J. Micromech. Microeng. **10** (2000) 108–115. Printed in the UK PII: S0960-1317(00)09314-1

Thick-layer resists for surface micromachining

Bernd Loechel

BESSY GmbH, Anwenderzentrum Mikrotechnik, Albert-Einstein-Strasse 15,
D-12489 Berlin, Germany

E-mail: `loechel@bessy.de`

Received 16 December 1999

Abstract. Interest in thick-photoresist applications is steadily growing. In addition to bump fabrication and wire interconnect technology (WIT), the process of patterning thick-layer photoresists by UV lithography is specially qualified for applications in microelectromechanical systems (MEMS). Specialized equipment and new photoresists have been developed or are under development to cope with the new challenges in the field of preparing extremely thick photoresist layers, the process of patterning these thick resists, and to deal with the difficulties of the following galvanoplating step.

As one of the most critical steps in thick-photoresist processing, the baking procedure was investigated. Positive tone photoresists (AZ 4562, ma-P 100) were processed by means of three different baking methods: air-forced oven, ramped hotplate, and IR radiation.

It could be shown that IR baking is advantageous compared to the other methods with respect to process duration and energy consumption. As for edge steepness, resolution, edge loss, and surface roughness, all methods deliver nearly the same results. A minimum width of 2–3 μm for the resist bars was found to be necessary to withstand the fabrication process of lines and spaces in about 15 μm thick resists. For thicker layers, high aspect ratios of about 10 as well as steep edges of more than 88° could be fabricated.

The development of SU-8, a chemically amplified negative tone photoresist for the 300–450 nm region opened totally new dimensions for the UV depth lithography. Even under development, SU-8 delivers results otherwise only achievable by x-ray lithography.

The deposition of photoresist on highly-structured surfaces demands advanced methods. Electrodeposition of resist is one solution. PEPR 2400 was used for patterning by UV light in order to generate resist patterns around a free standing silicon bar. The achieved resist patterns were moulded by using electroplating. For microsystem applications some metals and alloys were deposited. Three-dimensional micro components were fabricated as demonstrators for the new technique. Electrodeposition allows the use of materials with interesting properties which could not be provided by standard processes in microelectronics.

1. Introduction

In addition to the LIGA process [1], thick photoresist layers were used for fabricating moulds for electrodeposition (*3D UV-Microforming*) as well as for manufacturing of spherically-shaped resist patterns (*Grey-tone lithography*). 3D UV-Microforming is a microfabrication method that combines UV patterning of very thick photoresist layers with the moulding of the resulting patterns by galvanoplating. It allows the construction of arbitrarily shaped three-dimensional micro components and the use of materials with interesting properties.

The application of resist patterns for fabricating three-dimensional components on substrate surfaces is of great interest. For bump fabrication in packaging the method was successfully applied using about a 30 μm thick positive tone photoresists patterned by UV contact exposure and immersion development [2]. The resist patterns were filled with gold by means of electroplating. A similar process was reported to fabricate wire interconnects. Wire interconnect technology (WIT) fabricates arrays of narrow, standing metal contact pins, which were used for contacting a board level to active elements [3].

A wide field of applications is opened for the 3D UV-Microforming technology in MEMS [4–12]. In contrast to the already mentioned process steps, the technology is here expanded to higher resist thicknesses, multi-level applications, and for depositing materials normally not available in microelectronic processes. Major progress has been made in the last few years in producing high aspect ratio patterns in thick photoresists [9, 13]. Patterning of Novolak photoresist layers up to 200 μm using UV light and contact printing was reported [14]. Using the same equipment, the application of chemically amplified resists such as SU-8 allows patterning of resist layers up to more than 1 mm in thickness [15].

Based on a special exposure method called Grey-tone lithography, arbitrarily curved resist profiles can be realized using a raster-screen photomask [16]. By means of 5:1 projection lithography and mask pixels of

0960-1317/00/020108+08$30.00

sub-resolution size, smoothly curved resist shapes were achieved. Depending on the depth of focus of the exposure tool, resist layers of up to 20 μm were applied for this lithographic method. Subsequently the fabricated resist contours could be transferred to the substrate by dry etching or could be moulded by galvanoplating.

There are a number of photoresists at the market [17] that can be used for the fabrication of very thick photoresist layers. Two of them, both Novolak types, AZ 4562 (Clariant) and ma-P 100 (Micro Resist Technology), were investigated in more detail and results will be given here. Besides the Novolak resists SU-8 (Microlithography Chemical Corporation, MCC), a chemically amplified negative tone photoresist on an epoxy resin base, was tested. For highly-patterned surfaces the electrodepositable photoresist PEPR 2400 (Shipley) was successfully applied to fabricate micro-solenoids. Novolak resists and SU-8 can be processed by using standard equipment such as standard spin coaters, baking ovens or hotplates, and immersion or spray development tools. Good quality resist layers of up to 20 μm thickness can be achieved by means of this equipment in a short time [14]. For thicker layers some additional equipment can facilitate and shorten processes. In particular, the resist set up can extend the process times for a thicker layer set-up because repeating of the coating and the baking step are necessary. Newly developed equipment such as spin coaters with a co-rotating cover enable a resist layer set-up of 100 μm and more during a single step [18].

