METHOD OF FABRICATING SEMICONDUCTIVE DEVICES AND THE LIKE

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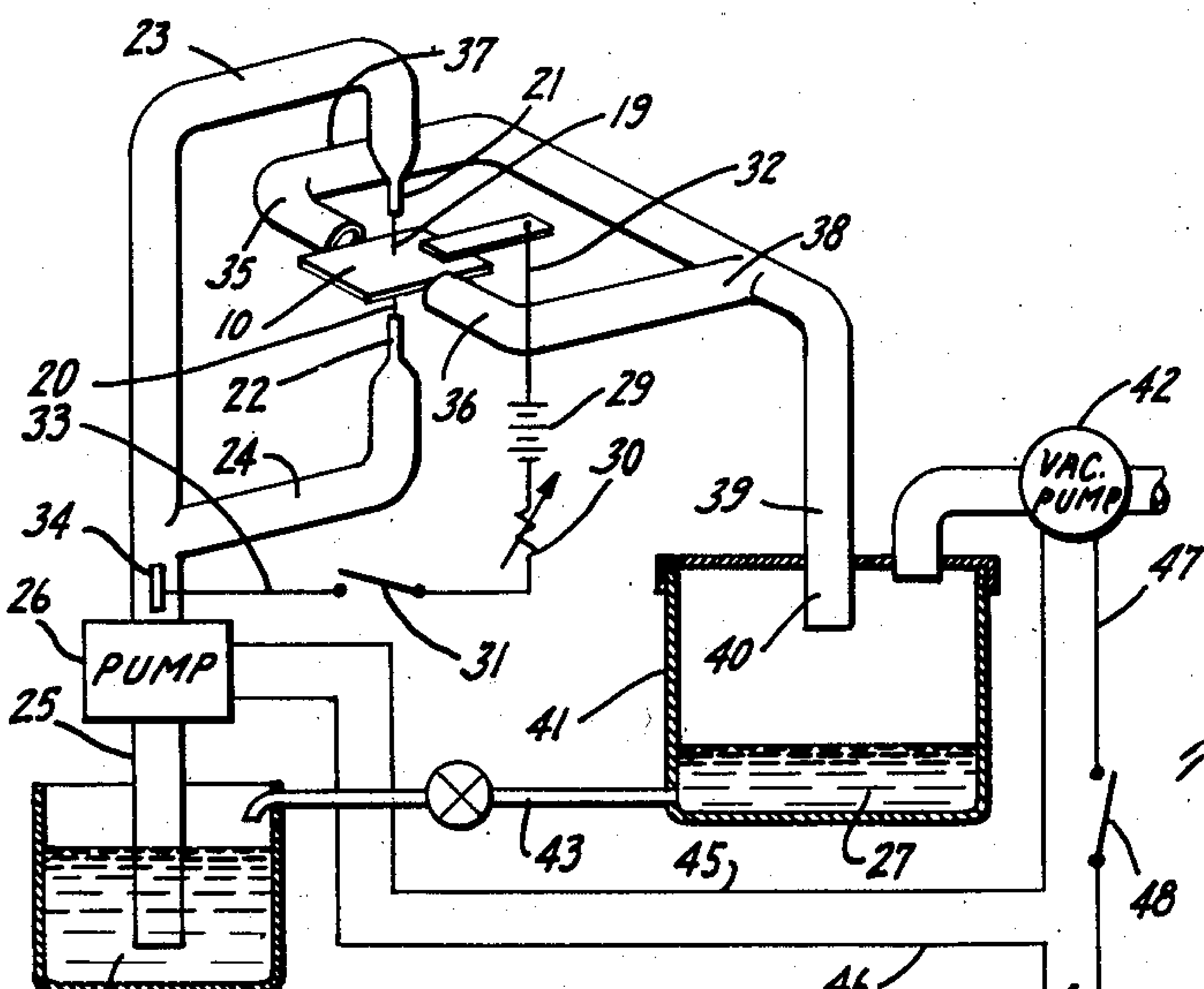

FIG. 1.

