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Spindt et al.

[11] **3,812,559**

[45] **May 28, 1974**

[54] **METHODS OF PRODUCING FIELD IONIZER AND FIELD EMISSION CATHODE STRUCTURES**

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[21] Appl. No.: **216,539**

Related U.S. Application Data

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[52] **U.S. Cl.** **29/25.18**
[51] **Int. Cl.** **H01j 9/02**
[58] **Field of Search** 29/25.17, 25.18; 313/309, 313/351; 117/210, 212

[56] **References Cited**

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C. A. Spindt, "A Thin-Film Field-Emission Cathode," J. of Applied Physics, Vol. 39, No. 7, June 1968, pp. 3,504–3,505.

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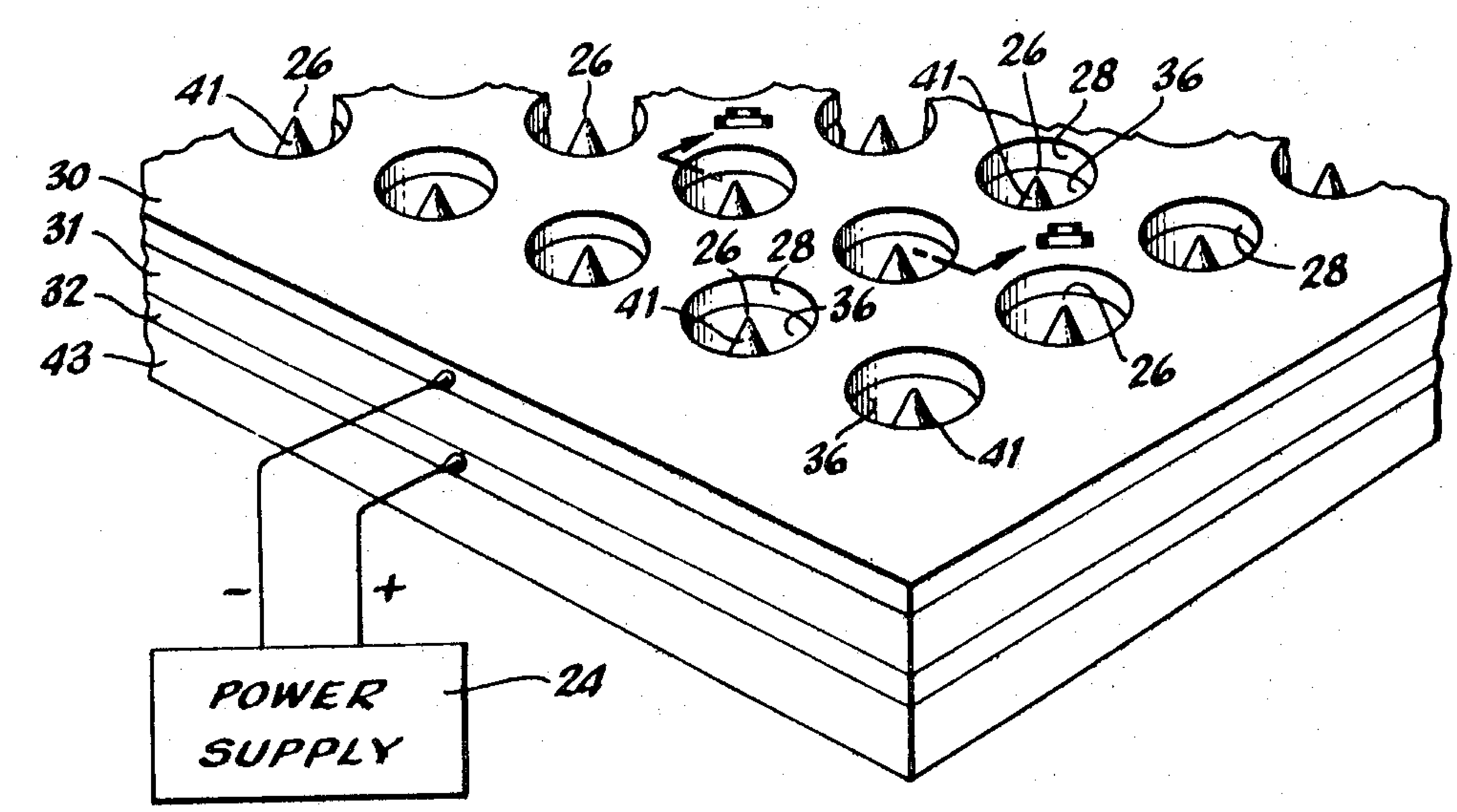
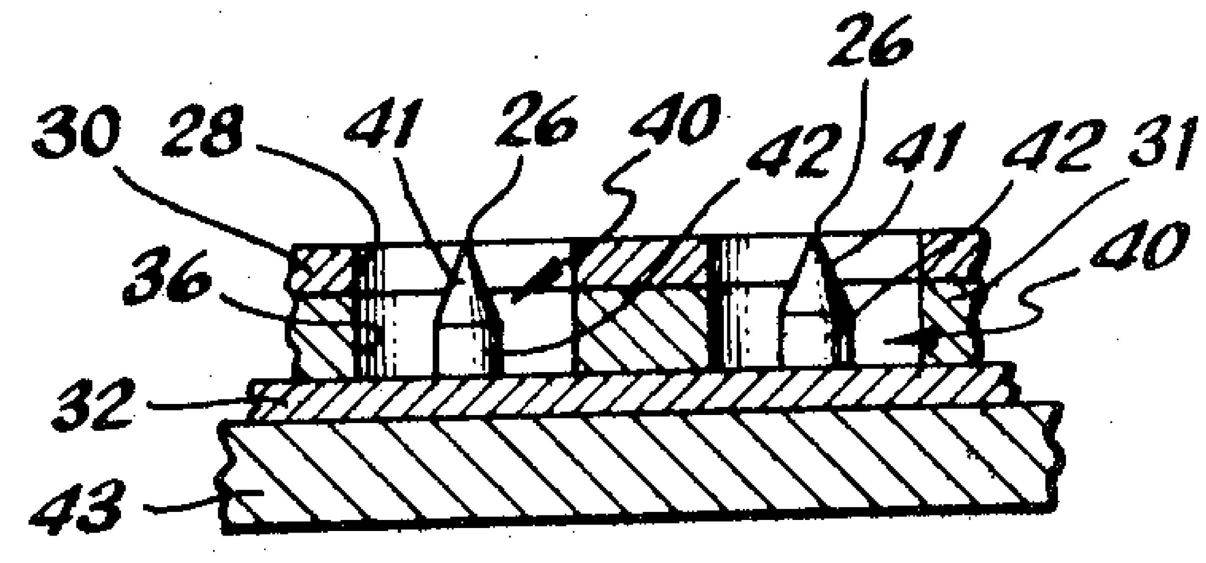
[57] **ABSTRACT**

Field-forming devices primarily useful as field ionizers and field emission cathodes and having as a basic element an array of closely spaced cones with sharp points supported on a substrate (in the most usual case conductive or semiconductive) are disclosed. Preferably, the field-forming structure is completed by a screen-like structure, e.g. as fine mesh screen, insulatively supported above the points with the center of apertures in the screen substantially aligned with the longitudinal axis of corresponding cones. A novel method of forming such structures includes placing a screen with a mesh corresponding to the desired number and packing density of sharp conical points in close proximity to, or in contact with, the substrate and projecting material through the screen onto the substrate whereby sharp cones of the material are formed on the substrates.

