Microelectronics Journal 38 (2007) 120–124

Microelectronics Journal

www.elsevier.com/locate/mejo

Multi-layer microstructure fabrication by combining bulk silicon micromachining and UV-LIGA technology

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Received 21 June 2006; accepted 23 September 2006
Available online 9 November 2006

Abstract

A novel method for fabrication of multi-layer microstructures of microelectro-mechanical system (MEMS) devices is described. This technique, which combines bulk silicon micromachining technique and UV-LIGA technique can overcome some shape limitations of single technique on complex microstructures. To demonstrate this combination, the SU-8 microstructure fabricated in the etched silicon grooves is presented. In this fabrication process, a SU-8 removal method by fuming sulfuric acid was introduced and a novel type of plastics PETG was tried in microhot embossing process. The proposed fabrication process can be applied to fabricating a high-aspect-ratio microstructure for a large displacement actuator and precision sensors. Moreover, this combined process enables the fabrication of more complex structures, which cannot be fabricated by bulk micromachining or UV-LIGA alone.

Keywords: UV-LIGA; Bulk silicon micromachining; 3-D-microfabrication; SU-8 removal; PETG

1. Introduction

With the increasing demands on integrated and miniaturized industrial systems, intensified research has been directed towards microelectro-mechanical system (MEMS) technologies. Most MEMS technologies use silicon as the substrate material and a CMOS-compatible fabrication process. Therefore, it can provide low-cost small features by mass production [1–3]. However, conventional micromachining technologies, i.e. surface micromachining and bulk micromachining technologies, have some difficulties when the device requires complex or three-dimensional (3-D) shapes as well as vertical sidewalls. Some authors have investigated several new methods to realize the 3-D microfabrication. Ling et al. [4] have presented some 3-D microstructures by using the modified SU-8 solutions with reduced PAG concentrations, while great efforts should be made to optimize the process for each modified resist. Bertsch et al. [5] have presented 3-D microfabrication by combining microstereolithography and thick resist UV lithography. This technique can overcome some shape limitations of the planar technologies. However, microstereolithography has the limited resolution and the problems associated with the manipulation and assembling of the obtained polymer structures.

This paper reports a novel micromachining process based on a UV-LIGA process and silicon anisotropic etching to fabricate high-aspect-ratio microstructures (HARMS). Wet chemical anisotropic etching is frequently used for shaping quite intricate silicon microstructures due to its low process cost, simple etch setup, higher etch rate, better surface smoothness, high degree of anisotropy and lower environmental pollution. Although the silicon structures fabricated by anisotropic etching have limited shapes, complex structures can be fabricated by additional UV-LIGA micromachining processes, which can overcome the limited number of possible structures fabricated by an anisotropic wet etching process. The proposed fabrication process can be applied to fabricating a high-aspect-ratio microstructure for a large displacement actuator and precision sensors. Moreover, this combined process enables the fabrication of more complex structures, which cannot be fabricated by bulk micromachining or UV-LIGA alone.

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0026-2692/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.mejo.2006.09.003

2. Fabrication process

Bulk silicon micromachining technique is used to fabricate the first layer or other patterns that can be easily made by this technique. Then the upper layers and complex graphics are fabricated by UV-LIGA technique on the patterned silicon wafer. The schematic fabrication process of the proposed microstructure is shown in Fig. 1. First, a silicon wafer is thermally grown to produce a thick silicon dioxide layer. This layer is used as a shield mask for the later etching process. Following near-UV lithography, the insulation layer is patterned in the desired positions. Next, the SiO_2- and the silicon-etching processes are utilized to form some graphics or high aspect ratio microstructures of silicon in these positions. The required depth inside the substrate depends on the function and need of certain device. Then SU-8 photoresist is spun over the surface of etched silicon wafer and the high aspect ratio SU-8 photoresist microstructures are patterned by using the near UV-lithographic technique. Metal mold with complex and multi-layer microstructures is obtained after electroplating and SU-8 removal processes. Last, mass replica of plastic microstructures is achieved by microhot embossing process.

