(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 739 732 B1

(12) EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:
30.12.1998 Bulletin 1998/53

(51) Int. Cl.[6]: **B41J 2/04**

(21) Application number: **96302898.0**

(22) Date of filing: **25.04.1996**

(54) Variable focal length acoustic ink printhead

Akustischer Tintendruckkopf mit veränderbarer Brennweite

Tête d'impression acoustique à encre avec distance focale variable

(84) Designated Contracting States:
DE FR GB

(30) Priority: **27.04.1995 US 431195**

(43) Date of publication of application:
30.10.1996 Bulletin 1996/44

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Description

The present invention relates generally to acoustic ink printers with lenses for focusing acoustic energy. More particularly, the present invention relates to an acoustic ink printer head having an ink filled channel that supports varying focal length fresnel lenses positioned along the channel.

Acoustic ink printing systems provide a nozzleless alternative to conventional thermal ink jet systems. Instead of supporting a large number of easily clogged nozzles, acoustic ink printing systems typically use an ink covered printhead that supports multiple acoustic lenses. Each of the acoustic lens attached to the printhead can focus a beam of sound energy against a free surface of the ink. This focused acoustic beam exerts sufficient acoustic radiation pressure against the surface to cause ejection of individual droplets of ink, which are directed to impact upon a sheet of paper or other printing medium.

Precise control of droplets ejected by acoustic ink printheads conventionally is performed by independently modulating the rf excitation of acoustic radiators acoustically coupled to the acoustic lenses. The acoustic radiators (commonly piezoelectric transducers) are amplitude modulated in accordance with a desired input pattern that typically corresponds to pixel level representations of text or imagery. Modulating the transducers in this defined input pattern transiently increases the acoustic radiation pressure to generate brief, controlled excursions to a sufficiently high pressure level for overcoming the ink restraining force of surface tension. These transient overpressures cause individual droplets of ink to be ejected from the free ink surface at a sufficient velocity to cause deposition in a desired image configuration on a nearby printing medium. Advantageously, acoustic ink printing does not rely upon easily clogged nozzles or small ejection orifices, eliminating mechanical constraints that cause many of the reliability and pixel placement accuracy problems in conventional drop on demand or continuous stream ink jet printers.

As one would expect, for best operation an acoustic ink printhead must be supplied with a constant and consistent flow of ink to present a stable ink ejection surface. Use of a flowing and appropriately filtered ink supply system also simplifies stabilization of ink temperature, keeps the ink free of various contaminants, and encourages mixing of ink constituents to minimize adverse differential ink evaporation effects that may reduce uniformity of the ink composition and the associated uniformity of droplet ejection.

Unfortunately, one problem with a flowing ink supply relates to equalization of hydrostatic pressure of the free ink surfaces associated with each acoustic lens. Differing hydrostatic pressures resulting from viscous resistance to fluid flow leads to differing distances between the free surface of the ink and each acoustic lens. If this change in distance is substantial (e.g., greater than a few μm), an individual acoustic lens in an array of identical lenses may be focused above or below the free surface of the ink, rather than at the surface, eliminating uniformity of droplet ejection, and reducing print reliability. Equalization of pressure may be relatively simple with a small number of lenses and consequently limited ink flow path, but as the number of lenses increases (and with it the required free surface ink flow path) in higher-performance and higher-resolution printers, the ink supply system for delivering ink to the lenses becomes more complex and the equalization of pressure at each lens more difficult.

EP-A-550,148 discloses an acoustic ink printhead, according to the preambles of claims 1 and 5, employing a flowing stream of ink past the ejectors to maintain a fresh ink supply at the ejector sites. An apertured plate-like member aligned with the ejector sites suppresses sideways droplet ejection components. A secondary pressure field using acoustic pulses or a pulsed heater provides dynamic level control in addition to controlled switching of the ink droplets.

In EP-A-434,931 acoustic radiators which are focused diffractively by multi-discrete-phase binary Fresnel lenses are provided for applications, such as acoustic ink printing. Standard semiconductor integrated circuit techniques are available for fabricating such lenses in compliance with design specifications having relatively tight tolerances, including specifications for integrated lens arrays demanding substantial precision in the relative spatial positioning of several lenses. The diffractive performance of these lenses simulate concave refractive lenses, even though the lenses preferably have generally flat geometries. To that end, the lenses are defined by patterning acoustically flat surfaces, such as an acoustically flat face of a substrate or an acoustically flat face of a layer of etchable material which is grown or otherwise deposited on an acoustically flat surface of an etch resistant substrate.

The present invention provides an acoustic ink printhead according to claims 1 and 5 of the appended claims.

Accordingly, the present invention substantially mitigates the problem of pressure equalization of the free ink surfaces in an acoustic ink printer with a constant flow ink transport system. Typically, focal length of acoustic lenses positioned adjacent to the ink outlet is less than the focal length of acoustic lenses positioned adjacent to the ink inlet. In those printhead designs with a continuous pressure drop along all definable paths between the ink inlet and the ink outlet, the focal length of the acoustic lenses sequentially decreases between the ink inlet and the ink outlet to compensate for the progressive reduction in surface level of the ink. Each acoustic lens in an array of acoustic lenses is adjusted to have a focal length that ensures focusing a predefined acoustic frequency at the surface level of ink flowing above the respective lens, consequently reducing non-uniformity in droplet size, speed, and travel characteristics.