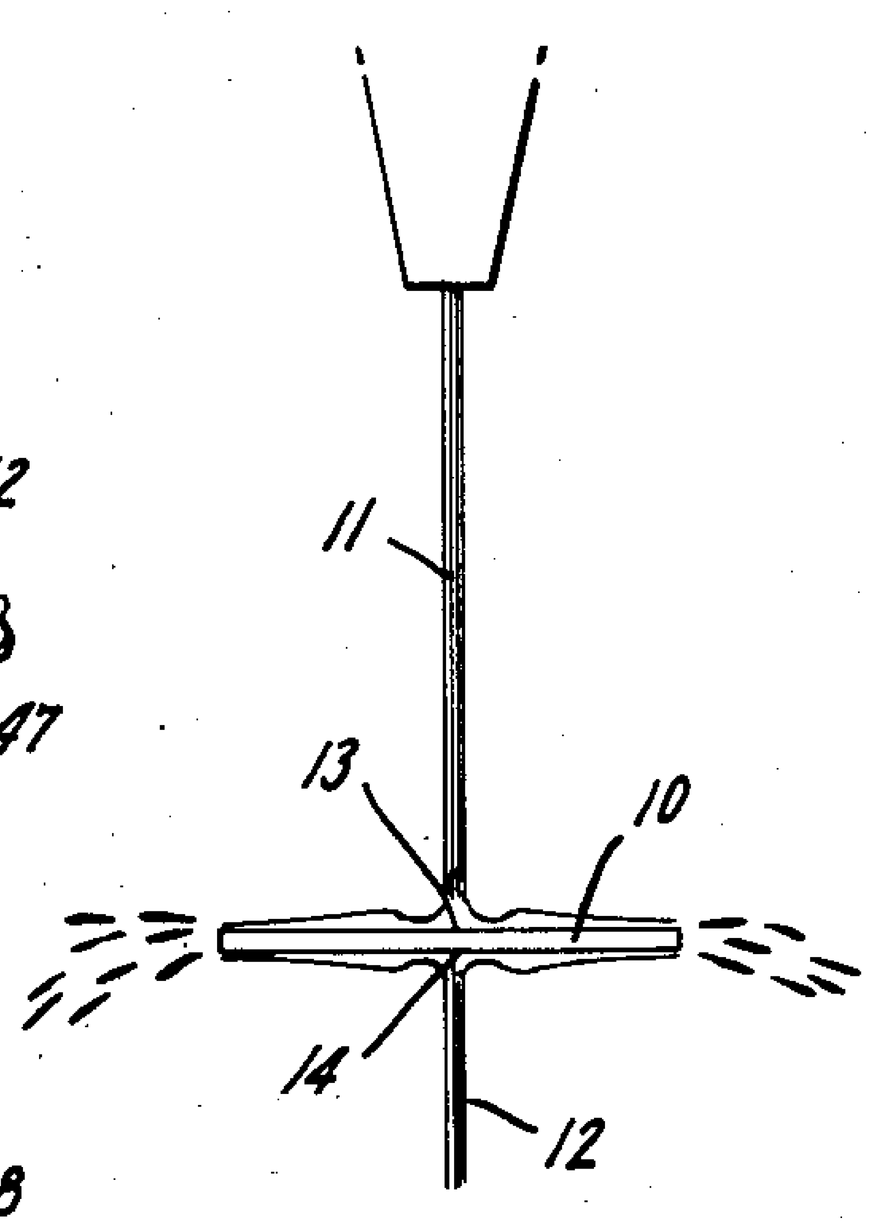

FIG. 2.

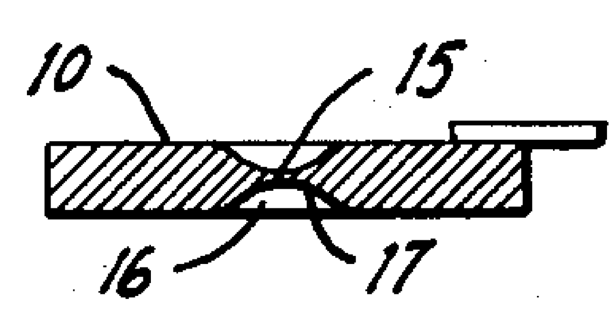

FIG. 5.

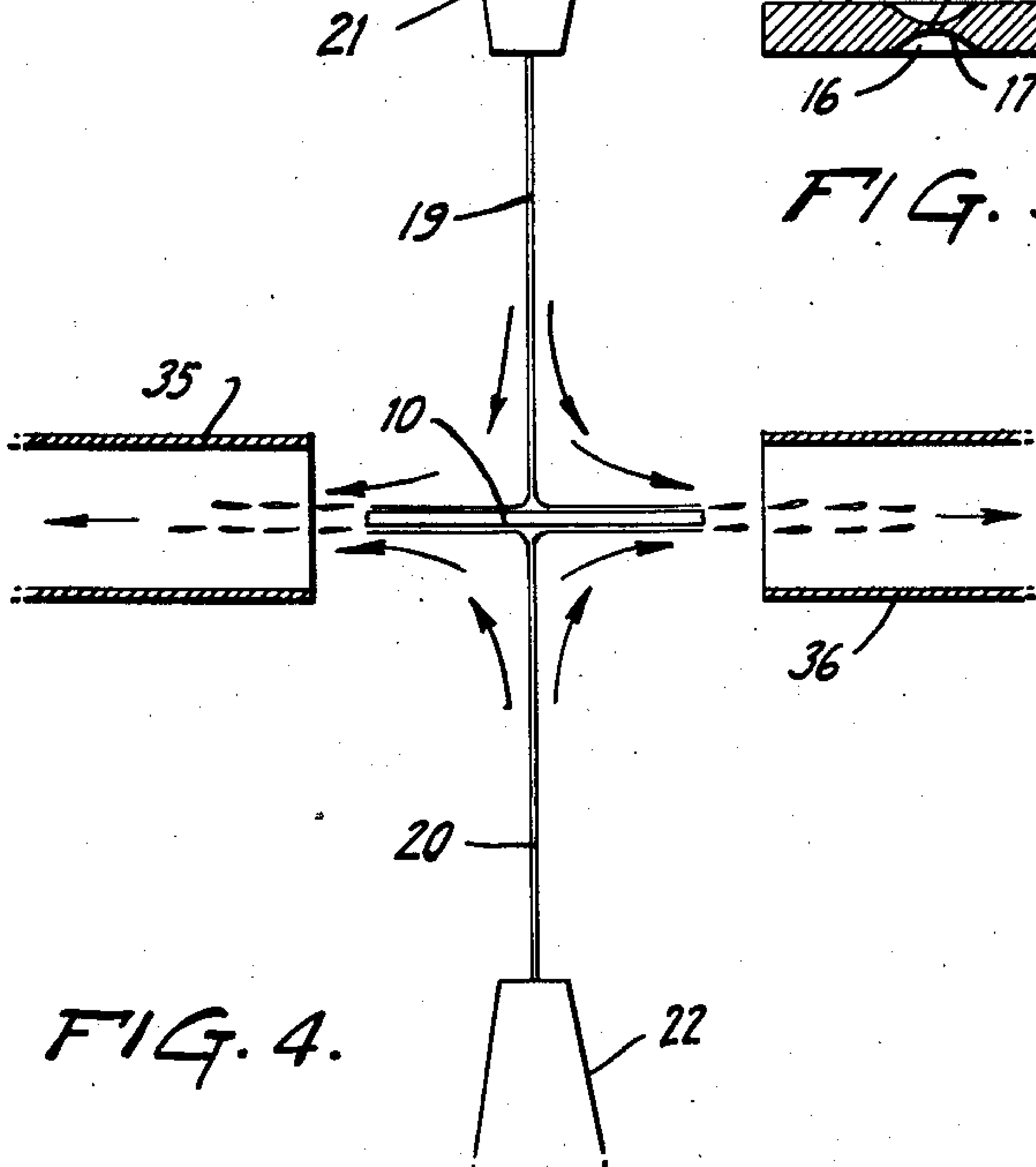

FIG. 4.

