Advanced Lithography for High Aspect Ratio MEMS Technology

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Abstract- **MEMS (Micro-electrical Mechanical Systems) devices require thick and high aspect ratio film processing for their novel microstructures. The development of high-aspect-ratio processing, in which the vertical dimensions can be large compared to the lateral dimensions, has made it possible to move from planar to three-dimensional micromechanical structures. High aspect ratio microstructures can be fabricated by deep x-ray lithography, energy beams and physical cutting tools, and replication in metals, plastics, and ceramics. This paper investigated fabrication methods for high aspect ratio microstructures.**

I. INTRODUCTION

HARMST (High Aspect-Ratio MicroStructure Technology) is a common word to classify this technology. Common techniques for fabricating HARMST include LIGA, LIGA-like, and deep reactive ion etching (DRIE) process. The following sections describe the high aspect ratio processes very briefly.

II. LIGA

The most well known application of HARMST technology is the LIGA process shown in Fig 1.

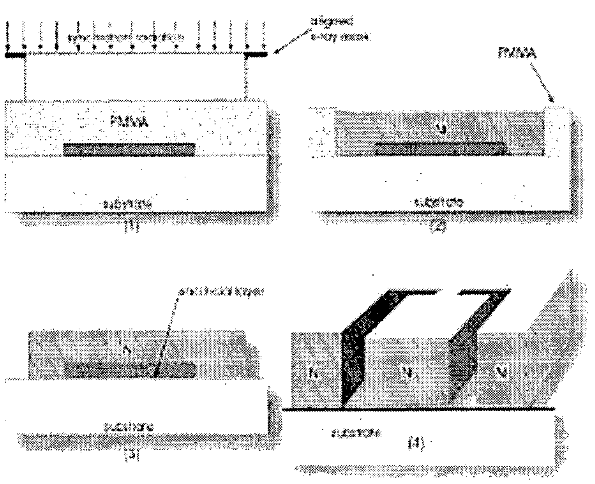

Fig 1. Schematic drawing of the LIGA process flow with a sacrificial layer that is removed at the end of the process to form both fixed and suspended microstructures [2].

The LIGA process was initially developed in the late 1970s at Forschungszentrum Karlsruhe (KfK, now FZK). LIGA is a German acronym for lithography with synchrotron radiation (LI), electroplating (G, Galvanoformung), and molding (A, Abformung).

In this process, hard X-rays from a synchrotron source expose a thick PMMA (polymethylmethacrylate) resist layer (up to millimeters thick). Once developed, the resulting structure may then be plated. Finally the resist is removed to leave a free standing metal master. This micromachined metal master may then be used for the injection molding of plastic parts [1]. LIGA process provides very high aspect ratio structures (>100:1) but it has limited uses due to high fabrication costs and access to a high energy X-ray synchrotron source. In its place a number of LIGA-like technologies have arisen including deep RIE etching and UV light based (UV LIGA) high aspect ratio resist processes.

III. AUTOMATED SU-8 PROCESS

Another method for producing high aspect ratio structures is the use of SU-8, a negative tone EPON epoxy based resin photoresist, developed by IBM and commercially available by MicroChem Corp. (MCC) as well as Soitec Microsystem. In this paper, SU-8 produced by MCC was investigated. Table 1 shows the grades determined by the percent of solids with respect to the solvent. The process details for spin curve, pre-exposure bake, and exposure dose were developed in EV150 and EV640 mask aligner.

Table 1. SU-8 grade

SU-8	%Solids	Viscosity (cSt)	Thickness (μm) at 900 rpm
5	51.8	265	12
10	59.1	989	30
25	63.3	2646	58
50	69.1	14953	150
100	72.9	52407	320

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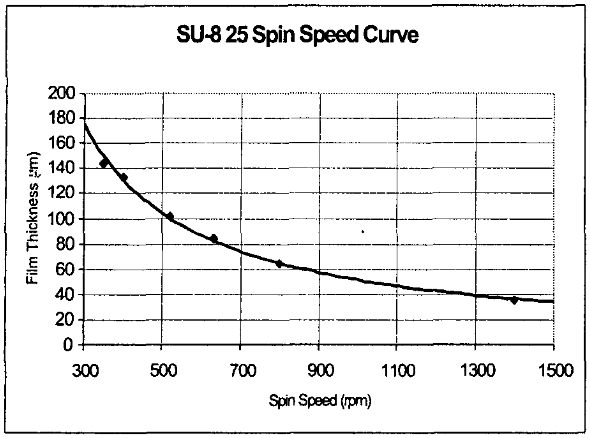

Fig 2. SU-8 25 Spin Speed Curve

A. Resist Spin Curve

SU-8 can be spun in thickness ranges as determined by viscosity. Fig 2 shows the spin curve for SU-8 25. This data from EV Group experimentation was performed on the EV150 production coating and the EV640 exposure systems. Resist thickness measurements were made on a TENCOR P1 Long Scan Profiler instrument and a VEECO Wyko NT-2000 depending on SU-8 resist thickness. Static dispense is the preferred method of resist application, in amounts of 3mL for 4" and 6mL for 6" wafers. As a rule of thumb, we used 1mL of SU-8 per inch diameter of the wafer to be coated.

SU-8 does benefit from being spun in an enclosed bowl, as do thick positive photoresists. A programmable resist bowl cover lid is on the EV150 resist coater system facilitates the coating of thick resists.