As will be appreciated, the present invention is of particular utility for use in conjunction with acoustic printhead systems having longitudinally extending channels. For example, an acoustic ink printhead that includes a plurality of channels configured to receive ink has well defined hydrostatic characteristics in each channel, with the free surface level diminishing along the channel between the inlet and outlet. This is particularly true when each channel is connected to a common inlet manifold and a common outlet manifold, so that inlet pressure and outlet pressure (and ink flow velocity) in all channels is substantially equal.

A linear array of channels with a sequentially decreasing hydrostatic pressure easily supports use of varying focal length acoustic lenses constructed as multiphase Fresnel lenses. Standard semiconductor integrated circuit techniques are available for fabricating these lenses in compliance with design specifications. Such construction permits relatively tight tolerances, allowing for integrated lens arrays demanding substantial precision in the relative spatial positioning of several lenses. The diffractive performance of these lenses simulate concave refractive lenses, even though the lenses provided by this invention preferably have generally flat geometries. Use of fresnel lenses simplifies machining, etching, growing, or otherwise depositing an acoustic lens having the required focal length on a flat surface such as a channel bottom of an acoustic printhead.

Other objects and advantages of the present invention will become apparent to those skilled in the art upon consideration of the following description, in conjunction with the drawings, in which:

Figure 1 schematically illustrates an acoustic ink printhead system with an ink pump, ink heater, and a printhead having machined channels in a glass substrate;
Figure 2 is a cross section along line 2-2 of Figure 1, illustrating a channel having a free ink surface and a plurality of independently addressable acoustic lenses;
Figure 3 is schematic view along line 3-3 of Figure 2, illustrating ejection of an ink droplet in response to application of a focused acoustic wave at the free surface of the ink;
Figure 4 is an enlarged top view of a planar fresnel lens for focusing acoustic waves in accordance with the present invention;
Figure 5 is a cross section taken along line 5-5 of the fresnel lens of Figure 4;
Figure 6 is a cross section of another fresnel lens having a focal length of about 360 micrometers, suitable for use near an ink inlet of a hypothetical channel (not shown) having a hydrostatic pressure drop along the channel corresponding to a level difference of about 10 μm, with a calculated wavefront surface illustrated; and
Figure 7 is a cross section of a fresnel lens having a focal length of about 350 micrometers, suitable for use near the ink outlet of the hypothetical channel discussed with reference to Figure 5.

An acoustic ink printhead system is illustrated in Figures 1, 2, and 3. As best seen in Figure 1, the system 10 includes a printhead 12, with an inlet 18 and an outlet 20, coupled in fluid communication to an ink pump 14 and heater 16 for recirculation of ink. Ink entering the printhead 12 through inlet 18 is distributed by inlet manifold 22 to a plurality of longitudinally extending channels 26 inscribed in the printhead 12. Positioned along the channel are a large number of acoustic lenses 28, typically being a spherical lens or a fresnel lens having a ring structure 42 such as shown in Figure 3-5. Functionally, the acoustic lenses 28 provide an array of electronically controlled ink ejectors that are capable of forcing ejection of an ink droplet from an ink surface in response to application of a suitable frequency and amplitude of focused acoustic energy. The ejected ink droplet can be directed to contact a piece of paper or other recording medium (not shown). After moving through the channels 26, the ink enters an outlet manifold 24 that funnels the ink to the outlet 20 for passage into pump 14. The ink is filtered and reheated by ink heater 16 to ensure maintenance of optimal flow characteristics, and again directed to enter the printhead through inlet 18.

As best seen in schematic cross section in Figures 2 and 3, the channels 26 in printhead 12 are exposed to atmospheric pressure, yet remain constrained in the channel through capillary effects. Each channel 26 is defined in a top plate 34, the top plate in turn being integrally bonded to a glass substrate 36 supporting the acoustic lenses 28. Ink 30 having an ink surface 32 flows along the channel over the acoustic lenses 28, which are individually controlled by application of a matching number of transducers 38. The transducers 38 are positioned beneath the acoustic lenses 28 to supply acoustic energy that can be focused to emit an ink droplet 40.

Advantageously, the Fresnel-type acoustic lenses 28 positioned at the base of the ink containing channels 26 (such as illustrated in the Figures) can be fabricated through the use of a conventional photolithographic patterning process. For example, an acoustically flat layer of etchable material (e.g., amorphous silicon or oxynitride) is grown or otherwise deposited on an acoustically flat face of an etch resistant substrate 36, such as a quartz or glass substrate. Using a photographic mask and conventional etching procedures known to those skilled in the art, Fresnel acoustic lenses 28 having a desired pattern are created. In fact, the thickness of the acoustic lenses 28 can be controlled with sufficient precision while being deposited to yield an acoustically flat layer having a thickness essentially equal to the height of the highest desired phase steps of the Fresnel lenses, so that no further pre-etch processing is required. However, it sometimes may be easier to first grow acoustic lenses 28 as a somewhat thicker layer on the substrate and to thereafter polish that layer down to the desired thickness and acoustical flatness. Alternatively, it is of course possible to employ a procedure such electron beam etching or other microfabrication techniques known to those skilled in the art to create an appropriate acoustic lens.

