United States Patent

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[54] OPTICAL MACHINING PROCESS

7 Claims, 9 Drawing Figs.

[52] U.S. Cl. 137/81.5
[51] Int. Cl. F15c 5/00
[50] Field of Search 137/81.5; 204/159.23

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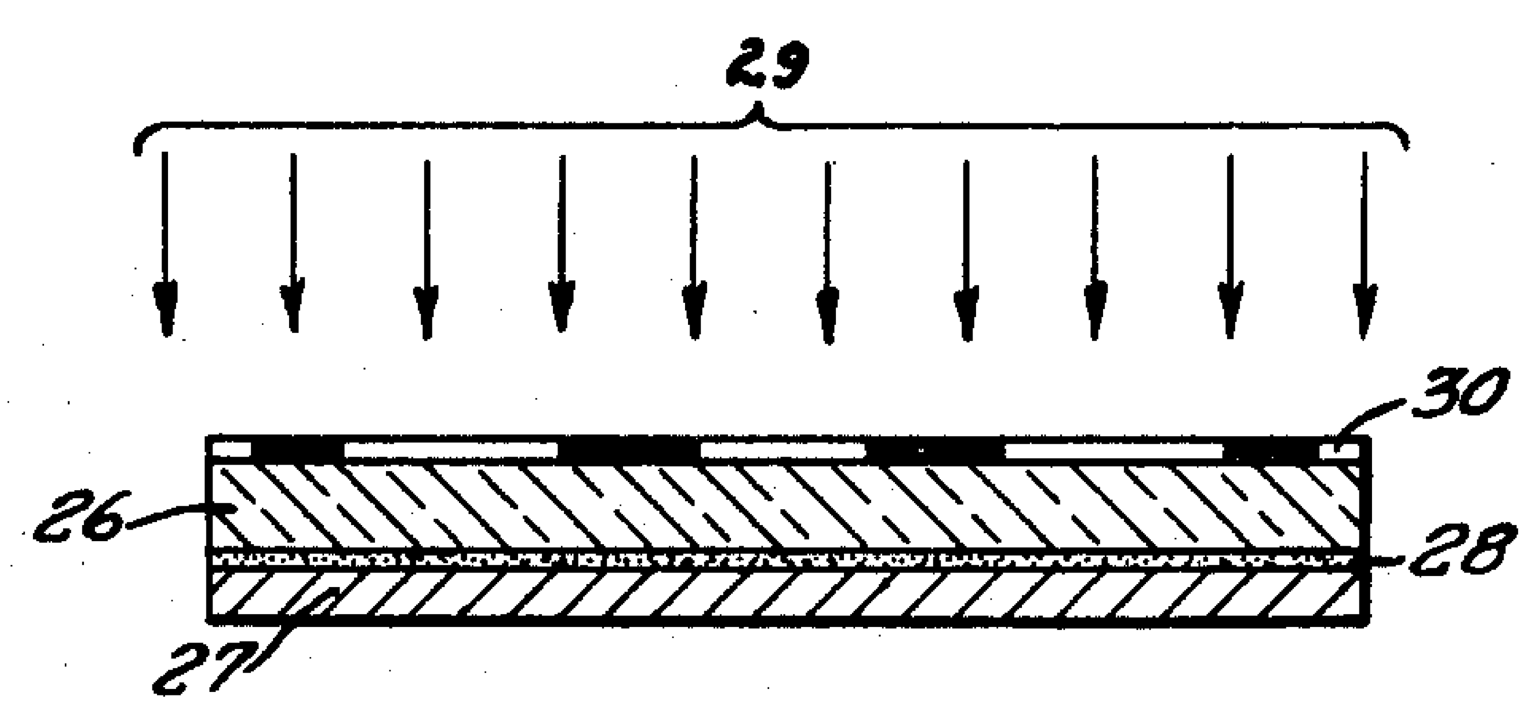
ABSTRACT: A fluid amplifier includes a rigid base, a layer of light-absorptive adhesive overlying a surface of the base and a layer of light-polymerizable plastic bonded to the base by the adhesive; the light-polymerizable material being solid in the unpolymerized state and in the polymerized state having a plurality of channels and nozzles formed therein to define a fluidic element. A cover plate seals the channels and nozzles to complete the element.