One of the main process problems is the baking of very thick resist layers. An optimized procedure guarantees high-quality resist patterns, in particular high edge steepness, high resolution, high aspect ratio, high resist stability, and short process duration. During the process, mechanical stress has to be reduced to a minimum [19, 20]. Different strategies are under investigation. In addition to baking in convection ovens or air-forced ovens, temperature-controlled hotplates and equipment using IR radiation for baking were investigated. For industrial application, a process with a short baking time for very thick resist layers with low internal stress for layers without cracks has to be available and should be developed now. Therefore, the baking tool and process have to ensure that no great temperature contrast will occur.

In thick-photoresist printing, the photoresist thickness can easily be larger than the mask–wafer gap. The resist layer is thus patterned, like exposures, at large gaps. The kind of diffraction reduction employed in standard proximity printers is clearly outside its validity range. For very thick photoresist layers the influence of the diffraction effect results in a typical line shape: inclined side walls. This influence can be minimized but cannot be totally prevented. It is possible, however, to produce relatively good, vertical side walls with the help of well collimated light [12]. Using optimized optics in the exposure tool, the best results were achieved by means of vacuum contact printing. Both mask and substrate were hardly attacked by contact printing. Any resulting defects end in degradation of complicated patterns and prevent higher resolution. Defects caused by contact lithography can only be neglected for relatively large structures in MEMS technology. Therefore, process variations are under discussion which avoid direct mask–substrate contact without loss in patterning quality [3].

In order to understand the wall profile generated via contact printing of thick resist layers, process simulations were carried out [21]. They allow us to understand the achieved resist profiles and give hints on resist quality and process parameters in order to achieve maximum wall steepness and pattern accuracy.

The mask aligners employed were able to expose Novolak resist thicknesses of up to 100 μm in one step. Extremely thick layers can be patterned by repeating exposure and development steps several times [10].

The resolution of shadow printing is limited by the diffraction of light at the edges of opaque features on the mask as the light passes through an adjacent clear area. The typical intensity distribution of light incident on the photoresist surface is characterized by a slow increase around the edge region towards the clear area with local minima and maxima. The resulting theoretical resolution capability of shadow printing with a mask consisting of equal lines and spaces of the width b is given by

$$2b_{min} = 3\sqrt{\lambda(s + \tfrac{1}{2}d)}$$

where $2b$ is the grating period, s is the gap width between the mask and the photoresist surface, λ is the wavelength used and d is the photoresist thickness. For hard contact, s is equal to zero. Thus, the minimum grating period for a 1 μm thick photoresist and 400 nm exposure wavelength would be 1.3 μm in the contact printing mode. Other photolithographic shadow casting techniques can approach, but never exceed, these resolution capabilities.

The situation is similar in thick-photoresist printing, where the photoresist thickness can easily be larger than the mask–wafer gap. The resist layer is thus patterned, as prints, at large gaps. The kind of diffraction reduction employed in standard proximity printers is clearly outside its validity range. For very thick photoresist layers the influence of the diffraction effect results in a typical line shape: an undercut in the upper line region and increasing line width towards the bottom. This influence can be minimized, but cannot be totally prevented.

3D UV-Microforming is of interest to manufacturers because of the low processing costs and the well established equipment. Typical fields of application of this additive patterning technique can be found throughout the range of microsystem technology and problems regarding precision mechanics will equally find a solution by this method. As schematically demonstrated in figure 1, the exposure is carried out by means of standard optical aligners as well as conventional micro-electrodeposition equipment. The galvanic moulding of the resist profiles could be carried out in micro-plating installations. For higher structures the application of rack platers is advantageous. The possibilities of 3D UV-Microforming are even further enhanced when they are combined with the sacrificial layer technique. Many different micro-components can be fabricated in smart and low-cost processes. In simple cases, the photoresist itself or layers such as poly silicon, silicon nitride, silicon oxide, or aluminium can be used as sacrificial materials. Micro-ducts, three-dimensional micro-coils, micro-switches, or membranes are some examples of the application of the sacrificial layer technique [5, 6, 8, 22].

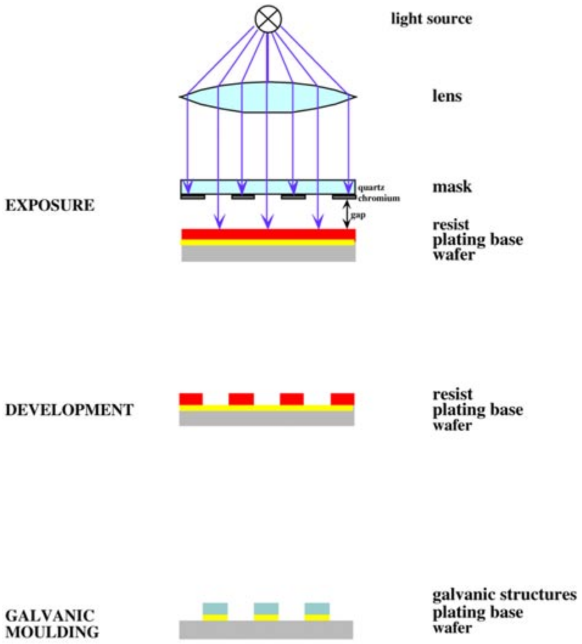

Figure 1. Flow chart of the 3D UV-Microforming process.