In operation, radiofrequency (rf) drive voltages are applied across the piezoelectric transducers 38 (by means not shown) on spatially separated centers each acoustically aligned with the acoustic lenses 28. The excited transducers 38 generate longitudinally propagating acoustic plane waves (schematically illustrated as waves 50 in Figure 3)within the substrate 36 for substantially independent, axial illumination of each of the acoustic lenses at near normal angles of incidence. The acoustic lenses 28 are acoustically coupled to the ink 30, either directly (as shown in the Figures) or through an intermediate monolayer or multilayer acoustic coupling medium. In response to driving the transducers 38 at various amplitude levels in a predetermined pattern, text or images based on the pattern of ejected droplets on paper (or other suitable media) can be created.

For best results in creating text and images of a desired quality, it is important to ensure ejection of droplets having essentially uniform size, shape, and travel characteristics. This is achieved in part by consistently focusing acoustic energy at the same position relative to the ink surface 32. For maximum utilization of acoustic energy, it is generally best to focus the acoustic lenses at the surface, rather than above or below the surface, although alternative focal surfaces can of course be used. In typical example, the surface of the ink directly above each acoustic lens/transducer combination is taken to define a desired focus point. This focal point changes along the channel, because the distance between the ink surface 32 and the base of the channel 26 diminishes as a function of the corresponding pressure drop (attributable mainly to fluid resistance against walls and bottom of the channel) between the inlet 18 and the outlet 20. To compensate, a suitable mechanism must be employed to maintain focus of the acoustic lenses 28 at designated positions on the ink surface 32 along the channel, even though a pressure drop corresponding to an ink surface level drop of fifty (50) microns or more may exist in the channel between inlet and outlet.

The present invention alleviates the problems associated with pressure drop by adjusting the focal length of the acoustic lenses 28. Fresnel lenses such as seen in top view in Figure 4, and in cross section in Figure 5, can have their ring spacing slightly altered, along with other appropriate modifications known to those skilled in the art, to decrease the focal length of acoustic lenses as one proceeds from the inlet toward the outlet of each channel in the printerhead.

For example, Figure 6 illustrates a profile of a four phase Fresnel lens suitable for positioning adjacent to the inlet of the channel, with an acoustic lens to surface distance of 360 microns, and the same focal length. Figure 7 illustrates a Fresnel lens suitable for positioning in the same channel, but adjacent to the outlet. At this position, the acoustic lens to surface distance is 350 μm, requiring a slightly changed focal length to ensure focusing of acoustic energy at the ink surface. The following table 1 presents some characteristics of Fresnel lenses sequentially spaced apart a distance of 66 millimeters, a typical length for a printhead having a longitudinally extending channel with a change in the depth of the ink surface of 10 μm:

TABLE 1

	Ring Radii (μm) Focal Length = 360 μm	Ring Radii (μm) Focal Length = 350 μm
1	40.5	40.0
2	57.4	56.6
3	70.4	69.4
4	81.4	80.3
5	91.2	89.9
6	100.0	98.6
7	108.2	106.7
8	115.9	114.3
9	123.1	121.4
10	129.9	128.2
11	136.5	134.6
12	142.8	140.8
13	148.8	146.8
14	154.7	152.6
15	160.3	158.2

TABLE 1 (continued)

	Ring Radii (μm) Focal Length = 360 μm	Ring Radii (μm) Focal Length = 350 μm
16	165.8	163.6
17	171.2	168.9
18	176.4	174.1
19	181.5	179.1
20	186.5	184.1

While the present invention has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications, and variations will be apparent to those skilled in the art. Accordingly, the various embodiments described herein should be considered illustrative, and not limiting the scope of the present invention as defined in the following claims.

Claims

1. An acoustic ink printhead (12) comprising

a substrate (36) coated with an ink layer having an ink surface (32), with a distance between the substrate (36) and the ink surface (32) varying over the substrate (36), and
a plurality of acoustic lenses (28) defined in the substrate (36), each acoustic lens (28) having a respective predefined focal length, characterised in said respective focal length varying to correspond to said varying distance between the substrate (36) and the ink surface (32).

2. The acoustic ink printhead of claim 1, wherein the substrate (36) further comprises a plurality of channels (26) configured to receive ink, with each channel connected to an inlet manifold (22) and an outlet manifold (24).

3. The acoustic ink printhead of claim 2, wherein the focal length of acoustic lenses (28) adjacent to the outlet manifold (24) is less than the focal length of those acoustic lenses (28) positioned adjacent to the inlet manifold (22).

4. The acoustic ink printhead of claim 2 or 3, wherein the focal length of the acoustic lenses (28) sequentially decreases between the ink inlet (18) and the ink outlet (20) to compensate for a pressure drop and reduction in distance between the substrate (36) and the ink surface (32) for an ink layer flowing through the channel (26).

