# A Novel Method for Stereolithographic Alignment of MEMS Structures

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## ABSTRACT

This paper presents a method of achieving integration of stereolithographic and microfabricated structures. Extending the principle of metal-plated microfabrication masks to stereolithography (SLA), it is possible to ensure alignment and bonding. A conventional mask aligner is used and planarization of the SLA part to allow for Cr metalization and bonding with spin-coated SLA resin. The method has been applied to the fabrication of a micro-four point probe array. Good alignment was achieved in this process.

***Keywords***: Stereolithography, alignment, HARMS, wafer-scale packaging, micromachining

## 1 INTRODUCTION

### 1.1 Stereolithography and microfabrication

In recent years there has been a fair amount of interest in integration of stereolithography with MEMS devices for packaging of microfluidic devices [1] or to build new MEMS devices that are able to leverage from the high aspect ratio 3D structures [1] that can be built using stereolithography (SLA) [2,3]. While a fair amount of work exists on submicron-level stereolithography [4,5], little success has been possible in fabrication where accurate alignment with devices fabricated by micromachining of silicon is required. This work seeks to address the issue of alignment of SLA with microdevices fabricated by using traditional MEMS techniques.

### 1.2 Using SLA with microfabrication

The motivation for investigation of the integration of stereolithography and microfabrication comes from the ability of stereolithography to create accurate, complex 3-dimensional structures that can be used for packaging of electronics with interconnects, fluidic systems and sensors. Integration with microfabricated devices may be possible on micrometer scales. If successful, this will allow for better packaged devices and extend the applicability and scope of MEMS devices and make system on a package (SOP) a more realizable concept.

### 1.3 State of the art

Existing techniques for integration of SLA and microfabricated devices [1,2] involve insertion of the wafer or silicon die into the stereolithographic build and alignment using a SLA built fixture created in the lower half of the SLA package. However these methods preclude the possibility of accurate alignment given that neither the wafer nor the SLA package has an accurately defined shape and dimensions. Hence it is quite impossible to *ensure* alignment when inserting the silicon die into the SLA package in the middle of the SLA build. Further the introduction of the silicon die in the SLA in the middle of the build also introduces error and misalignment in the system since platform or SLA build position may be altered due to the force or manner of insertion.

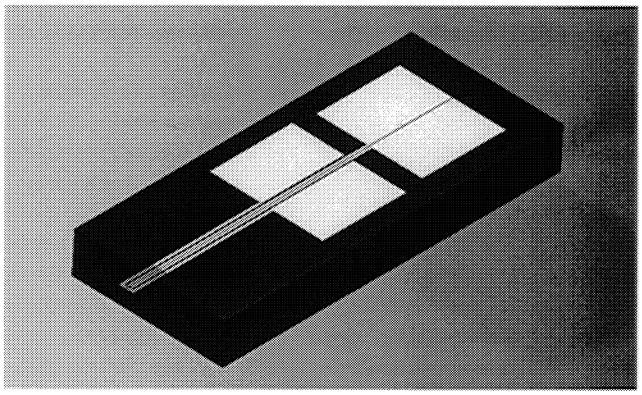

Figure 1: Micro four-point probe

### 1.4 Scope of this paper

Any study on the integration of SLA with microfabricated devices requires:

a. Accurate SLA structures
b. Accurate alignment with respect to microfabricated devices
c. A procedure for integration of the two fabrication regimes

In this paper no attempt is made to address issues such as accuracy of the SLA build. We explore new techniques for alignment of SLA structures with microfabrication. We will attempt to show the feasibility of the method rather than provide a definitive measure of alignment accuracy.

## 1.5 An overview of the problem

The present technique was developed for a micro-four point probe device (fig. 1). This device consists of microfabricated silicon carbide cantilevers and a probe body made of SLA. The said cantilevers are 200μm in length and are defined on two distinct parallel planes. Most SLA machines have line resolution of the order of 50-100μm and are ill suited for integration with microfabrication since very marginal error can completely destroy the functionality of the microfabricated device (in this case the cantilever). Hence there is a definite need for a method of alignment of SLA and microfabrication that can aid integration of these two fabrication regimes.