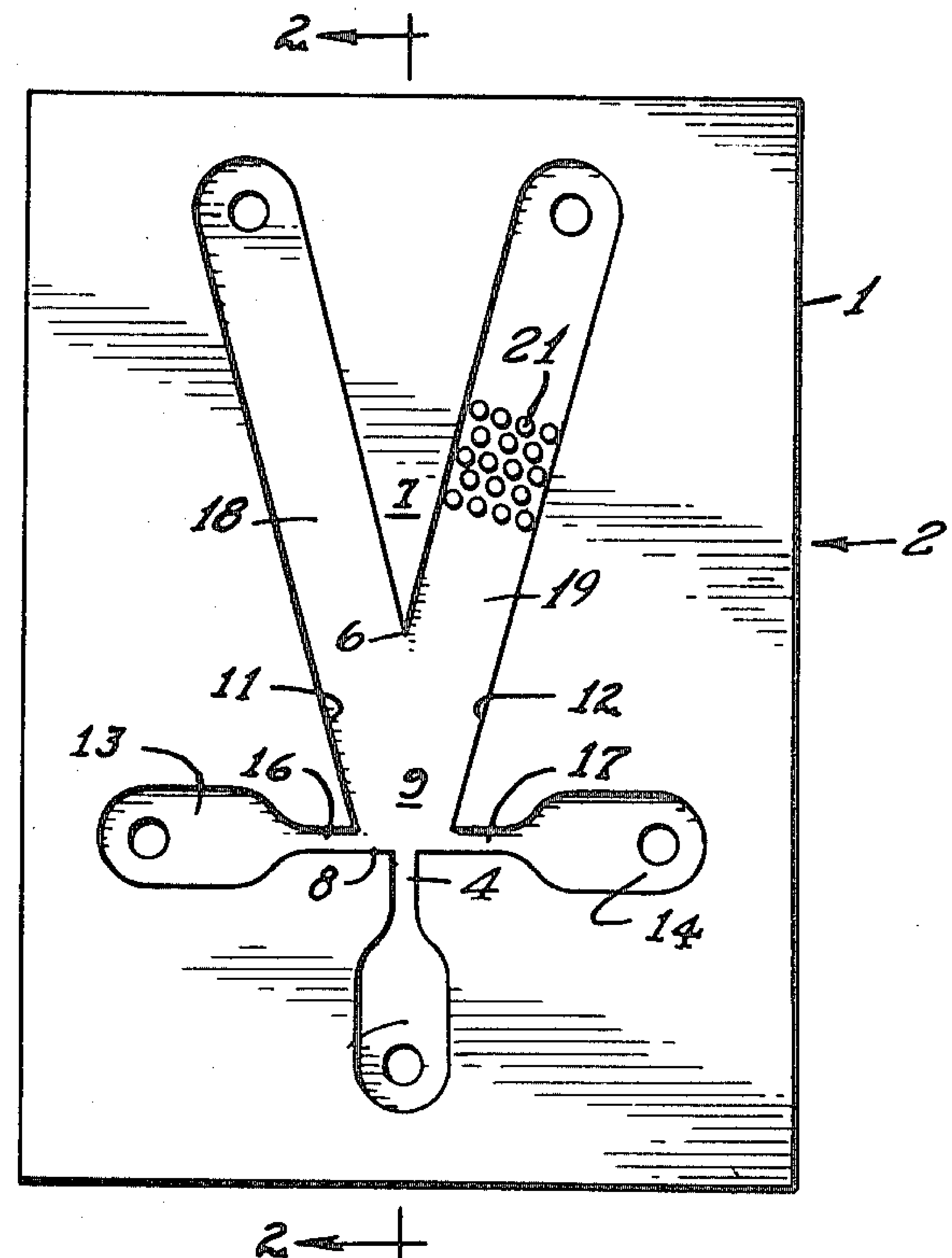


Fig. 1

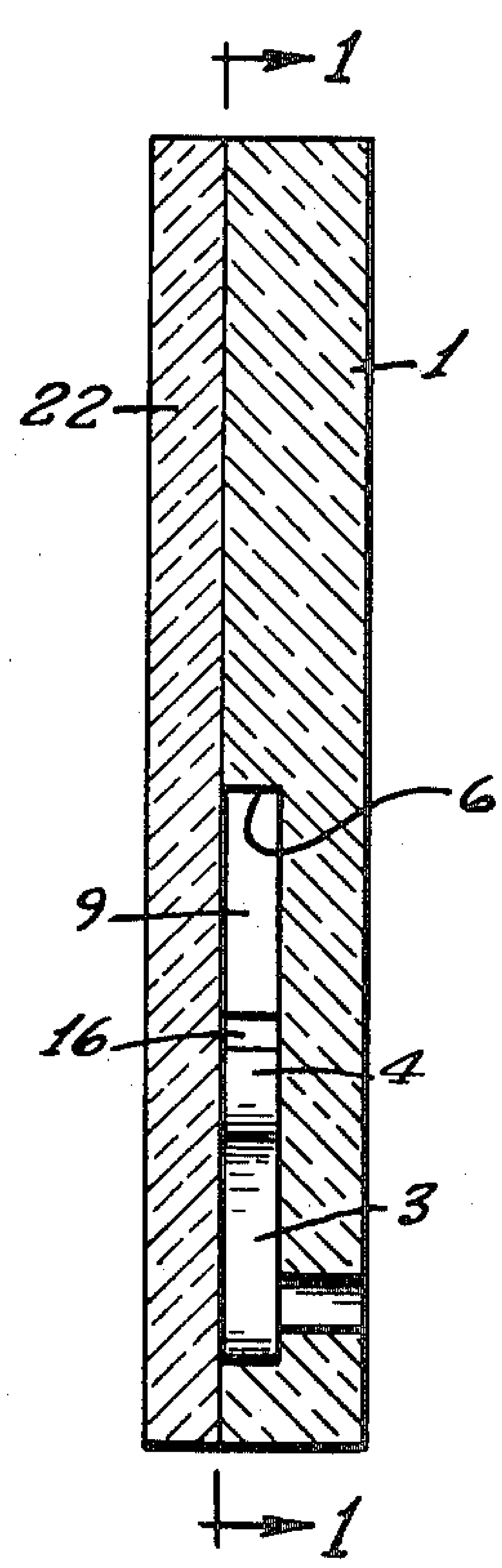


Fig. 2

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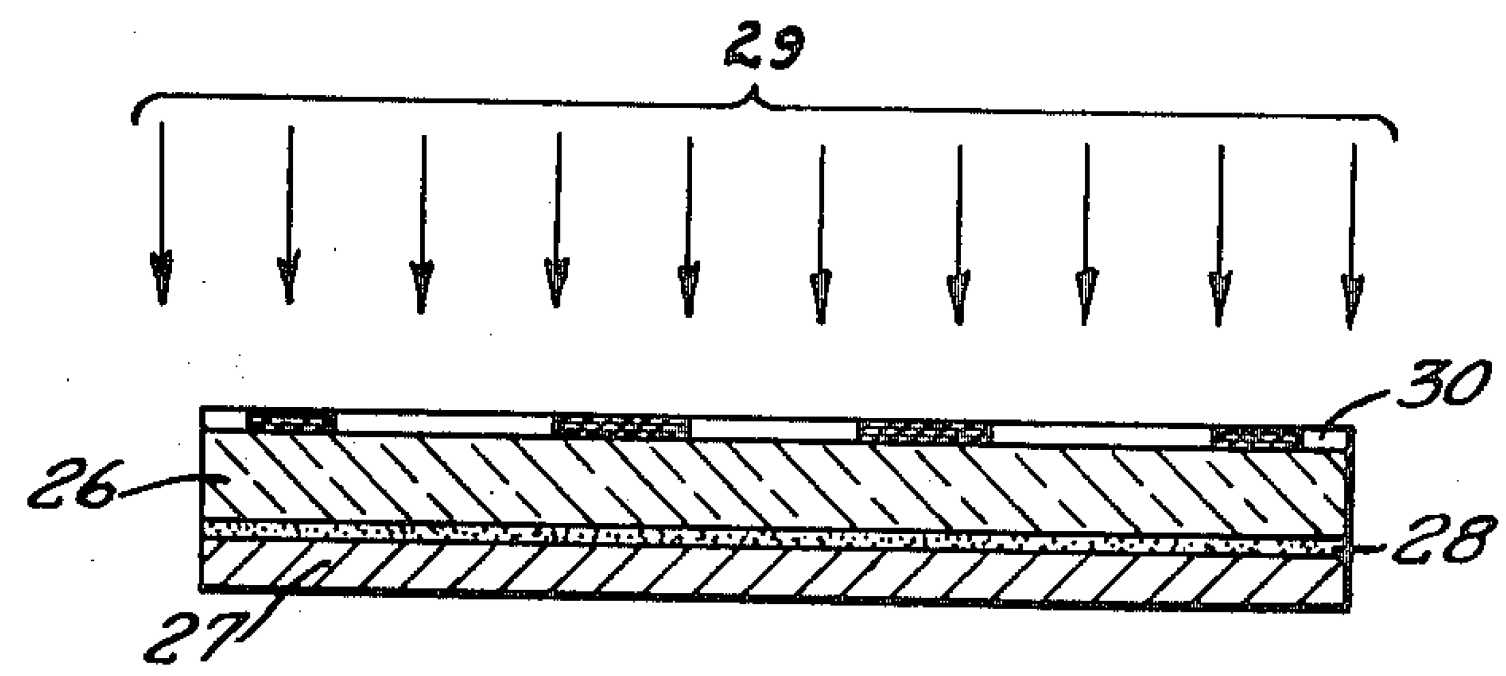

