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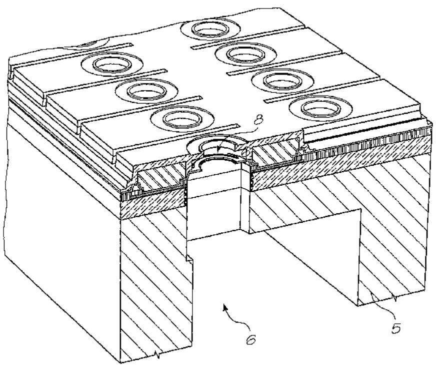
(54) Title: METHOD SUITABLE FOR ETCHING HYDROPHILIC TRENCHES IN A SUBSTRATE



(57) Abstract: A method suitable for etching hydrophilic trenches into a substrate, such as silicon, is provided. The method comprises etching and sidewall passivation processes for achieving anisotropy. Sidewalls of the etched trench are made hydrophilic during the etch by virtue of a hydrophilizing dopant in a passivating gas plasma. The method is useful for etching ink supply channels in inkjet printheads.

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METHOD SUITABLE FOR ETCHING HYDROPHILIC TRENCHES IN A SUBSTRATE

Field of the Invention

This invention relates to a method of etching a substrate and is suitable for forming deep or ultradeep trenches having hydrophilic sidewalls. It has been developed primarily to provide hydrophilic trenches or channels in silicon substrates, whilst avoiding the use of complex etching procedures or post-etching treatments.

Background of the Invention

The impact of MEMS (Microelectromechanical Systems) devices on the microelectronics industry has been extremely significant in recent years. Indeed, MEMS is one of the fastest growing areas of microelectronics. The growth of MEMS has been enabled, to a large extent, by the extension of silicon-based photolithography to the manufacture of micro-scale mechanical devices and structures. Photolithographic techniques, of course, rely on reliable etching techniques, which allow accurate etching of a silicon substrate revealed beneath a mask.

MEMS devices have found applications in a wide variety of fields, such as in physical, chemical and biological sensing devices. One important application of MEMS devices is in inkjet printheads, where micro-scale actuators for inkjet nozzles may be manufactured using MEMS techniques. The present Applicant has developed printheads incorporating MEMS ink ejection devices and these are described in the following patents and patent applications, all of which are incorporated herein by reference.

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6394573	6622923	6747760	10/189459	10/884881	10/943941	10/949294
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Typically a MEMS inkjet printhead ("MEMJET printhead") is comprised of a plurality of printhead integrated circuits, with each integrated circuit having several thousand nozzles. Each nozzle comprises an actuator for ejecting ink, which may be, for example, a thermal bend actuator (*e.g.* US 6,322,195) or a bubble-forming heater element actuator (*e.g.* US 6,672,709). The integrated ciruits are manufactured using MEMS techniques, meaning that a high nozzle density and, hence, high resolution printheads can be mass-produced at relatively low cost.

In the manufacture of MEMS printhead integrated circuits, it is often required to perform deep or ultradeep etches to depths of over 10 *micron*. A problem with deep etches, especially ultradeep etches, is maintaining anisotropy during the etch – that is, ensuring the trench is etched in a vertical direction, but not in a horizontal direction. Ideally, the sidewalls of the trench should be substantially perpendicular with respect to the surface of the substrate.

It is particularly important to have perpendicular sidewalls in ultradeep trenches when etching ink supply channels through silicon wafers. MEMS printhead integrated circuits require delivery of ink to each nozzle through either an individual or a common ink supply channel. These ink channels are typically etched through wafers having a thickness of about 200 *micron*, and therefore place considerable demands on the ultradeep etching method employed. It is especially important that each ink channel is substantially perpendicular to the wafer surface and does not contain kinks or sidewall projections (*e.g.* grassing), which can interfere with the flow of ink.

In the Applicant's US patent application nos. 10/728,784 (Applicant Ref: MTB08) and 10/728,970 (Applicant Ref: MTB07), both of which are incorporated herein by reference, there is described a method of fabricating inkjet printheads from a wafer having a drop ejection side and an ink supply side. Referring to Figure 1, there is shown a typical MEMS nozzle arrangement 1 comprising a bubble-forming heater element actuator assembly 2. The actuator assembly 2 is formed in a nozzle chamber 3 on the passivation layer 4 of a silicon wafer 5. The wafer typically has a thickness "B" of about 200 *micron*, whilst the nozzle chamber typically occupies a thickness "A" of about 20 *micron*.

Referring to Figure 2, an ink supply channel 6 is etched through the wafer 5 to the CMOS metallization layers of an interconnect 7. An inlet 8 provides fluid connection between the ink supply channel 6 and the nozzle chamber (removed for clarity in Figure 2). CMOS drive circuitry 9 is provided between the wafer 5 and the interconnect 7. The actuator assembly 2, associated drive circuitry 9 and ink supply channel 6 may be formed on and through a wafer 3 by lithographically masked etching techniques, as described in US application no. 10/302,274, which is incorporated herein by reference.

Referring to Figure 3, the ink supply channel 6 is formed in the wafer 5 by first etching a trench partially through the wafer 5 from the drop ejection side (*i.e.* nozzle side) of the wafer. (This trench will become the inlet 8, shown in Figure 2). Once formed, the trench is plugged with photoresist 10, as shown in Figure 3, and the ink supply channel 6, is formed by ultradeep etching from the ink supply side of the wafer 5 to the photoresist plug 10. Finally, the photoresist 10 is stripped from the trench to form the inlet 8, which provides fluid connection between the ink supply channel 6 and the nozzle chamber 3.

Alternatively, each ink supply channel may be configured to supply ink to a plurality of nozzles which all eject the same colored ink. This arrangement is illustrated in Figure 4 and is described in detail in the Applicant's copending application no. 10/760,254 (Applicant Ref: RRC022), the contents of which is incorporated herein by reference.