7 Claims, 9 Drawing Figures





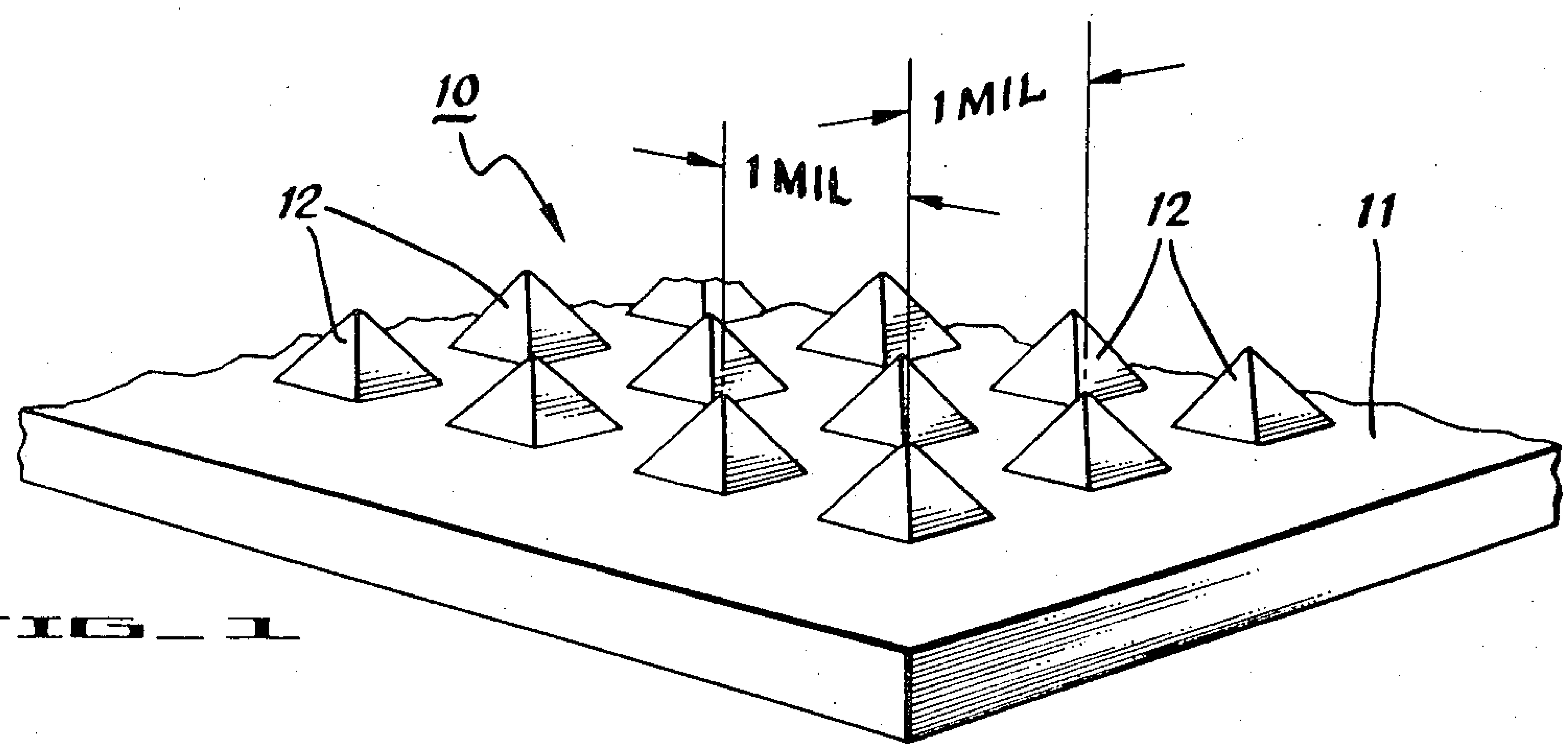


FIG_1

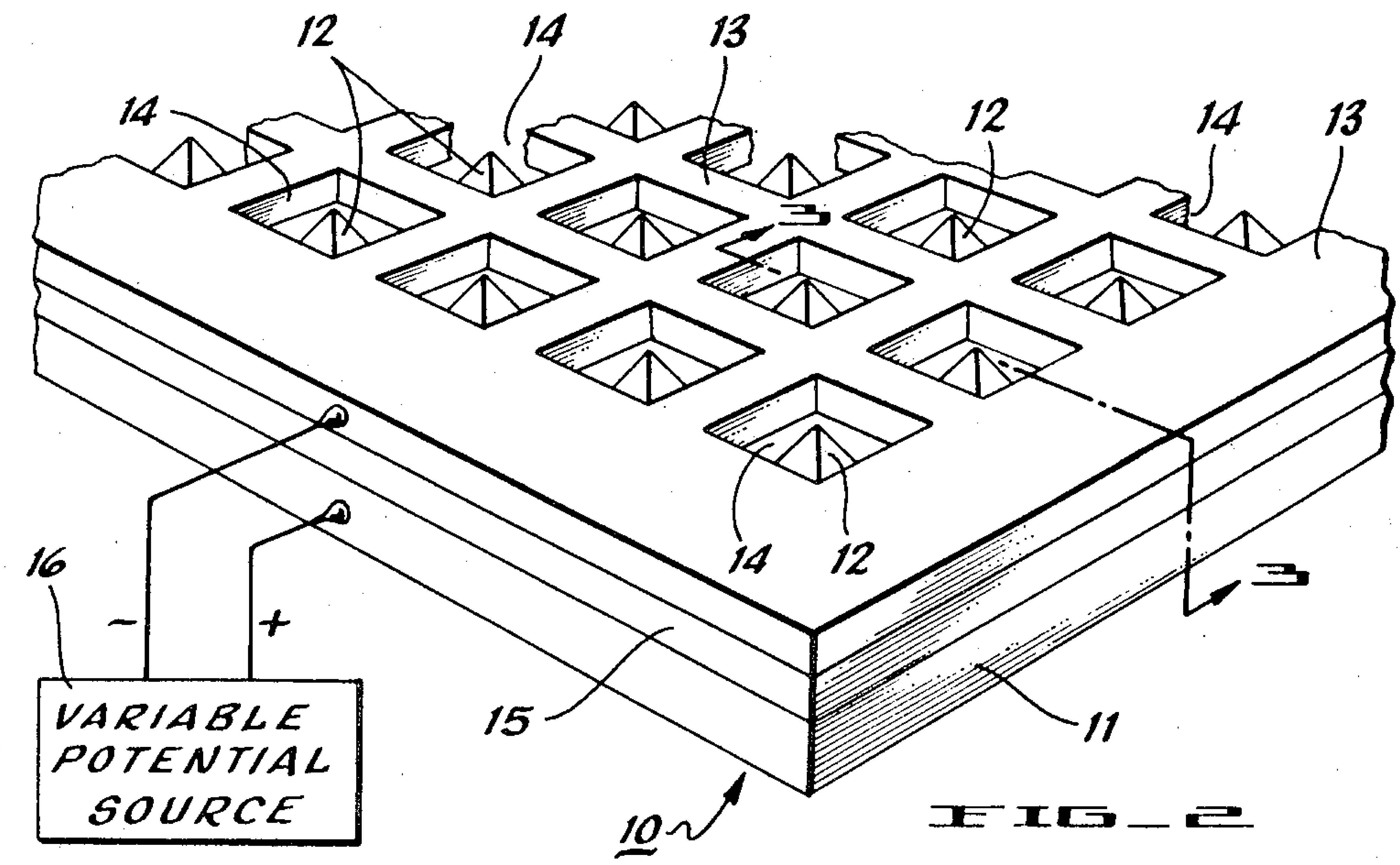
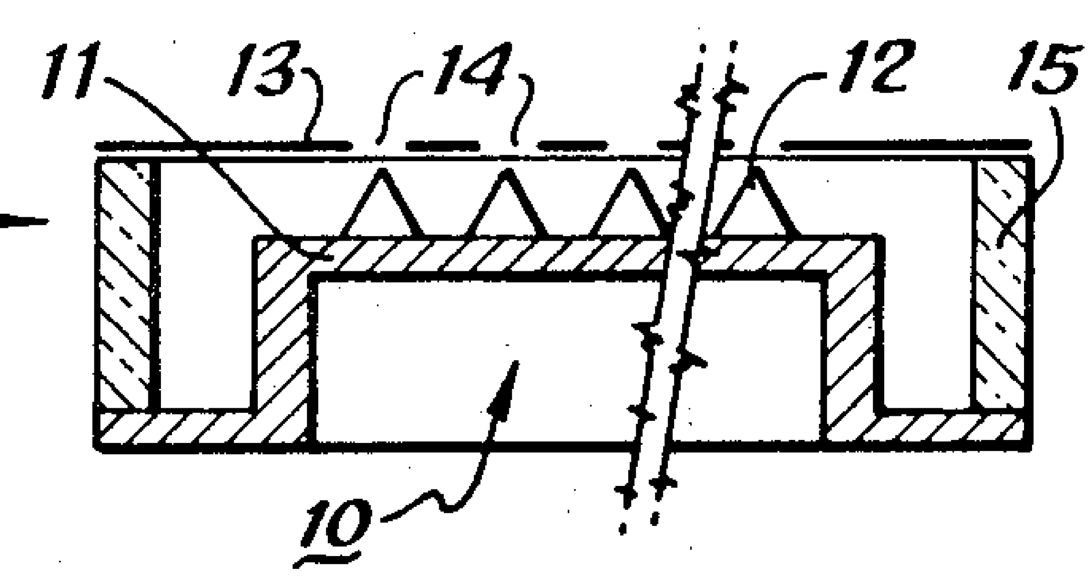


