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(54) **Nozzleless droplet projection system.**

(57) A nozzleless droplet projection system is disclosed. A thin film of fluid (26) with a constant thickness travels at a constant velocity across a tubular transducer head (16a, 16b). A smooth perimetrical surface (18) is formed between the input (22) and the output (24) sides of the transducer head (16a, 16b). An array of electro-acoustic transducers (15) submerged beneath the transducer head support surface (17) generate tone bursts (20, Figs 3 and 4) of acoustic energy which are focused by a corresponding array of acoustic lenses (19) inscribed along the length of the transducer head (16a, 16b). The constant thickness and constant velocity fluid film (26) is generated by forcing pre-regulated, pressurized fluid through a narrow slit (30) and across the smooth perimetrical surface (18) of the transducer head (16a, 16b). The fluid film (26) is maintained at the acoustic focus of the lenses (19) in order to control the resultant droplet (12) size. A pattern of droplets (12) is ejected by pulsing the appropriate electro-acoustic transducers (15) as the projection medium (14) is moved across the droplet formation apparatus at a constant velocity.

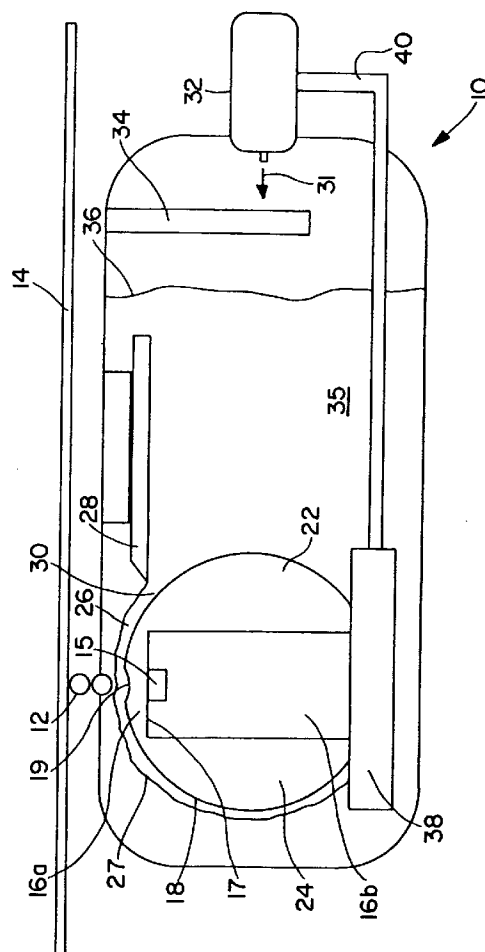


FIG. 2

The present invention relates to ink jet printing and, more particularly, to apparatus for delivering fluid droplets onto a projection surface.

In a common ink jet printer, manufactured by the computer peripherals industry, a nozzle based droplet projection system is typically used to project ink onto paper. Though these printers tend to be very slow in producing hardcopy, they are an attractive product to many consumers interested in a low cost product. The problem of accurately projecting fluid droplets, such as ink, onto a projection medium, such as paper, at very high rates and low cost has presented a major challenge to designers in the computer peripherals field. Surface contamination problems and clogging of the ink nozzles is a common problem. Limitations in the droplet ejection rate impede the development of a significantly faster system with the current nozzle based technology.

A printer is a device which transfers information, either graphics or text, from a computer medium to hardcopy, such as paper. The speed at which the paper hardcopy may be produced, the clarity and the resolution of the hardcopy are measures of the quality of the printer. Resolution is a measure of the capability of a printer to reproduce fine detail on paper. A printer which produces high resolution output can create a faithful reproduction of the original text or graphics. Higher resolution printers generate a more impressive final product and are, consequently, in greater demand. The technology utilized determines the quality of the printer and its ultimate cost. Ink jet printing is a relatively inexpensive direct marking technology which has been slow to mature at least in part because most "continuous stream" and "drop on demand" ink jet print heads include nozzles. Although steps have been taken to reduce the manufacturing cost and increase the reliability of these nozzles, experience suggests that the nozzles will continue to be a significant obstacle to realizing the full potential of the technology.