Fig. 3

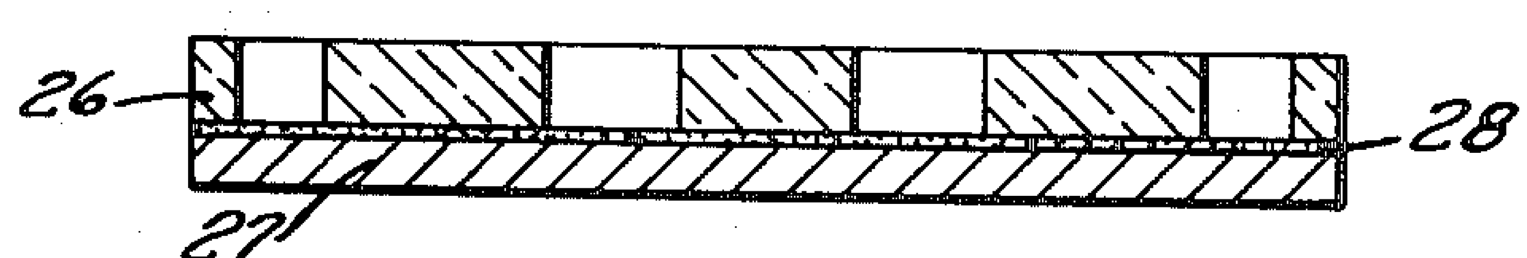

Fig. 4

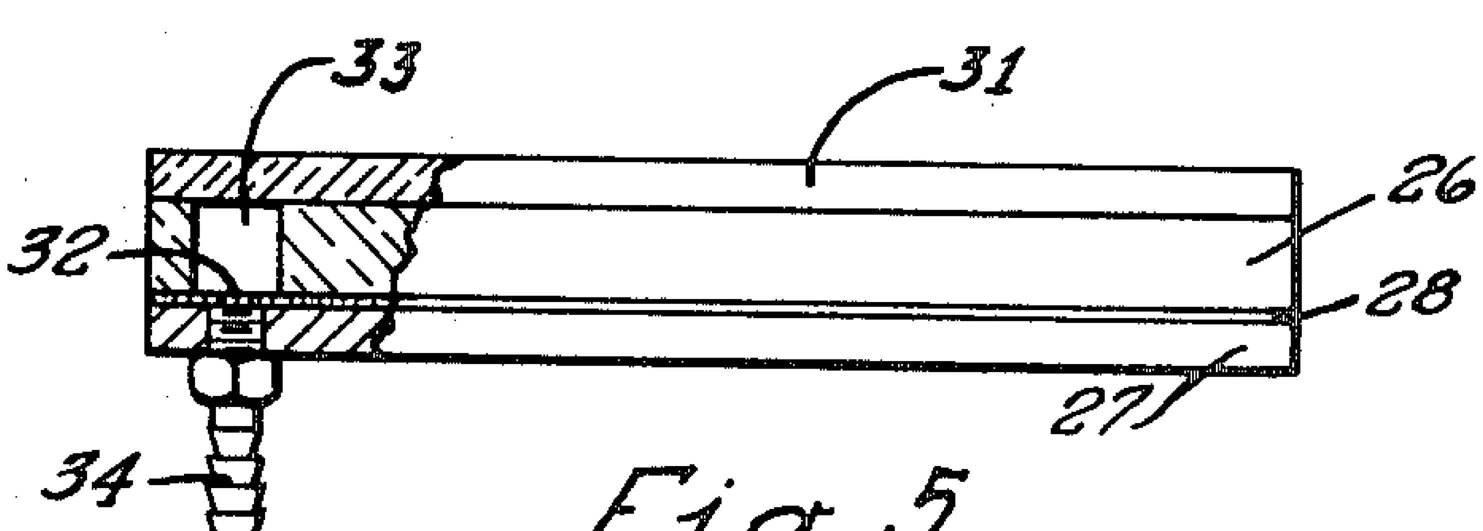

Fig. 5

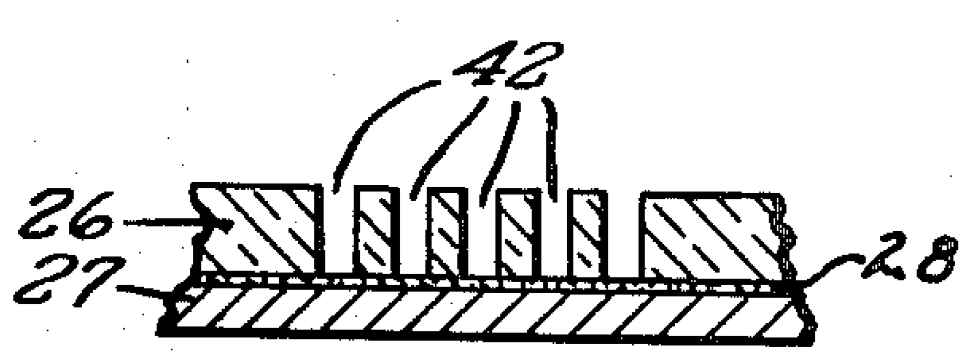

Fig. 7

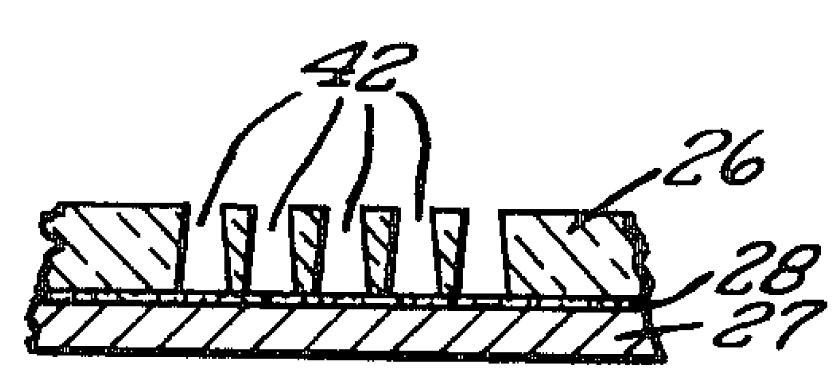

Fig. 8

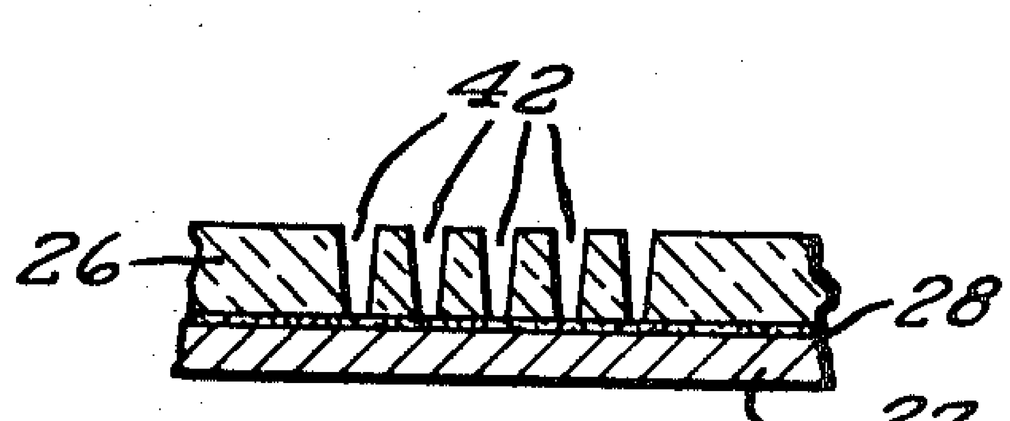

Fig. 9

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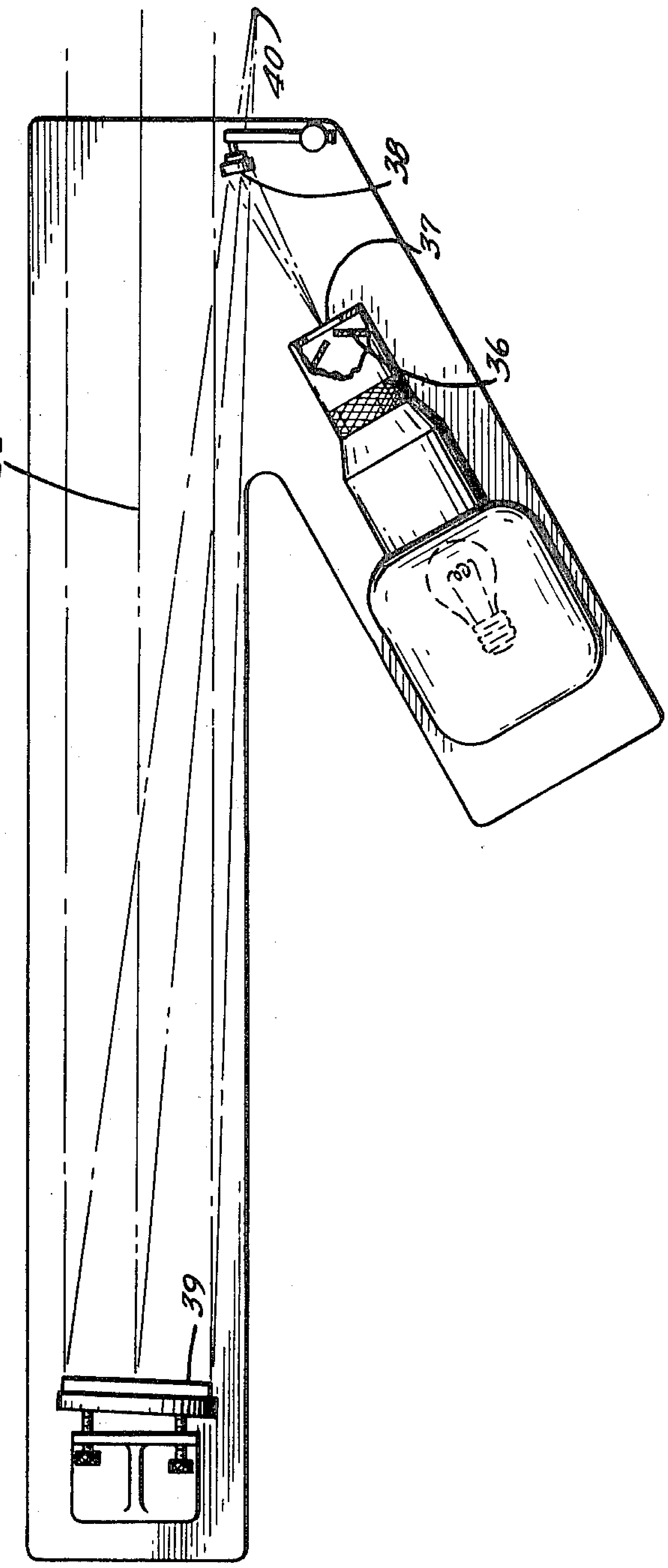

Fig. 6

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OPTICAL MACHINING PROCESS

This application is a division of our application, Ser. No. 219,168, filed Aug. 24, 1962, and entitled "Optical Machining Process."

The present invention relates to fluid amplifier devices and more particularly to methods of making fluid amplifiers and the articles resulting from such method.

The term "fluid amplifier" as used herein refers to a recent development in fluid systems in which amplification of one or more of the parameters of a flowing stream can be effected in an apparatus employing no moving parts. A typical example of such a device is an apparatus having fluid supplied to a power nozzle which issues a stream of fluid toward the apex of a divider located downstream from the nozzle. Control nozzles are disposed on opposite sides of the stream closely adjacent to the power nozzle and upon the issuance of fluid streams from the control nozzles, the main stream is deflected from its center position causing more (or all) of the fluid to flow along one side of the divider than along the other side of the divider. The energy, pressure, or mass flow supplied to the control nozzle is less than the change in the corresponding parameter in the side of the divider to which the main stream is deflected. In consequence, the apparatus provides a gain of output signal over input signal and may be classified as an amplifier.

In order to provide significant amplification in such a system, the region of interaction between the main stream and the control stream or streams is normally confined between top and bottom plates so that the main stream is confined, at least in the region of interaction, to its plane of deflection. As such the main stream appears as a deflectable divider passing through the interaction region and when a control stream impinges thereupon, it cannot flow around or through the main stream and therefore deflects the main stream.

