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DE FR GB(71) Applicant: Hewlett-Packard Company
3000 Hanover Street
Palo Alto California 94304(US)(72) Inventor: Meyer, John David
1359 Latham Street
Mountain View California 94041(US)(74) Representative: Oliver, Peter Anthony
Hewlett-Packard Limited Nine Mile Ride Easthampstead
Wokingham, Berkshire RG11 3LL(GB)

(54) Thermal ink jet printer utilizing secondary ink vaporization.

(57) A thermal ink jet printer utilizes secondary vaporization of the ink to minimize cavitation damage to a printhead resistor. The printhead resistor comprises a resistive portion for heat generation and a storage portion for storing heat after the resistive portion cools and for presenting a surface having a temperature in excess of the ink boiling temperature when the initial ink vapor bubble collapses.

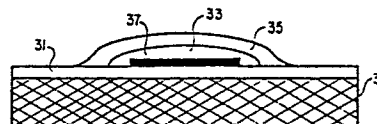


FIG. 3

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THERMAL INK JET PRINTER UTILIZING
SECONDARY INK VAPORIZATION

This invention is concerned with thermal ink jet printers.

Application of a current pulse to a thermal ink jet printer, as described, for example, in UK Patent Application 5 No. 8217710, causes an ink droplet to be ejected by heating a printhead resistor located within an ink supply. This resistive heating causes a bubble to form in the ink and the resultant pressure increase forces the desired ink droplet from the printhead. Thermal ink jet printer life time is 10 dependent upon printhead resistor life time and a majority of resistor failures result from cavitation damage which occurs during bubble collapse. In order to make multiple printhead, e.g., page width, arrays economically feasible, it is important that thermal ink jet printer life times 15 exceed at least one billion ink droplet ejections.

The present invention provides a thermal ink jet printer printhead resistor comprising a substrate and a resistive layer attached to the substrate, and characterized by a storage layer attached to and overlying the resistive 20 layer and a passivation layer attached to and overlying the storage layer.

In a resistor as set forth in the last preceding paragraph, it is preferred that the thermal diffusivity of the resistive layer is greater than the thermal diffusivity of

the storage layer.

In a resistor as set forth in the last preceding paragraph, it is preferred that the thermal diffusivity of the substrate is less than the thermal diffusivity of the resistive layer.

In a resistor as set forth in the last preceding paragraph or the last but one, it is preferred that the thermal diffusivity of the passivation layer is greater than or equal to the thermal diffusivity of the storage layer.

10 In a resistor as set forth in the last preceding paragraph, it is preferred that the storage layer is composed essentially of aluminium oxide and the passivation layer is composed essentially of a material which is selected from silicon carbide, silicon oxide and aluminium oxide.

15 The present invention further provides a method of ejecting an ink droplet from a thermal ink jet printer, the method being characterized by the steps of covering a print-head resistor comprising a resistive layer and an overlying storage layer with an ink, passing a current through the resistor so that the temperatures of both the resistive layer and the storage layer exceed the boiling temperature of the ink, generating an ink vapor bubble within the ink, maintaining the temperature of the storage layer substantially constant, and cooling the resistive layer.

25 A method as set forth in the last preceding paragraph may further comprise the step of generating a secondary bubble after the step of cooling the resistive layer.

Preferably, the current is passed as a pulse which has an amplitude which is sufficient to raise the temperature of the resistive layer and the storage layer above the boiling temperature of the ink.

The current pulse amplitude is preferably at least 40% greater than an amplitude which is sufficient to raise the temperature of the resistor above the boiling temperature of the ink.

The present invention further provides a thermal ink jet printer for ejecting ink droplets from an ink supply, the thermal ink jet printer comprising a capillary region for containing the ink supply, pulse means for creating a
5 current pulse, and heater means, within the capillary region and coupled to the pulse means, for generating heat in response to the current pulse, the printer being characterized by storage means, attached to the heater means, for storing a portion of the heat generated by the heater means.
10 Preferably the heater means comprises a resistive layer attached to a substrate; the storage means is preferably attached to and overlies the heater means.