The development of a straightforward apparatus which would allow one to solve the speed and maintainability problems of nozzle based print heads, at a lower cost, would represent a major technological advance in the computer peripheral industry. The enhanced performance which could be achieved using such innovative technology would satisfy a long felt need within the industry.

The present invention provides a nozzleless droplet projection system for projecting droplets of fluid onto a projection surface. Apparatus in accordance with the invention employs a suitable geometry for developing a thin film of fluid with a constant thickness traveling at a constant velocity across a transducer head. The head structure has a smooth perimetrical exterior surface, and a distribution of submerged electro-acoustic transducers to generate tone bursts of acoustic energy. Each transducer has an

associated acoustic lens, to focus the tone bursts onto the surface of the thin fluid film. The focused tone bursts eject droplets of fluid from the fluid film onto the projection surface. The thickness of the fluid film and the flow velocity are maintained constant by a laminar flow regulator such that the position of the exterior surface of the fluid and the head generally coincides with the acoustic focus, and the fluid velocity is generally constant during pressure surges in the fluid supply. Maintaining this spatial relationship produces ejected droplets of a desired diameter. A continuous supply of fluid passes over the head during operation of the projection system.

The present invention further provides, in an acoustic printer having a printhead including an electro-acoustic transducer means and a droplet ejector means for supplying an acoustic beam which converges to eject ink droplets on demand from a supply of ink; an ink transport for delivering said supply of ink to said printhead, said ink transport comprising:

a pump means for applying pressure to said supply of ink;

a filter means for filtering said supply of ink;

a regulating means for transforming said supply of ink into a thin film of ink;

an input means for conducting said thin film of ink continuously to said droplet ejector means;

an output means for conducting said thin film of ink away from said droplet ejector means;

a sump means for collecting said thin film of ink; and

a return means for returning said thin film of ink to said pump means.

By way of example only, an embodiment of the invention will be described with reference to the accompanying drawings, in which:

Figure 1 is a perspective view of a system incorporating apparatus in accordance with the present invention.

Figure 2 is a schematic representation of a side view of the system.

Figure 3 is a schematic representation of a lengthwise view of the system.

Figure 4 is a schematic diagram depicting the regulation of fluid flow in the system.

Figure 1 is a perspective view of apparatus 10, in accordance with the present invention, in a nozzleless droplet projection system. Fluid droplets 12, such as ink, are projected onto projection surface 14, such as paper, as the projection surface 14 is moved across apparatus 10. The apparatus 10 may be conveniently sized to match the width of the projection surface 14 so that only one pass is required to complete a printing process.

Figure 2 is a schematic representation of a side view of the system. In the apparatus 10, at least one electro-acoustic transducer 15 is connected to a head structure 16a having a head cavity 16b. Each electro-

acoustic transducer 15 intimately contacts head structure 16a at transducer support surface 17. Head structure 16a has a smooth perimetrical exterior surface 18 with at least one inscribed acoustic lens 19, which is advantageously aligned with each electro-acoustic transducer 15. Tone bursts 20 (Figs. 3 and 4) of acoustic energy are transmitted through head structure 16a to acoustic lens 19 by pulsing the electro-acoustic transducer 15 with an electrical excitation (not shown). The lens shape is preferably spherical, but a Fresnel lens structure (not shown) may be considered an alternative. The boundaries of the perimetrical exterior surface 18 are defined by the input side 22 and the output side 24 of head structure 16a. A laminar flow of fluid 26, with a velocity typically between 0.1 and 0.5 m/sec, is developed across smooth exterior surface 18 by laminar flow regulator 28, which maintains the fluid surface 27 at a generally constant distance from the smooth exterior surface 18. This distance is designed to advantageously correspond to the focal distance (typically between 0.1 and 0.5 mm) of the acoustic lens 19 which is utilized. The distance between the fluid surface 27 and the smooth exterior surface 18 may be adjusted by varying the separation or slit 30 between laminar flow regulator 28 and head 16a at input side 22. This geometry assures optimum droplet size. Pre-regulated, pressurized fluid 31 is injected into the apparatus 10 by fluid pump 32 in the direction shown. The pressurized fluid input 31 is deflected from baffle 34 and filtered by fluid filter 36. The filtered fluid supply 35 is forced by pump 32 through laminar flow regulator 28 at slit 30. A fluid sump 38 collects the laminar fluid flow 26 from the output side 24 of head structure 16a and feeder tube 40 returns the fluid to fluid pump 32 to complete the fluid flow cycle.

