Investigation into the use of SU8 in High Aspect Ratio Applications

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Abstract—**The objective for this project was to investigate the feasibility of making high aspect ratio SU8 structures via contact lithography with a target of 10:1 and line width resolution of about 2μm. Factors investigated include exposure dose of 150mJ/cm^2, 200mJ/cm^2, 250mJ/cm^2 and PEB times of 1.5min, 3min and 4.5min. The responses were line width CD and sidewall angle. The approach was first to optimize the thickness of the resist coated. This was done by generating a spin speed curve for the SU8 formulation used. Secondly, was to optimize the line width CD. A 3^2 full factorial experiment was performed. From earlier screening experiments, the center point treatment combination was using a dose of 200mJ/cm^2, and PEB time of 3min. Statistical analysis showed a large residual error in the response data and thus unexplained variation in the process as it pertains to controlling line width CD and sidewall angle. The treatment combination with the smallest 8μm line width was dose of 200 mJ/cm^2, PEB time of 1.5min and the measured feature width was 7.1μm to give an aspect ratio of approximately 3:1. Across all treatment combinations, dose of 250mJ/cm^2, PEB time of 4.5min gave the smallest line width CD resolved with a CD of 5.1μm giving approximately 4:1 aspect ratio.**

Index Terms— **Aspect ratio, contact lithography, line width CD, PEB time**

I. INTRODUCTION

While SU8 high aspect ratio capabilities are well-known and studied along with the processing challenges it presents, certain applications of those high aspect ratio structures require that critical dimensions be kept to a minimum to improve the packing density on a device surface. Prior to the undertaking of this project, some experimental lithographic work had been done in the RIT's Semiconductor and Microsystems fabrication Laboratory using SU8 photoresist. The best resolved line CD from the results has been about 6μm obtained from initial resist coat thicknesses of less than 10μm, as determined by the SU8 formulation used. This study attempts to establish a repeatable SMFL process for achieving better than 6μm line width resolution with the added challenge of repeatably resolving less than 6μm line width CD from resist thicknesses of about 20μm.

Two key lithographic parameters that are critical when imaging with chemically amplified photoresist are the exposure step and the post exposure bake due to the determinant chemical reactions that are activated by those steps. The study investigated, through a design of experiment, the effects of varying the abovementioned lithographic parameters on the ultimate objective of achieving high aspect ratio SU8 structures.

II. THEORY

SU8 is an epoxy-based, chemically amplified, negative, i-line that is highly transparent outside of the UV range. As a thick-coating photoresist, it is used to make high aspect ratio structures with near vertical sidewalls, sometimes exceeding 50:1 in dimensions, and is widely employed in the area of MEMS, with applications in areas such as microfluidics. After the epoxy-based resin has been crosslinked, SU8 is extremely stable at high temperatures and very resistant to harsh chemical treatment, hence its use sometimes as a permanent part of devices in the abovementioned applications. As a chemically amplified resist, it has 3 components namely, a photoinitiator that produces the photoacid upon appropriate exposure, an acid hardening resin and a solvent system which, for the improved SU8 formulation used, is mainly an aromatic solvent called cyclopentanone.

The exposure process of a chemically amplified resist has what could be considered two critical chemical reactions, namely photoacid generation, when the onium salts photoinitiator component is irradiated, and PEB step where the determinant chemical reaction between the photogenerated acid and the resin matrix results in the crosslinking or hardening of the resin.

III. EXPERIMENTAL PROCEDURE

The experiment approach was first to verify that the desired resist coat thickness was consistently achievable under the experimental conditions. The measurement could not be performed until after the hard bake step due to the limitation of available optical tools in measuring exceedingly thick films, i.e. > 5μm. Because the resist was measured post-process, there was a possibility of thickness loss before measurement that had to be quantified. A spin speed vs. thickness curve was generated for 1000RPM, 1500RPM, 2000RPM and 2500RPM. (See fig. 1 for spin speed vs. thickness table and curve)

RPM	Thickness (μm)
1000	20.3
1500	15.7
2000	12.5
2500	11.0

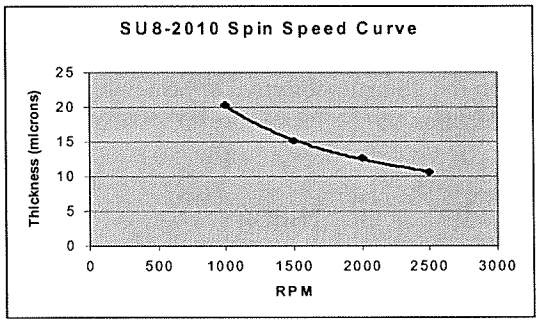

Fig.1: Spin speed versus thickness curve

To start processing, the wafers were RCA cleaned to remove surface particulates thus promote resist adhesion and then dehydration baked at 200°C for 5min on Fairweather hotplates. The resist was then hand coated using the SCS spin coater by first using a 5 sec spread cycle at 500RPM and then ramping to the designated speed of 1000RPM for the experiment. Both soft bake and the ensuing post exposure bake were two step bakes at 65°C and 95°C, to minimize the effects of thermal cracking on imaged features. The soft bake step was at 65°C for 2min and 95°C for 5min. The lithography requirements included ETM 1X photomask for imaging on the Karl Suss contact aligner. