

Microstructure Formation Technique

FIELD OF INVENTION

The present invention relates broadly to a method of fabricating a microstructure, and to a method of fabricating a mould for microstructures.

BACKGROUND

Conventional microstructures, such as microneedles, are typically made of Si, plastic and metals. The major drawbacks of Si and plastic microneedles are that they are too brittle or soft, respectively. Metal microneedles can be fabricated by metallization of Si or plastic moulds followed by a releasing process in which the mould is dissolved. Therefore, the moulds must be newly fabricated for each microneedle fabrication process.

Silicon microneedles are typically fabricated using a silicon wafer as the raw material and fabrication technologies for semiconductor IC chips. Lithography is the key process step, followed by bulk processing through either wet etching or deep reactive ion etching (DRIE).

A problem with silicon microneedles is the high capital investment (mainly clean room micro fabrication facilities) and high production cost, which renders silicon microneedles unsuitable as disposable products. In addition, silicon is not deformable at temperatures below 800°C, making silicon needles brittle. Therefore, silicon needles may break and remain in the human body, raising a safety concern.

For plastic microneedles, the major fabrication method is to use cheap polymers such as polycarbonate or acrylate as the raw materials and injection molding or hot embossing as the processing means.

A problem with injection molding polymer microneedle technology is the high cost due to high capital investment of the facilities and the use of expensive photosensitive materials. A problem with the hot embossing technology is that microneedles are too soft for penetration into the skin.

A need therefore exists to provide a microneedle fabrication technique that seeks to address at least one of the above mentioned problems.

SUMMARY

In accordance with a first aspect of the present invention there is provided a method of fabricating a microstructure comprising the steps of providing a mould comprising a template structure; forming a first material layer on a surface of the template structure; forming a microstructure layer on the first material layer; and releasing the microstructure layer from the mould.

The step of providing the mould may comprise exposing, developing and etching a photosensitive material to form the template structure.

The template structure may comprise holes formed in the photosensitive material, and the first material layer is formed directly on the surface of the template structure.

The template structure may comprise protrusions extending from a surface of the photosensitive material, and the method further comprises forming a second material layer on the template structure prior to formation of the first material layer on the second material layer.

The method may comprise performing a single or multi-step exposure of the photosensitive material to modify the template structure.

The photosensitive material may comprise glass or ceramic materials.

The first material may comprise a polymer or plastic material.

The releasing of the microstructure layer may comprise dissolving the first material in a solvent.

The releasing of the microstructure layer may comprise heating the first material layer for softening the first material layer and applying a mechanical force to release the microstructure layer.

The second material layer may have a mechanical strength greater than that of the photosensitive glass.

The second material layer may comprise a metal.

The microstructure layer may comprise a metal.

The microstructure layer may comprise an array of microneedles.

The array of microneedles may comprise one or more beveled tip microneedles.

The array of microneedles may comprise one or more side open microneedles.

The array of microneedles may comprise microneedles of different size, shape, or both.

In accordance with a second aspect of the present invention there is provided a method of fabricating a mould for microstructures comprising the steps of providing a photosensitive material; exposing the photosensitive material; developing the photosensitive material; and etching the photosensitive material to form a template structure of the mould.

The photosensitive material may be masklessly exposed.

The photosensitive material may be exposed utilising a mask.

The exposing may comprise focusing a light beam such that a desired exposure trace pattern is created across the photosensitive material for shaping the template structure.

The exposing may comprise a multi step exposure including turning an exposure direction by about 90° to obtain a side open or beveled tip mould.

The photosensitive material may be etched from two sides at different time periods for developing to form a through-hole converging from both sides to a waist portion of the through-hole.

The photosensitive material may comprise glass or ceramic materials.

The method may further comprise forming a coating on the template structure; wherein a mechanical strength of a material of the coating is greater than that of the photosensitive material.

Said material may comprise metal.

In accordance with a third aspect of the present invention there is provided a microstructure fabricated utilising a method according to the first aspect.

In accordance with a fourth aspect of the present invention there is provided a mould for microstructures fabricated utilising a method according to the second aspect.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

Figure 1 shows a flowchart illustrating a microneedle fabrication process flow according to a first embodiment.

Figure 2 is a schematic drawing illustrating an exposure step of the first embodiment.

Figures 3(a) and (b) show scanning electron microscopy (SEM) images of different hole shapes in a micro needle mould in the first embodiment.

Figure 4 is a schematic drawing illustrating different exposure traces during the exposure of the photosensitive glass material in the first embodiment.

Figures 5(a) and (b) are schematic drawings illustrating electroplating for different hole shapes in the first embodiment.

