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Hart et al.

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(54) **NOZZLE MEMBERS, COMPOSITIONS AND METHODS FOR MICRO-FLUID EJECTION HEADS**

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B41J 2/14 (2006.01)

(52) **U.S. Cl.** **347/47; 347/44**

(58) **Field of Classification Search** **347/20, 347/44, 47, 56, 63-65, 67**

See application file for complete search history.

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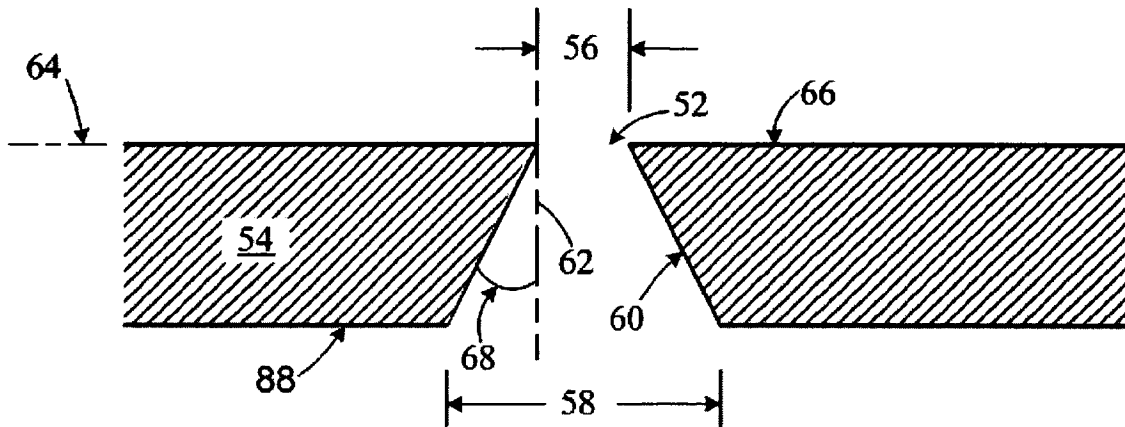
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(57) **ABSTRACT**

An improved photoimaged nozzle plate for a micro-fluid ejection head, a micro-fluid ejection head containing the nozzle plate, and methods for making a micro-fluid ejection head. The improved nozzle plate is provided by a photoresist nozzle plate layer applied to a thick film layer on a semiconductor substrate containing fluid ejector actuators. The photoresist nozzle plate layer has a plurality of nozzle holes therein. Each of the nozzle holes are formed in the nozzle plate layer from an exit surface of the nozzle plate layer to an entrance surface of the nozzle plate layer. Each of the nozzle holes has a reentrant hole profile with a wall angle greater than about 4° up to about 30° measured from an axis orthogonal to a plane defined by the exit surface of the nozzle plate layer.