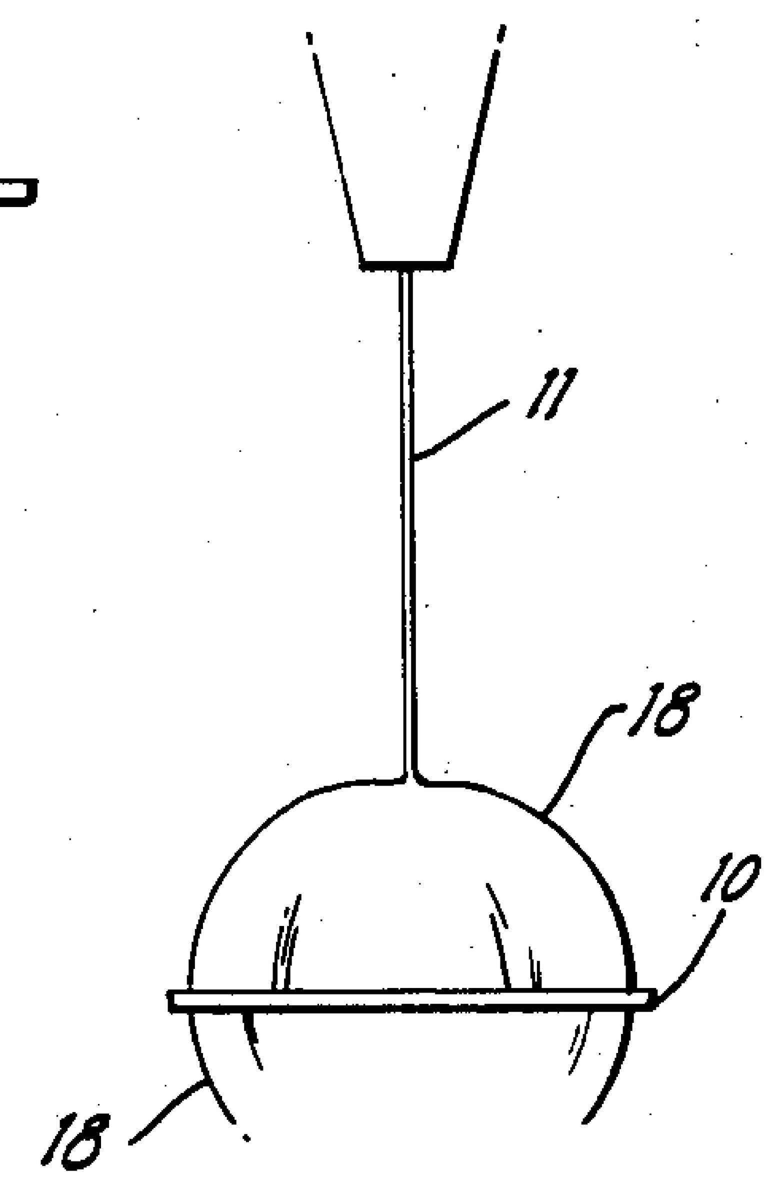

FIG. 3.

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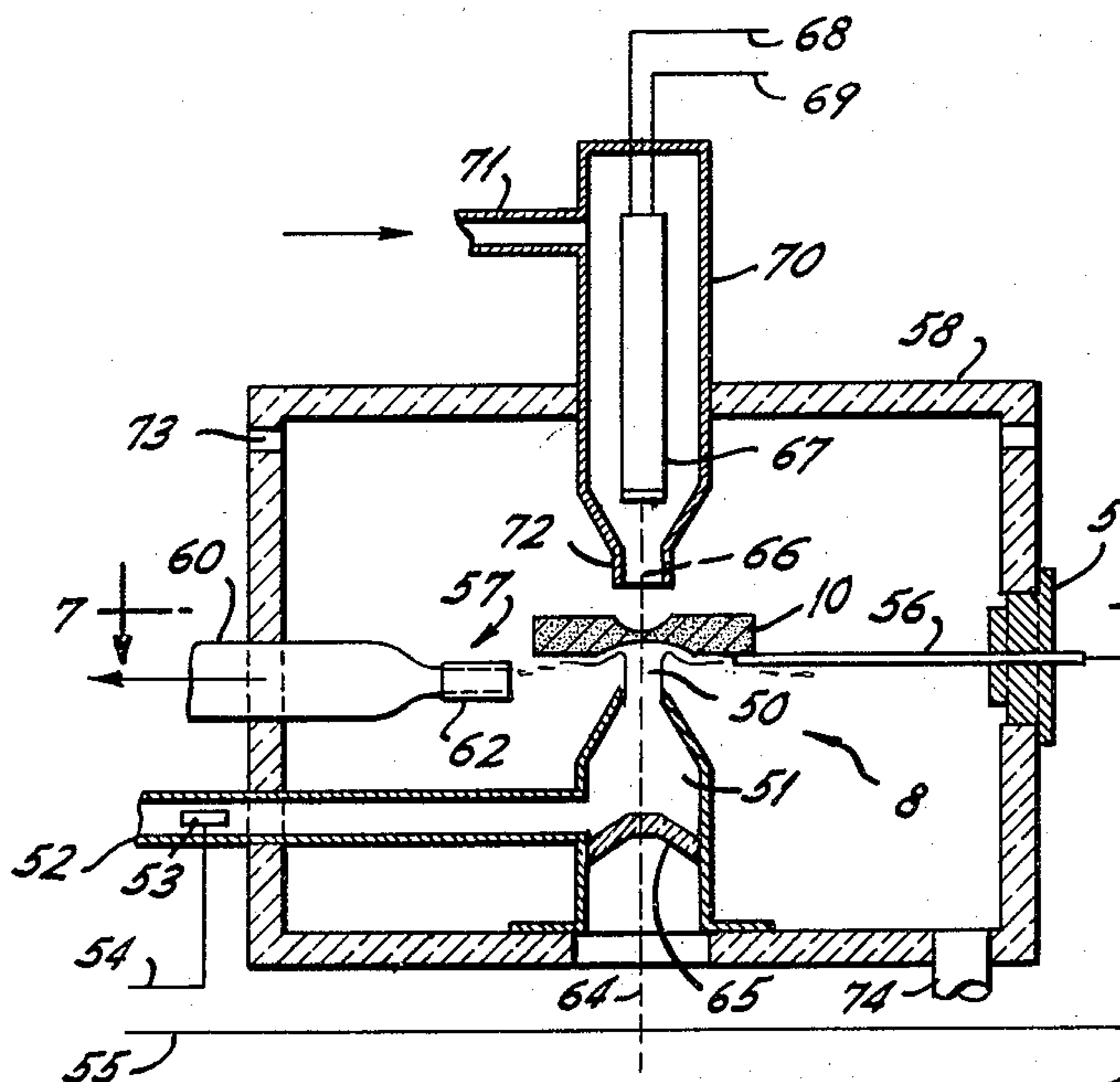

FIG. 6.