FIG_2

FIG_9



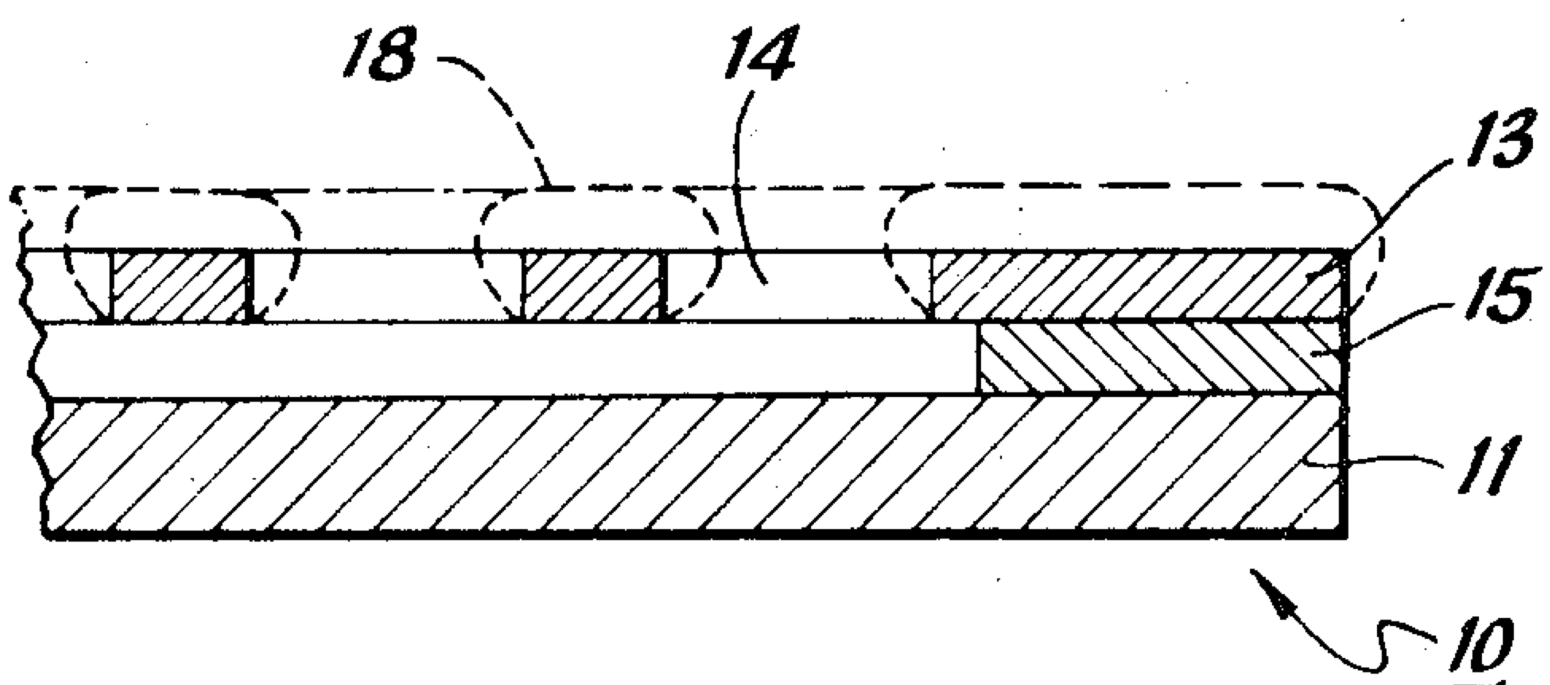


FIG_3

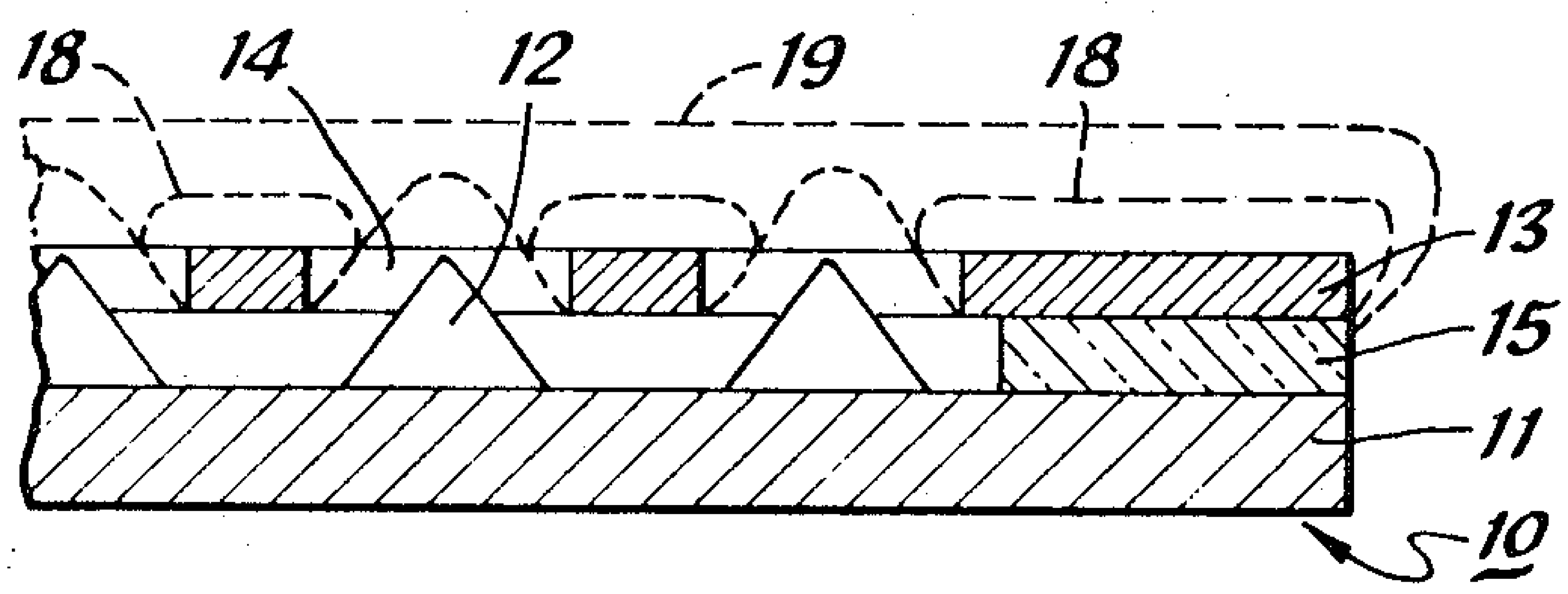


FIG_4

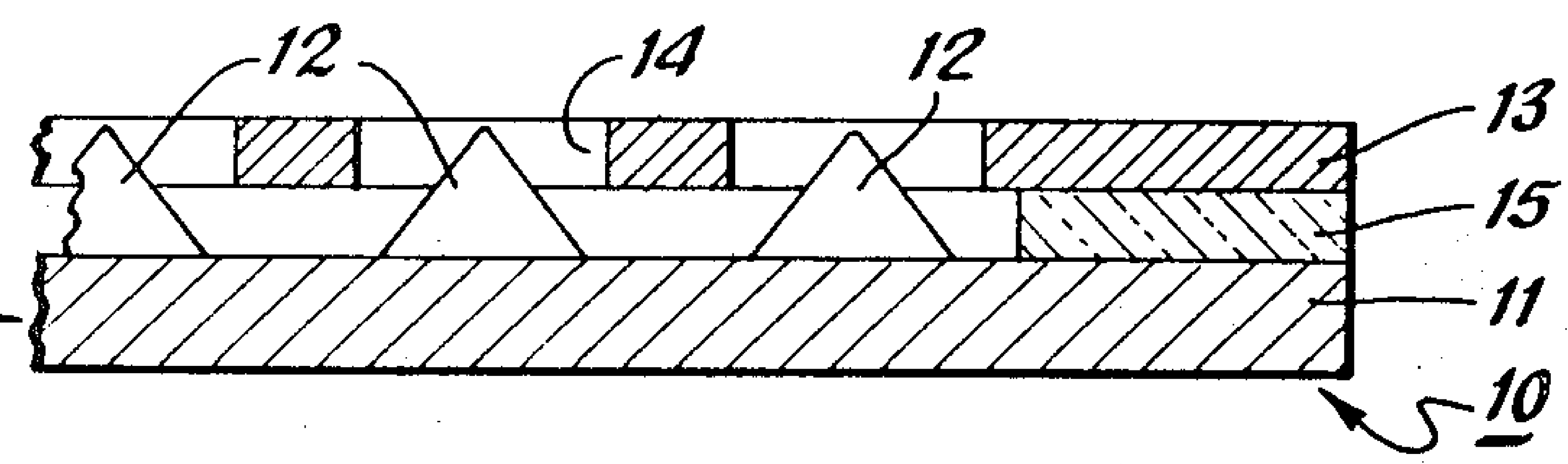


FIG_5

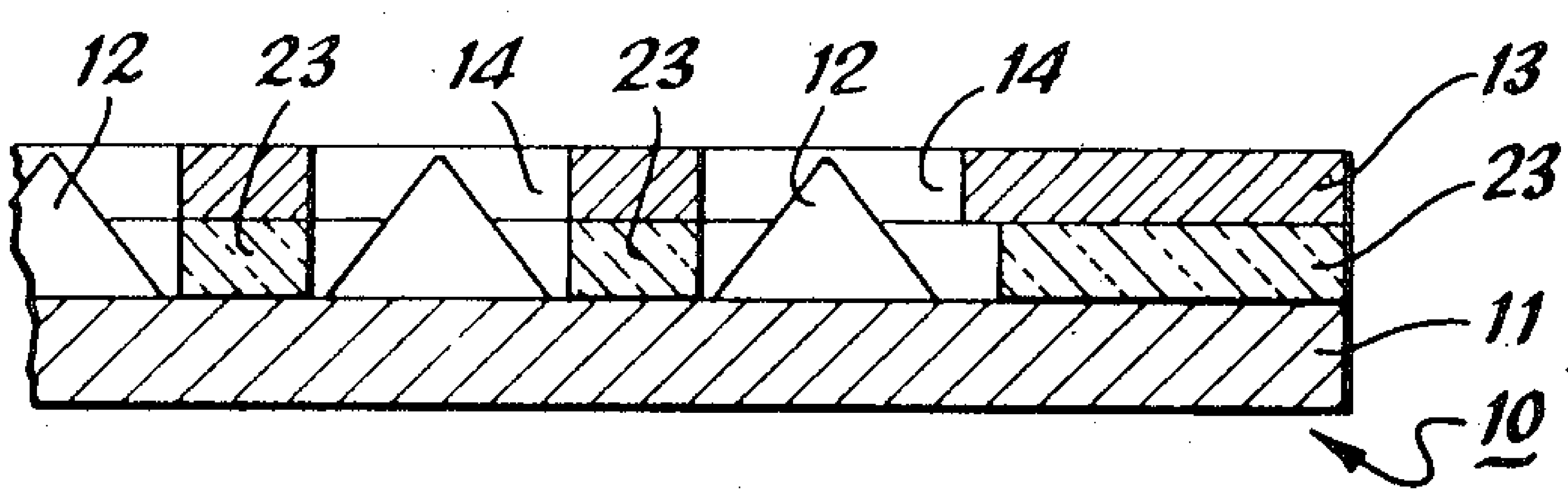


FIG_6

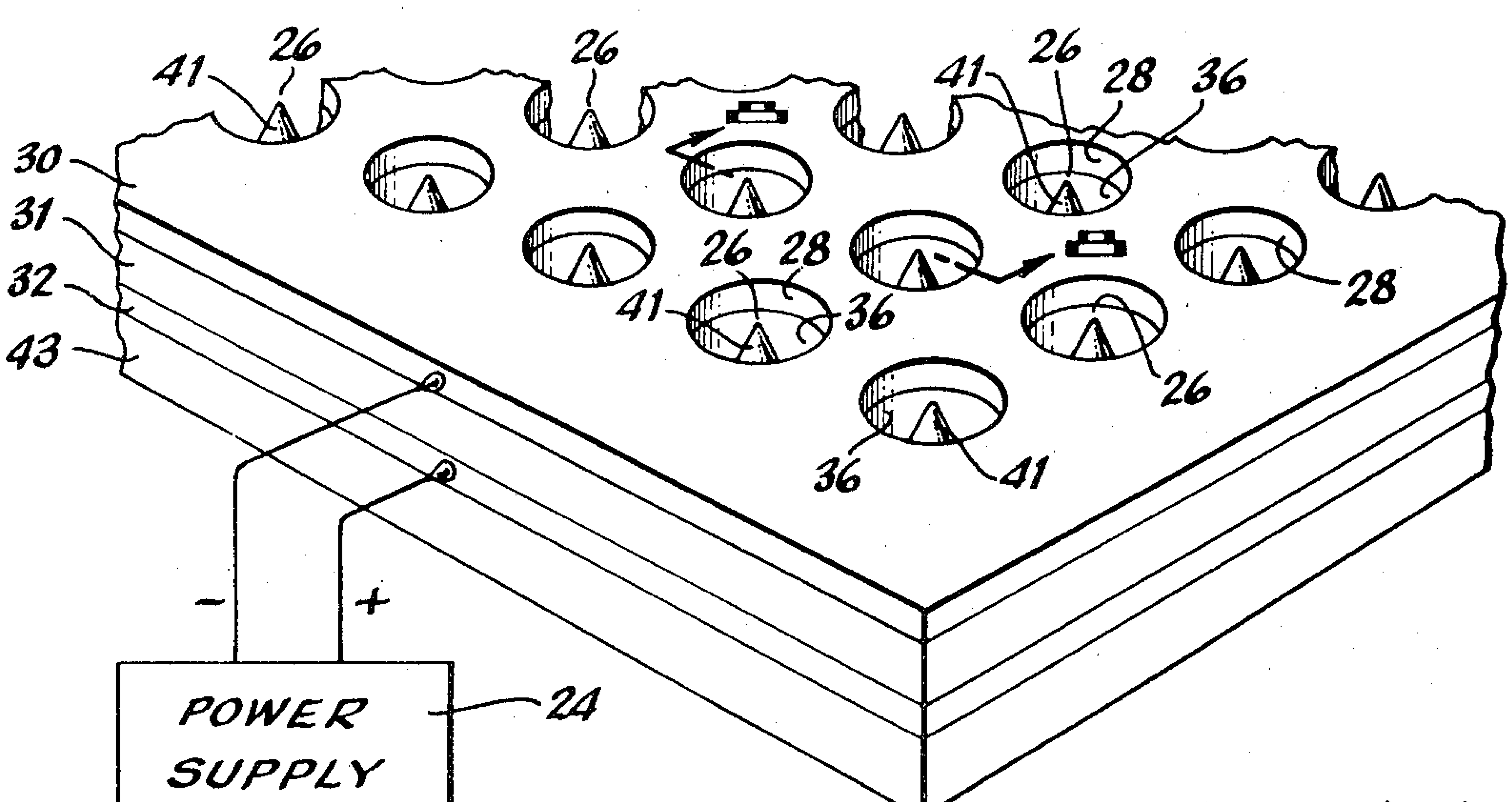


FIG_7

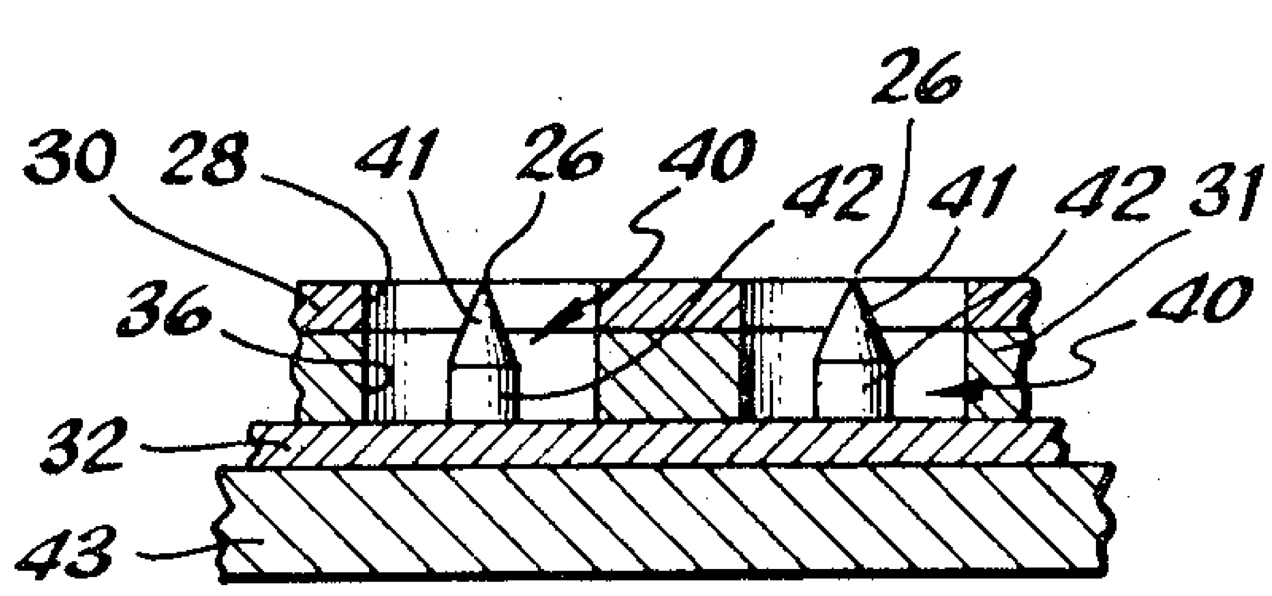


FIG_8

METHODS OF PRODUCING FIELD IONIZER AND FIELD EMISSION CATHODE STRUCTURES

This is a division of application Ser. No. 54,222, filed July 13, 1970, now Patent No. 3,665,241.

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to field-forming structures such as field-ionizing and electron-emitting structures and particularly to such structures employing many cone-like emitters or ionizers on a single substrate.

Structures for forming electric fields are required for many practical applications. An electric field on the order of several megavolts per centimeter (cm) can be used to produce electron emission from materials. Electric fields on the order of 10^8 to 10^9 volts per centimeter are useful in ionizing molecules by field extraction and collection of electrons therefrom (known as field ionization).

Electron emission is of course the heart of devices utilizing electron beams or clouds such as the many varieties of electron tubes upon which the electronics industry is built. The phenomenon of ionization plays a significant role in many scientific instruments and experiments; e.g. in ionization gauges and mass spectrometers. In mass spectrometry, an unknown material under investigation is ionized prior to injection into the analyzer or mass-separator section of the mass spectrometer. Ionization is usually produced by electron impact with the unknown material, utilizing a suitable electron source such as a thermionic emitter. However, electron impact with molecules not only ionizes them, but also tends to fragment them into two or more species, so that the mass spectrum, obtained by this ionization method, may show the presence of the daughter species but little or nothing of the parent species. Moreover, if any of the daughter species is the same as, or has a mass-to-charge ratio approximately equal to, another species originally present in the unknown material, then the mass spectrum obtained can be difficult or impossible to interpret correctly