Figure 3 is a schematic representation of a lengthwise view of the system. A linear array of electro-acoustic transducers 15 with corresponding acoustic lenses 19 is depicted along a length of head structure 16a. Head cavity 16b and transducer support surface 17 extends along the length of the head structure 16a. The number and the relative size of the electro-acoustic transducers 15 and acoustic lenses 19 in the linear array determines the spatial resolution of the projection system. Center-to-center spacings on the order of 50 microns may be considered high resolution for the purpose of droplet 12 ejection onto a projection surface 14. Tone bursts 20 of acoustic energy are shown emanating from the electro-acoustic transducers 15 and are transmitted through head structure 16a, which has favorable acoustic properties. Electronic power supply 21 is connected to the array of electro-acoustic transducers 15 through an electronic multiplexer 41 which selectively excites any sequence of electro-acoustic transducers 15 to project a desired pattern of droplets 12 onto the projection surface 14. Electronic multiplexer 41 is selectively

addressed at very high speeds by a control circuit (not shown) which is external to the apparatus 10.

Figure 4 is a schematic diagram depicting the focusing action of lens 19 upon the acoustic tone bursts 20, creating converging acoustic tone bursts 42, and the regulation of fluid flow in the apparatus 10. The height of the fluid surface 27 with respect to the exterior surface 18 of head structure 16a is regulated against pressure fluctuations in the filtered fluid supply 35 by laminar flow regulator 28. Due to surface tension forces created by forcing the pressurized fluid 35 through narrow slit 30 in the direction shown at 44, a pressure increase in the filtered fluid supply 35 essentially creates a convex meniscus 46 and a pressure drop in the filtered fluid supply creates a concave meniscus 48 between laminar flow regulator 28 and exterior surface 18. The elastic action of the fluid within slit 30 tends to regulate the fluid velocity and depth along smooth exterior surface 18 during operation of the apparatus 10. Head structure 16a and head cavity 16b form a tubular means for supporting the electro-acoustic transducers 15, which tubular means may be circular, elliptical or polygonal in cross section. In fact, any shape that provides a smooth exterior surface which supports the elastic properties of fluid flow may be employed. To achieve the ejection of droplets 12 of a desired size, the fluid depth must be maintained substantially within the focal plane of the acoustic lens 19. The radiation pressure of the converging acoustic tone bursts 42 acts to overcome the restraining force of surface tension and expel droplets 12 from the fluid surface 27. For lenses with low spherical aberration and an F/number of approximately 1.0, the diameter of the ejected droplets 12 scale inversely with the acoustic frequency used to excite the electro-acoustic transducers 15. Droplet diameters from 300 to 5 microns would correspond to an acoustic frequency range of 5 to 300 MHz.

The nozzleless droplet projection system described above provides for constant renewal of an ink surface which reduces surface contamination problems which are common to many low-cost printing technologies. Disturbances in the laminar flow 26, including surface ripple waves due to droplet 12 ejection, are swept away before they can propagate to other points along the transducer array. The drop 12 ejection rate may be varied without altering the laminar flow depth since the pressurized fluid input 31 is constantly regulated. The curved trajectory of the laminar flow 26 allows the spacing between projection surface 14 and droplet formation apparatus 10 to be as small as desired while maintaining larger clearances between the projection surface and the rest of the projection system.

It will be appreciated that the system described above with reference to the drawings constitutes an acoustic printer in which the printhead comprises the

drop formation apparatus 10. Through operation of the transducers 15, ink droplets are expelled from the printhead 10 by the acoustic lenses 19 and directed towards the projection surface 14.