An amplifier of this type may function in numerous ways and for a more detailed description of the various forms which such elements may take, references is made to Reilly U.S. Pat. No. 3,030,979 for Induction Fluid Amplifier, issued Apr. 24, 1962, Wadey U.S. Pat. No. 3,005,533, for Fluid Keyboard Using Jet-Pipe Valves, issued Oct. 24, 1961, Wadey U.S. Pat. No. 3,034,628, for Pneumatic Keyboard, issued May 15, 1962, U.S. Pats. No. 3,024,805 for Negative Feedback Fluid Amplifier by B. M. Horton issued March 13, 1962; No. 3,016,066 for Fluid Oscillator by R. W. Warren issued Jan. 9, 1962; No. 3,001,698 for Fluid Pulse Converter by R. W. Warren issued Sept. 26, 1961; No. 3,004,547 for Bounded Jet Fluid Amplifiers by H. Hurvitz issued Oct. 17, 1961; No. 3,001,539 for Suction Amplifier by H. Hurvitz issued Sept. 26, 1961.

Briefly summarizing the various types of devices which may be realized by the apparatus described above, the units are capable of operation as analogue amplifiers per se, or amplifiers with positive or negative feedback, bistable devices, oscillators and may be incorporated in systems for approximating many of the functions now performed substantially only by electronic circuits. Thus, analogue amplifiers may be cascaded to provide high-gain units or may employ varying amounts of feedback to provide units of high stability and low noise or may employ various passive elements in the feedback loops to provide narrow-band or wide-band amplifiers or may employ positive feedback with a loop gain of less than one, to provide high-gain amplifiers. The bistable elements on the other hand may be combined with fluid logic elements to provide pulse counters, shift registers and other logical gating and control circuitry.

It is apparent from the above that if these fluid elements are to be able to perform the various functions intended, they must have long term stability, which means low drift in the absence of or in the presence of a sustained input signal, must be relatively noise free, must not generate spurious signals or pulses particularly when employed in pulse logic and the engineer who wishes to employ such devices in a system must be able to provide a design which when reduced to a physical device performs in the manner anticipated. This, of course, is analogous to design in electronic circuits where an engineer selects a particular tube and then designs a circuit including the values of resistors, capacitors, inductors or other elements necessary for utilization with the tube to effect the desired function. It is necessary for the manufacturers of the tubes and resistors and other passive or active elements to be able to produce these elements on a mass basis while maintaining their desired functional characteristics.