5. An acoustic ink printhead (12) comprising

a substrate (36) having an inlet side and an outlet side, the substrate being configured to support ink flowing from the inlet side to the outlet side,
a plurality of acoustic lenses (28) acoustically coupled to the substrate (36), each acoustic lens having a respective predefined focal length for focusing acoustic energy at an associated position adjacent to the substrate (36), characterised in said respective focal length of those acoustic lenses (28) acoustically coupled adjacent to the inlet side of the substrate (36) being greater than the respective focal length of those acoustic lenses (28) acoustically coupled adjacent to the outlet side of the substrate (36).

6. The acoustic ink printhead of claim 5, wherein the substrate (36) is etched to define said plurality of acoustic lenses (28).

7. The acoustic ink printhead of claim 5 or 6, wherein the focal length of the acoustic lenses sequentially decreases between the ink inlet (18) and the ink outlet (20) to compensate for the pressure drop and reduction in surface level in ink flowing through the channel.

8. The acoustic ink printhead of any of claims 5 to 7, further comprising an ink pump to recirculate ink from the ink outlet side back to the ink inlet side.

9. The acoustic ink printhead of any of the preceding claims, wherein the acoustic lenses are multiphase Fresnel lenses.

10. The acoustic ink printhead of any of claims 5 to 7, wherein the substrate (36) further comprises a plurality of channels (26) configured to receive ink, with each channel connected to an inlet manifold (22) and an outlet manifold (24).

Patentansprüche

1. Akustischer Tintendruckkopf (12) mit

   einem Substrat (36), das durch eine Tintenschicht mit einer Tintenoberfläche (32) bedeckt ist, wobei der Abstand zwischen dem Substrat (36) und der Tintenoberfläche (32) entlang des Substrats (36) variiert, und

   einer Vielzahl von akustischen Linsen (28), die in dem Substrat (36) definiert sind, wobei jede akustische Linse (28) eine entsprechende vorbestimmte Brennweite aufweist, dadurch gekennzeichnet, daß die entsprechende Brennweite variiert, um dem variierenden Abstand zwischen dem Substrat (36) und der Tintenoberfläche (32) zu entsprechen.

2. Akustischer Tintendruckkopf nach Anspruch 1, wobei das Substrat (36) weiterhin eine Vielzahl von Kanälen (26) umfaßt, die zum Aufnehmen von Tinte ausgebildet sind, wobei jeder Kanal mit einem Einlaßverteiler (22) und einem Auslaßverteiler (24) verbunden ist.

3. Akustischer Tintendruckkopf nach Anspruch 2, wobei die Brennweite der akustischen Linsen (28) in der Nähe des Auslaßverteilers (24) kleiner ist als die Brennweite der akustischen Linsen (28) in der Nähe des Einlaßverteilers (22).

4. Akustischer Tintendruckkopf nach Anspruch 2 oder 3, wobei die Brennweite der akustischen Linsen (28) sequentiell zwischen dem Tinteneinlaß (18) und dem Tintenauslaß (20) abnimmt, um einen Druckabfall und eine Verringerung des Abstandes zwischen dem Substrat (36) und der Tintenoberfläche (32) für eine durch den Kanal (26) fließende Tintenschicht zu kompensieren.

5. Akustischer Tintendruckkopf (12) mit

   einem Substrat (36), das eine Einlaßseite und eine Auslaßseite aufweist, wobei das Substrat dafür ausgebildet ist, von der Einlaßseite zur Auslaßseite fließende Tinte zu halten,

   einer Vielzahl von akustischen Linsen (28), die akustisch mit dem Substrat (36) gekoppelt sind, wobei jede akustische Linse eine entsprechende vorbestimmte Brennweite zum Fokussieren der akustischen Energie an einer assoziierten Position in der Nähe des Substrates (36) aufweist, dadurch gekennzeichnet, daß die entsprechende Brennweite der in der Nähe der Einlaßseite des Substrates (36) akustisch gekoppelten akustischen Linsen (28) größer ist als die entsprechende Brennweite der in der Nähe der Auslaßseite des Substrates (36) akustisch gekoppelten akustischen Linsen (28).

6. Akustischer Tintendruckkopf nach Anspruch 5, wobei das Substrat (36) geätzt ist, um die Vielzahl von akustischen Linsen (28) zu definieren.

7. Akustischer Tintendruckkopf nach Anspruch 5 oder 6, wobei die Brennweite der akustischen Linsen sequentiell zwischen dem Tinteneinlaß (18) und dem Tintenauslaß (20) abnimmt, um den Druckabfall und die Reduktion der Oberflächenhöhe der durch den Kanal fließenden Tinte zu kompensieren.

8. Akustischer Tintendruckkopf nach wenigstens einem der Ansprüche 5 bis 7, der weiterhin eine Tintenpumpe umfaßt, um die Tinte von der Tintenauslaßseite zurück zu der Tinteneinlaßseite zu rezirkulieren.

9. Akustischer Tintendruckkopf nach wenigstens einem der vorstehenden Ansprüche, wobei die akustischen Linsen Fresnel-Linsen mit mehreren Phasen sind.

10. Akustischer Tintendruckkopf nach wenigstens einem der vorstehenden Ansprüche 5 bis 7, wobei das Substrat (36) weiterhin eine Vielzahl von zum Aufnehmen von Tinte ausgebildeten Kanälen (26) umfaßt, wobei jeder Kanal mit

einem Einlaßverteiler (22) und einem Auslaßverteiler (24) verbunden ist.