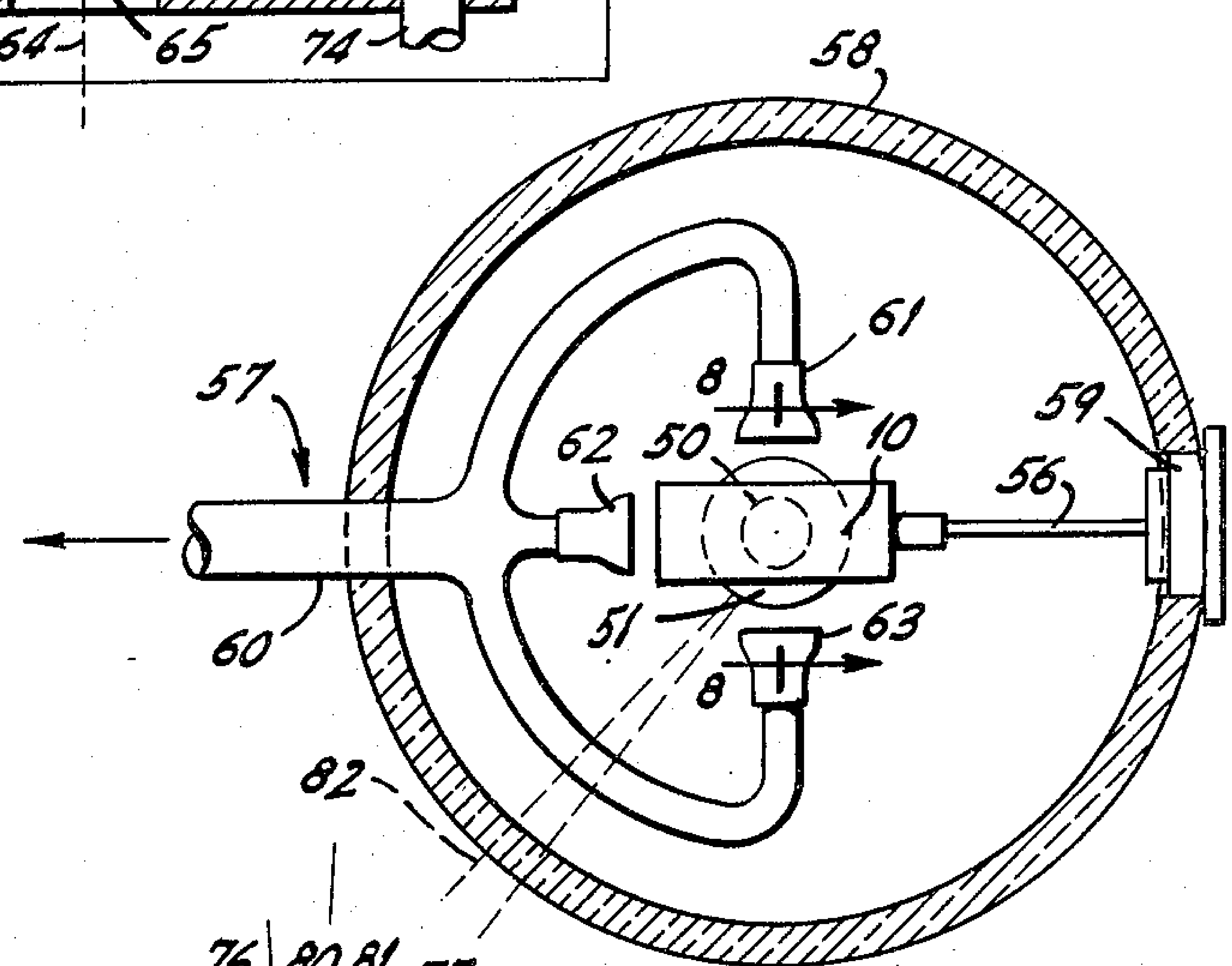

FIG. 7.

