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HEWLETT-PACKARD COMPANY

CV-S-01-0060-RLH-RJJ

MZ

UNITED STATES DISTRICT COURT

DISTRICT OF NEVADA

HEWLETT-PACKARD COMPANY, a Delaware corporation Plaintiff, vs. MICROJET TECHNOLOGY CO., LTD., a Taiwanese corporation Defendant.	CV-S- **COMPLAINT FOR PATENT INFRINGEMENT** **JURY DEMAND**

Plaintiff HEWLETT-PACKARD COMPANY ("HP"), by and through its undersigned attorneys, alleges as follows:

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JURISDICTION

1. This is an action for patent infringement. This Court has subject matter jurisdiction over this patent infringement claim under 28 U.S.C. §§ 1331 and 1338, and pursuant to the Patent Laws of the United States of America, 35 U.S.C. § 101, *et seq.*

VENUE

2. Venue properly lies within the District of Nevada pursuant to 28 U.S.C. §§ 1391(b),(c) and (d) and 28 U.S.C. § 1400(b).

THE PARTIES

3. HP is a corporation incorporated under the laws of the State of Delaware and has its principal place of business at 3000 Hanover Street, Palo Alto, California.

4. Defendant MICROJET TECHNOLOGY CO., LTD. ("Microjet"), on information and belief, is a Taiwanese corporation and has its principal place of business in Taiwan. Upon information and belief, Microjet transacts business in the District of Nevada, including selling and importing for sale various infringing products within that District, and Microjet has sufficient contacts with the District of Nevada on that basis to subject Microjet to the jurisdiction of this Court.

5. Upon information and belief, Microjet is also selling infringing products embodying the patented inventions to customers in the United States, including customers in the District of Nevada, through various intermediaries and distributors located throughout the United States, including intermediaries and distributors located in the District of

Nevada, and Microjet has sufficient contacts with the District of Nevada on that basis to subject Microjet to the jurisdiction of this Court.

FACTUAL BACKGROUND

6. HP engineers, designs, develops and markets a broad offering of computer equipment and systems, networking products, printers, print cartridges, scanners, and enabling technologies. Having invested substantial resources in the development of these technologies, HP maintains a portfolio of patents covering its inventions, including the patents at issue.

7. On May 2, 1989, United States Letters Patent No. 4,827,294 ("the Hanson '294 Patent") was duly and legally issued. A true and correct copy of the Hanson '294 Patent is attached hereto as Exhibit 1. HP is the assignee and owner of all right, title and interest in and to the Hanson '294 Patent, and has the right to bring this suit for damages and injunctive relief.

8. On January 6, 1987, United States Letters Patent No. 4,635,073 ("the Hanson '073 Patent") was duly and legally issued. A true and correct copy of the Hanson '073 Patent is attached hereto as Exhibit 2. HP is the assignee and owner of all right, title and interest in and to the Hanson '073 Patent, and has the right to bring this suit for damages and injunctive relief.

9. On July 21, 1987, United States Letters Patent No. 4,680,859 ("the Johnson '859 Patent") was duly and legally issued. A true and correct copy of the Johnson '859 Patent is attached hereto as Exhibit 3. HP is the assignee and owner of all right, title and interest in and to the Johnson '859 Patent,

and has the right to bring this suit for damages and injunctive relief.

10. On October 3, 1989, United States Letters Patent No. 4,872,027 ("the Buskirk '027 Patent") was duly and legally issued. A true and correct copy of the Buskirk '027 Patent is attached hereto as Exhibit 4. HP is the assignee and owner of all right, title and interest in and to the Buskirk '027 Patent, and has the right to bring this suit for damages and injunctive relief.

11. On February 12, 1991, United States Letters Patent No. 4,992,802 ("the Dion '802 Patent") was duly and legally issued. A true and correct copy of the Dion '802 Patent is attached hereto as Exhibit 5. HP is the assignee and owner of all right, title and interest in and to the Dion '802 Patent, and has the right to bring this suit for damages and injunctive relief.

12. On April 25, 1995, United States Letters Patent No. 5,409,134 ("the Cowger '134 Patent") was duly and legally issued. A true and correct copy of the Cowger '134 Patent is attached hereto as Exhibit 6. HP is the assignee and owner of all right, title and interest in and to the Cowger '134 Patent, and has the right to bring this suit for damages and injunctive relief.

13. The Hanson '294 Patent, the Hanson '073 Patent, the Johnson '859 Patent, the Buskirk '027 Patent, the Dion '802, Patent and the Cowger '134 Patent are collectively referred to herein as "the Patents at Issue."

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14. Microjet sells and imports into the District of Nevada, and the rest of the United States through its national network of distributors, various ink jet print cartridges that infringe each of the Patents at Issue. These infringing ink jet print cartridges are hereinafter referred to as "the Accused Print Cartridges."

COUNT ONE

PATENT INFRINGEMENT OF U.S. PATENT NO. 4,827,294

15. HP incorporates by reference the allegations in paragraphs 1 through 14 above.

16. HP is informed and believes that Microjet has directly infringed, and continues to directly infringe, under 35 U.S.C. § 271(a), the '294 Patent by importing the Accused Print Cartridges into the United States and by selling the Accused Print Cartridges in the United States.

17. HP is informed and believes that Microjet has actively induced infringement, and continues to actively induce infringement, under 35 U.S.C. § 271(b), of the '294 Patent by causing others to directly infringe the '294 Patent.

18. HP is informed and believes that Microjet has contributorily infringed, and continues to contributorily infringe, under 35 U.S.C. § 271(c), the '294 Patent by causing others to directly infringe the '294 Patent.

19. HP is informed and believes that Microjet has actual notice of the '294 Patent under 35 U.S.C. § 287. The filing of this Complaint also constitutes notice to Microjet under 35 U.S.C. § 287. Despite such notice, Microjet has willfully infringed, and continues to willfully infringe, the '294 Patent.

20. HP has been irreparably harmed by these acts of willful infringement and will continue to be harmed unless Microjet's further acts of infringement are restrained by order of this Court. HP has no adequate remedy at law.

21. As result of Microjet's infringement of the '294 Patent, HP has suffered and will continue to suffer damages in an amount to be proven at trial.

22. This case is an "exceptional" case within the meaning of 35 U.S.C. § 285.

COUNT TWO

PATENT INFRINGEMENT OF U.S. PATENT NO. 4,635,073

23. HP incorporates by reference the allegations in paragraphs 1 through 22 above.

24. HP is informed and believes that Microjet has directly infringed, and continues to directly infringe, under 35 U.S.C. § 271(a), the '073 Patent by importing the Accused Print Cartridges into the United States and by selling the Accused Print Cartridges in the United States.

25. HP is informed and believes that Microjet has actively induced infringement, and continues to actively induce infringement, under 35 U.S.C. § 271(b), of the '073 Patent by causing others to directly infringe the '073 Patent.

26. HP is informed and believes that Microjet has contributorily infringed, and continues to contributorily infringe, under 35 U.S.C. § 271(c), the '073 Patent by causing others to directly infringe the '073 Patent.

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27. HP is informed and believes that Microjet has actual notice of the '073 Patent under 35 U.S.C. § 287. The filing of this Complaint also constitutes notice to Microjet under 35 U.S.C. § 287. Despite such notice, Microjet has willfully infringed, and continues to willfully infringe, the '294 Patent.

28. HP has been irreparably harmed by these acts of willful infringement and will continue to be harmed unless Microjet's further acts of infringement are restrained by order of this court. HP has no adequate remedy at law.

29. As result of Microjet's infringement of the '073 Patent, HP has suffered and will continue to suffer damages in an amount to be proven at trial.

30. This case is an "exceptional" case within the meaning of 35 U.S.C. § 285.

COUNT THREE

PATENT INFRINGEMENT OF U.S. PATENT NO. 4,680,859

31. HP incorporates by reference the allegations in paragraphs 1 through 30 above.

32. HP is informed and believes that Microjet has directly infringed, and continues to directly infringe, under 35 U.S.C. § 271(a), the '859 Patent by importing the Accused Print Cartridges into the United States and by selling the Accused Print Cartridges in the United States.

33. HP is informed and believes that Microjet has actively induced infringement, and continues to actively induce infringement, under 35 U.S.C. § 271(b), of the '859 Patent by causing others to directly infringe the '294 Patent.

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34. HP is informed and believes that Microjet has contributorily infringed, and continues to contributorily infringe, under 35 U.S.C. § 271(c), the '859 Patent by causing others to directly infringe the '859 Patent.

35. HP is informed and believes that Microjet has actual notice of the '859 Patent under 35 U.S.C. § 287. The filing of this Complaint also constitutes notice to Microjet under 35 U.S.C. § 287. Despite such notice, Microjet has willfully infringed, and continues to willfully infringe, the '859 Patent.

36. HP has been irreparably harmed by these acts of willful infringement and will continue to be harmed unless Microjet's further acts of infringement are restrained by order of this court. HP has no adequate remedy at law.

37. As result of Microjet's infringement of the '859 Patent, HP has suffered and will continue to suffer damages in an amount to be proven at trial.

38. This case is an "exceptional" case within the meaning of 35 U.S.C. § 285.

COUNT FOUR

PATENT INFRINGEMENT OF U.S. PATENT NO. 4,872,027

39. HP incorporates by reference the allegations in paragraphs 1 through 38 above.

40. HP is informed and believes that Microjet has directly infringed, and continues to directly infringe, under 35 U.S.C. § 271(a), the '027 Patent by importing the Accused Print Cartridges into the United States and by selling the Accused Print Cartridges in the United States.

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41. HP is informed and believes that Microjet has actively induced infringement, and continues to actively induce infringement, under 35 U.S.C. § 271(b), of the '027 Patent by causing others to directly infringe the '027 Patent.

42. HP is informed and believes that Microjet has contributorily infringed, and continues to contributorily infringe, under 35 U.S.C. § 271(c), the '027 Patent by causing others to directly infringe the '027 Patent.

43. HP is informed and believes that Microjet has actual notice of the '027 Patent under 35 U.S.C. § 287. The filing of this Complaint also constitutes notice to Microjet under 35 U.S.C. § 287. Despite such notice, Microjet has willfully infringed, and continues to willfully infringe, the '027 Patent.

44. HP has been irreparably harmed by these acts of willful infringement and will continue to be harmed unless Microjet's further acts of infringement are restrained by order of this court. HP has no adequate remedy at law.

45. As result of Microjet's infringement of the '027 Patent, HP has suffered and will continue to suffer damages in an amount to be proven at trial.

46. This case is an "exceptional" case within the meaning of 35 U.S.C. § 285.

COUNT FIVE

PATENT INFRINGEMENT OF U.S. PATENT NO. 4,992,802

47. HP incorporates by reference the allegations in paragraphs 1 through 46 above.

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48. HP is informed and believes that Microjet has directly infringed, and continues to directly infringe, under 35 U.S.C. § 271(a), the '802 Patent by importing the Accused Print Cartridges into the United States and by selling the Accused Print Cartridges in the United States.

49. HP is informed and believes that Microjet has actively induced infringement, and continues to actively induce infringement, under 35 U.S.C. § 271(b), of the '802 Patent by causing others to directly infringe the '802 Patent.

50. HP is informed and believes that Microjet has contributorily infringed, and continues to contributorily infringe, under 35 U.S.C. § 271(c), the '802 Patent by causing others to directly infringe the '802 Patent.

51. HP is informed and believes that Microjet has actual notice of the '802 Patent under 35 U.S.C. § 287. The filing of this Complaint also constitutes notice to Microjet under 35 U.S.C. § 287. Despite such notice, Microjet has willfully infringed, and continues to willfully infringe, the '802 Patent.

52. HP has been irreparably harmed by these acts of willful infringement and will continue to be harmed unless Microjet's further acts of infringement are restrained by order of this court. HP has no adequate remedy at law.

53. As result of Microjet's infringement of the '802 Patent, HP has suffered and will continue to suffer damages in an amount to be proven at trial.

54. This case is an "exceptional" case within the meaning of 35 U.S.C. § 285.

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COUNT SIX

PATENT INFRINGEMENT OF U.S. PATENT NO. 5,409,134

55. HP incorporates by reference the allegations in paragraphs 1 through 54 above.

56. HP is informed and believes that Microjet has directly infringed, and continue to directly infringe, under 35 U.S.C. § 271(a), the '134 Patent by importing the Accused Print Cartridges into the United States and selling the Accused Print Cartridges in the United States.

57. HP is informed and believes that Microjet has actively induced infringement, and continues to actively induce infringement, under 35 U.S.C. § 271(b), of the '134 Patent by causing others to directly infringe the '134 Patent.

58. HP is informed and believes that Microjet has contributorily infringed, and continues to contributorily infringe, under 35 U.S.C. § 271(c), the '134 Patent by causing others to directly infringe the '134 Patent.

59. HP is informed and believes that Microjet has actual notice of the '134 Patent under 35 U.S.C. § 287. The filing of this Complaint also constitutes notice to Microjet under 35 U.S.C. § 287. Despite such notice, Microjet has willfully infringed, and continues to willfully infringe, the '134 Patent.

60. HP has been irreparably harmed by these acts of willful infringement and will continue to be harmed unless Microjet's further acts of infringement are restrained by order of this court. HP has no adequate remedy at law.

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61. As result of Microjet's infringement of the '134 Patent, HP has suffered and will continue to suffer damages in an amount to be proven at trial.

62. This case is an "exceptional" case within the meaning of 35 U.S.C. § 285.

WHEREFORE, HP prays:

1. That Microjet be adjudged to have infringed each of the Patents at Issue;

2. That Microjet, its officers, principals, agents, attorneys, servants, employees and all others acting by or under its direction and authority, and each of its successors and assigns, be permanently enjoined from importing, making, using and/or selling in the United States any products infringing the Patents at Issue or any other product substantially equivalent thereto which is also within the scope of any claim of the Patents at Issue;

3. That HP be awarded an accounting for and recovery of damages adequate to fully compensate it for the infringement by Microjet of the Patents at Issue;

4. That HP be awarded treble damages in view of the reckless, willful and deliberate nature of the infringement by Microjet, pursuant to 35 U.S.C. section 284;

5. For costs and attorneys' fees pursuant to 35 U.S.C. section 285;

6. For interest thereon at the legal rate; and

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7. For such other and further relief as the Court may deem just and proper.

Dated: January 17th, 2001

LIONEL SAWYER & COLLINS

By [signature]
DENNIS KENNEDY

Attorneys for Plaintiff
HEWLETT-PACKARD COMPANY

GRAY CARY WARE & FREIDENRICH LLP

JOHN ALLCOCK
RANDALL E. KAY
STEWART M. BROWN
RICHARD T. MULLOY

DEMAND FOR JURY TRIAL

Pursuant to Federal Rule of Civil Procedure 38 and Local Rule 38-1, plaintiff HEWLETT-PACKARD COMPANY hereby demands a trial by jury.

Dated: January 17th, 2001

LIONEL SAWYER & COLLINS

By ______________________
DENNIS KENNEDY

GRAY CARY WARE & FREIDENRICH LLP

JOHN ALLCOCK
RANDALL E. KAY
STEWART M. BROWN
RICHARD T. MULLOY

Attorneys for Plaintiff
HEWLETT-PACKARD COMPANY

EXHIBIT 1

U 202887

THE UNITED STATES OF AMERICA

TO ALL TO WHOM THESE PRESENTS SHALL COME:

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office

February 04, 2000

THIS IS TO CERTIFY THAT ANNEXED HERETO IS A TRUE COPY FROM THE RECORDS OF THIS OFFICE OF:

U.S. PATENT: *4,827,294*
ISSUE DATE: *May 02, 1989*

By Authority of the
COMMISSIONER OF PATENTS AND TRADEMARKS

N. Woodson

N. WOODSON
Certifying Officer

United St s Patent [19]
Hanson
[11] Pat. Number: 4,827,294
[45] Date of Patent: * May 2, 1989

[54] THERMAL INK JET PRINTHEAD ASSEMBLY EMPLOYING BEAM LEAD INTERCONNECT CIRCUIT

[75] Inventor: Gary E. Hanson, Boise, Id.
[73] Assignee: Hewlett-Packard Company, Palo Alto, Calif.

[*] Notice: The portion of the term of this patent subsequent to Jan. 6, 2004 has been disclaimed.
[21] Appl. No.: 93,924
[22] Filed: Oct. 26, 1987

Related U.S. Application Data

[60] Division of Ser. No. 937,945, Dec. 4, 1986, abandoned, which is a continuation of Ser. No. 801,034, Nov. 22, 1985, Pat. No. 4,635,073.

[51] Int. Cl.[4] G01D 15/16
[52] U.S. Cl. .... 346/140 R; 346/139 R
[58] Field of Search 346/140, 139

[56] References Cited

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3,672,034	6/1972	Clark	29/471.1
3,700,156	10/1972	Hermanns	29/470.1 X
4,499,478	2/1985	Matsufuji	346/140
4,580,148	4/1986	Domoto	346/140
4,610,495	9/1986	Landi	439/492 X
4,612,554	9/1986	Poleshuk	346/140
4,628,150	12/1986	Luc	361/408 X
4,635,073	1/1987	Hanson	346/140 X
4,675,693	6/1987	Yano	346/140 X

OTHER PUBLICATIONS

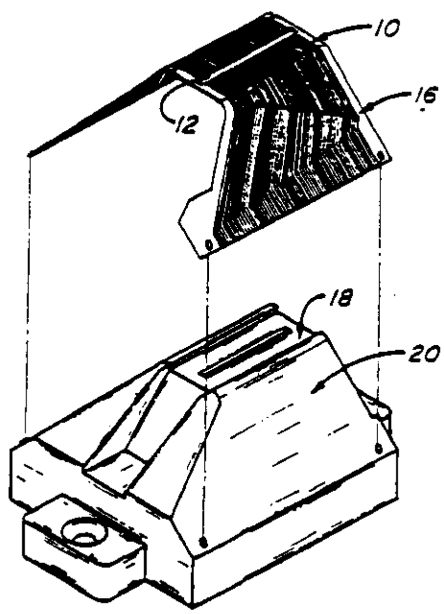
Bailx et al.; Sequential Bonding, Western Electric Technical Digest, No. 12, Oct. 1968, p. 1-2.

Primary Examiner—Joseph W. Hartary
Attorney, Agent, or Firm—William J. Bethurum

[57] ABSTRACT

This application discloses a new and improved thermal ink jet printhead and method of manufacture wherein a tape automated bond (TAB) flexible circuit is sequentially thermosonically bonded in a one-by-one wire bonding process to aligned conductive traces on a thin film resistor substrate. These traces provide electrical current paths for a corresponding plurality of heater resistors on the substrate, and these resistors function to heat a corresponding plurality of ink reservoirs in a thermal ink jet printhead.

3 Claims, 5 Drawing Sheets



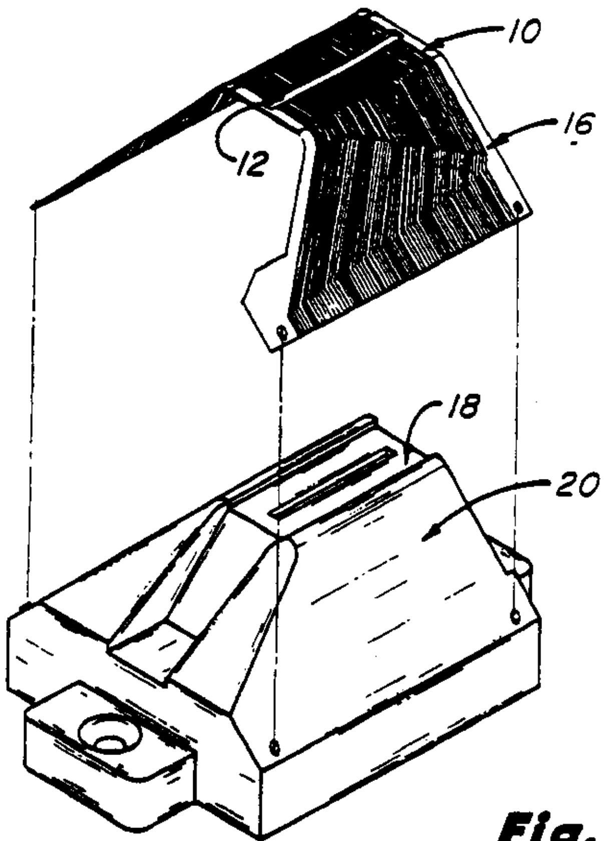


Fig. 1a

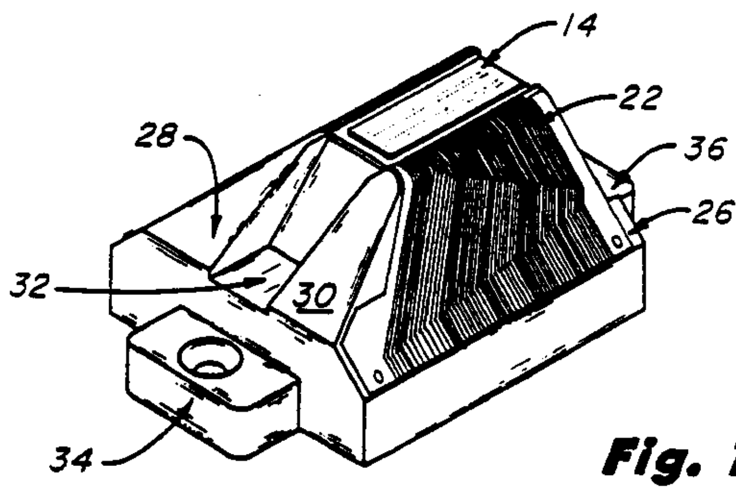


Fig. 1b

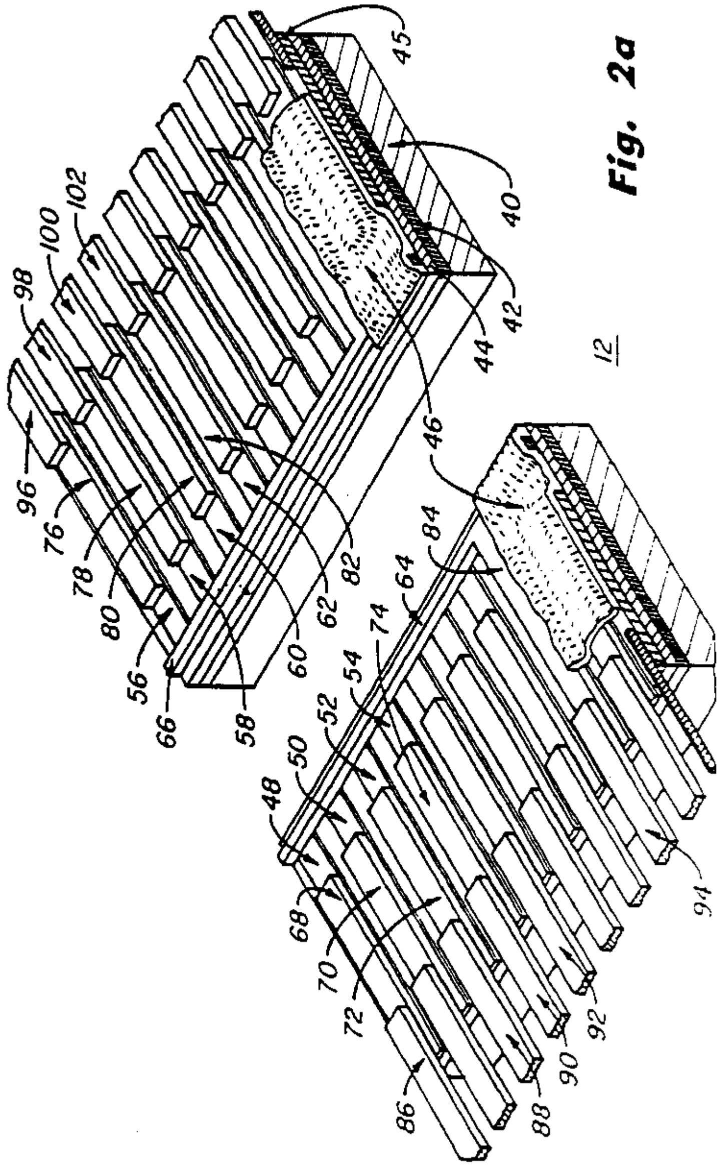

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Fig. 2a

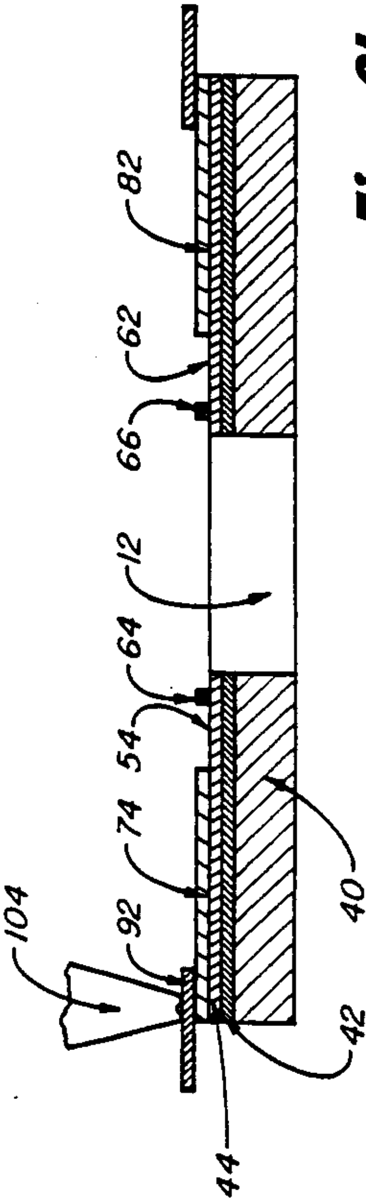

Fig. 2b

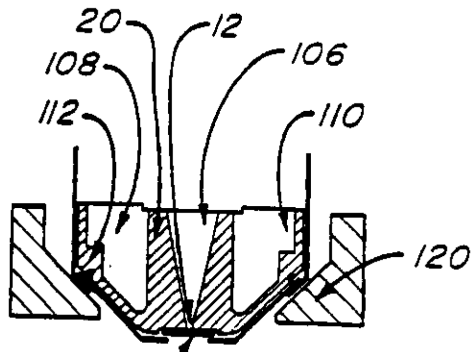

Fig. 3a

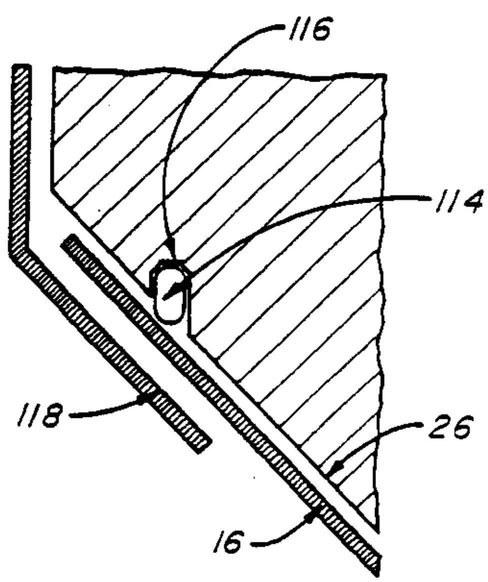

Fig. 3b

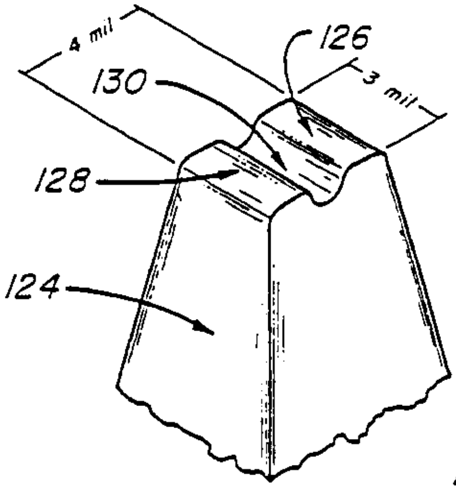

Fig. 4a

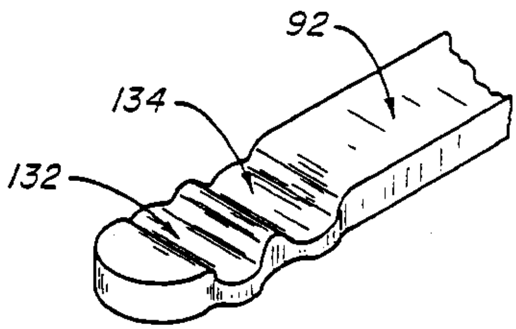

Fig. 4b

THERMAL INK JET PRINTHEAD ASSEMBLY EMPLOYING BEAM LEAD INTERCONNECT CIRCUIT

RELATED APPLICATIONS

This application is a divisional of U.S. application Ser. No. 937,945, filed Dec. 4, 1986, now abandoned, which in turn is a continuation of application Ser. No. 801,034, filed Nov. 22, 1985, now U.S. Pat. No. 4,635,073 issued Jan. 6, 1987.

TECHNICAL FIELD

This invention relates generally to thermal ink jet printing and more particularly to a new and improved low cost, high density thermal ink jet print head assembly and process for manufacturing same. This process features thermosonic beam lead bonding in the plane of the thermal ink jet thin film resistor substrate.

RELATED APPLICATION

Background Art

Thermal ink jet printing has been described in many technical publications, and one such publication relevant to this invention is the *Hewlett Packard Journal*, Volume 36, No. May 5, 1985, incorporated herein by reference.

In the art of thermal ink jet printing, it is known to provide ball and stitch wire bonding to a thermal ink jet thin film resistor substrate in order to complete elecrical signal paths to the individual resistive heater elements on the substrate. Whereas these wire bonding techniques have proven generally satisfactory in many respects, they impose a limiting factor upon the reduction in substrate size used for housing a give number of resistive heater elements. Since the cost of the substrate, especially in the case of monocrystalline silicon, represents a significant percentage of the overall cost of the thermal ink jet print head, then the desirability of even further reducing the substrate size is manifest.

In addition to imposing a limitation on the reduction in substrate size, the ball and stitch wire bonding process of the prior art also imposed a limitation on the achievable packing density of the complete print head assembly.

DISCLOSURE OF INVENTION

Accordingly, it is an object of the present invention to provide a new and improved thermal ink jet print head assembly and process of fabricating same which allows for a reduction in substrate size relative to the above prior art, and thereby provides a corresponding reduction in the overall cost of the thermal ink jet print head assembly being fabricated.

Another object is to provide a new and improved thermal ink jet print head assembly of the type described which is characterized by an increased packing density and improved performance characteristics.

Another object is to provide an assembly of the type described which exhibits the above improvements in substrate size reduction and increased packing density without sacrificing performance or reliabililty.

A feature of this invention is the provision of a print head assembly of the type described which has an extremely low profile print head, thus minimizing the spacing between print head and paper and optimizing

the printing speed and printing quality of characters formed on the paper.

These and other objects and novel features of this invention are accomplished by the provision of a new and improved planar bonded thermal ink jet print head substrate and thermosonic beam lead attachment process for fabricating same wherein a thin film resistor print head substrate of predetermined dimensions is mounted on a header member. This header member in turn provides a source of ink supply to the print head. The print head substrate contains a plurality of conductive traces thereon which make electrical connection to resistive heater elements in the substrate. These conductive traces are thermosonically bonded to a plurality of beam leads in an interconnect circuit which extends in the plane of the upper surface of the substrate to thereby maximize packing density of the print head assembly.

The beam leads to the interconnect circuit also extend over a predetermined slanted surface portion of the header member and are resiliently mounted to protrude away from the surface of the header member to thus enable the print head assembly to be firmly, yet removably, connected to mating conductors on a printer housing. Advantageously, the beam leads of the interconnect circuit are resilienty extended toward the printer housing by means of an elongated material having elastomeric properties which is positioned between the beam leads and the surface of the header member over which they extend.

The present invention and above objects and features thereof will better understood by referring to the following description of the accompanying drawings wherein:

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1*a* is an exploded view of the header, the semiconductor thin film substrate, and the beam lead flexible circuit portion of the print head assembly according to a preferred embodiment of the present invention.

FIG. 1*b* is an isometric view of the completely assembled print head assembly, including the top orifice plate which is bonded atop the thin film substrate and beam lead connections thereto.

FIG. 2*a* is a partially cut-away isometric view of the thin film resistor substrate and beam lead electrical interconnects therefor.

FIG. 2*b* is a cross-section view taken along lines B—B of FIG. 2A.

FIG. 3*a* is a schematic cross-section view of the print head assembly according to the invention in its pressure connect position in a printer carraige.

FIG. 3*b* is a greatly enlarged view of the pressure connect portion of the slanted header wall, including the elastomer insert portion thereof.

FIGS. 4*a* and 4*b* are an isometric view of the bonding tool and the portion of a beam lead of the flexible circuit which has been bonded to an underlying aluminum conductive trace on the thin film substrate.