Figure 6 shows a perspective schematic drawing of a polymer layer coating on a photosensitive glass mould in the first embodiment.

Figures 7(a) and (b) show SEM images of released metal microneedles and the photosensitive glass mould in the first embodiment.

Figure 8 shows a flowchart illustrating a microneedle fabrication process flow in a second embodiment.

Figure 9 is a schematic diagram illustrating exposure of a photosensitive material in the second embodiment.

Figures 10(a) and (b) show SEM images of a detailed and a perspective view respectively of a structured glass needle mould in the second embodiment.

Figures 11(a) and (b) show SEM images of a released metal microneedle array and a metal master mould respectively in the second embodiment.

Figures 12(a) to (g) are schematic drawings illustrating a microneedle fabrication process flow according to a third embodiment.

Figure 13 shows a schematic diagram of a system for fabrication of a mould for microstructures.

DETAILED DESCRIPTION

Figure 1 shows a flowchart 100 illustrating a microneedle fabrication process flow in a first embodiment: Step 102, formation of photosensitive glass mould, step 104 coating a polymer layer on the mould, step 106 metallization and step 108 releasing of microneedles from the mould. In the following, details of the respective process steps will be described.

Formation of the photosensitive glass mould

a) Laser exposure

An ESI Microvia Drill M5200 is used, in which a Q-switched third harmonic of a Nd:YAG pulsed laser operates at 355 nm. The average laser power used is about 0.1~0.4 W at a repetition rate of 10 kHz. The laser pulse energy is a Gaussian distribution with a duration of 50-60 ns. The laser beam is focused onto the sample surface at a radius of about 25 μm at $1/e^2$ density. The laser beam selectively spiral scans, with the pitch size about 5~12 μm , over a spot, e.g. 202, shown in Figure 2, to form a patterned array 204 after UV exposure.

b) Annealing

The exposed photosensitive glass is annealed in air for developing: First target temperature of about 500 °C at a heating rate of about 5 °C/min, hold for about 1 hr; second target temperature of about 605 °C at a heating rate of 2 °C/min, hold for about 1 hr. Cooling to room temperature at cooling rate of about 2 °C/min.

c) Etching

The annealed sample is chemically etched in about 5~10% HF solution in an ultrasonic bath for about 1.5 ~2.5 hrs. Because the etch rate of the UV exposed portions is about 10~20 times faster than for the un-exposed portions, depending on the laser parameters and etching conditions, the exposed area is etched away leaving an array of through holes 300, 301 in the glass 302, 303 as shown in Figures 3(a) and (b) for two example hole shapes. The taper formation is due to the unexposed area being gradually slightly etched from top to bottom. The holes 300, 301 provide a template structure for the microneedle fabrication.

d) Hole shapes after etching

Different hole's taper angles can be obtained by using lenses 400, 402 with different convergent angles as shown in Figure 4. When a laser beam 404 is focused at a position below a bottom surface 406 of a photosensitive glass 408, different laser exposure traces 410, 412 are obtained using lenses 400, 402 with different convergent angles. These exposed traces 410, 412, which are etched away subsequently, form holes with different taper angles. The taper angle can also be slightly adjusted by choosing various etching rate differences between exposed and un-exposed areas. For example, a larger etching rate difference results in a steep taper hole.

An alternative way to control taper angle in the etched holes, especially in the circumstance when a large taper angle is required, will now be described. Figure 13 shows a schematic diagram of a mould fabrication system 1300. The system 1300 comprises a translation stage 1305 on top of a tilted rotating stage 1302 coupled to a stage control unit 1304, which is in turn coupled to a PC 1306. The PC 1306 is further coupled to a UV light source 1308 for exposing a photosensitive mould material 1310 mounted on the translation stage 1305. An optical system 1312 is disposed between the UV source 1308 and the translation stage 1305 for focusing of a UV beam from the UV source 1308 onto the photosensitive material 1310. Before laser firing, a center of exposure spot 1311 is aligned with the center 1313 of the rotating stage 1302 by utilising the translation stage 1305. The photosensitive material 1310 is rotated by rotating the rotating stage 1302 during laser exposure. The tilted angle α of the rotating stage 1302 determines the taper angle of the hole after etching.

Returning now to Figure 3, it is noted that the "vase" shape of the hole 300 (Figure 3a) is preferred in the subsequent electroplating process compared to the funnel shape of the hole 302 (Figure 3b). In the vase shape, the through-hole converges from both sides of the mould to a waist portion of the through-hole.