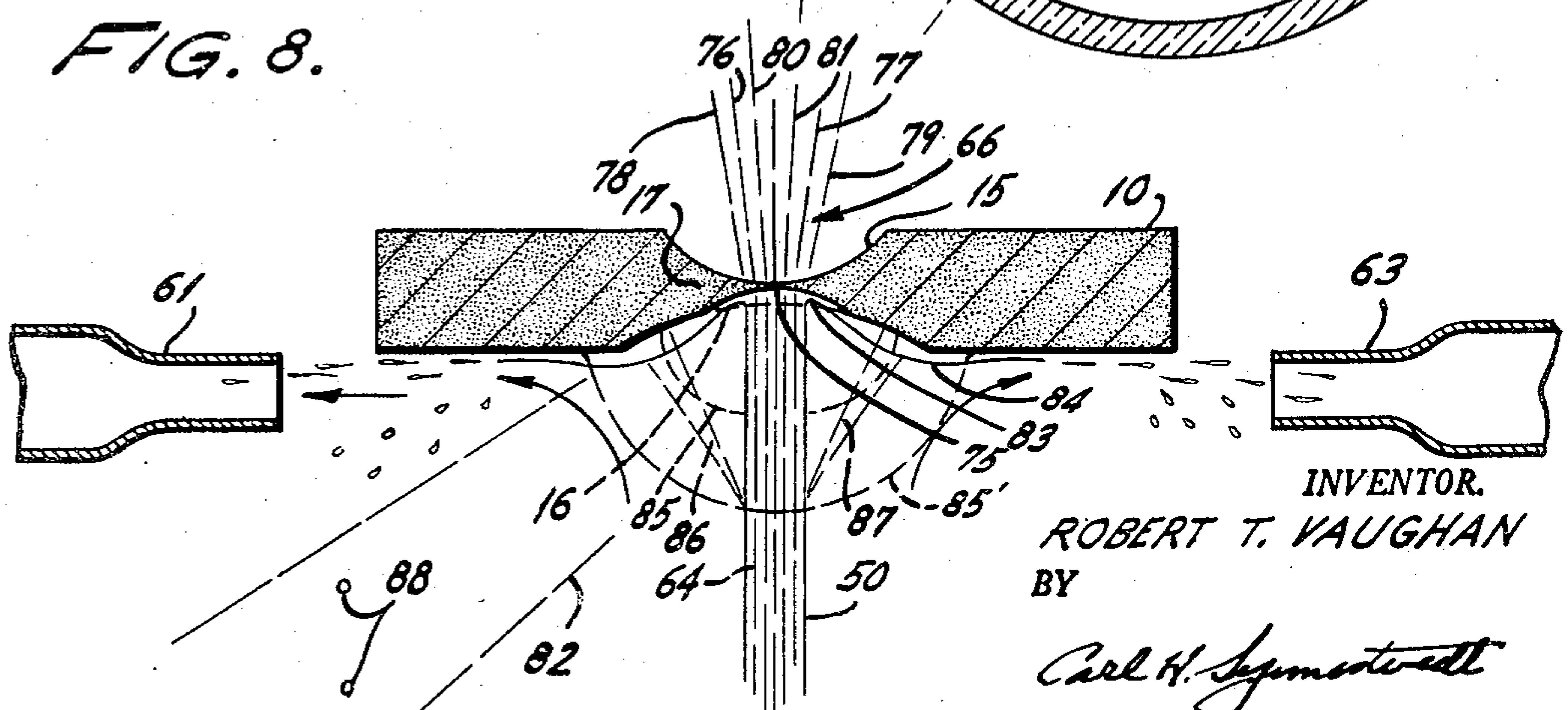

FIG. 8.

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METHOD OF FABRICATING SEMICONDUCTIVE DEVICES AND THE LIKE

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Application February 4, 1957, Serial No. 637,972

7 Claims. (Cl. 204—143)

The invention hereinafter described and claimed has to do with the fabrication of solid bodies having predetermined characteristics as to form, thickness, surface condition and the like. While being of broader applicability, the invention is particularly concerned with the fabrication of semiconductor diodes, transistors and the like; and it may be used both in the electrolytic etching of a semiconductive body and in the electrolytic plating of electrode elements thereon.

The present disclosure is a continuation-in-part of a parent application Serial No. 559,695, filed January 17, 1956, and now abandoned, entitled "Method of Fabricating Semiconductive Devices," which in turn was a continuation-in-part of an original parent application Serial No. 517,453, filed June 23, 1955, and now Patent No. 2,830,697, and entitled "Method of Etching."

The invention may be considered as an improvement upon the electrolytic jet-etching and plating methods, described and claimed in the copending application of Tiley and Williams, entitled "Semiconductive Devices and Methods for the Fabrication Thereof," Serial No. 472,824, filed December 3, 1954. It may also be considered as an improvement over the etch-controlling method and apparatus described and claimed in the application of Noyce, entitled "Infrared Thickness Control for Transistor Blanks," bearing Serial No. 449,347, and filed August 12, 1954, and now Patent No. 2,875,141. Said copending applications are assigned to the assignee of the present invention.

According to said method of Tiley and Williams, an electrolyte liquid is applied to a semiconductor or the like, as a fine jet which carries an electrical current; and according to said method of Noyce, the jet carries a beam of light or other wave energy. It is desired that the liquid of the jet will flow off from an impingement area on the blank, in form of a thin, flat, flowing sheet. However, disturbing tendencies have been encountered. For instance, if the jet stream is too fast, it may break up and cause breaking up of the light beam therein. If the jet stream is very fine, it tends to cause accumulation of a liquid drop or ball, adhering to and gradually growing on the surface of the solid body and maintained thereon against the force of gravity; and the development of such a ball of liquid tends to interfere with the electrolytic processes.

It is therefore a basic object of this invention to control or preferably to prevent such undue breaking up of the jet and also to control or prevent such undue accumulation of a ball of jet liquid.

A related object is to insure smooth and uniform configuration of the flowing electrolyte liquid. Particularly in and adjacent the impingement area it is preferred to provide a thin, coherent jet column, directly transforming itself into an even thinner, coherent, flowing liquid sheet. Controlled forces, in opposition to the forces of liquid cohesion in the electrolyte liquid, are applied according to the present invention.

Another object is to provide methods whereby controlled pneumatic forces, such as those of a flow of air or other gas, are applied to a liquid body and thereby to a flow of electrical and/or light energy which in turn serves to modify the configuration of a solid body. In particular, aspirating means may be used for such control.

The objects have been achieved by applying certain pneumatic and particularly aspirating means and forces to an atmosphere surrounding an electrolytic and/or light-guiding liquid column, adjacent a solid contact area. The details will be noted from the following description, taken together with the accompanying drawing, wherein:

Figure 1 is a schematic perspective representation of apparatus for operation according to the invention; Figure 2 is a detailed view on a larger scale, showing a central part of such apparatus and a certain flow pattern therein, as produced by comparatively large diameter jets; Figure 3 is a detailed view generally similar to Figure 2, showing however the undesirable balling-up condition arising with the use of extremely fine jets when the present invention is not used; Figure 4 is another view generally similar to Figure 2 but showing the flow pattern of an extremely fine electrolyte jet, produced with the aid of the invention; and Figure 5 is a schematic, sectional view of a transistor blank treated in accordance with the present invention.

Figure 6 is a schematic cross-sectional elevation of a further embodiment of apparatus for operation in accordance with this invention; Figure 7 is a sectional plan view taken along line 7—7 in Figure 6; and Figure 8 is an enlarged, schematic, sectional detail view of a transistor blank in process of being precision etched in the apparatus of Figure 6.

Figures 1 to 5

Referring initially to Figure 2, a flat, plane-parallel semiconductor blank **10** is treated by two electrolyte liquid jets **11**, **12**, directed against the two surfaces of the blank in opposite and mutually aligned directions and desirably at right angles to the blank, thus providing mutually opposed jet impingement areas **13** and **14** on the blank. As shown in Figure 5, such treatment is applied to form mutually opposed cavities **15** and **16** on the blank **10**, leaving between these cavities only a thin semi-conductor region **17**. Subsequently, the semiconductor device, particularly of the surface barrier type, can be completed by forming and especially by plating certain electrode elements, not shown herein, in the cavities **15**, **16**.

In the manufacture of many types of semiconductor devices and mainly in the manufacture of surface barrier units, it is important to provide certain critical configurations in small plates, blocks or blanks **10** of germanium or similar materials, and particularly to reduce certain regions **17** of such blanks **10** to a very minute and accurately controlled thickness. It is also important to shape the thin region **17** without disturbance of the material therein, particularly on the surface thereof, and accordingly to avoid all ordinary grinding, machining, rolling and similar operations. These results can be achieved by the use of electrolytic treatments, as disclosed in the application of Tiley and Williams, but only if the electrolyte liquid, supplied by jets **11**, **12** to the solid **10**, flows off smoothly.