BEST MODE FOR CARRYING OUT THE INVENTION

Referring now to FIG. 1*a*, there is shown a thin film resistor silicon substrate **10** having an elongated slot **12** therein which serves as an ink intake port for providing ink to a plurality of ink reservoirs (not specifically shown) and to corresponding ink ejection orifices in an orifice plate **14** shown in FIG. 1*b*. The thin film resistor silicon substrate **10** has a plurality of aluminum conductive traces thereon which have been deposited using conventional aluminum evaporation techniques, and these conductive tracings extend to a location near the outer edges of the substrate where they are bonded to corresponding beam leads of a flexible interconnect circuit 16. This flexible interconnect circuit 16 is preferably a tape automated bond (TAB) circuit of the type manufactured and sold by the Minnesota Mining and Manufacturing (3M) Company of Minneapolis, Minn.

Once the TAB bonding step illustrated in the top view of FIG. 1a has been completed (as described in greater detail below with reference to FIGS. 2a and 2b), the top portion of FIG. 1a is positioned in place on the top surface 18 of the plastic header 20. This positioning of the semiconductor substrate and associated TAB bond flexible circuit 16 in place on the header 20 is shown in the assembled view of FIG. 1b which further includes the placement and bonding of the upper orifice plate 14 in place as shown. Here the multiple beam leads 22 of the TAB bond circuit 16 are folded downwardly at an angle and then outwardly of the semiconductor thin film substrate 10 and are tied down at the lower edge of the slanted outer wall 26 of the header.

The header 20 also uses slanted end walls 26 on both sides for mounting and alignment of the printhead assembly in a carriage of an ink jet printer. Additionally, the print head assembly of FIG. 1b includes a pair of end tabs 34 and 36 which facilitate the handling of the print head assembly prior to mounting in a printer carriage.

Referring now to FIG. 2a there is shown a silicon substrate 40 having respectively layers of silicon dioxide 42, tantalum aluminum 44, aluminum 45 and silicon carbide 46 deposited thereon using vapor deposition processes known to those skilled in the semiconductor processing arts. The silicon dioxide layer 42 provides a first layer of silicon surface passivation for the substrate 40 whereas the tantalum aluminum layer 44 serves as the thermal resistor material in areas which have been photolithographically defined adjacent the surface conductor terminations to be further described. The silicon carbide layer 46 is a highly inert refractory material and is deposited atop the tantalum aluminum layer 44 to provide a good barrier layer for ink reservoirs (not shown) subsequently formed over the thermal heater resistors within the tantalum aluminum layer 44.

The tantalum aluminum resistors have been photolithographically defined, for example, in the areas 48, 50, 52, 54 on the near side of the ink feed slot 12 and in the areas 56, 58, 60 and 62 on the far side of the ink feed slot 12. At the inside edge of these resistors, or edge nearest the slot 12, there are a pair of ground return or buss bar connections 64 and 66 which extend along the lengthwise edge of the slot 12 and provide a return or ground line for the electronic drive circuitry for these resistors. Electrical drive current pulses are fed to the tantalum aluminum resistors 48, 50, 52, 54, 56, 58, 60 and 62 by means of a plurality of conductive aluminum traces which are indicated at 68, 70, 72 and 74 on the near side of the isometric structure of FIG. 2 and at 76, 78, 80 and 82 on the far side of the structure in FIG. 2a. There may also be one or more aluminum traces 84 leading into the bus bar or grid line 64 for providing a ground or return line to the electronic drive circuitry for the thin film resistor structure 10.

Each of the conductive traces such as 68, 70, 72 and 74 are brought into perfect alignment with a corresponding plurality of beam leads 86, 88, 90 and 92 of the previously identified TAB bond flexible circuit, and there may be one or more additional ground leads such as 94 which make connection to the corresponding ground line 84 leading into the bus bar 64. Once these beam lead members 86, 88, 90, 92, and 94 are positioned in place as shown, they are bonded one by one in sequence to the corresponding conductive aluminum traces using a preferred type of bonding tool (see FIG. 4) and a controlled combination of ultrasonic energy, pressure, heat and time so as to provide a good metal-to-metal thermosonic bond between each beam lead member of the TAB flexible circuit and its corresponding conductive trace member leading into the tantalum aluminum heater resistors. These beam lead members on the far side of the structure of FIG. 2a are indicated as 96, 98, 100 and 102 respectively.

Referring now to FIG. 2b, which is a cross-section view taken along lines B—B of FIG. 2a, there are shown the tantalum aluminum resistors 54 and 62 on opposite sides of the slot 12 and laterally defined on one side by the inside edges of the bus bars 64 and 66. The other edges of the tantalum aluminum heater resistors 54 and 62 are defined by the ends of the aluminum traces 74 and 82, respectively, and the beam leads, e.g. 92, are bonded by a precision bonding tool 104 to be described in more detailed below with reference to FIG. 4.

Referring now to FIG. 3a, there is shown a cross-sectional view of the plastic header 20 which includes a central ink storage region 106 for receiving a supply of ink and feeding the ink into the elongated slot 12 of the thin film resistor substrate 10. The configuration of the header 20 is further defined by a pair of hollowed out regions 108 and 110 on each side of the inkwell 106, and these regions 108 and 110 are constructed during the injection molding process used to make the header 20. During this process, an interior cylindrical flange 112 is formed in the geometry indicated in order to receive a circular elastomer 114 in an outer cavity or receptacle 116. This elastomer 114 or other equivalent member having the required elastomeric properties is brought in contact with the TAB bond flex circuit 16 where it extends over the slanted outer wall 26 of the header 20. Here the TAB bond flex circuit 16 makes pressure contact with another flexible circuit 118 which extends vertically along the outer vertical side walls of the header 20. Here it is accessable to driving circuitry (not shown) which provides driving current pulses for the heater resistors previously described.

The use of the elastomer 114 enables the TAB bond flex circuit 16 and the flexible circuit 118 to the driving electronics to be brought into good firm electrical contact when the ink jet print head structure of FIG. 1b is inserted into the carriage 120 of the thermal ink jet printer. The carriage 120 includes a slanted interior wall 122 for receiving the circuits 16 and 118 on each side of the thermal ink jet print head. Approximately 25 pounds of pressure are applied to the electrical connection adjacent the elastomer ring 114.

Referring now to FIG. 4, there is shown in an enlarged isometric view the tip 124 of the previously identified bonding tool 104 (FIG. 2b). This tip 124 has a bonding surface which includes a pair of flat areas 126 and 128 on each side thereof separated by a trough 130. The dimensions of the total bonding surface areas are, as indicated, 3 mils by 4 mils, and these dimensions clearly illustrate the very small geometries involved when bonding the ends of the beam leads of the TAB bond flex circuit 16 to the corresponding ends of the conductive traces 74 on the surface of the thin film resistor substrate 10.

When the bonding tip 124 is brought into thermosonic contact with the beam lead 92 and then removed after applying predetermined heat, sonic energy and pressure for a predetermined time, the geometrical indentations 132 and 134 are left in the beam leads. The effect of this thermosonic bond is to compress the original thickness of the beam lead 92 of about 1 mil down to between 0.6 and 0.75 mils. This step provides a good strong electrical bond for each beam lead as the bonding tool is sequentially moved in a step-by-step process to sequentially and separately bond all of the beam leads of the TAB bond flex circuit 16 to all of the aligned aluminum conductive traces on the print head substrate. This gold-aluminum bonding system which is capable of producing good strong bonds at bonding temperatures of 70° C. or less avoids the well known and undesirable intermetallic gold-aluminum interaction known as the "purple plague".

Various modifications may be made to the above described embodiments of the invention without departing from the spirit and scope thereof. For example, it is not necessary that the geometry of the semiconductor substrate be configured in a slot ink-feed arrangement, and instead the ink may be fed to the reservoirs above the various heater resistors using a different geometrical feed configuration. Similarly, the conductive traces on top of the tantalum aluminum resistive layer as well as the gold plated copper beam leads may be changed to different, yet bonding compatible, electrical materials within the scope of the present invention.

I claim:

1. An ink jet printhead assembly adapted for insertion into a printhead carriage, said assembly including in combination:

a. a printhead substrate mounted on a header member and operative to receive ink therefrom,

b. a plurality of thin conductors disposed atop said substrate and electrically connected to a plurality of transducer elements therein, and

c. a beam lead interconnect circuit having a plurality of beam leads bonded, respectively, to said plurality of thin conductors and extending over a chosen outer surface of said header member, and said header member having a surface geometry configured for insertion into a printhead carriage, whereby the portions of said beam leads on said chosen outer surface of said header member may be brought into electrical contact with corresponding mating conductors on said printhead carriage.

2. The assembly defined in claim 1 wherein said beam leads are resiliently extended away from said chosen surface of said header member and thereby enable said assembly to be firmly, yet removably, connected to mating conductors on said printhead carriage.

3. An ink jet pen including in combination:

(a) a pen body housing having an ink storage compartment therein and an ink flow port adjacent one surface thereof and further having outer surfaces which are contoured to mate with adjacent surfaces of a pen carriage member,

(b) a thin film printhead mounted on said one surface of said pen body housing and adjacent to said ink flow port therein for receiving ink from said ink flow port during an ink jet printing operation, and

(c) a flexible electrical circuit member including a plurality of beam leads bonded at predetermined locations on said thin film printhead for supplying electrical power and signals thereto during an ink jet printing operation, said flexible electrical circuit being extended over one of said contoured outer surfaces of said pen body housing and secured thereto, whereby electrical conductors in a pen carriage are adapted to mate with certain ones of said beam leads of said flexible electrical circuit for supplying power and electrical drive signals to said beam leads when said pen body housing is mounted in said carriage.

* * * * *

EXHIBIT 2

U 202887

THE UNITED STATES OF AMERICA

TO ALL TO WHOM THESE PRESENTS SHALL COME:

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office

February 04, 2000

THIS IS TO CERTIFY THAT ANNEXED HERETO IS A TRUE COPY FROM THE RECORDS OF THIS OFFICE OF:

U.S. PATENT: *4,635,073*
ISSUE DATE: *January 06, 1987*

By Authority of the
COMMISSIONER OF PATENTS AND TRADEMARKS

N. Woodson
N. WOODSON
Certifying Officer

United States Patent [19]

Hanson

[11] **Patent Number:** **4,635,073**

[45] **Date of Patent:** **Jan. 6, 1987**

[54] **REPLACEABLE THERMAL INK JET COMPONENT AND THERMOSONIC BEAM BONDING PROCESS FOR FABRICATING SAME**

[75] Inventor: **Gary E. Hanson**, Boise, Id.

[73] Assignee: **Hewlett Packard Company**, Palo Alto, Calif.

[21] Appl. No.: **801,034**

[22] Filed: **Nov. 22, 1985**

[51] **Int. Cl.**⁴ **G01D 15/18**

[52] **U.S. Cl.** .... **346/1.1; 228/110; 228/180.2; 346/140 R**

[58] **Field of Search** .... 346/140, 1.1, 139 C; 361/398, 421; 228/110, 180.2

[56] **References Cited**

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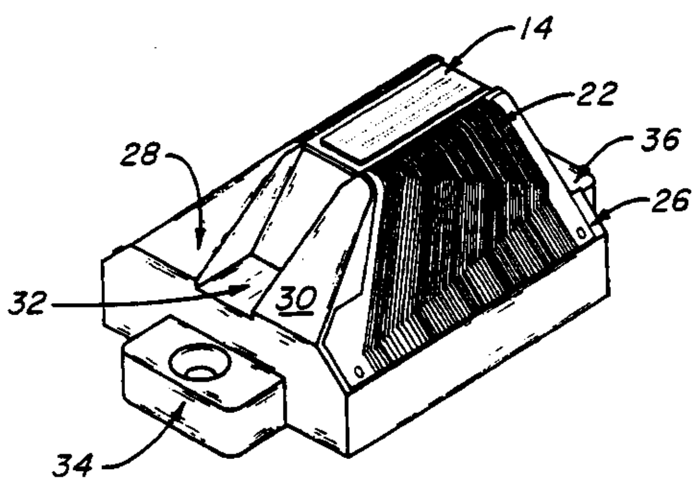
Primary Examiner—Joseph W. Hartary
Attorney, Agent, or Firm—William J. Bethurum

[57] **ABSTRACT**

This application discloses a new and improved thermal ink jet printhead and method of manufacture wherein a tape automated bond (TAB) flexible circuit is sequentially thermosonically bonded in a one-by-one wire bonding process to aligned conductive traces on a thin film resistor substrate. These traces provide electrical current paths for a corresponding plurality of heater resistors on the substrate, and these resistors function to heat a corresponding plurality of ink reservoirs in a thermal ink jet printhead.

12 Claims, 8 Drawing Figures



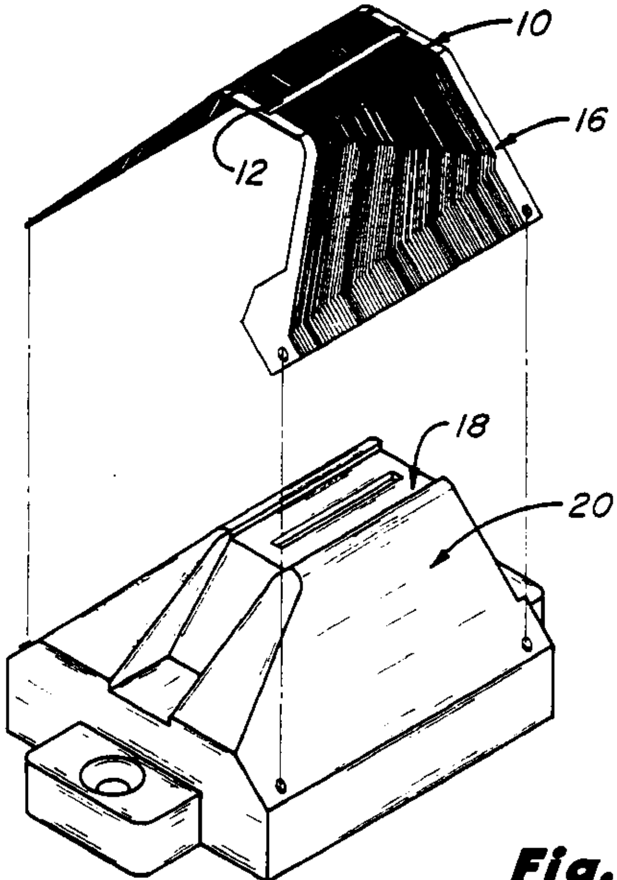


Fig. 1a

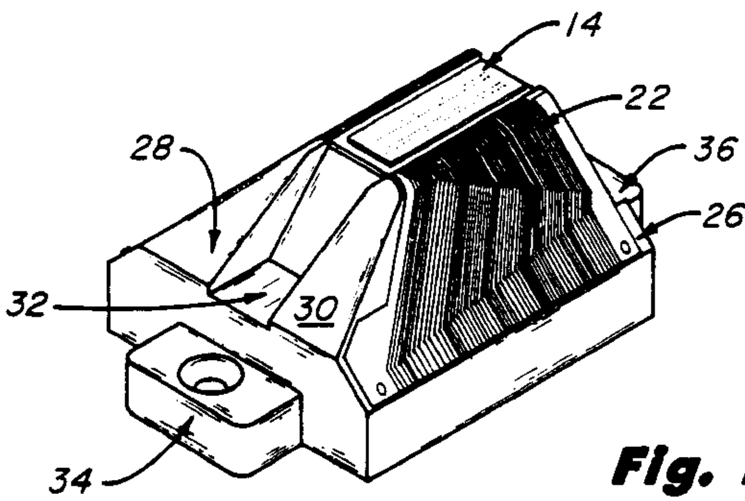


Fig. 1b

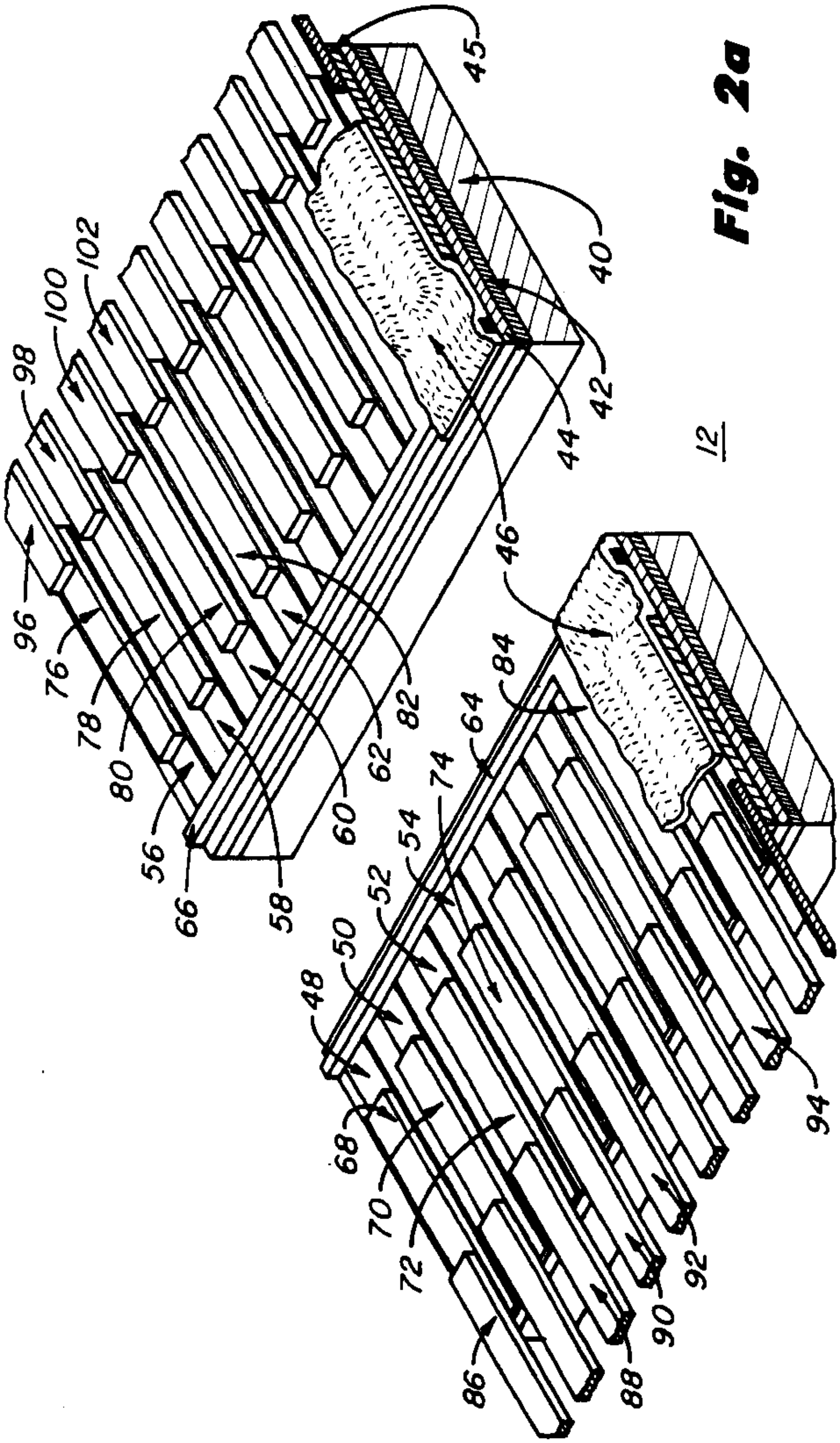

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Fig. 2a

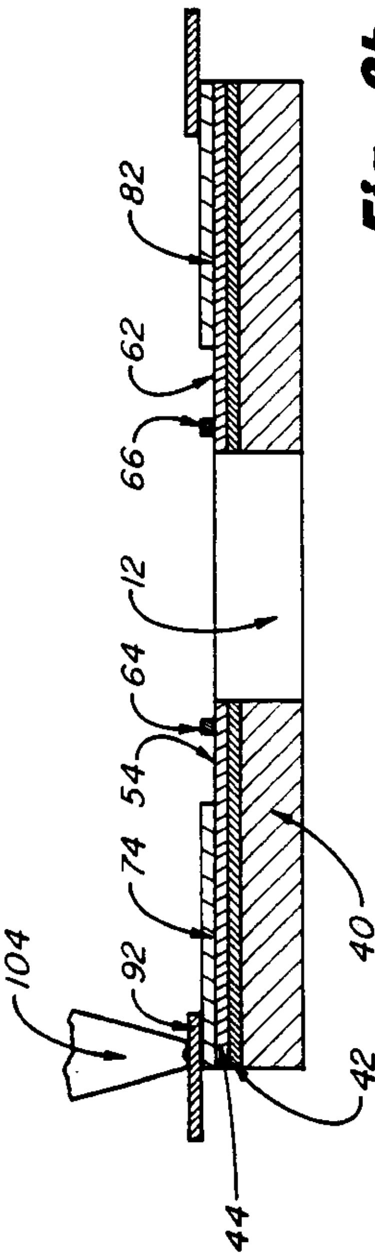

Fig. 2b

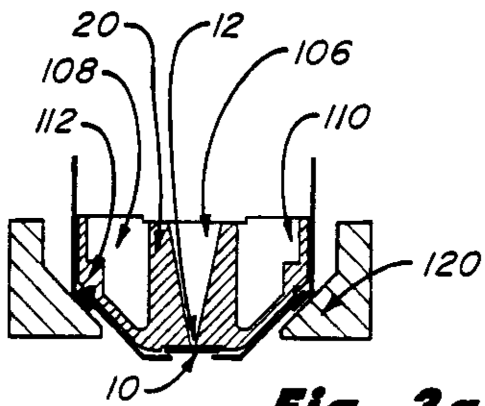

Fig. 3a

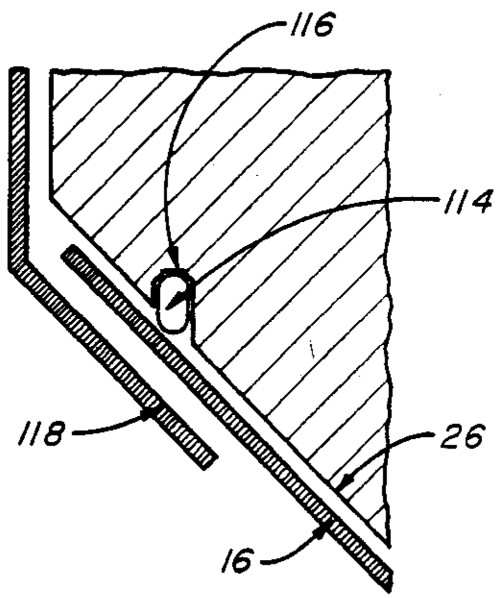

Fig. 3b

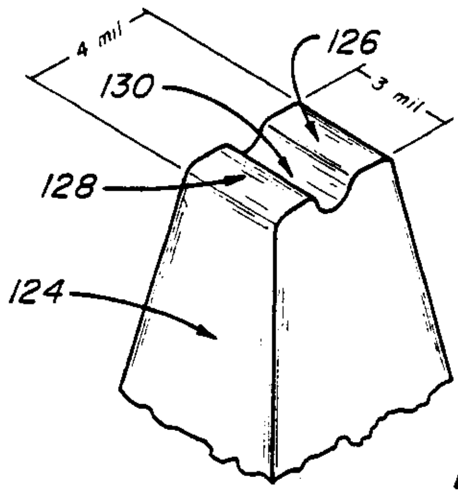

Fig. 4a

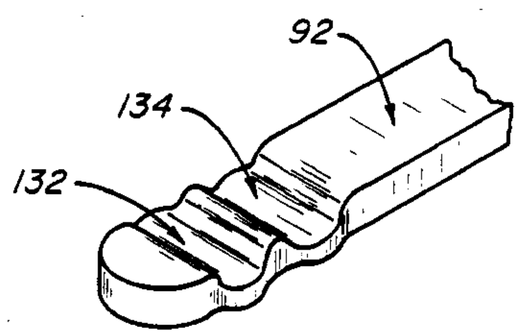

Fig. 4b

REPLACEABLE THERMAL INK JET COMPONENT AND THERMOSONIC BEAM BONDING PROCESS FOR FABRICATING SAME

TECHNICAL FIELD

This invention relates generally to thermal ink jet printing and more particularly to a new and improved low cost, high density thermal ink jet print head assembly and process for manufacturing same. This process features thermosonic beam lead bonding in the plane of the thermal ink jet thin film resistor substrate.

BACKGROUND ART

Thermal ink jet printing has been described in many technical publications, and one such publication relevant to this invention is the *Hewlett Packard Journal*, Volume 36, Number 5, May 1985, incorporated herein by reference.

In the art of thermal ink jet printing, it is known to provide ball and stitch wire bonding to a thermal ink jet thin film resistor substrate in order to complete electrical signal paths to the individual resistive heater elements on the substrate. Whereas these wire bonding techniques have proven generally satisfactory in many respects, they impose a limiting factor upon the reduction in substrate size used for housing a give number of resistive heater elements. Since the cost of the substrate, especially in the case of monocrystalline silicon, represents a significant percentage of the overall cost of the thermal ink jet print head, then the desirability of even further reducing the substrate size is manifest.

In addition to imposing a limitation on the reduction in substrate size, the ball and stitch wire bonding process of the prior art also imposed a limitation on the achievable packing density of the complete print head assembly.

DISCLOSURE OF INVENTION

Accordingly, it is an object of the present invention to provide a new and improved thermal ink jet print head assembly and process of fabricating same which allows for a reduction in substrate size reltive to the above prior art, and thereby provides a corresponding reduction in the overall cost of the thermal ink jet print head assembly being fabricated.

Another object is to provide a new and improved thermal ink jet print head assembly of the type described which is characterized by an increased packing density and improved performance characteristics.

Another object is to provide an assembly of the type described which exhibits the above improvements in substrate size reduction and increased packing density without sacrificing performance or reliability.

A feature of this invention is the provision of a print head assembly of the type described which has an extremely low profile print head, thus minimizing the spacing between print head and paper and optimizing the printing speed and printing quality of characters formed on the paper.

These and other objects and novel features of this invention are accomplished by the provision of a new and improved planar bonded thermal ink jet print head substrate and thermosonic beam lead attachment process for fabricating same wherein a thin film resistor print head substrate of predetermined dimensions is mounted on a header member. This header member in turn provides a source of ink supply to the print head.

The print head substrate contains a plurality of conductive traces thereon which make electrical connection to resistive heater elements in the substrate. These conductive traces are thermosonically bonded to a plurality of beam leads in an interconnect circuit which extends in the plane of the upper surface of the substrate to thereby maximize packing density of the print head assembly.

The beam leads of the interconnect circuit also extend over a pretermined slanted surface portion of the header member and are resiliently mounted to protrude away from the surface of the header member to thus enable the print head assembly to be firmly, yet removably, connected to mating conductors on a printer housing. Advantageously, the beam leads of the interconnect circuit are resilienty extended toward the printer housing by means of an elongated material having elastomeric properties which is positioned between the beam leads and the surface of the header member over which they extend.

The present invention and above objects and features thereof will better understood by referring to the following description of the accompanying drawings wherein:

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1A is an exploded view of the header, the semiconductor thin film substrate, and the beam lead flexible circuit portion of the print head assembly according to a preferred embodiment of the present invention.

FIG. 1B is an isometric view of the completely assembled print head assembly, including the top orifice plate which is bonded atop the thin film substrate and beam lead connections thereto.

FIG. 2A is a partially cut-away isometric view of the thin film resistor substrate and beam lead electrical interconnects therefor.

FIG. 2B is a cross-section view taken along lines B—B of FIG. 2A.

FIG. 3A is a schematic cross-section view of the print head assembly according to the invention in its pressure connect position in a printer carraige.

FIG. 3B is a greatly enlarged view of the pressure connect portion of the slanted header wall, including the elastomer insert portion thereof.

FIGS. 4*a* and 4*b* are an isometric view of the bonding tool and the portion of a beam lead of the flexible circuit which has been bonded to an underlying aluminum conductive trace on the thin film substrate.

BEST MODE FOR CARRYING OUT THE INVENTION

Referring now to FIG. 1A, there is shown a thin film resistor silicon substrate 10 having an elongated slot 12 therein which serves as an ink intake port for providing ink to a plurality of ink reservoirs (not specifically shown) and to corresponding ink ejection orifices in an orifice plate 14 shown in FIG. 1B. The thin film resistor silicon substrate 10 has a plurality of aluminum conductive traces thereon which have been deposited using conventional aluminum evaporation techniques, and these conductive tracings extend to a location near the outer edges of the substrate where they are bonded to corresponding beam leads of a flexible interconnect circuit 16. This flexible interconnect circuit 16 is preferably a tape automated bond (TAB) circuit of the type manufactured and sold by the Minnesota Mining and Manufacturing (3M) Company of Minneapolis, Minn.

Once the TAB bonding step illustrated in the top view of FIG. 1A has been completed (as described in greater detail below with reference to FIGS. 2A and 2B), the top portion of FIG. 1A is positioned in place on the top surface 18 of the plastic header 20. This positioning of the semiconductor substrate and associated TAB bond flexible circit 16 in place on the header 20 is shown in the assembled view of FIG. 1B which further includes the placement and bonding of the upper orifice plate 14 in place as shown. Here the multiple beam leads 22 of the TAB bond circuit 16 are folded downwardly at an angle and then outwardly of the semiconductor thin film substrate 10 and are tied down at the lower edge of the slanted outer wall 26 of the header.

The header 20 also uses slanted end walls 26 on both sides for mounting and alignment of the printhead assembly in a carriage of an ink jet printer. Additionally, the print head assembly of FIG. 1B includes a pair of end tabs 34 and 36 which facilitate the handling of the print head assembly prior to mounting in a printer carriage.

Referring now to FIG. 2A there is shown a silicon substrate 40 having respectively layers of silicon dioxide 42, tantalum aluminum 44, aluminum 45 and silicon carbide 46 deposited thereon using vapor deposition processes known to those skilled in the semiconductor processing arts. The silicon dioxide layer 42 provides a first layer of silicon surface passivation for the substrate 40 whereas the tantalum aluminum layer 44 serves as the thermal resistor material in areas which have been photolithographically defined adjacent the surface conductor terminations to be further described. The silicon carbide layer 46 is a highly inert refractory material and is deposited atop the tantalum aluminum layer 44 to provide a good barrier layer for ink reservoirs (not shown) subsequently formed over the thermal heater resistors within the tantalum aluminum layer 44.

The tantalum aluminum resistors have been photolithographically defined, for example, in the areas 48, 50, 52, 54 on the near side of the ink feed slot 12 and in the areas 56, 58, 60 and 62 on the far side of the ink feed slot 12. At the inside edge of these resistors, or edge nearest the slot 12, there are a pair of ground return of buss bar connections 64 and 66 which extend along the lengthwise edge of the slot 12 and provide a return or ground line for the electronic drive circuitry for these resistors. Electrical drive current pulses are fed to the tantalum aluminum resistors 48, 50, 52, 54, 56, 58, 60 and 62 by means of a plurality of conductive aluminum traces which are indicated at 68, 70, 72 and 74 on the near side of the isometric structure of FIG. 2 and at 76, 78, 80 and 82 on the far side of the structure in FIG. 2A. There may also be one or more aluminum traces 84 leading into the bus bar or grid line 64 for providing a ground or return line to the electronic drive circuitry for the thin film resistor structure 10.

Each of the conductive traces such as 68, 70, 72 and 74 are brought into perfect alignment with a corresponding plurality of beam leads 86, 88, 90 and 92 of the previously identified TAB bond flexible circuit, and there may be one or more additional ground leads such as 94 which make connection to the corresponding ground line 84 leading into the bus bar 64. Once these beam lead members 86, 88, 90, 92, and 94 are positioned in place as shown, they are bonded one by one in sequence to the corresponding conductive aluminum traces using a preferred type of bonding tool (see FIG. 4) and a controlled combination of ultrasonic energy, pressure, heat and time so as to provide a good metal-to-metal thermosonic bond between each beam lead member of the TAB flexible circuit and its corresponding conductive trace member leading into the tantalum aluminum heater resistors. These beam lead members on the far side of the structure of FIG. 2A are indicated as 96, 98, 100 and 102 respectively.

Referring now to FIG. 2B, which is a cross-section view taken along lines B—B of FIG. 2A, there are shown the tantalum aluminum resistors 54 and 62 on opposite sides of the slot 12 and laterally defined on one side by the inside edges of the bus bars 64 and 66. The other edges of the tantalum aluminum heater resistors 54 and 62 are defined by the ends of the aluminum traces 74 and 82, respectively, and the beam leads, e.g. 92, are bonded by a precision bonding tool 104 to be described in more detail below with reference to FIG. 4.

