Self-Supporting Polymer Films for MEMS Applications

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Summary: The fabrication of a self supporting novolac-based photoresist layer is demonstrated. A technology is presented using a sacrificial layer of PMMA and a carrier layer of photosensitive PI. The solely use of polymers for the creation of a self-supporting structure is distinguished by simple processing and relatively low cost materials. Additionally the mechanical stability of the self-supporting layer is under consideration. Finally the cross-linking process of the novolac-based photoresist by curing is discussed using FTIR, DSC and TGA measurements.

Keywords: cross-linking; novolac; PMMA; sacrificial layer technique; self-supporting layer

Introduction

Microelectromechanical systems (MEMS) allow the implementation of three-dimensional structures like sensors, actuators or passive structures within the range of a few micrometers. Conventional MEMS technology is based on standard semiconductor processes, because of the large amount of experience existing from CMOS technology. Nevertheless semiconductor-based technologies have the disadvantage of being quiet expansive due to the complex equipment needed and the cost-intensive materials.

In recent days great efforts have been made to integrate polymer materials in MEMS applications. Polymer technology benefits from the advantages of relatively low cost materials, simple processing, and variety of material properties available. The latter arises from tailoring polymers by combining useful chemical structures and morphologies.

This work deals with the fabrication of self-supporting polymer films with dimensions of a few microns. This three-dimensional arrangement enables optimized solutions for special MEMS problems. One possible application for these tunnel-like structures is in microfluidics. Further potential applications are sensor systems where thermal or electric isolation is needed. Thereby, highly sensitive thermal or mechanical resistive sensors can be created by filling conducting particles into the self-supporting polymer.

To realize self-supporting polymer structures soft lithography technologies have been applied. By using elastomeric molds of poly(dimethylsiloxane) self-supporting films of poly(carbonate),[1] poly(methyl-methacrylate) (PMMA)[2] and different kinds of photoresists[3,4] were reported.

In this work another approach using a sacrificial layer technique is implemented. By varying the thickness of the sacrificial layer, this technique enables an adjustable distance between the self-supporting layer and the substrate down to a few microns or even below. Previous works realized self-supporting polymer structures by using a metallic sacrificial layer.[5,6] The definition of the metallic structures requires a comparatively complex technology usually based on lift-off processes. In addition, the removing step with an acid can lead to serious compatibility problems during the technology process. Often other metallization

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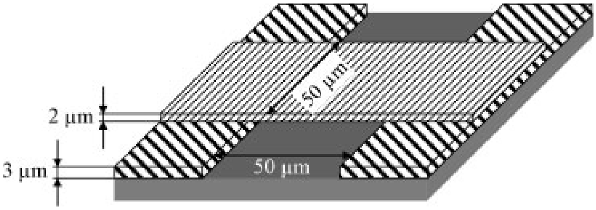

Figure 1.
Schematic design of the self-supporting structure.

layers are affected by this fabrication procedure.

Therefore a polymeric sacrificial layer is used in this work implicating the advantage of easy structuring and removing.

Materials

Photosensitive polyimide (PI) Pyralin PI2722 and the adhesion promoter VM-651 were supplied by HD Microsystems. PMMA with a molecular weight of 35,000 was supplied by ACROS. The used photoresist is AZ 1514 from Allresist. The main solid component in this photoresist is a novolac resin. The active component of the corresponding photoinitiator is 1,2-naphthoquinonediazide (DNQ). The solvent of the photoresist is propylene glycol monomethyl ether acetate (PGMEA).

Technology

To realize a polymer-only sacrificial layer technique, the polymers used and the corresponding technology steps have to meet several conditions: (i) The polymer layers have to be structurable to achieve the desired geometry. (ii) The solvent used for film casting of the self-supporting layer has to keep the sacrificial layer unharmed. (iii) The sacrificial layer has to be easily removable without affecting the self-supporting layer.

The desired dimensions of the final structures are presented in Figure 1. The self-supporting layer is mounted on top of a polymer carrier layer due to advantages in the technology process (Figure 2).

On top of a SiO_2 substrate the photosensitive PI is spin-coated. After UV exposure and development a mechanically and

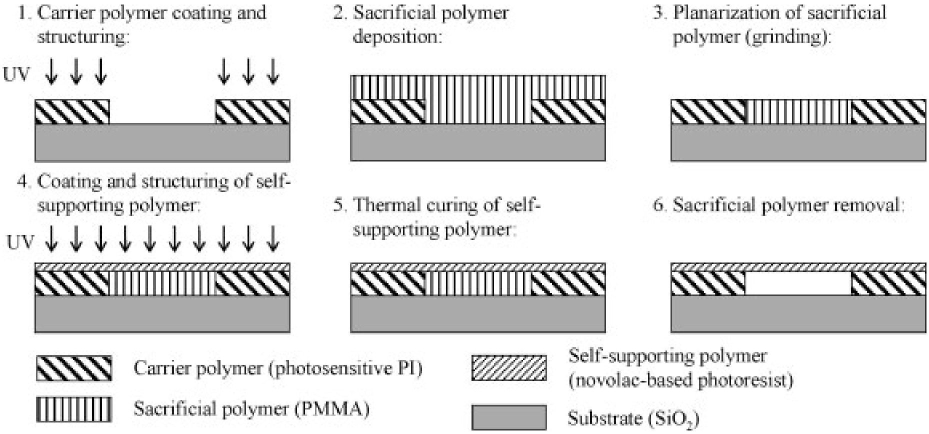

Figure 2.
Concept of the used sacrificial layer technique with supporting PI carrier layer.