B. Pre-Exposure Bake

Baking is necessary for removing solvent from the resist layer after spin coating. The pre-exposure bake was performed at 95°C for a time determined by the graph in Figure 8. To keep internal stresses to a minimum, an initial bake at 65-70°C for around 3 minutes was performed prior to pre-exposure bake

C. Exposure

Exposure to UV light promotes cross-linking of the SU-8 negative photoresist. The exposure was performed on a broadband UV 350 – 450nm mask aligner using the intensity value measured on the 365nm-spectrum line to calculate an exposure time.

D. Post-Exposure Bake

Post-exposure baking is best performed on a hot plate. Typically, a post-exposure bake is performed at either 95°C or 200°C. A 15 minute bake at 95°C is used for high aspect ratio patterning of SU-8 films. Post-exposure baking at 200°C continues the polymerization process and results in a very hard material, typically used as a final product. High temperature post-exposure bakes harden the resist to a point where it can withstand most metal etchants and solvents. To minimize internal film stresses, an intermediate bake is performed at 75°C for around 3 minutes before allowing the wafers to cool to room temperature. The EV150 coating systems can automatically perform this annealing step since each of the system hotplates can be programmed to different setpoint temperatures.

E. Develop

SU-8 can be developed in the same solvent used to dilute the original epoxy resin. PGMEA (propylene glycol methyl ether acetate) is used for this purpose.

Fig 3. shows an SEM photomicrograph of SU-8 free-standing structures in 100 microns of SU-8, processed at EV Group (EVG). The SU-8, with a viscosity of 2646 cSt, was coated on a silicon substrate spun at 600 RPM for 15 sec on the EV150 Automated Resist Coater. Exposure was performed on the EV640 Mask Aligner using broadband illumination (350 - 450nm) with a dose of 350 mJ/cm^2. The process

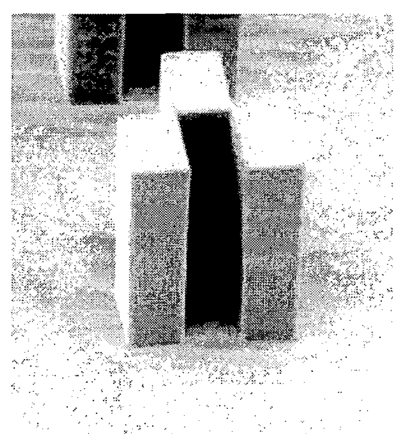

Fig 3. SEM photomicrograph of 100 micron tall freestanding structures from a single SU-8 coat. The SU-8 photoresist was processed on the EV150 automated resist coating system and the EV640 production mask aligner.

High aspect ratios in thick SU-8 films with smooth vertical sidewalls are shown by the cross-sectional SEM in Fig 3. and Fig 4. using EVG lithography systems. Some of these applications include microfluidics, ink jet nozzles, micro-molds and LIGA-type processes.

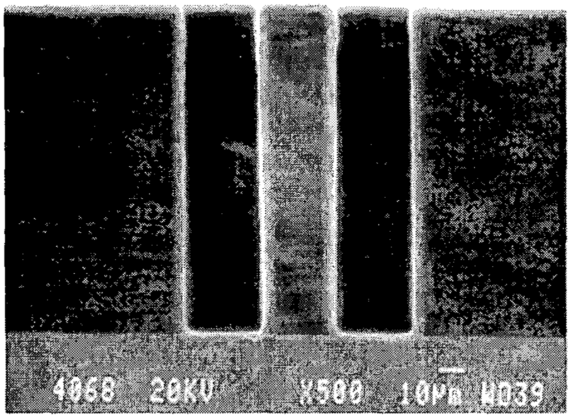

Fig 4. SEM photomicrograph of an SU-8 photoresist image showing smooth, near vertical sidewall resist profile with a 5:1 aspect ratio.

Deep Reactive Ion Etching (DRIE) Process

An elaborate process characterization study has recently been published on deep RIE technology by the micromachining group at MIT draper laboratory[3]. An excellent example of a high volume HARMST MEMS is the gyro sensor developed by Delphi-Delco shown in Fig 5.

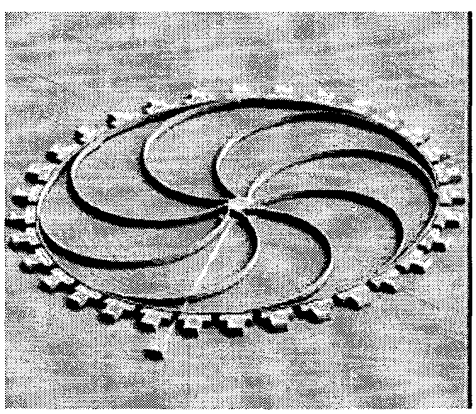

Figure 4. The Delphi-Delco CMOS integrated single-chip surface micromachined angular rate sensor (Photo courtesy of Delphi-Delco, Kokomo, IN.

IV. CONCLUSIONS

While there have been many accomplishments towards making HARMST processes as economically viable as integrated circuit processes, much work still to be done. Clearly SU-8 fills in this hole at a certain extent.Because of the great variety of devices, and device processing steps, that exist today, some changes have had to occur in the field of photolithograpy. Fortunately, manufacturers have been able to answer these demands with a variety of materials and equipment. The combination of resist processing equipment and thick resist could explore this technology economically viable in future.

REFERENCES

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