Preferably the outflowing liquid is formed into a thin sheet, as shown in Figure 2. In some cases this can be achieved by means of the fluid jets **11**, **12**, alone; in such cases the jet streams can be used substantially in the way in which they are used in various other processes and industries, that is, with adequate kinetic energy remaining in the liquid, after the impingement at **13**, **14**, to insure a rapid, lateral flow of the liquid, as a coherent sheet, along the surfaces of the solid body **10**. It is important to note, however, that atomization of the liquid, caused for instance by excessive jet velocity, would tend to interfere with the maintenance of such a smooth and thin sheet of liquid; atomization is therefore to be avoided in processes of the present kind.

Paradoxically, difficulty has arisen also upon the use of a very fine jet 11 or 12; and this presents a serious problem, as the use of extremely fine jets may otherwise be desirable or even necessary in processes of the present kind. The liquid of such a jet frequently forms a single, small, more or less hemispherical droplet, coaxial with jet 11 or 12 in the impingement area 13 or 14, adhering to the solid body 10 in said area; and, as liquid continues to be added to the area, by the jet 11 or 12, such a droplet grows, until it forms a fairly large drop or ball 18, see Figure 3. This occurs whenever the kinetic energy remaining in the liquid is so reduced, upon the impingement at 13, 14, as to become insufficient to overcome the forces of cohesion which tend to form the liquid into a sphere. The figure shows a liquid drop 18 which adheres to the top or bottom of semiconductor blank 10 and the diameter of which almost equals the width of said blank; and it also shows that the diameter of the liquid jet 11 is substantially smaller than the diameter of this liquid drop. It will be realized that the maximum size of a liquid drop, overcoming the force of gravity by that of liquid cohesion or surface tension, is fairly small by itself and is usually limited to a few millimeters. The point of importance is that the diameter of the jet potentially creating and feeding such a drop, in the method considered herein, is even smaller than the maximum size of a drop of the same liquid; this jet diameter usually amounts only to a fraction of a millimeter.

Eventually, sufficient liquid is accumulated in such a drop 18 to cause running off of the liquid; that is, the weight of the liquid in the drop ultimately overcomes the forces of cohesion, or breaks the surface tension. Immediately, however, the fine jet 11 causes a new drop to accumulate, repeating the cycle.

With typical jets of aqueous electrolyte liquid, a smooth and thin flow over the solid surface, as shown in Figure 2, can usually be expected when the jet has a comparatively large diameter such as about 9 mils or more. With the use of jets ranging from this order of magnitude down to about 3 mils in diameter, the etching fluid frequently balls up, particularly when the jet has a thickness smaller than about 5 mils. When jets of 3 mils diameter or less are used, the balling-up occurs almost invariably.

This tendency is of considerable practical significance, inasmuch as jet streams of diameters down to about 5 mils are usually required for all etching and plating procedures on a semiconductor or the like, and jet streams of 5 mils thickness or less are frequently required, mainly for the precision etching. Incidentally, the typical diameter of rough-etched pits may range from about 8 mils upward; and a precision-etched cavity may be about half as wide as the rough-etched pit.

The apparatus of Figure 1 serves to maintain conditions, in and around the electrolyte flow, which militate against the balling-up tendency, even in the case that extremely fine electrolyte streams are used.

These streams are here shown at 19 and 20 and are formed by small electrolyte discharge nozzles 21, 22, facing one another and discharging against the blank 10. The nozzles are respectively fed by conduits 23, 24, which are branch extensions of a main conduit 25, comprising means such as a pump 26, for drawing electrolyte 27 from a reservoir 28. This electrolyte may comprise any of a large variety of readily ionizable alkali salts or acids in aqueous solution, when it is desired to etch germanium or the like. Electric current is applied to the jets 19 and 20 and the wafer 10 by means of a potential source 29, a current regulating resistor 30, switch 31 and leads 32 and 33. The electric circuit is completed by attachment of lead 33 to an electrode 34 which is disposed within the conduit 25, and attachment of the lead 32 to the semiconductor 10.

The apparatus as described up to this point is substantially similar to that shown in the Tiley-Williams application; and, as indicated above, such apparatus by itself is adequate for the forming of semiconductive bodies, so long as it is possible to use jets of about 9 mil diameter or more and to produce cavities 15, 16 and electrodes of correspondingly large diameter, on the semiconductor body 10. However, where relatively close control of the diameter of the cavities and plated elements is required, it is necessary to use extremely fine jets 19, 20, typically having diameters such as 5 or 3 mils or less.

Therefore the present invention, as shown in Figure 1, uses, additionally, a pair of mutually opposed suction nozzles or aspirators 35 and 36, disposed in the plane of the wafer 10, adjacent the jets 19, 20, and connected respectively to branches 37 and 38 of a conduit 39, the end 40 of which extends into a vacuum tank 41. This tank may be maintained below atmospheric pressure by a vacuum pump 42 and may also serve as an electrolyte trap; liquid 27 may return from this tank to the supply reservoir 28 by a valve-controlled conduit means 43. Any well-known electrical circuit means or the like may be used to operate the pumps 26 and 42; for instance a power source 44 may be connected with the motors of said pump by leads 45, 46, 47, including a switch 48.

In the operation of the apparatus of Figure 1, switch 48 is closed; pump 26 forces the etching fluid 27 from reservoir 28 through nozzles 21, 22 to direct fine hydraulic jets 19, 20, against the blank 10; and vacuum pump 42 reduces the pressure in tank 41 and aspirator system 35, 36, 37, 38, 39, thereby producing an area of low pneumatic pressure in the atmosphere wherein blank 10 is exposed and particularly in the plane of blank 10, adjacent the impingement areas 13, 14, of jets 19, 20.

The presence of this low pressure area causes a rapid flow of air into the same, from and through the adjacent portions of the atmosphere; and these portions include the regions overlying and surrounding said impingement and low pressure areas. Thus there results an atmospheric flow pattern on each side of the blank, as shown by arrows in Figure 4; that is, a pattern including an air flow which surrounds and parallels the jet 19 or 20, and continues directly as an outward flow over the face of the blank 10.