Figure 5(a) shows that a hooker 500 is formed at the bottom 502 of the mould 504 for a funnel shape hole 506 due to throwing power effects during the electroplating process. The hooker 500 may become a problem in the subsequent needle releasing process. The hooker 500 can be eliminated when the backside 502 of the mould 504 is covered. However, covering the backside 502 of the mould 504 blocks fresh plating solution from reaching the tip of needles, slowing down the plating process and resulting in severe differences of plating thickness between the needle tip and needle base. Figure 5(b) shows that a mould with a vase shape hole 510 eliminates or significantly reduces hooker formation without slowing down the plating rate. The vase shape hole 510 can be obtained by first etching from one side for a period of time, then etching from both sides of the photosensitive glass.

e) PMMA coating

In a conventional technique, the metal microneedle is directly formed on the microneedle mould. The mould is etched away to obtain metal microneedles. In order to make a permanent mould, a polymer layer 600 is formed on the surface of the mould 602 (including the surfaces 604 inside the holes 606) prior to metal deposition, as shown in Figure 6. The polymer layer 600 acts as a release agent. Different from a

conventional release agent, the polymer layer 600 is preferably able to withstand an acidic environment for electroplating. PMMA is used for coating layer 600. A typical recipe of a PMMA solution for coating is 18 gram of PMMA (Paraloid® A-11) granular solids dissolved in 100ml mixed solvents of 1:6 1-butanol : butyl acetate. The photosensitive glass mould 602 is dipped in the PMMA solution for a few seconds. The sample is gently blown with compressed air to avoid PMMA blocking the holes 606 in the mould 602. The sample is then placed in an about 100 °C oven for about 1hr. The process is repeated for 2~3 times to increase the thickness of the polymer layer 600 to about 15 μm . A thicker polymer layer 600 preferably leaves a larger gap between needle and mould for the releasing process.

f) Metallization

Metallization includes sputtering an Au seed layer on the surface of the mould followed by a Ni electroplating process. The Ni electroplating solution is a nickel sulphamate concentrated solution; specific gravity is about 1.53-1.56, PH about 3.8-4.2. Plating duration is about 1.5 ~2.5 hrs at an electric current of about 0.35A.

g) Microneedle releasing

After electroplating, the metallized glass mould is immersed in butyl acetate in an ultrasonic bath at room temperature for about 2hrs. The PMMA is dissolved in butyl acetate and the metal microneedles are released from the mould. Figures 7(a) and (b) illustrate the released hollow metal microneedles array 702 and the mould 704, respectively. It is noted that the release process may be longer for fabrication of solid microneedles due to needing more time for the butyl acetate to reach the tip.

Another way to release the microneedle includes heating up the metal plated mould to about 150~200°C to soften the PMMA. Mechanical force can then be used to separate the mould and microneedles. The microneedles and mould may then be cleaned in butyl acetate.

Figure 8 shows a flowchart 800 illustrating a microneedle fabrication process flow in a second embodiment: Step 802 producing a structured glass microneedle basic mould at one side of a photosensitive glass, step 804 converting the glass mould to a metal mould, step 806 polymer coating, step 808 metallization and step 810 microneedle releasing. Details of the process flow will be described below.

Fabrication of structured basic needle glass mould

a) Laser exposure

The laser processing parameters are the same as for the first embodiment. However, the exposure area is opposite to that in the first embodiment. The UV laser scans over an area and leaves an un-exposed array 900 of spots 902 as shown in Figure 9. This exposure method results in formation of a tapered needle mould after the annealing and etching processes described below. Alternatively, the laser exposure may be performed utilising a mask to shield the array 900 of spots 902.

b) Annealing

The annealing step for developing is the same as that described above for the first embodiment.

c) Etching

A jig is used for the etching process. The jig only allows one side of the annealed glass contact with the HF solution. The UV exposed area is etched away. The non-exposed spots remain after etching, and form tapered needles on one side of the glass. The taper angle can be adjusted by changing the laser parameters and etching conditions as described above for the first embodiment. Figures 10(a) and (b) show a detail and a perspective view of respectively of the structured glass needle mould 1000, referred to hereinafter as the basic mould, providing a template structure for the microneedle formation.

d) Converting glass basic mould to metal master mould

Since a glass needle is very brittle and fragile, the basic mould 1000 cannot be used as a permanent mould. Converting the glass mould 1000 to a metal mould is a way to obtain a permanent mould. A thick metal layer (not shown) is deposited on top of the basic mould 1000 to form a master metal mould. The metallization process is the same as that described above for the metallization step in the first embodiment. A typical metallization thickness is about 100~130 μm . The mechanical strength of the metal layer is greater than that of the glass basic mould.

e) Polymer coating, metallization and microneedle releasing

The polymer coating of the metal master mould, metallization and releasing processes are the same as the corresponding processes described above for the first embodiment. In order to obtain a hollow metal microneedle, a mask is utilised to prevent formation of a metal seed layer on the needle tip during the metallization sputtering process. Figures 11(a) and (b) show a released metal microneedle array 1102 and the metal master mould 104 respectively.