Three-dimensional wiring systems for electrostatic motors, moving parts for micro-valves, recording heads, magnetic field printing heads, or interdigital capacitors have been fabricated with this method [4, 7–9, 13, 23, 24].

2. Experimental details

2.1. Resist preparation and patterning

There are a number of photoresists on the market [17] that can be used for the fabrication of very thick photoresist layers. Two of them, the AZ 4562 (Clariant) and the ma-P 100 (Micro Resist Technology), were investigated in more detail and results will be given here. Both resists can be processed using standard equipment such standard spin coaters, baking ovens or hotplates, and immersion or spray development tools.

Uniform coating of a thick photoresist could be best achieved using a coater with a solvent saturated, co-rotating atmosphere above the substrate, thus avoiding drying of the resist. Tests also showed that coating uniformity over severe topography was substantially improved using this technique. An increasing edge bead that is formed under these conditions could be either thinned or removed altogether, depending on the application.

For the investigations described here an air-forced oven (Ing. Hoffmann GmbH) was used for baking. During the process a flow of nitrogen was used to remove the evaporated solvent. Substrates coated with AZ 4562 were brought into the oven at room temperature, heated up to baking temperature, and cooled down to room temperature. Depending on the specific properties of the oven, the complete baking time takes some hours. Therefore, the throughput is limited for this method. The energy consumption of baking in ramped ovens is high.

Shorter baking times and higher throughput could be achieved by using hotplates for baking. Standard hotplates for baking thin-layer resists were set to a fixed temperature. The prepared substrates were brought to the hotplate by means of a handling system, baked, and removed by the handler immediately. The large temperature contrast induces mechanical stress resulting in cracks in the resist layers. Therefore, baking on hotplates can only be carried out successfully when the hotplate temperature will be ramped during the baking process. This temperature procedure takes time and limits the throughput of the method. For the reported experiments a programmable hotplate (Gestigkeit GmbH) was used. The energy consumption of baking on ramped hotplates is high.

A very interesting method is given by applying IR radiation for baking. The main advantage of the method is that no unnecessary volume will be heated up. Therefore, the heated matter is low, the baking process will be short and the energy balance is positive compared to the other methods. For our experiments special equipment (Micro Resist Technology GmbH) was developed and applied, which enables the application of temperature programmes and strict temperature control during baking.

The employed mask aligners were able to expose Novolak resist thicknesses of up to 100 μm in one step. Long exposure times of several minutes have to be chosen for patterning of very thick resist layers up to 100 μm. For SU-8 the maximum thickness is more than 1 mm.

The baking temperature depends on the resist layer thickness and the resist type used. In order to avoid degradation of the photoactive compound [25], however, it should not exceed 110 °C.

UV shadow printers with a wavelength range of 350–450 nm were used for patterning. They were equipped with a 350 W light source, standard collimation optics, and an appropriate alignment system.

SU-8 (MCC) in dilution for 50 μm thick layers was spun on silicon wafers by means of a standard spin coater. The deposited resist was prebaked and treated according to the commercial process description. The exposure was carried out on a Suss MA 56 mask aligner. Immersion development was applied for finishing the resist patterns.

Conventional photoresist spin coating does not allow for conformal coating of highly-structured surfaces. Electrodeposition of photoresist opens a way to overcome this disadvantage. Due to the self-stopping deposition chemistry, electrodeposited resist can coat uneven surfaces with a uniform layer thickness. The PEPR 2400 ED photoresist (Shipley) has a low water content and therefore only a small tendency to flow. After baking the exposure was carried out at the Suss MA56 mask aligner.

2.2. Micro-electrodeposition

For a long time micro-electroplating processes using adapted equipment and special plating solutions have become well known in electronics. The resist profiles generated by UV lithography can easily be moulded by using electrodeposition methods, enabling the manufacture of components of pure metals or alloys of the desired dimensions directly onto the system surfaces.

During the micro-electroplating process, materials of different chemical characteristics can be deposited into

Table 1. Characteristics of the photoresists investigated.

Resist type	Tone	Maximum thickness (μm)	Exposure dose (mW cm^{-3})
AZ 4562	Positive	200	6.3
ma-P 100	Positive	80	12.5

the fabricated photoresist patterns, and also as multi-layer systems.

Some of the fabricated resist patterns were moulded using pulse and dc electroplating. Different metals and alloys were deposited to build up metal structures on silicon wafer surfaces. The pH range of the applied plating solutions should not exceed 10 in order to avoid further resist development. In such cases an attack on the resist caused by the extremely alkaline solution was observed.