9 Claims, 8 Drawing Sheets



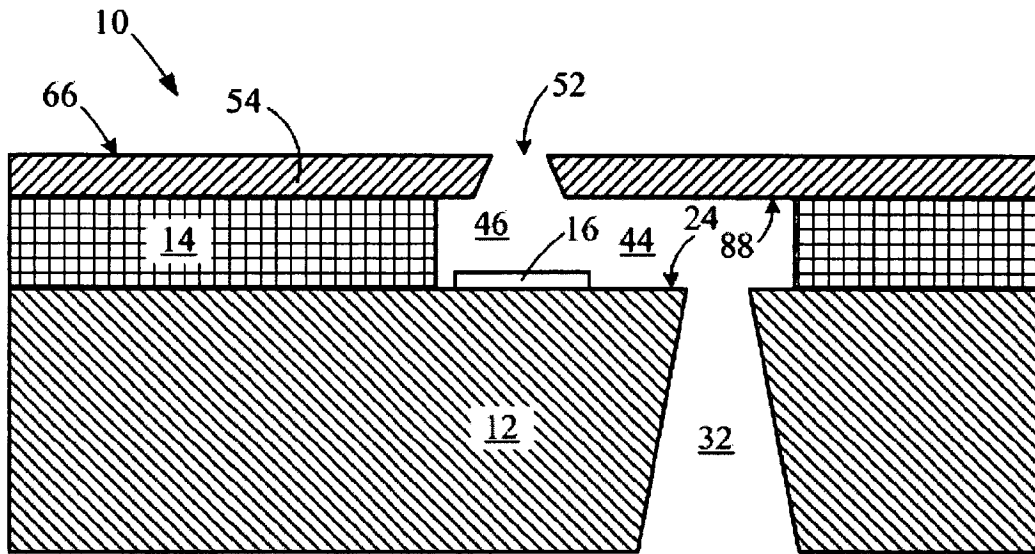


FIG. 1

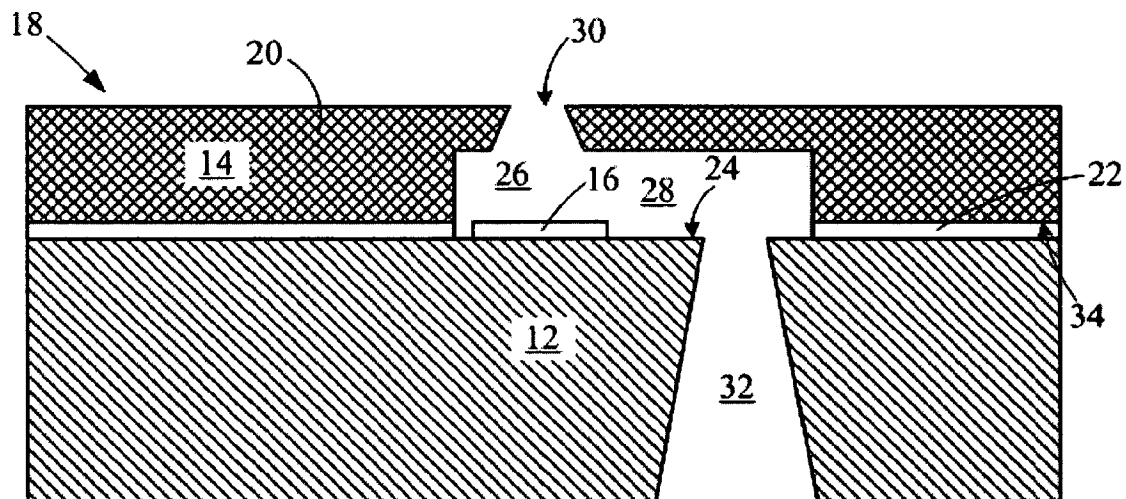


FIG. 2
Prior Art

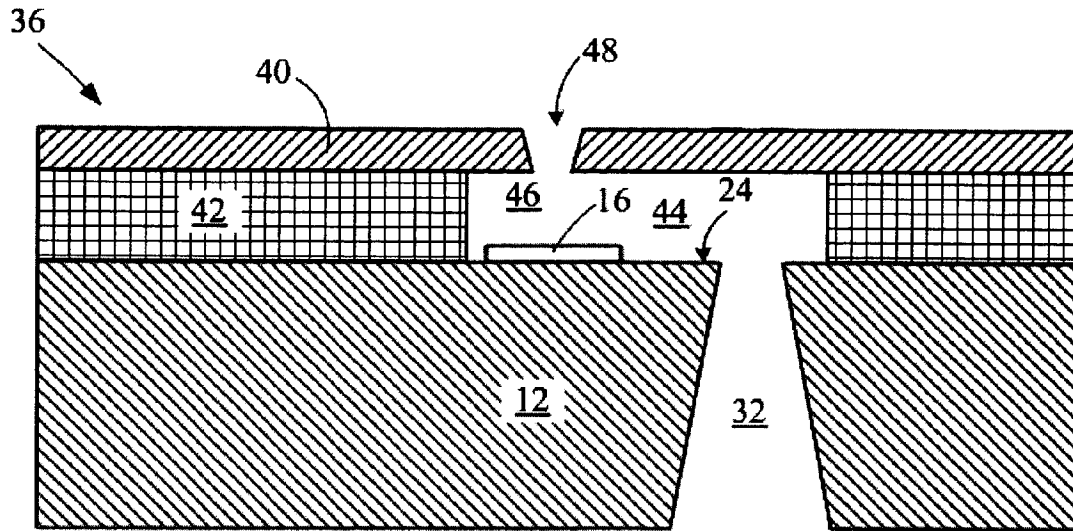


FIG. 3
Prior Art

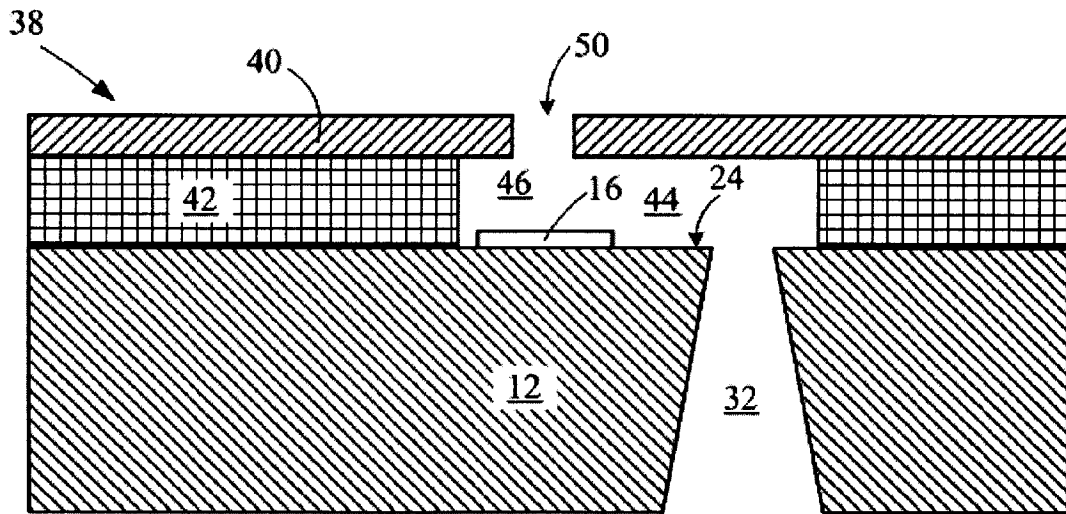
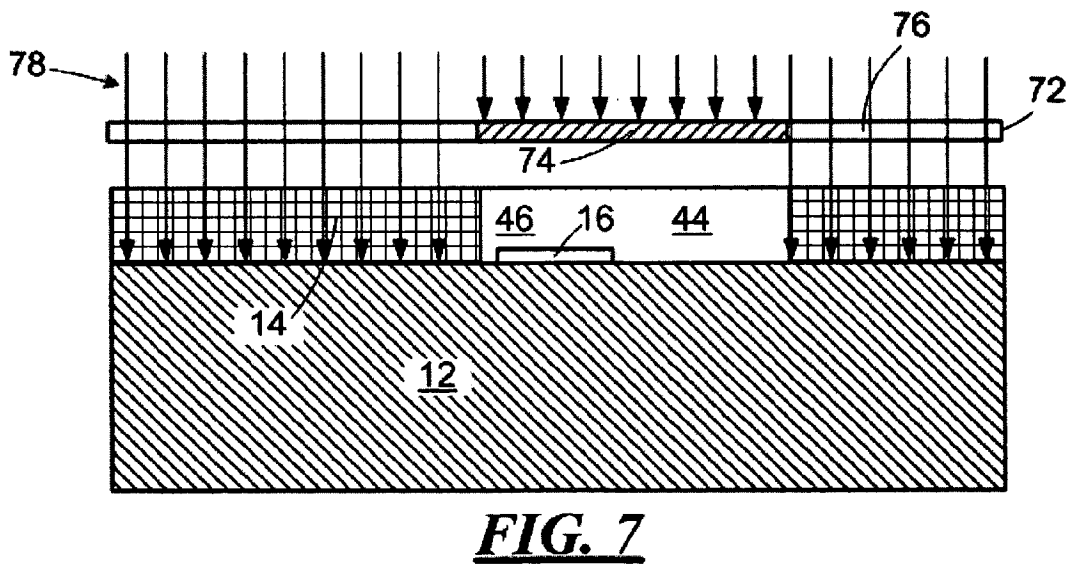
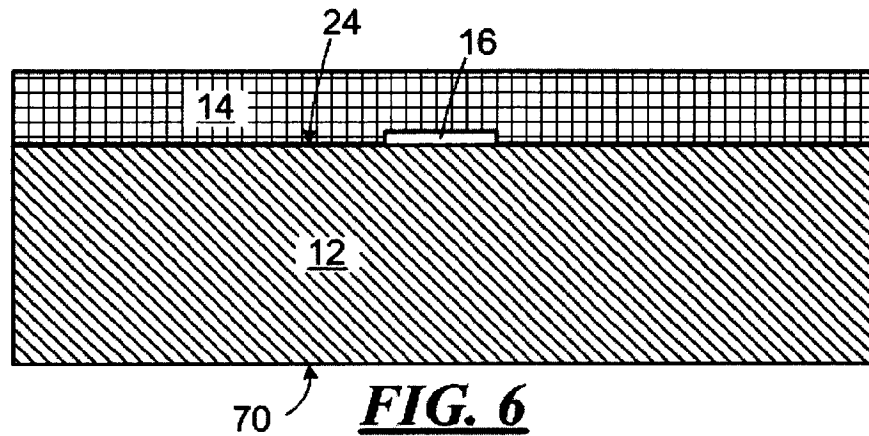
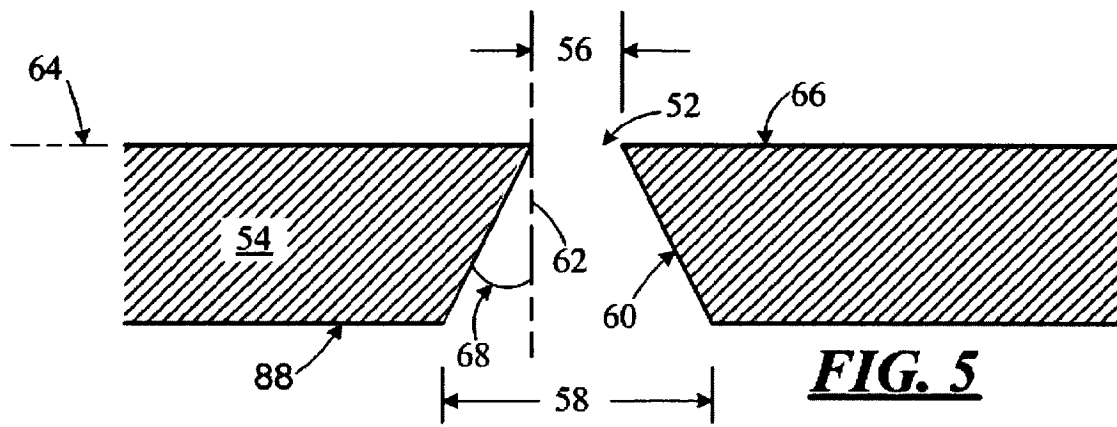


