

**METHOD SUITABLE FOR ETCHING HYDROPHILIC TRENCHES IN A
SUBSTRATE**

Field of the Invention

5 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.

10 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
15 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
20 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.

10/727181	10/727162	10/727163	10/727245	10/727204	10/727233	10/727280
10/727157	10/727178	10/727210	10/727257	10/727238	10/727251	10/727159
10/727180	10/727179	10/727192	10/727274	10/727164	10/727161	10/727198
10/727158	10/754536	10/754938	10/727227	10/727160	10/934720	10/296522
6795215	10/296535	09/575109	6805419	6859289	09/607985	6398332
6394573	6622923	6747760	10/189459	10/884881	10/943941	10/949294
11/039866	11/123,011	11/123010	11/144769	11/148237	10/854521	10/854522
10/854488	10/854487	10/854503	10/854504	10/854509	10/854510	10/854496
10/854497	10/854495	10/854498	10/854511	10/854512	10/854525	10/854526
10/854516	10/854508	10/854507	10/854515	10/854506	10/854505	10/854493

10/854494	10/854489	10/854490	10/854492	10/854491	10/854528	10/854523
10/854527	10/854524	10/854520	10/854514	10/854519	10/854513	10/854499
10/854501	10/854500	10/854502	10/854518	10/854517	10/934628	10/728804
10/728952	10/728806	10/728834	10/728790	10/728884	10/728970	10/728784
10/728783	10/728925	10/728842	10/728803	10/728780	10/728779	10/773189
10/773204	10/773198	10/773199	6830318	10/773201	10/773191	10/773183
10/773195	10/773196	10/773186	10/773200	10/773185	10/773192	10/773197
10/773203	10/773187	10/773202	10/773188	10/773194	10/773193	10/773184
11/008118	11/060751	11/060805	6623101	6406129	6505916	6457809
6550895	6457812	10/296434	6428133	6746105	10/407212	10/407207
10/683064	10/683041	6750901	6476863	6788336	6322181	11/097308
11/097309	11/097335	11/097299	11/097310	11/097213	11/097212	10/760272
10/760273	10/760187	10/760182	10/760188	10/760218	10/760217	10/760216
10/760233	10/760246	10/760212	10/760243	10/760201	10/760185	10/760253
10/760255	10/760209	10/760208	10/760194	10/760238	10/760234	10/760235
10/760183	10/760189	10/760262	10/760232	10/760231	10/760200	10/760190
10/760191	10/760227	10/760207	10/760181	11/003786	11/003354	11/003616
11/003418	11/003334	11/003600	11/003404	11/003419	11/003700	11/003601
11/003618	11/003615	11/003337	11/003698	11/003420	11/003682	11/003699
11/071473	11/003463	11/003701	11/003683	11/003614	11/003702	11/003684
11/003619	11/003617	10/760254	10/760210	10/760202	10/760197	10/760198
10/760249	10/760263	10/760196	10/760247	10/760223	10/760264	10/760244
10/760245	10/760222	10/760248	10/760236	10/760192	10/760203	10/760204
10/760205	10/760206	10/760267	10/760270	10/760259	10/760271	10/760275
10/760274	10/760268	10/760184	10/760195	10/760186	10/760261	10/760258
11/014764	11/014763	11/014748	11/014747	11/014761	11/014760	11/014757
11/014714	11/014713	11/014762	11/014724	11/014723	11/014756	11/014736
11/014759	11/014758	11/014725	11/014739	11/014738	11/014737	11/014726
11/014745	11/014712	11/014715	11/014751	11/014735	11/014734	11/014719
11/014750	11/014749	11/014746	11/014769	11/014729	11/014743	11/014733
11/014754	11/014755	11/014765	11/014766	11/014740	11/014720	11/014753
11/014752	11/014744	11/014741	11/014768	11/014767	11/014718	11/014717
11/014716	11/014732	11/014742	11/097268	11/097185	11/097184	