Claims

1. Droplet formation apparatus (10) comprising:
 - at least one electro-acoustic transducer means (15, 19) for generating tone bursts (42) of focused acoustic energy;
 - tubular means (16a, 16b) supporting said electro-acoustic transducer means (15); and
 - regulating means (28, 32, 38, 40) for supplying, across said tubular means (16a, 16b), a film of fluid having a generally constant velocity and thickness.
2. Apparatus (10) as claimed in Claim 1, in which said tubular means (16a, 16b) is substantially circular in cross-section.
3. Apparatus (10) as claimed in Claim 1, in which said tubular means (16a, 16b) is substantially elliptical in cross-section.
4. Apparatus (10) as claimed in Claim 1, in which said tubular means (16a, 16b) is generally substantially polygonal in cross-section.
5. Apparatus (10) as claimed in any one of the preceding Claims, in which said electro-acoustic transducer means (15, 19) produces tone bursts (20) of focused acoustic energy having a focal distance which is generally between 0.1 and 0.5 millimeter.
6. Apparatus (10) as claimed in any one of the preceding Claims, in which said regulating means (28, 32, 38, 40) provides a fluid velocity which is generally between 0.1 meter per second and 0.5 meter per second.
7. Droplet formation apparatus (10) comprising:
 - a head structure (16a) having an input side (22), an output side (24) and a transducer support surface (17); said head structure (16a) having a perimetrically smooth exterior surface (18) disposed between said input side (22) and said output side (24);
 - a linear array of acoustic lenses (19) inscribed along a length of said smooth exterior surface (18) of said head structure (16a);
 - a linear array of electro-acoustic transducers (15) for generating tone bursts (20) of acoustic energy substantially coincident with said transducer support surface (17) of said head

structure (16a), each said electro-acoustic transducer (15) being generally aligned with one of said acoustic lenses (19);

a power supply (21) and an electronic multiplexer (41) connected to said linear array of electro-acoustic transducers (15);

a laminar flow regulator (28) adjustably mounted in proximity to said perimetrically smooth exterior surface (18) at said input side (22) of said head structure (16a); and

means (32, 34, 38, 40) for continuously supplying pressurized fluid (33) through said laminar flow regulator (28).

8. An acoustic printer having a printhead which comprises apparatus as claimed in any one of the preceding claims, wherein the said fluid is ink and the said transducer means is operable to cause droplets of ink to be expelled by the printhead on demand.

9. An acoustic printer having a printhead which comprises apparatus as claimed in any one of claims 1 to 6, wherein the said fluid is ink and the said transducer means is operable to cause droplets of ink to be expelled by the printhead on demand, and wherein the regulating means comprises:

pump means (32) for applying pressure to an ink supply (33);

filter means (36) for filtering said ink supply;

means (28) for transforming the supply of ink into a thin film of ink;

input means (22) for supplying the thin film of ink continuously across the tubular means;

output means (24) for conducting the thin film of ink away from the tubular means;

sump means (38) for collecting the ink; and

return means (40) for returning ink to the pump means.

10. An acoustic printer having a printhead which comprises apparatus as claimed in claim 7, wherein the said fluid is ink and the said transducers are operable to cause droplets of ink to be expelled from the printhead, on demand, by the acoustic lenses, and wherein the means (32, 34, 38, 40) for continuously supplying pressurized ink through the laminar flow regulator comprises:

pump means (32) for applying pressure to an ink supply (33);

filter means (36) for filtering said ink supply;

sump means (38) for collecting ink from the output side (24) of the head structure (16a); and return means (40) for returning ink to the pump means.