In either of these ink supply channel configurations, the "back-etching" technique avoids filling and removing an entire ink supply channel with resist whilst nozzle structures in the wafer are being lithographically formed. Notwithstanding the problems of etching anisotropically to a depth of up to 200 *micron*, it is also desirable when etching ink supply channels to provide hydrophilic channel sidewalls. Optimum printing conditions in an inkjet printhead are generally achieved by having a hydrophobic nozzle face and hydrophilic ink supply channels. Hydrophilic ink supply channels ensure that the aqueous-based inkjet ink is drawn into the ink supply channels from a bulk ink reservoir. A hydrophobic nozzle face ensures the formation of discrete ink droplets when the ink is ejected from each nozzle and also minimizes surface flooding during printing.

Several methods for etching ultradeep trenches into silicon are known in the art. All these methods involve deep reactive ion etching (DRIE) using a gas plasma. The semiconductor substrate, with a suitable mask disposed thereon, is placed on a lower electrode in a plasma reactor, and exposed to an ionized gas plasma formed from a mixture of gases. The ionized plasma gases (usually positively charged) are accelerated towards the substrate by a biasing voltage applied to the electrode. The plasma gases etch the substrate either by physical bombardment, chemical reaction or a combination of both. Etching of silicon is usually ultimately achieved by formation of volatile silicon halides, such as SiF_4, which are carried away from the etch front by a light inert carrier gas, such as helium.

Anisotropic etching is generally achieved by depositing a passivation layer onto the base and sidewalls of the trench as it is being formed, and selectively etching the base of the trench using the gas plasma.

One method for achieving ultradeep anisotropic etching is the "Bosch process", described in US 5,501,893 and US 6,284,148. This is the current method of choice in commercial MEMS foundries and involves alternating polymer deposition and etching steps. After formation of a shallow trench, a first polymer deposition step deposits a polymer onto the base and sidewalls of the trench. The polymer is deposited by a gas plasma formed from a fluorinated gas (*e.g.* CHF_3, C_4F_8 or C_2F_4) in the presence or in the absence of an inert gas. In the subsequent etching step, the plasma gas mix is changed to SF_6/Ar. The polymer deposited on the base of the trench is quickly broken up by ion assistance in the etching step, while the sidewalls remain protected. Hence, anisotropic etching may be achieved. However, a major disadvantage of the Bosch process is that polymer deposition and etching steps need to be alternated, which means continuously alternating the gas composition of the plasma. This alternation, in turn, leads to slow etch rates and uneven trench sidewalls, characterized by scalloped surface formations. Plasma instability as the gas chemistry is switched also tends to exacerbate the formation of uneven sidewalls.

Moreover, the Bosch etch leaves a hydrophobic polymer coating on trench sidewalls. As discussed above, hydrophobic sidewalls are undesirable in fluidics applications, such as ink supply channels for inkjet printheads. Accordingly, in inkjet printhead applications, the Bosch etch is usually followed by a post-etch cleaning process, such as EKC wet cleaning, dry O_2 plasma ashing or combinations thereof. The post-etch cleaning process is intended to remove the hydrophobic polymer and leave channel sidewalls coated with SiO_2. However, post-etch cleaning processes undesirably add to the number of fabrication steps and can also lead to their own inherent problems, such as wafer-cracking during EKC cleaning.

A modification of the cyclical Bosch process is described in US 6,127,278, assigned to Applied Materials, Inc. In the Applied Materials process, a first passivation etch is performed using a HBr/O_2 plasma, followed by a main etch using a $SF_6/HBr/O_2$ in alternating succession. The HBr enhances passivation, probably by formation of relatively nonvolatile silicon bromides in the passivation layer. However, the problem of hydrophobically coated sidewalls still remains with the Applied Materials process.

In order to avoid the cumbersome Bosch process, in which plasma gases need to be continuously alternated, anisotropic etching techniques were developed, which use *simultaneous* sidewall passivation. In such etching methods, a plasma mix is formed from a passivating component and an etching component. A typical plasma mix is formed from O_2/SF_6 with the addition of He as a carrier gas being highly recommended to enhance ion dispersement. The plasma mix simultaneously passivates and etches, which avoids the disadvantages of the Bosch process. Nevertheless, it is the general view that mixing the gases gives less effective anisotropic etching, because the two processes tend to be self-cancelling. Accordingly, simultaneous sidewall passivation etching has been mostly confined to etching relatively shallow trenches. For ultradeep anisotropic etching, alternating passivation/etching is by far the most preferred technique.

One successful process for etching ultradeep trenches, which does not require alternating plasma gas mixtures, is the "Lam process" described in US 6,191,043. In the Lam process, a passivating/etching plasma is formed from a mixture of O_2, SF_6, He and Ar – the O_2 is a passivating gas; the SF_6 is an etching gas; the He is a carrier gas; and the Ar is a bombardment-enhancing gas. Trench depths of up to 60 *micron* have been reported using the Lam process with acceptable etch rates. However, the process has not been used widely and etch depths of greater than 60 *micron* have not been reported.

None of the above-described etch processes can be used to etch trenches through a typical wafer to a depth of over 100 *micron*, whilst leaving hydrophilic sidewalls. Even when the etch process (or post-etch treatment) leaves SiO_2-coated sidewalls, these SiO_2-coated sidewalls are not particularly hydrophilic, having a contact angle of about 60°. Truly hydrophilic surfaces have contact angles of less than 50°, preferably less than 40° or preferably less than 30°.

It would be desirable to provide a new reactive ion etching process, which is capable of anisotropically etching ultradeep trenches of over 100 *micron*. It would be particularly desirable for the process to leave hydrophilic sidewalls after the etch, without the need for any post-etch hydrophilization treatments.

Summary of the Invention

In a first aspect, the present invention provides a method of deep reactive ion etching a trench into a substrate, said method comprising an etching process using an etching gas plasma and passivation process using a passivating gas plasma, wherein said passivating gas plasma comprises a hydrophilizing dopant.