# 2 CONCEPT AND PROCEDURE

In the current work we have attempted to ensure more accurate alignment of the stereolithographically fabricated feature with the microfabricated device by using a mask aligner (Quintel 7900) to align and integrate SLA structures to the silicon die. Both wafer-scale and chip-scale alignment was performed. Bonding between the SLA and silicon was performed by spinning the SL5510 photopolymer (Vantico) on the silicon wafer or die, aligning the SLA and silicon on a mask-aligner and exposing them to UV light after bringing them into contact. While alignment with SLA structure is achieved in a manner similar to conventional alignment, ensuring selective bonding regions is possible in two ways. The first is making through holes in the SLA mask corresponding to the non-bonding regions (fig. 2) of SLA and silicon and etching these in oxygen plasma. The process flow for the second approach, more appropriate for devices that cannot be subjected to plasma etching, is detailed below. Certain procedural issues have also been discussed herein.

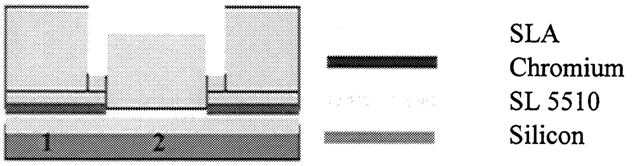

Figure 2: Scheme for alignment of SLA and silicon. Region 1 is a non-bonding region and region 2 is a bonding region

## 2.1 Procedure

1. ***SLA holder-mask design and build:*** The SLA setup consists of two parts the mask-holder and the SLA mask. Two sets of holders were made- one of chip-scale alignment and the other for the wafer-scale alignment. These were put together in the manner shown in figs. 3,4. The mask holder was fabricated in a 3D Systems DSM 3500 (DSM Somos 8120 photopolymer) and the SLA mask in a 3D Systems SLA Viper Si2 (Vantico SL5510 resin). The 5" mask-holder was designed for use in place of a maskplate in a conventional mask aligner. The mask contains both the structures that are to be aligned with the microfabricated device as well as the through holes for alignment with alignment marks on the silicon die. The alignment holes are rather large (squares of side 600μm) on account the difficulty of making smaller through holes using stereolithography [2]. The SLA device structure was a cuboid of dimensions 1.45mmx3.38mmx1mm. Walls separating the individual SLA cells were 300μm thick (fig. 5 shows the CAD file for the mask). The SLA device structures designed so as to allow for the individual devices to be broken off the mask at the end of the fabrication process.

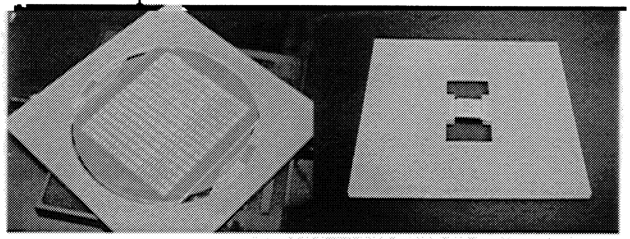

Figure 3: SLA mask and mask holders

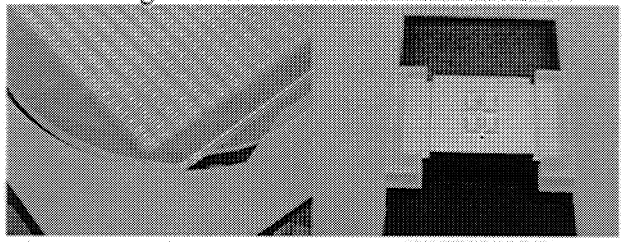

Figure 4: Wafer and chip scale mask holders

2. ***Planarization of contact surface:*** The need for planarization in this method arises from nature of the bonding of the SLA and silicon desired. Essentially there are three device-SLA interaction regions (fig. 2):

a. Regions where bonding between the die and SLA structures is desired
b. Regions where bonding is not desired
c. Regions on the silicon die that underlie the alignment through holes