Different types of sacrificial material have been applied for different systems. The simplest case for a sacrificial material is the photoresist itself. If covered by a sputtered or electrodeposited base, the resist bars can be buried. Sputtered aluminium or electroplated metals such as copper or zinc are best qualified for application as sacrificial materials, especially, if several sacrificial layers are demanded in a stack. After removing the selectively soluble material, free standing three-dimensional structures can be achieved. For the three-dimensional construction process both dc and pulse plating techniques have been applied.

3. Results

Table 1 gives an overview of the photoresists investigated. The new positive tone photoresist ma-P 100 is still under development and delivers promising results. Compared to AZ 4562 it is less sensitive to UV light between 350 and 450 nm, but can be handled more easily during baking. A sensitivity improvement is under development for ma-P 100. The resists investigated were best qualified for electroplating, even for medium alkaline plating solutions.

Figure 2 shows spin coating curves for AZ 4562 and ma-P V100 using Gyrset systems and, also, standard spin coaters. The layer thicknesses achievable for the same procedures for both resists are in the same range. Gradation curves for 10 and 20 μm thick AZ 4562 are given in figure 3. Decreasing developer concentrations, increasing baking temperature, and baking time improve the contrast. For thicker resist layers a lower contrast was observed. The baking temperature and time depend on the resist layer thickness and the resist type used. In order to avoid cracks and resist degradation, however, the baking temperature should not exceed 110 °C. Values for the measured mechanical stress are given in table 2 determined by means of wafer bending.

The resist layer thickness is reduced during the baking procedure. During 60 min baking at 100 °C a thickness reduction of about 10%, compared to a 10 min baking time, was observed.

By means of a spin coater with a rotating cover (such as RC 8, Suss) the layer set-up could be realized with high homogeneity in a shorter time. During a single coating step AZ 4562 layers of more than 100 μm thickness were fabricated.

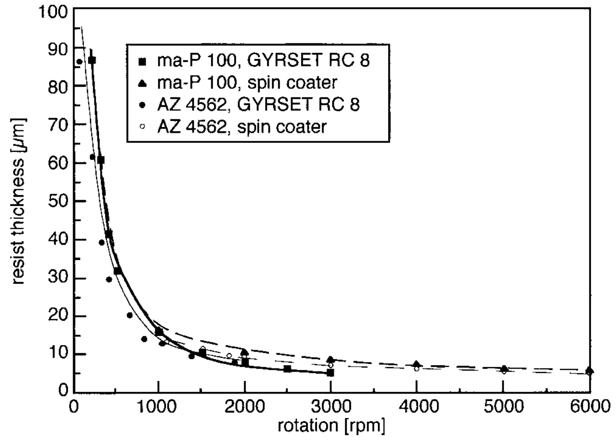

Figure 2. Spin coating curves for AZ 4562 and ma-P 100.

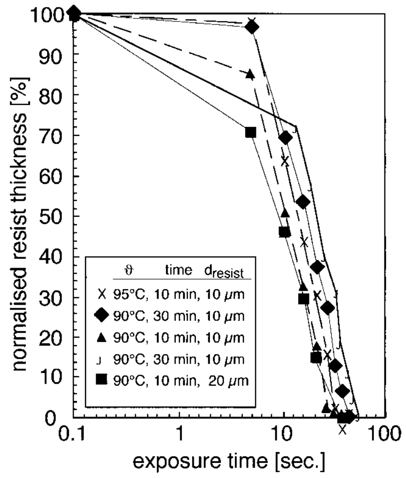

Figure 3. Resist gradation curves for AZ 4562 after standard baking in a convection oven.

Table 2. Mechanical stress (mean value) in 15–90 μm thick photoresist layers after baking under different conditions.

Baking type	AZ 4562 ($\times 10^6$ N m^{-2})	ma-P 100 ($\times 10^6$ N m^{-2})
Air-forced oven	0.5–2.5	0.2–1.2
Ramped hotplate	4	0.1–1.1
IR radiation	1–1.5	0.1–3.1

Resist profiles manufactured on the base of this technology show high edge steepnesses, aspect ratios of up to 10:1, and, depending on the resist thickness, a resolution limit of 3–20 μm.

In UV resist patterning, the line shapes of Novolak photoresists are not completely perpendicular. The typical line shape of UV patterned AZ 4562 photoresist is shown in figure 4. Standard baking procedures in an air-forced oven, as described by the resist producer, were applied. UV exposure was carried out on a Suss MA 56 mask aligner in vacuum contact mode. The undercut was found to be in the order of 1–2 μm per edge with a maximum in a depth of about 5 μm for 40 μm high lines and could be reduced by variations in the

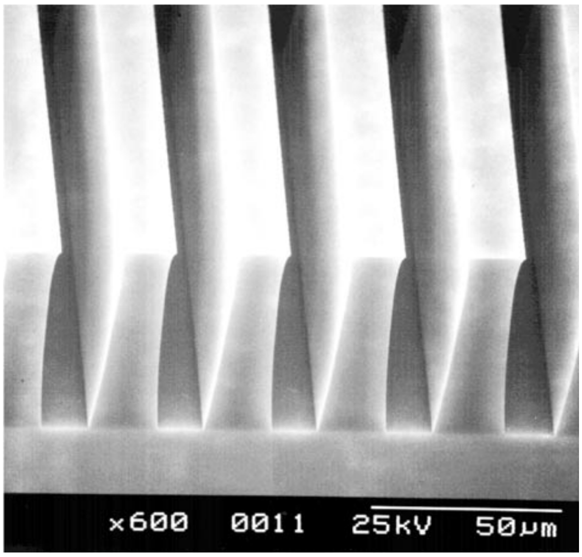

Figure 4. Typical line shape of UV patterned AZ 4562 positive tone photoresist after standard baking.