In a second aspect, there is provided a method of fabricating an inkjet printhead comprising the steps of:

(i) providing a wafer having a drop ejection side and an ink supply side;

(ii) etching a plurality of trenches partially through said drop ejection side of said wafer;

(iii) filling said trenches with photoresist;

(iv) forming a plurality corresponding nozzles, ejection actuators and associated drive circuitry on said drop ejection side of said wafer using lithographically masked etching techniques;

(v) etching a plurality of corresponding ink supply channels from said ink supply side of said wafer to said photoresist; and

(vi) stripping said photoresist from said trenches to form nozzle inlets, thereby providing fluid connection between said ink supply side and said nozzles,

wherein said ink supply channels are etched using the etching method described above.

In a third aspect, there is provided a substrate comprising at least one feature etched in a surface of the substrate, said feature having the characteristics of:

(a) a depth of over 100 *micron*;

(b) sidewalls substantially perpendicular to said surface; and

(c) sidewalls having a contact angle of less than 50°.

In a fourth aspect, there is provided an inkjet printhead comprising:

a substrate having a drop ejection side and an ink supply side;

a plurality of nozzle assemblies formed on said drop ejection side of said wafer, each nozzle assembly having an ink inlet; and

a plurality of ink supply channels defined in said ink supply side, each ink supply channel being in fluid communication with at least one ink inlet,

wherein said ink supply channels have the characteristics of:

(a) a depth of over 100 *micron*;

(b) sidewalls substantially perpendicular to a surface defined by the ink supply side of the substrate; and

(c) sidewalls having a contact angle of less than 50°.

The etching method of the present invention provides a means by which trenches or channels can be formed in substrates. The trenches or channels advantageously have hydrophilic sidewalls by virtue of the hydrophilizing dopant present in the etching plasma gas chemistry. Hence, the method is highly suitable for forming trenches or channels used in aqueous fluidic applications, such as ink supply channels in inkjet printheads.

The etching method may be used for etching ultradeep trenches into silicon, having a depth of at least 100 *micron*, with acceptable etch rates. Moreover, minimal RIE lag is observed using this method. The method also provides highly anisotropic etching, whereby the trenches formed have substantially perpendicular sidewalls with respect to the substrate surface. By "substantially perpendicular", it is meant that the taper angle of the sidewalls is between 85° and 95°, preferably between 87° and 93°, and more preferably between 88° and 92°.

Additional practical advantages of the present invention include the potential avoidance of any post-etch cleanup steps such as EKC wet cleaning or O_2 plasma dry ashing.

Detailed Description of Optional Features

The etching plasma is typically generated in a plasma etching reactor, such as an inductively coupled plasma etching reactor. Plasma etching reactors are well known in the art and are commercially available from various sources (*e.g.* Surface Technology Systems, PLC). Typically, the etching reactor comprises a chamber formed from aluminium, glass or quartz, which contains a pair of parallel electrode plates. However, other designs of reactor are available and the present invention is suitable for use with any type of plasma etching reactor.

A radiofrequency (RF) energy source is used to ionize plasma gases introduced into the chamber. The ionized gases are accelerated towards a substrate disposed on a lower electrode (electrostatic chuck) by a biasing voltage. Hence, etching is achieved by a combination of physical bombardment and chemical reaction. Various control means are provided for controlling the relative ratios of plasma gases, the biasing voltage, the RF ionizing energy, the substrate temperature, the chamber pressure *etc.* It will, of course, be within the ambit of the skilled person's common general knowledge to vary plasma reactor parameters in order to optimize etching conditions. For example, the chamber pressure is usually in the range of 5 to 100 mTorr, which is typical for deep reactive ion etching (DRIE).

Optionally, the total amount of hydrophilizing dopant is such that it comprises less than 10 vol%, less than 8 vol%, or less than 5 vol% of the passivating gas plasma. The dopant may be introduced into the plasma chamber as either a liquid or a gas. The toxic or explosive nature of some hydrophilizing dopants (e.g. B_2H_6) means that liquids are sometimes preferred to gases. Liquids will, of course, be rapidly vaporized in the plasma chamber.

Optionally, the hydrophilizing dopant comprises a boron-containing compound, a phosphorus-containing compound or combinations thereof. Optionally, the hydrophilizing dopant comprises a compound selected from B_2H_6, PH_3, trimethyl borate (TMB), trimethyl phopshite (TMP) or combinations thereof.

Boron and phosphorus dopants are well known in the formation of silicon glasses. Accordingly, trench sidewalls resulting from the etch typically comprise phosphosilicate glass (PSG), borosilicate glass (BSG), borophosphosilicate glass (BPSG) or combinations thereof. Such glasses are known to be more hydrophilic than silicon dioxide.

Optionally, the trench sidewalls resulting from the etch have a contact angle of less than 50°, less than 40°, or less than 30°. These are hydrophilic contact angles and contrast with the highly hydrophobic sidewalls resulting from the Bosch etch. They are also significantly more hydrophilic than SiO_2 sidewalls, which typically have a contact angle of about 60°.

As mentioned above, the method of the present invention generally provides substantially anisotropic etching, providing trenches with substantially perpendicular sidewalls, to depths of over 100 *micron*, over 200 *micron* or over 300 *micron*, with aspect ratios of over 1.5:1, over 2:1, over 5:1, over 10:1 or over 20:1. This is particularly advantageous for etching ink supply channels during printhead fabrication.

Optionally, the method is used to etch a plurality of trenches in a substrate simultaneously, wherein the positions of the trenches are defined by a mask layer on the substrate. Typically, the mask is an oxide layer (*e.g.* Thermally Enhanced Oxide Silicon ("TEOS") or a photoresist.

Surprisingly high substrate : mask selectivities are observed using the method of the present invention. Selectivity is important, because it is imperative that the mask does not wear away when etching ultradeep trenches. In general, higher substrate : mask selectivities are achievable using hard oxide masks as compared to soft photoresist masks. With a soft photoresist mask, the present invention typically gives a substrate : mask selectivity of least 30:1, optionally at least 40:1 or optionally at least 50:1. With a hard oxide mask, the present invention typically gives a substrate : mask selectivity of least 80:1, optionally at least 90:1 or optionally at least 100:1. Such high selectivities are surprising, given that the method relies, to a large extent, on physical bombardment of the substrate.