Revendications

1. Tête d'impression acoustique à encre (12) comprenant :

   un substrat (36) revêtu d'une couche d'encre ayant une surface d'encre (32), la distance entre le substrat (36) et la surface d'encre (32) étant variable sur toute l'étendue du substrat (36), et
   une pluralité de lentilles acoustiques (28) définies dans le substrat (36), chaque lentille acoutique (28) ayant une distance focale respective prédéfinie, caractérisée en ce que la distance focale respective varie pour correspondre à la distance variable entre le substrat (36) et la surface d'encre (32).

2. Tête d'impression acoustique à encre selon la revendication 1, dans laquelle le substrat (36) comprend en outre une pluralité de rainures (26) ayant une configuration pour recevoir de l'encre, chaque rainure étant reliée à un distributeur d'entrée (22) et à un distributeur de sortie (24).

3. Tête d'impression acoustique à encre selon la revendication 2, dans laquelle la distance focale des lentilles acoustiques (28) qui sont adjacentes au distributeur de sortie (24) est inférieure à la distance focale des lentilles acoustiques (28) qui sont positionnées au voisinage du distributeur d'entrée (22).

4. Tête d'impression acoustique à encre selon la revendication 2 ou 3, dans laquelle la distance focale des lentilles acoustiques (28) diminue par séquences entre l'orifice d'entrée d'encre (18) et l'orifice de sortie d'encre (20) pour compenser une chute de pression et une réduction de distance entre le substrat (36) et la surface d'encre (32) pour une couche d'encre s'écoulant à travers la rainure (26).

5. Tête d'impression acoustique à encre (12) comprenant :

   un substrat (36) possédant un côté entrée et un côté sortie, le substrat ayant une configuration pour supporter l'encre s'écoulant depuis le coté d'entrée vers le côté sortie,
   une pluralité de lentilles acoustiques (28) accouplées acoustiquement au substrat (36), chaque lentilles acoustiques ayant une distance focale respective prédéfinie pour focaliser l'énergie acoustique au niveau d'une position associée adjacente au substrat (36), caractérisée en ce que la dite distance focale respective de ces lentilles acoustiques (28) accouplées acoustiquement au voisinage du côté entrée du substrat (36) est plus grande que la distance focale respective des lentilles acoustiques (28) accouplées acoustiquement au voisinage du côté sortie du substrat (36).

6. Tête d'impression acoustique à encre selon les revendications 5, dans laquelle le substrat (36) est grave pour définir la dite pluralité de lentilles acoustiques (28).

7. Tête d'impression acoustique à encre selon la revendication 5 ou 6, dans laquelle la distance focale des lentilles acoustiques diminue par séquences entre l'orifice d'entrée d'encre (18) et l'orifice de sortie d'encre (20) pour compenser la chute de pression et la réduction du niveau de la surface de l'encre s'écoulant à travers la rainure.

8. Tête d'impression acoustique à encre selon l'une quelconque des revendications 5 à 7, comprenant en outre une pompe à encre pour remettre en circulation l'encre provenant du côté sortie d'encre pour la faire revenir vers le côté entrée d'encre.

9. Tête d'impression acoustique à encre selon l'une quelconque des revendications précédentes, dans laquelle les lentilles acoustiques sont des lentilles de Fresnel à plusieurs phases.

10. Tête d'impression acoustique à encre selon l'une quelconque des revendications 5 à 7, dans laquelle le substrat (36) comprend en outre une pluralité de rainures (26) ayant une configuration pour recevoir de l'encre, chaque rainure étant reliée à un distributeur d'entrée (22) et à un distributeur de sortie (24).

