

BRITISH PATENT APPLICATION

APPLICANT: Seiko Epson Corporation

TITLE: A Nozzle Plate for an Ink Jet Printer
and Method of Manufacturing said Nozzle
Plate.

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INVENTORS: Kiyohiko Takemoto
Shuichi Yamaguchi
Akio Yamamori
Kazushige Haketa
Yukiyoshi Icyu

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J.MILLER & CO

34 Bedford Row, Holborn, London WC1R 4JH

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NOZZLE PLATE FOR AN INK JET PRINTER AND METHOD OF MANUFACTURING SAID NOZZLE PLATE

The present invention relates to a nozzle plate for an ink jet printer and a method of manufacturing such nozzle plate.

An ink jet printer of a type in which a recording image is written onto a recording medium by ink droplets jetted from nozzles has a problem in that the direction in which each ink droplet travels deviates from a prescribed course because a portion in the vicinity of the nozzle becomes wet with ink.

To overcome this problem, a nozzle plate, disclosed in Japanese Unexamined Patent Publication No. 57-107148, is designed to control the wetness of the neighbourhood of the nozzle by uniformly forming, by sputtering, an ink-repellent coating layer such as a fluorescent film on both the inner surface of the nozzle and the front surface of the nozzle plate.

Keeping the vicinity of the nozzle from becoming wet with ink, this nozzle plate is advantageous in successfully stably splashing an ink droplet in the axial direction. However, the method of forming the ink-repellent coating employed is not successful in making step coverage of the ink-repellent coating consistent. As a result, if the step coverage is too large and excessive, the centre of vibration of the meniscus of the ink in the nozzle is further away from the front surface of the nozzle plate, the distance depending on the degree of excess coverage. This in turn demands greater energy for jetting the predetermined amount of ink and thus deteriorates jetting efficiency. If the step coverage is too small, the centre of vibration of the meniscus of the ink in the nozzle is closer to the front surface of the nozzle plate, which in turn causes a "misfire". That



is, another ink droplet is jetted due to its meniscus being vibrated after an ink droplet has been jetted, and thus causes great inconsistency among products, impairing reliability.

It is an object of the present invention to overcome the aforementioned problems. It is another object of the present invention to provide a nozzle plate which can achieve substantially stable jetting of ink droplets by limiting the step coverage of an ink-repellent substance over the inner surface of a nozzle to within a predetermined range.

Another object of the present invention is to provide a method of preparing a nozzle plate which can limit the step coverage of an ink-repellent coating over the inner surface of a nozzle to within a predetermined range.

According to one aspect of the present invention there is provided a nozzle plate comprising at least one nozzle for the ejection of ink droplets and an ink repellent coating formed on a surface of said nozzle plate surrounding the at least one nozzle and on the inner surface of said at least one nozzle to a depth from said nozzle plate surface such that the volume of space within the nozzle from said nozzle plate surface to a meniscus forming surface is within the range 0.04 to 0.5 times the volume of ink to be ejected.

According to another aspect of the present invention there is provided a method for regulating the depth of ink repellent coating within a nozzle from one surface of a nozzle plate, comprising forming a mask on the other surface of the nozzle plate, causing part of the mask to enter the nozzle such that a volume of space in the nozzle between the mask and said one surface of the nozzle plate is within the range of 0.04 to 0.5 times the volume of ink to be ejected from the nozzle, and hardening the mask.

The present invention is applied to a nozzle plate of an ink jet printer in which a part of an ink-repellent coating layer for covering the front surface of the nozzle plate is



caused to step into the inner surface of a nozzle so that the volume of a space within the nozzle from the front surface of the nozzle plate to a meniscus forming surface is limited to a range of from 0.05 to 0.50 with respect to the amount ink to be jetted.

In addition, the method of preparing a nozzle plate for an ink jet printer involves the steps of putting a photosensitive resin member in pressure contact with the back surface of the nozzle plate, and heating the photosensitive resin member to cause a part of the photosensitive resin member to step into the inner surface of a nozzle so that the volume of a space within the nozzle from the surface of the nozzle plate can be limited to a range of from 0.05 to 0.50 with respect to the amount of ink to be jetted; and then hardening the photosensitive resin member by rays of light, and forming an ink-repellent coating layer at least on the inner surface of the nozzle and the front surface of the nozzle plate with the hardened photosensitive resin member as a masking member.