The method of the present invention generally provides acceptably high etch rates. In a typical silicon etch, etch rates of at least 4 *micron*/min, optionally at least 5 *micron*/min, optionally at least 6*micron*/min, or optionally at least 7 *micron*/min are usually achievable. Accordingly, the method is suitable for etching ultradeep trenches (*e.g.* 200 *micron* long trenches), which can be used as ink supply channels in printheads.

In one embodiment, the invention employs simultaneous sidewall passivation during etching. With simultaneous etching/sidewall passivation, the method comprises the step of etching a trench into the substrate using an etching and passivating gas plasma. The etching and passivating gas plasma optionally comprises: (a) a passivating gas comprising oxygen; (b) an inert sputtering gas; (c) a fluorinated etching gas; and (d) a hydrophilizing dopant (as described above).

Optionally, the inert sputtering gas is argon. Optionally, the flow rate of the inert sputtering gas is in the range of 100 to 300 sccm, or 150 to 250 sccm. Optionally, the gas chemistry may comprise other inert gases, such as helium. However, it is generally preferred to use Ar alone in order to simplify control of the gas chemistry.

The fluorinated etching gas may be any fluorine-based gas, which can produce fluorine radicals and etch silicon in a plasma etching reactor. The fluorinated gas may be, for example SF_6, NF_3 or mixtures thereof. Optionally, the fluorinated gas is SF_6. Optionally, the flow rate of the fluorinated gas is in the range of 10 to 100 sccm, or 20 to 80 sccm. Optionally, the ratio of inert sputtering gas (*e.g.* argon) to fluorinated gas is in the range of 2-20 to 1, or 2-10 to 1.

The passivating gas may comprises other passivating components in addition to oxygen. For example, HBr may also be present in order to assist with passivation. Optionally, the flow rate of passivating gas is in the range of 10 to 80 sccm, or 15 to 60 sccm. Optionally, the ratio of inert sputtering gas to passivating gas is in the range of 2-20 to 1, more preferably, 3-15 to 1. Optionally, the ratio of fluorinated etching gas to passivating gas is in the range of 3:1 to 1:3, or 2:1 to 1:2, or 3:2 to 2:3.

Without wishing to be bound by theory, the source of anisotropy during simultaneous etching/passivation may be understood by the following processes:

Oxygen and fluorine radicals are first generated in the plasma according to equations [1] and [2]:

$$SF_6 + e^- \rightarrow S_xF_y^+ + S_xF_y^{\cdot} + F^{\cdot} + e^- \qquad [1]$$

$$O_2 + e^- \rightarrow O^+ + O^{\cdot} + e^- \quad [2]$$

The oxygen radicals passivate the silicon surface by first adsorbing onto the surface and then reacting to form an oxide film:

$$O^{\cdot} + Si(s) \rightarrow Si(s)\text{-}nO \rightarrow SiO_n(sf) \quad [3]$$

The oxide passivation layer covers both the sidewalls and the base of the trench. However, at the base of the trench, the oxide layer can be removed by the following processes:

$$SiO_n(sf) + F^{\cdot} \rightarrow SiO_n(sf)\text{-}F \quad [4]$$

$$SiO_n(sf)\text{-}nF \rightarrow \textit{ion energy} \rightarrow SiF_x(ads) + SiO_xF_y(ads) \quad [5]$$

The adsorbed silicon fluoride and silicon oxyfluoride species dissociate from the silicon surface, either by their natural volatility or by physical sputtering. With the silicon at the base of the trench revealed, the fluorine radicals in the plasma can proceed with etching. The etching is driven by the volatility of silicon fluoride species:

$$Si(s) + F^{\cdot} \rightarrow Si\text{-}nF \quad [6]$$

$$Si\text{-}nF \rightarrow \textit{ion energy} \rightarrow SiF_x(ads) \quad [7]$$

$$SiF_x(ads) \rightarrow SiF_x(g) \quad [8]$$

In preceding equations [1] to [8], (s) represent surface; (sf) represents surface film; (ads) represents adsorbed; (g) represents gas; and x, y and n are arbitrary integers representing indefinable potentially mixed oxidation state species.

In terms of achieving anisotropy during the etch, equation [5] represents the key step. The passivation layer at the base of the trench is removed by a process assisted by ion energy. Since the etching plasma is accelerated perpendicularly towards the silicon substrate in the plasma reactor, the sidewalls of the trench do not receive the same ion energy as the base. Hence, anisotropic etching can be achieved.

In general, the greater the ion energy in the plasma, the greater the degree of anisotropy that can be achieved. One way of achieving high ion energy is to increase the bias power in the plasma reactor. However, an alternative way of achieving high ion energy is to use heavy ions, such as argon ions, in the plasma.

In an alternative embodiment, the invention employs alternating etching and sidewall passivation steps in a *quasi* Bosch process. With alternating etching/passivation, the method comprises the steps of:

(i) etching into the substrate using an etching gas plasma, the etching gas plasma comprising:

(a) a fluorinated etching gas; and

(b) an inert sputtering gas;

(ii) passivating exposed surfaces of the substrate using a passivating gas plasma, the passivating gas plasma comprising:

(a) a silicon-containing deposition gas; and

(b) a hydrophilizing dopant; and

(iii) alternatingly repeating steps (i) and (ii).

The fluorinated etching gas, the inert sputtering gas and the hydrophilizing dopant are generally as described previously.

Typically, the silicon-containing deposition gas comprises SiH_4, although any silicon-containing deposition gas (*e.g.* vaporized TEOS) may be used Other gases that may be optionally present in the passivating gas plasma include N_2, N_2O, NH_3, O_2 or combinations thereof. Hence, the passivating step (ii) resembles a typical process for depositing phosphosilicate glass (PSG), borosilicate glass (BSG) or borophosphosilicate glass (BPSG) onto a substrate. The etching step (i) resembles a typical etching step in a Bosch process.