Planarization, metalization and patterning were done to prevent photopolymer from crosslinking in regions where bonding was not desired. This we attempted by patterning chromium on the contact surface between the SLA mask and the silicon die. The chromium prevents exposure of photopolymer (step 5) in regions under it just as in a conventional litho-mask and allows for selective bonding to the silicon surface (fig. 2). Further the SL5510 photopolymer tends to cure and harden hence it was considered important to be able to access these regions immediately after the exposure and rinse them with glycol ether (SL5510 developer). These regions are designed as through holes on the SLA mask. At the end of the process it was expected that we would be able to etch the chromium mask from the back and flush these regions with glycol ether. Planarization allows fabrication of a thick chromium membrane over the non-bonding regions such that while these regions are not cured, the through holes in the SLA mask allows for access to these regions and cleaning in the manner described above.

To achieve this planarization (fig. 5 shows effect of planarizing agent), a thin polymer film was stuck on (Kapton tape) or laminated (Riston dry film resist) at 120°F. The planarizing agent was then poured in from the non-contact side of the SLA mask. While the Kapton film had to be physically peeled off leading to some defects in planarization. The Riston film in general showed better results when the film was removed by a short acetone rinse, but fell short in that the low lamination temperature led in imperfect lamination. At the higher temperatures normally used in Riston lamination the SLA mask showed signs of thermal deformation. Planarization agents used were paraffin wax, PDMS and photoresist (AZ4620, NR5-8000, Shipley 1827, NR9- 1500). Wax was later discarded when it was discovered that wax solvents tend to attack the cured SLA material and would therefore not allow for removal of wax prior to the alignment step.

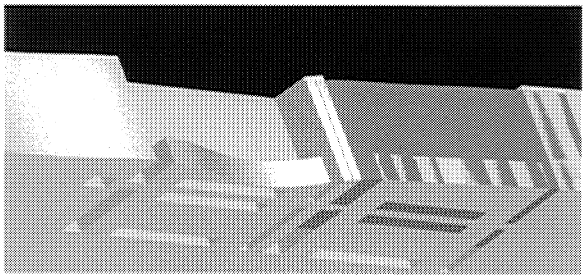

Figure 5: SLA mask design: The cell on the left is a cutaway of the SLA mask. The dark region on the cell on the right shows the effect of planarizing agent

3. ***Metal deposition:*** A sputtered chromium (1.5 µm thick) is deposited in a D.C. sputtering system (CVC Products) to ensure a thick and conformal coat over the planarized mask surface. While deposition on PDMS, wax and photoresist showed good results, good metalization with photoresist required total soft bake times of 6 to 8 hours at 60°C. Without adequate baking the resist bubbled and oozed out of the planarized regions.

4. ***Patterning of metal mask:*** Patterning of the chromium mask is done on a conventional mask aligner (Quintel 7900). Shipley 1827 was spin-coated on the SLA mask and baked in a convection oven for 40 minutes. The SLA wafer was mounted on the wafer chuck and alignment and exposure were performed as with conventional silicon wafers. After a short bake at 60°C, the chromium was etched using a commercial chromium etchant (CR-7S Chromium Etchant with Surfactant, Cyantek Corp.). A second method of patterning did not employ alignment at all. Most of the SLA samples planarized with photoresist showed some of depression through the hole regions. A thick coat of AZ4620 was spun on these samples and soft baked for 6 hours at 60°C. The sample was then flood exposed to ensure that the resist was not completely exposed in the depressed regions. Thus we were able to patterning the resist without using the aligner. After this the chromium was etched to complete the chromium-patterning step.

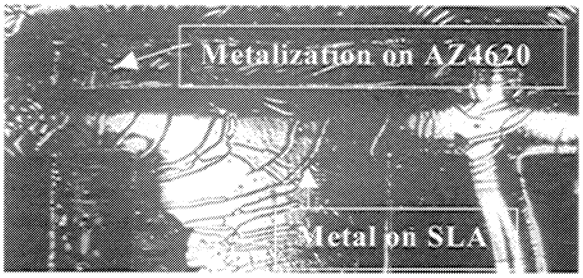

Figure 6: Metalized SLA surface planarized with AZ4620. The lower left corner shows resists that has bubbled due to sputtering

5. ***Alignment and bonding:*** Alignment is performed on a mask-aligner by fixing the SLA mask on the mask-holder and placing this in place of the maskplate. The silicon wafer in spin-coated with SL5510 (15-27µm) and aligned using a large alignment gap (100µm- 800µm). After alignment the SLA mask and silicon wafer/die are brought into contact and exposed (365nm, 12,000mJ/cm$^2$). The adhesion in this process was found to be excellent.

