Fabrication Process for Ultra High Aspect Ratio Polysilazane-Derived MEMS

Tsali Cross, Li-Anne Liew, Victor M. Bright, Martin L. Dunn, John W. Daily, and Rishi Raj
High-Temperature Materials Laboratory
Center for Advanced Manufacturing and Packaging of Microwave, Optical and Digital Electronics

Department of Mechanical Engineering, ECME 150, Campus Box 427, University of Colorado at Boulder
Boulder, CO, USA 80309-0427
Phone (303) 735-2651, Fax (303) 492-3498, email: crosst@ucsub.colorado.edu

ABSTRACT

We present a new process for fabricating polysilazane-derived MEMS components with ultra high aspect ratios. The width-to-height ratio of actual structures fabricated at this time is (~20:1), but shows promising results to achieve aspect ratios of 50:1. Polysilazane-derived materials are a group of polymers and ceramics that can be functionalized to have a wide range of material properties such as electronic, magnetic, dielectric, and optical. The fabrication process is based on contact lithography of a liquid photopolymer precursor, poly urea methyl vinyl silazane, PUMVS (Kion, Corp.), with photoinitiator 2,2 dimethoxy, 2-acetophenone, DMPA (Aldrich) for polysilazane. Contact lithography of aqueous photopolymers presents a substantial improvement in resolution, flatness of structures, and aspect ratios compared to microcasting, and proximity printing for polysilazane-derived MEMS. In the future, this fabrication technique may be extended beyond polysilazane-derived materials to a wide variety of aqueous photopolymerizable sol-gels, preceramics, and photopolymers.

INTRODUCTION

A variety of fabrication techniques for potentially high (height-to-width) aspect ratio microcomponents of different materials have been developed. Some of these techniques include but are not limited to: deep reactive ion etching [1], ion diffusion in glass, photosensibilization of glass, excimer laser ablation and melting, diffractive techniques, proton irradiation of poly(methyl methacrylate) (PMMA), synchrotron irradiation [2], micro-molding techniques, embossing [3], direct photolithography of inorganic-organic sol-gels [4], and ink jet printing [5]. However, key deterrents to using these fabrication processes for polysilazane-derived materials were availability, complexity, cost, and performance.

Polysilazane-derived materials are a group of polymers and ceramics that can be functionalized to have a wide range of material properties such as electronic, magnetic, dielectric, and optical [6, 7, 8, 9]. Polysilazane, the crosslinked form of poly urea methyl vinyl silazane (PUMVS, Kion Corp.), is a novel hybrid organic/inorganic polymeric glass that is highly transparent in the infrared to ultraviolet [9] Polysilazane microcomponents have potential applications in optical MEMS, and microfluidics [10]. Polysilazane may also be converted into a black-colored, novel Silicon Carbon Nitride ceramic, which has potential use in high temperature and corrosive environment applications for MEMS [6].

Our previous work focused on the fabrication of such polysilazane, and polysilazane-derived silicon carbon-nitride (SiCN) ceramic MEMS by micro-casting [10,11]. Some disadvantages to this fabrication process are its ability to generate completely flat structures, its resolution, and number of processing steps [10]. We therefore present a cost-effective fabrication technique that shows substantial improvement to microcasting's flatness, resolution, and processing steps.

In this paper we will describe the process developed to improve fabrication of polysilazane MEMS structures over microcasting, and discuss some key design issues.

FABRICATION

The process is shown in Figure 1. First, a negative glass photomask is generated from the CAD layout of the device. The emulsion side of the mask is then coated with a thin layer of Teflon (a). For this, 1% liquid Teflon AF solution (from Dupont Corp) is spun onto the mask and subjected to a series of heat treatments in an oven, during which the solvent in the Teflon solution evaporates, leaving behind a thin conformal coating on the mask. Next, a sacrificial layer (for example SiO_2) is deposited on a silicon wafer (b). The liquid photopolymer precursor solution is then dispensed at an arbitrary thickness onto the wafer (c) Our precursor solution for polysilazane is a mixture of the liquid photopolymer precursor, PUMVS, with photoinitiator 2,2 dimethoxy, 2-acetophenone, DMPA (Aldrich). The mask is then placed on the wafer with the Teflon-coated side in contact with the PUMVS (d). The mask is supported by spacers that keep the mask at a predetermined distance from the wafer, thereby setting the thickness of the PUMVS structures. The system is exposed to UV light. The dark areas in the mask prevent the UV from penetrating the glass through to the PUMVS, thus the PUMVS solidifies in regions corresponding to the clear sections of the mask (e). Following photopolymerization, the still-liquid PUMVS is removed from the wafer by a high-speed spin-rinsing with a solvent such as acetone or hexane (f). Solid polymer structures thus remain on the wafer (g). The sacrifical