Brief Description of the Drawings

Figure 1 is a perspective view of a nozzle arrangement for a printhead;

Figure 2 is a cutaway perspective view of the nozzle arrangement shown in Figure 1 with the actuator assembly removed;

Figure 3 is a cutaway perspective view of the printhead nozzle arrangement shown in Figure 2 before stripping away the photoresist plug; and

Figure 4 is a cutaway perspective view of an alternative ink supply channel arrangement.

General Experimental Procedure

All etches are performed in a standard inductively coupled plasma DRIE reactor. The reactor is configured as follows:

ICP:	1.9 – 2.2 MHz, 2000 W Max
Bias:	13.56 MHz, 1250 W Max
Lower Electrode:	Anodized Electrostatic Chuck (ESC), 1000W Max
Chamber:	Anodized, 1.4 litre chamber volume
Pump:	2 litre turbo
Cooling:	Backside helium cooling

It will, of course, be appreciated that the present invention has been described purely by way of example and that modifications of detail may be made within the scope of the invention, which is defined by the accompanying claims.

CLAIMS

1. A method of etching a trench into a substrate, said method comprising an etching process using an etching gas plasma and a passivation process using a passivating gas plasma, wherein said passivating gas plasma comprises a hydrophilizing dopant.

2. The method of claim 1, wherein said substrate is silicon.

3. The method of claim 1, wherein said etching gas plasma is generated in a plasma etching reactor, and said substrate is etched in said reactor.

4. The method of claim 1, wherein the trench sidewalls resulting from the etch have a contact angle of less than 50°.

5. The method of claim 1, wherein the hydrophilizing dopant comprises a boron-containing compound, a phosphorus-containing compound or combinations thereof.

6. The method of claim 1, wherein the hydrophilizing dopant comprises a compound selected from the group consisting of B_2H_6, PH_3, trimethyl borate (TMB), trimethyl phopshite (TMP) or combinations thereof.

7. The method of claim 1, wherein the trench sidewalls resulting from the etch comprise phosphosilicate glass (PSG), borosilicate glass (BSG), borophosphosilicate glass (BPSG) or combinations thereof.

8. The method of claim 1, wherein said trench has a depth of over 100 *micron*.

9. The method of claim 1, wherein a plurality of trenches is etched into said substrate simultaneously, the positions of said trenches being defined by a mask layer disposed on said substrate.

10. The method of claim 9, wherein said mask layer is an oxide layer or a photoresist layer.

11. The method of claim 10, wherein the substrate : mask selectivity is at least 30 : 1.

12. The method of claim 1, wherein the etch rate is at least 4 *micron*/min.

13. The method of claim 1 comprising simultaneous etching and passivation processes, wherein a single etching and passivating gas plasma comprises said etching gas plasma and said passivating gas plasma.

14. The method of claim 13, wherein said etching and passivating gas plasma comprises:

(a) a passivating gas comprising oxygen;
(b) an inert sputtering gas;
(c) a fluorinated etching gas; and
(d) a hydrophilizing dopant.

15. The method of claim 14, wherein said inert sputtering gas is argon.

16. The method of claim 14, wherein said fluorinated etching gas is selected from the group consisting of SF_6, NF_3 and mixtures thereof.

17. The method of claim 1 comprising alternating etching and passivation processes.

18. The method of claim 17, comprising the steps of:

(i) etching into said substrate using an etching gas plasma, said etching gas plasma comprising:

(a) a fluorinated etching gas; and
(b) an inert sputtering gas;

(ii) passivating exposed surfaces of the substrate using a passivating gas plasma, said passivating gas plasma comprising:

(a) a silicon-containing deposition gas; and
(b) a hydrophilizing dopant;

(iii) alternatingly repeating steps (i) and (ii).

19. The method of claim 18, wherein said inert sputtering gas is argon.

20. The method of.claim 18, wherein said fluorinated etching gas is selected from the group consisting of SF_6, NF_3 and mixtures thereof.

21. The method of claim 18, wherein said silicon-containing deposition gas comprises SiH_4.

22. The method of claim 18, wherein said passivating gas plasma further comprises a gas selected from O_2, N_2, N_2O, NH_3 or combinations thereof.

23. The method of claim 18, wherein the passivation step deposits, on the exposed surfaces, a phosphosilicate glass (PSG), a borosilicate glass (BSG), a borophosphosilicate glass (BPSG) or combinations thereof.

24. A method of fabricating an inkjet printhead comprising the steps of:

(i) providing a wafer having a drop ejection side and an ink supply side;

(ii) etching a plurality of trenches partially through said drop ejection side of said wafer;

(iii) filling said trenches with photoresist;

(iv) forming a plurality corresponding nozzles, ejection actuators and associated drive circuitry on said drop ejection side of said wafer using lithographically masked etching techniques;

(v) etching a plurality of corresponding ink supply channels from said ink supply side of said wafer to said photoresist; and

(vi) stripping said photoresist from said trenches to form nozzle inlets, thereby providing fluid connection between said ink supply side and said nozzles, wherein said ink supply channels are etched using the etching method according to claim 1.

25. A substrate comprising at least one feature etched in a surface of the substrate, said feature having the characteristics of:

(a) a depth of over 100 *micron*;

(b) sidewalls substantially perpendicular to said surface; and

(c) sidewalls having a contact angle of less than 50°.

26. The substrate of claim 25, which is an inkjet printhead, wherein said etched features are ink supply channels.

27. An inkjet printhead comprising:

a substrate having a drop ejection side and an ink supply side;

a plurality of nozzles formed on said drop ejection side of said wafer, each nozzle having an ink inlet; and

a plurality of ink supply channels defined in said ink supply side, each ink supply channel being in fluid communication with at least one ink inlet, wherein said ink supply channels have the characteristics of:

(a) a depth of over 100 *micron*;

(b) sidewalls substantially perpendicular to a surface defined by the ink supply side of the substrate; and

(c) sidewalls having a contact angle of less than 50°.

