An Alternative Method for SU-8 Removal Using PDMS Technique*

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Abstract: An alternative method for SU-8 removal is proposed. Instead of directly using SU-8 microstructure as the electroplating mold, a polydimethysiloxane (PDMS) replica is employed. The metallic micromold insert obtained through this method can be easily peeled off from the PDMS replica, meanwhile with high resolution and smooth surfaces.

Key words: SU-8 removal; electroplating; PDMS; micromold insert; high-aspect-ratio microstructures

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1 Introduction

There is a need to fabricate high aspect ratio microstructures (HARMs) since these are critical for the performance of microsensors and microactuators such as micro mixers, micro electrophoresis chips for bioanalysis, and micronozzles for generating thrust force, etc.[1,2]. LIGA (lithographite, galvano-formung, abformung) technique is the major process to produce HARMs with vertical sidewalls and high resolution. However, the need for a synchrotron radiation source limits its application for researchers and the process is inherently time consuming and expensive. To reduce fabrication costs, some alternative micromachined methods have been investigated recently, such as deep reactive ion ething (DRIE) based on inductively coupled plasma (ICP), excimer laser, and UV-LIGA, etc. Among these methods, UV-LIGA based on SU-8 photoresist has shown great potential for industrial application due to its wide availability and low cost, and has become popular in the microelectromechanical systems (MEMS) community[3~5].

SU-8 photoresist has excellent resolution in thick film applications, and has been utilized as an electroplating mold. This mold is then used for a large-scale production of desired components. However the highly crosslinked epoxy remaining after development is difficult to remove reliably from high-aspect-ratio microstructures without damage or alteration to the electroplated metal[6]. Up to now, a variety of techniques have been developed to remove this crosslinked polymer. They can be mainly classified into two categories, physical techniques and chemical techniques. Physical techniques such as water jetting, laser ablation and liquid nitrogen freeze/thawing are used to directly destroy or demolish the crosslinked SU-8. These physical techniques can be fairly selective to the polymer over metal molds, but suffer from the ability to reliably remove small included areas of polymer from high aspect ratio features due to the fundamental size regime of the incident etchant. The method that using a sacrificial layer is reported by

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McGall[7], but again, one would suffer from the ability to get the etchant into areas completely surrounded by electroplated metal. In addition, some solvents are reasonably effective at swelling, cracking and crazing the polymer. However, without pure dissolution, the solvent or physical methods remain potentially effective removal techniques for some sample geometries, but not for general application.

Chemical methods are the other kind of approaches for SU-8 removal. Oxidative chemicals, such as fuming sulphuric acid and hydrogen peroxide are often used to decompose the crosslinked SU-8 and subsequent cleaning[8]. However, during the etching and oxidizing processes, which are caused by H_2SO_4 and H_2O_2 simultaneously, the underlying Ni surface is also serious damaged. Successful strip with oxygen plasma was reported, but the etching rate was slow, around 0.25μm/min under 40sccm O_2 plasma at 5.33Pa with 120W RF power[9]. Additionally, other highly oxidizing materials have been studied. Unfortunately, these highly oxidizing materials tend to be rather non-specific and oxidize most metals as well.

In this work, an alternative method is proposed for preparing an electroplating mold using UV-LIGA technique without the difficulty of SU-8 removal. Instead of directly electroplating a micromold insert from SU-8 mold, the PDMS replica against SU-8 microstructure is employed for metallic mold preparation.

2 Experiment

Normally, to obtain a metallic micromold insert, a reverse SU-8 microstructure is processed and electroplating. However this process meets with difficulty of SU-8 removal. In this work, an alternative method is proposed to prepare a metallic micromold insert using PDMS technique. The sequence of this process is shown in Fig. 1. A SU-8 master was first prepared. Detailed process is available elsewhere[10]. The PDMS used in this experiment is a commercially available silicone rubber compound from Rhodia (Shanghai, China). A set of RTV 3040A (pre-polymer) and RTV 3040B (a curing agent) were mixed with a 10 : 1 weight ratio and degassed using a vacuum pump to remove air bubbles entrapped during mixing. It was directly cast onto the SU-8 microstructures and baked in a convection oven. It was cured at 95 ℃ for 1h to create replicated PDMS HARMs. Then the replicated PDMS HARMs were peeled off from the SU-8 microstructures.