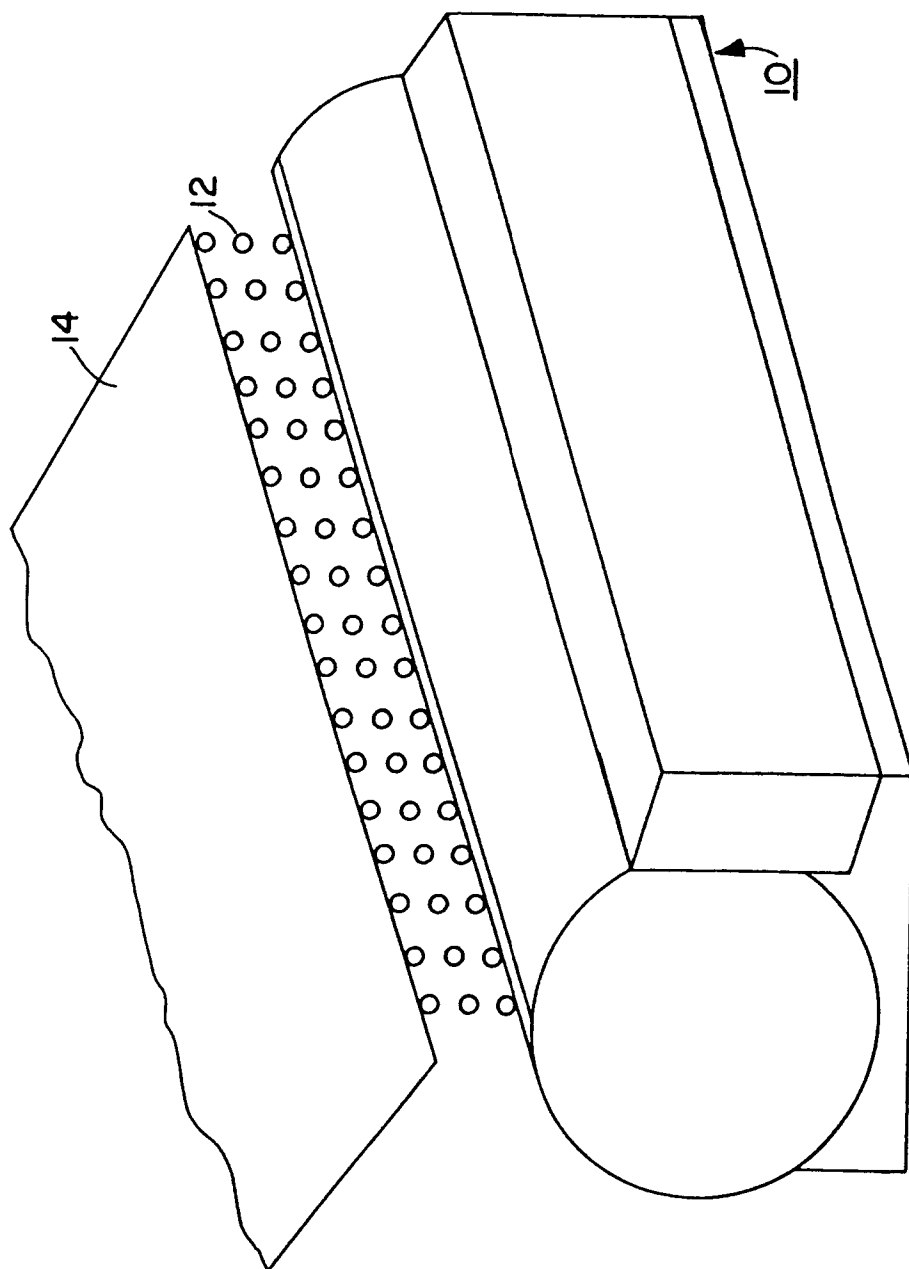


FIG. 1