In accordance with the illustrated preferred embodiment of the present invention, a thermal ink jet printer is shown
15 in which cavitation damage is minimized and in which an extended life time can be achieved. The printhead resistor is fabricated upon a substrate and comprises a resistive layer over which a storage layer and a passivation layer are placed. The current pulse which is applied to the print-
20 head resistor comprises two sections, a lower section which is sufficient to cause initial bubble formation in the ink and an additional upper section which is used to cause re-vaporization of the ink. When the current pulse is applied to the printhead resistor, the temperatures of the three
25 layers rise and an initial ink vapor bubble is created. When the current pulse is removed, the resistive layer cools rapidly because of a thermal conduction path through the substrate. But, because of the resistive layer on one side and the ink vapor on the other, the storage layer is
30 insulated and cools much more slowly. The total amplitude of the current pulse is large enough that the storage layer temperature is still sufficient to cause secondary ink vaporization when the initial bubble collapses and intruding ink contacts the printhead resistor. This secondary ink
35 vaporization softens the acoustic shock which is generated

by the collapse of the initial bubble. The passivation layer overlying the resistive layer and the storage layer is used to provide chemical and mechanical protection of the printhead resistor.

5 There now follows a detailed description which is to be read with reference to the accompanying drawings of a print-head resistor, printer and method according to the invention; it is to be clearly understood that this printer and method have been selected for description to illustrate the
10 invention by way of example and not by way of limitation.

In the accompanying drawings:-

Figure 1 is a block diagram of a thermal ink jet printer which is constructed in accordance with the preferred embodiment of the present invention;

15 Figure 2 shows a cutaway view of the printhead which is used in the thermal ink jet printer of Figure 1;

Figure 3 is a side view of the printhead resistor which is used in the printhead of Figure 2;

20 Figure 4 is a temperature profile through the printhead resistor of Figure 3 after a current pulse is applied;

Figure 5 shows a test set-up which may be used to select the current pulse; and

Figure 6 is a representative plot of pressure versus time which may be observed in the test set-up of Figure 5.

25 Figure 1 is a block diagram of a thermal ink jet printer incorporating a resistor which is constructed in accordance with the preferred embodiment of the present invention. The general construction of the thermal ink jet printer of Figure 1 is more fully described in the above-
30 referenced patent application. When it is desired that an ink droplet be ejected from printhead 3, a current pulse generator 1 is used to generate a current pulse which is applied to a printhead resistor 5. IR heating of the resistor 5 causes a droplet of ink, which is supplied from a
35 reservoir 7 via a tube 15, to be ejected from the printhead

reservoir 7 via a tube 15, to be ejected from the printhead 3.

Figure 2 provides a more detailed cutaway view of the printhead 3. Ink is supplied to a capillary region 11 via the tube 15. When the current pulse is applied to the resistor 5 (through conductors which are not shown), an ink vapor bubble is created in the ink overlying the resistor 5 and a resultant pressure increase causes a desired ink droplet to be ejected from a nozzle 9. If multiple resistors 5 are used in the printhead 3, barriers 13 are utilized to eliminate crosstalk between adjacent nozzles 9.

Figure 3 presents a side view of the resistor 5 which is mounted upon a five micron thick silicon oxide layer 31 which overlies a silicon substrate 39. The resistor 5 comprises a resistive layer 37, a storage layer 33 which overlies the resistive layer 37, and a passivation layer 35 which overlies the storage layer 33. The resistive layer 37 is an 80 micron square of a half tantalum half aluminium alloy having a thickness of 600 angstroms, a total resistance of fifty ohms, and a thermal diffusivity of .225 centimeters squared per second. The resistive layer 37 is fabricated utilizing well known thin film techniques. The function of the storage layer 33, which overlies the resistive layer 37, is to conduct heat to the ink while the current pulse is applied to the resistor 5 and then to act as a thermal storage element from the time that the current pulse is removed to the time that the initial bubble collapses. Thus, it is essential that the thermal diffusivity of the storage layer 33 be less than the thermal diffusivity of the resistive layer 37. In the thermal ink jet printer of Figure 1, the storage layer 33 was a one micron thick layer of aluminium oxide having a thermal diffusivity of .065 centimeters squared per second.

Finally, the passivation layer 35 covers both the storage layer 33 and the resistive layer 37 in order to

provide chemical and mechanical protection during operation. It is important that the thermal diffusivity of the passivation layer 35 be roughly equal to, or greater than, the diffusivity of the storage layer 33 so that there is a rapid conduction of heat through the passivation layer 35. A thin layer of such materials as silicon carbide, silicon oxide, or aluminium oxide may be used in fabricating the passivation layer 35. In the thermal ink jet printer of Figure 1, the passivation layer 35 comprises a half micron thick layer of aluminium oxide.