regarding the original constituents of the unknown material. In some applications where mass spectrometry is used to monitor or control other processes, e.g. the preparation of photoemissive surfaces, the use of a thermionic emitter for ionization is disadvantageous because the heat or light from the emitter tends to disturb the process. The use of a cold, non-luminous ionizer in such applications constitutes a significant improvement. Field ionization, a phenomenon in which molecules entering a region of very high electric field (10^8 to 10^9 V/cm) are ionized by extraction and collection of electrons by the field, causes substantially less fragmentation than electronimpact ionization. Also, this phenomenon does not require or involve the generation of light or heat.

In order to reduce to a practical level the voltage required for producing the required high fields, sharp needles or points are used as emitters or field ionizing electrodes, a counter electrode is spaced from the needle-like structures and a voltage of appropriate polarity is applied therebetween. For field emission the counter electrode is made positive relative to the needle-like structures and for field ionization the reverse polarities are used (counterelectrode negative relative to the needle-like structures). However, even with the use of

sharp points, if the counter electrode is spaced a macroscopic distance from the points, e.g., of the order of centimeters (usual in prior art devices), the voltages required for electron emission are of the order of kilovolts and for field ionization, approximately tenfold higher.

Despite the high field emission current density capability of a single needle-like emitter (on the order of 10 million amps per sq. cm), the total emission current from a single needle emitter is low, e.g., on the order of milliamperes, because of the minute size of its emitting area. Furthermore, the electrons are emitted over a large solid angle, and they obtain almost the total energy of the applied voltage, e.g., several thousand electron volts, within a short distance from the emitter tip. Therefore, the formation of narrow electron beams that are suitable, for example, for use in high-power, beam-type electron tubes, requires elaborate and expensive focusing apparatus.