Fabrication of beveled tip or side open microneedles

Figures 12(a) to (g) show the process flow of fabrication of beveled tip or side open microneedles in a third embodiment. A basic structured glass mould 1200 with beveled tip or side open needle 1202, 1204 respectively is formed by two UV exposure steps as shown in Figures 12(a) and (b). The first step UV exposure in Figure 12(a) is the same as described above with reference to Figure 9. The exposed photosensitive glass 1206 is turned 90 degrees for a second selective exposure at the non-exposed area, e.g. 1207, Figure 12(b). The glass 1206 then proceeds to annealing and etching to form the basic mould 1200 with beveled tip side open needles 1202, 1204 respectively, Figure 12(c) moulds. Figures 12(d) to (g) illustrate the subsequent processes of thick metal layer 1208 formation, polymer layer 1210 coating, second metallization layer 1212, and microneedle array 1214 releasing, respectively, as described above for the second embodiment.

The embodiments disclosed provide methods of fabricating permanent microneedle moulds using photosensitive glass, which can significantly reduce the cost of microneedle fabrication in various aspects, e.g. mould materials, mould fabrication processes and timing.

The embodiments use a PMMA layer coated on a surface of the mould prior to metallization. This polymer layer separates mould and metal microneedles. The polymer layer is dissolved in a solvent during the releasing process, leaving a gap between mould and microneedles for releasing. Since a polymer layer is used to separate the metal microneedles from the mould, the microneedles can be released from the mould without or with reduced risk of damage to both the needles and the mould. This can save the cost of mould materials and fabrication process cost.

The second and third embodiments use a method in which a glass needle mould is converted to a metal mould. This method can overcome the weakness of glass as a mould material, i.e. being brittle and fragile. This technique may also be applied to converting moulds made from other materials than glass, such as ceramic materials, to a metal mould, for providing a permanent mould for metal microneedle formation. Beveled or side open needle moulds can be fabricated by a two step laser exposure technique described with reference to Figure 12.

The photosensitive glass fabrication arrangement is flexible on shape control. In utilising photosensitive glass's isotropic etching characteristics and variable UV exposure techniques, photosensitive glass structuring can be more flexible than Si

techniques. Microstructures with widely different aspect ratios and shape can be co-fabricated on a common photosensitive glass substrate in a single etching process. For example, a simple process of beveled tip and side port needles mould fabrication has been disclosed.

Using lenses with various convergent angles can provide a way to fabricate holes with different taper angles, e.g. about 10~15 degree differences, to meet different requirements for different applications.

Vase shape holes in metallization can eliminate or reduce hooker formation at the bottom of the mould. The hooker is an obstruction for metal microneedle release from the mould. Also, since the backside of the mould is not covered during plating, the plating process is not slowed down and the thickness difference between needle tip and needle base can be reduced.

Compared to hot embossing technology, one needle mould with needles of different height, configuration, or both, can be fabricated in one etching process by programming a two- or multi-step laser exposure process. For instance, a two step laser exposure can be used to fabricate a side open and beveled tip needles mould. This is difficult, if not impossible, for example in hot embossing techniques, where embedded channels are required to create the side ports.

Needle moulds for different needle heights can also be obtained by exposing photosensitive glass to different laser energies or scanning speeds followed by single etching processes. In Si technology, a 2 heights needle mould has to be obtained in two etching processes, in other words, two masks are needed. The first mask covers the higher needle portion and is removed away once the first etch process is finished. The second mask is used for the second etching process. It is also noted that a side open needle mould is extremely difficult or almost impossible in current Si technology.

Compared to Si technology, a mask is not necessary for laser exposure of photosensitive glass. Most patterns can be obtained by programming a laser scanning path.

Compared to Si technology, the etching rate for photosensitive glass is about 10~20 $\mu\text{m}/\text{min}$, which is much faster than the Si etch rate (1~2 $\mu\text{m}/\text{min}$).

Utilising a laser to directly fabricate moulds enables fabrication of microneedles of many shapes, including circular or elliptical, or polygon, etc.

