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Two steps micromoulding and photopolymer high-aspect ratio structuring for applications in piezoelectric motor components

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Abstract We report on recent advances in micro fabrication technology using micromoulding and high-aspect ratio structuring of photopolymer. The direct application is the realization of components for millimeter-size, ultrasonic piezoelectric motors. A new fabrication process using a thick epoxy-based material (SU-8) and the electroplating of nickel is demonstrated. Photopolymer structures have also been realized and released using a positive tone resist as sacrificial layer. The main advantages over past fabrication methods are better design flexibility, simplicity of the fabrication process, the capability to combine metallic materials (Ni) with polymeric materials (SU-8), and the use of positive tone resist as a sacrificial layer.

1
Introduction

High aspect ratio technologies are a promising field for the fabrication of millimeter-size components for wristwatch applications and MEMS devices. The rotor fabrication of the Elastic Force Motor (EFM) [Racine et al. (1993)] is presented as an example. The integration of the EFM was proposed in [Racine et al. (1993)] using both silicon micromachining and more classical fabrication technologies. In order to miniaturize the device and reduce the costs, commercially available thick photoresist with UV inclined multidirectional illumination and electroplating was tried [Beuret et al. (1994)]. The development of a micromachined rotor with inclined legs [Beuret et al. (1994)] was not achieved, however, the realization of reproducible inclined moulds for electroplating by photolithography is very difficult. It was decided to replace the inclined rotor legs by vertical elements having the same mechanical charactristics as the laser cut-rotor [Dellmann et al. (1997)].

Recently, important progress in thick resist structuring using an epoxy-based photoresist developed by IBM (SU-8) has been demonstrated [Lee et al. (1995)].

A new approach for fabrication of a rotor with vertical legs is presented here. To build the rotor wheel, a standard thick positive tone photoresist (AZ-4562) mould is used. Nickel is electrodeposited into this mould. To build the legs, a double layer of negative tone, near UV photoresist (SU-8) is then deposited on top of the nickel wheel.

Test structures in SU-8 have also been realized and released using a sacrificial layer of positive tone resist.

2
Fabrication

2.1
Sacrificial and seed layer

A silicon wafer is prepared with a sacrificial and seed layer.

Different seed and sacrificial layers were tested. To achieve a uniform nickel electrodeposition, the layer should be a good conductor. It must also be possible to remove the layer selectively with respect to nickel, in order to release structures.

Gold is the best conductor layer, but is very difficult to etch without damaging the nickel.

Titanium is the most commonly used seed layer. It is important to have a thick enough layer to achieve good conductivity. If the thickness is too low, the electrodeposited nickel will not be uniform due to electrical resistivity, being too high. Titanium is released with a BHF (buffered hydrofluoric acid) etch or with titanium etchant [Williams et al. (1996)] without affecting nickel and SU-8 structures.

Copper and titanium are alternatives for the seed layer. Copper can be used to increase the low conductivity of the thin titanium layer. During electron gun metal deposition, some reactions inducing pinholes between the two layers were observed, which reduced dramatically the adhesion of the electrodeposited nickel.

2.2
Nickel electroplating of elastic structures (wheels)

The fabrication process is shown in Fig. 1 and described below.