The fluid amplifier must also be capable of performance in the manner for which it is designed. However, there are a number of critical parameters in such systems which have rendered the fabrication of the apparatus to a particular design difficult and expensive when the prior art techniques are employed. One of the difficulties which is encountered in the mass fabrication of fluid amplifiers to specific tolerances is the maintenance of laminar flow in the system. Turbulence in any fluid system is a random phenomenon which becomes lesser or greater on a completely random basis. Turbulence may introduce sufficient noise to obliterate or completely mask a signal in an analogue system after several stages of amplification or may alternatively or concurrently introduce long term instability in the beam, which is reflected as a drift in the absence of a signal or in the presence of a long term signal. In order to minimize turbulence in fluid systems, and to maintain substantially laminar flow throughout such a device, or a system in which the device is included, there must be no abrupt discontinuities in the wall and top and bottom plates of the apparatus and the side and end walls must be extremely smooth. Since the passages in devices of this type are long relative to the cross-sectional dimensions of the device even minor imperfections in the surface of the walls or grainness therein may introduce sufficient turbulence to have serious consequences on the operation of such a device.

Another important design parameter of such systems relates to the dimensions of the various channels forming the fluid amplifier. The sizes of the various nozzles are quite critical. In a specific system, the relative size of the main nozzle as opposed to the control nozzle or nozzles determines the gain of the system. Therefore, when designing a system with a specific gain it is necessary in fabricating such a device to have the nozzle cross-sectional areas to conform closely to the design size. Also the termination of a nozzle at the interaction region is a critical parameter since an imperfection in the geometry in this area may produce undue spreading of the beam which will prevent complete switching of the beam in a bistable device or digital circuitry or produce a sluggish or improper response of the amplifier when employed in analogue systems. A further consideration relative to size of channels is the slope of the sidewalls. In most instances, it is desirable to have substantially vertical walls with no more than a 5° convergence toward the center of the channel and preferably a convergence of 2° to 3° for each wall. Greater variations in tolerances produce devices which do not conform to their design performance with sufficient accuracy for wide commercial applicability.

Design of fluid equivalents of electrical capacitors and inductors, which are known as inertances and capacitances, are relatively simple in that the inertance constitutes a channel which is long relative to its cross-sectional dimensions and a capacitance is merely an enlarged region in a channel. The realization, however, of a fluid resistor, in systems of this type where no moving parts are employed, is more difficult and in the past resort has been had to porous plugs which are cut to size to fit in a channel and having a length which, taken in consideration with the porosity of the plug, provides the necessary fluid resistance. Such a technique for providing fluid resistors is not always satisfactory since material of the proper porosity when taken in consideration with the length of the channel available for insertion of the porous material may not provide the actual resistance desired.

Several techniques for fabricating fluid amplifiers and systems have been previously developed but are expensive and time consuming and in certain instances do not provide the characteristics required for low-noise, longterm stability, etc.

as set forth above. One such technique is conventional machining in metal or plastic which provides excellent results in larger units but is, necessarily, time consuming and expensive. On the other hand when employing metal machining on small units where orifices may be only a few mils wide and deep, the devices are often extremely difficult if not impossible to fabricate.

Another technique previously employed for fabricating such devices is a photoglass etching technique in which a photo resist is applied to a glass plate and the negative of the fluid amplifier optically projected onto the photo resist. Thereafter acid is applied to the plate and the glass is etched where the photoresist has not been struck by light and is therefore not developed. This technique is also quite slow and has the disadvantage that the channels often have sloping sides due to under cutting of the glass behind the developed photoresist. Also graininess may result from such a technique unless extreme care is exercised and even then it cannot always be eliminated. Such graininess tends, as indicated above, to introduce turbulence into the system and severely limits the ability to cascade fluid amplifiers to form large operational units.

The difficulty of providing fluid resistors particularly in small units has been indicated previously in the above discussion.

It is therefore a broad object of the present invention to provide a method of fabricating fluid amplifiers or pure fluid systems which is quick, economical, may be practices by unskilled personnel and which provides a finished unit conforming closely to the performance desired by the designer.

It is another object of the present invention to provide a method for fabricating pure fluid elements which have substantially vertical and extremely smooth sidewalls, and have channels of uniform depth and which method is equally applicable to small as well as medium size units.

It is another object of the present invention to provide a method of fabricating pure fluid elements in which fluid resistors may be fabricated as a part of the fabrication process for the basic element and in which the porosity of the element may be selected from a wide range of resistance values.

In accordance with the present invention it has been discovered that fluid amplifiers having all of the desirable characteristics set forth above may be made by a process including a photopolymerization step. More specifically a photopolymerizable plastic or substance, which forms a uniform layer on a base material, has a photographic negative or positive, depending upon the type of device to be fabricated, laid over and in contact with its exposed surface. The areas which are to be ultimately removed from the polymerizable material appear on the negative as completely opaque regions whereas the areas which are to remain are represented on the negative by substantially completely transparent regions. An appropriate source of light provides a bundle of substantially parallel rays which are perpendicular to the surface of the plastic. The light source is selected to produce polymerization of the plastic upon which the rays are incident. After complete exposure is effected the plastic plate is washed in a solution in which the unpolymerized material is soluble. This causes the unpolymerized material to be removed and the plastic remaining forms the body in which the channels of the amplifier are cut. Thereafter a cover plate is bonded to or otherwise maintained in fluid sealing relationship with the exposed surface of the plastic thereby providing independent channels through the plastic which form the pure fluid amplifier. Materials suitable for such a process are disclosed in the U.S. Pat. to Plambeck No. 2,760,863 issued Aug. 28, 1956, among others.

The process described above has a number of important advantages over the prior art processes which advantages however establish several critical parameters in the system to obtain the full benefit of the process. Unlike a photoetch technique employed on glass, the solvents employed in the present process do not attack the polymerized plastic and therefore undercutting of the pattern is not a serious problem as it is where a material is used that attacks the basic constituent of the plate. In consequence, the sides of the channels formed in the plate maintain an angle as determined substantially by the angle of the rays from the light source relative to the surface of the plate and the degree of parallelism of the rays. The design of the optical system employed in this process therefore is relatively critical. It has been found that the rays of the source should have a divergence angle of no greater than 5° and no less than 1°. The tolerance in sidewall slope provided by such a source of light falls within the design tolerances of systems of this type.

Another critical factor in determining the degree of divergence of light rays permissible in a system of this type is determined by the depth of penetration of the light relative to the width of the channels. This problem becomes particularly critical when forming nozzles and fluid resistors as integral parts of the design. In accordance with a further feature of the present invention, the fluid resistors are formed by a dot screen process. In utilizing the dot screen process for fabricating fluid resistors, the degree of porosity in a particular region is determined and this FIG. is converted to a FIG. representing the diameter of and spacing between the plastic stalks extending over a predetermined length of a passage. The channels between the stalks may be staggered to provide the desired degree of resistance over as short a length as possible. The dot screen is formed directly on the photographic negative on which the remainder of the amplifier is laid out. As indicated above the spacing between such elements, that is, between the stalks, is ordinarily quite small and in order to insure penetration of the light the bottom of the plastic layer the light rays must be substantially parallel; that is parallel to within a 5° divergence angle. It is of course necessary in such a system as this for the plastic to be substantially transparent to the activating light to provide the requisite degree of polymerization at the base of the stalk. Such materials are disclosed in the aforesaid patent. These materials should also be relatively thermally inactive at temperatures to which they are raised by the impinging light so as to prevent polymerization in regions adjacent those through which the light passes.