Figure 4 presents a thermal profile of the resistor 5 at an instant of time just after application and removal of the current pulse, but before the collapse of the initial vapor bubble. Note that because of the high thermal diffusivity of the resistive layer 37, the thermal gradient through the resistive layer 37 is flat and that the resistive layer 37 will cool due to thermal conduction through the silicon oxide layer 31 and the silicon substrate 39. Since the storage layer 33 and the passivation layer 35 both have thermal diffusivities which are less than the thermal diffusivity of the resistive layer 37, the thermal gradients therethrough are steep and heat flows from the resistive layer 37 to the ink vapor bubble. Because the ink vapor bubble is a thermal insulator, the temperature of the storage layer 33 decays much more slowly than does the temperature of the resistive layer 37 after removal of the current pulse. Thus, if the total amplitude of the current pulse is sufficiently large, the temperature of the storage layer 33 (and of the passivation layer 35) will still be greater than the boiling point of the ink when the initial bubble collapses and inrushing ink contacts the printhead resistor 5. In such a case, revaporization occurs and cavitation damage is minimized.

Figure 5 depicts a test apparatus which may be utilized for selecting a current pulse in order that the desired ink

revaporization occurs. The printhead resistor to be used is placed at the bottom of a container of ink and a high frequency pressure transducer, such as a Matchlett Co. model PVF-2 device is placed directly over the printhead resistor at a distance of approximately one centimeter. The output of the pressure transducer is monitored on a digital storage oscilloscope such as a Tektronix Corporation model 468. A current pulse is applied to the printhead resistor and the output of the pressure transducer is recorded as the amplitude of the current pulse is varied.

Figure 6 depicts a representative plot of the pressure transducer output which may be observed in the test set-up of Figure 5. The first pressure spike represents the acoustic shock which is generated by the collapse of the initial bubble. As the amplitude of the current pulse is increased from that necessary to create an initial ink vapor bubble, the detected amplitude of the first pressure spike remains relatively constant until a threshold current pulse amplitude is reached. At this threshold current pulse amplitude, revaporization occurs and the amplitude of the first spike falls by roughly a factor of two. As the current pulse amplitude is further increased, the amplitude of the second spike increases slowly indicating undesired tertiary vaporization of the ink. Ultimately, at some extreme current pulse amplitude, thermal stresses cause failure of the printhead resistor.

The above-described printhead resistor was analyzed in the test set-up of Figure 5 with water and a six microsecond wide current pulse. It was found that the minimum current pulse amplitude which was needed to cause ejection of an ink droplet was .42 amperes and that revaporization occurred at a current pulse amplitude of .62 amperes. Optimum printhead resistor life time was achieved when a current pulse was used which had an amplitude of .62 to .64 amperes.

CLAIMS

1. A thermal ink jet printer printhead resistor comprising:

a substrate (39) and a resistive layer (37) attached to the substrate; and characterized by

5 a storage layer (33) attached to and overlying the resistive layer; and

a passivation layer (35) attached to and overlying the storage layer.

10 2. A printhead resistor according to claim 1, characterized in that the thermal diffusivity of the resistive layer is greater than the thermal diffusivity of the storage layer.

15 3. A printhead resistor according to claim 2, characterized in that the thermal diffusivity of the substrate is less than the thermal diffusivity of the resistive layer.

20 4. A printhead resistor according to either one of claims 2 and 3, characterized in that the thermal diffusivity of the passivation layer is greater than or equal to the thermal diffusivity of the storage layer.

25 5. A printhead resistor according to claim 4, characterized in that the storage layer is composed essentially of aluminium oxide and the passivation layer is composed essentially of a material which is selected from silicon carbide, silicon oxide and aluminium oxide.

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6. A method of ejecting an ink droplet from a thermal ink jet printer, the method being characterized by the steps of

covering a printhead resistor (5) comprising a resistive layer (37) and an overlying storage layer (33) with an ink;

5 passing a current through the resistor so that the temperatures of both the resistive layer and the storage layer exceed the boiling temperature of the ink;

generating an ink vapor bubble within the ink;

maintaining the temperature of the storage layer substantially constant; and

10 cooling the resistive layer.

7. A method according to claim 6, further comprising the step of generating a secondary bubble after the step of cooling the resistive layer.

15

8. A method according to either one of claims 6 and 7, characterized in that the current is passed as a pulse which has an amplitude which is sufficient to raise the temperature of the resistive layer and the storage layer
20 above the boiling temperature of the ink.

9. A method according to claim 8, characterized in that the current pulse amplitude is at least 40% greater than an amplitude which is sufficient to raise the
25 temperature of the resistor above the boiling temperature of the ink.