Referring now to FIG. 3A, there is shown a cross-sectional view of the plastic header 20 which includes a central ink storage region 106 for receiving a supply of ink and feeding the ink into the elongated slot 12 of the thin film resistor substrate 10. The configuration of the header 20 is further defined by a pair of hollowed out regions 108 and 110 on each side of the inkwell 106, and these regions 108 and 110 are constructed during the injection molding process used to make the header 20. During this process, an interior cylindrical flange 112 is formed in the geometry indicated in order to receive a circular elastomer 114 in an outer cavity or receptacle 116. This elastomer 114 or other equivalent member having the required elastomeric properties is brought in contact with the TAB bond flex circuit 16 where it extends over the slanted outer wall 26 of the header 20. Here the TAB bond flex circuit 16 makes pressure contact with another flexible circuit 118 which extends vertically along the outer vertical side walls of the header 20. Here it is accessable to driving circuitry (not shown) which provides driving current pulses for the heater resistors previously described.

The use of the elastomer 114 enables the TAB bond flex circuit 16 and the flexible circuit 118 to the driving electronics to be brought into good firm electrical contact when the ink jet print head structure of FIG. 1B is inserted into the carriage 120 of the thermal ink jet printer. The carriage 120 includes a slanted interior wall 122 for receiving the circuits 16 and 118 on each side of the thermal ink jet print head. Approximately 25 pounds of pressure are applied to the electrical connection adjacent the elastomer ring 114.

Referring now to FIG. 4, there is shown in an enlarged isometric view the tip 124 of the previously identified bonding tool 104 (FIG. 2B). This tip 124 has a bonding surface which includes a pair of flat areas 126 and 128 on each side thereof separated by a trough 130. The dimensions of the total bonding surface areas are, as indicated, 3 mils by 4 mils, and these dimensions clearly illustrate the very small geometries involved when bonding the ends of the beam leads of the TAB bond flex circuit 16 to the corresponding ends of the conductive traces 74 on the surface of the thin film resistor substrate 10.

When the bonding tip 124 is brought into thermosonic contact with the beam lead 92 and then removed after applying predetermined heat, sonic energy and pressure for a predetermined time, the geometrical indentations 132 and 134 are left in the beam leads. The effect of this thermosonic bond is to compress the original thickness of the beam lead 92 of about 1 mil down to between 0.6 to 0.75 mils. This step provides a good strong electrical bond for each beam lead as the bonding tool is sequentially moved in a step-by-step process to sequentially and separately bond all of the beam leads of the TAB bond flex circuit 16 to all of the aligned aluminum conductive traces on the print head substrate. This gold-aluminum bonding system which is capable of producing good strong bonds at bonding temperatures of 70° C. or less avoids the well known and undesirable intermetallic gold-aluminum interaction known as the "purple plague".

Various modifications may be made to the above described embodiments of the invention without departing from the spirit and scope thereof. For example, it is not necessary that the geometry of the semiconductor substrate be configured in a slot ink-feed arrangement, and instead the ink may be fed to the reservoirs above the various heater resistors using a different geometrical feed configuration. Similarly, the conductive traces on top of the tantalum aluminum resistive layer as well as the gold plated copper beam leads may be changed to different, yet bonding compatible, electrical materials within the scope of the present invention.

I claim:

1. A process for fabricating a replaceable thermal ink jet print head which includes the steps of:

a. providing a thin film resistor print head substrate having a plurality of resistive heater elements thereon and a corresponding plurality of conductive leads connected to said resistive heater elements,

b. providing a beam lead interconnect circuit having a plurality of beam leads with spacings to match those of said conductive leads on said print head substrate, and

c. thermosonically bonding in sequence each of said beam leads to each of said corresponding plurality of conductive traces so that said beam leads and said conductive traces lie in a adjacent parallel planes to thereby enhance the packing density of said thermal ink jet print head.

2. The process defined in claim 1 further includes:

a. mounting said substrate on a header member,

b. extending said beam lead interconnect circuit over a chosen surface area of said header member, and

c. resiliently protruding said beam lead circuit outwardly of said chosen surface area, whereby said thermal ink jet print head may be brought in to firm, yet removable, electrical contact with mating connectors on the surface of an adjacent printer housing.

3. The process defined in claim 2 wherein the resilient protrusion of said beam lead circuitry is provided by inserting an elongated member having elastomeric properties between said beam lead members and the surface of said header member.

4. A thermal ink jet print head assembly including in combination:

a. a print head substrate mounted on a header member and operative to receive ink therefrom,

b. a plurality of conductive traces deposited atop said substrate and electrically connected to a plurality of resistive heater elements therein, and

c. a beam lead interconnect circuit having a plurality of beam leads bonded, respectively, to said plurality of conductive traces in adjacent abutting parallel planes to thereby maximize packing density in said print head assembly.

5. The assembly defined in claim 4 wherein said beam leads extend over a predetermined surface portion of said header member and extend resiliently away from said surface portion to thereby enable said assembly to be firmly, but removeably, connected to mating conductors on a printer housing.

6. The assembly defined in claim 5 wherein said beam lead members are resiliently extended away from said surface portion of said header by means of a resilient member having elastomeric properties positioned between said beam leads and an outer surface portion of said header member.

7. The assembly defined in claim 4 wherein said conductive traces are aluminum and said beam leads have a gold plated outer surface and thereby form a strong bond at the relatively low thermosonic bonding temperature on the order of about 70° C. or less, and are unaffected by the intermetallic purple plaque produced by exposing said bond to significantly higher temperatures.

8. The assembly defined in claim 5 wherein said conductive traces are aluminum and said beam leads have a gold plated outer surface and thereby form a strong bond at the relatively low thermosonic bonding temperature on the order of about 70° C. or less, and are unaffected by the intermetallic purple plaque produced by exposing said bond to significantly higher temperatures.

9. The assembly defined in claim 6 wherein said conductive traces are aluminum and said beam leads have a gold plated outer surface and thereby form a strong bond at the relatively low thermosonic bonding termperature on the order of about 70° C. or less, and are unaffected by the intermetallic purple plaque produced by exposing said bond to significantly higher temperatures.

10. A process for making electrical interconnects to a thin film print head substrate which includes:

a. providing thin conductive traces to heater resistors on said substrate, and

b. thermosonically and individually bonding a plurality of thin beam leads, respectively, to said plurality of thin conductive traces at a relatively low bonding temperature on the order of about 70° C. or less.

11. The process defined in claim 10 wherein said conductive traces are aluminum and said beam leads are copper plated with gold, whereby the gold-aluminum bonding system forms a strong bond and substantially unaffected by any undesirable intermetallic interaction at the above relatively low bonding temperature.

12. The process defined in claim 11 wherein said beam leads are flexibly extended over a header support member for said print head substrate and are elastomerically extended vertically therefrom in order to make firm and removable contact with mating conductors on a printer carriage.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 4,635,073

DATED : Jan. 6, 1987

INVENTOR(S) : Gary E. Hanson

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 1, line 43 of the Patent, delete "reltive, insert --relative--.

Column 2, line 42 of the Patent, delete "carraige", insert --carriage--.

Column 2, line 46, delete "an isometric view", insert --isometric views--.

Column 3, line 43 of the Patent, after return, delete "of", insert --or--.

Column 6, line 38 of the Patent, delete "termp-", insert --temp---.

Signed and Sealed this

Twenty-second Day of December, 1987

Attest:

DONALD J. QUIGG

Attesting Officer *Commissioner of Patents and Trademarks*

EXHIBIT 3

U 202887

THE UNITED STATES OF AMERICA

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UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office

February 04, 2000

THIS IS TO CERTIFY THAT ANNEXED HERETO IS A TRUE COPY FROM THE RECORDS OF THIS OFFICE OF:

U.S. PATENT: *4,680,859*
ISSUE DATE: *July 21, 1987*

By Authority of the
COMMISSIONER OF PATENTS AND TRADEMARKS

N. WOODSON
Certifying Officer

United tes Patent [19]
Johnson

[11] Patent Number: **4,680,859**
[45] **Date of Patent: Jul. 21, 1987**

[54] **THERMAL INK JET PRINT HEAD METHOD OF MANUFACTURE**

[75] Inventor: **Samuel A. Johnson**, Eagle, Id.

[73] Assignee: **Hewlett-Packard Company**, Palo Alto, Calif.

[21] Appl. No.: **915,292**

[22] Filed: **Oct. 3, 1986**

Related U.S. Application Data

[62] Division of Ser. No. 860,294, Dec. 6, 1985, abandoned.

[51] **Int. Cl.**[4] **G01D 15/16**; H05B 3/00; B05D 5/12; G03C 5/00

[52] **U.S. Cl.** .... **29/611**; 29/157 C; 29/620; 29/621; 156/272.2; 156/273.9; 346/75; 346/140 R; 427/49; 427/58; 427/88; 427/402; 430/311

[58] **Field of Search** .... 346/75, 140 R; 29/157 C, 611, 620, 621; 156/272.2, 273.9; 427/49, 58, 88, 402; 430/311

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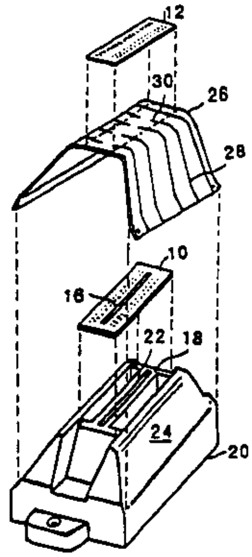
Primary Examiner—E. A. Goldberg
Assistant Examiner—Gerald E. Preston
Attorney, Agent, or Firm—William J. Bethurum

[57] **ABSTRACT**

In a thin film resistor substrate for a thermal ink jet printhead, there is provided an elongated ink feed slot for supplying ink to a plurality of heater resistors on the substrate. Ink flows from this slot vertically through the substrate and then laterally along predetermined ink flow paths in an orifice plate and barrier layer members to ink reservoirs above the heater resistors. In this manner ink flow pressure drops to all of the reservoirs are equal and thereby enhance ink pressure control for all of the reservoirs.

3 Claims, 4 Drawing Figures



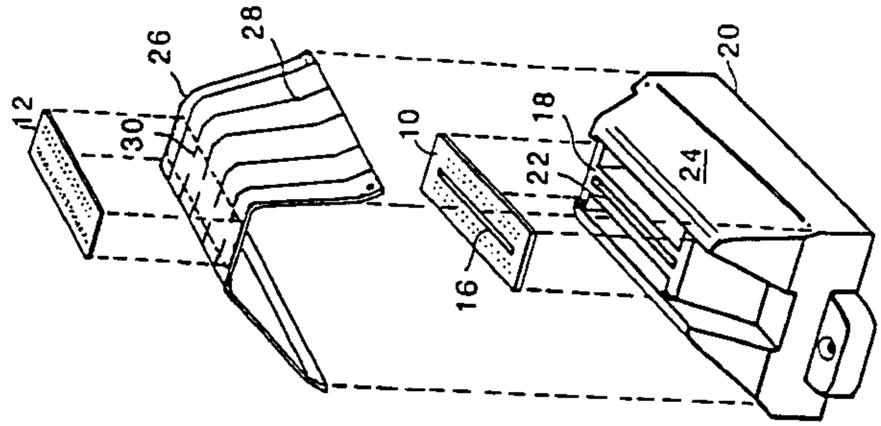


FIG 2

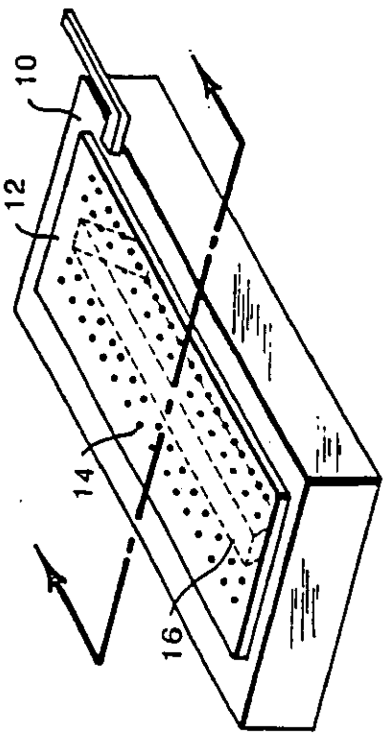


FIG 1

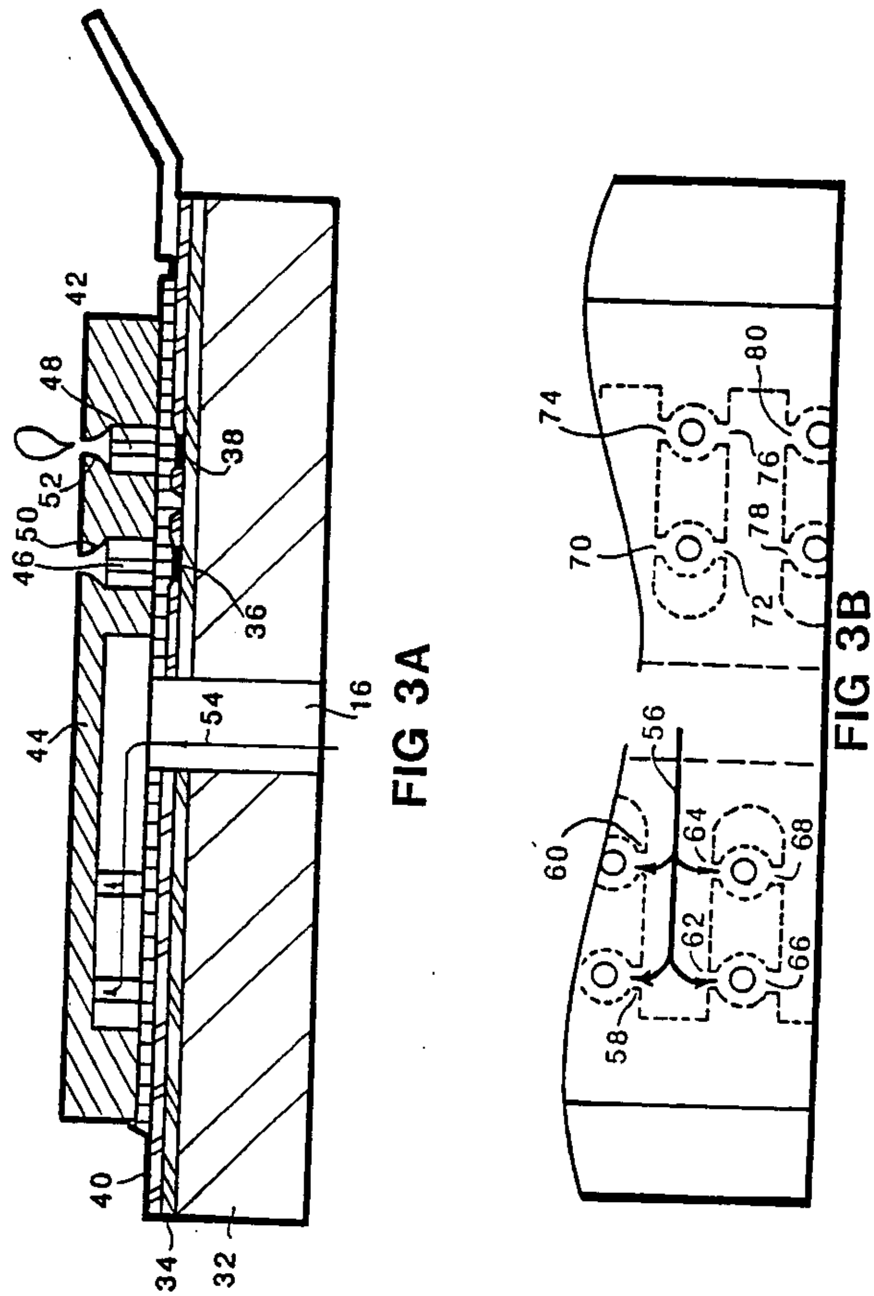

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FIG 3A

FIG 3B

THERMAL INK JET PRINT HEAD METHOD OF MANUFACTURE

CROSS REFERENCE TO RELATED APPLICATION

This application is a divisional of application Ser. No. 860,294, filed Dec. 6, 1985, now abandoned.

TECHNICAL FIELD

This invention relates generally to thermal ink jet printing and more particularly to a new and improved thermal ink jet printhead assembly.

BACKGROUND ART

Thermal ink jet printing has been described in many technical publications, and one such publication relevant to this invention is the *Hewlett Packard Journal*, Volume 36, Number 5, May 1985, incorporated herein by reference.

In the art of thermal ink jet printing, it is known to provide a plurality of electrically resistive elements on a common thin film substrate for the purpose of heating a corresponding plurality of adjacent ink reservoirs during the ink ejection and printing process. Using such an arrangement, the adjacent ink reservoirs are typically provided as cavities in a barrier layer above the substrate for properly concentrating thermal energy emanating from the resistive elements to predefined volumes of ink. Also, a plurality of ink ejection orifices are provided above these cavities and provide exit paths for ink during the printing process.

In constructing the above type of printhead assembly, one practice has been to drill vertical holes in a common substrate in order to provide ink flow paths from a common ink reservoir to the individual reservoir cavities within the barrier layer. However, the use of multiple holes (vertical cylindrical channels) in a single substrate possesses several disadvantages. One of these disadvantages is that the boring bit used for drilling holes in the substrate places a substantial pressure on the substrate material and thus can cause fracturing of this material. On the other hand, if laser drilling is utilized, the laser beam will leave channels with fratured side walls as a result of heating, and thus produce a weakened substrate structure.

The per se creation of mulitiple vertical channels in the silicon substrate weakens the printhead structure, and with some types of prior art printhead structures, these channels are used to provide ink flow to a plurality of resistive heater elements located at different distances from the channels. In such a structure, these varying ink-flow distances produce corresponding different pressure drops in the ink flow paths. That is, the pressure drop along a liquid ink flow path is proportional to the cube of the distance of the path. This fact has sometimes resulted in pressure drops over large ink flow distances sufficiently great as to prevent adequate vaporization during ink jet propulsion from the ink jet orifice.

Another disadvantages of using small diameter vertical channels to supply ink to the ink reservoirs is tha these channels simply do not have the capacity to adequately respond to certain ink volume demands at the required increasingly higher frequencies of operation.

A further disadvantage of using a plurality of ink flow channels in a common substrate is that they normally require a special routing of conductive leads on

the substrate surface. In addition to the added costs associated with this special routing, this requirement also greatly reduces the achievable packing density because of the surface area required to accomodate such special routing schemes.

DISCLOSURE OF INVENTION

The general purpose of this invention is to provide a new and improved ink jet printhead assembly which eliminates the above problems associated with the use of drilled holes through a common printhead substrate member. In this new assembly, a single elongated slot is cut in the substrate and provides ink flow to a plurality of ink reservoirs associated with resistive heater elements formed above the top surface of the substrate. These heater elements are spaced around the periphery of the slot at predetermined distances therefrom. Conductive leads are provided on the substrate between each resistive heater element and external electrical connections, and a barrier layer and orifice plate member covers all of the resistive heater elements and defines a plurality of individual ink reservoirs respectively above each of the resistive heater elements.

The above described slotted geometry structure greatly increases the packing density of heater resistors on the common printhead substrate. This increase in packing density is partially a result of the fact that, in the prior art multiple hole printhead structures, the conductive traces to the individual resistor elements had to be routed around the holes, thus increasing the required substrate area. Thus, by using the elongated slot arrangement of this invention instead of vertical holes in the prior art structures, a packing density increases of 8:1 to 10:1 may be achieved.

After the orifice plate and associated barrier layer member are secured to the thin film substrate, the substrate is die bonded to a header manifold member. This manifold member has an elongated slot therein for passing ink from a well section of the header manifold and through the substrate slot to the individual reservoirs of the barrier layer and orifice plate member.

Accordingly, it is an object of the present invention to provide a new and improved thermal ink jet printhead assembly having an improved packing density for the heater resistors and their associated ink jet orifices and reservoirs.

Another object is to provide a new and improved manufacturing process for realizing this assembly using latest state-of-the-art semiconductor processing techniques.

A novel feature of this invention is the provision of improved control of ink flow pressures from a common ink supply source and through a single slot in a thin film resistor structure and then through a common ink flow path simultaneously to a plurality of ink reservoirs in the printhead assembly.

These and other objects and features of this invention will become more readily apparent from the following description of the accompanying drawing.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is an isometric view of the slotted thin film resistor die (substrate) used in a preferred embodiment of the invention.

FIG. 2 is an exploded view showing the die placement, the external lead attachment, and the orifice plate attachment steps used in fabricating the complete thermal ink jet printhead assembly in a preferred embodiment of the invention.

FIGS. 3A and 3B are fragmented and greatly enlarged plan and cross section views respectively, of the novel slot and lateral ink feed sections of the above printhead structure.

BEST MODE FOR CARRYING OUT THE INVENTION

Referring now to FIG. 1, there is shown a thin film resistor substrate 10 for a thermal ink jet printer and including a metal orifice plate 12 thereon. The orifice plate 12 is typically constructed of nickel and includes a plurality of ink ejection openings or nozzles 14 spaced uniformly around the edges of an ink feed slot 16 indicated by the dotted lines in FIG. 1.

Referring now FIG. 2, the thin film resistor substrate 10 will be mounted on the top, I-beam shaped surface 18 of a header manifold 20. The header manifold 20 will include an ink reservoir (not shown) within the confines thereof which communicates with an ink feed slot 22. The slot 22 is aligned with the ink feed slot 16 in the thin film resistor substrate 10. The header manifold 20 further includes contoured walls 24 which have been shaped to match corresponding contoured walls of an ink jet printer carriage assembly (not shown) for receiving the printhead structure of FIG. 2 when completely assembled.

When this printhead structure is completed and all the piece parts shown in FIG. 2 brought together, the thin film resistor substrate 10 is positioned directly on the upper surface 18 of the header 20, and a flexible, tape automated bond (TAB) circuit 26 is brought into electrical contact with conductive traces on the top surface of the thin film resistor substrate 10. A plurality of thin conductive leads 28 overlie the contoured side walls 24 of the heater 20, and the interior leads 30 of the tab bond flex circuit 26 are thermocompression bonded to conductive traces on the thin film resistor substrate 10 by a process disclosed and claimed in copending application Ser. No. 801,034 as now U.S. Pat. No. 4,635,073 of Gary E. Hanson and assigned to the present assignee. In addition, the orifice plate 12 will be brought into alignment with the thin film resistor substrate 10 by means of an orifice plate and barrier layer manufacturing process disclosed and claimed in copending application Ser. No. 801,169 of C. S. Chan et al., also assigned to the present assignee.

Referring now to FIGS. 3A and 3B, the thin film resistor substrate 10 will typically include a silicon substrate 32 upon which is deposited a thin layer 34 of silicon dioxide for passivating and insulating the surface of the silicon substrate 32. A plurality of heater resistors 36 and 38 are formed on the upper surface of the silicon dioxide layer 34 and will typically be either tantalum aluminum or tantalum pentoxide and fabricated using known photolithographic masking and etching techniques. Aluminum trace conductors 40 make electrical contact to the heater resistors 36 and 38 for providing electrical pulses thereto during an ink jet printing operation, and these conductors are formed from a layer of aluminum previously evaporated on the upper surface of the silicon layer 34 using conventional metal evaporation processes.

After the formation of the aluminum conductors 40 is completed, a surface barrier layer 42, typically of silicon carbide or silicon nitride, is deposited over the upper surfaces of the conductors 40 and the heater resistors 36 and 38 to protect these members form cavitation wear and the ink corrosion which would otherwise be caused by the highly corrosive ink located in the reservoirs directly above these heater resistors. The silicon carbide layer 42, as well as the previously identified S_iO_2 surface layer 34, resistors 36 and 38 and aluminum conductors 40 are all formed using semiconductor processes well known to those skilled in thermal ink jet and semiconductor processing arts and for that reason are not described in detail herein. However, for a further detailed discussion of such processes, reference may be made to the above *Hewlett Packard Journal*, Volume 36, Number 5, May 1985.

A nickel orifice plate 44 is positioned as shown on top of the silicon carbide layer 42 and includes ink reservoir areas 46 and 48 located directly above the heater resistors 36 and 38 for receiving ink therein by way of the horizontal slot 16. These ink reservoirs 46 and 48 extend vertically upward of the substrate 10 as shown and merge into the output ink ejection orifices defined by the convergent contoured walls 50 and 52. These contoured walls 50 and 52 have been designed to reduce cavitational wear and prevent "gulping" during an ink jet printing operation as described in more detail in the above identified copending Chan et al. application.

During an ink jet printing operation, ink will flow along the path indicated by the arrow 54 and laterally along the path 56 and into the ink flow ports 58, 60, 62, 64, 66 and 68 as identified on the left-hand portion of the structure of FIGS. 3A and 3B. Likewise, ink will enter the ink flow ports 70, 72, 74, 76, 78 and 80 on the right-hand portion of the structure of FIG. 3B. By flowing ink form a common ink reservoir into the plurality of flow ports identified above, the pressure drops in the ink from the ink feed slot 16 to the individual heater resistors, such as 36 and 38, will be equal and thus insure proper ink bubble evaporation and firing during an ink jet printing operation. The advantages of this feature of the invention in contrast to the prior art have been previously discussed above.

I claim:

1. A process for fabricating a thermal ink jet printhead assembly which includes the steps of:
   (a) providing a thin film resistor structure having a common ink feed opening therein and a plurality of resistive heater elements spaced around the periphery of said opening,
   (b) bonding a plurality of conductive leads into electrical contact with said resistive heater elements at the surface of said thin film resistor structure,
   (c) affixing an orifice plate to the surface of said thin film resistor structure, and
   (d) bonding said thin film resistor structure to an insulating header having an ink feed opening therein of dimensions corresponding to the dimensions of said ink feed opening in said thin film resistor structure, whereby ink may be fed through both of said openings in said header and said thin film resistor structure, respectively and into reservoir cavities in said orifice plate, and ink in said reservoir cavities may be heated from energy from said resistive heater elements and caused to expand through openings in said orifice plate during and ink jet printing operation.

2. A process for maximizing packing density of resistor heater elements and associated ink jet orifices in thermal ink jet printheads which includes:

(a) providing a thin film resistor structure having an ink feed opening therein around which resistor heater elements are spaced at predetermined distances,

(b) making electrical contacts to said resistor heater elements,

(c) mounting an orifice plate member atop said thin film resistor structure for ejecting ink therefrom

upon receiving thermal energy from said resistor heater elements, and

(d) affixing said thin film resistor structure to an insulating header having a matching ink feed opening therein for providing ink to said ink feed opening in said thin film resistor structure.

3. The process defined in claim 2 which also includes extending said electrical contacts along surfaces of said insulating heater, whereby the packing density of said contacts is also maximized.

* * * * *

EXHIBIT 4

U 212734

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UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office

February 24, 2000

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U.S. PATENT: *4,872,027*
ISSUE DATE: *October 03, 1989*

By Authority of the
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P. SWAIN
Certifying Officer

United .ates Patent [19]
Buskirk et al.
[11] .ent Number: 4,872,027
[45] Date of Patent: Oct. 3, 1989

[54] **PRINTER HAVING IDENTIFIABLE INTERCHANGEABLE HEADS**

[75] Inventors: **William A. Buskirk**, Albany; **Carl J. Landsness**, Corvallis, both of Oreg.; **John D. Rhodes**, Vancouver, Wash.

[73] Assignee: **Hewlett-Packard Company**, Palo Alto, Calif.

[21] Appl. No.: **116,093**

[22] Filed: **Nov. 3, 1987**

[51] Int. Cl.⁴ **G01D 15/16; B41J 3/04**
[52] U.S. Cl. .... **346/140 R**; 346/139 C; 400/175
[58] Field of Search .... 346/140, 139 C; 400/175, 126

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4,771,295	9/1988	Baker	346/140 X
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4,803,500	2/1989	Milbrandt	346/140
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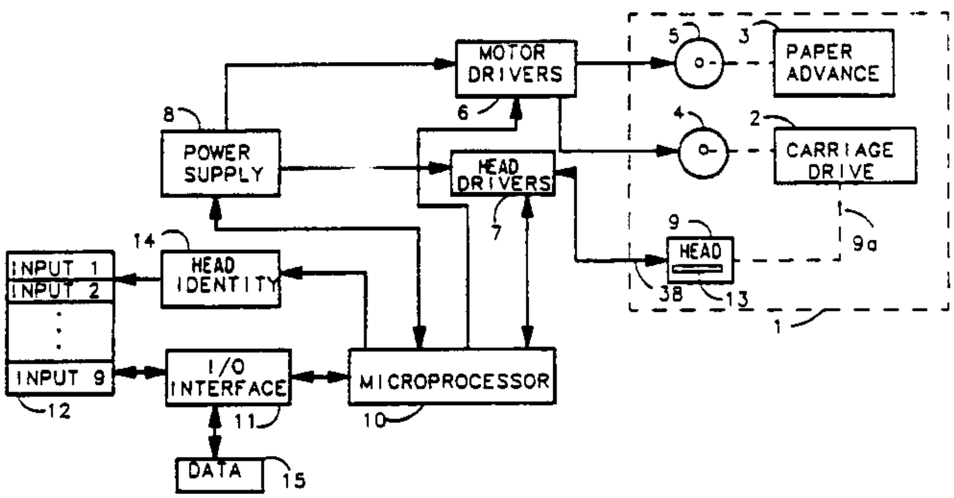
Primary Examiner—Joseph W. Hartary
Attorney, Agent, or Firm—William J. Bethurum

[57] **ABSTRACT**

A dot-matrix printer is provided with different types of printheads which are interchangeably attachable to the printer carriage. The heads are provided with individual codes which are read by the printer control system and used to reconfigure its control function to suit the control requirements of the identified head. Such a system may include a microprocessor responsive to individual sets of instructions or programs providing new and different processing capabilities for printing control in response to the insertion of a new printhead.