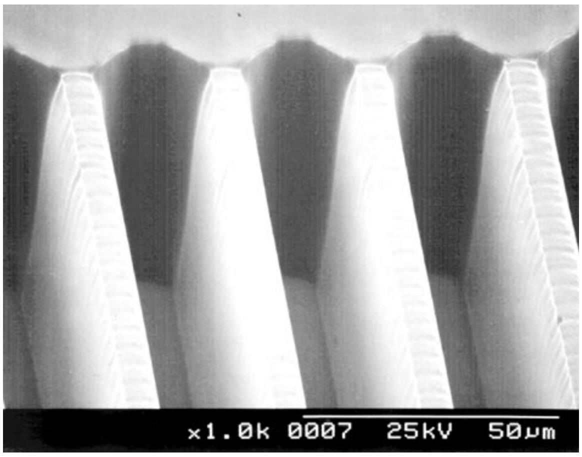

Figure 5. Resist bars of AZ 4562, 6 μm wide and 60 μm high, fabricated by a single UV exposure, optimized resist baking, exposure dose and developing time.

resist preparation process and by using improved collimation optics.

Figure 5 shows a SEM micrograph of a resist profile fabricated with a single UV exposure in the vacuum contact mode. An improved resist baking was applied to the AZ 4562 resist layers. Exposure dose and developing time were optimized for a 60 μm thick resist layer. The resist lines were 60 μm high and 6 μm thick at the top. Compared to the lines shown in figure 4, the undercut is minimized. The edge steepness was in the range of 88°. An aspect ratio of 10 or more could be achieved. Resist layers up to 100 μm could be patterned by a single UV exposure.

In figure 6 lines and spaces in a 15 μm thick photoresist are depicted. While resist bars of 3 μm width were found to be strong enough for the development and handling procedures, the slimmer lines of 2 μm resulting width, shown in figure 6, were found to be unstable. The upper parts of the resist bars break down and limit the resolution of the method.

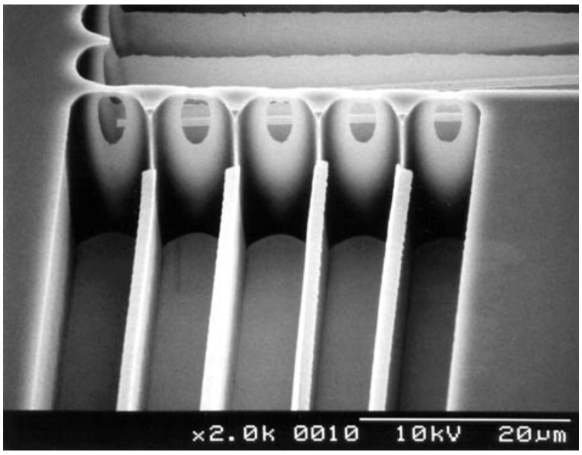

Figure 6. Lines and spaces in AZ 4562 photoresist with a thickness of 15 μm and line width of 2 μm, the top parts of the lines break down, caused by the undercut.

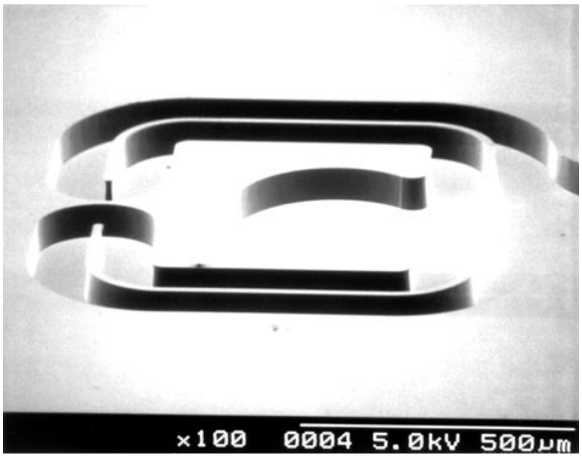

Figure 7. Resist mould of the head section of a fixing spring for reading/writing heads of a hard disc.

Figure 7 shows resist patterns of the front area of a micro springclip for reading/writing heads of hard disks. The resist height is about 55 μm. A moulded product on the substrate surface after removing the resist is depicted in figure 8. The deposited material can easily be removed from the substrate if a sacrificial layer of copper is deposited into the forms before depositing the NiFe. A layer thickness of 2–3 μm is sufficient for this application to remove the springs in a wet etching solution.

