relatively thin layer of an electrically conductive substance, means for producing a source of ionized particles capable of reacting chemically with said layer to form a layer having other preselected electrical characteristics, means for forming a beam of said particles, and means for focusing said beam in a predetermined pattern on said layer.

3. Means for producing material having preselected electrical properties comprising a body of material, means

for securing a relatively thin layer of a substance on said body, means generating a beam of ionized particles capable of chemically reacting with the substance of said layer to change the chemical structure thereof to a material having preselected electrical properties, and means for exposing said layer to said beam.

4. Means for producing a layer of material having preselected electrical properties comprising means forming a substantially evacuated chamber, means for securing a member having an exposed surface in said chamber, means for producing a source of ionized particles capable of chemically reacting with said member, means for projecting said particles in a collimated and geometrically defined beam into the chamber and against the exposed surface of said member whereby said particles penetrate said surface to a predetermined depth and chemically react with said member to produce a surface layer thereon of material having different electrical properties than the member itself.

5. Means for producing material having preselected electrical properties comprising a layer of a metallic substance, a source of oxygen gas, means for positioning said layer in an atmosphere of oxygen gas, means capable of generating ion particles of an inert substance and means forming the particles into a collimated geometrically defined beam, and means for exposing said layer to said beam of ionized particles in the presence of said oxygen atmosphere.

6. Means for producing a layer of material having preselected electrical properties comprising means forming a partially evacuated chamber, means for securing a member having an exposed surface in said chamber, means for evaporating a metallic substance in said chamber whereby a portion of said evaporated substance condenses and settles on the exposed surface of said member, means forming a collimated beam of ionized particles, and means for exposing said substance to said beam of ionized particles during evaporation and condensation thereof.

7. Means for producing a layer of material having preselected electrical properties comprising means forming a partially evacuated chamber, means securing a member having an exposed surface in said chamber, means for evaporating a metallic substance in said chamber whereby a portion of said evaporated substance condenses and settles on the exposed surface of said member, means for producing a source of ionized particles including means for projecting said particles in a beam into the chamber and into exposure with said evaporated substances, and means for focusing and deflecting the beam into a predetermined geometry to expose a corresponding preselected area only of said evaporated substance thereto.

8. Means for making electrical components having preselected electrical characteristics comprising means for securing a layer of a substance from which an electrical component is to be produced, said means including a member having a surface thereon, means for producing a source of ionized particles, and means collimating said particles into a beam of predetermined geometry and exposing said surface to said ionized particles to form a deposit of said particles thereon.

9. The means for making electrical components defined in claim 8 wherein said means for collimating said particles includes means forming said particles into a beam and means for focusing and deflecting said beam.

10. A method of producing a layer of an element comprising the steps of providing a closed container, securing a member having an exposed surface in the container, ionizing an element to produce a supply of ionized particles thereof, projecting said ionized particles into the container, focusing said particles in a beam onto said exposed surface, and deflecting the beam to expose a preselected area only of said surface to produce a deposit of the element thereon.

11. The method defined in claim 10 wherein the preselected area is exposed to the beam for a preselected time interval depending on the layer thickness desired.

12. An electric element produced by the method set forth in claim 11.

13. A method of changing the characteristics of a material to produce preselected electrical properties therefrom comprising the steps of providing a closed and partially evacuated container, positioning a member of a metallic substance in said container, ionizing a non-metallic substance to produce a source of ionized particles, forming said particles into a beam of determinable geometry, directing said particle beam into said container and onto the member whereby said ionized particles react chemically therewith and produce a layer of material having preselected electrical properties.

14. A method of producing material having preselected electrical properties comprising the steps of providing a closed container, securing a member having an exposed surface in the container, evaporating particles of a metallic substance in said container, ionizing another substance to produce a supply of ion particles therefrom, collimating said particles into a beam of predetermined geometry, projecting said ionized particles into the container through the evaporated particles, focusing said particles in a beam onto the exposed surface, and allowing said exposed metallic substance to condense into a layer on said exposed surface in the container.

15. A method of producing material having preselected electrical properties comprising the steps of providing a closed and partially evacuated container, securing a member having an exposed surface in the container, evaporating particles of a metallic substance in said container, producing a supply of ionized oxygen particles and forming said particles into a beam of predetermined geometry, projecting said ionized particles into the container to expose said evaporated metallic substance thereto whereby said beam particles react chemically with said evaporated metallic substance to form an oxide thereof, and condensing said oxide into a layer on the exposed surface of said member in the container.

16. Means for doping materials by injecting impurities therein comprising means securing a member having an exposed surface thereon, means for producing a source of ionized particles, and means for exposing the exposed surface of said member to said ionized particles including means collimating said particles into a beam of predetermined geometry, and means for focusing said beam on said exposed surface whereby said particles penetrate said surface and make said member impure to the depth of the particle penetration.

17. Means for depositing a layer of a substance on a substrate comprising means securing a substrate member, means including a substance capable of being ionized, means for ionizing said substance to produce a source of ionized particles, means for accelerating said ionized particles into a beam directed toward said substrate member, and means for focusing and deflecting the particles in said beam to form a predetermined beam pattern on said substrate.

18. The means for depositing a layer of a substance defined in claim 17 wherein said ionizing means includes an arc discharge device.

19. The means for depositing a layer of a substance defined in claim 17 including means for controlling the rate of deposition of said layer on the substrate.

20. An apparatus for producing devices having predetermined properties comprising a body of material, means for securing a relatively thin layer of a substance on the body, means for producing a supply of ionized particles, means forming said supply of particles into a beam, means for focusing and deflecting said beam to form a beam of predetermined geometry directed at said body, and means for controlling the speed of the

particles in the beam to control the rate of deposition of
said particles on the body.

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