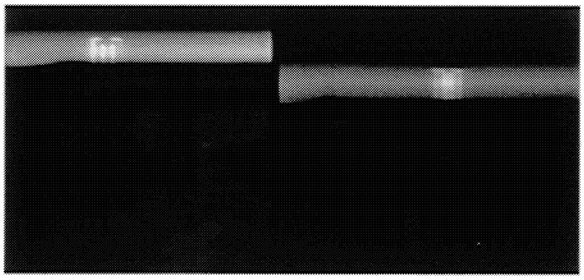

Figure 7: Alignment in left and right cameras of aligner: Cantilevers (see fig. 1) can be seen through the SLA mask

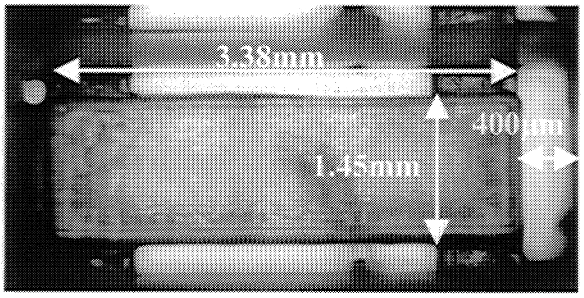

Figure 8 Alignment of gold pads with SLA: The translucent nature of resin allows for optical alignment with gold pads in the silicon substrate.

## 3 EXPERIMENTAL RESULTS AND DISCUSSION

We have been able to show the feasibility of alignment on the mask aligner and integration of the SLA and microfabrication regimes. The process of alignment is no more difficult than conventional alignment and accuracy of alignment was much higher and more controlled (fig. 7) compared to that obtainable by previous methods. However we were unable to achieve selective bonding in the manner desired. The chromium-patterning step did not work well. Chromium was chosen as a mask material not only for its high opacity and ease of etch but also for its good adhesion to polymers. However the adhesion of chromium to photoresist was found to be suspect. Some samples had regions where the chromium membrane over the non-bonding regions held however this was not uniform.

Several issues need to be addressed to improve the proposed method:
***Material Properties:*** Most stereolithographic photopolymer have low glass transition temperatures and high susceptibility to damage in conventional organic solvents (chloroform, acetone, etc.). These proved to be the prime hurdles to successful implementation of this method. While the photopolymer used for the initial experiments (SL5510) was more resistant to these effects, the last few were performed with DSM Somos Waterclear 10120 which was not quite as effective and showed greater thermal distortion and lower resistance chemical processing. Some samples at the end of processing showed a perceptible surface curvature that rendered them useless for purposes of alignment.
***Mask design:*** The metal layer was based on the four-point probe masks and thermal distortion effects were not considered. Finite element modeling could help improve the design.
***Choice of planarizing agent:*** A wider selection of planarizing agents needs to be sampled. While photoresist seems the best option with ease of application and removal the processing was both tedious and detrimental to the SLA mask.

## 4 CONCLUSION

A technique of stereolithographic alignment for MEMS structures has been reported. While good alignment was shown, selective bonding of SLA and silicon has not be achieved at the present time. The questions plaguing this method are related, as has been indicated, to choice of stereolithographic photopolymer, mechanical design and planarizing techniques. While the process in still in need of more work in the areas mentioned, we were able to show a superior method of alignment than possible before. Also if the said issued were to be resolved this would imply that conventional MEMS fabrication could move to creation of more complex and packaged devices and from a serial mode of manufacture to a parallel manufacturing scheme wherein the microfabrication and SLA could be processed in parallel till the actual integration step.

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