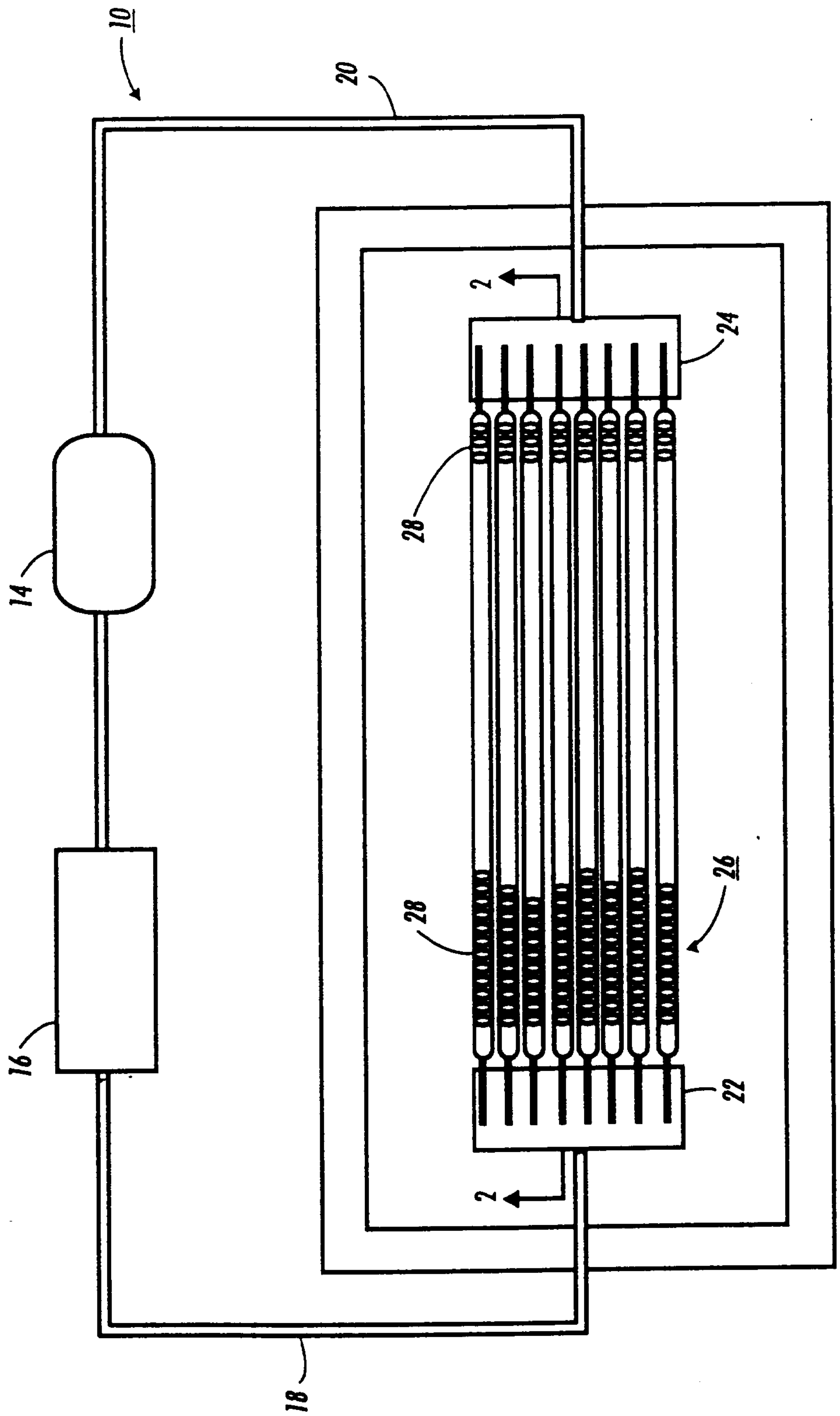

FIG. 1

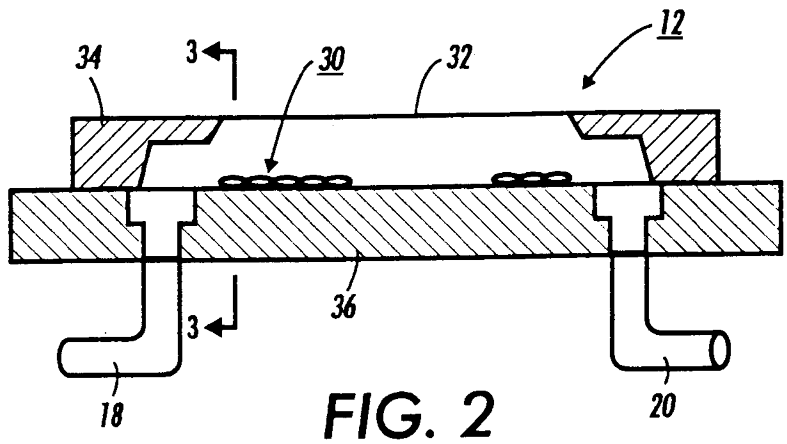

FIG. 2