FIG. 4
Prior Art



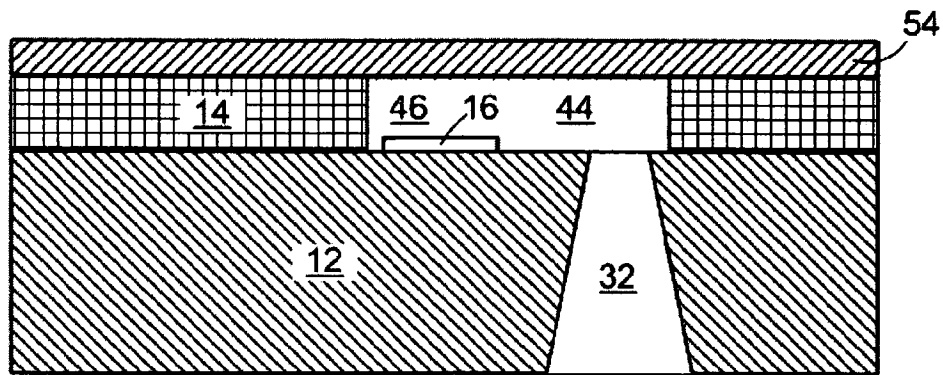


FIG. 8

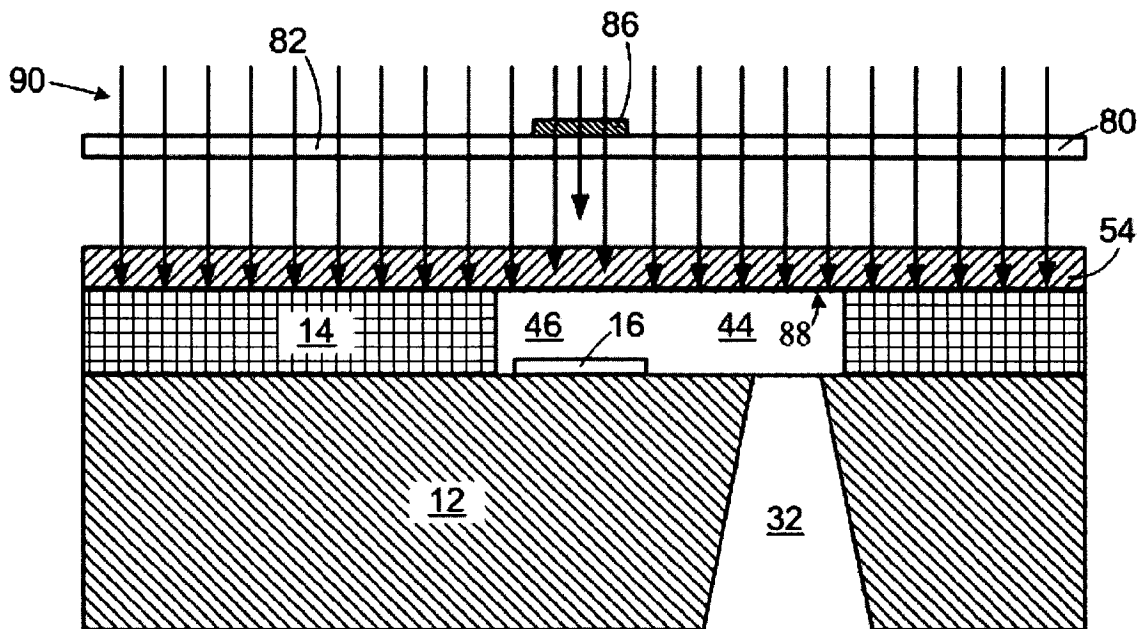


FIG. 9

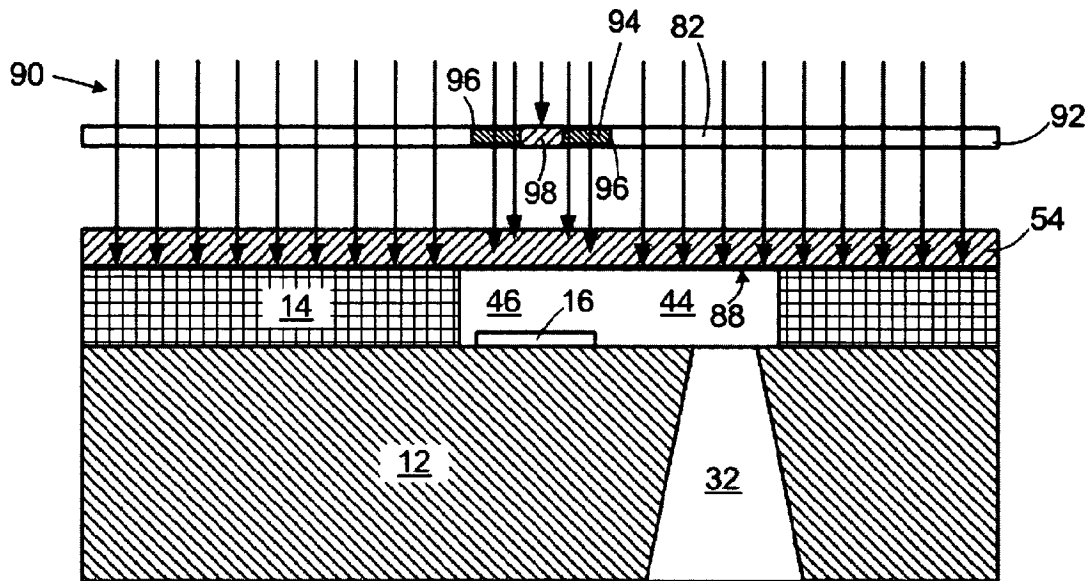


FIG. 10

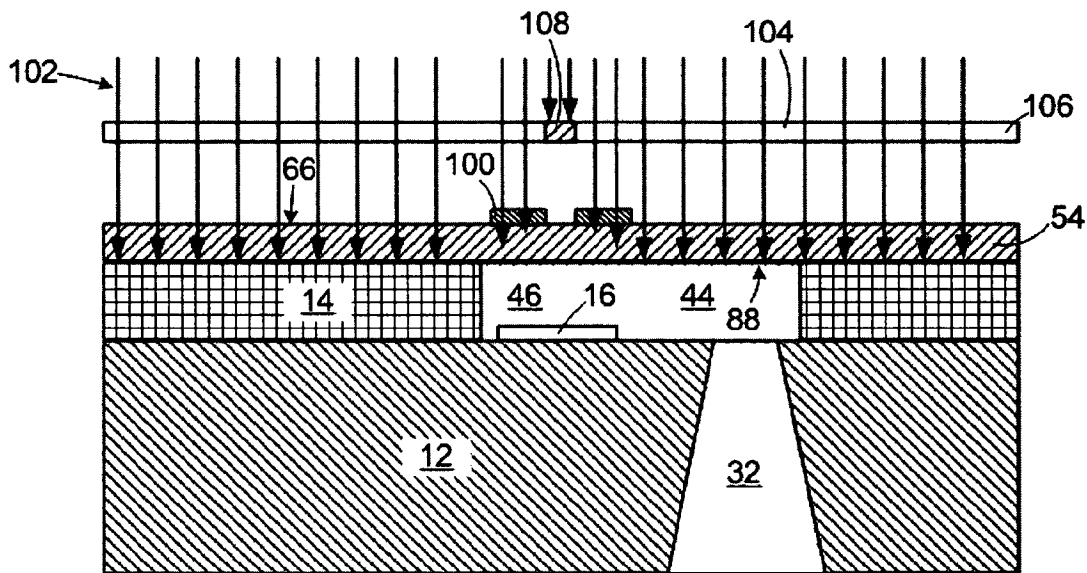


FIG. 11

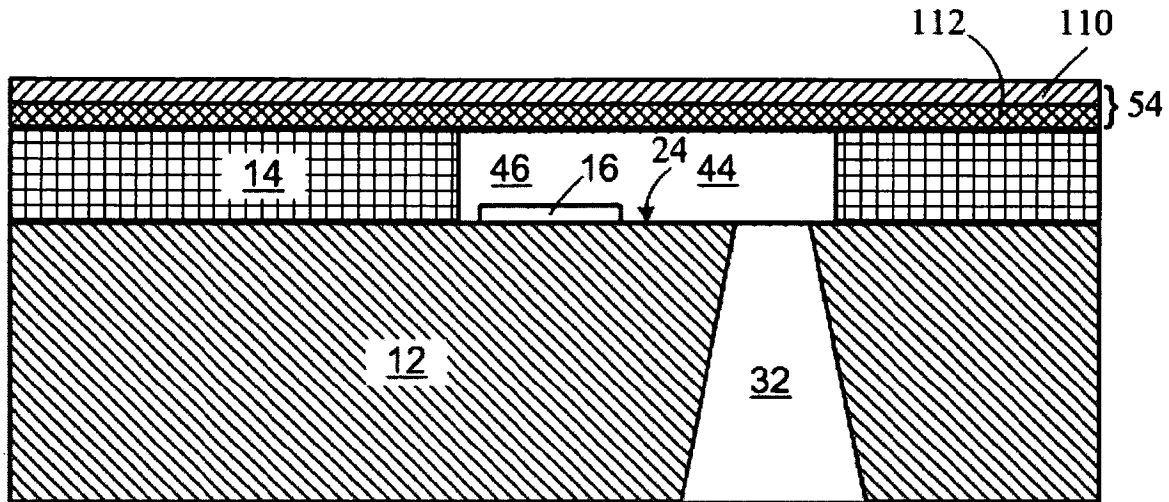


FIG. 12

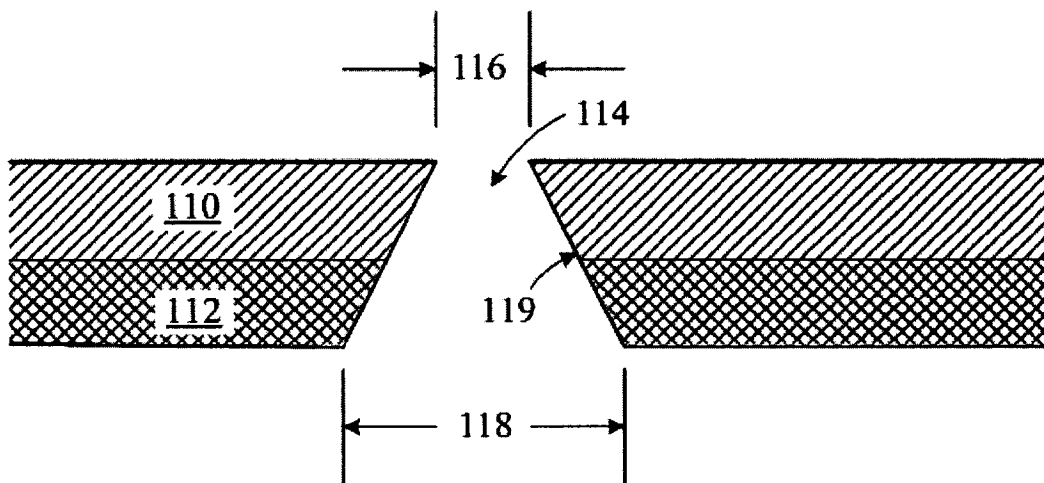


FIG. 13

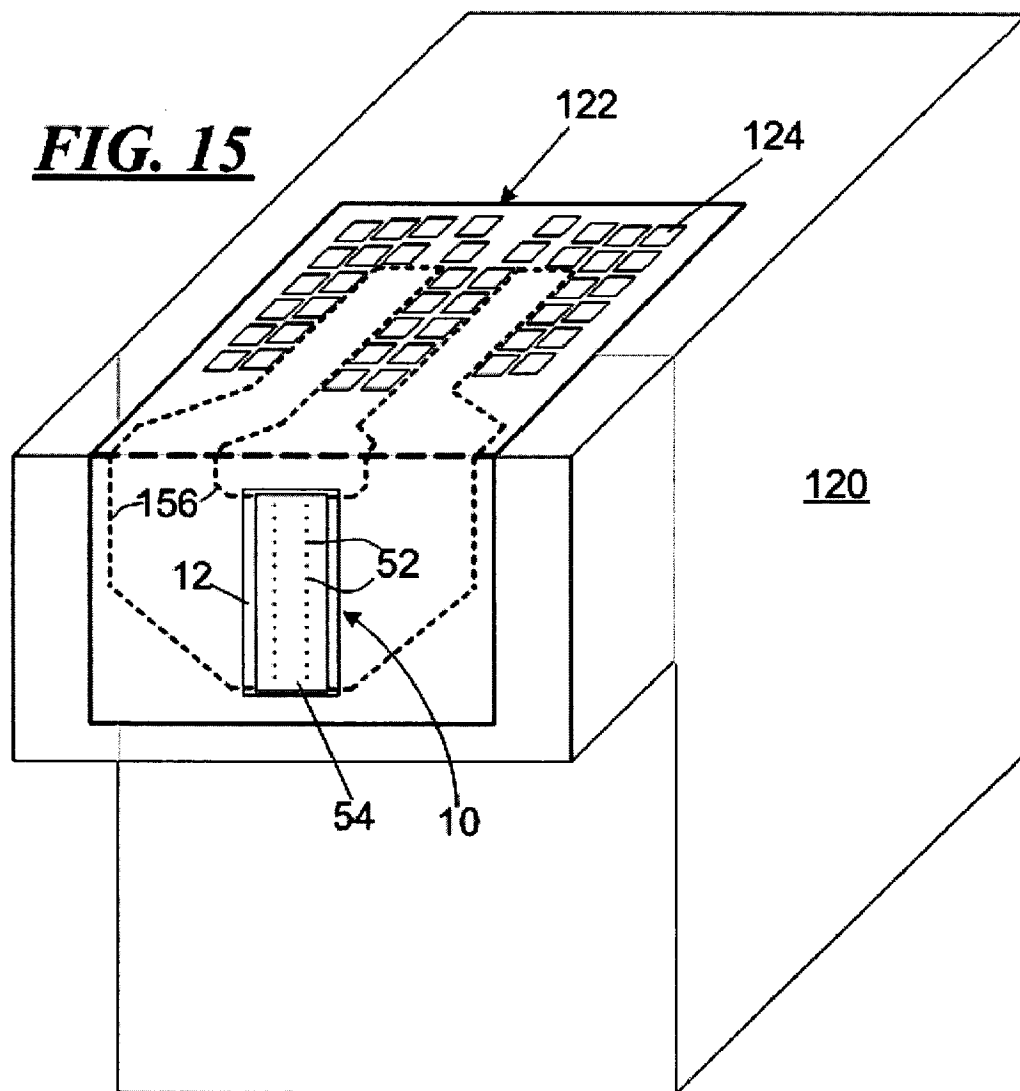
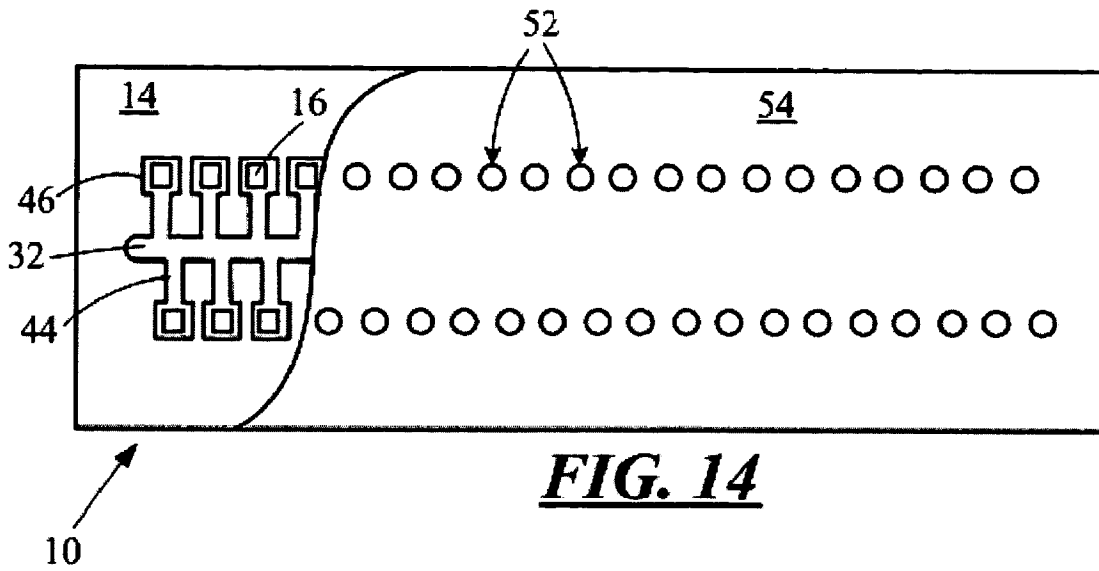
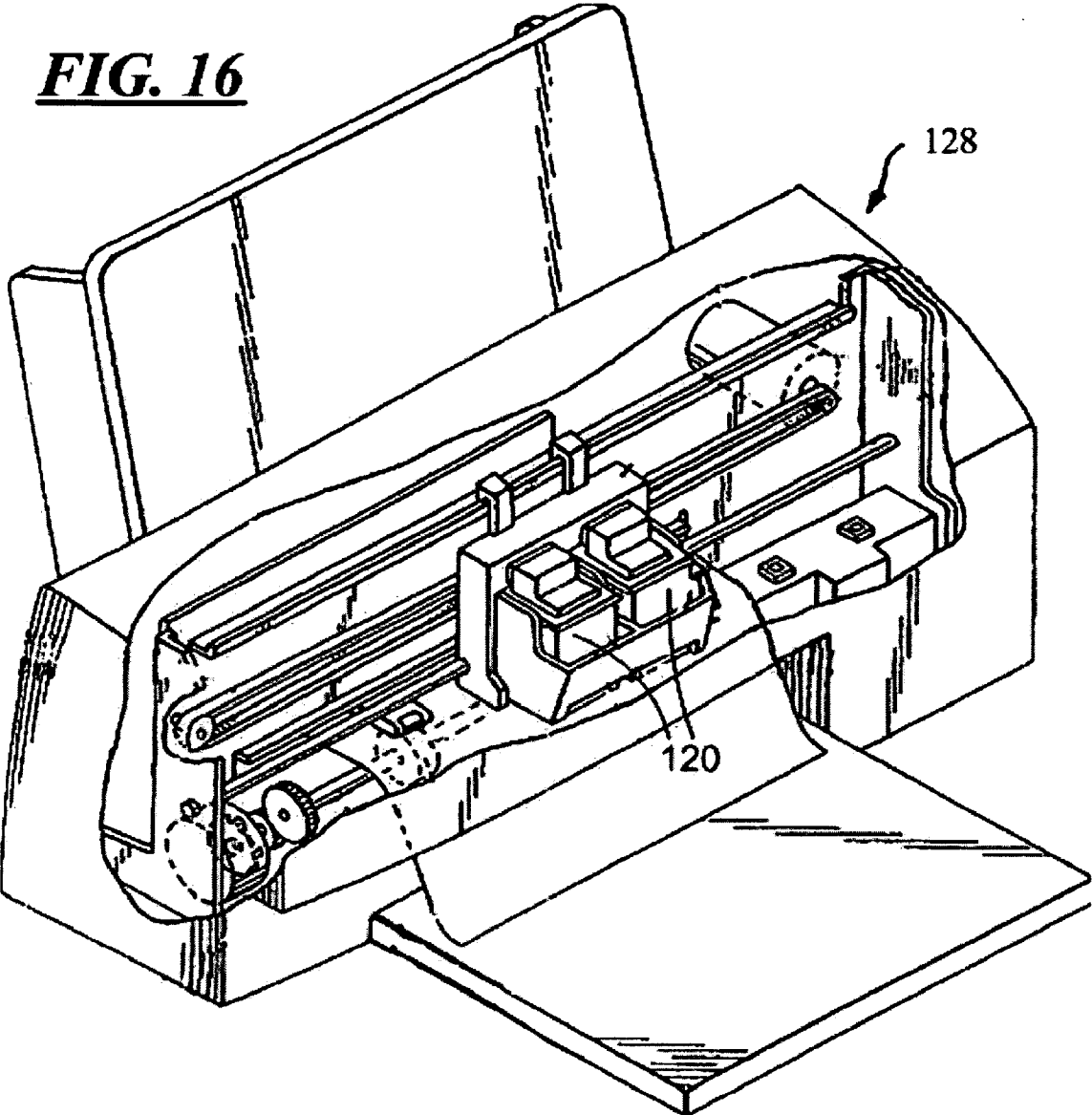


FIG. 16



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NOZZLE MEMBERS, COMPOSITIONS AND METHODS FOR MICRO-FLUID EJECTION HEADS

FIELD

The disclosure relates to improved nozzle members for micro-fluid ejection heads, and in particular embodiments to methods and compositions for forming reentrant nozzles in photoimageable materials.

BACKGROUND AND SUMMARY

Micro-fluid ejection devices, such as ink jet printers continue to evolve as the technology for ink jet printing continues to improve to provide higher speed, higher quality printers. However, the improvement in speed and quality does not come without a price. The micro-fluid ejection heads are more costly to manufacture because of tighter alignment tolerances.

For example, some conventional micro-fluid ejection heads are made with nozzle members (e.g., nozzle plates) containing flow features. The nozzle plates are then aligned and adhesively attached to a semiconductor substrate. However, minor imperfections in the substrate or nozzle plate components of the ejection head or improper alignment of the parts has a significant impact on the performance of the ejection heads.

One advance in providing improved micro-fluid ejection heads is the use of a photoresist layer applied to a device surface of the semiconductor substrate as a thick film layer. The thick film layer is imaged to provide flow features for the micro-fluid ejection heads. Use of the imaged thick film layer enables more accurate alignment between the flow features and ejection actuators on the device surface of the substrate.