10. A thermal ink jet printer for ejecting ink droplets from an ink supply, the thermal ink jet printer
30 comprising:

... a capillary region (11) for containing the ink supply;
pulse means (1) for creating a current pulse; and a

heater means (5), within the capillary region and coupled to the pulse means, for generating heat in response
35 to the current pulse; the printer being characterized by

storage means (33), attached to the heater means (5), for storing a portion of the heat generated by the heater means.

5 11. A thermal ink jet printer according to claim 10, characterized in that the heater means comprises a resistive layer (37) attached to a substrate (39).

12. A thermal ink jet printer according to claim 11,
10 characterized in that the storage means is attached to and overlies the heater means.

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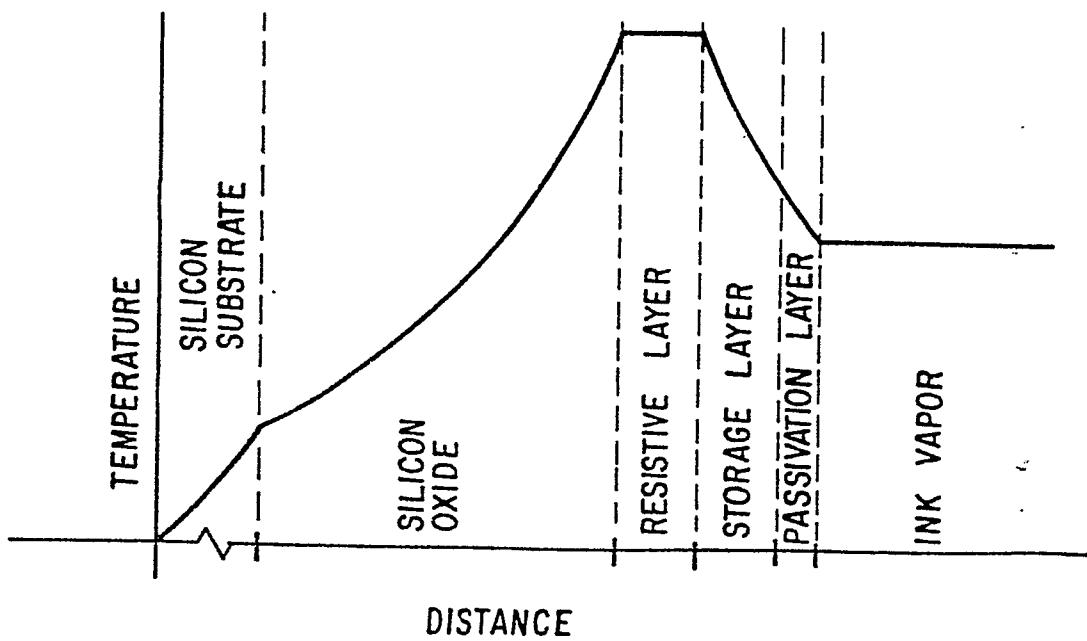
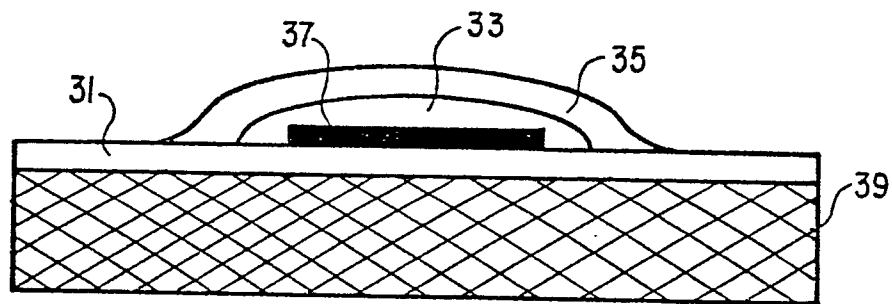
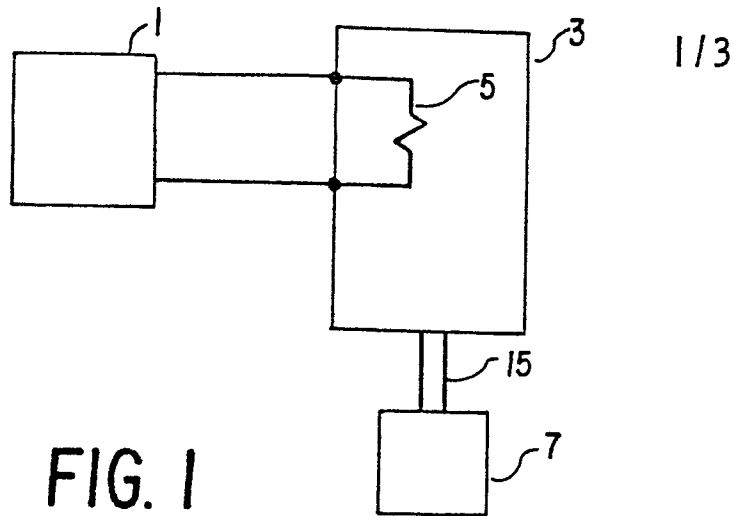