6 Claims, 5 Drawing Sheets



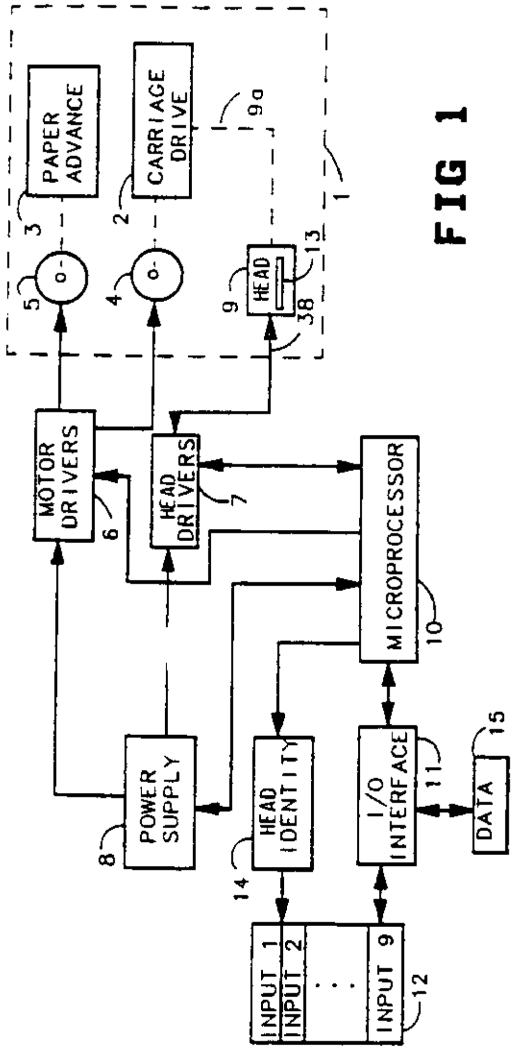

PAPER ADVANCE
CARRIAGE DRIVE
HEAD
MOTOR DRIVERS
HEAD DRIVERS
MICROPROCESSOR
POWER SUPPLY
HEAD IDENTITY
I/O INTERFACE
DATA
INPUT 1
INPUT 2
INPUT 9
1
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FIG 1

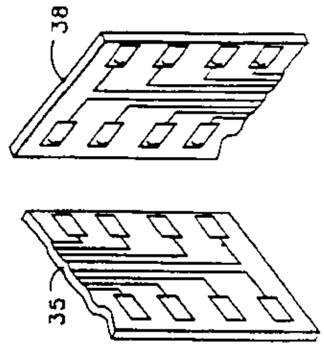
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FIG 3

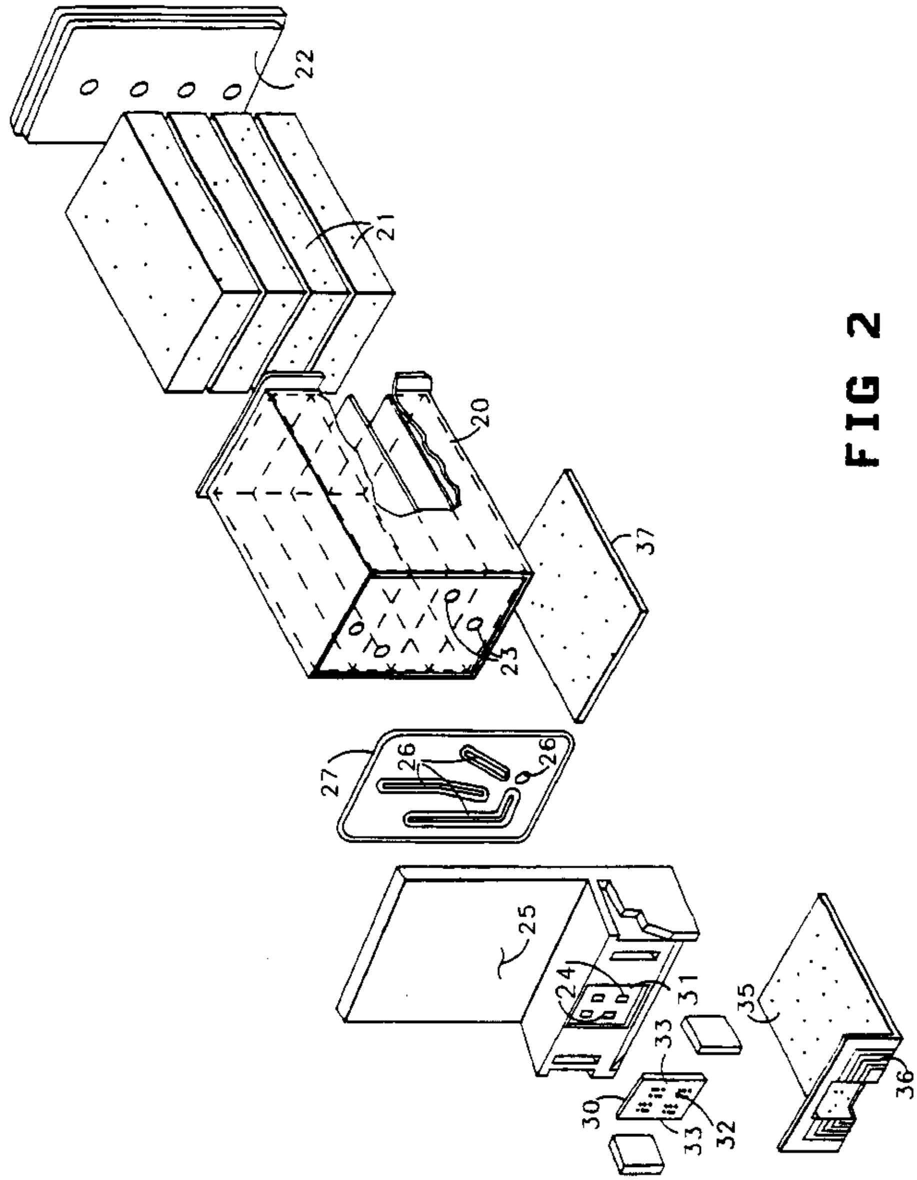
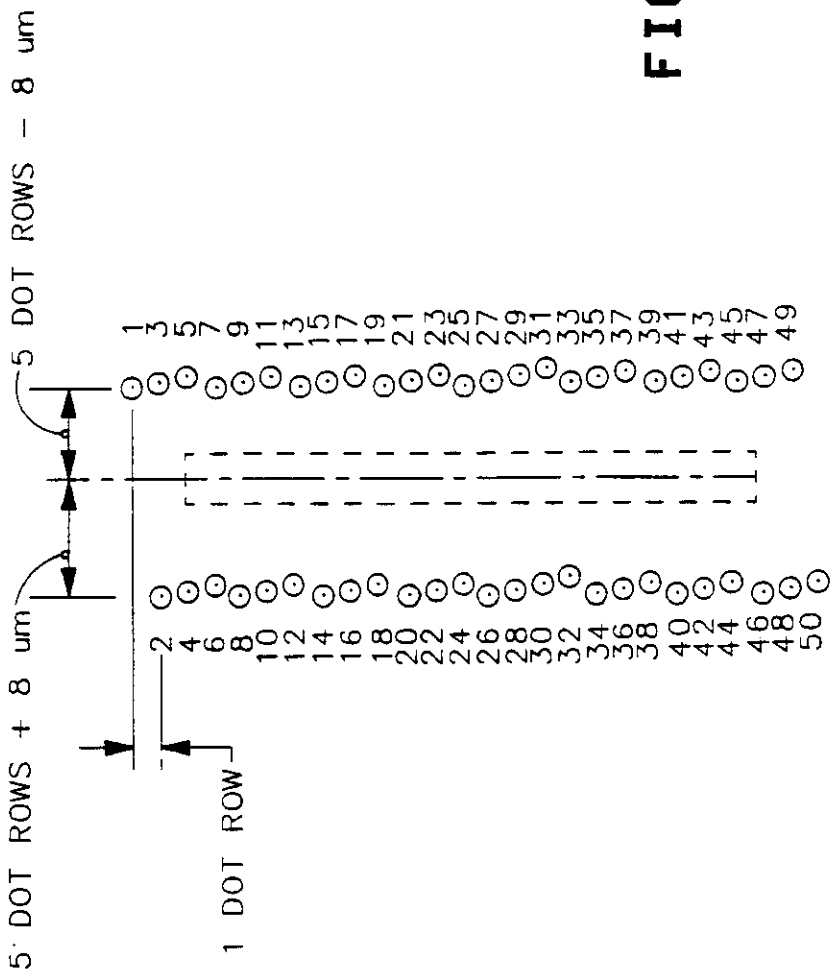
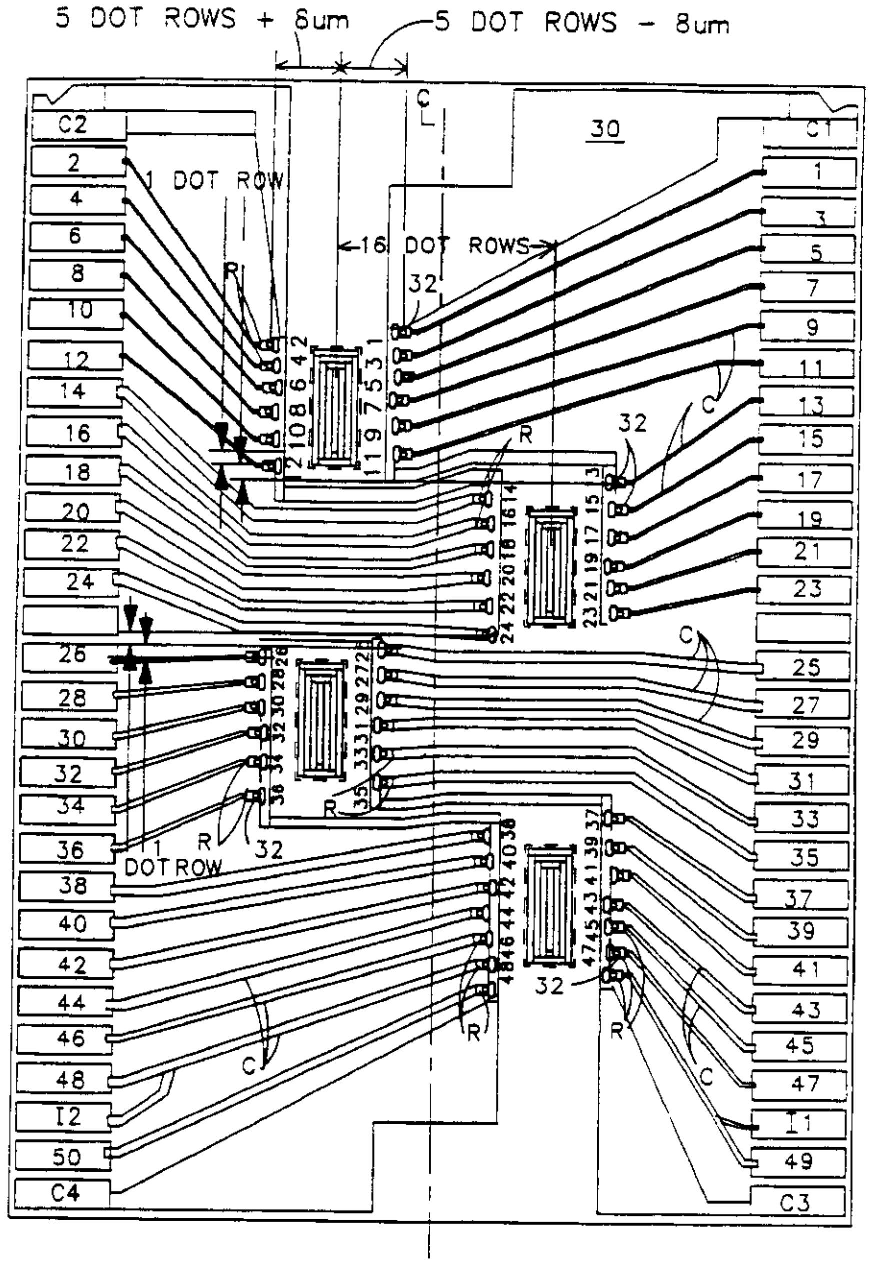


FIG 2

FIG 4


5 DOT ROWS – 8 um
5 DOT ROWS + 8 um
1 DOT ROW
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50



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16 DOT ROWS
32
R
C
1 DOT ROW
C3
C4
I2
I1

FIG 5

		ID PAD #2 (I2)		
		R48	OPEN	R50
ID PAD #1 (I1)	R47		MULTIDROP SINGLE COLOR	SINGLE COLOR
	OPEN			
	R49	SINGLE DROP SINGLE COLOR	MULTIDROP MULTICOLOR	MULTICOLOR

FIG 7

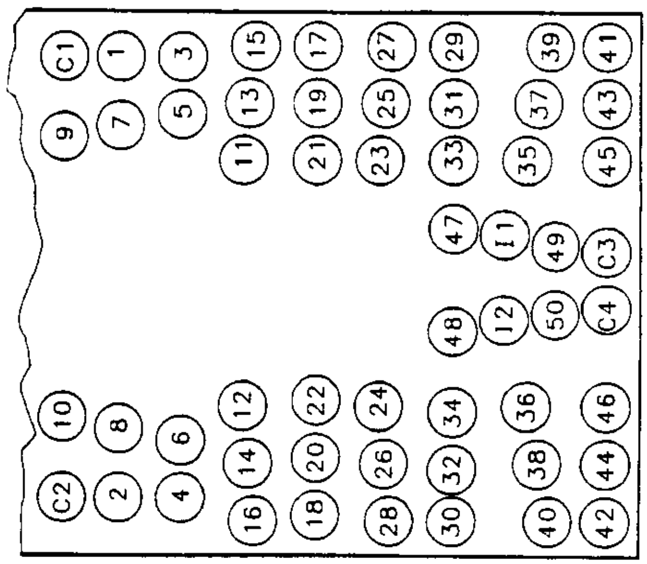

FIG 6

PRINTER HAVING IDENTIFIABLE INTERCHANGEABLE HEADS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to printers particularly dot-matrix types of printers. More particularly this invention relates to drop-on-demand types of dot-matrix printers, such as thermal inkjet printers in which provision is made for interchanging and identifying the printheads for the purpose of producing text or graphics in different colors and/or differing ink dot densities, sizes, for example.

2. Description of the Related Art

Inkjet printheads are used in printers and plotters. These include thermal and piezoelectric types of heads for expelling ink. The term printer and printhead as used herein is used as a term of convenience and is not intended to exclude the other types of recording such as plotting.

Thermal inkjet printers are described in the Hewlett-Packard Journal, May 1985, Volume 36, No. 5, which is included herein in its entirety by reference thereto. The production of ink drops by thermal exitation means is described in detail in terms of a specific implementation including a disposable head which could be replaced by another similar head.

As noted hereinabove there are a number of reasons for interchanging heads of different types, for example, black ink is used in most printing applications but there is a developing need for the use of colored inks in printing text and graphics. Heretofore printers having heads designed for single color printing have not been retrofited with color heads which may be interchangably fitted into the printer carriage designed for the single color head because of differing requirements resulting from printhead body configurations, usually larger for accommodating several colors of ink, nozzle spacing and grouping, and control requirements to name a few. While multicolor heads can be provided with a chamber for black ink, where a printer is predominately used for black text or graphics, a supply of black ink in a multicolor head fitting in the printer carriage of an all black or other single color head, is limited in volume. Thus interchangeable single color/multicolor heads in a printer increase the utility of an otherwise single color printer or recorder.

Although U.S. Pat. Nos. 4,511,907; 4,540,996; 4,611,219; 4,630,076 and 4,631,548 are directed to multicolor inkjet printers, none appear to suggest or teach configurations for a multicolor head which is interchangeable with a single color head in a single color printer. Likewise, none of these patents, lacking the concept of interchangability, provide any arrangement whereby interchangeable heads each carry an identifying code for which specific printing controls are required. Thus these patents are related to this invention only in the sense of the use of individual nozzle groups for differing colors and in the employment of dot-matrix techniques for printing, but interchangability of the heads for any purpose together with their individual identities for control purposes, appear to be lacking.

Still further there appears to be no reference in the prior art with regard to the interchangability of heads in a particular printer to provide different dot densities, different drop volumes or combinations of such factors in single color and multicolor printheads.

SUMMARY OF THE INVENTION

The present invention is directed to a printer having interchangable heads each of which is provided with a specific code which identifies the type of head that has been mounted on the printer carriage. The printer reads this code and provides a control for controlling the head in printing text or graphics according to the requirements for that particular head. In one practical embodiment of this invention applied to thermal inkjet printheads extra electrical contact pads are provided on the resistor network which fires the nozzles of the head. These contact pads are selectively electrically connected in the resistor network which fires the individual nozzles in several unique configurations each of which defines a specific head such as single color, multicolor, single drop, multiple drop and so on. The code provided by these unique configurations of the electrical pads is detectable by the printer so that the type of head which is inserted is determined with certainty and the printer provides the appropriate control of the head during printing. In this embodiment, the individual electrical pads are selectively connected (or not connected) to the resistor circuits or circuit traces. By individually toggeling the resistor lines at high or low voltage levels and detecting a voltage level shift on the lines associated with the extra contact pads, which are the head identity contact pads, a connection (or lack of connection) may be detected. With this implementation (connection or no connection), using two extra pads, nine unique connections may be made to identify the particular head that is in the printer. Thus multi-drop single color, multi-drop multicolor, single drop single color, single drop multicolor, heads of differing drop sizes, colors, etc., may be individually identified.

While it is convenient in a thermal inkjet type of printhead to implement the code for a particular head in the resistor network for firing the individual nozzles, the code may be implemented on the head by other means including electrical pad configurations which are not associated with the resistor network, projections or depressions at convenient locations on the body of the printhead which can be sensed by switches on the printer carriage, a conventional bar code on the body of the printhead which can be read by a bar code reader, or reflecting strips on the body of the printhead which can be detected by light sensitive devices on the printer carriage. This listing of alternatives is by no means exhaustive or intended to be exhaustive of arrangements for providing an identifiable code associated with a specific head in a printer.

The utility of this invention in enlarging the printing capabilities of the printer is apparent from the single color/multicolor enlargement in printing scope alone, as discussed above. This invention provides a printer which is capable of reconfiguring its control capabilities according to the code which is sensed when the different types of heads are mounted on the carriage. By this expedient, new and different printing capabilities are provided with the insertion of a new head. Using a multiprocessor in the printer control system for processing input defined by the identity code of the printhead, reconfigured control potentials are achieved in the selection, for example, of instructions or instruction changes resident in a host controller for the microprocessor.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a thermal inkjet printer system;

FIG. 2 is an exploded perspective view of one type of a thermal inkjet printhead which is employable in practicing this invention;

FIG. 3 is a schematic fragment of the end of a flexible circuit in FIG. 2 which engages the pickup end of a flexible circuit on the printer carriage, showing how the electrical connections are made;

FIG. 4 illustrates the layout or the format of the nozzles of a single color head of a type that may be employed in practicing this invention;

FIG. 5 illustrates the layout of the nozzle or orifice plate of FIG. 2 showing the resistor networks;

FIG. 6 shows the actual electrical pad layout of the end of the flexible circuit attached to the detector of the printer carriage; and

FIG. 7 illustrates the logical concept of nine printhead identity codes, according to one specific embodiment of this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The block diagram of FIG. 1 illustrate one type of printer control system. Such a system comprises a printer (shown here schematically) having a chassis 1 on which a carriage 2 is slidable mounted for movement from one side to the other of paper in a paper advance mechanism 3 mounted in the chassis. The paper advance mechanism 3 moves the paper in an orthogonal direction with respect to the carriage. A carriage motor 4 and a paper advance motor 5 drive the carriage and advance the paper under the control of motor drivers 6 supplied with power from a power supply 8. Printhead drivers 7, also supplied with power from the power supply 8, individually energize the ink drop firing resistors of a head 9 which is secured on the printer carriage 4 by means of a head attachment mechanism 9a. The ink drop firing resistors are not shown at this point. The system is controlled by a microprocessor 10 which receives data and instructions via an input-output interface 11 coupled to an instruction and data source 12 for the system. Head identification code 13 on the head 9, which may be a part of the head ink drop firing resistor network or some other identification, is detected and the head identification is used by the head identity circuit 14 to select one of a plurality of inputs associated with the particular head at the input source 12, to provide instructions to the microprocessor 10 for controlling that particular head. Data for the particular text or graphics to be printed by the head placed in the printer may be part of the selected input or may be separately programmed via the inputoutput interface 11 by a data source 15 where such provision is convenient.

In instances where head identification code 13 comprises a part of the resistor network which fires the droplets from the individual nozzles of the head, the head drivers under the control of the microprocessor may interrogate the specific resistor circuits associated with the identification contact pads to obtain the head identification code. This is done under the control of the microprocessor in which case the microprocessor, interpreting the signals derived from the specific code, provides a head identification signal which may be coupled to the separate head identity circuit 14, or used directly, to select one of the inputs, Input 1-Input 9, from the instru . source 12, which may also include data for programming the microprocessor in its control of the printhead drivers as well as instructions for controlling the level of input of the power supply 8, where needed, to properly control that particular head.

Otherwise the microprocessor may look to a code derived from switches, from bar codes, or light reflective devices, for information identifying the particular head.

One type of head which may be employed in practicing this invention is illustrated in the exploded perspective view of FIG. 2. This is a thermal inkjet type of printhead having a plurality of chambers individually isolated from one another for containing different colors of ink. The head comprises a body 20 having four individual chambers each of which receives a block of foam 21 saturated with ink of a selected color. A back plate 22 seals the body 20 and the individual chambers. Individual holes 23 in the front face of the body 20 provide communication for each chamber with individual openings 24 in a front plate 25 via four openings 26 in a gasket 27 which seals the front plate 25 to the body 20 and provides isolated communication of each chamber with a selected one of the openings 24 through the front plate 25. A nozzle plate 30 which fits into a cavity 31 in the front of the front plate 25 is provided with groups of nozzles 32 aligned with the openings 24 in the front plate. Contact pads 33 along the opposite side edges of the nozzle plate 30 provide connection via circuit traces within the individual resistors at the individual nozzles. These details are shown in FIG. 5. The individual contact pads 33 provide a means for selectively connecting electrical energy to the individual resistor circuits. Such connection is accomplished by means of a flexible circuit 35 provided with circuit traces 36 terminating in contact pads along the back of the side edges of the slot in the flexible circuit. The pads are not visible here. This slot straddles the nozzle plate 30 in assembled position so that the contact pads on the back face of the flexible circuit engage the contact pads 33 on the nozzle plate. The flexible circuit in assembled position extends beneath the body 20 where it is secured by pressure sensitive adhesive 37, or by other means, to the bottom side of the body 20.

There are electrical pad connections at both ends of the flexible circuit traces 36. One set of electrical contact pads, as stated above, is on the back side of the flexible circuit 35 on the opposite sides of the slot therein, each of which engages a circuit trace in the flexible circuit. The ends of the circuit traces at the opposite end of the flexible circuit 35 are terminated in contact pads on the bottom side of the flexible circuit 35, as viewed. FIG. 3 illustrates such typical connections. FIG. 3 is not intended to represent specific connection configurations on the flexible circuit 35, but is intended merely to indicate how these connections are made. A fragment of the flexible circuit 35 is shown on the left in FIG. 3 and may typically represent the contact pads on both ends of the flexible circuit 35. A second flexible circuit 38, also comprising circuit traces and contact pads, represents, for example, a flexable circuit end on the printer carriage 2 which engages the end of the flexible circuit 35 beneath the body 20, to provide electrical connection between the printhead 9 on the carriage 2 and printer drivers 7 (FIG. 1) which are located off the carriage. The contact pads on the flexible circuit 38 are provided with projecting dimples to provide positive engagement with the contact pads on the confronting section of the flexible circuit **35**. Similar contacts may be provided between the contacts on the flexible circuit **35** and the contact pads **33** on the nozzle plate **30**. Such specific connections are illustrative and not limiting.

Simplifications in the control system firmware and programming are realized if formating of the nozzle configurations on the different types of pens are similar, for example, nozzle formats on a multicolor head being similar to the nozzle format on a single color head. FIG. **4** illustrates the nozzle format for one type of single color head. The nozzle plate of FIG. **4** comprises two columns of nozzles there being 25 nozzles in each column. The nozzles in each column are arranged in staggered groups of 3 as seen. The nozzles in the right column which are odd numbered nozzles **1–49** are displaced vertically as viewed with respect to the nozzles in the left column which are the even numbered nozzles, 2–50, by one-half the distance between the nozzles in the columns.

TABLE I

FIRING SEQUENCE	SHIFT OFFSET (1PP) 0	10	TIMING OFFSET (UM)
0	20,46	19,45	0.0
1	14,40	13,39	2.5
2	8,34	7,33	5.5
3	2,28	1,27	8.0
4	22,48	21,47	11.0
5	16,42	15,41	13.5
6	10,36	9,35	16.5
7	4,30	3,29	19.0
8	24,50	23,49	22.0
9	18,44	17,43	24.5
10	12,38	11,37	27.5
11	6,32	5,31	30.0
12	26	25	33.0

Table I illustrates the firing sequence of the resistors associated with each of the nozzles of FIG. 4. The location of these resistors will be apparent from FIG. **5** discussed hereinafter. The resistors on the head must be fired in a particular order to minimize cross talk. The location of the nozzles is set so that that dots will all be fired in the same vertical column when there is a constant scan or printing velocity. The dot firing sequence and relative nozzle locations in microns for a specific example are specified in Table I. When printing left to right the indicated sequence is used. When printing right to left the resistors are fired in the reverse sequence.

The nozzle format of FIG. 4 is retained in the individual nozzle groups of the printhead **30** as seen in FIG. **5**. In effect, the nozzle column of FIG. 4 is divided by 4. Each nozzle group comprises 12 nozzles arranged in 2 columns of 6 having the dot row spacing between corresponding nozzles of respective rows and having the same column spacings as those of the single color head. Since this multicolor head has the same continuous dot per inch spacing with four color capability as the single color head all of the single color printer text and graphics control characteristics are utilized. Only firmware and software require color capability. Formatting is required to provide the dot stagger offset between the nozzle groups. Thus within each nozzle group the ink drop firing sequence is the same as that of the single color head. FIG. **5** illustrates at an enlarged scale the layout of the nozzle plate **30** of FIG. 2. Only the location of the nozzles **32** of the nozzle plate **30** are shown in this FIG. **5**, since the figure is already highly detailed.

These nozzles **32** are shown in their individual locations over the individual resistors R in the respective nozzle groups. The individual resistors R are connected by circuit traces C to the respective contact pads. The even numbered contact pads 2 through **50** appear on the left side of FIG. **5** and the odd numbered contact pads **1** through **49** are shown on the right side of the substrate of FIG. **5**. The common contact pads C1, C2, C3 and C4 for this substrate circuit system appear in the four corners of the substrate.

Only 48 of the 50 nozzles of FIG. **4** are needed in developing the nozzle and circuit format of the nozzle plate **30** of FIG. **5**. In this situation the nozzles **49** and **50** are not used, although they still appear on the nozzle plate as seen. This layout retains the firing sequence of the single color head with respect to the nozzles in the individual color groups. Table II below shows the firing sequence for the nozzles and resistors based upon the development of the nozzle plate of FIG. 5 and shows the shift offset required in dot rows or logical print positions in firing the individual resistors.

TABLE II

FIRING SEQUENCE	0		10		16		26		TIMING OFFSET (UM)
0					20	44	19	43	0
1					14	38	13	37	2.5
2	8	32	7	31					5.5
3	2	36	1	25					8.0
4					22	46	21	45	11.0
5					16	40	15	39	13.5
6	10	36	9	35					16.5
7	4	28	3	27					19.0
8					24	48	23	47	22.0
9					18	42	17	41	24.5
10	12	36	11	35					27.5
11	6	30	5	29					30.0
12									33.0

Further and additional details with respect to nozzle formats for multicolor heads may be had by reference to a co-pending application of C. S. Chan, et al, Ser. No. 07/098/840 filed 9-17-87, now U.S. Pat. No. 4,812,859, entitled Multi-Chamber Ink Jet Recording Head for Color Use, assigned to the assignee of this invention and incorporated in its entirety in this application by reference thereto.

Although the approach described above in formatting the nozzles in a multicolor head provide simplications noted above with respect to the control system and its programming, such nozzle formatting is not essential in practicing this invention. One approach to providing individual codes for identifying individual heads is discussed in connection with FIG. **5**. Similar considerations of course apply to other types of heads including resistor substrates **31** having individual circuit pads, circuit traces and resistors for firing the ink drops. This of course applies to the single color nozzle format of FIG. **4** except for the lateral displacement of the nozzles of the individual color groups as seen in FIG. **5**.

In reference to FIG. **5** identification contact pads I1 and I2 are provided. The contact pad I1 is located between the contact pads **47** and **49** and the contact pad I2 is located between the contact pads **48** and **50**. In these positions the contact pad I1 may be connected to contact pad **47** or **49** or it may be connected to neither. The contact pad I2 may be connected to the contact pad **48** or the contact pad **50** or it may be connected to neither. The actual physical location of the contact pads at the end of the flexible circuit 35 beneath the body 20 may be seen by referring to FIG. 6. Here the location of the common contact pads C1, C2, C3 and C4 at the end of the flexible circuit 35 are shown together with the locations of the individual contact pads 1 through 50. Note in FIG. 6 that the head identity contact pads I1 and I2 are located respectively between contact pads 47 and 49 for I1 and for I2 between contact pads 48 and 50.

In the circuit configurations described above there are nine possible code identities. These are depicted in FIG. 7. Only some of the heads or pens are identified with a particular code to demonstrate the principal. In practice the head needs to be interrogated only at the time that a printing operation is initiated. This therefore preferably occurs whether or not a head is replaced with a different head. By using this approach, there is certainty that a head is always properly identified and a head identification operation will therefore not be overlooked. Since head identification interrogation occurs and is terminated prior to the commencement of a printing operation, head identification in no way interferes with a printing operation. Additionally, although the resistor circuits 49 and 50 used in pen identification are not used in a printing operation associated with the specific resistor formatting of FIG. 5, this in no way interfers with the head identification function or with the printing function which follows.

In this connection it should be observed that the identification contact pads I1 and I2 may be located at any convenient location in the contact pad format of FIG. 5. Additionally more than one contact pad in each column of contact pads may be used to provide a higher number of identification codes.

While it is convenient to provide head identification codes using contact pads and connections forming part of the resistor circuit format, the means for generating the different identification codes is not necessarily a part of the resistor format, but as noted hereinabove may be separate and apart therefrom and need only be located in some convenient location on the printhead itself to be sensed electrically, magnetically, optically, or otherwise, in a way providing intelligence via the microprocessor, or otherwise, for selecting the proper printer system input for controlling the head in the printer.

We claim:

1. A dot matrix printer, comprising:
- a movable printhead carriage;
- a print media;
- means for advancing said print media in a direction orthogonal to printhead carriage movement;
- single color and multicolor thermal inkjet printheads;
- a nozzle plate on each printhead having a plurality of nozzles and means for admitting ink to said nozzles;
- each multicolor printhead having a nozzle group for each color of ink in the nozzle plate thereat, each nozzle group having the same nozzle format as the nozzles of a single color printhead but of a lesser number of nozzles than the number of nozzles for the single color of ink of the single color printhead;
- means for mounting single color or multicolor printheads on said printhead carriage;

- motor means for driving the printhead carriage to move the printhead thereon across said print media;
- a resistor network on each printhead having a resistor at each nozzle, which resistor when energized heats and expels ink from the nozzle thereat;
- a print control system for selectively energizing resistors of said resistor network of said printhead for printing on said print media during printhead carriage movement;
- printhead identification means on each printhead comprising patterns of resistors forming part of said resistor network providing a unique code for each printhead;
- detection means for energizing said patterns of resistors of said printhead identification means for providing electrical signal identifying a specific printhead; and
- means in said print control system responsive to said electronical signals for initiating operation of said print control system to selectively energize resistors at the nozzles of said specific printhead.

2. The dot matrix printer according to claim 1, in which:
- said detection means energizes said patterns of resistors of said printhead identification means prior to printing.

3. The dot matrix printer according to claim 1, in which:
- said means in said print control system selects input control for said print control system to provide the required control of said printhead.

4. Thermal inkjet printhead identification means, comprising;
- a printhead body having at least one ink chamber;
- a nozzle plate on said printhead body having nozzles communicating with said chamber;
- a resistor network having an ink expulsion resistor at each nozzle;
- contact pads in said resistor network and individual circuits connecting individual contact pads to individual resistors; and
- at least two printhead identification contact pads, each disposed between selected different pairs of said contact pads, and forming part of a printhead identification resistor network including at least two resistors for each printhead identification contact pad.

5. The thermal inkjet printhead according to claim 4, comprising;
- means for coupling electrical energy at different times to each resistor at each printhead identification contact pad to determine by the resulting voltage response, if an electrical connection exists between a printhead identification resistor and the associated printhead identification contact pad.

6. The thermal inkjet printhead according to claim 5, comprising;
- means for utilizing said voltage responses to provide a code identifying said thermal inkjet printhead.

* * * * *

EXHIBIT 5

U 202887

THE UNITED STATES OF AMERICA

TO ALL TO WHOM THESE PRESENTS SHALL COME:

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office

February 04, 2000

THIS IS TO CERTIFY THAT ANNEXED HERETO IS A TRUE COPY FROM THE RECORDS OF THIS OFFICE OF:

U.S. PATENT: *4,992,802*
ISSUE DATE: *February 12, 1991*

By Authority of the
COMMISSIONER OF PATENTS AND TRADEMARKS

N. WOODSON
Certifying Officer

United [illegible]tes Patent [19]
Dion et al.

[11] P[illegible]t Number: 4,992,802
[45] Date of Patent: Feb. 12, 1991

[54] METHOD AND APPARATUS FOR EXTENDING THE ENVIRONMENTAL OPERATING RANGE OF AN INK JET PRINT CARTRIDGE

[75] Inventors: John H. Dion; Thomas H. Winslow, both of Corvallis, Oreg.

[73] Assignee: Hewlett-Packard Company, Palo Alto, Calif.

[21] Appl. No.: 289,876

[22] Filed: Dec. 22, 1988

[51] Int. Cl.[5] G01D 15/18
[52] U.S. Cl. .... 346/1.1; 346/75; 346/140 R
[58] Field of Search .... 346/1.1, 75, 140 R

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Primary Examiner—Bruce A. Reynolds
Assistant Examiner—Gerald E. Preston

[57] ABSTRACT

An ink jet print cartridge includes an ink reservoir, a print head for ejecting ink from the reservoir and first and second pressure control mechanisms for limiting the reservoir underpressure. The first pressure control mechanism limits reservoir underpressure by controllably introducing replacement fluid (i.e. air or ink) thereto. The second pressure control mechanism limits reservoir underpressure by changing the volume thereof. The two pressure control mechanisms cooperate to regulate the underpressure in the reservoir at a desired value over a broad range of environmental excursions and permit use of a volumetrically efficient package.