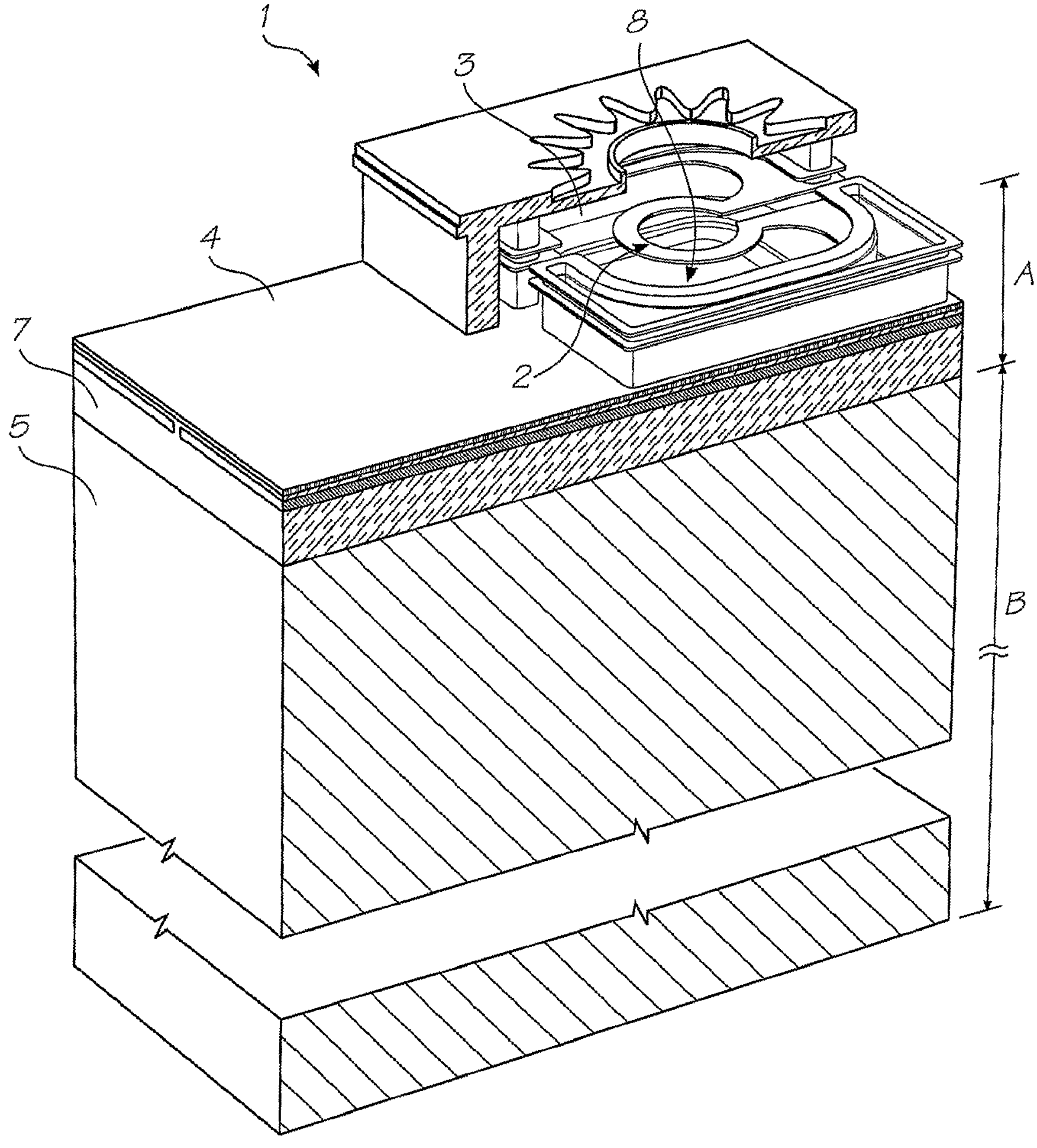

FIG. 1

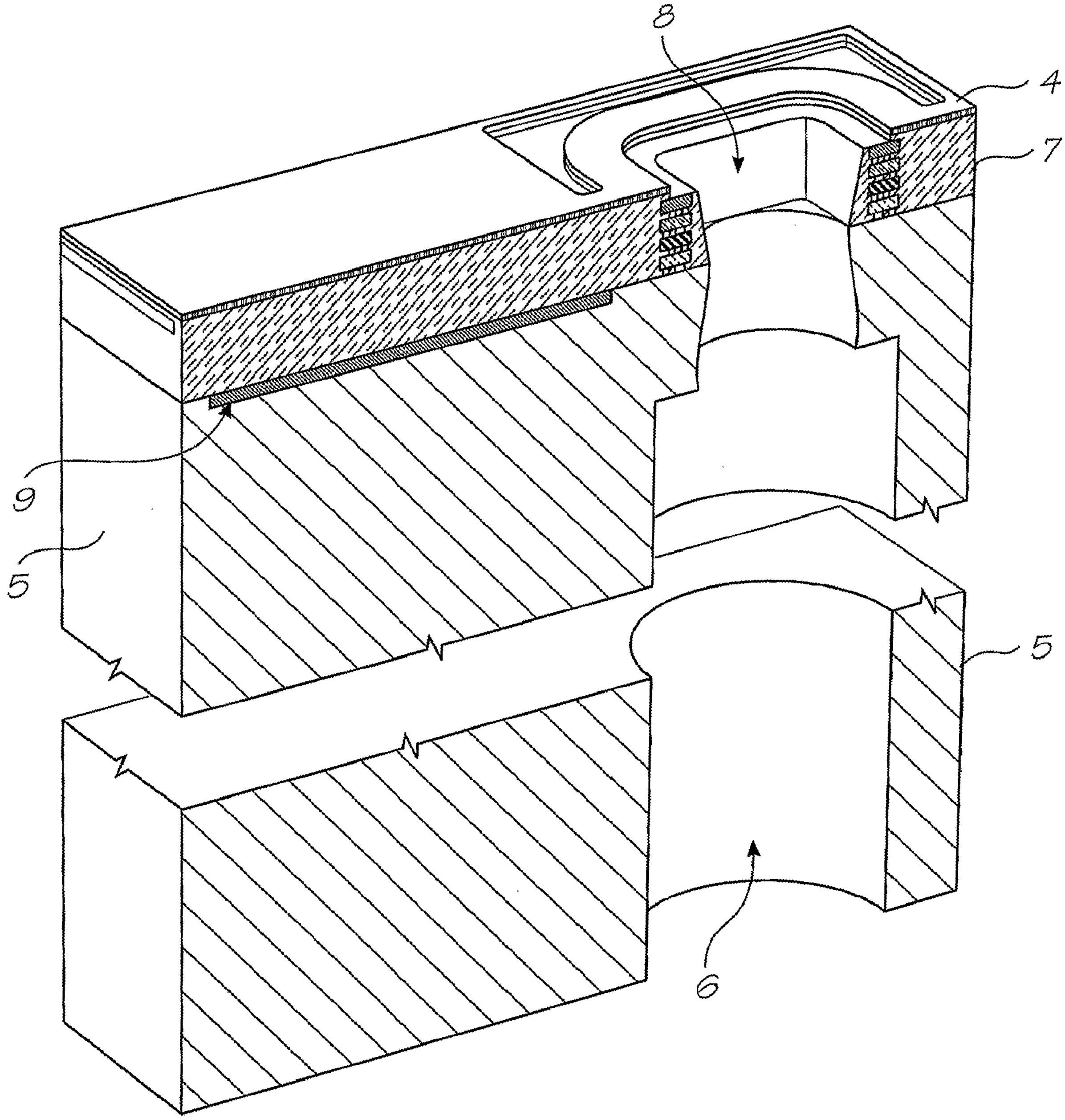

FIG. 2

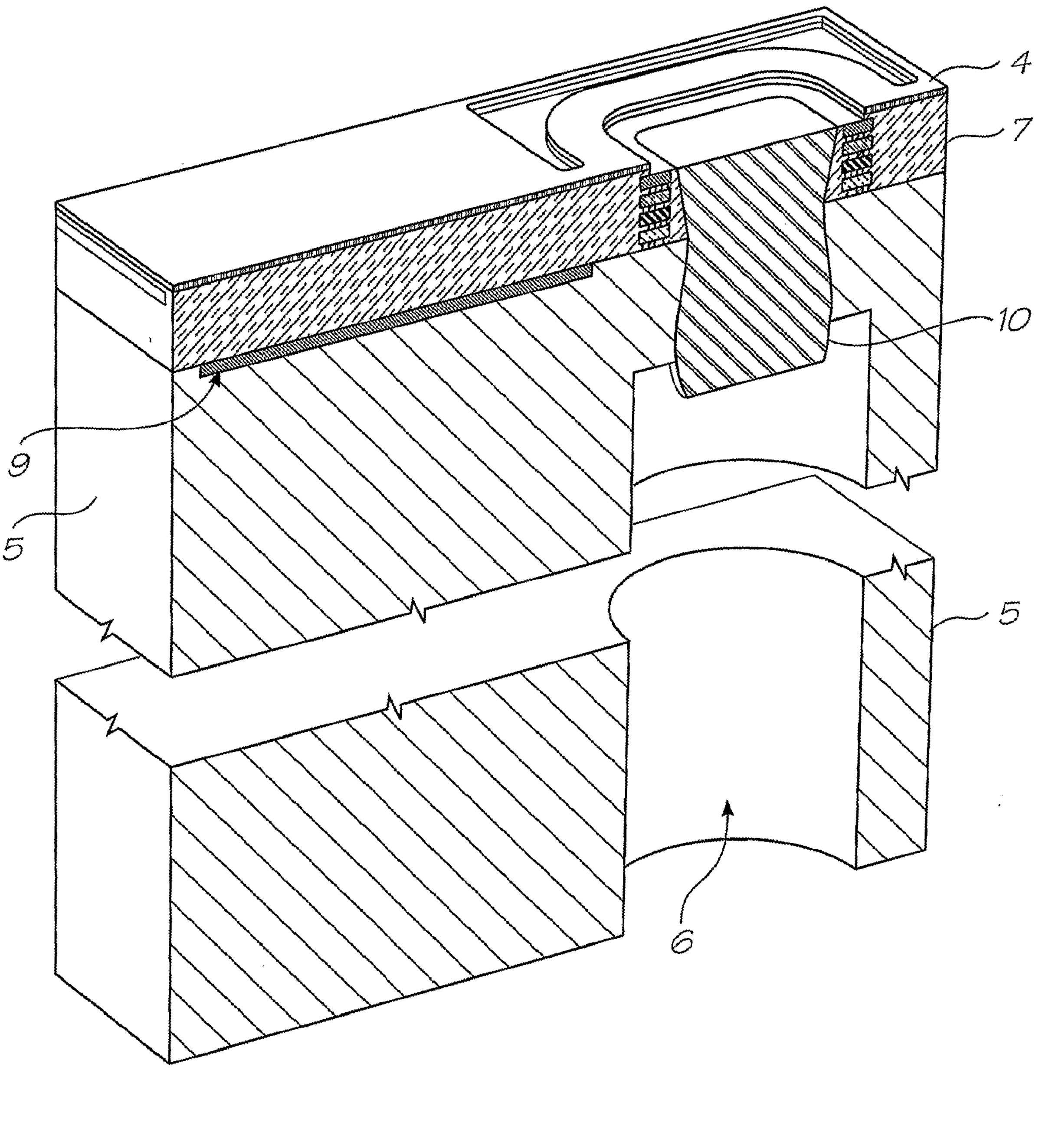

FIG. 3

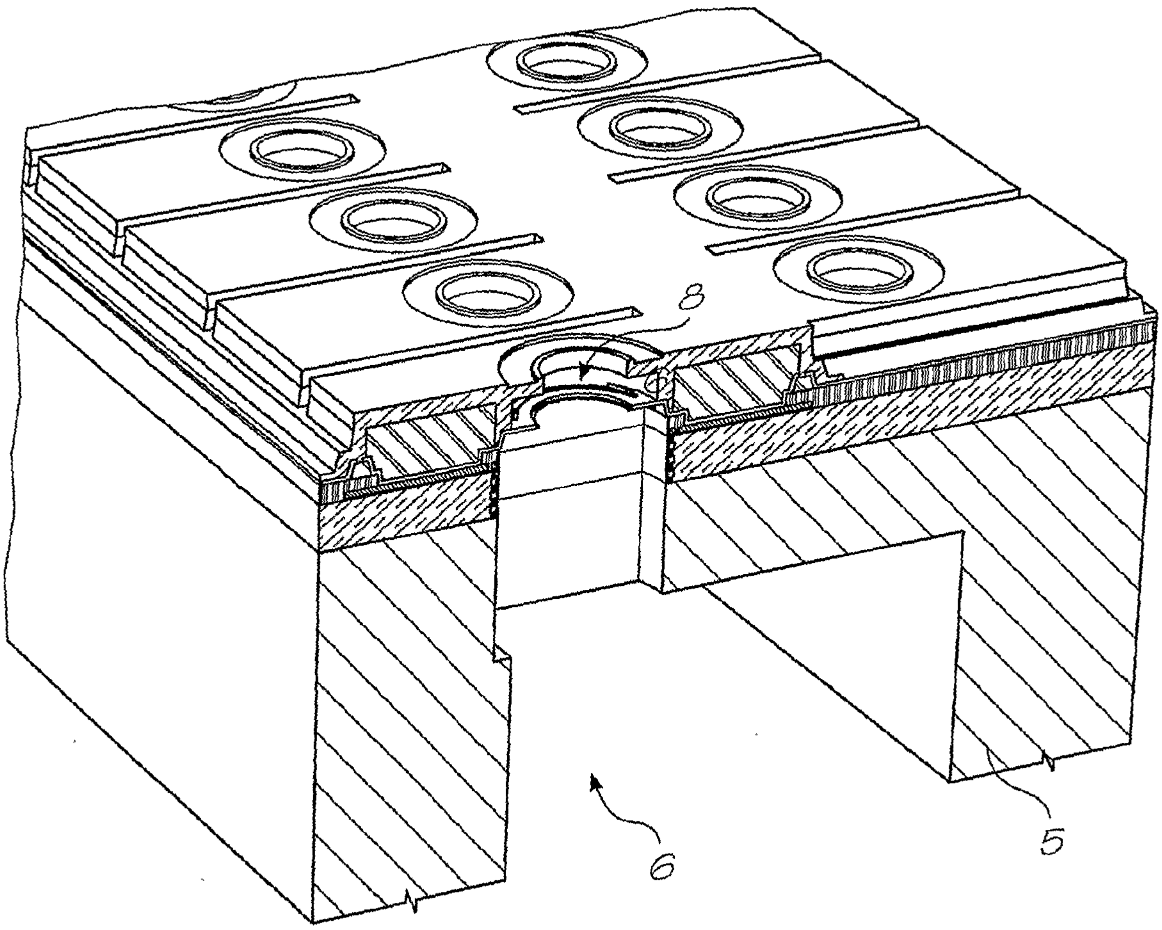

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU2006/000995

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. ***H01L 21/00*** (2006.01) ***B41J 2/16*** (2006.01) ***H01L 21/3065*** (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
DWPI and JAPIO with keywords including plasma, ion, etching, RIE, doping, dopant, hydrophilic, boron, phosphate, TMP, TMB, passivating, printhead, nozzle, inkjet, ultradeep, sidewall, trench, channel and similar terms.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2005/0093912 A1 (VAIDEESWARAN et al.) 5 May 2005 Paragraphs [0001]-[0008], [0022]-[0042].	1-25
A	EP 1079424 A1 (MOTOROLA Inc.) 28 February 2001 Abstract, claims.	1-25

☐ Further documents are listed in the continuation of Box C ☐ See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 September 2006	- 4 OCT 2006

Name and mailing address of the ISA/AU	Authorized officer
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Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