FIG. 4

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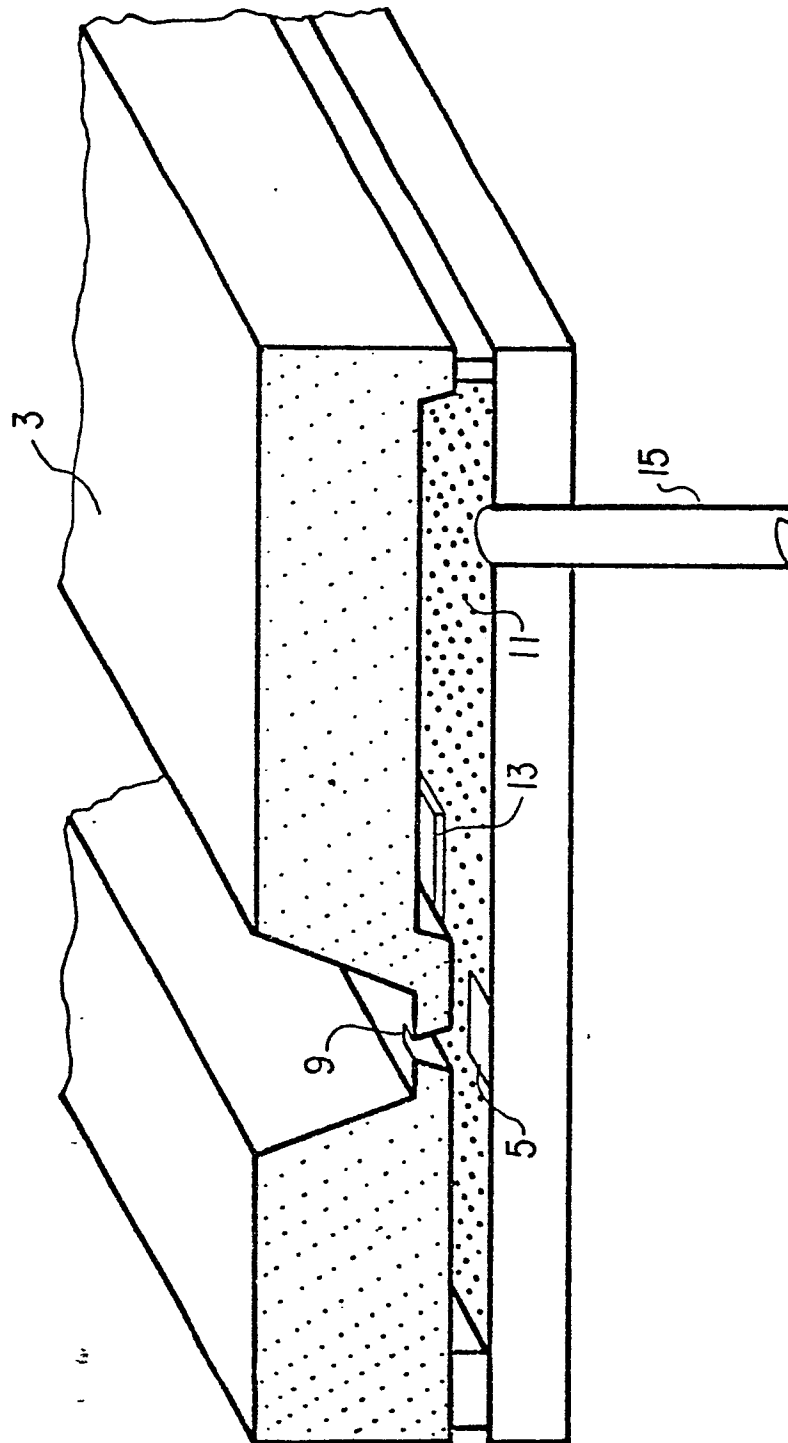