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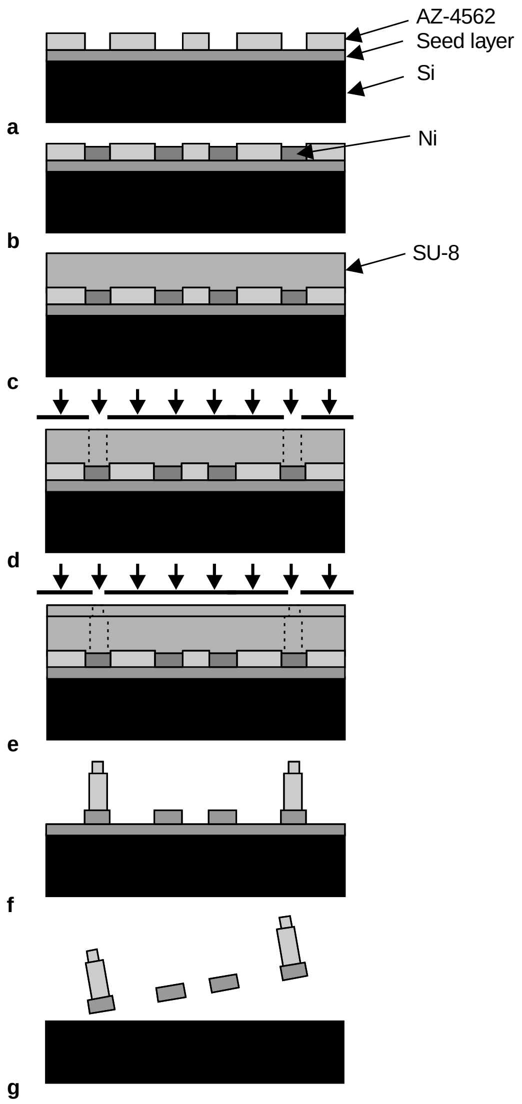

Fig. 1a–g. A schematic diagram of the microfabrication process

A thick positive photoresist layer (AZ-4562/30 μm) is spun with a rotating cover spinner (Karl Süss RC8 Spin Coater). Thick and uniform layers are deposited in one step by minimizing air turbulence effects. Resist accumulation along wafer borders (edge bead) can prevent good contact between the mask and the resist layer. This can be reduced to 2–3 mm for a 3″ wafer, however, by introducing huge but very brief accelerations during the spinning process. Prebake is one of the most critical steps, because of its direct influence on the illumination energy, the development duration, the structure resolution and the mould walls [Moreau et al. (1988)]. Prebake is realized with a ramped hotplate. The resist adhesion is improved by ramping the temperature from 40 °C to 90 °C, after which the temperature plateau of 90 °C is maintained. The illumination (mask 1) is realized with a mask aligner (Electronic Vision AL6-2, mercury lamp 355 nm, 405 nm and 436 nm) in vacuum contact mode. This improves structure definition by reducing diffraction effects. During development with AZ-400K [1 : 4] (1 AZ-400K part for 4 DI water parts), the wafer has to be energetically shaken in the bath, enhancing penetration of developer into the small mould structures (Fig. 1a). The cleanroom humidity has to be very stable to insure good reproducibility. To avoid distortion of photoresist patterns, no postbake is done [Miyajima et al. (1994)]. Nickel (20 μm) is then electrodeposited from a commercial Watt type bath, after an oxygen plasma pretreatment (Fig. 1b).

2.3
Patterning of a double layers' vertical sidewall structures

Double layer structures are realized with a negative tone resist.

First a 95 μm thick SU-8 layer [Lorentz et al. (1996) & Despont et al. (1997)] is directly spun onto the resist mould and electrodeposited nickel using a conventional spin coater (Fig. 1c). No pretreatments such as priming or oxygen plasma are performed. The substrate is then prebaked on a ramped hotplate, with a ramp of 40 °C to 95 °C in 8 min and a plateau at 95 °C for 12 min. Illumination (mask 2) is realized with an Electronic Vision AL6-2 mask aligner in proximity mode (Fig. 1d). Before postbake, the resist is kept in air for 30 min to improve crosslinking of illuminated areas. Then postbake is performed on the hotplate with the same parameters as for prebake.

A second, 15 μm thick SU-8 layer is then directly spun and prebaked in an oven at 90 °C for 5 min. The oven prebake heats the upper SU-8 layer and prevents overtreatment of the lower SU-8 layer. The prebake is then followed by UV illumination (mask 3) and a postbake in an oven to perform crosslinking (Fig. 1e). Levels 2 and 3 are simultaneously developed in PGMEA (propylenglycolmonomethylether-acetate). At the end of this step, the positive photoresist mould is also dissolved (Fig. 1f). Finally, the wafer is rinsed with isopropanol and hardbaked at 200 °C for 30 min in oven. In the final step, the fabricated structures are released using a solution to etch away the sacrificial seed layer (Fig. 1g).