While the use of an imaged photoresist layer improves alignment of the flow features to the ejection actuators, there still exist alignment problems and difficulties associated with a nozzle member attached to the thick film layer and the ability to provide suitable nozzles (e.g., holes) in the nozzle layer after it is attached to the thick film layer. In order for micro-fluid ejection heads to provide precise ejection of fluid droplets, the nozzles in the nozzle layer should have a reentrant profile. There is less flow restriction with reentrant nozzles and thus less energy required to eject fluid droplets. The term "reentrant" is used to refer to side wall profiles of the nozzles, wherein exit diameters of the nozzles are smaller than entrance diameters of the nozzles so that the side walls of the nozzles are not perpendicular to a plane defined by an exit surface of the nozzle member.

Conventional nozzle plates are typically made from metal that is electroformed or a polyimide material that is laser ablated and then adhesively attached to the thick film layer. The formation of exit hole diameters smaller than entrance hole diameters is achieved in conventional nozzle plates by forming the holes from an entrance side of the nozzle plate. However, use of such nozzle plates requires an alignment step to attach the nozzle plate to the thick film layer and to align the nozzles with the flow features in the thick film layer and with the fluid ejector actuators.

In order to eliminate such alignment steps, photoimageable nozzle materials may be applied adjacent (e.g., to) the thick film layer by spin coating or lamination techniques. Such spin coating techniques and lamination techniques are done before the nozzles are formed in the nozzle material. Nozzles must then be formed from an exit side of the nozzle

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material. Conventional photoimaging and developing techniques do not provide suitable reentrant nozzles. For example, conventional photoimaging and developing techniques cannot readily provide nozzles having wall angles of greater than about 4°. Typically, such conventional techniques provide vertical walled nozzles or nozzles having an exit diameter larger than an entrance diameter. For the purposes of this disclosure the term "diameter" is used for simplicity in describing the dimensions of nozzles. However, the term "diameter" is not limited to the dimension of circular holes as the nozzles may have other shapes, such as ellipses, stars, etc.

Accordingly, there is a need for, among other things, improved photoresist or photoimageable materials that may be used as nozzle materials and improved techniques for forming reentrant nozzles in such nozzle materials.

In some of the exemplary embodiments of the present invention, there is provided, for example, improved photoimaged nozzle members for a micro-fluid ejection heads, micro-fluid ejection heads containing such nozzle members, and methods for making the same. In one embodiment, a photoresist nozzle layer is applied adjacent a thick film layer on a substrate having fluid ejector actuators. The photoresist nozzle layer has a plurality of nozzles therein. The nozzles are formed in the nozzle layer from an exit surface of the nozzle layer to an entrance surface of the nozzle layer. The nozzles have a reentrant profile with a wall angle greater than about 4° up to about 30° measured from an axis orthogonal to a plane defined by the exit surface of the nozzle layer.

In another embodiment, there is provided a method for making a micro-fluid ejection head. The method includes applying a negative photoresist nozzle layer adjacent a thick film layer on a substrate having a plurality of micro fluid ejection actuators. The nozzle layer has a thickness ranging from about 10 to about 30 microns. A plurality of nozzles are imaged in the nozzle layer from an exit surface of the nozzle layer to an entrance surface of the nozzle layer using a mask. The imaged nozzle layer is developed to provide nozzles having reentrant profiles with wall angles greater than about 4° up to about 30° measured from an axis orthogonal to a plane defined by the exit surface of the nozzle layer.

An advantage of at least certain of the exemplary embodiments described herein is that nozzles may be made in a photoimageable material from an exit side thereof while still providing nozzles having improved fluid flow characteristics. The terms "exit side" and "exit surface" refer to a side or surface of the nozzle member that is opposite to a surface or side that is attached adjacent to a thick film layer on a substrate. In particular, the compositions and methods described herein may enable the formation of reentrant nozzles in a photoimageable nozzle material after the nozzle material is applied adjacent a thick film layer on a substrate. Hence, alignment problems associated with aligning a nozzle material to fluid ejection actuators and flow features on a substrate can be substantially reduced. Unlike conventional photoimaging methods, the compositions and methods described herein enable the formation of nozzles with wall angles greater than about 4°.

For purposes of the disclosure, "difunctional epoxy" means epoxy compounds and materials having only two epoxy functional groups in the molecule. "Multifunctional epoxy" means epoxy compounds and materials having more than two epoxy functional groups in the molecule.

BRIEF DESCRIPTION OF THE DRAWINGS

Further advantages of the exemplary embodiments will become apparent by reference to the detailed description when considered in conjunction with the figures, which are not to scale, wherein like reference numbers indicate like elements through the several views, and wherein:

FIG. 1 is a cross-sectional view, not to scale, of a portion of a micro-fluid ejection head according to the disclosure;

FIGS. 2-4 are cross-sectional views, not to scale, of portion of prior art micro-fluid ejection heads;

FIG. 5 is a cross-sectional view, not to scale of a portion of a nozzle member made according to the disclosure showing a reentrant nozzle formed therein;

FIGS. 6-7 are cross-sectional views, not to scale, illustrating a method for forming flow features in a thick film layer attached to a semiconductor substrate;

FIGS. 8-11 are schematic views of processes for imaging a nozzle member according to embodiments of the disclosure;

FIG. 12 is a cross-sectional view, not to scale, of a portion of a micro-fluid ejection head containing an alternate nozzle member according to the disclosure;

FIG. 13 is a cross-sectional view, not to scale, of a portion of the nozzle member of FIG. 12 showing a reentrant nozzle formed therein;

FIG. 14 is a plan view, not to scale, of a nozzle member made according to the disclosure attached to a thick film layer and semiconductor substrate providing a micro-fluid ejection head;

FIG. 15 is a perspective view of a fluid reservoir containing a micro-fluid ejection head made according to the disclosure; and

FIG. 16 is a perspective view, not to scale, of an ink jet printer containing micro-fluid ejection heads attached to the fluid reservoirs of FIG. 15.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

With reference to FIG. 1, there is shown, in partial cross-sectional view, a portion of a micro-fluid ejection head 10. The micro-fluid ejection head 10 includes a thick film layer 14 attached to a substrate, such as semiconductor substrate 12 having various insulative, conductive, resistive, and passivating layers providing a fluid ejector actuator 16.

FIG. 2 depicts a prior art micro-fluid ejection head 18, wherein a nozzle member, such as nozzle plate 20, is attached as by an adhesive 22 to a device surface 24 of the semiconductor substrate 12. In such a micro-fluid ejection head 18, the nozzle plate 20 is made out of a laser ablated material such as polyimide. The polyimide material is laser ablated to provide a fluid chamber 26 in fluid flow communication with a fluid supply channel 28. Upon activation of the ejector actuator 16, fluid is expelled through a nozzle 30 that is also laser ablated in the polyimide material of the nozzle plate 20. The fluid chamber 26 and fluid supply channel 28 are collectively referred to as "flow features." A fluid feed slot 32 is etched in the substrate 12 to provide fluid via the fluid supply channel 28 to the fluid chamber 26 and ejection actuator 16.

In order to provide the laser ablated nozzle plate 20, the polyimide material is laser ablated from a flow feature side 34 thereof before the nozzle plate 20 is attached to the semiconductor substrate 12. Accordingly, misalignment between the flow features in the nozzle plate 20 and the fluid ejector actuator 16 may be detrimental to the functioning of

the micro-fluid ejection head 10. For alignment purposes, it is more effective to form the nozzle holes in a nozzle plate after the nozzle plate is attached to the substrate.

Prior art micro-fluid ejection heads 36 and 38 having nozzles formed in a nozzle plate 40 after the nozzle plate is attached to a thick film layer 42 are illustrated in FIGS. 3 and 4, respectively. In these prior art micro-fluid ejection heads 36 and 38, the thick film layer 42 provides the flow features, i.e., a fluid supply channel 44 and a fluid chamber 46 for providing fluid to the fluid ejector actuator 16. In such ejection heads 36 and 38, the thick film layer 42 is a photoresist material that is spin coated onto the device surface 24 of the substrate 12. The photoresist material is then imaged and developed using conventional photoimaging techniques to provide the flow features.

The separate nozzle plate 40 material is attached to the thick film layer 42 as by roll lamination, thermal compression bonding or by use of an adhesive. The nozzle plate 40 is then imaged and developed to provide nozzles 48 and 50. As in FIG. 1, the nozzle plate 40 may be made of a photoresist material. However, as shown in FIGS. 3 and 4, conventional photoimaging techniques used to form nozzles 48 and 50 after the nozzle plate 40 is attached to the thick film layer 42 lead to nozzles 48 having a larger exit diameter than entrance diameter or nozzles 50 having substantially vertical walls. Compared to nozzles 52 (FIG. 1) in nozzle member 54 having a reentrant profile, the nozzles 48 or 50 provide less effective flow characteristics for a micro-fluid ejection head.

An enlarged view of a portion of the nozzle member 54 showing nozzle 52 is illustrated in FIG. 5. As set forth above, the nozzle 52 preferably has a reentrant profile so that an exit diameter 56 is smaller than an entrance diameter 58. Side walls 60 of the nozzle 52 are angled with respect to an axis 62 that is orthogonal to a plane 64 defined by exit surface 66 of the nozzle member 54. Accordingly, the side walls 60 of the nozzle 52 form an angle 68 that ranges from above about 4° to about 30° with respect to the axis 62. Conventional prior art methods are not suitable for forming such angles 68 in nozzle members 54 having a thickness ranging from about 10 to about 20 microns.