Embodiments of the present invention will now be described with reference to the accompanying drawings, of which:

Figs. 1 (a) to (d) are diagrams showing a process of forming a nozzle plate, according to an embodiment of the present invention;

Fig. 2 is an enlarged sectional view showing a main portion of the nozzle plate, according to another embodiment of the present invention;

Fig. 3 is an enlarged sectional view showing a main portion of a nozzle plate, according to yet another embodiment of the present invention;

Figs. 4 (a) to (d) are diagrams showing a process of forming a nozzle plate, according to a still further embodiment of the present invention;

Fig. 5 is a diagram showing the relationship between the temperature and the step coverage of a particular photosensitive resin film; and

Fig. 6 is a diagram showing the relationship between V_m/V_i (the ratio of the volume of space within the nozzle from the front surface of the nozzle to the centre of



vibration of the meniscus of the ink to be jetted and the volume of that ink) and the frequency of stray fly and defective jetting.

Fig. 1 shows a process of preparing a nozzle plate, according to an embodiment of the present invention. More particularly, it shows a surface treatment process to which the nozzle plate is subjected. Figs. 2 and 3 show a nozzle plate prepared by such a process.

A nozzle plate, denoted by reference numeral 1 in Fig. 1 may be made of metal, ceramic, silicon, glass, plastics and the like. Preferably it is made of a single material, such as titanium, chromium, iron, cobalt, nickel, copper, zinc, tin, gold; or of an alloy such as a nickel-phosphor alloy, a tin-copper-phosphor alloy (phosphor bronze), a copper-zinc alloy, a stainless steel; or of polycarbonate, polysulfone, an ABS resin (acrylonitrile butadiene styrene copolymer), polyethylene terephthalate, polyacetal; or of one or more of a variety of photosensitive resin materials. Generally, a nozzle plate 1 has a plurality of nozzle holes 4, each nozzle hole including a funnel-shaped portion 4a opening to the back surface 3 and a cylinder-like orifice portion 4b opening to the front surface 2.

A photosensitive resin film 5 that is hardened by light, such as DAIYARON FRA304-38 (trade name), a dry film resist manufactured by Mitsubishi Rayon Co. Ltd. is laminated on the back surface 3 of the nozzle plate 1. Part of the photosensitive resin film 5 is then "stepped" into the nozzle 4 to a depth of 5 to 40 μm from the front surface 2 of the nozzle plate 1 by heating the photosensitive resin film 5 to a temperature of 40 to 70°C while applying a pressure of approximately 4.0 kgf/cm^2 (39.23 N/cm^2) to the photosensitive resin film 5 (Fig. 1 (a)).

Then, both the back surface 3 and the front surface 2 of the nozzle plate 1 are exposed to ultraviolet radiation. Consequently, the photosensitive resin film 5 formed on



the back surface 3 of the nozzle plate 1 and stepped into the nozzle 4 is hardened as a whole (Fig. 1 (b)).

This process may be considered as a pre-process for regulating the step coverage d of a eutectoid plating 6 in the nozzle 4 in a subsequent eutectoid plating layer forming process. An example of such a process is outlined below.

The viscosity of the photosensitive resin material used to regulate the step coverage d of the plating layer 6 generally changes greatly with temperature. Therefore, to enable the correct amount of the photosensitive resin film 5 to step into the nozzle 4 to obtain the predetermined step coverage d , it is advantageous to fix the pressure applied to the photosensitive resin film 5 to a constant level and control the temperature t at which the film 5 is heated.

Experiments were conducted in respect of the aforementioned pre-process. An ordinary nozzle plate 1, having a thickness T of 80 μm , a nozzle diameter D of 40 μm and a nozzle length (cylinder-like portion) 1 of 35 μm was used. A photosensitive resin film 5 having a thickness of 38 μm was bonded to the back surface 3. The photosensitive resin film 5 was then heated. Fig. 5 shows the relationship between temperature t and step coverage f of the photosensitive resin film 5, which was heated for 20 seconds at various temperatures t with pressures of 4.0 kgf/cm^2 (39.23 N/cm^2) and 5.0 kgf/cm^2 (49.03 N/cm^2) applied thereto.