layer is then removed in an appropriate solvent, thereby freeing the polymer structures (h). The polymer components may then be put in a high-temperature furnace and the ensuing heat treatments convert the material into a ceramic, if so desired (i).
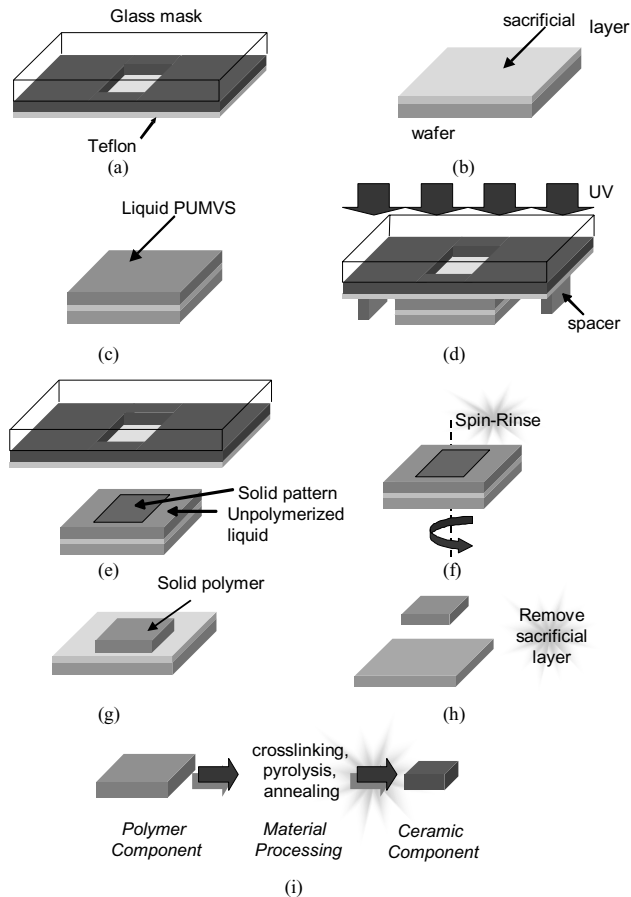
Contact Lithography Method

Figure 1 is an illustration of the fabrication process discussed in this paper. It is based on a contact lithographic printing method of liquid photopolymer solutions.

MICROFABRICATION IMPROVEMENT THROUGH CONTACT LITHOGRAPHY

As previously mentioned, microcasting of polysilazane-derived microcomponents has some limitations: the flatness of structures and resolution. The flatness of structures created by microcasting was affected by the tendency of the polymer solution to form a meniscus. Meniscus formation should adversely affect the performance of polysilazane optical and other MEMS components requiring flat surfaces. The resolution was found to be greater than 50 microns in width to

allow for complete mold filling due to the viscosity of the liquid [10].

Masking and direct photopolymerization of PUMVS with initiator DMPA offers a different approach to work out the limitations of microcasting. However, until recently, we have been unsuccessful in fabricating polysilazane microcomponents by photopolymerization. Our lack of success was because "proximity printing" was used in the early trials for microcomponent fabrication. Proximity printing is a lithography process where the photopolymer is exposed through a mask held at some finite distance above the top surface of the photopolymer solution. In these beginning photopolymerization experiments, proximity printing was used for two reasons: to avoid all contact with the mask so that cured components would only have to be removed from one substrate (the bottom), and to protect the mask from the polysilazane precursor (cured and uncured). From this technique, as shown in Figure 2 (a), diffracted UV light exiting the mask proximity printing created poorly resolved features.

"Contact printing" where the solution is exposed to UV through a mask placed directly on the photopolymer, eliminates all diffraction effects from the UV light exiting the mask. The resolution of contact printing is higher than any other optical lithography process [1]. The elimination of diffraction effects is shown in Figure 2 (b). The key to making polysilazane and other aqueous polymer structures by our contact method is the application of the thin Teflon coating to the mask. The coating serves two purposes: to ensure that cured polymer structures will not stick to the mask itself, which optimizes de-molding., and to protect the mask and
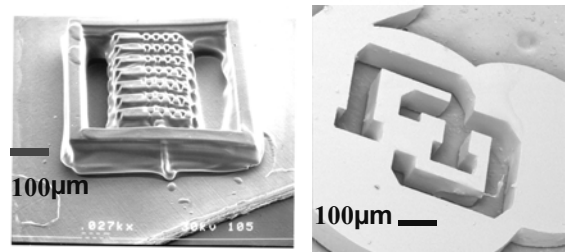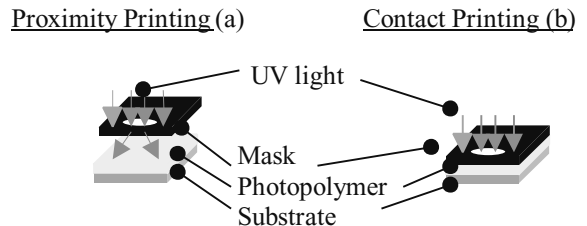
Figure 2 shows in (a) the poor resolution achieved by "Proximity printing" due to the diffracted UV light exiting from the mask, and the result of eliminating diffracted light by contact printing shown in (b).
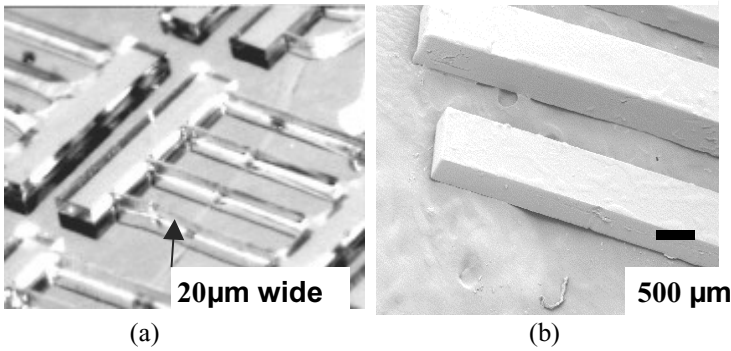
render it re-usable.