Methods for making micro-fluid ejection heads, such as the head 10 will now be described with reference to FIGS. 6-13. In a first step, illustrated in FIG. 6, a photoresist material is applied adjacent (e.g., to) the device surface 24 of the substrate 12 to provide a thick film layer 14. A suitable photoresist formulation for providing thick film layer 14 (FIG. 6) includes a multi-functional epoxy compound, a first di-functional epoxy compound, a photoacid generator, and, optionally, an adhesion enhancing agent. A suitable multi-functional epoxy component may be selected from aromatic epoxides such as glycidyl ethers of polyphenols. An exemplary multi-functional epoxy resin is a polyglycidyl ether of a phenolformaldehyde novolac resin, such as a novolac epoxy resin having an epoxide gram equivalent weight ranging from about 190 to about 250, and a viscosity at 130° C. ranging from about 10 to about 60 poise, which is available from Resolution Performance Products of Houston, Tex. under the trade name EPON RESIN SU-8.

The multi-functional epoxy component of the photoresist formulation may have a weight average molecular weight of about 3,000 to about 5,000 Daltons as determined by gel permeation chromatography, and an average epoxide group functionality of greater than 3, such as from about 6 to about 10. The amount of multifunctional epoxy resin in the photoresist formulation for the thick film layer 14 may range

from about 30 to about 50 percent by weight based on the weight of the cured thick film layer **14**.

A second component of the photoresist formulation for the thick film layer **14** is the first di-functional epoxy compound. The first di-functional epoxy component may be selected from di-functional epoxy compounds which include diglycidyl ethers of bisphenol-A (e.g. those available under the trade designations "EPON 1007F", "EPON 1007" and "EPON 1009F", available from Shell Chemical Company of Houston, Tex., "DER-331", "DER-332", and "DER-334", available from Dow Chemical Company of Midland, Mich., 3,4-epoxycyclohexylmethyl-3,4-epoxycyclo-hexene carboxylate (e.g. "ERL-4221" available from Union Carbide Corporation of Danbury, Connecticut, 3,4-epoxy-6-methylcyclohexylmethyl-3,4-epoxy-6-methylcyclohexene carboxylate (e.g. "ERL-4201" available from Union Carbide Corporation), bis(3,4-epoxy-6-methylcyclohexylmethyl) adipate (e.g. "ERL-4289" available from Union Carbide Corporation), and bis(2,3-epoxycyclopentyl) ether (e.g. "ERL-0400" available from Union Carbide Corporation).

An exemplary first di-functional epoxy component is a bisphenol-A/epichlorohydrin epoxy resin available from Shell Chemical Company of Houston, Tex. under the trade name EPON resin 1007F having an epoxide equivalent of greater than about 1000. An "epoxide equivalent" is the number of grams of resin containing 1 gram-equivalent of epoxide. The weight average molecular weight of the first di-functional epoxy component is typically above 2500 Daltons, e.g., from about 2800 to about 3500 weight average molecular weight. The amount of the first di-functional epoxy component in the thick film photoresist formulation may range from about 30 to about 50 percent by weight based on the weight of the cured resin.

The photoresist formulation for the thick film layer **14** also includes a photoacid generator devoid of aryl sulfonium salts. The photoacid generator can be a compound or mixture of compounds capable of generating a cation such as an aromatic complex salt which may be selected from onium salts of a Group VA element, onium salts of a Group VIA element, and aromatic halonium salts. Aromatic complex salts, upon being exposed to ultraviolet radiation or electron beam irradiation, are capable of generating acid moieties which initiate reactions with epoxides. The photoacid generator may be present in the photoresist formulation for the thick film layer **14** in an amount ranging from about 5 to about 15 weight percent based on the weight of the cured resin.

Of the aromatic complex salts which are suitable for use in exemplary photoresist formulation disclosed herein, suitable salts are di- and triaryl-substituted iodonium salts. Examples of aryl-substituted iodonium complex salt photoacid generates include, but are not limited to:

diphenyliodonium trifluoromethanesulfonate,
 (p-tert-butoxyphenyl)phenyliodonium trifluoromethanesulfonate,
 diphenyliodonium p-toluenesulfonate,
 (p-tert-butoxyphenyl)-phenyliodonium p-toluene-sulfonate,
 bis(4-tert-butylphenyl)iodonium hexafluorophosphate, and
 diphenyliodonium hexafluoroantimonate.

An exemplary iodonium salt for use as a photoacid generator for the embodiments described herein is a mixture of diaryliodonium hexafluoroantimonate salts, commercially available from Sartomer Company, Inc. of Exton, Pa. under the trade name SARCAT CD 1012

The photoresist formulation for the thick film layer **14** may optionally include an effective amount of an adhesion enhancing agent such as a silane compound. Silane compounds that are compatible with the components of the photoresist formulation typically have a functional group capable of reacting with at least one member selected from the group consisting of the multifunctional epoxy compound, the difunctional epoxy compound and the photoinitiator. Such an adhesion enhancing agent may be a silane with an epoxide functional group such as a glycidoxyalkyltrialkoxysilane, e.g., gamma-glycidoxypropyltrimethoxysilane. When used, the adhesion enhancing agent can be present in an amount ranging from about 0.5 to about 2 weight percent, such as from about 1.0 to about 1.5 weight percent based on total weight of the cured resin, including all ranges subsumed therein. Adhesion enhancing agents, as used herein, are defined to mean organic materials soluble in the photoresist composition which assist the film forming and adhesion characteristics of the thick film layer **14** on the device surface **24** of the substrate **12**.

In order to provide the thick film layer **14** adjacent the device surface **24** of the substrate **12** (FIG. 6), a suitable solvent can be used. A suitable solvent includes a solvent, such as one which is non-photoreactive. Non-photoreactive solvents include, but are not limited to gamma-butyrolactone, C₁₋₆ acetates, tetrahydrofuran, low molecular weight ketones, mixtures thereof and the like. An exemplary non-photoreactive solvent is acetophenone. The non-photoreactive solvent is present in the formulation mixture used to provide the thick film layer **14** in an amount ranging of from about 20 to about 90 weight percent, such as from about 40 to about 60 weight percent, based on the total weight of the photoresist formulation. In an exemplary embodiment, the non-photoreactive solvent does not remain in the cured thick film layer **14** and is thus removed prior to or during the thick film layer **14** curing steps.

According to an exemplary procedure, the non-photoreactive solvent and first di-functional epoxy compound are mixed together in a suitable container such as an amber bottle or flask and the mixture is put in a roller mill overnight at about 60° C. to assure suitable mixing of the components. After mixing the solvent and the di-functional epoxy compound, the multi-functional epoxy compound is added to the container and the resulting mixture is rolled for two hours on a roller mill at about 60° C. The other components, the photoacid generator and the adhesion enhancing agent, are also added one at a time to the container and the container is rolled for about two hours at about 60° C. after adding all of the components to the container to provide a wafer coating mixture.

In order to apply the photoresist thick film layer **14** adjacent the device surface **24** of the substrate (FIG. 6), a silicon substrate wafer is centered on an appropriate sized chuck of either a resist spinner or conventional wafer resist deposition track. A suitable photoresist formulation mixture is either dispensed by hand or mechanically into the center of the wafer. The chuck holding the wafer is then rotated at a predetermined number of revolutions per minute to evenly spread the mixture from the center of the wafer to the edge of the wafer. The rotational speed of the wafer may be adjusted or the viscosity of the coating mixture may be altered to vary the resulting resin film thickness. Rotational speeds of 2500 rpm or more may be used. The amount of photoresist formulation applied adjacent device surface **24** should be sufficient to provide the thick film layer **14** having the desired thickness for flow features imaged therein.

Accordingly, the thickness of the thick film layer **14** after curing may range from about 10 to about 25 microns or more.

The resulting silicon substrate wafer containing the thick film layer **14** is then removed from the chuck either manually or mechanically and placed on either a temperature controlled hotplate or in a temperature controlled oven at a temperature of about 90° C. for about 30 seconds to about 1 minute until the material is "soft" baked. This step removes at least a portion of the solvent from the thick film layer **14** resulting in a partially dried film on the device surface **24** of the substrate **12**. The wafer is removed from the heat source and allowed to cool to room temperature.

The flow features are then imaged and developed in the thick film layer **14**. In order to define flow features in the thick film layer **14**, such as the fluid chamber **46** and fluid supply channel **44**, the layer **14** is imaged through a mask **72** containing opaque areas **74** and transparent areas **76**. Areas of the thick film layer **14** (i.e., a negative acting photoresist layer **14**) masked by opaque areas **74** of the mask **72** will be removed upon developing to provide the flow features described above.

In FIG. 7, a radiation source provides actinic radiation indicated by arrows **78** to image the thick film layer **14**. A suitable source of radiation emits actinic radiation at a wavelength within the ultraviolet and visible spectral regions. Exposure of the thick film layer **14** to the actinic radiation may be from less than about 1 second to 10 minutes or more, such as from about 5 seconds to about one minute, depending upon the particular photoresist formulation used for the thick film layer **14**, the radiation source, distance from the radiation source, and the thickness of the thick film layer **14**. The thick film layer **14** may optionally be exposed to electron beam irradiation instead of ultraviolet radiation.