Ionization efficiency of prior art field ionizers of the single needle-like structure is very low for reasons similar or analogous to the problems described above relative to the cathodes. That is, one reason ionization efficiency is low is that the effective region where ionization takes place is confined to the small volume in the immediate vicinity of the apex of the sharp point so that the rate of ion production for a given pressure of material to be analyzed is much lower for field ionization than for electron-impact ionization. A second reason is that the field-produced ions attain velocities equivalent to the voltage applied between ionizer and counter electrode and the ions are impelled away from the ionizer over a very wide range of angles, so that only a small fraction of the ions are collimated into a beam suitable for injection into the analyzer of the mass spectrometer without employing complex ion-optical lenses.

Parallel operation of many needle-like members to increase the total current for a cathode and to provide a correspondingly large ionization volume in the case of the field ionizer is feasible, but the problems of formation of the parallel structures, focusing the electron beams (for the cathodes), and providing ion-optical collimation (in the field ionization structures) are formidable. For example, in the field ionizer case, ion-optical collimation is practical only if emission energies of the ions can be kept small, which necessitates spacings between the ionizer and counter-electrode of the order of microns with the ionizer point having a tip radius of a fraction of a micron, e.g., 0.1 micron. Also, it is desirable to sapce the needle-like structure as close together as possible without incurring significant decrease of the field at each point by the presence of its neighbors.

Many of the problems thought to be inherent in parallel operation of fine needle-like structures under consideration have been solved by a structure and the methods of producing that structure disclosed in U.S. Pats. Nos. 3,453,478 "Needle-Type Electron Source", dated July 1, 1969, and 3,497,929, "Method of Making a Needle-Type Electron Source", dated Mar. 3, 1970 in the names of Kenneth R. Shoulders and Louis N. Heynick, and assigned to Stanford Research Institute.