2.4
Realization of SU-8 structures on a positive tone resist sacrificial layer

Test structures in SU-8 have been realized using a positive tone resist as sacrificial layer. This process permits the realization of SU-8 structures without using a metallic sacrificial layer. It also simplifies structure liberation because it uses acetone for dissolving the resist layer.

A priming pretreatment is performed before spinning a 10 μm thick AZ-1518 resist layer. A thermal treatment (15 min at 90 °C on a hotplate) is then performed to harden the resist (Fig. 2a). A SU-8 layer is spun (Fig. 2b) and treated as described above (prebake, illumination (Fig. 2c) and postbake). Development (Fig. 2d) is done in PGMEA. The positive tone resist layer is more or less underetched during development, so that free standing or clamped zones are obtained, depending on the size of the SU-8 structures.

3
Results

Figure 3 shows the positive near-UV, 28 μm thick mould before electroplating. Thickness up to 85 μm have been realized, with aspect ratios up to 9 and sidewall angles of 2–3°. As noted

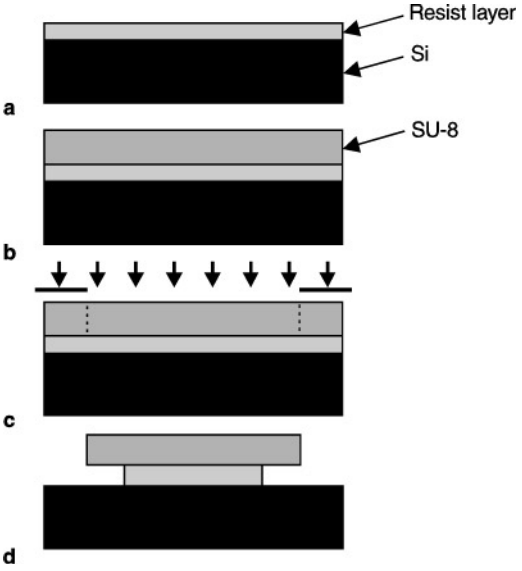

Fig. 2a–d. A schematic diagram of test structure fabrication using a positive tone resist as sacrificial layer

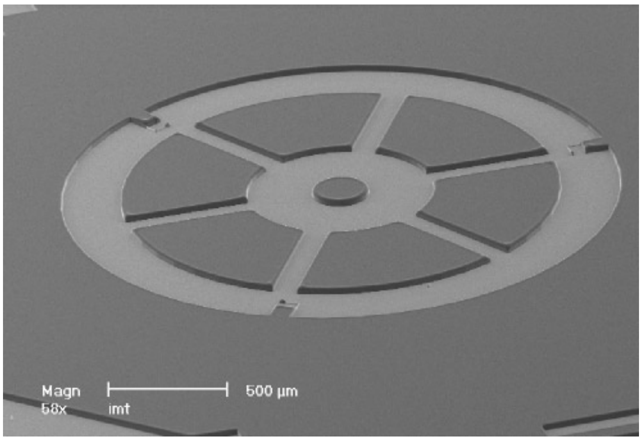

Fig. 3. SEM image of the first level mould (wheel)

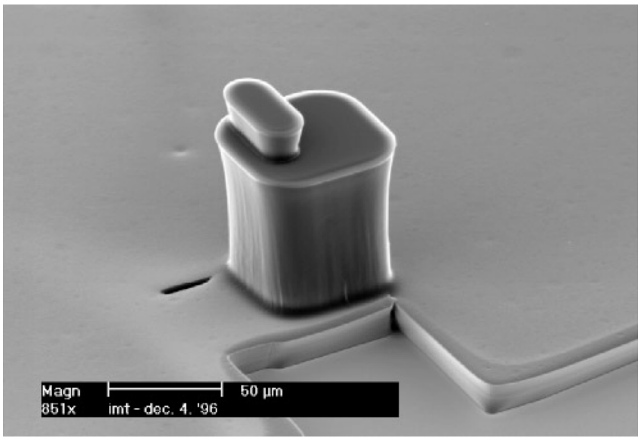

Fig. 4. SEM image of a double layer photoplastic leg on the top of the nickel wheel