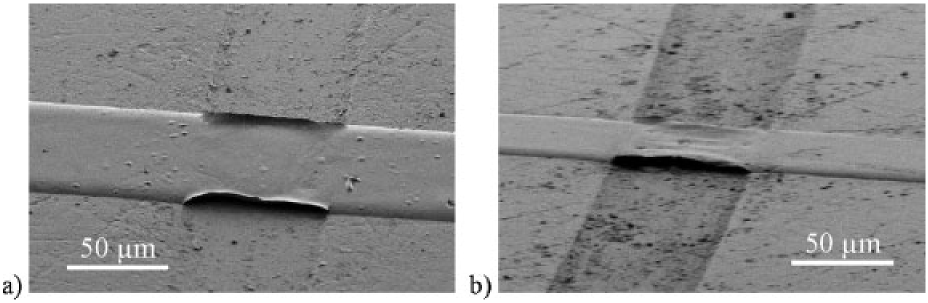

Figure 3.
Scanning electron microscopy (SEM) pictures of the self-supporting novolac-based photoresist layers at a tilting angle of a) 50° and b) 70°.

thermally very stable carrier polymer layer is defined, being well-suited for the following process steps. To increase contact properties of the subsequent PMMA layer, an adhesion promoter VM-651 is applied on top of the structured wafer. PMMA being the sacrificial layer is spin coated with a thickness much larger than the underlying PI structures. The brittleness and hydrophoby of the PMMA layer are good properties for the following wet grinding process. Due to the very stable PI layer this grinding process results in a homogeneous planar topography at the upper level of the PI structures. The final film of novolac-based photoresist is spin coated onto this planar underground leading to a similarly homogenous layer. UV exposure, development and a thermal curing step at 200 °C for 30 minutes yield in highly cross-linked and well-defined photoresist structures. They are rigid enough to withstand the capillary forces that occur during the removing step of the sacrificial PMMA layer in acetone.

Characterization

Differential scanning calorimetry (DSC) measurements were performed with a DSC2920 from TA Instruments. Thermogravimetric analysis (TGA) was done using

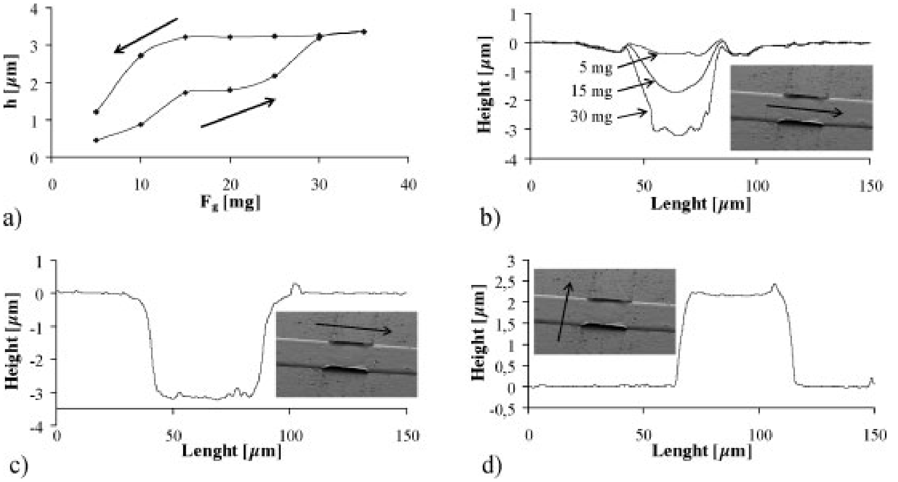

Figure 4.
a) Interrelation of pressing weight F_g and maximal bending h of the self-supporting layer; Height profiles b) on top of the self-supporting photoresist layer with varying pressing weights of 5 mg, 15 mg, and 30 mg, c) across the trench next to the self-supporting structure and d) across the photoresist structure.