   because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Please refer to the Supplemental Box on the final page of this report.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.: **1 – 25.**

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

Supplemental Box
(To be used when the space in any of Boxes I to VIII is not sufficient)

Continuation of Box No: III (Observations where unity of invention is lacking)

This International Application does not comply with the requirements of unity of invention because it does not relate to one invention or to a group of inventions so linked as to form a single general inventive concept.

In assessing whether there is more than one invention claimed, I have given consideration to those features which can be considered to potentially distinguish the claimed combination of features from the prior art. Where different claims have different distinguishing features they define different inventions.

This International Searching Authority has found that there are different inventions as follows:

1. Claims 1-25 are directed at a method of etching a trench into a substrate, comprising an etching process using an etching gas plasma and a passivation process using a passivating gas plasma comprising a hydrophilizing dopant. It is considered that the use of an etching gas plasma and a passivating gas plasma comprising a hydrophilizing dopant constitutes a first distinguishing feature.

2. Claims 26-28 are directed at a substrate with at least one feature etched into its surface and the use of this substrate in an inkjet printhead. The following properties of the etched feature/s characterise the substrate: a depth of over 100 micron, sidewalls substantially perpendicular to the substrate surface and sidewalls having a contact angle of less than 50°. It is considered that an etched substrate with these properties comprises a second distinguishing feature.

Since the abovementioned groups of claims do not share either of the technical features identified, a "technical relationship" between the inventions, as defined in PCT rule 13.2 does not exist. Accordingly the international application does not relate to one invention or to a single inventive concept and therefore the claims do not satisfy the requirement of unity of invention *a priori*.