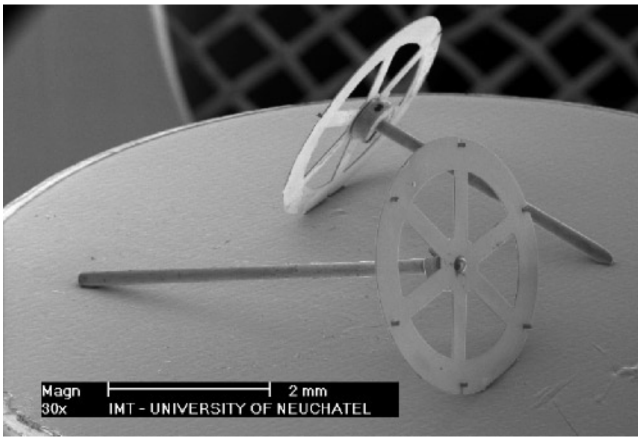

Fig. 5. SEM image of the component rotor mounted on a stainless steel axle

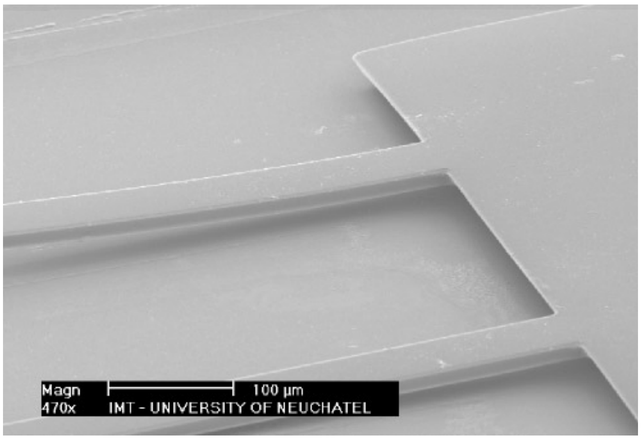

Fig. 6. SEM image of a test structure on a sacrificial resist layer. Beams bending induced by striction have been observed

above, room humidity and temperature have to be very stable to assure a good reproducibility.

Successful fabrication of a rotor for piezoelectric motors has been demonstrated. Figure 4 shows a detail of a Ni wheel surmounted by a two-level SU-8 vertical leg, before sacrificial etching of the Ti layer. The aspect ratio of the leg body is 2.1. Values up to 10 have already been obtained in test structures. The adhesion between Ni and the two SU-8 levels is very good.

Figure 5 demonstrates the capabilities of the process to fabricate components for the wristwatch industry. A released rotor of 3.2 mm diameter with 110 µm legs was mounted on a stainless steel axle (Ø 220 µm). The axle and the rotor were glued together with epoxy using a dedicated micro manipulator. A special mount was used to fix the rotor perpendicularly to the axle.

Figure 6 shows SU-8 structures realized on a positive tone resist sacrificial layer. Because the resist is partially dissolved under big surfaces during development, it can act as a clamping zone. This technique could be useful for structure assembly.

4
Conclusion

Nickel wheels with epoxy-based polymer multilevel vertical legs have been fabricated for piezoelectric motor applications.

The main advantages over past fabrication methods are better design flexibility, a simplified fabrication process, the potential for realizing free standing structures, and the combination of metallic materials (Ni) with polymeric materials (SU-8).

This process opens the way to low cost fabrication of complex metallic and plastic structures for use in MEMS applications.

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