13 Claims, 5 Drawing Sheets

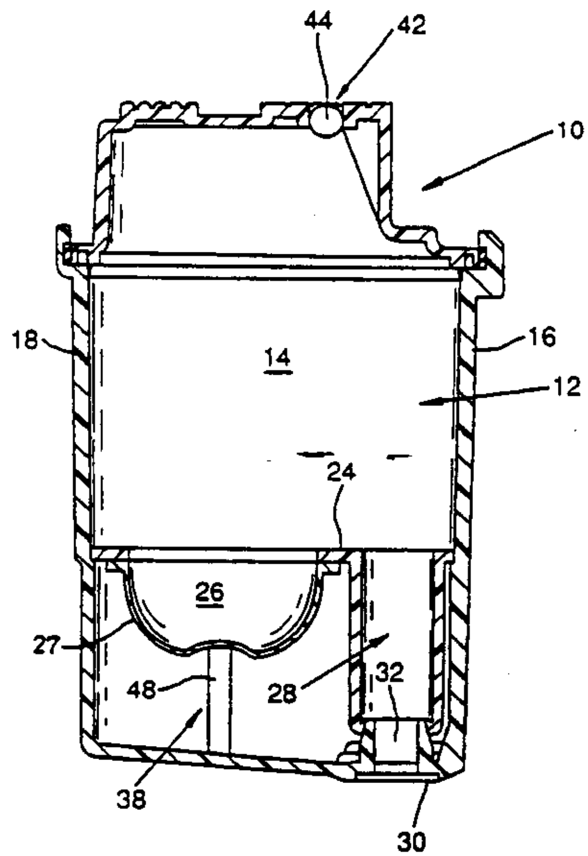


FIG. 1

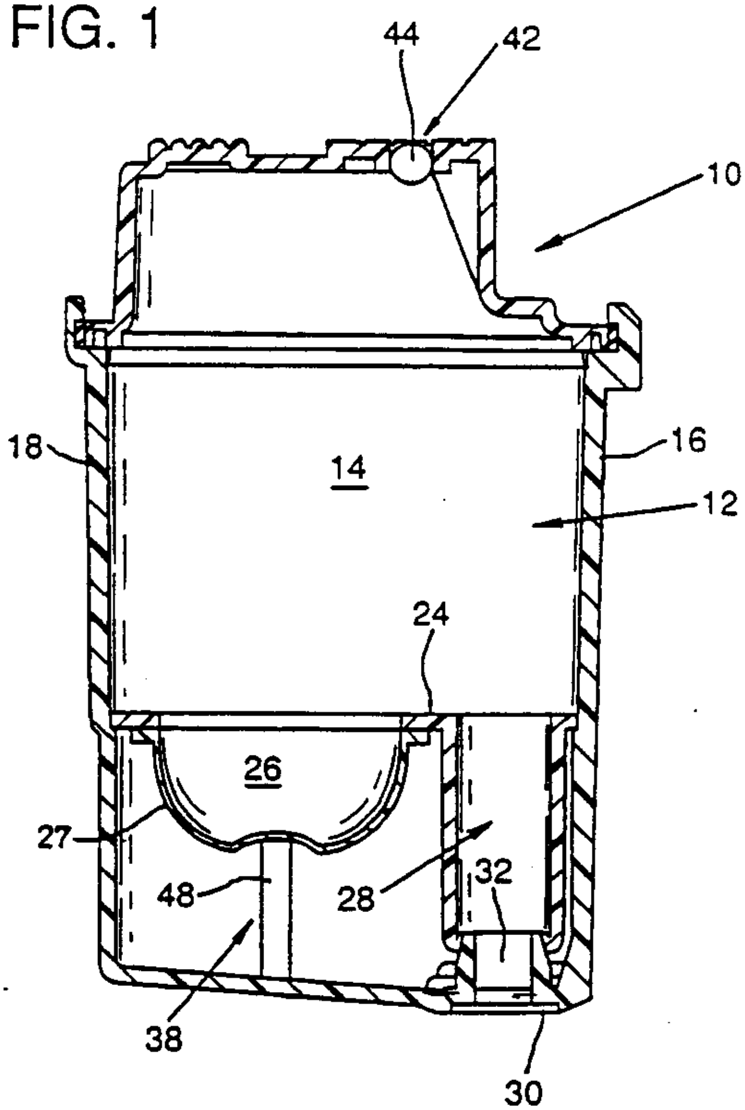


FIG. 2

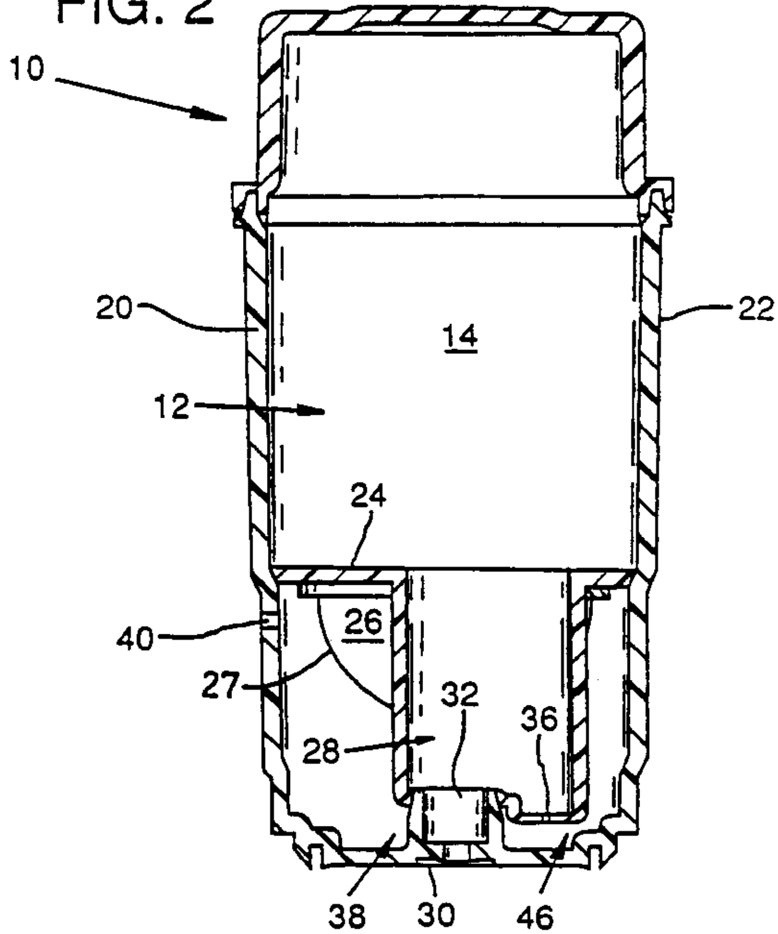


FIG. 2A

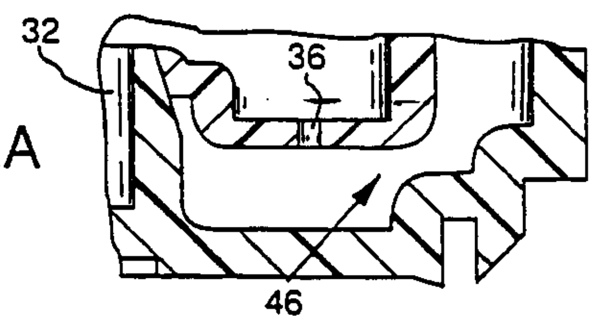
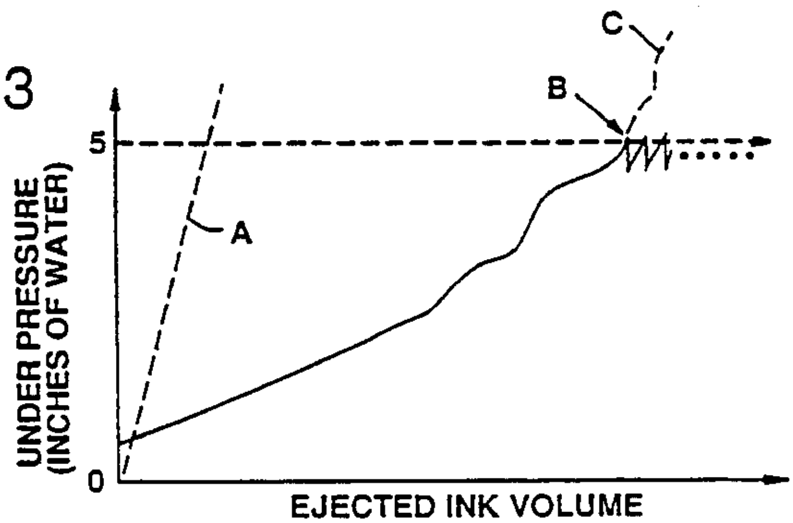
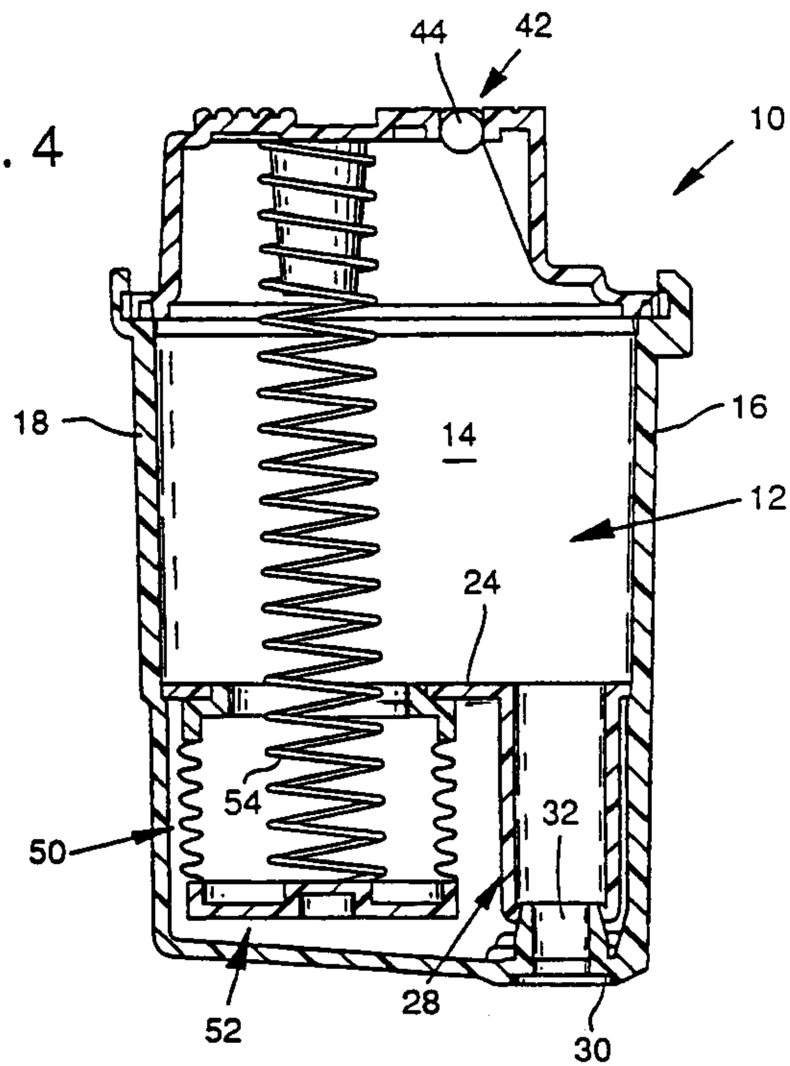


FIG. 3



C
B
5
A
0
UNDER PRESSURE (INCHES OF WATER)
EJECTED INK VOLUME

FIG. 4



44
42
10
18
16
14
12
24
54
32
50
52
28
30

FIG. 5

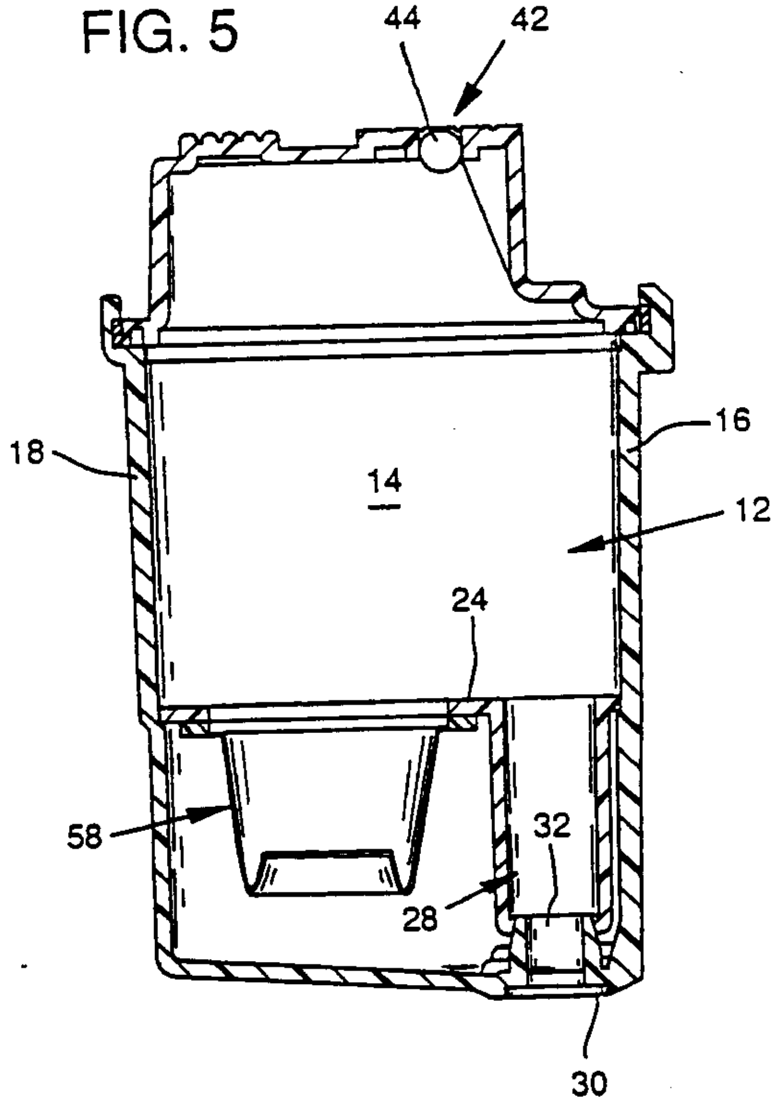
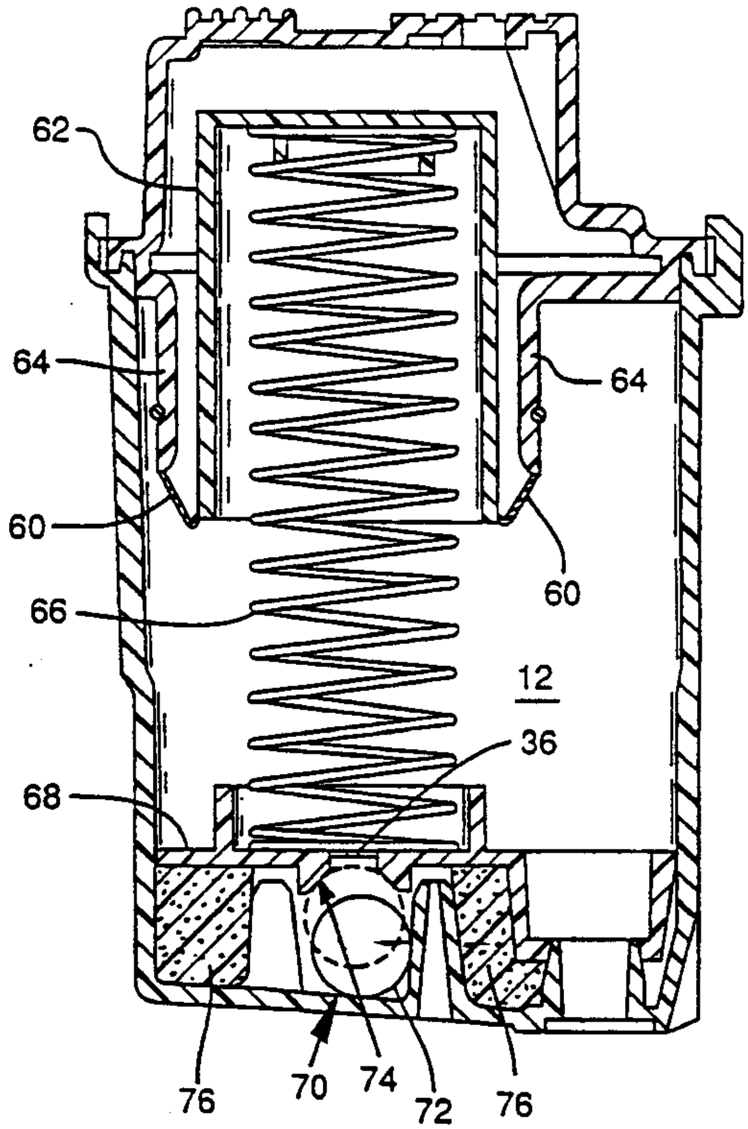


FIG. 6



METHOD AND APPARATUS FOR EXTENDING THE ENVIRONMENTAL OPERATING RANGE OF AN INK JET PRINT CARTRIDGE

FIELD OF THE INVENTION

The present invention relates to ink jet printing systems, and more particularly to a method and apparatus for extending the environmental operating ranges of such systems.

BACKGROUND AND SUMMARY OF THE INVENTION

Ink jet printers have become very popular due to their quiet and fast operation and their high print quality on plain paper. A variety of ink jet printing methods have been developed.

In one ink jet printing method, termed continuous jet printing, ink is delivered under pressure to nozzles in a print head to produce continuous jets of ink. Each jet is separated by vibration into a stream of droplets which are charged and electrostatically deflected, either to a printing medium or to a collection gutter for subsequent recirculation. U.S. Pat. No. 3,596,275 is illustrative of this method.

In another ink jet printing method, termed electrostatic pull printing, the ink in the printing nozzles is under zero pressure or low positive pressure and is electrostatically pulled into a stream of droplets. The droplets fly between two pairs of deflecting electrodes that are arranged to control the droplets' direction of flight and their deposition in desired positions on the printing medium. U.S. Pat. No. 3,060,429 is illustrative of this method.

A third class of methods, more popular than the foregoing, is known as drop-on-demand printing. In this technique, ink is held in the pen at below atmospheric pressure and is ejected by a drop generator, one drop at a time, on demand. Two principal ejection mechanisms are used: thermal bubble and piezoelectric pressure wave. In the thermal bubble systems, a thin film resistor in the drop generator is heated and causes sudden vaporization of a small portion of the ink. The rapidly expanding ink vapor displaces ink from the nozzle causing drop ejection. U.S. Pat. No. 4,490,728 is exemplary of such thermal bubble drop-on-demand systems.

In the piezoelectric pressure wave systems, a piezoelectric element is used to abruptly compress a volume of ink in the drop generator, thereby producing a pressure wave which causes ejection of a drop at the nozzle. U.S. Pat. No. 3,832,579 is exemplary of such piezoelectric pressure wave drop-on-demand systems.

The drop-on-demand techniques require that under quiescent conditions the pressure in the ink reservoir be below ambient so that ink is retained in the pen until it is to be ejected. The amount of this "underpressure" (or "partial vacuum") is critical. If the underpressure is too small, or if the reservoir pressure is positive, ink tends to escape through the drop generators. If the underpressure is too large, air may be sucked in through the drop generators under quiescent conditions. (Air is not normally sucked in through the drop generators because the drop generators comprise capillary tubes which are able to draw ink against the partial vacuum of the reservoir.)

The underpressure required in drop-on-demand systems can be obtained in a variety of ways. In one system, the underpressure is obtained gravitationally by lowering the ink reservoir so that the surface of the ink is slightly below the level of the nozzles. However, such positioning of the ink reservoir is not always easily achieved and places severe constraints on print head design. Exemplary of this gravitational underpressure technique is U.S. Pat. No. 3,452,361.

Alternative techniques for achieving the required underpressure are shown in U.S. Pat. No. 4,509,062 and in application Serial No. 07/115,013 filed Oct. 28, 1987, now 4,791,438, both assigned to the present assignee. In the former patent, the underpressure is achieved by using a bladder type ink reservoir which progressively collapses as ink is drawn therefrom. The restorative force of the flexible bladder keeps the pressure of the ink in the reservoir slightly below ambient. In the system disclosed in the latter patent application, the underpressure is achieved by using a capillary reservoir vent tube that is immersed in ink in the ink reservoir at one end and coupled to an overflow catchbasin open to atmospheric pressure at the other. The capillary attraction of ink away from the reservoir induces a slightly negative pressure in the reservoir. This underpressure increases as ink is ejected from the reservoir. When the underpressure reaches a threshold value, it draws a small volume of air in through the capillary tube and into the reservoir, thereby preventing the underpressure from exceeding the threshold value.

While the foregoing two techniques for maintaining the ink pressure below ambient have proven highly satisfactory and unique in many respects, they nevertheless have certain drawbacks. The bladder system, for example, is not as volumetrically efficient as might be desired. To minimize the variability of underpressure as a function of reservoir volume, the bladder is desirably of rounded shape. Best volumetric efficiency is obtained, however, if the bladder has a rectangular shape. (Even with a rounded shape, the underpressure is still a function of the bladder's state of collapse and eventually increases to the point that no more ink can be drawn therefrom, even though ink in the reservoir is not exhausted.)

The capillary system suffers with environmental excursions. If the ambient temperature increases, or if the ambient pressure decreases, the air trapped inside the ink reservoir expands. This expansion drives ink from the reservoir and out the printhead nozzles where it may contact the user.

Consequently, it is an object of the present invention to provide an ink jet ink reservoir that overcomes these drawbacks of the prior art.

It is a more particular object of the present invention to extend the pressure and temperature range over which a volumetrically efficient ink jet ink reservoir can operate without leaking.

According to one embodiment of the present invention, an ink jet print head is provided with an ink reservoir having two portions: a fixed volume portion and a variable volume portion. The fixed volume portion can be a rigid chamber. The variable volume portion can be a flexible bladder in a wall of the rigid chamber. Due to volumetric efficiency considerations, the fixed volume portion is desirably larger than the variable volume portion.

Beneath the reservoir is a catchbasin operated at ambient pressure into which ink can be pressure driven from the reservoir through a small coupling orifice. The coupling orifice serves both to convey ink from the reservoir into the catchbasin and to convey fluid (ink or air) from the catchbasin back into the reservoir, depending on the pressure differential. (Due to its occasional role of introducing air into the reservoir, the orifice is sometimes termed a "bubble generator.")

In normal operation, the partial vacuum left in the reservoir when ink is ejected out the print nozzles first causes the flexible bladder portion of the reservoir to collapse. After a certain amount of ink is ejected from the reservoir, the partial vacuum reaches a point at which it draws air into the reservoir from the catchbasin through the small bubble generator orifice. The orifice is sized to begin this bubbling action at a desired underpressure—five inches of water in the illustrated embodiment. Thereafter, as printing continues, the additional underpressure caused by the continued ejection of ink is regulated by the introduction of a corresponding volume of air through the bubble generator orifice.

If the ambient temperature rises, causing the air in the reservoir to expand (or if the ambient pressure diminishes, with similar effect), the bladder starts to restore and expand towards its uncollapsed state so as to contain the additional reservoir volume. In so doing, the bladder continues to exert the bladder restorative force on the ink, maintaining the pressure in the reservoir below ambient to keep the ink in the pen.

In the foregoing case of rising temperature (or decreasing ambient pressure), the bladder restorative force continues to keep the reservoir at a pressure slightly below ambient until the reservoir volume has increased to fully inflate the bladder. At this point, the bladder can no longer serve as a volumetric accumulator and ink is forced to flow through the bubble generator orifice into the catchbasin. (Ink is not driven out through the print nozzle orifii because these orifii are substantially smaller than the bubble generator orifice. Consequently, they require a higher reservoir pressure to drive ink therethrough. This higher pressure is generally never reached because the bubble generator orifice acts to relieve the reservoir pressure before the higher pressure can be attained.)

When the ambient temperature thereafter falls, causing the air pressure in the reservoir to diminish (or when the ambient pressure rises, or when ink is ejected from the reservoir by printing, all with similar effect), ink is drawn from the catchbasin by the pressure differential until it is exhausted. Thereafter, the bladder collapses until the partial vacuum in the reservoir is sufficient to draw air through the orifice from the catchbasin, as described above.

While the foregoing description has focused on a very particular embodiment of an ink jet pen according to the present invention, the invention can more generally be described as including:

a) an ink reservoir;

b) a print head for ejecting ink from the reservoir and thereby leaving a negative pressure therein;

c) a first pressure control mechanism for limiting the negative pressure in the ink reservoir by controllably introducing replacement fluid (i.e. air or ink) thereto; and

d) a second pressure control mechanism for limiting the negative pressure in the ink reservoir by changing the volume thereof.

The foregoing and additional objects, features and advantages of the present invention will be more readily apparent from the following detailed description, which proceeds with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side sectional view of an ink jet print head according to one embodiment of the present invention.

FIG. 2 is a front sectional view of the print head of FIG. 1.

FIG. 2A is an enlarged detail showing a bubble generator orifice in the print head of FIG. 2.

FIG. 3 is a chart illustrating ink reservoir underpressure as a function of ejected ink volume for the print head of FIGS. 1 and 2.

FIG. 4 is a side sectional view of an ink jet print head according to another embodiment of the present invention.

FIG. 5 is a side sectional view of an ink jet print head according to still another embodiment of the present invention.

FIG. 6 is a side sectional view of an ink jet print head according to yet another embodiment of the present invention.

DETAILED DESCRIPTION

Referring to FIGS. 1 and 2, an ink jet print head **10** according to one embodiment of the present invention includes an ink reservoir **12** having two portions. The first portion **14** is of fixed volume and is formed by rigid walls **16**, **18**, **20**, **22**, **24**, etc. The second portion **26** is of variable volume and comprises a flexible bladder **27** mounted behind an opening in one of the rigid walls.

Extending downwardly from the fixed volume portion **14** is a well **28** with a print head **30** at the bottom thereof. Ink from the reservoir **12** is drawn through a filter **32** and into the print head **30** from which it is ejected towards the printing medium by thermal or piezoelectric action, as is well known in the art.

Also in the bottom portion of well **28** is a small orifice **36** (FIG. 2) that couples the ink reservoir **12** to a catchbasin **38** positioned at the bottom of the assembly. Orifice **36** serves both to permit ink to pass from the reservoir **12** into the catchbasin **38** and to permit fluid (air or ink) to pass from the catchbasin into the reservoir, depending on the pressure difference between the two regions. (As noted earlier, this orifice **36** is sometimes termed a bubble generator orifice due to its occasional role in introducing air bubbles into the reservoir.) The size of the bubble generator orifice **36** is selected to be larger than the size of the print nozzle orifii so that, in over pressure conditions, ink will preferentially flow out the bubble generator orifice **36** instead of out the print nozzles. However, the bubble generator orifice **36** is small enough that the ink's surface tension prevents it from being gravitationally driven therethrough—there must be a driving pressure differential. In the illustrated embodiment, the bubble generator orifice diameter is 0.0078 inches and the print nozzle diameter is 0.0020 inches. Catchbasin **38**, to which the bubble generator orifice **36** leads, is vented to atmospheric pressure by a vent **40** located in the upper sidewall of the catchbasin, beneath the platform **24** in which the bladder **26** is mounted.

In operation, the reservoir **12** is initially filled with ink through an opening **42** which is thereafter sealed with a plug **44**. When the pen is first printed, ink ejected from the print head leaves a corresponding partial vacuum or underpressure in the reservoir **12** which causes the flexible bladder **27** to begin collapsing. The collapsing of the bladder reduces the reservoir volume and thus slows the rate at which the partial vacuum builds with continued ejection of ink.

Despite the bladder's moderating action on reservoir pressure, the underpressure nonetheless continues to increase with continued ejection of ink. This increase continues until the pressure differential between the ink reservoir 12 and the vented catchbasin 38 is sufficient to pull a bubble of air through the bubble generator orifice 36 and into the reservoir. This bubble of air replaces a volume of ink that has been ejected from the reservoir and thereby relieves part of the partial vacuum in the reservoir. Thereafter, continued ejection of ink will not further collapse the bladder 27 but will instead draw in additional bubbles of air through the bubble generator 36. The bubble generator thus acts as a pressure regulator that controllably introduces air into the reservoir so as to prevent the reservoir pressure from fully attaining ambient.

FIG. 3 is a chart illustrating the relationship between the reservoir underpressure and the ejected ink volume. Before any ink is ejected from the reservoir, the reservoir may be at a slight underpressure by reason of the restorative force of the flexible bladder pulling on the ink in the reservoir. As printing begins, the underpressure builds slowly as the bladder collapses, as shown by the solid curve. (If there was no flexible bladder present to moderate the underpressure, it would increase much more rapidly, as shown by the dashed curve labelled "A".)

As the ejected ink volume increases, the curve may become somewhat irregular, due to the non-linear behavior of the bladder as it folds onto itself while collapsing. At the point labelled "B", the underpressure is sufficient to start pulling bubbles through the bubble generator orifice 36 and the underpressure thereafter stabilizes around this "bubble pressure" (five inches of water in the illustrative embodiment). The underpressure drops suddenly each time a bubble is introduced and then increases back up towards the bubble pressure with continued ejection of ink. When the bubble pressure is again reached, another bubble is introduced and the underpressure falls again. The process continues until the reservoir is exhausted of ink. (Line "C" in FIG. 3 represents the underpressure that would occur if the bubble generator was omitted. As can be seen, the underpressure would rise rapidly and would soon prevent the ejection of ink from the pen.)

While ejection of ink is the principle mechanism causing reservoir underpressure to vary, it is not the only one. Environmental factors, such as ambient pressure and temperature, also play a role. For example, if the ambient pressure outside the reservoir increases, the reservoir underpressure (i.e. its partial vacuum relative to ambient) increases as well. Similarly, if the ambient temperature decreases, the air inside the reservoir contracts according to the ideal gas laws, causing a corresponding reduction in net reservoir volume and with it a corresponding increase in the reservoir underpressure. In both cases, the bladder and bubble generator orifice act as described earlier to counteract these changes in reservoir underpressure and regulate the underpressure near the desired value.

Environmental factors can also tend to decrease the reservoir underpressure (i.e bring the ink pressure up towards, or even above ambient pressure). This can occur, for example, if the ambient pressure falls or if the ambient temperature rises. In such cases, the bladder restores and expands towards its non-collapsed state to relieve the increased pressure and counteract this effect. In so doing, it continues to exert the bladder restoring force on the ink to hold it in the reservoir.

If the ambient pressure continues to fall, or if the ambient temperature continues to rise, the bladder will continue to exert its restorative force on the ink and maintain it below atmospheric pressure until the bladder becomes fully inflated. Thereafter, further increases in ink pressure will drive ink through the bubble generator 36 and into the catchbasin 38.

At this point the bladder 27 is fully expanded and the catchbasin 38 contains ink. When conditions thereafter change and the reservoir underpressure increases (i.e. by ejection of ink from the reservoir, by an increase ambient pressure, or by a decrease in ambient temperature), the pen 10 draws ink through the bubble generator 36 into the reservoir 12 from the catchbasin 38. Note that the pen in this circumstance operates differently than when the catchbasin contains only air. When the catchbasin contains only air and the underpressure increases, the underpressure is moderated by a collapse of the bladder. If the catchbasin contains ink, however, the underpressure is moderated by drawing ink into the reservoir from the catchbasin. The difference is attributed to the higher pressure differential required to pull a bubble of air into the ink-filled reservoir than to pull more ink. The air bubble has surface tension that must be overcome before it can bubble into the reservoir. The ink from the catchbasin does not.

Continued ejection of ink from the reservoir (or environmental change that tends to increase underpressure) continues to draw ink from the catchbasin into the reservoir until the ink in the catchbasin is exhausted. Thereafter, the situation is similar to that before the pen has been used—the catchbasin is dry and the bladder is fully expanded. Further ejection of ink from the pen (or corresponding environmental change) causes the bladder to collapse. In its collapsed (or partially collapsed) state, the bladder exerts a restorative force on the ink which maintains the pressure in the reservoir below ambient. The bladder continues to collapse with further ejection of ink until the bladder restorative force (i.e. the reservoir underpressure) reaches the point at which air bubbles are drawn through bubble generator 36. The process thereafter continues substantially as described earlier, with a bubble introduced through the bubble generator orifice 36 each time the reservoir underpressure exceeds the bubble pressure.

From FIG. 2 it can be seen that the bubble generator orifice 36 leading to the catchbasin is not at the lowest point of the catchbasin. However, the catchbasin is desirably formed of plastic that causes the ink thereon to bead in an upright geometry under the force of its own surface tension. This permits the orifice 36 to drain the catchbasin substantially completely despite its elevation above the catchbasin floor. The location of the orifice near the corner 46 of the catchbasin also aids in complete ink withdrawal since the ink tends to collect in this corner into which it was introduced.

From the foregoing discussion, it will be recognized that one important requirement is to design the bladder 27 (i.e. its material and geometry) so that its restorative pressure is between the bubble pressure and the ambient pressure. That is, the bladder should be designed to collapse over a range that includes partial vacuums of between zero and five inches of water. If the bladder does not operate in this range, it will be ineffective in regulating reservoir pressure since the bubble generator would always act to relieve any excessive reservoir underpressure before the bladder was prompted to collapse. In the illustrated embodiment, the bladder 27 is formed of ethylene propylene diene monomer having a thickness of 0.024 inches and a radius of curvature of 0.451 inches.

In the preferred embodiment, the bladder is not permitted to assume its fully hemispherical shape. Such a geometry resists collapsing. Instead, the bladder is dimpled, either during fabrication or by a dimpling finger 48 (FIG. 1). By this arrangement, the bladder can begin collapsing immediately as the underpressure increases, and does not require a high initial underpressure as would a hemispherical bladder before it begins its collapse.

FIGS. 4 through 5 illustrate alternative embodiments of the present invention. In the FIG. 4 embodiment, the variable volume portion of the reservoir is formed by a bag 50. Bag 50 has an end piece 52 positioned therein and is urged towards a fully open position by a spring 54. The spring 54 is biased between the bag end piece 52 and a spring boss 56 in the top of the reservoir. Operation of the FIG. 4 embodiment is substantially identical to that of the FIGS. 1-2 embodiment except that the reservoir underpressure is a more linear function of ejected ink volume since the irregular collapsing of a hemispherical bladder is avoided.