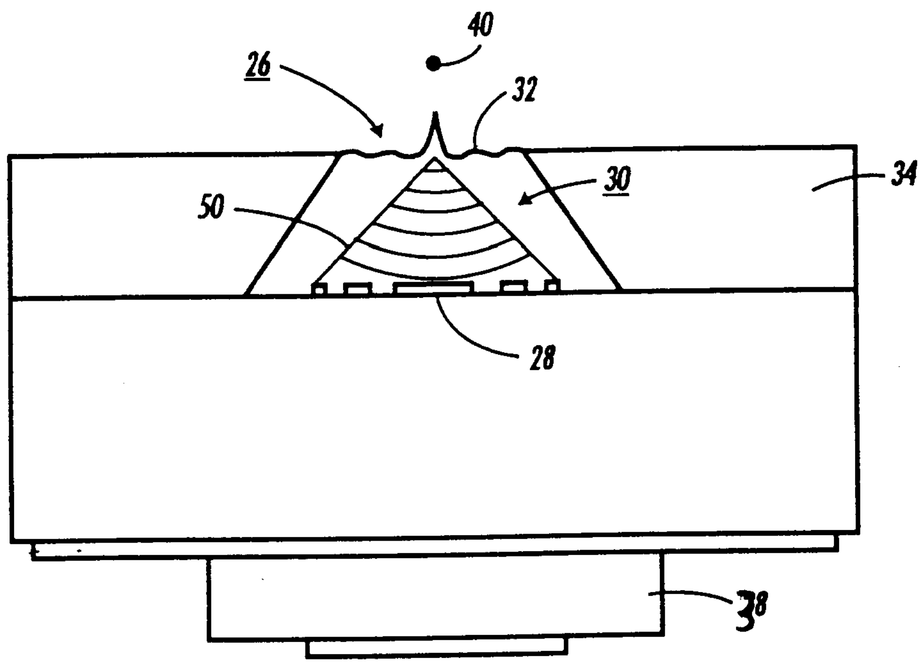

FIG. 3

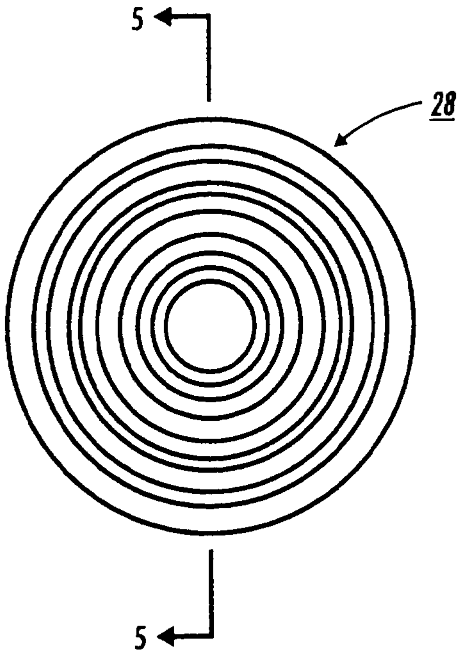

FIG. 4

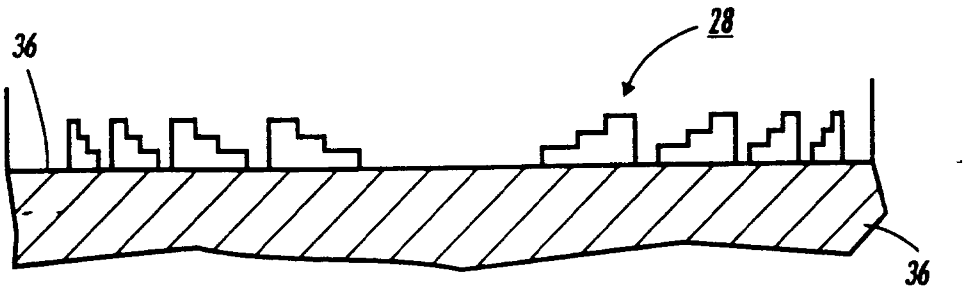