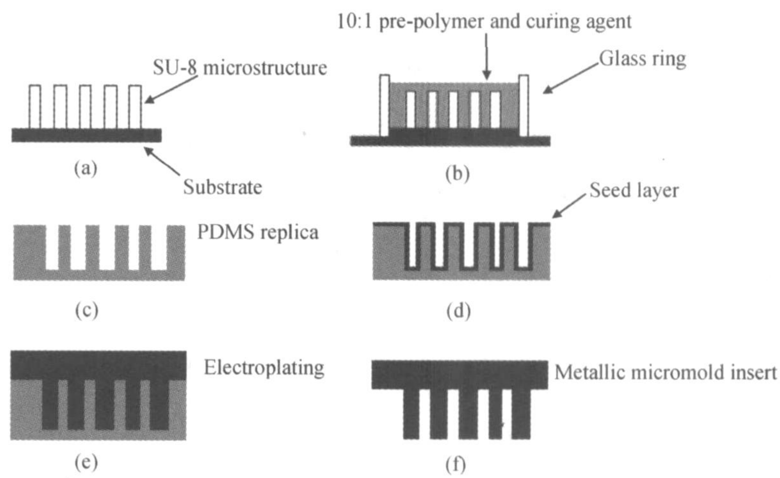

Fig. 1 Process sequence for micromold insert preparation using PDMS technique (a) SU-8 mold preparation; (b) Casting of 10 : 1 mixture of pre-polymer and curing agent; (c) Curing and peeling off replicated PDMS mold; (d) Sputtering seed layer; (e) Electroplating onto PDMS mold; (f) Metallic micromold insert release

Subsequently, a seed layer (1μm thick copper) was deposited on the surface of the replicated PDMS using sputtering technology. Then nickel was electrodeposited on the copper-coated replicated PDMS using the bath composition described in Table 1. The bath condition, including solution composition, pH and operational temperature, can be referred to Table 2. After the electroplating, the PDMS mold was peeled off to release the replica metallic micromold insert. The seed layer for the electroplating was selectively etched away after the separation using an etchant composed of cupric sulfate ($CuSO_4 \cdot 5H_2O$) saturated with ammonium hydroxide (NH_4OH). The backside of the metallic micromold insert was planarized as needed.

Table 1　Composition of nickel electroplating solution

Component	Concentration / ($g \cdot L^{-1}$)
$NiSO_4 \cdot 7H_2O$ (nickel sulphate heptahydrate)	330
$NiCl_2 \cdot 6H_2O$ (nickel chloride hexahydrate)	45
H_3BO_3 (boric acid)	30

Table 2　Conditions of nickel electroplating

Material	Temperature/ ℃	Voltage/ V	Current/ mA	pH
Nickel	45	0.3	2.5	1.5～4.5

3　Results and discussion

In this work, microgear was employed as an example to describe SU-8 removal procedures. The microgear used in this study was 500μm in height. In order to make a comparison, metallic microgears were prepared by electroplating on SU-8 mold and subsequently metallic structure releasing through SU-8 removal. Chemical method for SU-8 removal was employed. Figure 2 shows the nickel microgear after the SU-8 removal process using wet chemical method. Figure 3 illustrates a close-up of the microgear. From above pictures, it can be seen that the surface of the electroplated mold is severely damaged. The oxidizing processes, which were caused by H_2SO_4 and H_2O_2 simultaneously in this case, produced this rough surface with noticeable surface pits and tips. Reducing H_2SO_4 concentration, batch temperature or etching time may improve the surface roughness.