In the patents referred to above, the electric field-producing structure effectively includes two closely spaced surfaces. On the first, or emitting surface, a large number of sharp needle-like emitting sites are distributed with a packing density limited only by the fabrication technology used. The surface can be planar or curved and of a size to suit the intended application. The second surface, called an accelerator surface, is the electrode used to produce the field. It consists of a very thin foil or film of metal of the same contour as the surface with the emitter sites, and is suitably supported and electrically insulated therefrom in spacings ranging from a fraction of a micron to several microns.

In the preferred embodiment, described in the patents, the accelerator surface is supported above the emitter surface by a dielectric layer therebetween, in the manner of a sandwich, and holes through the accelerator and dielectric layers are provided so as to expose the tips of several emitters at each hole location to the rim of the hole in the accelerator electrode. Because of the minimal separation range between the emitter surface and the accelerator surface, the voltage needed to produce field emission ranges from only a few volts to about 100 volts, and the emitted electrons emerge from the holes in the accelerator with correspondingly low energies.

While the structure referred to above represents a considerable advance over any of the structures known to the prior art, the method of producing the structure can yield needle-like electrodes that are not necessarily uniform in numbers and shapes from emitter site to emitter site, thus introducing corresponding variations in performance. Many of the problems of the multiple-needle structure are overcome by providing a single, uniform needle-like electrode at each site with specific, essentially identical, configuration. A means of producing a single needle-like electrode at each site is described in an article by C. A. Spindt (one of the inventors of the present invention) entitled "A ThinFilm Field-Emission Cathode" in the *Journal of Applied Physics*, Vol. 39, No. 7, 3,504–3,505, June 1968. Further, a means of providing a single uniform needle-like electrode at each site which represents an improvement over the method and structure described in the previous patents and the Spindt paper is described and claimed in a U.S. Patent application Ser. No. 9,139 (now Pat. No. 3,755,704, issued Aug. 28, 1973), entitled "Field Emission Cathode Structure, Devices Using Such Structure, and Method of Producing Such Structure", filed Feb. 6, 1970, in the names of Louis N. Heynick, Kenneth R. Shoulders, and Charles A. Spindt and assigned to the assignee of the present invention.

Subsequent to conception of the structures and methods described in the above-referenced patents, application and paper, use of similar structures operated in reverse polarity as a closely spaced parallel array of field ionizers, in which each sharp metal point produces positive ions was conceived. In the cathode structure sandwich, the dielectric film thickness is in the order of $1 - 2\mu$ and the metal points are of about the same height above the emitter surface. However, field ionization in any such structure having specific values of tip sharpness and distance between counter electrode and points requires voltages approximately ten-fold higher between electrodes than those required for field emission. Consequently, the dielectric layer between the emitter surface and counter-electrode must be capable of withstanding the higher fields without dielectric breakdown. This requirement can be met by making the dielectric thickness large relative to the distance between the counter-electrode and the tips, or by providing other means for insuring adequate insulation between the emitter surface and the counter-electrode.

In addition to providing a multi-point ionizer, the present invention provides uniform arrays of points, suitable electrode and counter-electrodes therefor, and improved means for producing such structures in which the ratio of dielectric thickness to distance between counter-electrode and tips and also geometrics chosen optimally for field emitters or ionizers or both.

Particularly in view of the fact that the spacing between emitter tips and the counter-electrode may be different for field emitters and field ionizers, it is highly desirable to be able to produce the fine needle-like points of uniform shape and spacing on a substrate independent of a metal/dielectric/metal film sandwich. That is, it is important to be able to produce a precision, highly uniform bare point array on a substrate (electrode most commonly). With such a structure, one or more counter-electrodes may be added with the desired spacing, dielectric thickness or other adequate insulation, and the proper registry relative to the points of the bare point array. The present invention provides the capability of producing such results.

As described in greater detail below, in accordance with the teachings of the present invention a bare-point structure is provided in which a regular array of closely spaced metallic points of controlled geometry is formed by deposition through a fine mesh plate or screen uniformly over the surface of a metal substrate which represents an electrode.

Where the bare-point array is desired, the screen may be removed. Where a counter-electrode is desired, the screen may be left in place or removed and replaced by another counter-electrode of desired configuration. A field ionization structure is provided by making the counterelectrode of the arrangement just described negative relative to the substrate electrode and providing the proper electrode-counter-electrode spacing as well as ratio of such spacing to the distance between counter-electrode and electrode points. The field emitter is provided by applying the opposite polarity between electrodes and providing optimally different spacings. Additional electrodes can be added to the structure to provide multi-electrode control of the electron or ion optical characteristics as well as the current emerging from the holes. Multi-element vacuum tubes can also be produced by adding appropriate electrodes and closing the device. Further, the field ionizer may be constructed by the same general method described in connection with the Heynick, Shoulders, and Spindt application referred to above with modifications described herein.

The novel features which are believed to be characteristic of the invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation, together with further objectives and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings in which:

FIG. 1 is an enlarged fragmentary perspective view, showing a bare-point array (pyramidal embodiment) constructed in accordance with the principles of the present invention;

FIG. 2 is an enlarged fragmentary perspective view of a portion of a device utilizing the bare-point array of

FIG. 1 and constructed in accordance with this invention;

FIGS. 3 through 5, inclusive, are cross-sectional views taken along the lines 3—3 of FIG. 2 for successive steps in the method of producing the structure of FIGS. 1 and 2;

FIG. 6 is a cross-sectional view similar to the device of FIG. 5, but illustrating another embodiment which is constructed in a different way;

FIG. 7 is an enlarged fragmentary perspective view of a field ionizer according to one embodiment of the present invention; and

FIG. 8 is a broken-away cross-sectional along lines 8—8 in FIG. 7.

FIG. 9 is a partially broken-away cross-sectional view of another embodiment of the invention.

A form of the basic bare-point array **10** useful for both field electron emitters and field ionization is illustrated in FIG. **1.** The structure **10** includes a substrate **11** and an array of bare points **12** formed thereon. In the embodiment shown, the bare points **12** are pyramidal but may be of other conical shapes. The substrate **11** is preferably conductive in order to form one electrode. In the embodiment illustrated, substrate **11** is a sheet of molybdenum but it may be of other suitable metal, or a non-metal coated with a conductive film as, for example, a plate of aluminum oxide coated with a film of molybdenum. For some applications, it may be preferable to use a semi-conductive material or even an insulator for the substrate **11.** As illustrated, the pyramids **12** are of molybdenum, have square bases, are 0.6 mil high, and are spaced apart by 1 mil (center to center). However, the pyramids **12** may be of resistive or insulating materials, or of composite materials, and the pyramid surfaces overcoated or otherwise treated to obtain the desired characteristics.