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 circuits 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.* CHF₃, C₄F₈ or C₂F₄) in the presence or in the absence of an inert gas. In the subsequent etching step, the plasma gas mix is changed to SF₆/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 O₂ plasma ashing or combinations thereof. The post-etch cleaning process is intended to remove the hydrophobic polymer and leave channel sidewalls coated with SiO₂. 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/O₂ plasma, followed by a main etch using a SF₆/HBr/O₂ 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 O₂/SF₆ 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 O₂, SF₆, He and Ar – the O₂ is a passivating gas; the SF₆ 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 SiO₂-coated sidewalls, these SiO₂-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
5 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;
- 10 (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.
- 15 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°.
- 20 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
25 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
 - 30 (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 O₂ 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 phosphite (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 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
10 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).

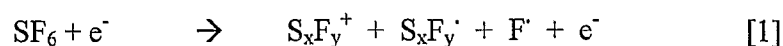
Optionally, the inert sputtering gas is argon. Optionally, the flow rate of the inert
15 sputtering gas is in the range of 100 to 300 sccm, or 150 to 250 sccm. Optionally, the gas chemistry may comprise other inert gases, such as helium. However, it is generally preferred to use Ar alone in order to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

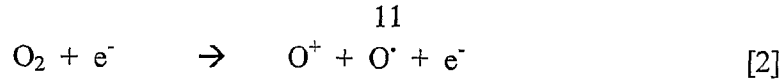
The fluorinated etching gas may be any fluorine-based gas, which can produce fluorine radicals and etch silicon in a plasma etching reactor. The fluorinated gas may be,
20 for example SF₆, NF₃ or mixtures thereof. Optionally, the fluorinated gas is SF₆. Optionally, the flow rate of the fluorinated gas 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
25 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.

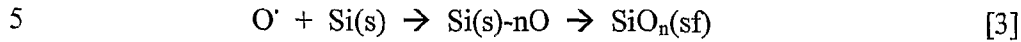
30 Without wishing to be bound by theory, the source of anisotropy during simultaneous etching/passivation may be understood by the following processes:

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

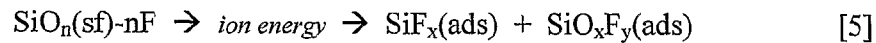
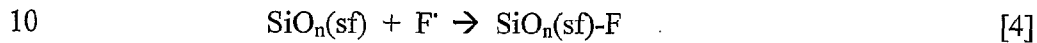




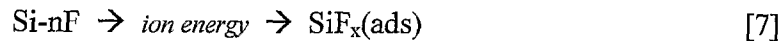
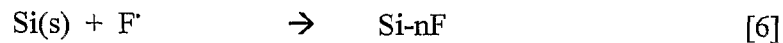
The oxygen radicals passivate the silicon surface by first adsorbing onto the surface and then reacting to form an oxide film:



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:



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:



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.

25 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.

30 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:

5 (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:

10 (a) a silicon-containing deposition gas; and

(b) a hydrophilizing dopant; and

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

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

15 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;

25 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

30 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
5	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
10 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
5 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
10 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°.
- 15 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 B₂H₆, PH₃, trimethyl borate (TMB), trimethyl
20 phosphite (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.
25
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
30 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.
- 5 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
10 comprises:
- (a) a passivating gas comprising oxygen;
 - (b) an inert sputtering gas;
 - (c) a fluorinated etching gas; and
 - (d) a hydrophilizing dopant.
- 15
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 SF₆, NF₃ and mixtures thereof.
- 20
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
25 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:
 - 30 (a) a silicon-containing deposition gas; and
 - (b) a hydrophilizing dopant;
 - (iii) alternately 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 SF₆, NF₃ and mixtures thereof.
- 5 21. The method of claim 18, wherein said silicon-containing deposition gas comprises SiH₄.
22. The method of claim 18, wherein said passivating gas plasma further comprises a gas selected from O₂, N₂, N₂O, NH₃ or combinations thereof.
- 10 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.
- 15 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;
 - 20 (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
 - 25 (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.
- 30 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.

5 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

10 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

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