Another consideration concerning the light properties of the unit is that the base material should be substantially light-absorptive so that that portion of the light passing completely through the plastic is absorbed rather than scattered back into the plastic. If the base material is metallic, as is preferable in the present invention, then a binder for binding the plastic to the base should be light absorptive to prevent such back reflection which would result in spreading of the light and therefore produce polymerization in regions where it is not desired.

A source of light for such a system is the sun, which is directed to the surface of the plastic through a long tube having nonreflective inner walls. That portion of the light from the sun which is not parallel as a result of light scattering in the earth's atmosphere, is removed by the light-absorptive inner surface of the tube and the light emanating from the far end of the tube at the surface of the plastic is composed substantially completely of parallel rays.

Another light source which lends itself more readily to commercial production is an adaptation of the optics employed in the so called Schlierin system of photography which provides substantially parallel bundles of light having a relatively large cross-sectional area. The light source of the Schlierin system may comprise numerous devices such as an optical maser (laser), an arc source, etc. The laser has certain distinct advantages in the system of the present invention, relating primarily to the high intensity of the light provided by such a source. In the Schlierin system, the light which is masked to provide a very small spot is located at the focal point of a mirror. The light from the source is expanded to the size of the mirror and reflected therefrom to provide a parallel bundle of rays, for instance, 6 inches in diameter. Due to the high intensity of the laser source, the intensity of light across the parallel bundle of rays is still sufficiently intense to produce rapid polymerization of the plastic. As indicated above there is a limit to the degree of heating which the plastic can withstand before it undergoes a certain degree of polymerization due to thermal effects. By employing the laser to produce a high intensity, short burst of light the time of exposure and therefore the heating effect is minimized. If the plastic is polymerizable in the presence of ultraviolet light, which is the type of plastic set forth in the aforesaid patent, then, since at this writing lasers which directly produce ultraviolet light are not available, the laser may be employed to excite a quartz crystal which doubles the frequency of the red light from the laser, in this case a ruby laser, to provide the requisite ultra violet light.

It is therefore another object of the present invention to provide a method and process for making pure fluid amplifiers employing a photopolymer process.

It is another object of the present invention to provide a process for making pure fluid systems having substantially vertical and extremely smooth sidewalls and bottom walls which process employs photopolymerization of a plastic material.

It is yet another object of the present invention to provide a method for making pure fluid systems which method includes illuminating a photopolymerizable material through a negative of the apparatus to be formed in which the light source provides a bundle of substantially parallel light rays of the proper wave length to effect photopolymerization.

It is another object of the present invention to provide a method for making pure fluid amplifiers having fluid resistors formed integrally therewith which process employs a photopolymerizable material illuminated by a substantially parallel bundle of rays through a photo negative of the apparatus to be formed; the photo negative providing appropriately spaced opaque or light transmittive regions of a density such as to provide the desired fluid resistor.

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of one specific embodiment thereof, especially when taken in conjunction with the accompanying drawings, wherein:

FIG. 1 is a plane view of a pure fluid amplifier to be fabricated by the method of the present invention;

FIG. 2 is a cross view taken along line 2–2 of FIG. 1;

FIG. 3 illustrates a first step in the method of the present invention;

FIG. 4 illustrates the produce produced by the process of which FIG. 3 illustrates one step;

FIG. 5 illustrates the method of providing communication with the various channels of apparatus illustrated in FIG. 4;

FIG. 6 is a schematic diagram of an optical system which may be employed in the process of the invention;

FIG. 7 is a cross-sectional view of a fluid resistor produced by the process of the invention;

FIG. 8 illustrates the light irradiation pattern produced by a divergent beam; and

FIG. 9 illustrates a fluid resistor produced by employing a beam of light having a divergence as illustrated in FIG. 8.

Referring specifically to FIGS. 1 and 2 of the accompanying drawings there is illustrated a pure fluid amplifier of the type with which the present invention is concerned. The amplifier is formed as channels in a plate 1. The amplifier which is generally designated by the reference numeral 2 comprises a power nozzle 3 adapted to be connected to a source of fluid under pressure (not illustrated). The nozzle 3 terminates in an orifice 4 for issuing a stream of fluid directed toward an apex 6 of a divider structure 7. The divider 7, as illustrated in FIG. 1, is symmetrical with respect to the center line of the orifice 4 and its apex 6 lies along this center line at a predetermined distance downstream from the orifice 4. The orifice 4 of the nozzle 3 is formed in an end wall 8 of an interaction region 9 further bounded by sidewalls 11 and 12 which are nominally parallel to the left and right sidewalls respectively of the divider 7. The amplifier 2 is provided with control nozzles 13 and 14 having orifices 16 and 17 respectively extending through sidewalls 11 and 12. The orifices 16 and 17 are defined on their lower side, as viewed in FIG. 1, by the end wall 8 and therefore the stream issued thereby are perpendicular to the undeflected position of the stream issued by the orifice 4.

The sidewall 11 and left sidewall of the divider 7 form a first output passage 18 and the sidewall 12 and right sidewall of the divider 7 form an output passage 19. For purposes of description only a fluid resistor 21 is formed in the outlet passage 19 and though formerly constituted by a plug or porous material, in accordance with the present invention the resistor 21 constitutes a group of generally cylindrical, upright stalks of the material comprising the plate 1. A cover plate 22 is provided to seal the top of the plate 1 so as to isolate the various passages in the plate 1 except to the extent that they are interconnected due to the intersections thereof in the plate 1.

In the type of structure illustrated in FIGS. 1 and 2, the channels are formed by removing material from the plate 1. Appropriate connections may be made either through the plate 1 or cover plate 22 to the source of pressurized fluid and to the various loads connected to the outlet passages 18 and 19.

In operation of the apparatus illustrated in FIGS. 1 and 2, fluid under pressure is supplied to the main or power nozzle 3 and issues from the orifice 4 in a wall defined stream which when undeflected divides equally at the apex 6 between the outlet passages 18 and 19. By determining the difference in a given flow parameter in the channels 18 and 19 one may derive, for instance, an output signal which in the case cited above would be a zero indicating a null condition. The fluid may be air or water or combinations thereof or any other fluid material and the parameters which may be measured are for instance mass flow, energy or pressure depending upon the dimensions of the various passages in the system. In the particular system illustrated the apparatus would measure changes in mass flow.

An input signal is applied to the system of FIG. 1 by applying fluid to the nozzle 14 which issues a stream from the nozzle 17 intersecting the path of flow of the main power stream issuing from the nozzle 4. Due to momentum interchange between the two streams, the power stream is deflected to the left by an amount proportionate to the momentum of the stream issuing from the orifice 17 and in consequence the mass flow in the outlet passage 18 is increased while the mass flow in the outlet passage 19 is decreased. This differential effect may be measured as indicated above by a differential detector to provide an indication of the degree of deflection of the stream which in itself is an indication of the momentum of the stream issuing from the nozzle 17. As the flow from the orifice 17 is increased or decreased, the degree of deflection of the main stream increases or decreases therewith, changing the proportions of the stream entering the channels 18 and 19 as a function of the input signal. The main stream may have a greater momentum than the momentum of the stream issuing from the nozzle 16 or 17 or both and therefore the amount of fluid switched to one or the other of the outlet passages is greater than the amount of fluid issuing from the orifice 17. In effect then, amplification of the signal applied to the nozzle 14 is effected and a pure fluid amplifier is provided.