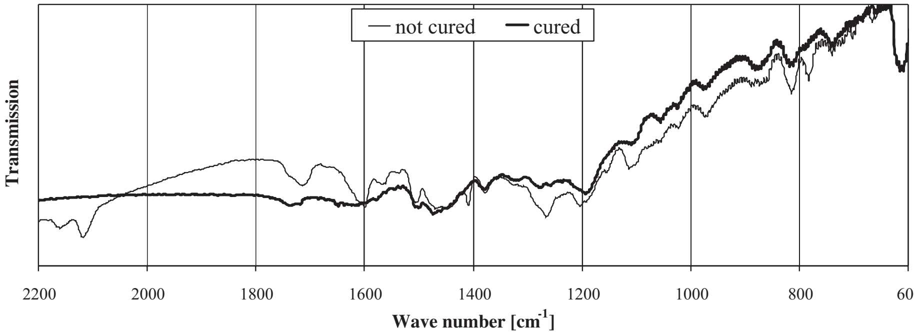

Figure 5.
FTIR curves of novolac-based photoresist before and after curing.

a TG50 from Mettler-Toledo. Both measurements were conducted in nitrogen atmosphere. The heating rate of the DSC was 5 K/min and the heating rate of the TGA was 10 K/min. The FTIR spectrometer used was a Spectrum 2000 from Perkin Elmer.

Height profiles were measured using a DEKTAK3ST from VEECO Instruments.

Results and Discussion

Final self-supporting polymer structures can be seen in Figure 3 at two different tilting angles. Major parts of the self-supporting area exhibit good planarity. However, the edges show some crimping effect.

Mechanical stability of these structures was measured using a height profilometer with varying pressing weights (Figure 4). Increasing pressing weight up to 25 mg leads to continuous descent of the self-supporting structure. At 30 mg pressing weight the layer comes into contact with the bottom level of the trench (compare Figure 4b and 4c). With the subsequent reduction of the pressing weight, a strong hysteretic effect occurs. Therefore, a visco-plastic deformation was caused during the pressing process. Because the structure rises again between (15...10) mg the deformation did not destroy the self-supporting structure completely.

This mechanical stability results from the thermal curing step at 200 °C before removing the sacrificial layer. The FTIR (Figure 5) shows the disappearance of significant bands of α-diazoketone (2114 cm^{-1}, 2158 cm^{-1}) and azo groups (1597 cm^{-1}).[7] This indicates a separation of the nitrogen

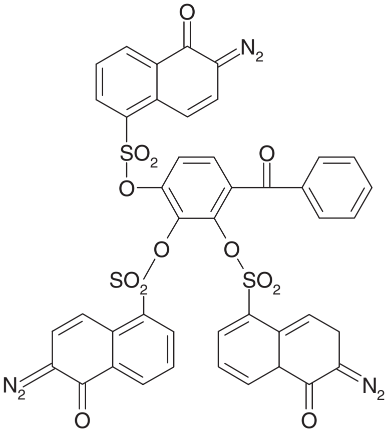

Figure 6.
Chemical structure of the photoinitiator in the novolac-based photoresist.

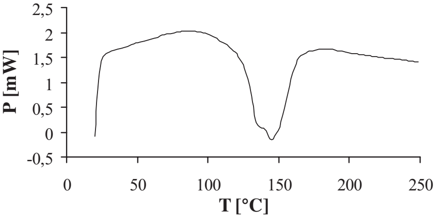

Figure 7.
DSC curve of the novolac-based photoresist.

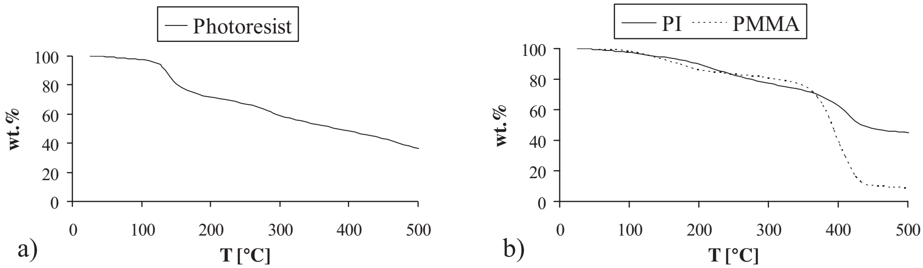

Figure 8.
TGA thermograms of a) novolac-based photoresist, b) PI and PMMA.

caused by the thermolysis of DNQ (Figure 6). Radicals being generated lead to thermal cross-linking of the DNQ with novolac.[8]

An exothermic process (Figure 7) and a weight loss (Figure 8a) at (100…180) °C support the former conclusion.

The TGA measurement of the other two polymers investigated here can be seen in Figure 8b. Up to 200 °C the curves do not exhibit any significant weight losses indicating their stability during the thermal curing process.

Conclusion

In this article we present a technological process allowing the simple creation of self-supporting polymer structures. A polymer-only sacrificial layer technique with a photosensitive PI as carrier layer, PMMA as sacrificial layer and a novolac-based photoresist as self-supporting layer is used. Sample structures are presented having a self-supporting layer thickness of 2 μm and a length of 50 μm. Those geometric parameters can be varied simply by altering the dimensions of both the carrier layer and the sacrificial layer.

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