FIG. 2

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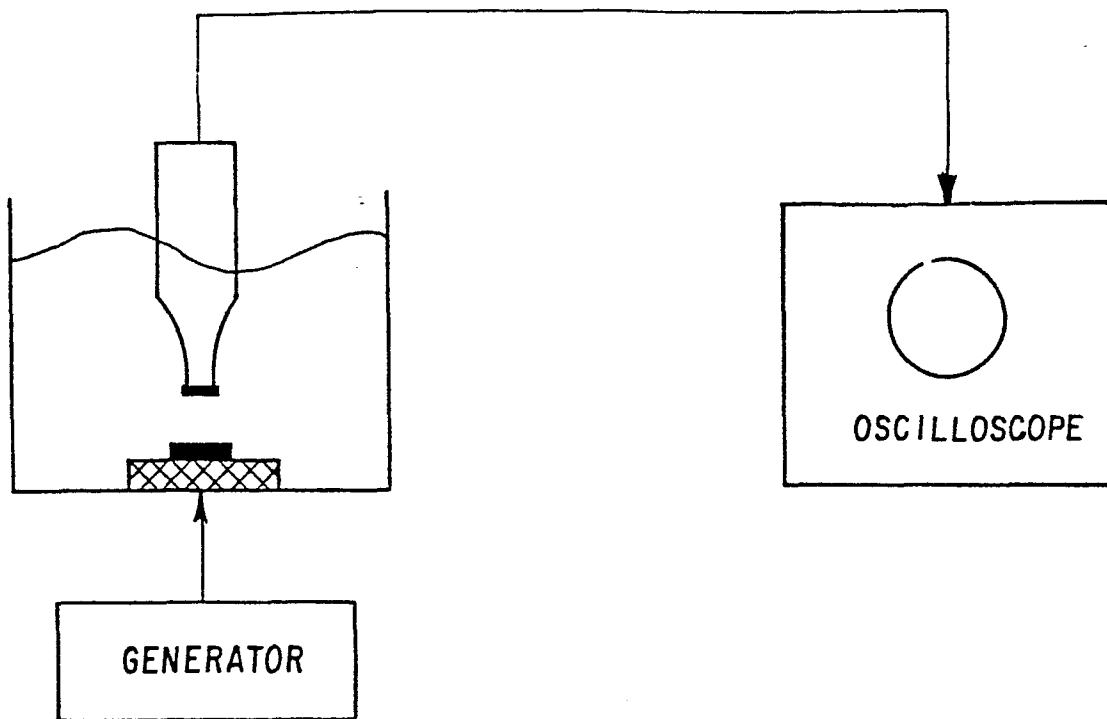


FIG. 5

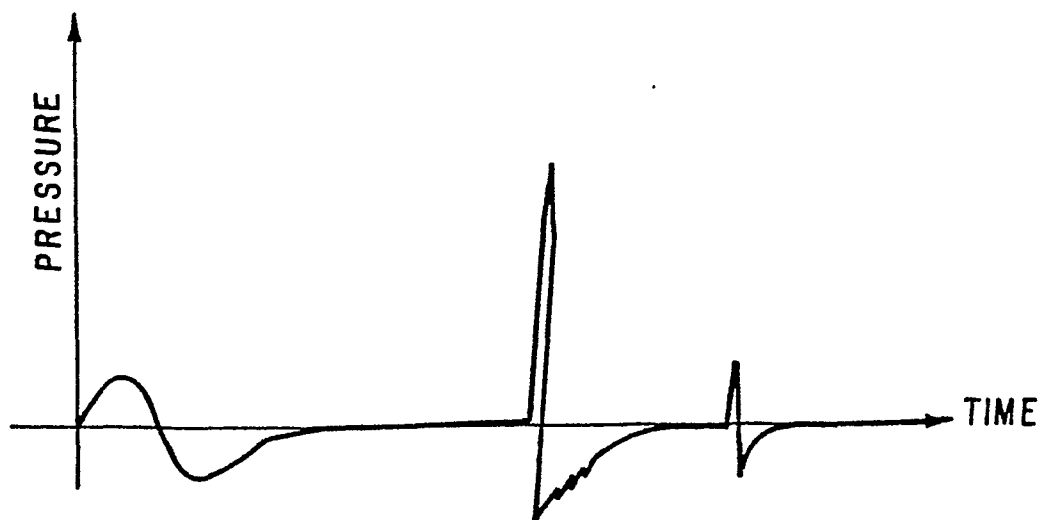


FIG. 6