A gold planar coil with an integrated contact bridge connecting safely the inner wire of the coil to the outer contact or bond pad is shown in figure 9. The height of the 1.8 mm long gold contact bridge is 55 μm above the planar wires of the coil. The thickness of the bridge is 40 μm. It was fabricated using a copper bar electroplated across the planar coil. The gold bridge was deposited on top of the copper bar. Finally the copper was removed and a free standing contact between the inner wire and the outer pad was achieved.

A three-dimensional micro-solenoid with integrated magnetic core, shown in figure 10, could also be fabricated using the 3D UV-Microforming process.

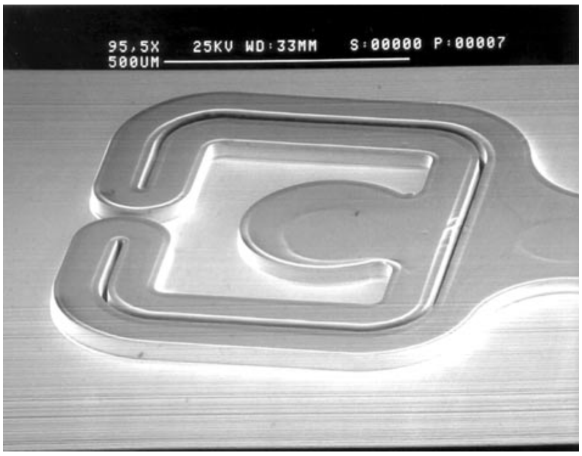

Figure 8. Galvanic moulding of the spring with NiFe before removal from the substrate.

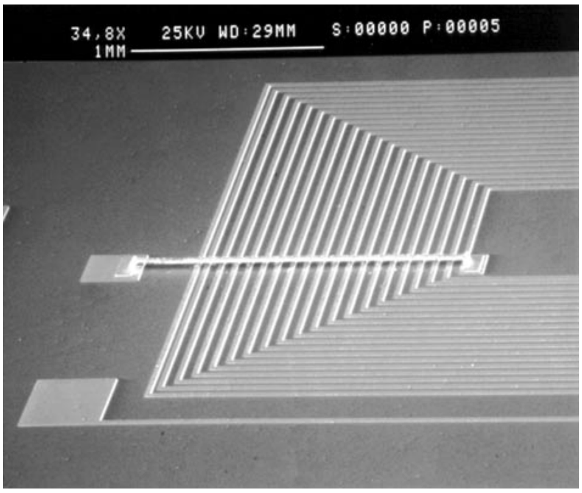

Figure 9. Planar gold micro-coil with integrated contact bridge, the bridge length is 1.8 mm and the bridge height is 55 μm above coil wires.

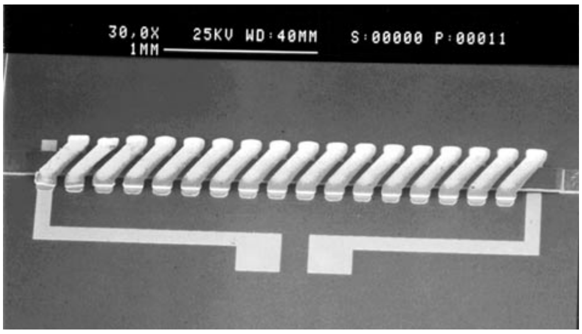

Figure 10. Gold micro-solenoid with 17 windings, the coil width is 300 μm, the coil height is 160 μm, and the core is 40 μm thick NiFe.

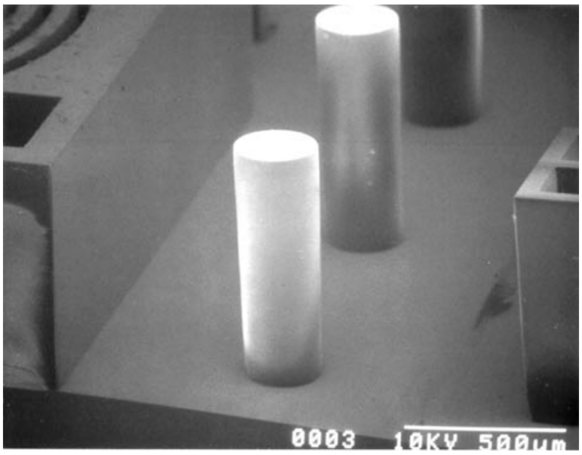

Figure 11. SU-8 resist columns, 100 μm in diameter and 1 mm, high.

The coil consists of gold, the inner core was fabricated of NiFe alloy. Electroplated copper was used as sacrificial material and had to be dissolved selectively to finish the coil.

Such three-dimensional micro-coils with an integrated magnetic core could be fabricated in a five-step UV lithography process. Using a nickel plating base and an AZ 4562 resist in the first step, the lower part of the coil was UV patterned and moulded by gold deposition. On top of this layer a second photoresist layer was spun and UV patterned to generate the lower sacrificial layer across the bottom wires as a distance holder for the magnetic core. This layer generates the gap between the bottom coil wires and the core. After removing the resist layers, a new, thick photoresist was spun on. The new layer was patterned to deposite the core. The shape of these patterns had to be longer, but slimmer, than the bottom sacrificial layer. After filling up these patterns with NiFe, the resist was UV exposed for a second time to generate the form of the upper sacrificial layer. The magnetic core was now covered on both sides and on the top with a 20 μm thick sacrificial layer. After covering the whole stack by an additional 25 μm thick resist layer, in the last lithographic step the forms for the upper coil wires were generated and moulded by gold. The resist layers had to be removed, and the sacrificial metal layer had to be dissolved chemically. In order to have a functional micro-component, the plating base had to be removed by means of chemical etching.