Bare-point arrays **10** require a field-producing electrode in order to produce the electric field required to cause electron emission or ionization in the region of the array of points or pyramids **12.** The electrode is preferably but not necessarily analogous to the top conduction film in the sandwich configurations described in the previously cited patents and application. FIG. 2 illustrates a device incorporating the bare-point array of FIG. **1** and the additional electrode **12** (referred to as a counter-electrode) to provide the required electric field. As illustrated, the counter-electrode **13** comprises a screen (or plate) having a distribution of holes or apertures **14** therein, shown square in this embodiment, corresponding substantially to the distribution of points **12** on the substrate. The broken-away cross-sectional view of FIG. **5** may help to visualize the device. Looking at the two Figures (**2** and **5**) it is seen that the device comprises a substrate **11** having points **12** formed thereon and a screen (counter-electrode **13**) supported above the substrate by an insulating spacer **15** at the periphery of the screen. In a preferred version of this embodiment, registration between the screen **13** and the substrate **11** is maintained by spacer **15** so that the center of each screen hole **14** is substantially aligned with the axis of a different point **12** of the base-point array **10,** and so that the tips of the points **12** are substantially in the plane of the screen **13.** Furthermore, the ratio of the height of points **12** above substrate **11** to the distance between the tips of the points **12** and the rims of the screen holes **14** is sufficiently large so that the requisite voltages for electron emission or field ionization may be applied between substrate **11** and counter-electrode **13** without causing electrical breakdown of insulator spacer **15.** One means of assuring that the breakdown doesn't occur is seen in another version of this embodiment which is illustrated in FIG. **9.**

For convenience and simplicity, the illustration of FIG. **9** has parts which correspond to those of FIGS. **2** through **6,** inclusive, numbered correspondingly. Here, the perimeter of the substrate **11** (or counter-electrode **13,** if preferred) is shaped so as to permit the use of a thicker insulator spacer **15,** thereby permitting the application of higher voltages between substrate **11** and counter-electrode **13** without causing electrical breakdown of insulator spacer **15.**

The basic mode of operation of the field ionizer may be best explained in connection with FIGS. **2** and **5** wherein the ionizer points **12** of array **10** are shown connected by means of their common conductive substrate **11** to a positive (+) terminal of a voltage power supply **16.** The sharp tip points **12** are each located in or near a hole **14** of counter-electrode (screen) **13,** which is connected to the negative (−) terminal of the power supply **16.** Application of a voltage from power supply **16** produces a high electric field in the region of the points **12.** In such an arrangement, electrically neutral particles entering the holes **14** are positively ionized by the high electric field, the action of the field being to remove electrons from the particles, which electrons are collected by the points **12.** The positive ions so created are impelled away from the ionizer points **12** through the holes **14** of the counter-electrode **13.**

For producing field electron emission, the potential source is connected with its positive terminal to counter-electrode (accelerator electrode) **13,** and its negative terminal connected to array (emitter electrode) **10.** The potential source may be made variable for the purpose of controlling the electron emission current. Upon application of a potential between the electrodes **10** and **13** an electric field is established between the points (emitting protuberances) **12** and the counter-electrode **13,** which is of a polarity to cause electrons to be emitted from the points **12** through the holes **14** in the screen **13.**

Thus it is seen that efficiency limitations of one ionizer point or one field emitter cathode point as well as the limitations of prior attempts at parallel operation of such single point devices are largely overcome by providing a structure consisting of an array **10** of closely spaced points **12** with sharp tips in close proximity to the counter-electrode **13** which has a corresponding array of holes **14.** In this structure the holes **14,** the distance between points **12** or holes **14,** as well as the spacing between point tips and the counter-electrode, are in the micron range, and most points **12** yield substantially equivalent performance. Insulator spacers **15** which separate the outer edges of the electrode **10** and counter-electrode **13** have the requisite thickness to withstand the electric field.

The ability to produce the bare-point array **10** with such uniformity of points **12** and hence the ability to produce field ionizers and field electron emitters of such precision and efficiency is highly dependent upon the methods of construction. The method of the present invention yields the precise results desired.

In order to understand the steps in one method used in the fabrication of the array **10** (of FIG. **1**) and the completed device (FIGS. **2** and **5**), reference may be had specifically to FIGS. **3** through **5**, inclusive, which represent sections through one portion of the device illustrated in FIG. **2**. FIG. **3** illustrates the substrate **11** of the bare-point array structure **10** before the field-forming points **12** are formed thereon. That is, FIG. **3** shows a starter structure consisting of only the substrate **11** and a fine mesh screen (plate) **13** having a multiplicity of holes or apertures **14** therein supported above the substrate **11** by an insulating dielectric spacer **15**. If the screen **13** is later to be removed to provide only the bare-point array **10** (of FIG. **1**), the screen may be placed in direct contact with substrate **11** and the dielectric spacer **15** may be eliminated. Since this embodiment contemplates that the masking screen and the counter-electrode **13** will be one and the same, the the spacer **15** is shown, and also a release layer **18** is provided on the screen **13** so that materials subsequently deposited thereon in the array-forming process may readily be removed.

In order to provide the sharp points **12** as shown in FIG. **4** and thereby complete the pyramidal array **10** of FIG. **1**, a simultaneous deposition from two sources is performed. That is, simultaneously a closure material (e.g., a molybdenum-alumina composite) is deposited at a grazing incidence, and the material for the pyramid, e.g. molybdenum, is deposited straight on the substrate surface. In this step, the purpose of the deposition at grazing incidence is to add material on screen **13** so as to provide a mask with holes **14** of decreasing size for the deposition of material on substrate **11**. As additional emitter material is deposited on substrate **11**, the molybdenum-alumina composite masking material gradually closes the aperture at the upper lip of the holes **14**, as shown in FIG. **4**. The closure is indicated by the additional film **19** deposited on the release layer **18**. In FIG. **4** the apertures **14** are shown as being completely closed and pyramids **12** completely formed. Thus, cone-shaped (pyramidal here) points are formed on the conductive substrate **11**. If the screen **13** used is provided with round apertures instead of the square ones shown, then the points **12** formed are right circular cones instead of the pyramids illustrated.

With the step just described, the array **10** of FIG. **1** is completed and the screen **13** and spacer **15** may be removed, leaving the bare-point array **10**. Another screen-like counter-electrode can then be added to form the structure of FIG. **2**. If it is desired to use the screen **13** as counter-electrode of FIG. **2**, screen **13** and spacer **15** need not be removed. Instead, the materials deposited on the screen, viz., release layer **18** and the subsequently deposited closure layer **19** may be selectively etched or floated away, leaving the bare screen structure as illustrated in FIGS. **5** and **2**.

If larger spacings between counter-electrode **13** and substrate **11** are desired, to accommodate thicker dielectric spacers **15**, the points **12** may be formed on previously produced pedestals (not shown), which pedestals are produced by a prior deposition step, utilizing a source which deposits material along a direction perpendicular to the surface of the substrate, and which material is preferably the same material, e.g. molybdenum, as the metal electrode (substrate) **11** or a more resistive material, e.g. a molybdenum-alumina composition. Such a deposition step would deposit a film on the release layer **18** without closing the screen holes **14** and, more importantly, pedestals with essentially vertical sides and bases of size and shape of apertures **14** in the screen **13** are deposited directly upon the substrate **11**. The pedestal height is selected by controlling the amount of material deposited. Since the array of FIG. **1** does not have such pedestals, this step is not illustrated. However, a specific embodiment of a complete device incorporating such pedestals is shown in FIGS. **7** and **8**, described later herein.

In the embodiment illustrated, the screen **13** has a uniform array of square holes **14**, spaced on 1 mil centers. The pyramids formed then have square bases of corresponding size and spacing to the screen mesh and of a height controlled by the relative rates of deposition of the sources. In other embodiments, the holes **14** may have other configurations and/or the deposition rates may be varied during the formation process to provide a variety of shapes. Further, the formation process may be halted prior to hole closure so as to form truncated pyramids, cones, or suitable variants thereof.

An alternative deposition technique incorporates the use of a single deposition source which is broad enough to perform both the hole-closure and point-formation functions. This deposition source and technique may also be applied to the sandwich starter structure described in the previously cited patents and applications.

One embodiment specifically designed for field ionizer application and utilizing a metal/dielectric/metal sandwich structure with a counter-electrode **30** which corresponds to the screen counter-electrode **13** of FIG. **2** is illustrated in FIGS. **7** and **8**. In this embodiment the counter-electrode **30** is formed of the upper metal film of the sandwich structure which is provided with a plurality of holes or apertures **28** therethrough. Dielectric film **31**, the center layer of the sandwich, is on top of a base metal film **32** which serves as a base electrode and which is connected to the positive terminal of the power supply **24**. As illustrated, the base metal film **32** is shown on a dielectric support substrate **43** which only serves to support the base metal film **32**. Films **30** and **32** are formed of metal such as molybdenum or tungsten, while film **31** which insulates films **30** and **32** from one another is formed of a dielectric material, e.g., aluminum oxide.