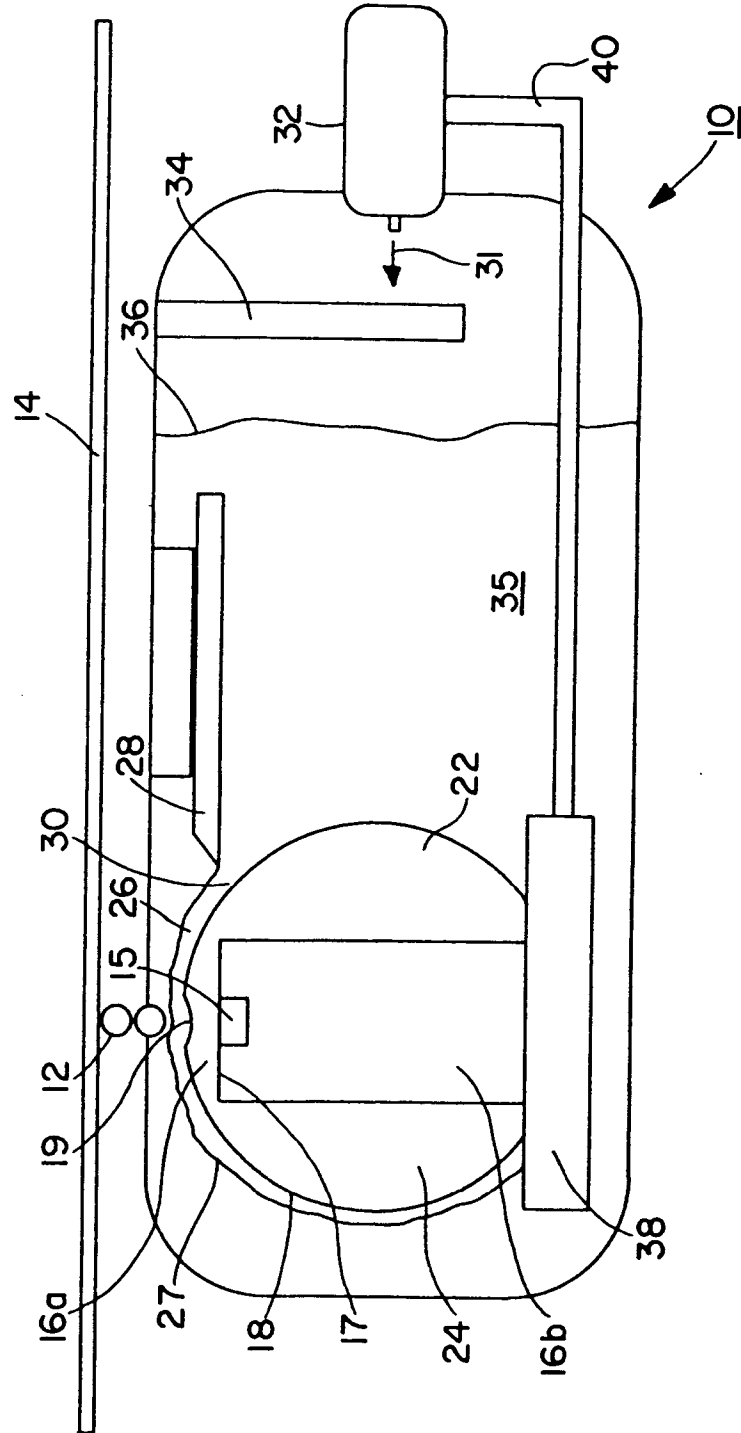
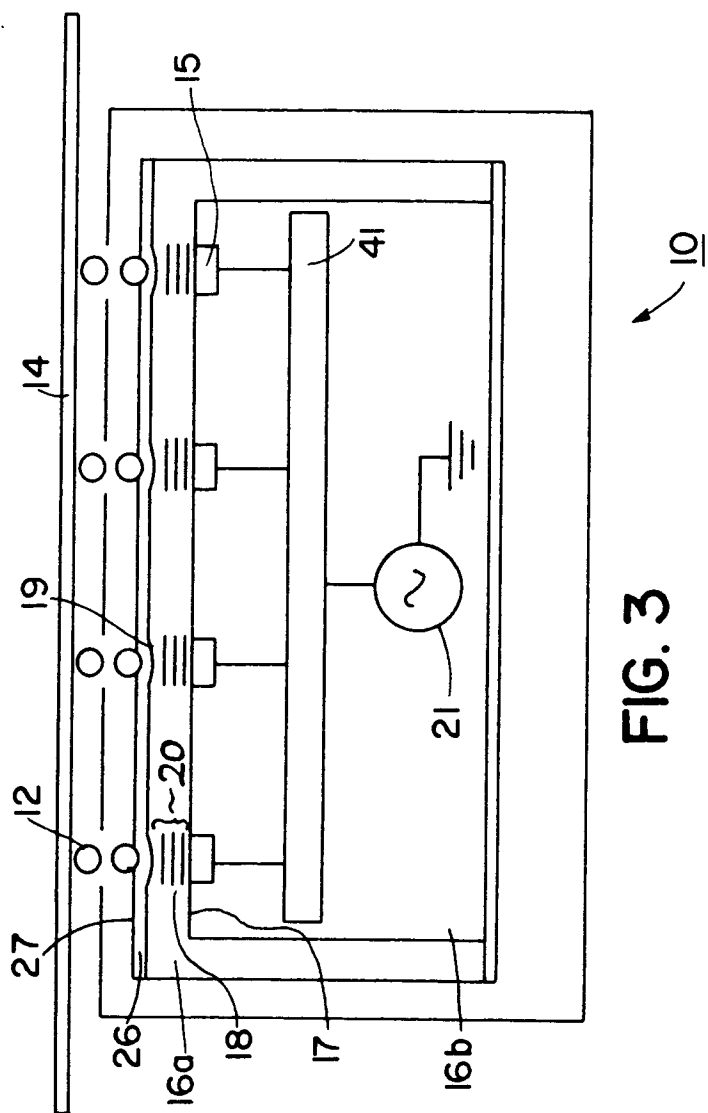


