Latest Micromachining Technology — Part 4

Reproduction of Small Shapes — Molding Technologies

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In this last part of this series of lectures, I would like to deal with technologies to transfer microscopic shapes, which are fabricated by the methods discussed previously, in other materials. These technologies feature two outstanding effects as follows: (1) The mass production of microscopic parts is possible. (2) Micromachining using various types of materials including silicon becomes possible. These technologies will be the basis for a number of applied micromachine technologies to be introduced into industries of different genres.

1. Transcription of etched shapes

By etching a pattern on a silicon single crystal substrate and molding the shape on the surface, a 3-D structure of a different material from the substrate can be formed. For example, nonplanner structures can be created with films such as silicon dioxide or silicon nitride. Fig. 1 shows an AFM-probe chip made of a silicon dioxide film with a thickness of 1.2 μm.

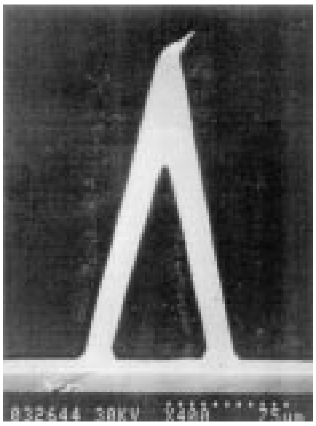

Fig. 1 AFM-probe chip made of silicon dioxide film 1.2 micron thick having a bend tip.

To produce a structure with a bend tip, steps equivalent to bend cross-sections are formed on the surface of the silicon substrate. Next, the entire surface is oxidized. Then the surrounding oxide film and silicon substrate are selectively etched away leaving the profile of the probe.

It is also possible to transcribe the shape on a silicon single crystal substrate, where deep recesses are machined by an etching method, in polycrystalline silicon film. In the second part of this lecture series, an example of a film structure with a T-shaped cross-section in connection with the technology to produce a high-rigidity structure with a film was introduced. In addition to these, a honeycomb type film structure is also available. Fig. 2 shows the cross-sectional view of the fabrication process of a honeycomb type film structure. A film structure is separated after processing a silicon single crystal substrate with a large depth-to-aperture ratio (aspect ratio) by reactive ion etching (RIE: Refer to the first part of this lecture series), laminating a sacrificial layer such as a silicon dioxide film and structure material such as polycrystalline silicon film in order over the substrate surface entirely, including inner surfaces of recesses, and finally etching away the sacrificial layer selectively. Through this procedure, a honeycomb structure with a thickness of 100 μm is produced with a film with a thickness of 1 to 2 μm.

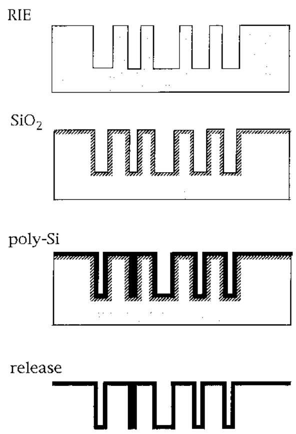

Fig. 2 Cross-sectional view of a fabrication process of a honeycomb structure made of polycrystalline silicon film.

In the field of biochemical technology that is expected to be one of the micromachine applications, disposable micro fluid devices are currently in demand. To meet such application purposes, the shape of a micro fluid channel created on a silicon substrate by an etching method is transcribed in styrol resin etc. for mass-replication. The technology to transcribe microscopic shapes, or replication technology, itself is not new. For example, in the field of spectroscopic devices, the technology of transcribing a surface profile of diffraction grating which is mechanically engraved on an aluminum film with a pitch of 0.1 μm in resin material has already been established.

2. Reproduction of shapes developed in photoresist

Fine patterns are developed in a thick photoresist layer by exposure to light to create micro cavities. Metal is deposited inside the cavities by electroplating method to produce micro metal parts.

2.1 LIGA process

The LIGA process was developed by Karlsruhe Research Center, Germany, in 1986. LIGA stands for the three processes mentioned below, using initials of German words.