Ultraviolet rays, having a wavelength of 365 nm, for hardening the photosensitive resin film 5 were irradiated in an amount of 750 mJ/cm^2 .

An example of a eutectoid plating layer forming process will now be described. A nozzle plate 1 having been pre-processed is immersed into an electrolyte in which, in this example, nickel ions and particles of water-repellent high molecular resin, namely



polytetrafluoroethylene, are dispersed by electric charges and stirred therein to form a eutectoid plating layer 6 on the front surface of the nozzle plate 1 (Fig. 1 (c)).

Other fluorine-containing high molecular materials which may be used for the eutectoid plating process include resins such as polytetrafluoroethylene, polyperfluoroalkoxybutadiene, polyfluorovinylidene, polyfluorovinyl, or polydiperfluoroalkylfumarate. Such resins may be used on their own or in combination.

The matrix of the plating layer 6 is not particularly limited. While metals such as, copper, silver, zinc or tin are appropriate, a metal such as nickel, or an alloy such as a nickel-cobalt alloy, a nickel-phosphor alloy, or a nickel-boron alloy, which exhibits a large surface hardness and excellent wear resistance is preferable.

In the example, the particles of polytetrafluoroethylene uniformly cover the front surface 2 of the nozzle plate 1 as well as the inner circumference of the nozzle 4 to a predetermined depth from the front surface 2.

The photosensitive resin film 5 formed on the back surface 3 of the nozzle plate 1 and stepped into the nozzle 4 is thereafter removed by using an appropriate solvent. Then, by preventing the nozzle plate 1 from warping while applying a load thereto, the nozzle plate 1 is heated to a temperature higher than the melting point of the fluorine-containing high molecular material (i.e., higher than the melting point of 350°C of polytetrafluoroethylene in the present example). This causes a hard ink-repellent plating layer 6 to form on the front surface 2, as well as on the inner circumference of the nozzle to a predetermined depth (Fig. 1 (d)).

Therefore, for the thus prepared nozzle plate 1, the lower edge of the ink-repellent plating layer 6 within the nozzle 4 plays an important role in determining the centre of vibration A of the meniscus of ink as shown in Fig. 2.

Assuming that the volume of a space within the nozzle from the front surface 2 of the nozzle 4 to the centre of vibration A of the meniscus is V_m , and the volume of ink within a space from the front surface 2 of the nozzle 4 to the front surface B of the ink immediately before the ink is jetted, (i.e. the volume of an ink droplet to be jetted) is V_i , then a smaller step coverage d of the plating layer 6 makes V_m/V_i smaller, which thereby allows the piezoelectric drive voltage to be decreased. The piezoelectric drive voltage serves to ensure that a desired amount of ink is jetted. Hence, an inexpensive driver can be achieved. However, if the step coverage d is set to too small a value, stray fly occurs as shown in Fig. 6 and Table 1 below.

On the other hand, if the step coverage d of the plating layer 6 is large, a position C to which the meniscus retreats after the ink has been jetted becomes so deep that air bubbles are picked up in the front of the nozzle 4 or defective jetting results due an insufficient supply of ink for the next ink droplet jetting operation.

Nozzle plates 1 having a thickness of 80 μm and having different step coverages d have been prepared, and attached to a piezoelectrically driven "on-demand" ink jet printer. Tests have been carried out in which 0.1 $\mu\text{g/dot}$ -ink droplets were continuously jetted from a nozzle 4 having a diameter of 40 μm for 30 seconds at a response frequency of 5 KHz. The test was repeated 100 times and the frequency of flight deviation, defective jetting, and the like was counted. The following results were obtained.

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Table 1

d μm	V _m x10 ⁻¹⁴ mm ³	PZT Drive Voltage v	PZT Displacement Energy x10 ⁷ J	V _m /V _i	Frequency of Flight Deviation	Frequency of Defective Jetting
0	0	20	4.5	0	62	0
2	0.25	20	4.5	0.025	13	0
4	0.5	21	5.0	0.05	0	0
5	0.6	21	5.0	0.06	0	0
15	1.9	23	6.0	0.19	0	0
40	5.0	26	7.6	0.50	0	0
50	7.5	42	19.8	0.75	0	24
60	9.0	70	55.1	0.90	0	89

It was verified from these tests that when V_m/V_i , (that is, the ratio of the volume of the space within the nozzle from the front surface 2 of the nozzle plate 1 to the meniscus forming surface A with respect to the amount of an ink droplet to be jetted) is smaller than 0.04, the frequency of flight deviation of the ink droplet increases drastically. It was also verified that when this ratio exceeds 0.50, the incidence of defective jetting increases drastically.