These atmospheric pressure and flow conditions have been found to maintain the desired conditions of smooth, uniform and thin, sheet-like liquid flow and to prevent the undesired balling-up, even in case that extremely fine jets of 5 or 3 mils diameter or less are used.

All or part of the sheet-like liquid flow may ultimately break up in form of droplets, remotely of the impingement area; and some or all of these droplets may be drawn into the aspirators 35 and 36. However, it is also possible to perform the present method in such a way that all or part of the liquid follows a trajectory different from the path of the aspirated air, as will hereinafter be described with respect to Figure 8.

When the essential conditions as described above have been established, the switch 31 is closed to energize the electrolytic circuit, which may presently be assumed to be an etching circuit. It uses the thin jet streams 19, 20, as conductors, carrying an etching current to the semiconductor surface to be provided with cavities 15, 16.

It is believed to be unnecessary at the present point to discuss in detail the potentials and other characteristics prevailing in the different portions of the semiconductor etching circuit, such matters being fully discussed for instance in the Tiley-Williams application mentioned above. However, it is important to note what would happen if the aspirating operation were interrupted during the electrolytic treatment: the resulting formation of a liquid ball 18 (Figure 3) would distribute the electrolytic current over the entire area of adhesion of this drop to the solid body 10, dissipating the current and causing excessively wide and flat etching.

If and when this balling-up is overcome, and the condition of Figure 4 established, this dissipation of current is effectively prevented. The reason is that any current to be dissipated must now flow outwardly through an extremely thin and very resistive sheet or film of liquid, extending along the semiconductor surface. The maximum thickness of this outwardly flowing sheet of liquid, prevented from coalescing into a drop, is usually kept to one quarter of the jet diameter, that is, usually only about 1 mil or less, by the inherent hydraulic behavior of the jet. The ohmic resistance of such a thin sheet of liquid is too great to allow any substantial spreading of the current, outwardly from the jet column.

For the purpose of plating electrode elements on the surfaces of transistor cavities 15, 16 suitable method adjustments can be applied, as described in the Tiley-Williams application. Such adjustments may include a reversal of the polarity of the electrolytic circuit, by means of well-known apparatus, not shown herein. The control over the configuration of the flow can be substantially similar to that used as in the etching process, described above.

From one viewpoint the process of this invention can be described as providing a static, outward, pneumatic pressure drop or gradient, maintained over the impingement area and effective to distort, flatten and destroy a liquid ball inadvertently formed or beginning to be formed in this area. From another viewpoint the process includes a dynamic, outward, pneumatic entrainment of surface liquid, thereby preventing and counteracting the formation of such a ball. These static and dynamic effects of the pneumatic treatment cooperate in maintaining the desired smooth liquid flow, away from the impingement area as shown.

Figures 6 to 8

Reference is now made to Figures 6 and 7, which illustrate means for operation according to this invention for the precision etching of a semiconductive body, pursuant to a preliminary or coarse etching treatment which has produced a body of the form shown in Figure 5.

The body 10 is accordingly shown as having preformed cavities on both sides and as being further exposed to a single, vertical, upward jet 50, issuing from a jet nozzle 51 and leading to a center part of the lower cavity. This jet is suitably supplied with electrolyte by a conduit 52 having an electrode 53 mounted therein; and an etching circuit is established, leading from a source of potential, not shown in this figure, through a conductor 54, electrode 53, jet 50, blank 10, holder 55 and another conductor 56 leading back to the source.

Liquid is withdrawn from the impingement area by aspirator means, generally shown at 57. The entire process is performed in a housing 58, in order to avoid fluctuations of the jet 50 resulting from any atmospheric drafts or the like. Advantageously, the blank 10 and holder 56 are oriented relative to the jet nozzle 51 by guide means 59, cooperating with a wall of the housing 58. Opposite this guide means a suction head or conduit 60, forming part of the aspirator system 57, enters the chamber 58; and within this chamber a plurality of suction nozzles 61, 62, 63, suitably connected with the header, are distributed around the jet 50, in or slightly below the plane of the blank 10. I have found it preferable to employ two, three or more nozzles 61, etc. with flat intake openings, machined of metal, and to regularly distribute the nozzles and their suction areas around the jet, while orienting them in an accurately spaced, parallel relationship with respect to the blank 10. The housing 58 is desirably made of glass or the like, in order to make it possible to observe the operation within.

For the control of the precision etching of germanium I preferably employ infrared light, as disclosed in the Noyce application, whereas other light is equivalent or preferable when etching silicon or the like. Accordingly I provide a beam 64 of suitable light or other electromagnetic radiation; and such light may enter the apparatus through a transparent plastic cone 65, forming a raised bottom part of the jet nozzle 51 positioned as close to the nozzle discharge aperture as possible. From here the light may pass upwardly, coaxially into and interiorly along the jet stream 50, which stream is desirably rather short. As explained by Noyce, there exists a critical relationship between the radiation-transmitting characteristics of the electrolytic jet liquid and those of germanium; and the use of this relationship will here be described, although the situation is somewhat different when light control is applied to the etching of silicone or the like.

When the material in the blank 10 has been reduced in thickness to a certain extent, there results a substantial transmission of light of certain wavelengths, so that a beam 66 begins to pass through the blank 10. This latter beam is intercepted by a photosensitive element 67 having conductors 68, 69, to actuate equipment for the control of the electrolytic process, for instance as shown by Noyce.

A duct 70 is shown as coaxially surrounding the cell 67. This duct is supplied with dry gas, for instance dry air, through inlet means 71, said gas being directed through a nozzle 72 at the end of the duct 70 and thereby against an area of the blank 10 opposite the impingement area of the jet 50. It has been found that such drying of the back of the blank sensibly improves the precision etching by eliminating or reducing noise which otherwise disturbs the infrared control signal. Excess air from nozzle 72 may be vented off from the housing 58 by vent means 73, even if the aspirators are not operating, whereas accumulated liquid or humidity, not intercepted by the aspirators, may be withdrawn by a drain 74.

The greatly enlarged diagram of Figure 8 shows how the fine jet 50 impinges on a solid surface area smaller than the original cavity 16 and how it causes further etching of the impingement area, thereby reducing the central surface barrier portion 17 of the semiconductive body 10 to a minute thickness, with a surface 75 spaced from the opposite cavity surface by not more than a thin lamina. This film may have for instance an ultimate thickness such as .02 to .2 mil.