FIG. 5

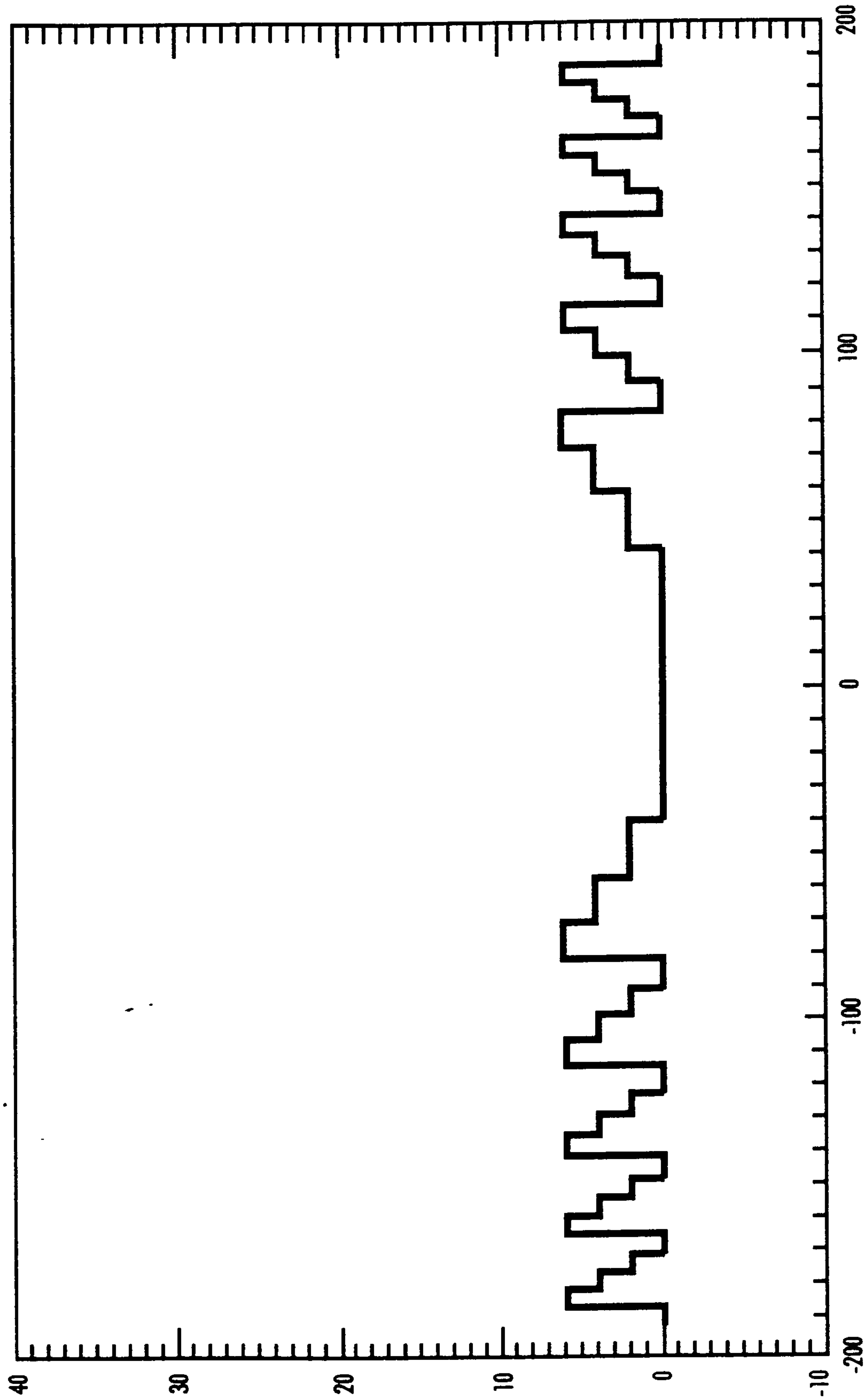

FIG. 6

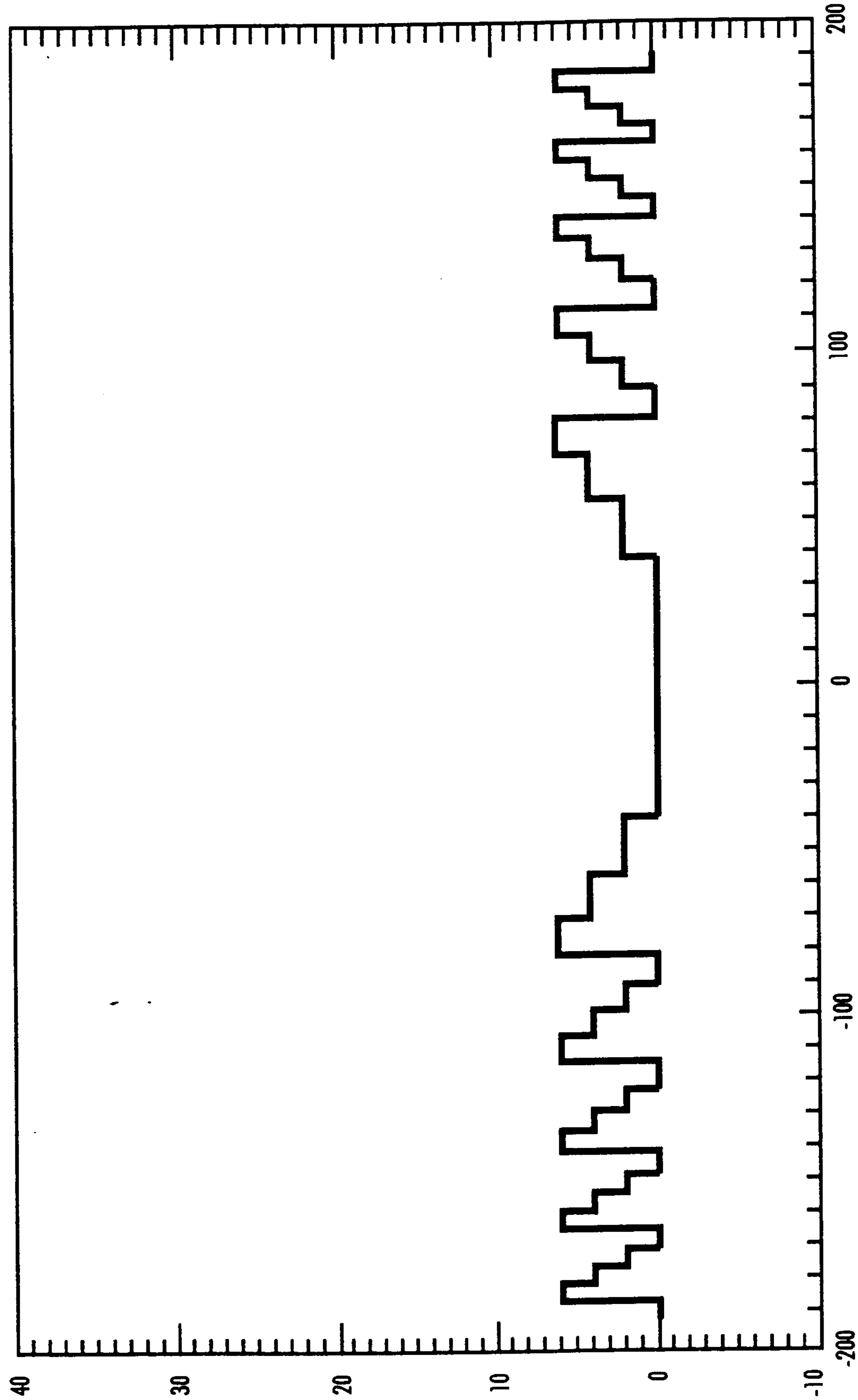

FIG. 7