The foregoing procedure is similar to a standard semiconductor lithographic process. The mask **72** is a clear, flat substrate usually glass or quartz with the opaque areas **74** defining the areas to be removed from the layer **14** (i.e. a negative acting photoresist layer **14**). The opaque areas **74** prevent the ultraviolet light from cross-linking the layer **14** masked beneath it. The exposed areas of the layer **14** provided by the substantially transparent areas **76** of the mask **72** are subsequently baked at a temperature of about 90° C. for about 30 seconds to about 10 minutes, such as from about 1 to about 5 minutes to complete the curing of the thick film layer **14**.

The non-imaged or masked areas of the thick film layer **14** are then solubilized by a developer and the solubilized material is removed leaving the imaged and developed thick film layer **14** on the device surface **24** of the substrate **12** as shown in FIG. 8. The developer comes into contact with the substrate **12** and the imaged thick film layer **14** through either immersion and agitation in a tank-like setup or by spraying the developer on the substrate **12** and thick film layer **14**. Either spray or immersion will adequately remove the non-imaged material. Illustrative developers include, for example, butyl cellosolve acetate, a xylene and butyl cellosolve acetate mixture, and C₁₋₆ acetates like butyl acetate.

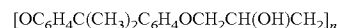
The fluid supply slot **32** can be formed through substrate **12** from a fluid supply side **70** to the device surface side **24** as shown in FIG. 8. Methods for forming fluid supply slots, such as slot **32**, include deep reactive ion etching, grit blasting, chemical etching and the like. In the alternative, the fluid supply slot **32** may be formed before imaging and developing the thick film layer **14**.

With reference to FIG. 8, after imaging and developing the thick film layer **14** and forming the fluid supply slot **32**, a second photoresist layer is laminated adjacent the thick film layer **14** to provide nozzle member **54**. The second photoresist layer may be provided by a dry film photoresist material derived from a di-functional epoxy compound, a relatively high molecular weight polyhydroxy ether, the photoacid generator described above, and, optionally, the adhesion enhancing agent described above.

The di-functional epoxy compound used for providing the nozzle member **54**, includes the first di-functional epoxy compound described above, having a weight average molecular weight typically above 2500 Daltons, e.g., from about 2800 to about 3500 weight average molecular weight in Daltons.

In order to enhance the flexibility of the nozzle member **54** for lamination purposes, for example, a second di-functional epoxy compound may be included in the formulation for the second photoresist layer. The second di-functional epoxy compound typically has a weight average molecular weight of less than the weight average molecular weight of the first di-functional epoxy compound. In particular, the weight average molecular weight of the second di-functional epoxy compound ranges from about 250 to about 400 Daltons. Substantially equal parts of the first di-functional epoxy compound and the second di-functional epoxy compound are used to make the nozzle member **54**. A suitable second di-functional epoxy compound may be selected from diglycidyl ethers of bisphenol-A available from DIC Epoxy Company of Japan under the trade name DIC 850-CRP and from Shell Chemical of Houston, Tex. under the trade name EPON 828. The total amount of di-functional epoxy compound in the nozzle layer **54** ranges from about 40 to about 60 percent by weight based on the total weight of the cured nozzle member **54**. Of the total amount of di-functional epoxy compound in the nozzle member **54**, about half of the total amount is the first di-functional epoxy compound and about half of the total amount is the second di-functional epoxy compound.

Another component of the second photoresist composition is a relatively high molecular weight polyhydroxy ether compound of the formula:



having terminal alpha-glycol groups, wherein n is an integer from about 35 to about 100. Such compounds are made from the same raw materials as epoxy resins, but contain no epoxy groups in the compounds. Such compounds are often referred to as phenoxy resins. Examples of suitable relatively high molecular weight phenoxy resins include, but are not limited to, phenoxy resins available from InChem Corporation of Rock Hill, S.C. under the trade names PKHP-200 and PKHJ. Such phenoxy compounds have a solids content of about 99 weight percent, a Brookfield viscosity at 25° C. ranging from about 450 to about 800 centipoise, a weight average molecular weight in Daltons ranging from about 50,000 to about 60,000, a specific gravity, fused at 25° C., of about 1.18, and a glass transition temperature of from about 90° to about 95° C. The nozzle member **54** contains from about 25 to about 35 percent by weight phenoxy resin based on the weight of the cured nozzle member **54**.

As with the photoresist material for the thick film layer **14**, the second photoresist composition for the nozzle member **54** includes the photoacid generator described above, and, optionally, the adhesion enhancing agent described above. The amount of the photoacid generator ranges from

about 15 to about 20 by weight based on the weight of the cured nozzle member **54**. The amount of adhesion enhancing agent, when used, ranges from about 0.05 to about 1 percent by weight based on the weight of the cured nozzle member **54**.

As set forth above, the nozzle member **54** is applied as a dry film laminate adjacent the thick film layer **14**. Accordingly, the foregoing components of the second photoresist composition used to provide the nozzle member **54** may be dissolved in a suitable solvent or mixture of solvents and dried on a release liner or other suitable support material. A solvent in which all of the components of the second photoresist composition are soluble is an aliphatic ketone solvent or mixture of solvents. A particularly useful aliphatic ketone solvent is cyclohexanone. Cyclohexanone may be used alone or, as in an exemplary embodiment, in combination with acetone. Cyclohexanone is used as the primary solvent for the second photoresist composition due to the solubility of the high molecular weight phenoxy resin in cyclohexanone. Acetone is optionally used as a solvent to aid the film formation process. Since acetone is highly volatile solvent it eludes off quickly after the film has been drawn down onto a release liner or support material. Volatilization of the acetone helps solidify the liquid resin into a dry film.

A suitable photoresist formulation for providing the nozzle material **54** is as follows:

TABLE 1

Component	Amount in photoresist formulation (wt. %)
First di-functional epoxy component (EPON 1007F)	9.6
Second di-functional epoxy component (DIC 850 CRP)	9.6
Polyhydroxy ether (InChem PKHJ)	12.8
Diaryliodoniumhexafluoroantimonate (SARCAT 1012)	7.2
Glycidoxypropyltrimethoxysilane (Z-6040)	0.3
Cyclohexanone	50
Acetone	10.5

With reference to FIGS. **9** and **13**, alternative methods for imaging the nozzle member **54** to provide reentrant nozzles will now be described, such as wherein a mask is used to define the nozzles in the nozzle member **54**. In FIG. **9**, a mask **80** having transparent areas **82** and an area containing a focus altering coating **86** is used to define the nozzles such as nozzle **52** (FIG. **1**) in the nozzle member **54**. The focus altering coating **86** attenuates the actinic radiation so that more cross-linking of the photoresist material occurs adjacent the exit surface of the nozzle member **54** and the radiation effective for cross-linking is reduced as the radiation travels through the nozzle member **54** to a surface **88** adjacent the thick film layer **14** as indicated by arrows **90**. The remainder of the nozzle member **54** is cured by the actinic radiation traveling through the transparent areas **82** of the mask **80**. Upon developing the nozzle member **54** with a suitable solvent as described above, the reentrant nozzles **52** are formed in the nozzle member **54** as shown in FIG. **1**. The focus altering coating may be selected from quartz, sapphire, fused silica, fluorite (such as CaF₂ and MgF₂), and specialized glasses from Melles Griot of Rochester, N.Y. under the trade names BK7, F2, and BaK1.

In another embodiment, illustrated in FIG. **10**, a gray scale mask **92** is used to form the nozzles **52** having reentrant side walls **60** (FIG. **5**). Like the focus altering coating **86**, the gray scale mask **92** attenuates the actinic radiation so that

more radiation is effective for cross-linking adjacent the exit surface **66** of the nozzle member **54**. The amount of radiation is reduced that passes through the nozzle member **54** to the surface **88** adjacent the thick film layer **14** to provide the entrance diameter **58** of the nozzle **52**. Gray scale areas **94** of the mask **92** are provided with increasing opacity toward ends **96**, while a central portion **98** between the gray scale areas **94** is completely opaque providing the exit diameter **56** of the nozzle **52**.

Another alternative method for forming reentrant nozzles **52** in the nozzle member **54** is illustrated in FIG. **11**. In this embodiment, a removable focus altering coating **100** is applied to the exit surface **66** of the nozzle member **54**. The focus altering coating **100** may be provided by UV transparent polymers such as oriented polyvinylidene fluoride; copolyester ethers and cellulosic plastics available from Eastman Chemical Company of Kingsport, Tenn. under the trade names ECDEL and TENITE respectively; polymethylpentenes available from Mitsui Plastics Inc. of White Plains, N.Y. under the trade name TPX; and fluoropolymers available from E. I. Du Pont De Nemours and Company Corporation of Wilmington, Del. under the trade name TEFLON. Other suitable materials include, but are not limited to, positive photoresist materials and light stabilized polyamide based materials such as the materials available from Allied Signal Incorporated of Morristown, N.J. These materials may act as a lens to change the depth through which the actinic radiation focuses on the nozzle member **54** material. As with the focus altering coating **86**, the focus altering coating **100** attenuates the actinic radiation so that more cross-linking of the photoresist material occurs adjacent the exit surface **66** of the nozzle member **54** and the radiation effective for cross-linking is reduced as the radiation travels through the nozzle member **54** to a surface **88** adjacent the thick film layer **14** as indicated by arrows **102**. The remainder of the nozzle member **54** is cured by the actinic radiation traveling through transparent areas **104** of a mask **106** containing an opaque area **108** defining the exit diameter **56** of the nozzle **52**.