(1) Cavity formation by lithography (Lithografie in German)
(2) Molding of cavity by metal electroplating (Galvanoformung in German)
(3) Reproduction of metal mold shape in resin by injection molding (Abformung in German)

Fig. 3 illustrates the cross-sectional view of steps (1) and (2) in the LIGA process above. This process features the use of synchrotron radiation (SOR) in place of ordinary UV light. With SOR used, exposure of the 2-D mask pattern is deeply and accurately made in PMMA-system photoresist with a thickness of several millimeters. By developing this pattern, a cavity with an aspect ratio in excess of 100 is formed. A metal structure as shown in Fig. 4 can be processed by electroplating the inside of the cavity and reproducing the shape. The structure in this phase can be directly put into practical use. However, by performing injection molding of plastics (Fig. 5) with the structure of a die, and reproducing the shape with electroplating further applied, or using the structure for ceramic molding (sol-gel method), the structure can be applied to various types of materials.

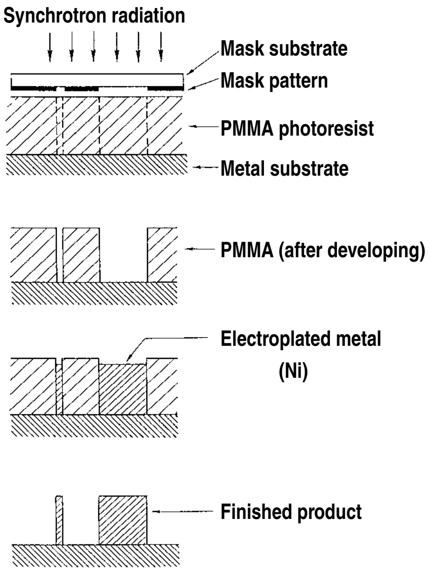

Fig. 3 Cross-sectional view of the LIGA process.

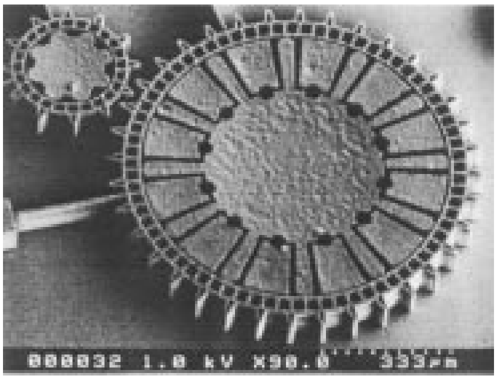

Fig. 4 Micromotor structure made of Ni by the LIGA process (Courtesy of Prof. S. Sugiyama of Ritsumeikan Univ.).

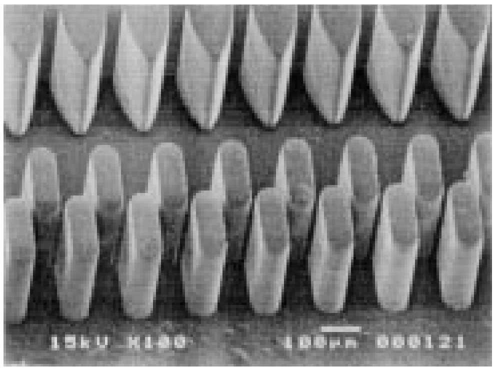

Fig. 5 Example of a molded plastic part made by using the LIGA process (Courtesy of Brother Industries, Ltd.).

The high-precision processing accuracy of the transcription technology as represented by the aspect ratio is used in such applications as optical communication devices, for example 3-D grating (diffraction grating) or optical waveguide, and chemical analysis devices with fine fluid channels.

The challenge in using the LIGA process is the limitation that it cannot produce anything without SOR equipment. It is true that the original die must be prepared by the use of SOR equipment. However, once the master mold is prepared, the following processes can be set for mass production. In Japan, a research team at Himeji Institute of Technology following the team at Ritsumeikan University has successfully started the LIGA process using radiation equipment.

2.2 High aspect ratio UV photoresist

Now available is a new type of photoresist that allows for high aspect ratio exposure and development by ordinary UV exposure techniques, though the processing accuracy is lower than that of the LIGA process. For example, SU-8 photoresist developed by IBM can be exposed to a layer depth of several hundred microns by the UV light method. The transcription process using plating technique of the shape of the cavity after exposure and development process is identical to that used in the LIGA process.

Though even oxygen plasma cannot easily decompose the photoresist resin for removal, the fact that UV exposure can be used is an advantage. Besides, the transparency of the resin is very high allowing the product to be used directly as an optical component material regardless of the transcription technique.

Summary

With transcription technologies of microscopic shapes, 3-D structures can be made of films. In addition, microscopic shapes can now be created from such materials as metal, resin, and ceramic. Increased material diversity is expected to expand the application range of micromachine technology.