The same effect is accomplished if fluid is applied to the nozzle 13 except for the fact that the main power stream is deflected to the right in response to application of the fluid to the nozzle 13 rather than to the left as when fluid is applied to the nozzle 14. Fluid may be applied simultaneously to both of the control nozzles 13 and 14 in which case the stream issuing from the nozzle 3 is deflected in accordance with the differences between the parameters of the two control streams. Due to the amplification function of the apparatus the output signal developed is an amplified function of this difference.

Where a device such as that illustrated in FIG. 1 is to be employed as an amplifier it must meet all of the rigid requirements of any analogue amplification system. Specifically the output signal must have a high signal-to-noise ratio; it must be a predetermined function of the input signal; it must have stability in the absence of an input signal or in the presence of a constant longterm signal and all of the parameters must be reproducible during successive periods of operation. Also as previously indicated it is essential that a device once designed perform, when fabricated, as originally intended.

Discussing for the moment this latter feature, in a specific example of an amplifier, the orifices 4, 16 and 17 may have a width equal to 20 mils; and the depths of the channels (orifices) may be one-tenth of an inch. Such a system would be normally employed for pressure gain, particularly in digital systems. If a wall converges inwardly at 1°, at a depth of one-tenth of an inch the channel reduced in width on one side by 1.75 mils; a total of 3½mils for both walls. This degree of convergence is permissible since under these circumstances the variation in nozzle width falls within the normal design tolerances of the system with the top of the nozzle being 20 mils wide and the bottom of the nozzle being 16½mils wide. However, in the same system if the angle of convergence of the sidewalls is 5° then the bottom of the channel is only 3½mils wide. Such a construction falls completely outside of the permissible tolerances in the system and the device is unacceptable. On the other hand if the apparatus is intended to be employed, for instance, as an energy or mass flow amplifier, the widths of the various nozzle are increased to a greater extent that the depth of the channels and the 5° angle of convergence provides an acceptable design parameter. It is apparent therefore that in order to provide devices by mass production processes, this angle of convergence must be maintained within very close tolerances.

As to the signal-to-noise ratio of the amplifier, this factor is basically a function of turbulence in the system.

In order to provide a low-noise signal, it is necessary to establish substantially laminar flow throughout the device since turbulence is a random effect having extensive regions of unpredictable eddies along the boundary layers of the various flow regions. These eddies are completely unpredictable as to continuity of a particular eddy and formations of new ones or sizes of the various eddies. It has been found that if care is not taken to insure substantially smooth walls in a device such as illustrated in FIG. 1, cascading of three stages produces a noise signal which completely overrides the signal information. Thus it is absolutely essential in such a system to obtain smoothness of walls to be able to cascade these elements into useful systems.

Another difficulty encountered in such systems is the longterm stability thereof. in certain regions of the apparatus if the wall has large discontinuities as opposed to grainness of the walls, large vortices may form in these regions which expand and contract and result in longterm drifts in the no-signal or constant-signal output flows from the apparatus. Such discontinuities have been found to occur primarily where machining techniques are employed to form a master whereas the turbulent flow producing eddies normally result where acid etching techniques are employed.

Referring now specifically to FIG. 3 of the accompanying there is illustrated a first step in the preparation of a fluid amplifier in accordance with the process of the present invention. A light polymerizable plastic 26 is previously mounted on a base member 27 which in this particular example illustrated is metallic. Under these circumstances a layer 28, employed to bind the plastic layer 26 to the base layer 27 which is substantially opaque or light-absorptive so as to prevent scattering of light from the metal into the polymerizable material. A photographic transparency 30 is disposed on top of the exposed layer of plastic 26 and has formed thereon areas which are opaque or light where ever the material from the plastic layer 26 is to be removed. The transparency 30 also has transparent areas where it is desired to have the light pass into the layer 26 to produce polymerization at which locations the material of the layer 26 will not be subsequently removed.

The light for polymerizing the plastic is derived from a source which provides parallel rays 29 by means to be described in greater detail subsequently. The parallel rays produce substantially vertical sidewalls of the various channels. After a predetermined time for exposure, which is calculated in accordance with the intensity of the light and the light energy required to produce sufficient polymerization of the plastic 26, the light is turned off and the negative is removed. Thereafter the laminated plate comprising the layers 26, 27 and 28 is washed in a bath of a suitable solvent for the unpolymerized material to produce the member as illustrated in FIG. 4. These portions of the layer 26, where light did not impinge thereupon, are removed down to the base or the binder layer 28. Thus the layer of binder material 28 forms the bottom of the channels whereas the polymerized material of the layer 26 forms the sides of the channel.

A finished fluid amplifier element is then produced by employing a further layer 31 of suitable material to seal the upper surface of layer 26 permitting communication between the passages only a result of interconnections thereof. The various connections to the appropriate channels may be made by drilling holes through the base plate 27 and layer 28, such as to provide an aperture 32 in communication with, for instance, a channel 33 formed in the basic element. Relating such a connection to the apparatus of FIG. 1 the aperture 32 may constitute the supply passage to the nozzle 3 of the fluid amplifier. The aperture 32 will normally be tapped and provided with a fitting 34 adapted to accept a connection with a member or a pipe or similar device which is returned to the supply source.

The layer 31 may constitute a plastic, such as a celluloid layer, which is bonded by a suitable bonder to the upper surface of the plastic layer 26. Addition techniques for providing a sealing relationship may be to employ a celluloid layer which is clamped by means of screws extending between the metal plate 27 and a further metal or plastic plate disposed over the layer 31. At times it is convenient to employ both techniques wherein a binder is placed between the layer 26 and the film 31 and then a further metal or plastic plate is laid over the plastic plate 31 and clamped by means of bolting with screws to the plate 27.

Referring now to FIG. 6 of the accompanying drawings there is illustrated a light source which is suitable for use with the apparatus of the present invention. The source utilizes a point source and a folded optical system so as to reduce the overall length of the apparatus. In this particular example a pair of electrodes 36 are utilized to establish a high-intensity arc which forms source of light and the light generated thereby passes through a pin hole in an optical mask 37. The light from arc is directed through the mask 37 to a mirror 38 which directs the beam to a concave mirror 39. The mirror 39 in a particular example has a focal length of 80 inches and is a 6-inch-diameter mirror. The mirror 38 provides a virtual image 40 of the small hole in the mask 37 at a distance of 80 inches from the surface of the concave mirror 39. The mirror 39 is set at such an angle relative to the angle which the rays are directed thereto by the mirror 38 so as to cause the beams to be directed along an axis 41, which is horizontal in the illustration of FIG. 6. The divergence of the beam passing through the hole in the mask 37 and reflected from the mirror 38 is such that the beam assumes a diameter slightly smaller than the diameter of the mirror 39 when it impinges thereupon. Since the virtual image of the aperture in the mask 37 is at the focal point of the mirror 39, the rays reflected therefrom constitute a substantially parallel bundle of rays which is suitable for use as the bundle of rays 29 illustrated in FIG. 3.