(a) 20µm wide   (b) 500 µm

Figure 3 shows the precision of this fabrication process to create (a) flat polysilazane test structures with good resolution imaged by a CCD camera (b) and high aspect ratios shown by an SEM micrograph.
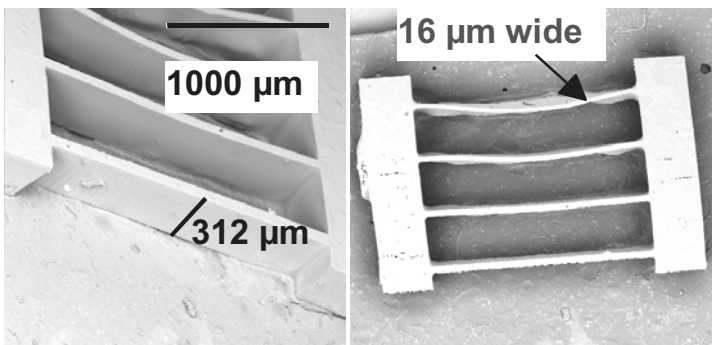

1000 µm   16 µm wide   312 µm

Figure 4 displays actual aspect ratios of ~20:1 for these structures made by contact lithography.   .

The resolution of polysilazane structures fabricated by the contact method is currently limited by the smallest resolvable line width of the mask manufacturer, which in our case was 20 microns. Large cure depths have been attained with this process to approximately 700 microns. Examples of structures fabricated by contact lithography are shown in Figure 3. Actual aspect ratios of ~20:1 from these structures were calculated from SEM's shown in Figure 4.

DESIGN ISSUES

Although cure depths of 700 microns have been attained by the contact lithography method, even higher aspect ratios are expected. In work cited in a previous paper, we calculated that a solution of PUMVS with 5 wt% DMPA with incident irradiation intensity of $20 mW/cm^2$ at 365 nm, 9 mW/cm^2 would be available to cure at a depth of 1 mm. This intensity is sufficient for photopolymerization of our solution within a reasonable amount of time (20 minutes) [10]. Therefore at a

fundamental level, our photopolymerizable material system is theoretically able to achieve ultra high aspect ratios of 50:1, assuming a width of 20 microns and depth of 1mm.

We will work towards attaining ultra high aspect ratios in the future. However, at those aspect ratios, care must be taken during the spin rinsing, or another de-molding technique may need consideration. De-molding by spin rinsing becomes progressively more difficult due to increased bending on the structure from torque developed by the flowing rinse on the upper regions of the structure and stiction at its base. An example of this bending can be seen in Figure 3 for the 20 micron wide feature. Also, to achieve maximum cure depths, it will be necessary to optimize the initiator concentration to find a balance between minimum absorbance of UV light at the top (incident) surface while providing enough initiator for primary radical generation at the bottom for polymerization through its depth.

CONCLUSIONS

Polysilazane-derived MEMS offer advantageous optical, mechanical, and thermal resistant properties to fill potential use in optical, microfluidics, and high temperature and corrosive environment applications for MEMS [6,10]. From our group's efforts into photopolymerization with preceramics, a new fabrication technique was developed and shown here as capable of creating flat, well-defined structures with high aspect ratios. This fabrication process utilizes masking and photopolymerization of PUMVS with DMPA via contact lithography of Teflon-coated masks. Future trials will work towards attaining ultra high aspect ratios by optimizing initiator concentration and improving de-molding techniques. This fabrication technique may be extended beyond polysilazane-derived materials to a wide variety of aqueous photopolymerizable sol-gels, preceramics, and photopolymers.

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