When using the focus altering coating **86** on the mask **80** or the focus altering coating **100** applied to the nozzle member **54**, such coatings **86** and **100** may be selectively patterned for imaging different areas of the nozzle member **54**. For example, the nozzles **52** may be formed with reentrant side walls **60** and openings in the nozzle member **54** for contact pad connections to the substrate **12** may be imaged to have substantially vertical side walls. The focus altering coating **100** is removed after imaging the nozzle member in a separate step, or as in one exemplary embodiment, when the nozzles **52** are developed in the nozzle member **54**.

Reentrant nozzles **52** in the nozzle member **54** may also be formed by altering the photoresist material used for the nozzle member **54** and imaging the nozzle member **54** with a conventional mask containing opaque and transparent areas. For example, a negative photoresist material for providing the nozzle member **54** may have dispersed therein ultraviolet light absorbing components that alter the cross-linking of the photoresist material as the radiation travels from the exit surface **66** to the surface **88** adjacent the thick film layer **14**. Such ultraviolet light absorbing components may be selected from carbon black particles, carbon nanotubes, photoacid generators, other pigments, dyes, and polyetheretherketone. The carbon nanotubes and carbon black particles absorb ultraviolet radiation. As the radiation used to image the nozzle member **54** travels through the nozzle member **54**, the radiation is absorbed by the nanotubes or

carbon black particles so that less radiation is available for cross-linking toward the thick film surface **88** of the nozzle member **54**. Also, the opaque areas of the mask reduce the amount of radiation traveling through the nozzle member adjacent the nozzle **52**.

Reducing the amount of photoacid generator in the photoresist material used for the nozzle member **54** reduces the amount of acid available for cross-linking. The photoacid generator absorbs ultraviolet radiation and releases acid in the photoresist material that is used for cross-linking the photoresist material. Typically, photoresist materials contain an excess of the photoacid generator. However, a photoresist material containing from about 0.5 to about 5.0 percent photoacid generator on a weight percent basis may result in areas adjacent the exit surface **66** of the nozzle member **54** cross-linking more than areas adjacent the surface **88** of the nozzle member **54** since the intensity of the radiation decreases as it passes through the nozzle member **54**. Areas receiving a higher intensity of radiation generate more acid than areas receiving a lower intensity radiation.

FIG. **12** illustrates an embodiment for making reentrant nozzles **52** wherein two or more photoresist layers are applied adjacent the thick film layer **14** to provide the nozzle member **54**. Each of the photoresist layers contain a light absorbing component dispersed therein. In one embodiment, a first photoresist layer **110** contains more ultraviolet light absorbing components than a second photoresist layer **112**. As described above, suitable light absorbing components may be selected from carbon black pigments, carbon nanotubes, polyetheretherketone, photoacid generators, dyes, naphthalene based solvents, polyimide particles, and other pigments that absorb ultraviolet radiation. As with the previously described embodiment, nozzles **114** are imaged in the nozzle member **54** using a conventional mask. Accordingly, due to the presence of different amount of light absorbing components in the layers **110** and **112**, more cross-linking will occur in layer **110** than in layer **112** thereby providing a reentrant nozzle **114** as illustrated in FIG. **13**. As is shown in FIG. **13**, the nozzle **114** has an exit diameter **116** smaller than an inlet diameter **118** and sloping side walls **119**.

In another alternative embodiment, a filter may be used with a conventional mask to filter out the peak wavelength of light, for example about 365 nanometer wavelength. The nozzle member **54** is very transparent to a wavelength of 365 nanometers, for example, and less transparent to other wavelengths. Using such a filter, the broad spectrum of light applied to image the nozzle member **54** will not be readily transmitted to lower portions of the nozzle member **54**, thereby cross-linking the upper portions of the nozzle member **54** more fully than the lower portions of the nozzle member **54**, thereby creating differential cross-linking through the nozzle member **54**. Accordingly, upon developing, reentrant nozzles **52** may be formed using such filters.

Additionally, a photoresist material containing a photoinitiator may be used for the nozzle member **54** wherein the photoinitiator in the photoresist material absorbs more ultraviolet light after exposure to ultraviolet radiation than before exposure to ultraviolet radiation. In this embodiment, a pulsed ultraviolet radiation may be used with a conventional mask to expose the nozzle member **54**. A short burst of ultraviolet radiation only exposes the upper portions of the nozzle member **54** causing cross-linking reactions to occur in the upper portions of the nozzle member **54** when the ultraviolet radiation is turned off. The photoinitiator exposed to the short burst of radiation may then absorb ultraviolet radiation when a second burst of radiation is applied to the

nozzle member thereby decreasing the radiation effective for cross-linking as the radiation travels through the nozzle member **54**. By using short burst of radiation, the uppermost portions of the nozzle member **54** are overexposed and the initiator in the uppermost portions causes dark field curing of the nozzle member **54**. In this embodiment, the opaque area of the mask would more closely resemble the entrance hole diameter **58** and the exit hole diameter **56** would be smaller than the entrance hole diameter **58** thereby providing the reentrant nozzle **52**.

In yet another embodiment, a dynamic mask rather than a conventional mask may be used to form the reentrant nozzles **52** in the nozzle member **54**. Like the previous embodiment, a dynamic mask having decreasing hole diameters would be used with short bursts of ultraviolet radiation to expose the nozzle member **54**. The dynamic mask may include a plurality of masks with different hole sizes or a ultraviolet transparent LCD display wherein a ultraviolet opaque hole diameter is continuously reduced in size from the entrance hole diameter **58** to the exit hole diameter **56** to provide the reentrant nozzle **52**. Using this technique, the nozzle **52**, measured at intervals from the entrance to the exit side of the nozzle member may not include identical shapes. Such a dynamic mask may be used to provide changing cross-sectional shapes in addition to changing the cross-sectional area of the nozzles from the entrance to the exit side of the nozzles **52**. It will be appreciated that one or more of the foregoing embodiments may be combined to provide reentrant nozzles **52**.

Subsequent to exposing the nozzle member **54** to ultraviolet radiation, the nozzles **52** are developed using conventional developers as described above. After developing the nozzle member **54**, the substrate **12** having the thick film layer **14** and nozzle member **54** is optionally baked at temperature ranging from about 150° C. to about 200° C., such as from about from about 170° C. to about 190° C. for about 30 minutes to about 150 minutes, such as from about 60 to about 120 minutes to post cure the photoresist materials.

A plan view of the micro-fluid ejection head **10** is illustrated in FIG. **14** wherein the nozzle member **54** containing nozzles **52** is attached adjacent the thick film layer **14** containing the flow channels **44**, and fluid ejection chambers **46**. The micro-fluid ejection head **10** may be attached to a fluid supply reservoir **120** as illustrated in FIG. **15**. The fluid reservoir **120** includes a flexible circuit **122** containing electrical contacts **124** thereon for providing control and actuation of the fluid ejector actuators **16** on the substrate **12** via conductive traces **126**. One or more reservoirs **120** containing the ejection heads **10** may be used in a micro-fluid ejection device **128**, such as an ink jet printer as shown in FIG. **16** to provide control and ejection of fluid from the ejection heads **10**. Other applications of the micro-fluid ejection head **10** will be evident to those skilled in the art.

Having described various aspects and exemplary embodiments and several advantages thereof, it will be recognized by those of ordinary skills that the disclosed embodiments is susceptible to various modifications, substitutions and revisions within the spirit and scope of the appended claims. For example, although the exemplary embodiments previously described herein might assume that all of the nozzles in a nozzle member should have a reentrant profiles, it is contemplated that other embodiments of the present invention may involve nozzle members where only some of the nozzles have such a reentrant profile.

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What is claimed is:

1. An improved photoimaged nozzle member for a micro-fluid ejection head, the nozzle member comprising a photoresist nozzle layer applied adjacent a thick film layer on a substrate having fluid ejector actuators, the photoresist nozzle layer having a plurality of nozzles therein, wherein the nozzles are formed in the nozzle layer from an exit surface of the nozzle layer to an entrance surface of the nozzle layer, and the nozzles have a reentrant profile with a wall angle greater than about 4° up to about 30° measured from an axis orthogonal to a plane defined by the exit surface of the nozzle layer.

2. The nozzle member of claim 1, wherein the photoresist nozzle layer comprises a single layer of photoresist material.

3. The nozzle member of claim 2, wherein the single layer of photoresist material comprises a negative photoresist resin containing one or more differential ultraviolet light absorbing components dispersed therein.

4. The nozzle member of claim 3, wherein the light absorbing components are selected from the group consist-

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ing of carbon black particles, carbon nanotubes, photoacid generators, and polyetheretherketone.

5. The nozzle member of claim 1, wherein the photoresist nozzle layer comprises at least a first layer of a first photoresist material and a second layer of a second photoresist material.

6. The nozzle member of claim 5, wherein the first photoresist material includes more ultraviolet light absorbing components than the second photoresist material.

7. The nozzle member of claim 6, wherein the light absorbing components are selected from the group consisting of carbon black particles, carbon nanotubes, photoacid generators, naphthalene based solvents, polyimide particles, and polyetheretherketone.

8. A micro-fluid ejection head structure comprising the nozzle member of claim 1.

9. A micro-fluid ejection device comprising the micro-fluid ejection head of claim 8.

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