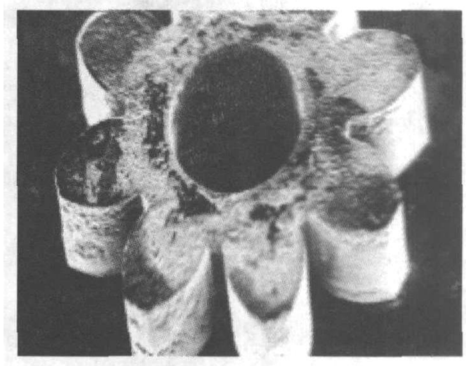

Fig. 2　SEM picture of nickel microgear after SU-8 removal

Fig. 3　Close-up of the microgear with rough surface

Since the volume shrinkage of the PDMS after the curing is only 0.2%, there are no observable dimensional changes in replicated PDMS replica compared to dimensions in the original SU-8 mold, which ensures that high precision metallic micromold can be made. Figure 4 shows the SEM picture of the microgear produced by PDMS technique proposed in this paper. Figure 5 illustrates a close-up of the microgear. It can be seen that the microgear obtained using PDMS technique has smooth surface since the PDMS can be simply peeled off to release the metallic micromold. From above comparison, the metallic micromold obtained using PDMS technique has better surface quality and easy to operate. So, PDMS technique partially solves the problem of SU-8 removal when preparing a micromold insert.

In order to show the applicability of this technique for much higher aspect ratio microstruc-

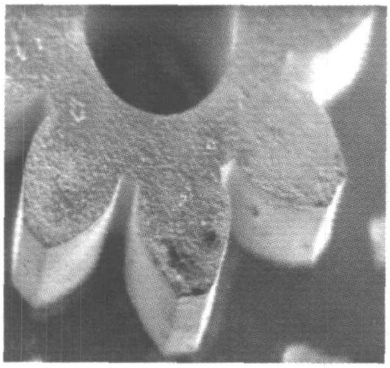

Fig. 4 Microgear fabricated by PDMS technique

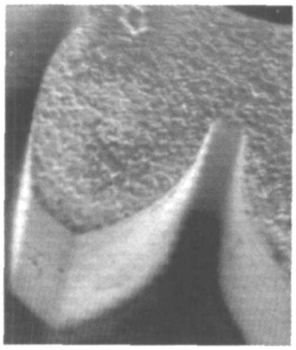

Fig. 5 Close-up of the microgear with smooth suface

tures, a micromold insert with aspect ratio up to 10 is attempted and successfully prepared, which is shown in Fig. 6. The trench shown in the picture is 10μm in width and 100μm in height, and the metallic micromold insert shows smooth surfaces and vertical walls. The experiments described above indicate that PDMS replication and subsequently electroforming is an effective alternative method for SU-8 removal.

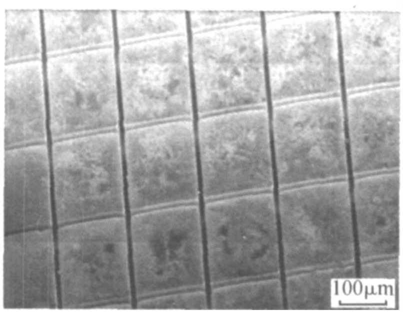

Fig. 6 Metallic micromold insert with aspect ratio up to 10 fabricated by PDMS technique

4 Conclusions

In this paper, an alternative method for SU-8 removal is proposed. PDMS replica of SU-8 microstructure is employed for the micromold insert electroplating. There are no observable dimensional changes in replicated PDMS replica compared to dimensions in the original SU-8 mold. The experimental results show that the metallic micromold insert obtained by this method has high resolution and smooth surfaces. This method can be applied to metallic micromold insert preparation and partially solve the difficulty of SU-8 removal.

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一种利用PDMS工艺解决SU-8去胶问题的方法*

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摘要：提出了一种解决SU-8去胶难题的方法. 该方法首先将SU-8微结构用PDMS进行复制，然后利用复制的PDMS微结构进行下一步的电铸，电铸完成后只要简单地将PDMS揭下即可释放出金属模具. 通过该方法制备得到了深宽比达到10的金属模具，而且模具表面光滑，侧壁垂直.

关键词：SU-8去胶；电铸；PDMS；金属模具；高深宽比微结构
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