The dielectric film **31** has holes corresponding to the holes in film **30** and each hole accommodates a point ionizer **40** with its base in contact with the base electrode **32** and tip **26** preferably aligned with the plane of the hole **28** in the top electrode **30** to minimize the distance between tip and hole rim. FIG. **8** is a cross-sectional view along lines **8—8** in FIG. **7**. In FIG. **8** the hole in dielectric film **31** is designated by numeral **36**. The point ionizer **40** is shown in the form of a cone **41** on top of a pedestal **42**, a configuration that permits independent selection of the height of the tips **26** above base **32**, the sharpness of the tip **26**, and the distance between tips **26** and hole rims **28** so as to provide optimum geometry for operation of the structure as a field ionizer.

Another highly practical way to utilize the bare-point arrays **10** is shown cross-sectionally in FIG. **6**. In this embodiment a conductive screen **13** having substantially the same distribution of holes as the points **12** on the substrate **11** is supported above the substrate **11** by insulator spacers **23** of appropriate height and distribution. One method for producing such structures is to form an insulator 23 of the requisite thickness on the screen 13 by deposition or other means, which insulator thereby conforms substantially to the cellular structure of the screen, after which the screen-insulator combination is set and maintained on the substrate. An advantage of this method is that self-registry of holes and points is achieved.

Bare arrays of points can be made to yield very large emission currents by the use of an electrode to which appropriate positive potentials relative to the points are applied, e.g., in diode rectifiers, x-ray generating tubes, and Lenard-ray tubes. Therefore, it is contemplated that bare-point arrays 10 or individual members of such arrays be sealed off opposed to another electrode either with or without intermediate electrodes. Substrate-screen assemblies having the points in substantial or complete registration with the holes in the screen can be used as large-emission current cathodes by applying suitable positive potentials to the screen relative to the substrate. In contradistinction to the operation of the diode configurations cited above, the screen provides the fields required for electron emission for the points, but most of the emission drawn passes through the screen holes, so that the screen functions to control the current in the manner of a grid. Additional grids may also be employed to render the emission more uniform or otherwise control the emission.

The methods for producing an array of points in registry with holes in screens are adaptable to the production of cathodes subdivided into areas containing one or more points, from which areas emission can be drawn separately by the application of appropriate potentials thereto. Such methods can also be adapted to the production of arrays of individual but suitably interconnected field emission diodes, triodes, tetrodes, etc.

All the operational advantages of the multipoint field ionizer described above are achieved also with the field emitters of the same general structure with parameters optimized for such use. Again, such structures constitute field ionizers when operated with reverse polarities to those used for obtaining field emitted electrons, and such structures can be produced by the methods previously described so that the values of the geometric parameters are optimum for field ionization use. This is not to say, however, that the method of producing the ionizer from the metal/dielectric/metal sandwich is equivalent to, or can be made with, the same degree of accuracy as the improved screen-forming techniques herein described.

While particular embodiments of the invention are shown, it will be understood that the invention is not limited to these structures since many modifications may be made both in the material and arrangement of elements. It is contemplated that the appended claims will cover such modifications as fall within the true spirit and scope of this invention.

We claim:

1. The method of producing an array of conical needle-like points on a surface comprising the steps of:

a. positioning a plate-like screen member adjacent to said surface, said plate-like member having apertures therethrough corresponding in number and location to the desired needle-like points;

b. depositing needle-forming material substantially perpendicular to the plane of said plate-like screen member from a single deposition source which is broad enough simultaneously to close the said apertures in said plate-like member and deposit material on said surface within said apertures, thereby forming conical needle-like points within said apertures; and

c. removing said plate-like screen member whereby a bare point array of conical needle-like points is left on the said surface.

2. The method of producing a field-forming device including the steps defined in claim 1 and the additional step of subsequently placing a plate-like counter-electrode having apertures therethrough corresponding in number and location to the needle-like points on said surface in insulated spaced relation relative to said surface and points on the said surface.

3. The method of producing an array of conical needle-like points on a surface comprising the steps of:

a. positioning a plate-like screen member adjacent the said surface, said plate-like member having apertures therethrough corresponding in number and location to the desired needle-like points;

b. depositing needle-forming material substantially perpendicular to the plane of said plate-like screen member from a single deposition source which is broad enough simultaneously to close the said apertures in said plate-like member and deposit material on said surface within said apertures, thereby forming conical needle-like points within said apertures; and

c. removing all material deposited on said plate-like screen member whereby said screen member can be used as an electrode of said field-producing structure.

4. The method of producing a field-forming device which includes an array of conical needle-like points on a surface comprising the steps of:

a. positioning a plate-like screen member adjacent to said surface, said plate-like member having apertures therethrough corresponding in number and location to the desired needle-like points;

b. depositing needle-forming material substantially perpendicular to the plane of said plate-like screen member whereby material is deposited on said second electrode within said apertures, thereby forming conical needle-like points within said apertures;

c. depositing a masking material at a shallow grazing angle on said plate-like screen member at the same time the said needle-forming material is deposited, thereby to provide a lip or mask of diminishing size around the rim of each aperture therein;

d. removing said plate-like screen member whereby a bare point array of conical needle-like points is left on the said surface;

e. depositing an insulating material on a plate-like counter-electrode having apertures therethrough corresponding in number and location to the needle-like points on said surface; and

f. positioning said plate-like counterelectrode adjacent to said surface whereby said insulation on said counterelectrode provides separation and insulation from said surface and also provides registration of said points on said surface and apertures in said counterelectrode.

5. The method of producing a field-forming device which includes an array of conical needle-like points on a surface comprising the steps of:

a. positioning a plate-like screen member adjacent to said surface, said plate-like member having apertures therethrough corresponding in number and location to the desired needle-like points;

b. depositing needle-forming material substantially perpendicular to the plane of said plate-like screen member whereby material is deposited on said second electrode within said apertures, thereby forming conical needle-like points within said apertures;

c. depositing a masking material at a shallow grazing angle on said plate-like screen member at the same time the said needle-forming material is deposited, thereby to provide a lip or mask of diminishing size around the rim of each aperture therein;

d. removing said plate-like screen member whereby a bare point array of conical needle-like points is left on the said surface; and

e. placing a plate-like counterelectrode having apertures therethrough corresponding in number and location to the needle-like points on said surface in insulated spaced relation relative to said surface and the points on the said surface.

6. The method of producing an array of conical needle-like points on a surface comprising the steps of:

a. positioning a plate-like screen member adjacent to said surface, said plate-like member having apertures therethrough corresponding in number and location to the desired needle-like points;

b. depositing a masking material at a shallow grazing angle on said plate-like screen member to provide a lip of diminishing size around the rim of each aperture thereon;

c. depositing needle-forming material substantially perpendicular to the plane of said plate-like screen member whereby material is deposited on said surface within said apertures, thereby forming protrusions thereon;

d. simultaneously depositing a masking material at a shallow grazing angle on said plate-like screen member and depositing needle-forming material substantially perpendicular to the plane of the said plate-like screen member, whereby needle-forming material is deposited on said surface within said apertures at the same time the said apertures are closed by said masking material, thereby forming conical needle-like points within said apertures; and

e. removing said plate-like screen member whereby a bare point array of conical needle-like points is left on the said surface.

7. The method of producing an array of conical needle-like points on a surface comprising the steps of:

a. positioning a plate-like screen member adjacent to said surface, said plate-like member having apertures therethrough corresponding in number and location to the desired needle-like points;

b. depositing a masking material at a shallow grazing angle on said plate-like screen member to provide a lip of diminishing size around the rim of each aperture thereon;

c. depositing needle-forming material substantially perpendicular to the plane of said plate-like screen member whereby material is deposited on said surface within said apertures, thereby forming protuberances within said apertures;

d. depositing a masking material at a shallow grazing angle on said plate-like screen member thereby to provide a lip of diminishing size around the rim of each cavity therein at the same time the said needle-forming material is deposited; and

e. removing all masking material and deposited needle-forming material from said plate-like screen member.

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