FIG. 5 shows another embodiment similar to FIGS. 1,2 and 4 but employing a rolling diaphragm 58 as the variable volume portion of the reservoir. The rolling diaphragm again behaves substantially linearly in response to increases in reservoir underpressure.

FIG. 6 shows yet another embodiment of the present invention. In this embodiment the variable volume portion of the reservoir is positioned above, rather than below, the fixed volume portion. The variable volume portion here includes a rolling diaphragm 60 in combination with a piston 62, a fitment 64 and a spring 66.

In operation, the reservoir 12 is initially filled with ink and the piston 62 is forced to a fully upward position by spring 66, thereby fully stretching diaphragm 60. As ink is ejected from the pen, the reservoir underpressure increases. As the underpressure increases, the piston 62 travels downwardly, with very little friction, until it finally stops in contact with a bottom platform 68. Further ejection of ink from the reservoir causes air to enter the reservoir through the bubble generator 36 to regulate the reservoir underpressure. This air accumulates.

Again, temperature and altitude changes (exogeneous effects) may act on the pen, causing the reservoir underpressure to diminish. When this occurs, the piston 62 moves vertically upward, acted on by the now unbalanced air pressure over piston force and the spring force. This movement causes the pen to reestablish a new underpressure equilibrium, just slightly less than the prior condition. This process can continue until the piston/diaphragm/spring components reach their original uppermost vertical position.

If desired, the pen of FIG. 6 can be equipped with a ball check valve 70 to prevent the inadvertent introduction of air into the reservoir. It will be recognized that if the pen (or the printer in which it is mounted) is inverted, ink will flow away from the bubble generator orifice 36 and may permit air to freely enter the reservoir, reducing underpressure to zero. This, in turn, may cause a small amount of ink to flow out the pen's printing orifii. The unrestricted introduction of air to the

reservoir also defeats the pen's temperature and elevation compensation capabilities by permitting the piston/diaphragm assembly to return to the original, extended position, with an air volume in the reservoir.

To prevent these undesirable conditions, a ball check 72 falls to a seat 74 provided near the location of the bubble generator whenever the pen is inverted, thereby effectively sealing the bubble generator and preserving the reservoir underpressure. When the pen is returned to the normal position, the ball falls from the seat and permits normal underpressure regulation to resume. Although shown in just this FIG. 6 embodiment, the ball check valve 70 can be used in any form of the invention.

Finally, the pen of FIG. 6 is shown as including absorbent foam 76 in the catchbasin. This foam captures and retains any ink driven to the catchbasin by exogenous effects and prevents any ink from flowing out the air vent. At the same time, and at all times, the absorbent foam allows air to pass freely between the vent and the bubble generator, thereby ensuring normal underpressure regulation. This foam can be used in any embodiment and is a last resort to keep ink off of the user.

The above-described arrangements provide a variety of advantages over the prior art. Principal among these is the extended pressure and temperature range over which the ink reservoirs can hold ink in the pen. As an added benefit, these arrangements permit the catchbasins to be used to store part of the initial load of ink, thereby increasing volumetric efficiency. Finally, these designs permit essentially all of the ink to be used for printing, since none is caught in a tightly collapsed bladder. (Any ink that remains in the bladder 27 of FIG. 1 can be dislodged by tilting the pen so the ink can flow into the well 28 from which it can be printed.)

Having described and illustrated the principles of our invention with reference to a preferred embodiment and several variations thereof, it should be apparent that the invention can be modified in arrangement and detail without departing from such principles. For example, while the invention has been illustrated with reference to a vent in the upper side of the catchbasin, other vent geometries, such as a chimney extending upwardly from the floor of the catchbasin as shown in FIG. 6, could alternatively be used. Similarly, while the invention has been illustrated with reference to a bubble generator orifice coupling the reservoir to the catchbasin, a variety of other valve mechanisms, such as the check valve disclosed in U.S. Pat. No. 4,677,447, could be substituted therefor.

In view of the wide range of embodiments and uses to which the principles of the present invention can be applied, it should be understood that the apparatuses and methods described and illustrated are to be considered illustrative only and not as limiting the scope of the invention. Instead, our invention is to include all such embodiments as may come within the scope and spirit of the following claims and equivalents thereof.

We claim:

1. An ink jet printing apparatus comprising:

an ink reservoir;

a print head for ejecting ink from the reservoir, the ejection of ink from the reservoir decreasing the pressure in the reservoir;

first pressure control means for limiting the decrease in the pressure in the ink reservoir by controllably introducing replacement fluid into the reservoir; and second pressure control means for limiting the decrease in the pressure in the ink reservoir by changing the volume thereof.

2. The ink jet printing apparatus of claim 1 in which the second pressure control means comprises a member movable in response to the pressure in the reservoir.

3. The ink jet printing apparatus of claim 2 in which, for excursions of negative pressure in the ink reservoir below a threshold value, the first pressure control means is inoperative.

4. The ink jet printing apparatus of claim 2 in which the movable member includes biasing means tending to increase the volume of the reservoir.

5. The ink jet printing apparatus of claim 1 in which the first pressure control means includes means for introducing replacement fluid to the ink reservoir only after the negative pressure therein passes a threshold value.

6. The ink jet printing apparatus of claim 5 in which the first pressure control means comprises:

a catchbasin;

means coupling the catchbasin to ambient pressure;

means defining an orifice establishing a fluid path through which the ink reservoir can draw fluid from the catchbasin in response to pressure differentials therebetween; and

pressure regulator means for limiting the flow of fluid from the catchbasin into the ink reservoir so as to prevent the pressure in the ink reservoir from fully attaining ambient pressure.

7. An ink jet printing apparatus comprising;

an ink reservoir for containing ink;

a catchbasin;

means for maintaining the catchbasin at ambient pressure;

orifice means for establishing a fluid path through which ink can be dispelled from the reservoir to the catchbasin when a sufficient pressure differential exists therebetween; and

movable means for changing the volume of the ink reservoir, said movable means being operative over a first range of reservoir pressure for relieving pressure in the reservoir to prevent ink from being driven in through the orifice means to the catchbasin by pressures in said range.

8. The ink jet printing apparatus of claim 7 in which the movable means includes means responsive to the pressure in the ink reservoir to change the volume thereof.

9. The ink jet printing apparatus that includes an ink reservoir with a movable member, said movable member permitting the reservoir to contract in volume as ink is ejected therefrom, said contraction in volume limiting the negative pressure in the reservoir until the movable member reaches the limit of its travel, after which point the negative pressure in the reservoir increases until the apparatus is no longer able to eject ink therefrom, an improvement comprising:

vent means responsive to the pressure in the ink reservoir for controllably introducing fluid thereto to permit the apparatus to continue to print after the movable member has reached the limit of its travel.

10. The ink jet printing apparatus of claim 9 in which the vent means includes valve means for preventing the unrestricted introduction of air into the reservoir if the apparatus becomes inverted.

11. An ink jet printing apparatus comprising:

a reservoir, said reservoir having a fixed volume portion and a variable volume portion, the fixed volume portion being larger than the variable volume portion;

a print head for ejecting ink from the reservoir, the ejection of ink from the reservoir decreasing the pressure in the reservoir;

said reservoir including means for varying the volume of the variable volume portion in response to the pressure therein and means for varying the volume of fluid in the reservoir in response to the pressure therein.

12. A method of operation an ink jet pen that includes a reservoir for containing ink, comprising the steps:

regulating the reservoir underpressure by varying the size of the reservoir during a first phase of operation; and

regulating the reservoir underpressure by introducing air thereto during a second phase of operation.

13. The method of claim 12 which further comprises the step of limiting reservoir pressure by transferring ink from the reservoir to a catchbasin during a third phase of operation.

* * * * *

EXHIBIT 6

U 202887

THE UNITED STATES OF AMERICA

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U.S. PATENT: *5,409,134*
ISSUE DATE: *April 25, 1995*

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N. WOODSON
Certifying Officer

US005409134A

United States Patent [19]

Cowger et al.

[11] Patent Number: 5,409,134

[45] Date of Patent: Apr. 25, 1995

[54] PRESSURE-SENSITIVE ACCUMULATOR FOR INK-JET PENS

[75] Inventors: Bruce Cowger; Marc A. Baldwin; Fred E. Tarver; Gary D. Tarver; John G. Wydronek; George M. Custer, all of Corvallis, Oreg.

[73] Assignee: Hewlett-Packard Corporation, Palo Alto, Calif.

[21] Appl. No.: 805,438

[22] Filed: Dec. 11, 1991

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 464,258, Jan. 12, 1990, abandoned.

[51] Int. Cl.⁶ G01D 18/00

[52] U.S. Cl. 222/1; 222/386.5; 347/87

[58] Field of Search .... 346/140 R, 140 PD; 222/386.5, 206, 207, 209, 263, 335, 336, 401, 95; 347/86, 87

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Primary Examiner—Kevin P. Shaver
Assistant Examiner—Kenneth DeRosa

[57] **ABSTRACT**

The accumulator regulates changes in the back pressure of an ink-jet pen reservoir so that ink does not leak from the pen print head and so that the print head is able to completely empty the reservoir of ink. The accumulator includes a flexible bag that is mounted to a flat curved spring. The elasticity of the spring tends to contract the bag as the bag expands in response to back pressure reduction in the reservoir.

40 Claims, 10 Drawing Sheets

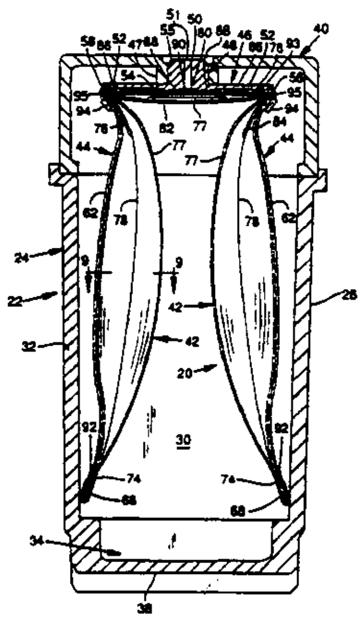

FIG. 1

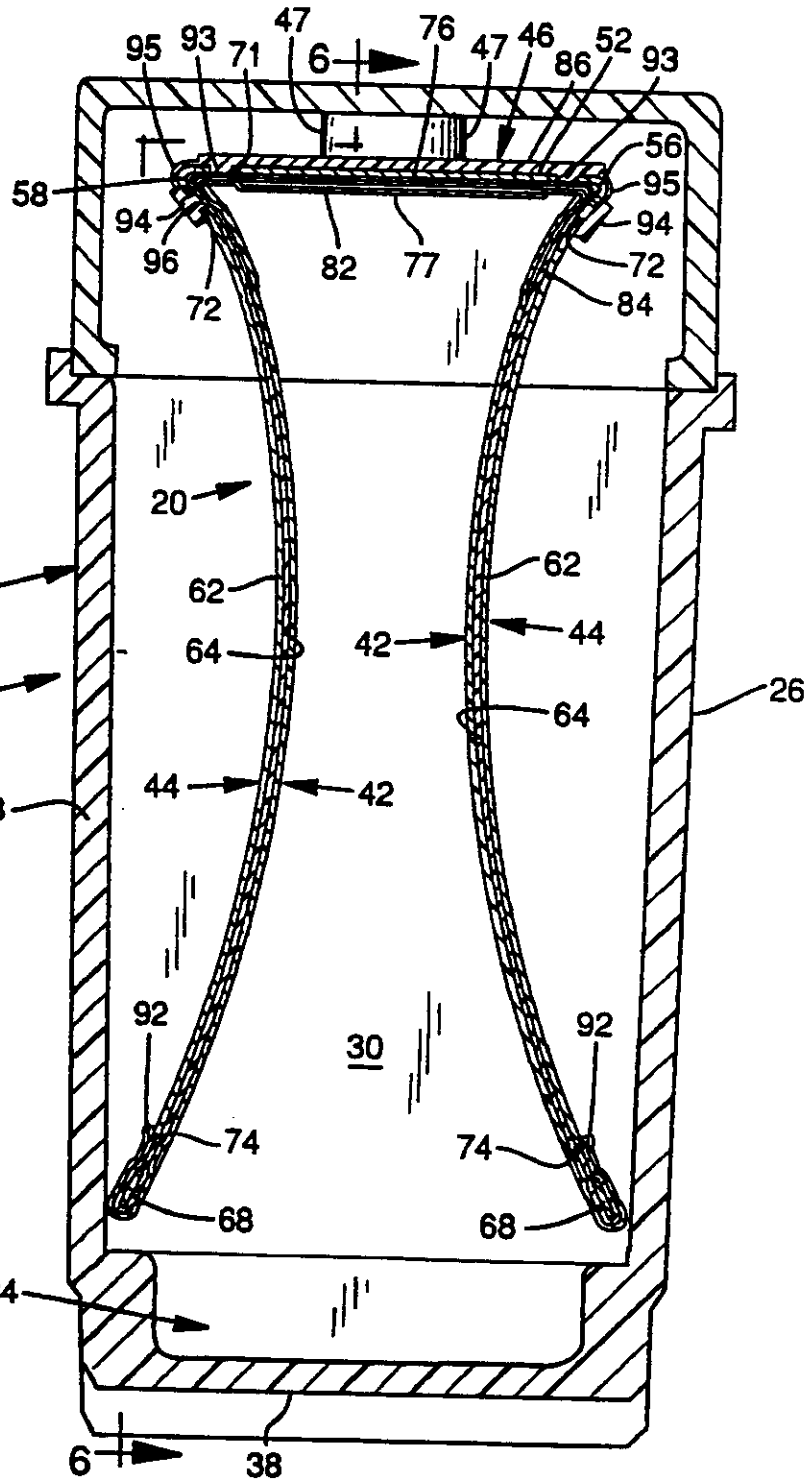
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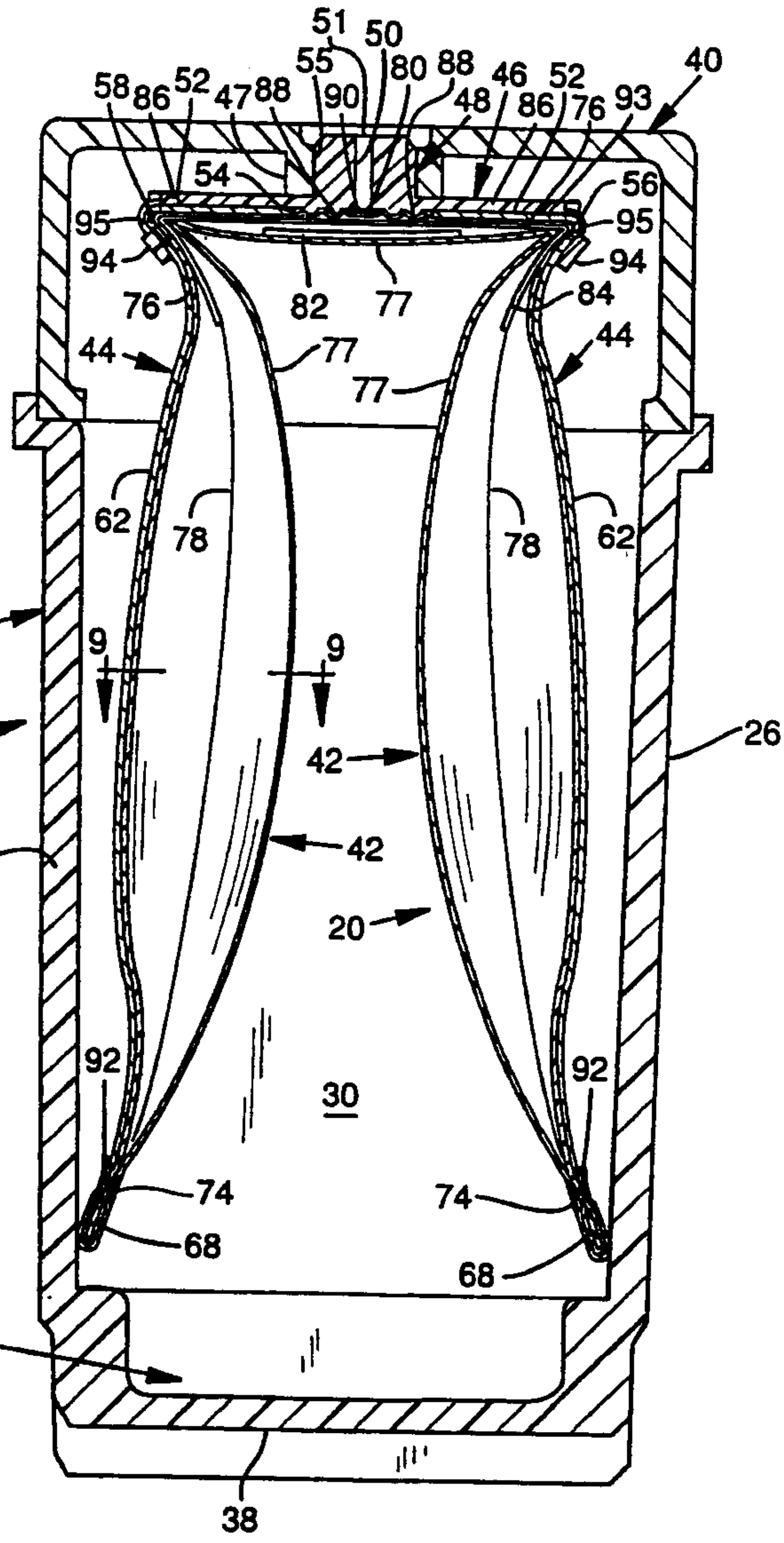
FIG. 2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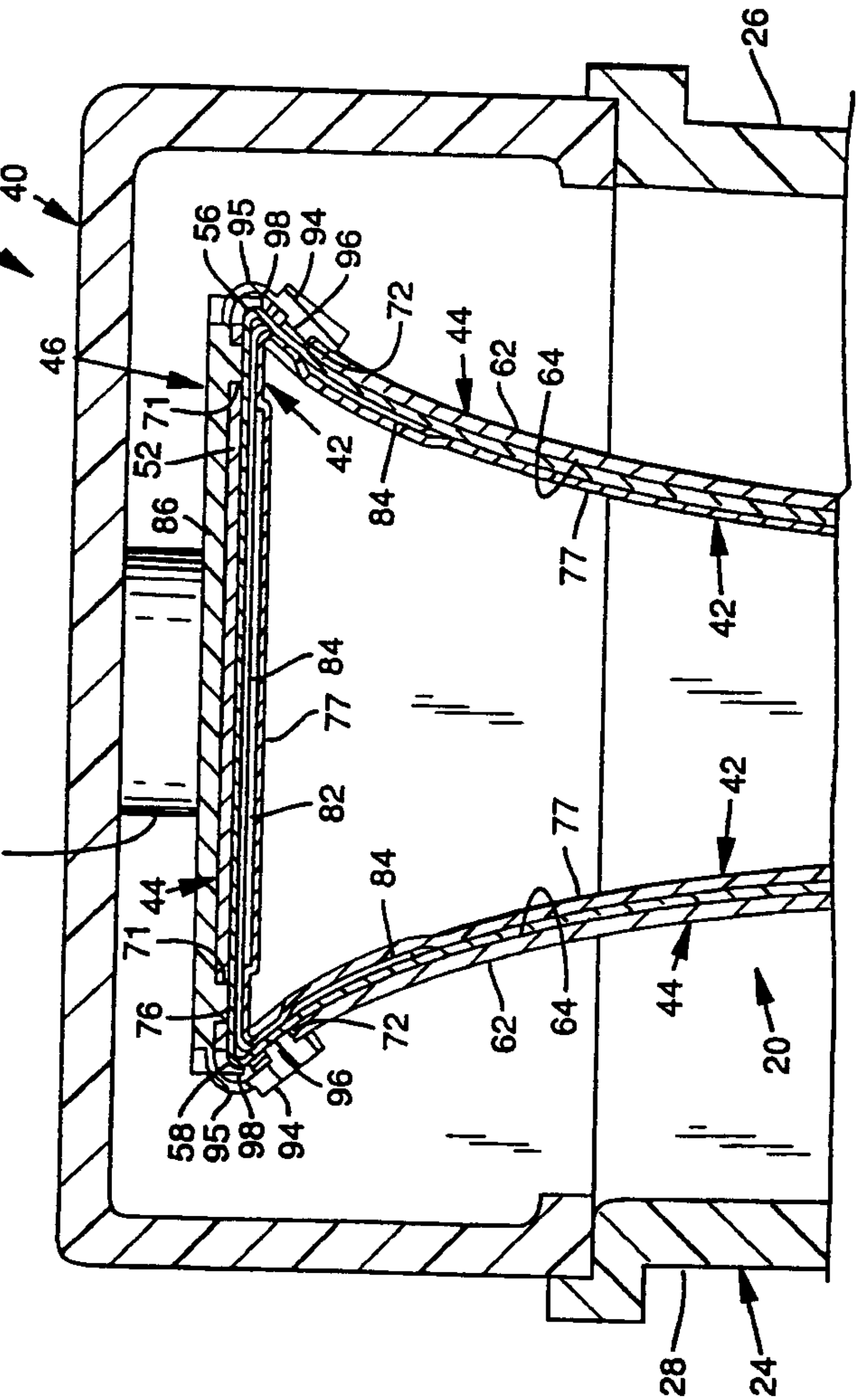
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FIG. 3

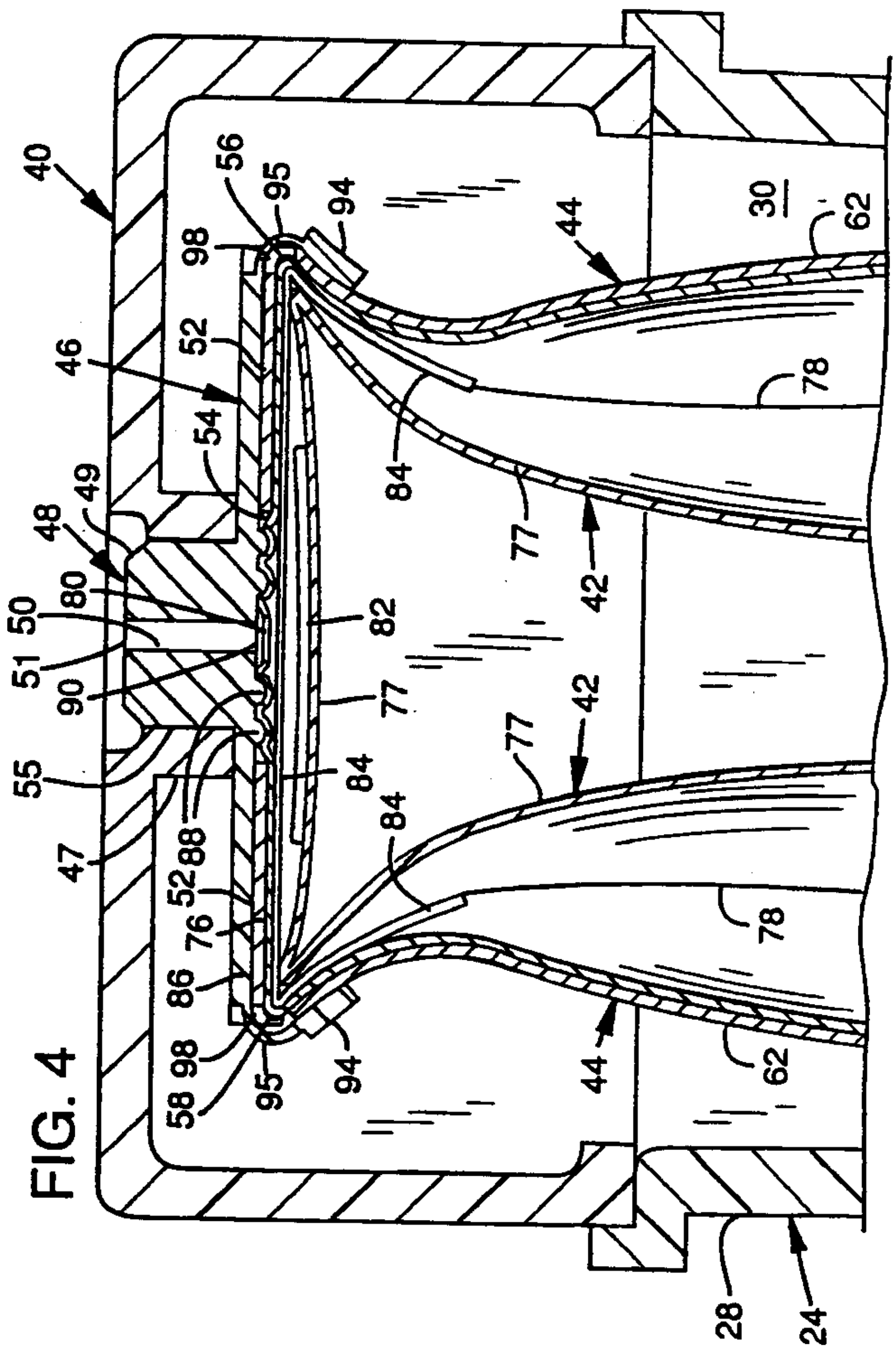
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FIG. 4

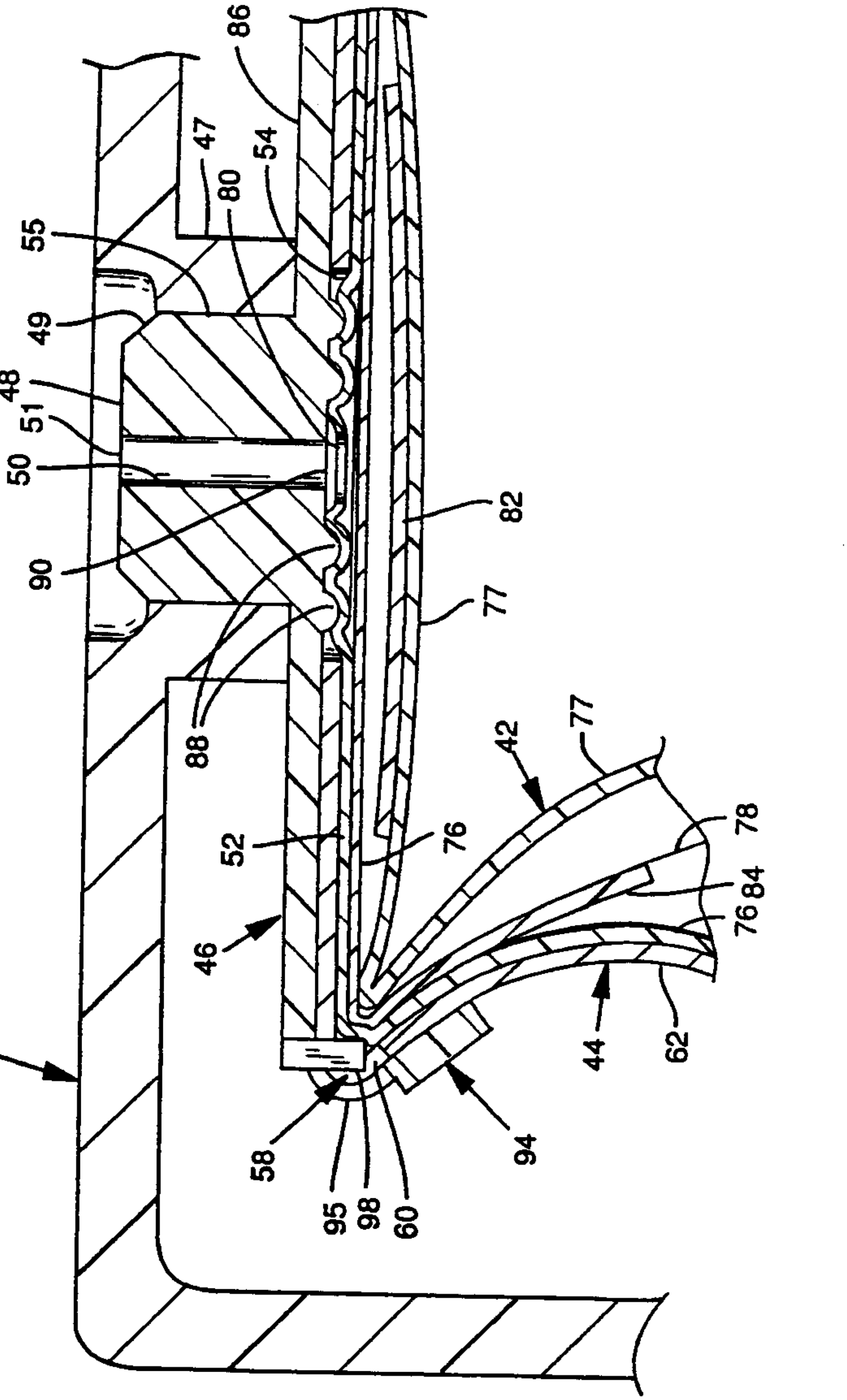
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FIG. 5

FIG. 6

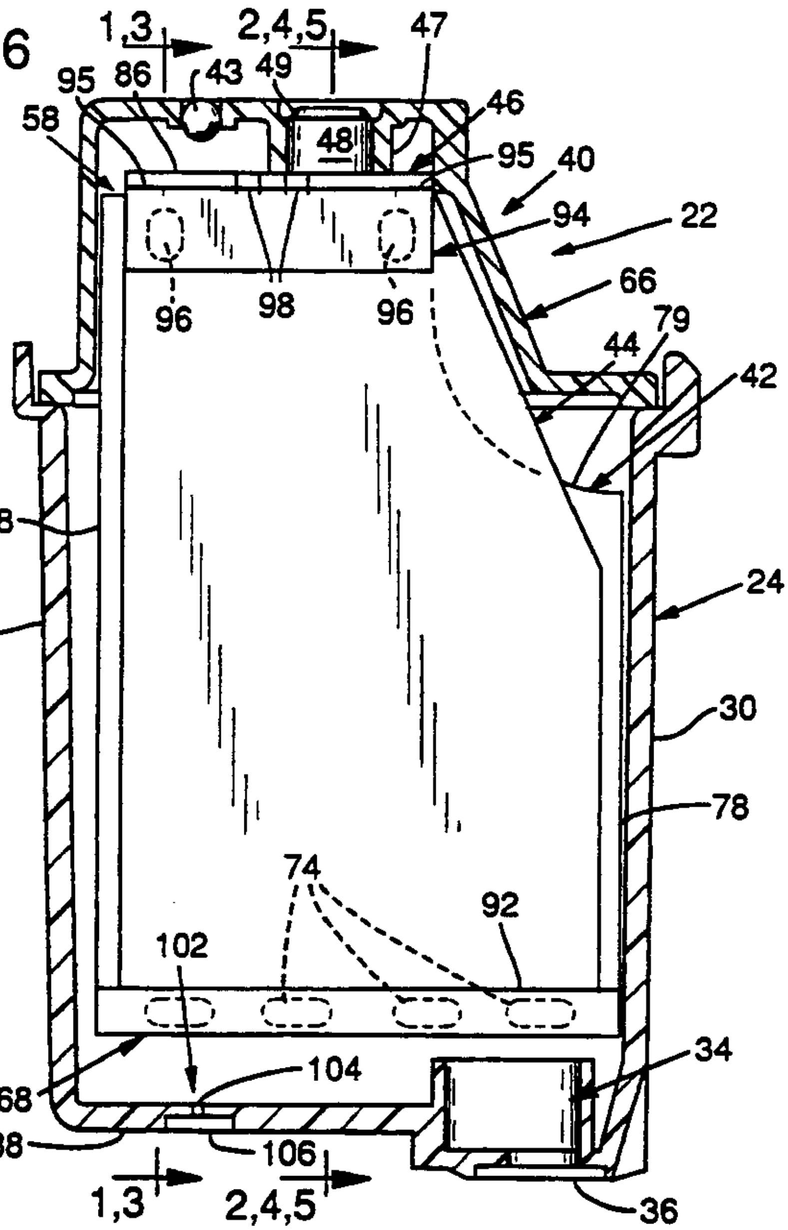
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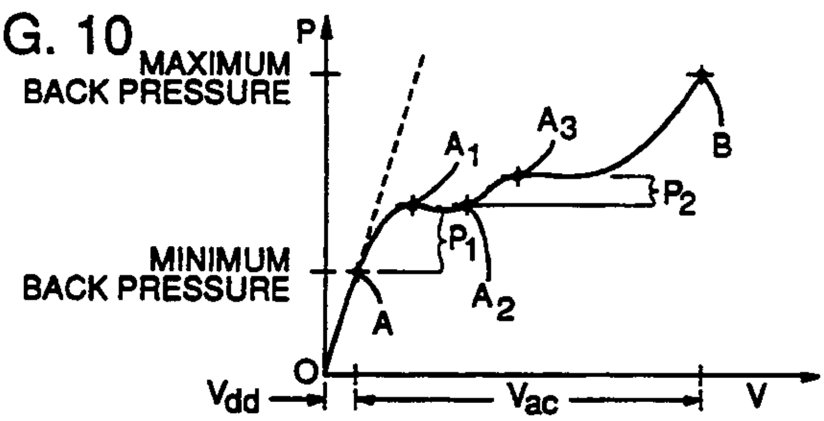
FIG. 10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MAXIMUM BACK PRESSURE
MINIMUM BACK PRESSURE
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A2
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P1
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FIG. 7