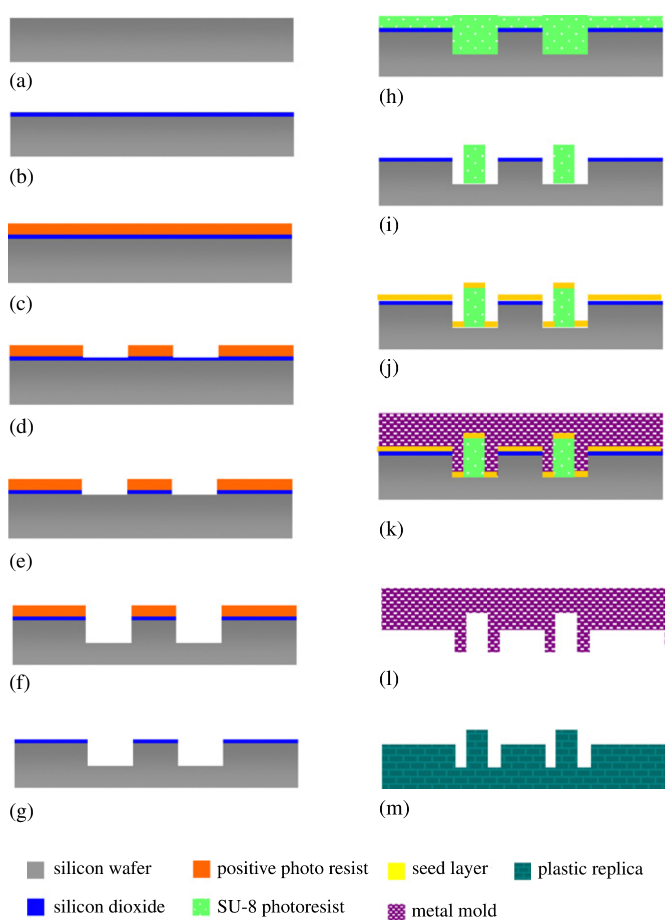

Fig. 1. Schematic figure of the combining processes for multi-layer microstructures: (a) silicon wafer; (b) silicon dioxide layer formation; (c) spin coating positive photoresist; (d) UV lithography; (e) SiO_2 etching; (f) deep silicon etching; (g) removal of positive photoresist; (h) SU-8 spin coating; (i) UV lithography; (j) seed layer deposition; (k) electroplating metal; (l) metal mold after removal of SU-8 and substrate; (m) plastic replica.

3. Results and discussion

By using this combining method, some pentagram SU-8 microstructures are fabricated in the square silicon groove as an example. The dimension of square-etched silicon groove is 200 μm × 200 μm with the depth of 140 μm. The height of SU-8 photoresist microstructures including the depth of etched groove is 200 μm. The process parameters and its equipment or chemical solvent of each step for these multi-layer microstructures fabrication are listed in Table 1. The SEM picture of SU-8 structures standing on silicon grooves is shown in Fig. 2.

After the deposition of a 100 nm Cr/Cu seed layer on the whole surface of wafer via physical sputtering, the wafer was electroplated in a nickel-sulfamate-based solution to form the metal mold [6]. The bath condition, including solution composition, pH and operational temperature, can be seen in Table 2. In the SU-8 mold-removal process, the wafer was immersed in the fuming sulfuric acid. During this etching process, the SU-8 mold surface broke into gel-like tiny pieces, and it was then cleaned, with ultrasonic agitation, in a mixed acid containing H_2SO_4 and H_3PO_4 (1:1 vol. parts). By repeating this etching and cleaning process several times, the lapped SU-8 mold with thickness of 200 μm could be completely removed within 90 min without causing Ni structures ablation, as shown in Fig. 3.

3.1. Interface between SU-8 resist and substrate

The surface of silicon after wet chemical etching is not absolutely smooth, but has tiny hillocks and pits. We have studied the adhesive characteristics between SU-8 resist and substrate [7]. The results show that Si and oxidized Ti have better adhesion to SU-8 photoresist, which has relationship with the index of refraction, as shown in Fig. 4. The roughness of substrate and the wetting property between SU-8 and substrate have no obvious influences on adhesion strength. It proves that the etched surface of silicon can be used as the substrate for the next SU-8 photoresist process.

3.2. Bubble removal process

When the SU-8 photoresist is spin coated on etched silicon wafer, bubbles will occur in the groove, as shown in Fig. 5(a). Since the region where has the bubbles cannot produce photoresist microstructures after lithography, these bubbles must be thoroughly removed. In our lab, we use two steps to remove the bubbles. The first step is by using vacuum oven where the air pressure of inner SU-8 solution is higher than the outer. With the vacuum pump working on, the bubbles can rise to the surface and burst.