Incidentally, the above are the results of the tests carried out on the nozzle 4 having a cylinder-like orifice portion 4b on the front surface 2 and a funnel-shaped portion 4a that opens widely to the back surface 3. As to a nozzle 14 that is opened so as to flare bell-like to the back surface 3 from an orifice portion 14b on the front surface 2, as shown in Fig. 3, a similar tendency was observed from the results of tests.

It is understood from the above that the step coverage d of the plating layer 6 should be determined so that V_m/V_i is within a range from 0.04 to 0.5 or, more preferably, within a range from 0.05 to 0.5.



Fig 4 shows a second embodiment of the present invention, which pertains to a method of treating the surface of the nozzle plate 1.

This method involves putting a resilient plate 7 made of, for example, rubber in pressure contact with the front surface 2 of the nozzle plate 1 with a predetermined biasing force. Part of the resilient plate 7 is caused to step into the nozzle 4 by a value equivalent to a predetermined step coverage d . A dry film resist or an appropriate plastic material 8 is then applied as a masking member 8 over the entire back surface 3 of the nozzle plate 1, including the nozzle 4 portion (Fig. 4 (a)).

When the dry film resist is used as a masking member 8, ultraviolet rays are thereafter irradiated from the back surface 3 to harden the dry film resist, whereas when the plastic material is used, the plastic material is either heated or subjected to an ordinary drying process to solidify the plastic material, and then the resilient plate 7 is removed from the front surface 2 of the nozzle plate 1 (Fig. 4 (b)).

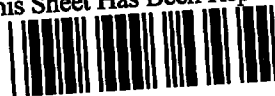
Further, the thus processed nozzle plate 1 is immersed into an electrolyte in which the particles of a water-repellent high molecular resin are dispersed by electric charges to form an ink-repellent coating layer 9, which is a eutectoid plating layer, on the front surface 2 thereof. Alternatively, a fluorine-containing high molecular water-repellent agent is applied to the front surface 2 of the thus processed nozzle plate 1 by sputtering or dipping (Fig. 4 (c)). The masking member 8 is then removed from the back surface 3 of the nozzle plate 1 using an appropriate treatment solution (Fig. 4 (d)).

As set forth in the foregoing description, according to the present invention the ink-repellent coating layer is caused to step into the nozzle so that the ratio of the volume of the space within the nozzle between the front surface of the nozzle plate and the meniscus forming surface with respect to the amount of ink to be jetted is in the range of 0.05 to 0.5. Therefore, the position at which the meniscus vibrates can be regulated

correctly by this coating layer not only to prevent stray fly and defective jetting but also to allow an ink droplet to be jetted with minimum piezoelectric drive energy.

In addition, according to the present invention the ink-repellent coating layer is formed on the front surface of the nozzle plate using a photosensitive resin member stepped into the nozzle from the back surface of the nozzle plate as a masking member. Therefore, satisfactory control can be effected over the step coverage of the coating layer which regulates the position at which the meniscus vibrates. This, in turn, contributes to the elimination of inconsistency among products, thus forming highly reliable nozzle plates.

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CLAIMS

1. A nozzle plate comprising at least one nozzle for the ejection of ink droplets and an ink repellent coating formed on a surface of said nozzle plate surrounding the at least one nozzle and on the inner surface of said at least one nozzle to a depth from said nozzle plate surface such that the volume of space within the nozzle from said nozzle plate surface to a meniscus forming surface is within the range 0.04 to 0.5 times the volume of ink to be ejected.
2. A nozzle plate as claimed in claim 1, wherein the volume of space within the nozzle from said nozzle plate surface to a meniscus forming surface is within the range 0.05 to 0.5 times the volume of ink to be ejected.
3. A nozzle plate as claimed in claim 1 or 2, wherein the ink repellent coating layer comprises a eutectoid plating layer.
4. A nozzle plate as claimed in claim 3, wherein the ink repellent coating layer comprises one or more fluorine-containing high molecular resin members.
5. A method for regulating the depth of ink repellent coating within a nozzle from one surface of a nozzle plate, comprising:
 - forming a mask on the other surface of the nozzle plate;
 - causing part of the mask to enter the nozzle such that a volume of space in the nozzle between the mask and said one surface of the nozzle plate is within the range of 0.04 to 0.5 times the volume of ink to be ejected from the nozzle; and
 - hardening the mask.
6. A method as claimed in claim 6, wherein the mask is a photosensitive resin member.