FIG. 2



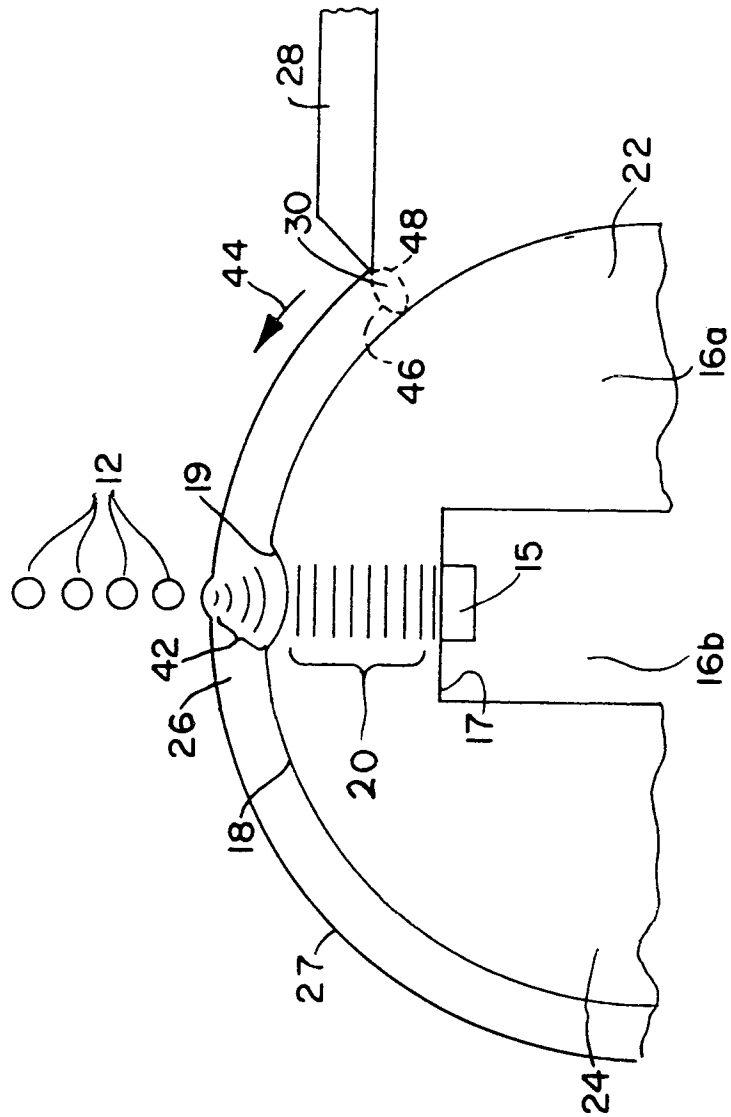


FIG. 4