Microstructures produced utilising the embodiments described can be applied in a number of applications. For example, a microneedle array may be fabricated for

medical applications, such as transdermal drug delivery, plasma extraction, and other diagnostic uses. Microneedle arrays may also be applied as dispensing tips for solder bumping in electronic packaging, and may replace conventional wire bonding in which the terminal number is limited, and the terminals are restricted to the edges of the package.

It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

For example, it will be appreciated that the present invention is not limited to the formation of microneedles, but extends to micro pattern transfer of other microstructures such as micro gratings, micro channels, micro orifices etc.

Furthermore, while the polymer layer disclosed comprises PMMA, it will be appreciated that the polymer layer may comprise other materials, including, but not limited to, other types of polymers, plastic materials, photoresists, and other materials that can be evenly coated on the mould in a manner such that the coating is able to withstand the subsequent metallization process, and is dissoluble during the release process.

Also, while the photosensitive material disclosed comprises glass, it will be appreciated that the photosensitive material may comprise other materials such as ceramic materials.

Also, while UV light has been disclosed for exposure of the photosensitive material, it will be appreciated that other light sources may be used depending on the photosensitive material.

CLAIMS

1. A method of fabricating a microstructure comprising the steps of:
providing a mould comprising a template structure;
forming a first material layer on a surface of the template structure;
forming a microstructure layer on the first material layer; and
releasing the microstructure layer from the mould.
2. The method as claimed in claim 1, wherein the step of providing the mould comprises exposing, developing and etching a photosensitive material to form the template structure.
3. The method as claimed in claim 2, wherein the template structure comprises holes formed in the photosensitive material, and the first material layer is formed directly on the surface of the template structure.
4. The method as claimed in claim 2, wherein the template structure comprises protrusions extending from a surface of the photosensitive material, and the method further comprises forming a second material layer on the template structure prior to formation of the first material layer on the second material layer.
5. The method as claimed in claims 3 or 4, comprising performing a single or multi-step exposure of the photosensitive material to modify the template structure.
6. The method as claimed in any one of claims 2 to 5, wherein the photosensitive material comprises glass or ceramic materials.
7. The method as claimed in any one of the preceding claims, wherein the first material comprises a polymer or plastic material.
8. The method as claimed in any one of the preceding claims, wherein the releasing the microstructure layer comprises dissolving the first material in a solvent.
9. The method as claimed in any one of the preceding claims, wherein the releasing the microstructure layer comprises heating the first material layer for softening the first material layer and applying a mechanical force to release the microstructure layer.
10. The method as claimed in any one of the preceding claims, wherein the second material layer has a mechanical strength greater than that of the photosensitive glass.

11. The method as claimed in claim 10, wherein the second material layer comprises a metal.

12. The method as claimed in any one of the preceding claims, wherein the microstructure layer comprises a metal.

13. The method as claimed in any one of the preceding claims, wherein the microstructure layer comprises an array of microneedles.

14. The method as claimed in claim 13, wherein the array of microneedles comprises one or more beveled tip microneedles.

15. The method as claimed in claims 13 or 14, wherein the array of microneedles comprises one or more side open microneedles.

16. The method as claimed in any one of claims 13 to 15, wherein the array of microneedles comprise microneedles of different size, shape, or both.

17. A method of fabricating a mould for microstructures comprising the steps of:

providing a photosensitive material;

exposing the photosensitive material;

developing the photosensitive material; and

etching the photosensitive material to form a template structure of the mould.

18. The method as claimed in claim 17, wherein the photosensitive material is masklessly exposed.

19. The method as claimed in claim 17, wherein the photosensitive material is exposed utilising a mask.

20. The method as claimed in any one of claims 17 to 19, wherein the exposing comprises focusing a light beam such that a desired exposure trace pattern is created across the photosensitive material for shaping the template structure.

21. The method as claimed in any one of claims 17 to 20, wherein the exposing comprises a multi step exposure including turning an exposure direction by about 90° to obtain a side open or beveled tip mould.

22. The method as claimed in any one of claims 17 to 21, wherein the photosensitive material is etched from two sides at different time periods for developing to form a through-hole converging from both sides to a waist portion of the through-hole.

23. The method as claimed in any one of claims 17 to 22, wherein the photosensitive material comprises glass or ceramic materials.

24. The method as claimed in any one of claims 17 to 23, further comprising forming a coating on the template structure; wherein a mechanical strength of a material of the coating is greater than that of the photosensitive material.

25. The method as claimed in claim 24, wherein said material comprises metal.

26. A microstructure fabricated utilising a method as claimed in any one of claims 1 to 12.

27. A mould for microstructures fabricated utilising a method as claimed in any one of claims 17 to 26.