7. A method as claimed in claim 6, wherein the mask is caused to enter the nozzle by applying heat.
8. A method as claimed in claim 7, wherein the amount of the mask to enter the nozzle is controlled by changing the temperature under a fixed pressure.
9. A method as claimed in claim 5 or 6, further comprising :
forming a resilient material on said one surface of the nozzle plate prior to forming the mask;
applying pressure to the resilient member to cause a part of it to enter the nozzle and thus control the amount of mask able to enter the nozzle from the other surface; and
removing the resilient material.
10. A method as claimed in claim 9, wherein the mask is a plastics material.
11. A method as claimed in any of claims 5 to 10, comprising forming an ink repellent coating on said one nozzle plate surface and on the inner surface of the nozzle to the regulated depth.
12. A method as claimed in claim 11, further comprising removing the mask.
13. A nozzle plate for an ink jet printer wherein a part of an ink-repellent coating layer for covering a front surface of the nozzle plate is caused to step into an inner surface of a nozzle so that a volume of a space within the nozzle from the front surface of the nozzle plate to a meniscus forming surface is limited to a range from 0.05 to 0.5 times a volume of ink to be jetted.





14. A nozzle plate for an ink jet printer according to claim 13, wherein the ink-repellent coating layer is formed of a eutectoid plating.
15. A nozzle plate for an ink jet printer according to claim 13, wherein the ink-repellent coating layer is formed of a fluorine-containing high molecular resin member other than the eutectoid plating.
16. A method of preparing a nozzle plate for an ink jet printer, comprising the steps of:
- putting a photosensitive resin member in pressure contact with a back surface of the nozzle plate;
 - heating the photosensitive resin member to cause a part of the photosensitive resin member to step into an inner surface of a nozzle so that a volume of a space within the nozzle from a front surface of the nozzle plate can be limited to a range from 0.05 to 0.5 times a volume of ink to be jetted;
 - hardening the photosensitive resin member using rays of light; and
 - forming an ink-repellent coating layer at least on the inner surface of the nozzle and the front surface of the nozzle plate with the hardened photosensitive resin member as a masking member.
17. A method of preparing a nozzle plate for an ink jet printer according to claim 16, wherein a step coverage of the photosensitive resin member into the inner surface of the nozzle is controlled by changing temperature under a fixed pressure.
18. A method of preparing a nozzle plate for an ink jet printer, comprising the steps of:
- laminating a resilient material on a front surface of the nozzle plate;
 - applying pressure to the resilient material to cause a part of the resilient material to step into an inner surface of a nozzle so that a step coverage of the resilient material

from the front surface of the nozzle plate to the inner surface of the nozzle is limited to a range from 0.05 to 0.5 times a volume of ink to be jetted;

forming a masking layer on a back surface of the nozzle plate by setting at least a part of the masking layer end-to-end with the resilient material within the nozzle;

removing the resilient material; and

forming an ink-repellent coating layer on at least the inner surface of the nozzle and the front surface of the nozzle plate with the masking layer as a masking member.

19. A method of preparing a nozzle plate for an ink jet printer according to claim 18, wherein the masking layer is made of a photosensitive resin member.

20. A method of preparing a nozzle plate for an ink jet printer according to claim 18, wherein the masking layer is made of a plastics material.

21. A nozzle plate substantially as hereinbefore described, with reference to any of Figures 1 to 6 of the accompanying drawings.

22. A method for regulating the depth of ink repellent coating within a nozzle from one surface of a nozzle plate substantially as hereinbefore described, with reference to any of Figures 1 to 4 of the accompanying drawings.

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