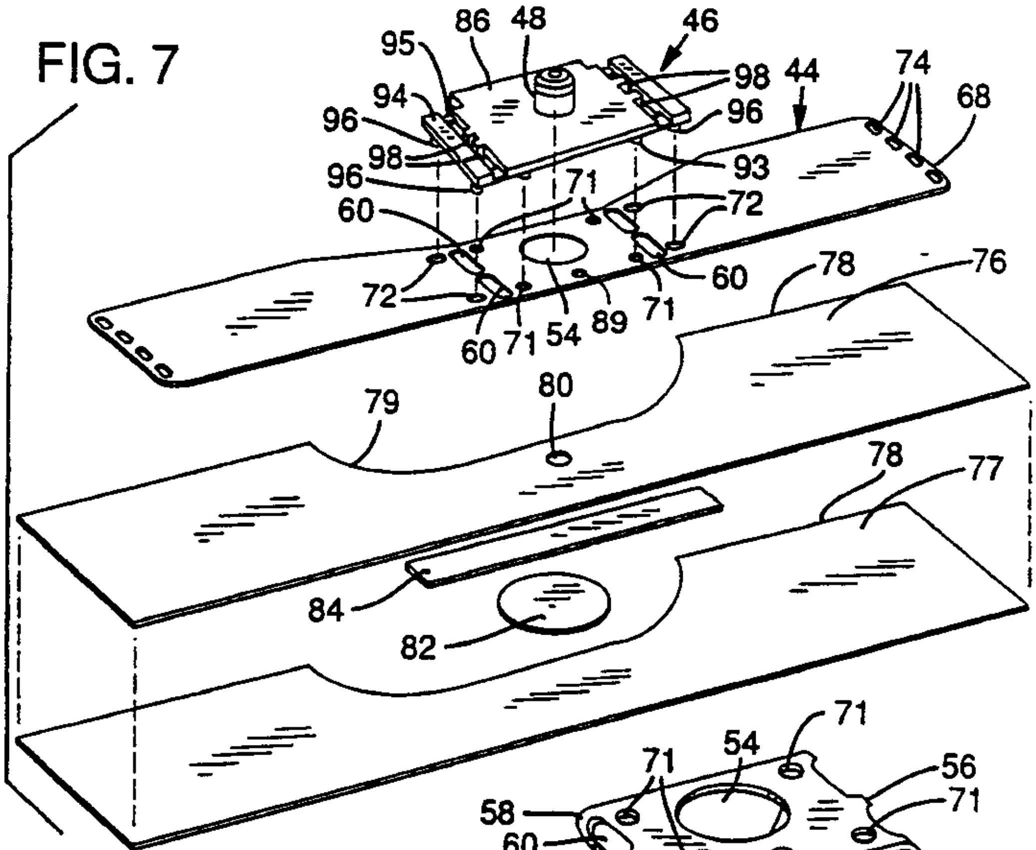


FIG. 8

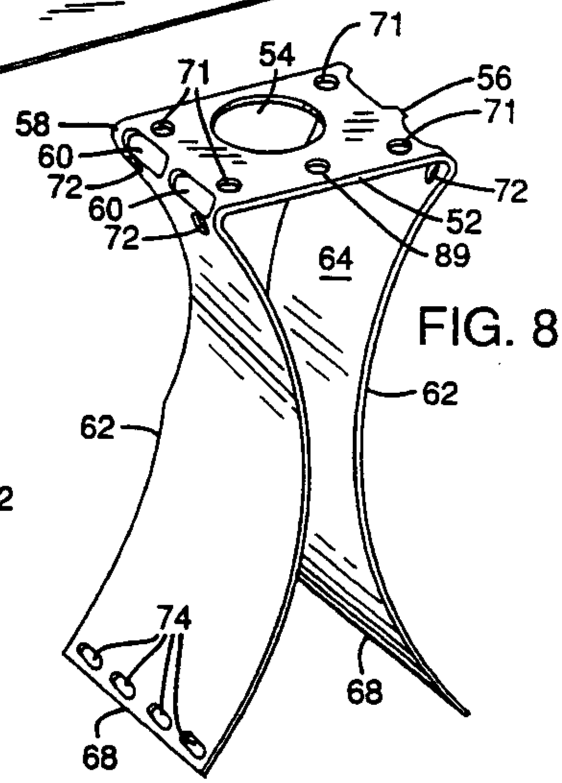


FIG. 9

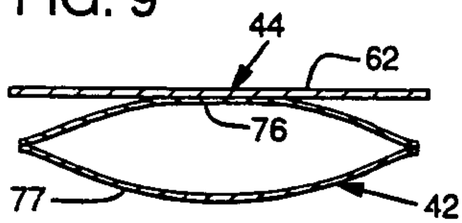


FIG. 11

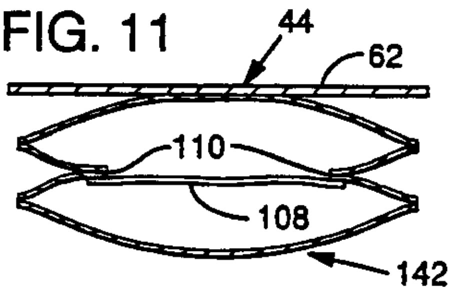


FIG. 12

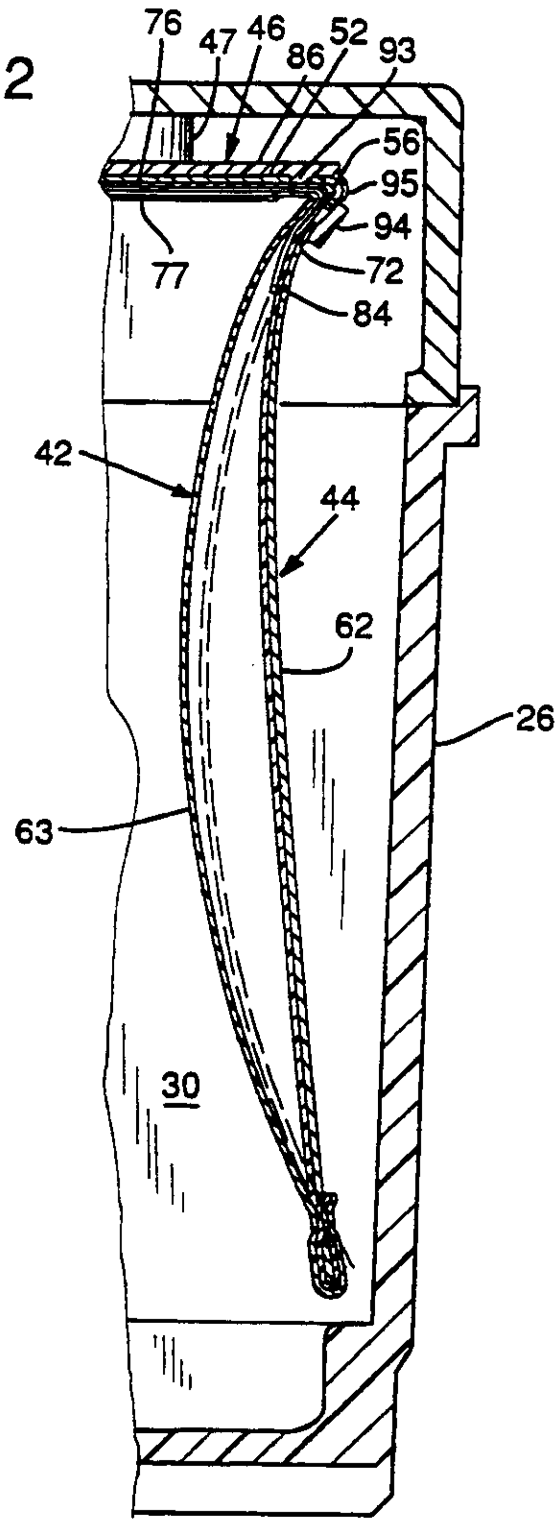


FIG. 13

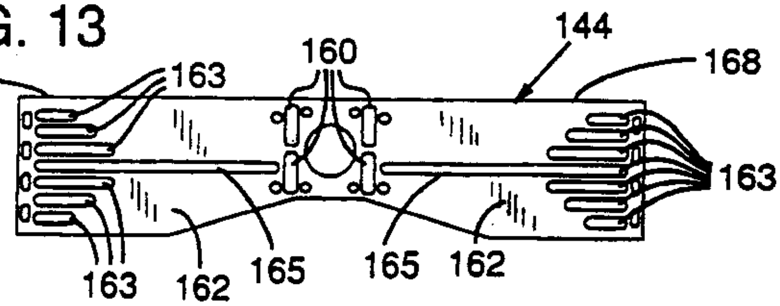


FIG. 15

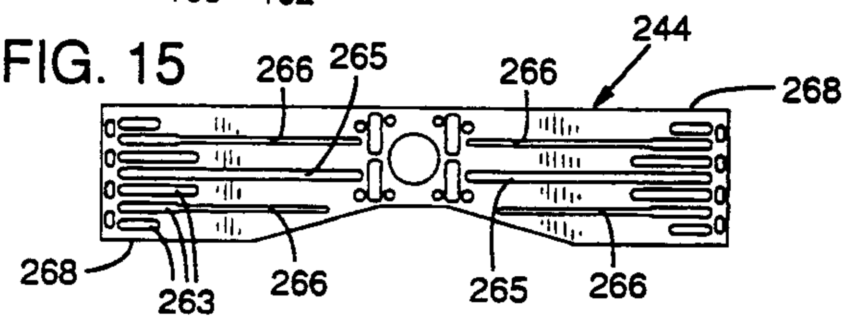


FIG. 16

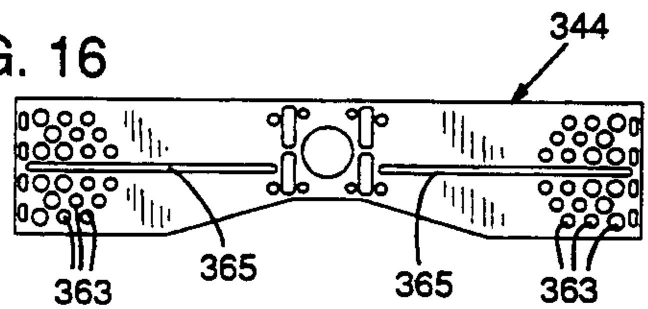


FIG. 17

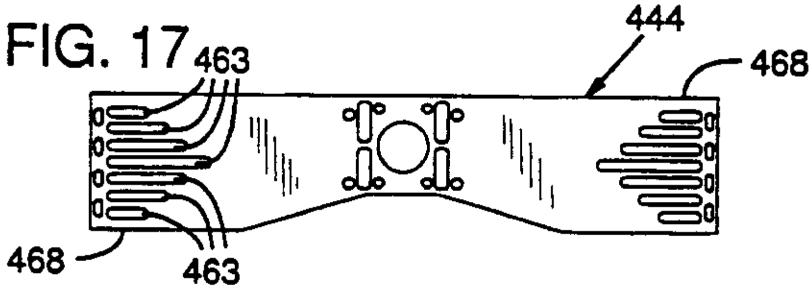


FIG. 18

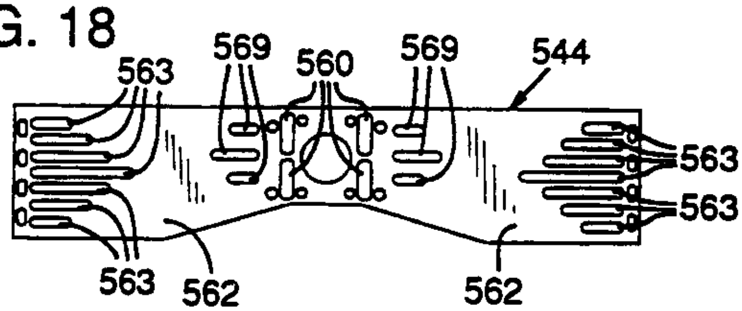
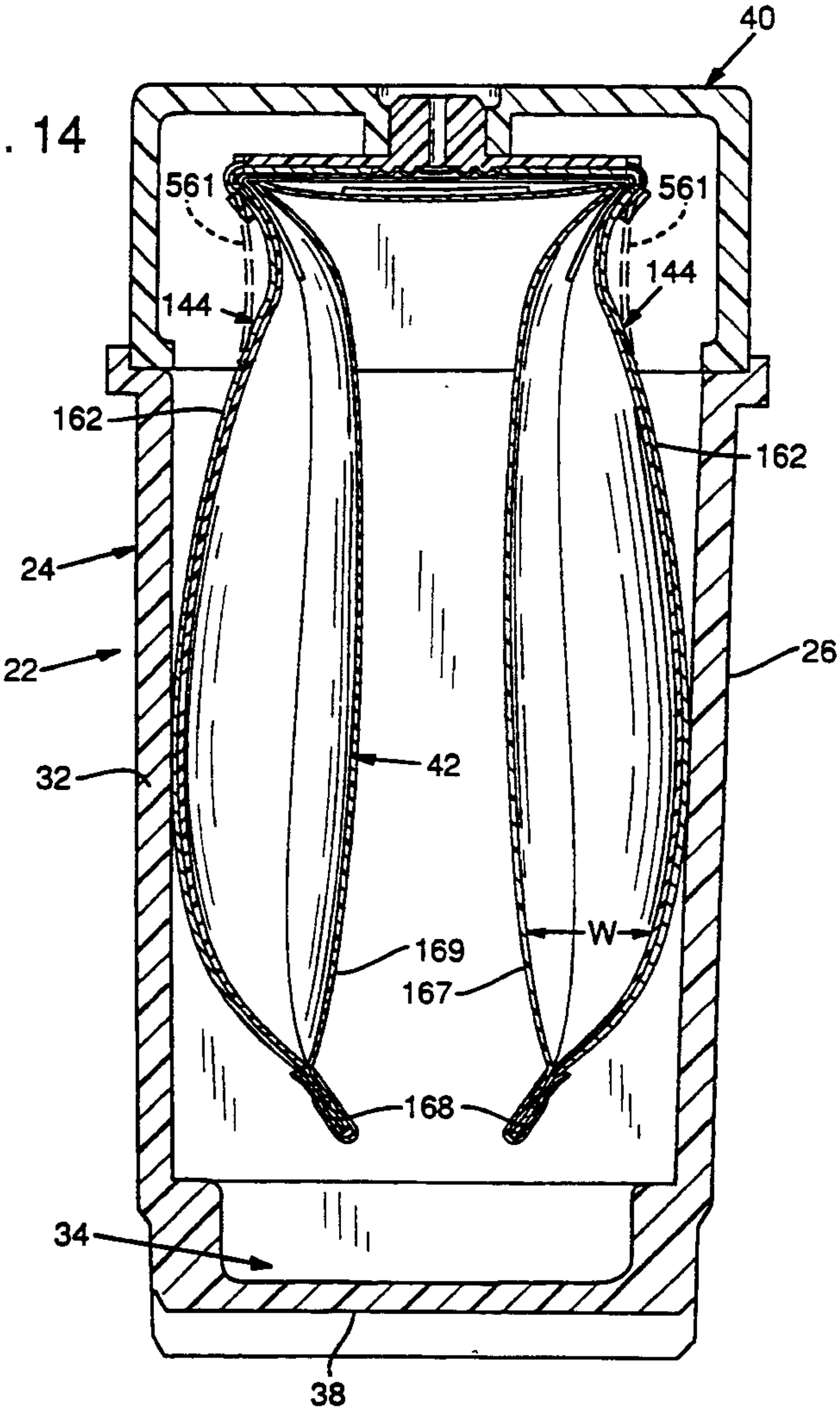


FIG. 14



PRESSURE-SENSITIVE ACCUMULATOR FOR INK-JET PENS

This is a continuation-in-part of application Ser. No. 07/464,258, filed Jan. 12, 1990, now abandoned.

TECHNICAL FIELD

This invention pertains to mechanisms for regulating the fluid pressure within the ink reservoir of an ink-jet pen.

BACKGROUND INFORMATION

Ink-jet printing generally involves the controlled delivery of ink drops from an ink-jet pen reservoir to a printing surface. One type of ink-jet printing, known as drop-on-demand printing, employs a pen that has a print head that is responsive to control signals for ejecting drops of ink from the ink reservoir.

Drop-on-demand type print heads typically use one of two mechanisms for ejecting drops: thermal bubble or piezoelectric pressure wave. A thermal bubble type print head includes a thin-film resistor that is heated to cause sudden vaporization of a small portion of the ink. The rapid expansion of the ink vapor forces a small amount of ink through a print head orifice.

Piezoelectric pressure wave type print heads use a piezoelectric element that is responsive to a control signal for abruptly compressing a volume of ink in the print head to thereby produce a pressure wave that forces the ink drops through the orifice.

Although conventional drop-on-demand print heads are effective for ejecting or "pumping" ink drops from a pen reservoir, they do not include any mechanism for preventing ink from permeating through the print head when the print head is inactive. Accordingly, drop-on-demand techniques require that the fluid in the ink reservoir must be stored in a manner that provides a slight back pressure at the print head to prevent ink leakage from the pen whenever the print head is inactive. As used herein, the term "back pressure" means the partial vacuum within the pen reservoir that resists the flow of ink through the print head. Back pressure is considered in the positive sense so that an increase in back pressure represents an increase in the partial vacuum. Accordingly, back pressure is measured in positive terms, such as water column height.

The back pressure at the print head must be at all times strong enough for preventing ink leakage. The back pressure, however, must not be so strong that the print head is unable to overcome the back pressure to eject ink drops. Moreover, the ink-jet pen must be designed to operate despite environmental changes that cause fluctuations in the back pressure.

A severe environmental change that affects reservoir back pressure occurs during air transport of an ink-jet pen. In this instance, ambient air pressure decreases as the aircraft gains altitude and is depressurized. As ambient air pressure decreases, a correspondingly greater amount of back pressure is needed to keep ink from leaking through the print head. Accordingly, the level of back pressure within the pen must be regulated during times of ambient pressure drop.

The back pressure within an ink-jet pen reservoir is subjected to what may be termed "operational effects". One significant operational effect occurs as the print head is activated to eject ink drops. The consequent depletion of ink from the reservoir increases (makes more negative) the reservoir back pressure. Without regulation of this back pressure increase, the ink-jet pen will eventually fail because the print head will be unable to overcome the increased back pressure to eject ink drops.

Past efforts to regulate ink-jet reservoir back pressure in response to environmental changes and operational effects have included mechanisms that may be collectively referred to as accumulators.

Generally, prior accumulators comprise an elastomeric bladder or cup-like mechanism that defines a volume that is in fluid communication with the ink-jet pen reservoir volume. The accumulators are designed to move between a minimum volume position and a maximum volume position in response to changes in the level of the back pressure within the reservoir. Accumulator movement changes the overall volume of the reservoir to regulate back pressure level changes so that the back pressure remains within an operating range that is suitable for preventing ink leakage while permitting the print head to continue ejecting ink drops.

For example, as the difference between ambient pressure and the back pressure within the pen decreases as a result of ambient air pressure drop, the accumulator moves to increase the reservoir volume to thereby increase the back pressure to a level, within the range discussed above, that prevents ink leakage. Put another way, the increased volume attributable to accumulator movement prevents a decrease in the difference between ambient air pressure and back pressure that would otherwise occur if the reservoir were constrained to a fixed volume as ambient air pressure decreased.

Accumulators also move to decrease the reservoir volume whenever environmental changes or operational effects (for example, ink depletion occurring during operation of the pen) cause an increase in the back pressure. The decreased volume attributable to accumulator movement reduces the back pressure to a level within the operating range, thereby permitting the print head to continue ejecting ink.

Accumulators are usually equipped with internal or external resilient mechanisms that continuously urge the accumulators toward a position for increasing the volume of the reservoir. The effect of the resilient mechanisms is to retain a sufficient minimum back pressure within the reservoir (to prevent ink leakage) even as the accumulator moves to increase or decrease the reservoir volume.

Prior accumulator designs suffer from at least two deficiencies. First, the working volume of the accumulator (that is, the maximum reservoir volume increase or decrease that is provided by the accumulator) was limited in size. Specifically, the working volume of the accumulator was limited to the maximum size of the bladder or similar structure that could be housed within the ink-jet pen. Accordingly, the environmental operating range of prior pens, which range may be quantified as the maximum ambient pressure drop the pen could sustain without leakage, was limited by the size of the working volume of the accumulator.

One prior approach to overcoming the working volume size limitation just described lead to the inclusion of a catch basin within the ink-jet pen. The catch basin provides a volume for receiving through an overflow orifice ink that is forced out of the reservoir as ambient pressure continues to drop after the accumulator moves into its maximum reservoir volume position. The continued drop in ambient pressure eventually eliminates the difference between ambient pressure and the back pressure within the reservoir. Eventually, a low-level positive pressure develops within the reservoir. The low-level positive pressure forces the ink through the overflow orifice into the catch basin. The inclusion of the overflow orifice and catch basin is intended to prevent the positive pressure in the reservoir from rising to a level that would permit ink to leak out of the inactive print head.

Use of catch basins is undesirable because they employ space within the ink-jet pen assembly that could otherwise be used as ink reservoir space. Moreover, it is difficult to design the pen so that ink is forced through the overflow orifice but not through the print head.

A second deficiency in prior accumulator designs pertains to a feature known as drawdown. Drawdown is the amount of ink volume that must be withdrawn from a filled ink-jet pen in order to establish within the reservoir a minimum back pressure to ensure ink does not leak through the print head. This minimum back pressure is typically established at the time the pen is filled with ink, that is, at the time the air volume in the reservoir is minimal. It is desirable to remove as little "drawdown" ink as possible in order to establish the minimum back pressure since the withdrawal of ink for this purpose reduces the amount of ink that can be used for printing.

Prior accumulators, being formed of moldable elastomers, generally allow significant volumes of air to diffuse through their walls. Correspondingly, larger drawdown volumes were required in prior accumulators so that the addition of air into the reservoir by diffusion did not cause the accumulators to expand to their maximum volume. It can be appreciated that the reservoir back pressure is lost when the accumulators attain their maximum volume.

SUMMARY OF THE INVENTION

The present invention is directed to a pressure-sensitive accumulator for ink-jet pens and provides an accumulator working volume that is sufficient for operating the pen notwithstanding extreme environmental changes and operational effects on the back pressure within a reservoir.

The accumulator of the present invention is constructed to provide a working volume of a size large enough to eliminate the need for a catch basin or similar overflow mechanism. Accordingly, the amount of ink available for printing is maximized with the accumulator of the present invention.

The accumulator of the present invention is configured so that the relationship between the reservoir back pressure and the movement of the accumulator is such that very little drawdown ink must be removed to establish the minimum back pressure within in the reservoir. Consequently, the amount of ink available for printing is only marginally reduced because of drawdown.

The invention can be generally described as including a spring having an expandable bag attached thereto. The spring and bag are positioned within the reservoir of an ink-jet pen so that the interior of the bag is in fluid communication with air outside of the reservoir. The bag and spring are configured so that the bag expands and contracts in response both to fluid pressure changes within the reservoir and to ambient pressure changes outside of the reservoir. The spring is deflected by the expansion of the bag. The deflected spring urges the bag toward a contracted or minimum volume position.

The bag and spring are configured so that the bag expansion and contraction affects the reservoir volume in a manner that maintains the reservoir back pressure with in an acceptable operating range despite extreme variations in the ambient air pressure.

As another aspect of this invention, the spring is configured to bend to conform to the bag shape when the spring is deflected by the expanding bag, thereby permitting the bag to expand to its maximum available volume. This configuration of the spring also makes more uniform the bag's expansion and contraction response to changes in ambient pressure and reservoir back pressure.

Other features and advantages of the present invention will be apparent from the following detailed description, which proceeds with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a front cross section of an ink-jet pen that includes the accumulator of the present invention shown in the contracted or minimum volume position.

FIG. 2 is a front cross section of an ink-jet pen that includes the accumulator of the present invention shown in the expanded or maximum volume position.

FIG. 3 is an enlarged cross section of the upper portion of the accumulator, showing the accumulator in the minimum volume position.

FIG. 4 is an enlarged cross section of the upper portion of the accumulator, showing the accumulator in the maximum volume position.

FIG. 5 is an enlarged cross section of a portion of the accumulator showing the assembly of some of the accumulator components.

FIG. 6 is a side cross section of an ink-jet pen that includes the accumulator of the present invention.

FIG. 7 is an exploded perspective view of the accumulator components.

FIG. 8 is a perspective view of the spring component of the accumulator after it is shaped into its undeflected position.

FIG. 9 is a cross sectional view taken along line 9—9 of FIG. 2.

FIG. 10 is a graph showing the relationship between the reservoir back pressure and changes in the ink volume within the reservoir.

FIG. 11 is a cross section of a portion of an alternative embodiment of the accumulator of the present invention.

FIG. 12 is a partial front cross section of an ink-jet pen that includes the accumulator of the present invention, a portion of the accumulator being shown in a position intermediate the fully contracted or minimal volume position of FIG. 1 and the expanded or maximum volume position of FIG. 2.

FIG. 13 is a plan view of an alternative spring component of the accumulator, depicting the spring as it appears before it is shaped into the undeflected position.

FIG. 14 is a front cross section of an ink-jet pen that includes the accumulator of the present invention utilizing the alternative spring component of FIG. 13 and showing the accumulator in the expanded or maximum volume position.

FIGS. 15–18 depict in plan view alternative embodiments of the spring component showing the spring components depicting the springs as they appear before they are shaped into the undeflected position.

DETAILED DESCRIPTION

The accumulator of the present invention is configured to have a working volume (that is, the maximum reservoir volume increase or decrease that is provided by the accumulator) that can regulate back pressure within an ink-jet pen reservoir despite extreme changes in ambient air pressure. In this regard, the most severe pressure change affecting ink-jet pens normally occurs when the pens are transported by air. During such transport, the pens are disposed within an aircraft cabin, which, at its greatest altitude, is pressurized to a level that is substantially below atmospheric pressure at sea level. Consequently, the working volume of the present accumulator is established to compensate for the ambient (i.e., cabin) pressure drop affecting the pens.

For example, the air pressure within an airborne aircraft may be about 26% lower than the air pressure at sea level. Consequently, the air pressure within the aircraft will drop about 26% after the aircraft leaves the ground. The accumulator of the present invention is movable to increase the pen reservoir volume by an amount (that is, the working volume of the accumulator) necessary to prevent the 26% drop in the ambient pressure from effecting a corresponding drop in the reservoir back pressure. As discussed earlier, the reservoir volume increase attributable to the accumulator maintains the back pressure at a level that prohibits ink from leaking through the print head of the pen.

The size of the reservoir volume increase necessary to compensate for any ambient pressure drop is related to the amount of air that is in the reservoir at the time the ambient pressure decreases. Consequently, the largest amount of reservoir volume change that must be provided by an accumulator will occur in instances where the greatest amount of air is in the pen, that is, when the pen is nearly empty of ink. In short, the working volume V_{ac} of the accumulator must be greater than or equal to the volume increase of air within the reservoir as a nearly empty pen is subjected to the extreme pressure decrease just described. In equation form:

$$V_{ac} \geq V_r{*}(P_o/P) - V_r \quad [1]$$

Where V_r is the reservoir volume determined with the accumulator displacing its maximum volume from the reservoir volume, and where P_o is the initial ambient (cabin) air pressure at sea level, and P is the minimum pressure level to which the aircraft cabin is pressurized after the aircraft becomes airborne.

The amount of ink remaining in the nearly empty pen reservoir is not subtracted from the volume V_r in equation 1 above. Consequently, the accumulator working volume V_{ac} calculated in equation 1 is slightly larger than that actually required. Nevertheless, it is preferable to have the accumulator working volume sized slightly larger than that calculated in order to compensate for variations in the accumulator production process and for any air diffusion through the accumulator as discussed more fully below.

The relationship among the reservoir volume V_r, pressures P_o, and P, and the accumulator working volume V_{ac}, may be expressed in terms of deliverable ink V_d. Deliverable ink V_d is the amount of ink stored in a pen that is ready for printing. The greatest quantity of deliverable ink is available when the pen is filled with ink and the accumulator is in its minimum volume position, or:

$$V_d = V_r + V_{ac} \quad [2]$$

or:

$$V_r = V_d - V_{ac} \quad [3]$$

Substituting equation 3 into equation 1 and solving for V_{ac} yields:

$$V_{ac} \geq V_d{*}(1 - P/P_o) \quad [4]$$

It can be appreciated that the quantity in parentheses in equation 4 is the fractional value of the relative air pressure increase occurring within the reservoir as a result of the ambient pressure drop $P_o - P$ experienced by the pen. Accordingly, under the extreme condition noted above, whereby the ambient pressure drop is about 26%, equation 4 shows that the working volume of the accumulator must be 26% of the volume of the deliverable ink in the pen. For example, a pen having a 40 cc volume of deliverable ink would require an accumulator having a working volume of 10.4 cc in order to withstand a 26% ambient air pressure drop without leaking.

It is noteworthy that although the ambient pressure decrease $P_o - P$ was discussed above with respect to air transport of pens, it can be appreciated that the air within the reservoir can expand and contract due to temperature changes as well as ambient pressure changes. For example, a pen subjected to high temperatures will incur an expansion of the air in its reservoir, and one skilled in the art can derive the quantitative analogy between pressure and temperature excursions. It is believed, however, that the ambient pressure decrease associated with air transport of pens provides the most severe ambient pressure change experienced by the pens. Accordingly, the accumulator of the present invention is designed to compensate for such a change.

With reference to FIGS. 1–9, an accumulator **20** formed in accordance with the present invention provides an accumulator working volume V_{ac} that effectively compensates for severe environmental changes or operational effects on the back pressure within an ink-jet pen reservoir. More particularly, the accumulator **20** is configured to fit into an ink-jet pen **22** that includes a reservoir **24** having rigid side walls **26, 28, 30, 32** that are configured to hold a quantity of ink. A well **34** is formed in the bottom of the reservoir **24** near one side wall **30**. A thermal-bubble type print head **36** is fit into the bottom wall **38** of the reservoir **24** for ejecting ink drops from the reservoir **24**. The configuration of the reservoir walls and print head may be substantially as provided in the pen component of an ink-jet printer manufactured by Hewlett-Packard Company of Palo Alto, Calif., under the trademark DeskJet.

The accumulator **20** is attached to a cap **40** that is sealed to the top of the side walls **26, 28, 30, 32** of the reservoir **24**. The accumulator **20** includes an expandable bag **42** that is mounted to a spring **44**. The bag **42** and spring **44** are fastened to a fitment **46** that has an upwardly projecting boss **48**. The boss **48** is sealed to a cylindrically shaped sleeve **47** that is integrally formed with the top of the cap **40**.

The bag **42** is fastened to the fitment **46** so that the interior of the bag is in fluid communication with the lower end 90 of a central duct 50 that passes through the boss 48. The fitment 46 is mounted to the cap 40 of the pen 22 with the duct 50 arranged so that the upper end 51 of the duct is in fluid communication with ambient air. Accordingly, the interior of the bag 42 is in fluid communication with ambient air.

With the accumulator 20 in place, the reservoir 24 is filled with ink through a sealable port 43. A slight back pressure (hereinafter referred to as the minimum back pressure) is established within the pen reservoir 24. The minimum back pressure is the minimum amount of back pressure necessary to keep ink from leaking through the print head 36 when the print head is inactive.

As the pen 22 is used for printing, the air pressure within the reservoir 24 decreases (hence, the back pressure increases) as ink is depleted. During printing, the bag 42 expands as a result of the back pressure increase. The bag expansion decreases the volume of the reservoir 24 to maintain the reservoir back pressure within a range such that the print head 36 is able to continue ejecting ink from the reservoir 24. If the ambient pressure should thereafter decrease (for example, during air transport of the pen), the bag 42 will contract to increase the reservoir volume so that the back pressure within the reservoir 24, relative to ambient, does not drop to a level that permits ink to leak from the print head 36.

Expansion of the bag 42 deflects the spring 44. The elasticity of the spring 44 tends to contract the bag 42. The spring 44 and bag 42 are configured and arranged to define a back pressure and bag volume relationship that maintains the reservoir back pressure within an operating range that is suitable for preventing ink leakage, while permitting the print head 36 to continue ejecting ink drops. Moreover, the accumulator 20 is configured so that the maximum volume of the bag 42, that is, the working volume V_{ac} of the accumulator, is large enough to maintain the reservoir back pressure within the operating range mentioned above, despite severe fluctuations in the pressure of the ambient air.