It should be noted that by moving the slit 37 relative to the mirror 38 the virtual image 40 of the aperture in the mask 37 can be shifted relative to the focal point of the mirror 39 thereby providing an accurate control on the degree of divergence or convergence of the beam reflected from the mirror 39. Thus, if large elements are being fabricated and a 5° divergence angle is permissible, the slit 37 may be shifted to provide such a degree of divergence. On the other hand, if small units are being fabricated and the degree of divergence should be no greater than 1° then the slit 37 may again be shifted so as to shift the virtual image 40 relative to the focal length of the mirror 39 to provide the desired degree of divergence. It is to be understood that the light source constituting an arc source in FIG. 6 may be replaced with a laser or other suitable high intensity source, the arc source being illustrated merely for purposes of simplicity of explanation. In fact, it is preferred to employ a laser in the apparatus in view of the high-intensity light which may be obtained from such a source.

In the process described in FIGS. 3 through 5 it is assumed that the element in FIG. 4 is to constitute the fluid amplifier and therefore the transparency 30 of FIG. 3 constitutes a photographic negative of the apparatus to be fabricated. If it is desired to employ the device produced in FIG. 4 as a master for making many fluid elements of the same configuration; that is, to employ the element of FIG. 4 as a mold, then the photographic transparency 30 of FIG. 3 would constitute a positive so that the element produced, as illustrated in FIG. 4, may be employed as a mold of the devices to be eventually produced.

As previously indicated, it may be desired to produce fluid resistors by the techniques of the present invention. In such case, a cross section of the fluid resistor produced by a dot screen process would be as illustrated in FIG. 7. Where it is desired to form the resistor directly in a passage of an element, such as that illustrated in FIG. 4, the area of the photographic transparency in the region in which the resistor is to be formed is rendered opaque except for a plurality of small transparent circles having the proper diameters and spacing to produce a resistor with the desired characteristics. The resistor is made up of a plurality of elongated solid cylinders or stalks 42 of the material of the layer 26, the sidewalls of the cylinders being generally parallel to the sidewalls of the passage in which the resistor is formed. The distance between adjacent sides of the stalks 42 is determined by the fluid resistance and is normally relatively small; in many instances being of the same order of magnitude as the width of the orifice of the power or control nozzle.

It can be seen that in an arrangement such as illustrated in FIG. 7, if the angle of divergence of the light beam employed to polymerize the plastic is not carefully controlled, complete penetration of the light to the layer 28 cannot be effected. Referring specifically to FIG. 8 which illustrates the process for making a resistor, if the angle of divergence of the beam is too great relative to the depth of the device, which divergence angle is taken to be about 5° in FIG. 8, then the light passing through adjacent transparent dots in the negative almost come together at the binder layer 28 of the blank. The effect of the use of a light source is illustrated in FIG. 9 where it becomes apparent that the width of the channels provided between the base of the stalks 42 are considerably less than they should be and in consequence the fluid resistance is of far greater magnitude than that for which it was designed. Thus, it becomes apparent, particularly when forming fluid resistors and nozzles in small elements, that the optical system provide closely controllable beam divergence angles. It should be pointed out that where the blank formed as illustrated in FIG. 4 is to be employed as a mold that some convergence of the sidewalls is required in order to expedite withdrawal of the molded article from the mold. Due to the size of the passages between the stalks 42, difficulty is experienced in producing a sufficient flow of solvent particularly at the base of the stalks to remove the unpolymerized material from therebetween.

In order to overcome the difficulty in certain instances where the passages between the stalks 42 are quite small, it is proposed in accordance with the invention to immerse the plate, during the washing operation, in a bath having an ultrasonic vibrator disposed therein. An ultrasonic vibrator sets up vibrations of sufficient amplitude and intensity to wash away layer after layer of the unpolymerized material until all material has been removed down to the binder layer 28.

It has been assumed previously that the entire surface, as illustrated in FIG. 3, is to be irradiated at one time. It is possible however to employ light beam sweeping techniques so as to utilize a higher intensity beam which produces less thermal effects. Explaining this statement, it is obvious that if the energy in a source of light is spread throughout a beam having a diameter of 6 inches, the energy at any point across that beam must be considerably less than a beam having the same energy concentrated and a diameter of one-fourth inch since in the latter case the entire energy in the beam is concentrated in a very small area. Therefore, it is necessary when employing the large diameter beam to utilize irradiation times considerably greater than if the beam were highly concentrated. Since the heating effect in the blank is a function of time as well as energy of the beam, the heating effect is greater under a lower intensity beam applied for a long period of time then if a very high energy beam is employed in a pulse type of operation. Therefore, in certain instances, it may be desired to use the light for instance from a ruby laser or from a quartz crystal energized from a ruby laser so as to produce ultraviolet light, and scan the surface of the structure, as illustrated in FIG. 3, relatively rapidly. The heating effects under such circumstances are quite low and the thermal effects become inconsequential.

It is apparent from the above discussion that the fluid amplifiers of the type illustrated in FIGS. 1 and 2 may be readily prepared by a process employing a lightly polymerizable material. As previously indicated, with such a process, the slope of the sidewalls of the apparatus may be carefully controlled. Further the process produces very smooth sidewalls. In a particular process, a dilute solution of sodium hydroxide is employed as the wash bath and this material does not appreciably effect the polymerized element since it does not constitute a solvent for such material but only for the unpolymerized material. In consequence one does not obtain the graininess of the sidewalls that may result from a photoetch process where the etching is effected by a highly reactive acid.

We claim:

1. A pure fluid amplifier or logic element comprising a metallic backing plate, a lower uniform layer of light-absorptive material covering a surface of said backing plate, an upper uniform layer of light polymerized material overlying said lower layer, and having a plurality of interrelated channels and nozzles formed therein and extending therethrough and to said lower layers, the walls defining said channels and nozzles forming an angle relative to the plane of said layers of not more than 5°.

2. The combination according to claim 1 wherein said angle is not more than 2°.

3. A pure fluid amplifier or the like comprising a body of light-polymerized material having appropriate channels and nozzles formed therein said amplifier having been formed with a fluid resistor located in one of said channels and comprising a plurality of cylindrical closely spaced stalks of said light-polymerized material, said plurality of stalks extending across said one of said channels from the bottom to the top thereof, the walls defining said channels, nozzles and stalks forming an angle relative to the plane of said layers of not more than 2°.

4. A pure fluid amplifier or logic element comprising a unitary structure including a metallic backing plate, a lower uniform layer of light-absorptive material covering a surface of said backing plate, an upper uniform layer of light polymerized material overlying said lower layer and having a plurality of interrelated channels and nozzles formed therein and extending therethrough and to said lower layer, and a cover plate sealed to the surface of said upper layer remote from said backing plate.

5. The combination according to claim 11 further comprising a plurality of threaded apertures extending through said metallic backing plate into registry with preselected regions of said channels, and fluid flow connectors threaded into said apertures.

6. The combination according to claim 4 wherein said light-polymerized material is a solid in the unpolymerized state.

7. A pure fluid amplifier or logic element comprising a unitary structure having a rigid backing plate, a lower uniform layer of light absorptive material covering and secured to a surface of said backing plate, an upper uniform layer of light polymerized material overlying and secured to said lower layer and having a plurality of interrelated channels and nozzles formed therein and extending therethrough to said lower uniform layer, and a cover plate sealed to the surface of said upper layer remote from said rigid backing plate, a plurality of apertures extending through said rigid backing plate into registry with preselected regions of said channels and fluid flow connectors secured in said apertures.