In processes of the present type, employing an electrolytic jet stream, the etched cavity tends to have a surface of the approximate form of a concave spherical segment. As a result, the solid body 10 forms a diverging lens for such radiation as it transmits. This is indicated by the diverging form of the beam 66, bounded by outer rays 76, 77. As the precision etching progresses and the surface 75 is more deeply etched into the semi-conductor body 17, the diverging effect becomes more pronounced, as suggested by the boundary lines 78, 79. The intensity of radiation, transmitted by the thin solid 17, is not initially increased to the same extent as the diverging effect. As a result, the photocell 67 (Figure 6) receives progressively reduced illumination, as the precision etching progresses; and correspondingly, the circuit 68, 69, shows progressively lower potentials. This operation continues until a critical central thickness of the solid lamina 17 has been reached, as explained by Noyce; thereupon, a central beam 80, 81, carrying relatively substantial intensity of radiation at certain wavelengths, begins to reach the photocell. This now causes a rise in potential in the photocell output circuit. When this change-over from gradually falling to rising photocell potentials has been initiated or established, the precision etching can be manually or automatically terminated.

In addition to the light beam 64, employed for the afore-mentioned control purposes, a lateral beam of light 82 may be directed onto the jet impingement area, from a strong red or white or similar light source, not shown. Strong illumination of the semiconductor has significant effects upon the etching process itself; it accelerates this process and sharpens the contours of the etched areas, as is known from said Tiley-Williams application.

In accordance with the present invention it is important to note the fact that the exact configuration of the liquid stream **50**, particularly in the impingement portion **83**, has certain effects upon the optical or equivalent processes connected with the illumination by the light beams **64**, **82**. The critical intensity of the illumination reaching the photocell, upon predetermined thinning of the solid film **17**, is largely dependent upon the optical characteristics of the medium through which the light passes; and the transition portion **83** of the liquid body is of particular significance in this respect. Assuming for instance that the cohesive forces of the electrolyte liquid are allowed to change this portion **83**, together with the outflow portion **84** surrounding the same, into an incipient liquid ball **85**; this would lead to considerable scattering of light from the incident beam **64**, due to the presence of unavoidable eddies in the liquid, among other things; and the scattering effect would vary if a larger liquid ball **85'** were gradually formed. The scattered light would be deflected along paths such as those schematically shown at **86**, **87**.

By contrast, so long as the column **50** retains a uniform, smooth, columnar shape, as shown, the outer boundaries thereof apply a constant light-guiding effect, thereby preventing the scattering and the irregularities thereof. It is therefore important for the illumination in general and mainly for the infrared control process to avoid irregularities such as those shown at **85**, **86**, **87**.

It is desirable also to avoid any serious irregularity in the application of the lateral light **82**; for instance, care should be taken to avoid the passage of liquid droplets **88** through the beam of lateral light, since the lens effects of such droplets could seriously disturb the illumination of the impingement area.

The controlled illumination obtained in this way improves also the effect of the electrolytic currents, basically described above and which is one of the important elements of the precision etching as well as of other electrolytic operations according to this invention. If light were caused by droplets or the like to reach all or different parts of the impingement area with variable intensity, this would lead to substantial variations of the electrolytic processes, aside from the diffusion of the electrolytic currents by the balling-up of the liquid. Thus the simple pneumatic-hydraulic device or method of the present invention improves not only the process of infrared wave control applied to a semi-conductor, it also improves, in several ways, the process of applying electrolytic currents to semiconductors and other materials.

While two embodiments of the invention have been described, it should be understood that the details thereof are not to be construed as limitative of the invention, except insofar as is consistent wtih the scope of the following claims.

I claim:

1. In a process of jet-electrolytic treatment of a semiconductor, maintaining a fine, coherent jet column of electrolyte liquid directed toward the semiconductor, which column tends to form a single, cohesive liquid ball, coaxial with said jet, larger than the diameter of said jet, and adherent on the semiconductor; counteracting such forming of liquid balls by applying suction to the atmosphere surrounding the jet; and applying sufficient electrical potential between jet liquid and semiconductor to accomplish said treatment.

2. In the fabrication of transistors and the like: holding a small body of semiconductive material, exposed in a gaseous atmosphere; maintaining an electrolyte liquid jet carrying an electrical current, traversing said atmosphere and ending in an impingement area on said body, for jet-electrolytic treatment of said body in said area, followed by passage of the liquid away from said area; the size and condition of the jet and of the impingement area being such that liquid from the jet tends to accumulate as a single coherent liquid droplet adherent to the impingement area on the semiconductive body, coaxially with the jet, which droplet would, on continued maintenance of the jet without other treatment of the liquid, grow into a coherent and adherent drop, larger than the diameter of the impingement area and interfering with said treatment; and counteracting the cohesion of the impinging liquid while leaving such liquid adherent to the impingement area by aspirating a current of gas over said impingement area.

3. A method of fabricating transistors and the like comprising the steps of: maintaining a jet column of aqueous electrolyte liquid, with an end portion of said column contacting a minute surface portion of a small body of semiconductive material, while limiting the diameters of said column and surface portion to a few thousandths of an inch; preventing the liquid of the column, in said region, from balling up on said semiconductive body into a liquid drop larger than said minute surface portion by drawing a current of gas over and from the region of contact between said liquid column and said semiconductive body; and passing electrolytic current through said liquid column and said semiconductive body, for electrolytic treatment of the latter.

4. In the treatment of transistor material and the like by a jet-electrolytic method wherein a minutely thin jet column of liquid electrolyte, carrying an electrical current, impinges against a semiconductive body and tends to adhere thereto, the improvement which comprises: counteracting cohesion of the liquid, and thereby preventing accumulation of a coherent liquid body, which otherwise would accumulate in the form of a single drop surrounding the end of the liquid column on the semiconductive body, by maintaining a pressure gradient in the atmosphere overlying the minute area of impingement of the liquid column.

5. In a method as described in claim 4, passing radiation through the area of liquid impingement, for aiding said treatment of the semiconductive body, while maintaining said pressure differential.

6. In a method as described in claim 4, passing a beam of radiation through the area of liquid impingement, for controlling the progress of treatment of the semiconductive body, while maintaining said pressure differential.

7. In a method as described in claim 6, passing said beam longitudinally through said column.

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