The resulting coil had 17 windings and a total length of 2000 μm. It was 300 μm wide and 160 μm high. The internal magnetic core was 100 μm $\times$ 40 μm (width $\times$ height). The core is anchored in the outer region of the coil to the wafer surface and does not contact the coil.

Resist columns, 1 mm high, on a silicon wafer were achieved by exposing a SU-8 resist layer with a test mask. The pattern of figure 11, 100 μm diameter and 1 mm high, impressively demonstrate the possibilities offered by SU-8. The exposure time of about 5 min for the 1 mm layer is acceptable. Edge steepness and pattern accuracy surpass the possibilities offered by Novolak resists drastically. The main disadvantage of SU-8 is the shrinking during polymerization after exposure and post exposure bake. This shrinking induces high tensile stress.

An example for another kind of thick-layer photoresist is depicted in figure 12. A silicon (100) wafer was etched from both sides by KOH in order to produce slots with the resulting slope caused by silicon (100) etching. After depositing a plating base on both sides, PEPR 2400 was electrodeposited with 20 μm thickness. After baking the exposure was performed from both sides by a MA 25 aligner from Suss. The resulting resist patterns were moulded by

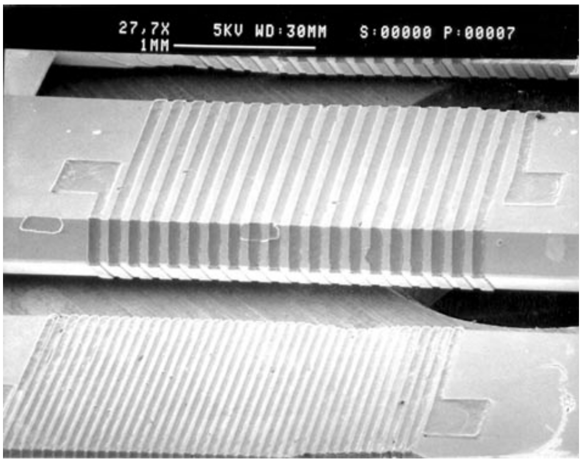

Figure 12. Cu solenoid wound around a Si cantilever, Cu electrodeposited into a PEPR 2400 resist form.

electrodeposited copper. The three-dimensional solenoid was finished by removing the resist and plating the base.

4. Discussion

UV lithography of very thick photoresist layers has qualified for microsystem application. During one single exposure step, resist layers of 100 μm Novolak resist and more than 1 mm thick SU-8 resist could be patterned successfully using the standard collimation optics and a standard mask aligners. The achieved pattern quality was excellent.

Special interest during the resist process development for microsystem applications was set on steep edges and pattern transfer fidelity. An additional aim was the deposition of very thick resist layers during a minimum number of spin coating steps. Using the spin coater type with a rotating cover, resist thicknesses of more than 50 μm could be achieved easily with AZ type resists. SU-8 resist could be deposited by means of a standard spin coater up to more than 1 mm in height.

Depending on the total resist height, the baking process must be carried out in a way to reduce mechanical stress and avoid cracks. The best results were achieved by using drying ovens for baking. Hot plates without temperature programmes created high stress and many of cracks for thick layers, but were successfully applied for thinner layers. The optimum equipment for baking thick photoresist layers have to be variable in temperature maximum and should be programmable.

The resolution limits for the method are given by physics. However, most applications in microsystem technology do not demand high resolution, but large structure heights for generating masses and forces. Achievable heights of more than 100 μm or 1 mm and an edge steepness up to 90° qualify the method for microsystem application. Combined with micro-electrodeposition and sacrificial layer techniques the material base for microsystem fabrication as well as the technological possibilities have been expanded.

During the micro-electroplating process, materials of different chemical characteristics can be deposited into the fabricated photoresist patterns and, also, as multi-layer systems.

5. Conclusions

Thick resist layer patterning using UV mask aligners combined with electroplating meets the requirements of microsystem technology, especially with regard to accuracy, process integration, and cost. The procedures described open a low-cost route for fabricating micro-components such as coils, ducts, cantilevers, and parts for micro-valves directly on the surface of substrates.

During the micro-electroplating process, materials of different chemical and physical properties could be deposited into the fabricated photoresist patterns, both as a single layer or as a multi-layer stack. A wide range of new materials and combinations opens new dimensions for developing industrial products.

Using selectively soluble sacrificial materials such as photoresist, sputtered aluminium, or electroplated copper or zinc in combination with NiFe or gold, free standing bridges and cantilevers as parts of more complicated microsystems could be realized. In a multi-level process of resist coating, UV patterning, and moulding the resist patterns by means of electroplating, three-dimensional gold micro-coils with integrated NiFe cores were fabricated.