Turning now to the particulars of the accumulator 20 formed in accordance with the present invention, the preferred embodiment of the accumulator spring 44 comprises a strip of metal, such as stainless steel, having a thickness of approximately 75 microns (μ) and a yield strength greater than 5,600 Kg/cm^2. The spring 44 may be stamped or etched from a flat sheet (FIG. 7) and shaped into the relaxed or undeflected configuration shown in FIG. 8.

The relaxed configuration of the spring 44 includes a flat base 52 having a round main aperture 54 formed therethrough. The spring 44 is bent at each edge 56, 58 of the base 52. A pair of elongated slots 60 are formed in the spring 44 at each base edge 56, 58 to facilitate bending of the spring 44 at the base edges 56, 58.

The spring 44 is formed to have curved legs 62. One leg 62 extends downwardly from each edge 56, 58 of the base 52. In a preferred embodiment, the legs 62 are approximately 5.7 cm long. The length of the legs 62 of the spring 44 are such that each end 68 of a leg 62 is very near the bottom wall 38 of the reservoir 24.

Each spring leg 62 is formed to have a radius of curvature of approximately 2.5 cm. Each leg 62 has a convex surface 64 facing inwardly toward the convex surface 64 of the other leg 62.

The spring 44 is sized to be substantially as wide as the space between side walls 30 and 32 (FIG. 6) of the pen reservoir 24. In a preferred embodiment, the legs 62 are approximately 2.5 cm wide.

As best seen in FIGS. 6 and 8, the spring 44 is relatively narrower in the region of the base 52. This shape of the spring 44 allows the accumulator 20 to fit within an ink-jet pen 22 that includes a cap 40 with a sloping front side 66 (FIG. 6). More particularly, the legs 62 of the spring 44 are tapered in width from each base edge 56, 58 to a location between the base edge and the end 68 of each leg 62. The spring width increases in the direction of the leg end 68. It is contemplated that a spring 44 having legs 62 of constant width would also be suitable. It is preferred, however, that the width of the spring 44 be shaped to fit across substantially the entire width of the reservoir 24 so that the bag 42 that is attached to the spring 44 will have the greatest width possible given the constraints of the reservoir side walls and cap configuration.

Four access holes 71 are formed in the spring base 52. One hole 71 is located near each corner of the base 52. Moreover, a pair of spaced apart access holes 72 are formed through the spring legs 62 beneath and near each base edge 56, 58. Four other spaced apart access holes 74 are formed through the ends 68 of each spring leg 62. The access holes 71, 72, 74 provide means for attaching the bag 42 to the spring 44, as described more fully below.

The bag 42 of the present invention is preferably formed of two thin flexible sheets 76, 77 (FIG. 7) that are sealed together at their outer edges 78. One sheet, the first sheet 76, has an opening 80 for permitting the passage of air into and out of the space between the edge-sealed first sheet 76 and second sheet 77. The sheets 76, 77 are shaped slightly larger (i.e., in width and length) than the spring 44. Moreover, the portion 79 of the edge 78 of each sheet that is near the tapered part of the spring 44 is shaped into a smooth curve.

Preferably, the first and second sheets 76, 77 are formed of a material that can be heat-welded (as at the edges 78) and that is substantially impermeable to air. Heat-weldable bag material is preferred because such material permits an efficient method for forming the bag 42 and for attaching the bag 42 to the spring 44 and fitment 46, as will be described more fully below.

Material that is substantially impermeable to air if preferred as bag material so that the back pressure within the pen reservoir 24 is not reduced by air that passes into the bag 42 through opening 80 and then diffuses through the walls of the bag sheets 76, 77 into the reservoir 24.

In view of the above, a preferred embodiment of the sheets 76, 77 that make up the bag 42 comprises a thin "barrier" film of material such as ethylene vinyl alcohol (EVOH) covered with thin outer layers of polyethylene. The EVOH film is preferably about 12 μ thick. The polyethylene layers are between 15 μ and 50 μ thick.

The EVOH film provides the desired low-air-permeability property. It is contemplated, however, that the barrier film for preventing diffusion of air through the bag 42 may be formed of a variety of materials such as PVDC (SARAN), nylon, polyester or metal foils, or combinations of such materials.

The polyethylene outer layers of the sheets 76, 77 provide the desired heat-weldable property. The use of polyethylene as outer bag layers is also advantageous because that material generally includes no cure accelerators or plasticizers that might leach into and thereby contaminate the ink within the reservoir 24.

Before the bag 42 is formed by edge-welding the sheets 76, 77, two elements are placed between the sheets. One element, hereinafter referred to as a "release patch" 82, comprises a thin (approximately 25 μ) sheet of material, such as polyester, having a melting point that is substantially higher than the melting point of the polyethylene outer layers of the bag sheets 76, 77. The release patch 82 is generally circular shaped and positioned beneath the opening 80 in the bag 42. Preferably, the release patch 82 includes an adhesive on one side for securing the patch 82 to the second sheet 77 of the bag 42. The release patch 82 provides a mechanism for facilitating attachment of the bag 42 to the fitment 46, as described more fully below.

The second element that is disposed within the bag 42 is a narrow strip, hereinafter referred to as a breather strip 84, of perforated polyethylene material having a maximum thickness of approximately 375 μ, such as that manufactured by Ethyl VisQueen Film Products under the trademark VISPORE. The breather strip 84 provides a mechanism for facilitating movement of air into and out of the bag 42, as described more fully below.

The spring 44 and the bag 42 are attached to the underside of the fitment 46. More particularly, the fitment 46 is formed of polyethylene having a higher melting point than the polyethylene outer layers of the bag sheets 76, 77 and includes a generally flat base plate 86 having an upwardly projecting boss 48. The boss 48 is generally cylindrically shaped and has a chamfered upper end 49. The boss 48 includes an internal duct 50 that extends completely through the boss.

The fitment base plate 86 includes two concentric annular mounting rims 88 that are integrally formed with the base plate 86 to protrude downwardly therefrom through the main aperture 54 in the base 52 of the spring 44. The mounting rims 88, which surround the lower end 90 of the duct 50 are employed for fastening the bag 42 to the fitment 46. To this end, the portion of the first bag sheet 76 that surrounds the bag opening 80 is pressed through the main aperture 54 in the spring 44 to bear upon the mounting rims 88. A heated chuck (not shown) is pressed against the second sheet 77 of the bag 42 immediately beneath the mounting rims 88. Heat from the chuck is transferred from the second sheet 77 via the release patch 82 to the interface of the mounting rims 88 and the first sheet 76. The mounting rims 88, which, as part of the fitment are formed of polyethylene having a higher melting point than the bag, are heated to until the rims 88 and the first sheet 76 flow together to form a weld. Upon cooling, the rims 88 bond with the first layer 76 to form an air-tight seal.

With the bag 42 sealed to the fitment 46 as just described, the only path for air into and out of the bag 42 is through the duct 50 in the fitment boss 48.

It can be appreciated that the release patch 82, in addition to transferring heat from the chuck to the interface of the first sheet 76 and mounting rims 88, separates the first and second sheets 76, 77 in the region where the heated chuck is applied. Accordingly, the release patch 82 prevents the two bag sheets 76, 77 from becoming bonded together at the mounting rims 88.

Preferably, the outermost mounting rim 88 of the fitment 46 is sized to have a diameter that is just slightly less than the diameter of the main aperture 54 in the spring 44. Accordingly, the spring base 52 fits snugly around the outermost rim 88. The effect of this fit is to provide a registration mechanism for centering the spring aperture 54 beneath the duct 50 in the fitment 46. Moreover, the spring base 52 also includes an alignment hole 89 formed therethrough that mates with a downwardly projecting pin (not shown) in the fitment base plate 86. The mating alignment hole 89 and pin provide a supplemental registration mechanism to ensure that the spring 44 is properly positioned relative to the fitment 46.

The bag 42 is fastened to the fitment 46 and spring 44 in a manner that urges the bag into a contracted or minimum volume state. The preferred means for fastening the bag 42 includes heat-welding the bag 42 to the fitment through the access holes 71, 72 at the base 52 of the spring 44, and securing each end 92 of the bag 42 to a corresponding end 68 of a spring leg 62.

More particularly, the underside of the fitment base plate 86 includes four downwardly extending posts 93, each post 93 being shaped and arranged to fit through an aligned access hole 71 in the corner of the spring base 52. The posts 93 pierce the bag sheets 76, 77 as a heated platen (not shown) is pressed against the bag sheets 76, 77. The platen then spreads and flattens the ends of the posts 93 to effectively form a rivet to attach the bag sheets 76, 77 to the fitment base plate 86. This operation is performed while the bag 42 is substantially completely contracted.

Each of two opposing ends of the fitment base plate 86 is formed to have an extension 94 that is attached to the base plate 86 by two spaced apart hinges 95. The hinges 95 are thinner (approximately 250 μ) than the base plate 86 and fold around the associated edges 56, 58 of the spring base 52 so that each extension 94 covers a pair of access holes 72 formed beneath and near each edge 56, 58. Each extension 94 includes on its underside an outwardly projecting pair of posts 96. Each of the posts 96 is sized and arranged to fit through an associated access hole 72. With the posts 96 extending through the access holes 72, both sheets 76, 77 of the bag 42 are pressed against the pairs of posts 96 at each edge 56, 58. The posts 96 are then heat riveted to the contacting bag sheets 76, 77 in a manner as previously described.

Within the space between each pair of hinges 95, a pair of protrusions 98 are formed in the fitment base plate 86 to extend downwardly through the slots 60 in the spring. One protrusion 98 extends through one slot 60. The protrusions 98 help to keep the fitment base plate 86 properly aligned over the base 52 of the spring 44. It is contemplated, however, that the projecting posts 93, 96 will provide adequate alignment of the bag 42 and spring 44 in the absence of protrusions 98.

The breather strip 84 within the bag 42 is aligned between adjacent access holes 72 in the spring and extends completely around each bent edge 56, 58 of the spring 44. Accordingly, the breather strip 84 facilitates air movement through the bag even though the bag is tightly fastened to the edges 56, 58 of the spring base 52 at the access holes 72. Moreover, the breather strip 84 ensures that the bag 42 will expand (i.e., the sheets 76, 77 will move apart) despite condensation within the bag, which condensation would tend to stick the sheets 76, 77 together.

The ends 92 of the bag 42 are wrapped around the ends 68 of the spring legs 62 so that each portion of the bag that is between the edges 56, 58 and the leg ends 68 is pulled firmly against the convex surface 64 of each leg 62 (FIG. 1). The ends 92 of the bag 42 cover the access holes 74 in the leg ends so that when heat is applied to the bag 42 at the access holes 74, the bag 42 will weld to itself within the holes 74 to secure the bag ends 92 to the spring leg ends 68.

The periphery 55 of the fitment boss 48 is sealed to the sleeve 47 in the reservoir cap 40 so that no air can pass between the fitment 46 and the cap 40. The cap 40 is then sealed to the reservoir side walls with the accumulator 20 suspended inside the reservoir 24. The reservoir 24 is then filled with ink, as described earlier.

As noted earlier, the filled pen 22 is provided with a minimum back pressure. Calculated at the print head 36, the minimum back pressure should be, for example, 2.5 cm water column. Accordingly, the minimum back pressure is established by removing some ink from the filled and sealed reservoir. The fluid volume removed to establish the minimum back pressure is referred to as the drawdown volume V_{dd}.

It is noteworthy that the bag 42, which is securely held against the spring 44, will not expand appreciably as the drawdown volume V_{dd} is removed. Accordingly, the back pressure attributable to the removal of the drawdown volume will rise rapidly (See line O-A in the graph of FIG. 10) as the drawdown volume V_{dd} is removed because the accumulator bag 42 does not appreciably expand to fill the space (hence, lower the back pressure) corresponding to the drawdown volume V_{dd}. It has been found that with an accumulator formed in accordance with the present invention, a very small amount of drawdown volume (for example, less than 5% of the reservoir capacity) is required to bring the back pressure up to the minimum level mentioned above.

The minimum back pressure level establishes the low end of the back pressure operating range referred to above. The maximum back pressure or upper level of the back pressure operating range is that level (for example, 11.5 cm water column) above which the print head 36 would be unable to "pump" against for ejecting ink drops. FIG. 10 illustrates a graph showing the relationship between reservoir back pressure P changes (ordinate) and changes in the fluid volume V (abscissa) of the reservoir. The origin O of the graph of FIG. 10 represents a filled reservoir volume with no back pressure. Also depicted in FIG. 10 is the accumulator working volume V_{ac} that is available for maintaining the back pressure within the reservoir (or, more precisely, at the print head 36) within the operating range between the minimum and maximum back pressure levels shown in the graph.

As the print head 36 operates to eject ink drops from the reservoir 24, the consequent reduction in ink volume in the reservoir increases the back pressure. If this increase were not regulated, the back pressure in the reservoir 24 would rapidly increase (dashed line in FIG. 10), beyond the maximum back pressure, and the print head 36 would become inoperative. With the present accumulator 20, however, the back pressure increase above the minimum level tends to expand the bag 42. More particularly, as the back pressure rises, the relatively higher pressure ambient air is drawn through the duct 50 in the fitment 46 and into the opening 80 in the bag 42. As the bag 42 expands, the first sheet 76 of the bag presses against the spring legs 62 so that those legs 62 are deflected out of the relaxed, curved configuration (FIG. 1) into a reverse bowed configuration (FIG. 2).

The elasticity of the spring legs 62, which tends to contract the bag 42 against the convex surfaces 64, is substantially overcome by the expansion of the bag 42 that is caused by the increase (over minimum) of the back pressure within the reservoir 24. The volume decrease in the reservoir 24 that is attributable to the expansion of the bag 42 maintains the back pressure beneath the maximum back pressure discussed above.

In a preferred embodiment, the bag 42 expands to its maximum volume condition as ink is printed out of the pen. During this expansion the bag 42 maintains the back pressure beneath the maximum back pressure level. At the point when the bag 42 of the preferred embodiment has expanded to its maximum volume condition, about 30% of the pen's ink has been printed out. Any further printing will cause a further increase in back pressure, which may be relieved by the introduction of ambient air into the reservoir 24. To this end, the pen 22 includes a bubble generator 102 formed in the bottom wall 38 of the reservoir 24. The bubble generator 102 may comprise a small orifice 104 extending from a recess 106 in the reservoir bottom wall 38.

The orifice 104 of the bubble generator 102 is sized, for example, about 200 μ in diameter, so that any air bubbles will move through the air/ink interface at the orifice 104 and into the reservoir air space only in instances where the back pressure begins to rise above the maximum back pressure level (FIG. 10). As air bubbles from the bubble generator 102 enter the reservoir 24, the back pressure will drop to a level just below the maximum level so that the print head 36 is able to continue ejecting ink drops.

As noted earlier, the greatest change in the reservoir back pressure will occur as a nearly empty pen is subjected to a significant ambient air pressure increase, such as would occur during air shipment of the pen. In such an instance, as the ambient air pressure begins to drop, the pressure in the bag 42 also drops. As the pressure drops, the bag 42, which just prior to the ambient air pressure drop is expanded to its maximum volume (See FIG. 2 and point B in FIG. 10), collapses to increase the reservoir volume and thereby keep the back pressure from dropping to a level so low that ink may leak from the print head 36. Moreover, the elastic recovery of the spring legs 62 in returning toward the undeflected state as the bag 42 collapses ensures that the bag will be contracted to its minimum volume configuration (FIG. 1) so that the entire amount of the accumulator working volume V_{ac} is employed for increasing the reservoir volume.

In the preferred embodiment, it has been found that an accumulator 20 formed as described above will provide a working volume large enough to compensate (for example, by contracting from its maximum to minimum volume level as just described) for ambient air pressure changes of up to approximately 30%. As noted earlier, the most severe ambient air pressure change experienced by a pen would likely be in the range of approximately 26%. Accordingly, for ambient air pressure decreases of 30% or lower, the accumulator 20 of the present invention provides sufficient working volume to keep the back pressure above the minimum back pressure level. It can be appreciated, therefore, that unlike accumulators of the past, the present accumulator 20 need not be supplemented with any overflow mechanisms, such as the overflow orifice and attached catch basin mentioned above. Moreover, the pen volume that would otherwise be necessary for a catch basin may instead be used to increase the ink capacity of the pen.

In the event that a pen 22 may be subjected to an ambient air pressure decrease of greater than about 26%, it is contemplated that the bag 42 of the accumulator 20 may be configured for providing a greater working volume than described above. For example, an alternative embodiment of the accumulator bag 142 may be pleated as shown in the cross-sectional view of FIG. 11. The pleated bag 142 will provide a significant amount of accumulator working volume because it will expand to a maximum volume that is substantially larger than the unpleated bag 42, and still be contractible against the convex surfaces 64 of the spring legs 62 to a minimum volume that is substantially equal to that of an unpleated bag 42.

With respect to the use of the pleated bag 142, it is preferred to attach thin webs 108 of film material between the inner folded edges 110 of the bag pleats. The webs 108 are placed at closely placed intervals along the length of the bag 142 and serve to keep the pleats from inverting under the influence of the back pressure within the reservoir. Consequently, the webs 108 ensure that the pleated bag will return to the flat minimum volume position as the back pressure in the reservoir decreases.

Another technique for increasing the accumulator working volume may include the use of a bag that is relatively longer than the earlier described bag 42 and which, after being attached to the spring leg ends 68 as described earlier is folded back over the portion of the bag overlying the convex surfaces 64 of the spring legs 62. The outermost end of the longer bag is then heat-welded to the posts 96 in the fitment extensions 94. With this embodiment, additional breather strips 84 would be included within the bag to be wrapped around the spring ends 68 between the access holes 74 in those ends 68 so that air may flow through the entire length of the bag.

Typically, slight variations in the materials and construction of the present accumulator will result in the near complete inflation of one portion of the bag 42 that is adjacent one spring leg 62 before inflation of the portion of the bag that is adjacent to the other spring leg 62. Referring to FIG. 10, the vertical component of the curve portion from point A to A_1 generally represents the back pressure increase that occurs as the print head begins to eject ink drops from a full reservoir. The back pressure increase P_1 between points A and A_1 causes the partial expansion of one bag portion (for convenience, referred to as the "first" bag portion 63, FIG. 12) that is adjacent to one spring leg 62. Put another way, the back pressure increase P_1 expands the first bag portion 63 to bend the spring leg 62 out of the relaxed state (FIG. 1) and into an intermediate position wherein the spring leg 62 has moved to a generally straight configuration as shown in FIG. 12.

After the spring leg 62 is bent into the generally straight configuration of FIG. 12, the spring offers only slight resistance to further deflection from the straight and into the reverse-bowed configuration (FIG. 2). Accordingly, the first bag portion 63 readily inflates to its fully expanded position as more ink is ejected from the pen as represented by curve section A_1–A_2, FIG. 10.

The inflation of the first bag portion 63 associated with the reservoir ink depletion represented by curve segment A_1–A_2 effectively regulates the reservoir back pressure so that substantially no incremental back pressure increase occurs during that period. Instead, there is usually a slight decrease in back pressure because the spring leg 62, in moving out of the generally straight configuration (FIG. 12) and into the reverse-bowed configuration, acts as a toggle mechanism having a slight snap-action that results in a rapid incremental expansion of the first bag portion 63 and consequent dip in the reservoir back pressure level.

The vertical component of the curve portion from point A_2 to A_3 generally represents the back pressure increase P_2 that occurs as the print head continues to eject ink from the reservoir after the first bag portion is fully inflated. The back pressure increase P_2 expands the bag portion that is mounted to the spring leg that is opposite the leg 62 to which the first bag portion 63 is mounted. Accordingly, the back pressure increase P_2 expands the other bag portion to bend the associated spring leg 62 out of the relaxed state (FIG. 2) into an intermediate position wherein a spring leg assumes a generally straight configuration. Thereafter, the bag portion is fully inflated, as described with respect to the first bag portion 63, and the leg 62 moves into the reverse-bowed configuration.

The above-described preferred embodiment of the present accumulator is designed to ensure that the incremental increases in back pressure P_1 and P_2 (FIG. 10), which cause straightening of the spring legs 62 as described above, are predictably small enough to avoid approaching the maximum back pressure allowable for a given pen. In other words, the spring 44 and bag 42 are configured and arranged to minimize these incremental back pressure increases P_1, P_2 so that once the reservoir back pressure is established above the required minimum back pressure, the pressure-volume curve (FIG. 10) will approach, as closely as practical, an ideal pressure-volume curve, which ideal curve is substantially parallel to the absisca of FIG. 10 and between the minimum and maximum back pressures.

The next-described preferred embodiment of the accumulator spring permits effective minimization of the incremental pressures P_1 and P_2 so that the corresponding actual pressure-volume curve can more closely approximate the ideal pressure-volume curve. Moreover, the alternative configuration of the spring provides relatively greater flexibility in the ends of the spring legs so that the spring legs can bend to better conform to the fully-inflated shape of the bag, thereby facilitating greater expansion of the bag and a corresponding increase in the overall working volume V_{ac} of the accumulator.

FIG. 13 shows the alternative embodiment of the spring 144 in plan, before it is shaped into the relaxed position (see FIG. 1) for use with the bag 42. The spring 144 is shaped so that each end 168 of a leg 162 is made to be slightly more flexible than the remaining portion of the spring. The relatively greater flexibility of the spring ends 168 is accomplished by forming an array of apertures 163 near each end 168, thereby reducing the mass of that portion of the spring 144. Preferably, the apertures 163 are generally elongated in the direction parallel to the long axis of the spring member 144. It is also preferred that near the center of the spring member 144, the apertures 163 are slightly longer, the length of the apertures generally decreasing in the direction away from the longitudinal center of the spring member 144.

FIG. 14 depicts a front cross-section of an ink jet pen that includes an accumulator utilizing the alternative spring member 144, showing the accumulator in the expanded or maximum volume position. It is noteworthy that as a consequence of the increased flexibility (that is, reduced resistance to deflection) of the spring ends **168**, the bag portions **167**, **169** mounted to the spring legs **162** are able near spring ends **168** to expand to a width "W" that is greater than would be possible were the ends of spring legs **162** not so flexible. This increased bag width W near the spring ends **168** provides a corresponding increase in the overall working volume V_{ac} of the accumulator. This working volume V_{ac} increase expands the environmental operating range of the pen without a corresponding reduction in the amount of deliverable ink within the reservoir because the alternative spring and attached bag resile to the substantially flat, relaxed configuration, thereby not displacing any more ink volume than displaced by the earlier described embodiment.

Also formed in the alternative embodiment of the spring member **144** is an elongated slit **165** that is formed generally along the longitudinal center line of the spring member to extend from the end **168** of each spring leg **162** to a location near the slots **160** in the spring member, through which slots **160** the spring member **144** is bent for attachment to the fitment as described above. Such a slit **165** reduces the spring mass along substantially the entire length of the spring leg **162**. The spring mass reduction associated with the longitudinal slit **165** increases the overall flexibility of the spring, thereby substantially eliminating the snap-action or toggle-like effect of the spring legs as mentioned above. As a result of the increased flexibility, the incremental back pressure increases P_1 and P_2 are substantially minimized. Put another way, the overall configuration of the spring **144** is more uniformly responsive to the forces applied to it by the expanding bag **42**. As was the case with the earlier-described embodiment, contraction of the bag permits the spring **144** to resile toward the relaxed configuration where the bag is flattened.

It will be appreciated by one of ordinary skill in the art that numerous alternative embodiments for a spring member may be used. For example, FIG. **15** depicts another alternative embodiment of the spring member **244** wherein a pair of additional longitudinal slits **266** extend generally along the length of the legs **262** from each end **268**, with a central longitudinal slit **265** between each pair of slits **266**.

FIG. **16** depicts another alternative embodiment of a spring member **144** where, in addition to a central longitudinal slit **365**, end apertures **363** are formed as generally circular in shape.

FIG. **17** depicts another alternative embodiment of a spring member **444** having no central longitudinal slit. A plurality of apertures **463**, configured and arranged substantially the same as apertures **163** in the embodiment depicted in FIG. **13**, are formed near the ends **468** of the spring member **444** for the same flexibility enhancement as mentioned above.

FIG. **18** depicts another alternative embodiment of a spring member **544** where, in addition to end apertures **563**, such as those shown as **463** in FIG. **17**, there is also included a few more apertures **569** formed in the spring legs **562** near the slots **560** through which the member **544** is bent for attachment to a fitment. These additional slots **569** make more flexible the portion of the spring legs **562** near those slots **560**. Accordingly, as shown in dashed lines **561** in FIG. **14**, the upper parts of bag portions **167**, **169** are able to expand to a slightly greater width than would otherwise be possible with a spring member not having the upper apertures **569**. As a result, the slightly increased volume depicted by dashed lines **561** increases the working volume V_{ac} of the accumulator.

Having described and illustrated the principles of the invention with reference to preferred embodiments and alternatives, it should be apparent that the invention can be further modified in arrangement and detail without departing from such principles. For example, a spring having only a single leg carrying a bag on its convex surface may provide a sufficient accumulator working volume. Moreover, an effective accumulator may include a spring that is curved about its longitudinal axis instead of about a lateral axis as described above. Furthermore, the spring may be configured with other arrangements of holes or slots, or thickness variations that will affect its elasticity and in turn will modify the back pressure as the bag expands and forces the spring to uncurl. It is also contemplated that the function of the spring in contracting the bag and in minimizing draw-down volume may be accomplished by a spring configuration having two layers with the bag contracted between those layers when the spring is in its undeflected configuration. It is also possible that the bag may be formed so that one of the two bag layers has the elastic characteristics of the spring, thereby eliminating the need for a discrete spring component.

In view of the above, it is to be understood that the present invention includes all such modifications as may come within the scope and spirit of the following claims and equivalents thereof.

We claim:

1. An accumulator apparatus comprising:
   an expandable and contractible bag;
   mounting means for mounting the bag within a fluid volume of a particular size so that expansion of the bag decreases the size of the fluid volume, the bag including an opening arranged so that an interior of the bag is in communication with ambient air outside the fluid volume; and
   a spring disposed within the fluid volume and having a first portion that assumes a curved relaxed state, part of the bag being adjacent to one side of the curved first portion, the bag part being urged by the spring to be substantially fully contracted when the spring first portion is in the relaxed state.

2. The apparatus of claim 1 wherein the first portion of the spring has a convex surface whenever the first portion is in a relaxed state, the bag part being adjacent to the convex surface.

3. The apparatus of claim 1 wherein the spring has a flat base connected to the first portion of the spring.

4. The apparatus of claim 3 wherein the spring includes a second portion connected to the base, the second portion assuming a curved relaxed state, another part of the bag being disposed adjacent to one side of the second portion and to one side of the base of the spring.

5. The apparatus of claim 1 wherein the spring includes a second portion that assumes a curved relaxed state, another part of the bag being disposed adjacent to one side of the curved second portion.

6. The apparatus of claim 1 wherein the spring is stainless steel.

7. The apparatus of claim 1 wherein the spring has a thickness of about 75 microns and a yield strength greater than about 5,600 Kg/cm^2.

8. An accumulator apparatus comprising:

an expandable and contractible bag;

mounting means for mounting the bag within a fluid volume of a particular size so that expansion of the bag decreases the size of the fluid volume, the bag including an opening mounted so that an interior of the bag is in continuous communication with ambient air outside the fluid volume, wherein the bag is formed of flexible material and is contractible into a generally flat configuration and

wherein the fluid volume is defined by a reservoir, the reservoir being sealed and containing ink therein under a back pressure, the back pressure being present irrespective of whether the bag is expanded or contracted.

9. The accumulator apparatus of claim 8 further comprising a print head connected to the reservoir for ejecting drops of ink from the reservoir.

10. The apparatus of claim 8 wherein the bag comprises sheets formed of heat-weldable material.

11. The apparatus of claim 9 wherein the bag sheets include a film of air-impermeable material attached thereto for rendering the bag substantially impermeable to air.

12. An accumulator for an ink-jet pen that has a substantially sealed reservoir volume, comprising:

a spring; and

an expandable and contractible bag attached to one side of the spring, the spring and bag being positionable within the reservoir volume, the bag including an opening arranged so that an interior of the bag is in communication with ambient air outside of the reservoir volume, the bag and spring being attached adjacent one another so that the bag expands to deflect the spring as fluid pressure inside the reservoir volume decreases relative to pressure of the ambient air outside of the reservoir volume.

13. The accumulator of claim 12 further comprising print head means for ejecting ink drops from the reservoir volume.

14. The accumulator of claim 12 wherein the spring contracts the bag as fluid pressure outside the reservoir volume decreases relative to fluid pressure inside the reservoir.

15. The apparatus of claim 12 wherein the spring includes a first portion that assumes a curved relaxed state, the bag being attached to one side of the curved first portion.

16. The apparatus of claim 15 wherein the first portion of the spring has a convex surface whenever the first portion is in a relaxed state, the bag being attached to the convex surface.

17. The apparatus of claim 12 wherein the spring is metal and the bag is formed of flexible material having a plastic outer surface.

18. An accumulator apparatus comprising:

a sealed reservoir for containing ink and having a back pressure established therein;

an expandable and contractible bag mounted within the reservoir, the bag having an opening therein arranged so that an interior of the bag is in communication with ambient air outside of the reservoir, the bag being arranged so that contraction of the bag increases back pressure in the reservoir; and

a print head mounted to the reservoir and adapted for ejecting ink drops from the reservoir.

19. The apparatus of claim 18, further comprising a spring disposed adjacent to the bag and arranged to urge contraction of the bag for increasing the reservoir back pressure.

20. The apparatus of claim 19 wherein the spring and bag are configured and arranged so that the bag is substantially fully contracted when the spring is in a relaxed state.

21. The apparatus of claim 19 wherein the bag is attached to the spring by a fitment, and the spring includes a plurality of access holes formed therein, the bag being attached to the fitment through the access holes.

22. The apparatus of claim 21 wherein the fitment includes other access holes for attaching the bag to said bag through the other access holes.

23. A method for making an accumulator apparatus, comprising the steps of:

attaching an expandable and contractible bag to a spring so that when the spring is in a relaxed state the bag will be substantially contracted;

configuring the bag and spring so that the bag will expand and deflect the spring whenever a pressure difference between the fluid inside and outside of the bag exceeds a predetermined minimum level; and

supporting the bag and spring to maintain the interior of the bag in fluid communication with fluid outside of the bag thereby to define an unobstructed path for fluid movement into and out of the bag.

24. The method of claim 23 wherein the configuring step includes the substep of shaping the spring to have a curved portion when in a relaxed state.

25. The method of claim 24 wherein the attaching step includes the substep of fastening the bag to the curved portion of the spring.

26. The method of claim 23 wherein the spring is metal and wherein the bag has a plastic outer surface, the attaching step including the substep of forming access holes in the spring for providing locations for attaching the bag to the spring.

27. The method of claim 23 wherein the accumulator is to be disposed within a fluid volume that may be subjected to a decrease in pressure, the configuring step including the step of sizing the bag to define a working volume that is equal to or greater than a change in the fluid volume attributable to the decrease in pressure.

28. An accumulator apparatus for an ink reservoir of a pen comprising:

an elongated spring member mounted inside the reservoir and shaped to resile to a relaxed state and to resist deflection out of the relaxed state;

an expandable and contractable bag mounted along the length of the spring member so that expansion of the bag deflects the spring member and so that contraction of the bag permits the spring member to resile toward the relaxed state; and

shaping means for reducing along only a portion of the length of the spring member the resistance of the spring member to deflection caused by bag expansion.

29. The apparatus of claim 28 wherein the elongated spring member has a longitudinal centerline and an end and a middle portion away from the end, and wherein the first portion of the spring member is located away from the middle portion of the spring member.

30. The apparatus of claim 29 wherein the first portion of the spring member has an array of apertures formed therein for reducing the resistance of the spring member to deflection.

31. The apparatus of claim 30 wherein the first portion of the spring member is located adjacent to the end of the spring member.

32. The apparatus of claim 30 wherein the first portion is located on opposite sides of the middle portion of the spring member.

33. The apparatus of claim 30 wherein the spring member is constructed with the array of apertures shaped to reduce the mass of the spring member near the longitudinal centerline by an amount greater than the amount of mass reduced by the apertures away from the longitudinal centerline of the spring member.

34. The apparatus of claim 33 wherein the first portion of the spring member is located adjacent to the end of the spring member.

35. The apparatus of claim 33 wherein the first portion is located on opposite sides of the middle portion of the spring member.

36. The apparatus of claim 30 wherein the spring member is constructed with the array of apertures shaped to reduce the mass of the spring member near the end of the spring member by an amount greater than the amount of mass reduced by the apertures away from the end of the spring member.

37. The apparatus of claim 36 wherein the first portion of the spring member is located adjacent to the end of the spring member.

38. The apparatus of claim 30 wherein the spring member is configured to include a slit formed along the longitudinal centerline of the spring member to extend substantially continuously from the end of the spring member through the middle portion of the spring member.

39. The apparatus of claim 30 wherein the spring member is configured to include a plurality of spaced apart slits extending along the length of the spring member.

40. The apparatus of claim 28 wherein the first portion of the spring member is thinner than the remaining portion of the spring member.

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