The 3D UV-Microforming enlarges the possibilities of microsystem technology in a low-cost manner. This technology may be very helpful for establishing microsystem technology in an industrial environment with affordable investment costs.

Acknowledgments

The author wants to thank his former colleagues Ms M Rothe, Mr A Maciossek, Mr H J Quenzer from the Fraunhofer Institute for Silicon Technology, Mr L Johansen from MIC in Lyngby, DK, Mr B Tierock from TU Berlin, and S Jung from BESSY Application Center for Microtechniques for their contribution to the development of the new fabrication technique.

A part of the reported development was carried out at the Fraunhofer Institute for Silicon Technology in Berlin.

Trademarks

AZ 4000 photoresist series is produced by Clariant GmbH, Wiesbaden; **ma-P100** is a product of Micro Resist Technology GmbH, Berlin; **SU-8** is a product of Microlithography Chemical Corporation, Newton, MA; **PEPR 2400** is a product of Shipley Corporation, Marlboro, MA.

For more information (catalogue of thick-layer photoresists) concerning available thick-layer photoresists please contact: Micro Resist Technology GmbH in Berlin (via internet) mrt@microresist.de

References

[1] Rogner A, Eichert J, Munchmeyer D, Peters R-P and Mohr J 1999 *J. Micromech. Microeng.* **2** 133–40

[2] Engelmann G, Ehrmann O, Simon J and Reichl H 1990 *Proc. Micro System Technologies (Berlin)* ed H Reichl, pp 435–40

[3] Love D, Boucher P, Chou B, Grilletto C, Holalkeri V, Moresco L and Wong C 1996 *Proc. 1996 Int. Flip-chip, BGA, TAB and AP Symp. (Sunnyvale, CA, February 14–16, 1996)*

[4] Engelmann G and Reichl H 1992 *Microelectron. Eng.* **17** 303–6

[5] Maciossek A, Löchel B, Quenzer H-J, Wagner B, Schulze S and Noetzel J 1995 *Microelectron. Eng.* **27** 503–8

[6] Cullmann E, Löchel B and Engelmann G 1994 *Proc. Micro System Technologies (Berlin)* ed H Reichl, pp 173–82

[7] Engelmann G, Ehrmann O, Leutenbauer R, Schmitz H and Reichl H 1993 *Proc. SPIE* **2045** 305–13

[8] Löchel B, Maciossek A, Quenzer H-J, Wagner B and Engelmann G 1995 *Sensors Actuators* A **46** 98–103

[9] Gobet J, Cardot F, Bergqvist J and Rudolf F 1993 *J. Micromech. Microeng.* **3** 123–30

[10] Loechel B, Maciossek M, Quenzer H-J and Wagner B 1996 *J. Electrochem. Soc.* **143** 237–44

[11] Loechel B and Maciossek A 1995 *Proc. SPIE* **2639** 174–84

[12] Löchel B, Maciossek A, König M, Quenzer H-J and Wagner B 1994 *Proc. Actuator'94 (Bremen, 1994)* pp 109–13

[13] Engelmann G, Ehrmann O, Leutenbauer R, Schmitz H and Reichl H 1993 *Proc. MME'93 (Neuchatel)* pp 85–8

[14] Löchel B, Maciossek A, König M, Quenzer H-J and Huber H-L 1994 *Microelectron. Eng.* **23** 455–9

[15] Lorenz H, Despont M, Fahrni N, LaBianca N, Renaud P and Vettinger V 1996 *Suss Report* **10** 1–3

[16] Wagner B, Quenzer H J, Henke W, Hoppe W and Pilz W 1995 *Sensors Actuators* A **46–47** 89–94

[17] Katalog hochaufbauender Resiste, Micro resist technology GmbH, Koepenicker Strasse 325 D-12555 Berlin, mrt@microresist.de

[18] Cullmann E 1996 *Elektronik Produktion Prüftechnik* **3** 70–2

[19] Loechel B, Maciossek A and Rothe M 1995 *J. Vac. Sci. Technol.* B **13** 2934–9

[20] Loechel B, Rothe M, Fehlberg S, Gruetzner G and Bleidiessel G 1996 *Proc. SPIE* **2879** 174–81

[21] Cheng Y, Lin Ch-Y, Wei D-H, Loechel B and Gruetzner G 1999 *IEEE J. Microelectromech. Syst.* **8** 18–26

[22] Engelmann G, Ehrmann O, Leutenbauer R, Schmitz H and Reichl H 1993 *J. Micromech. Microeng.* **3** 152–4

[23] Romankiw L T 1990 *Magnetic Materials, Processes, and Devices (Electrochemical Society Proceedings Series, PV 90-8, 39-53)* ed L T Romankiw and D A Herman (Pennington, NJ)

[24] Engelmann G, Ehrmann O, Simon J and Reichl H 1992 *Proc. MEMS 1992 (Travemünde, 1992)* pp 93–8

[25] Bleidiessel G, Gruetzner G, Reuther F, Fehlberg S, Loechel B and Maciossek A 1998 *Microlectron. Eng.* **41/42** 433–6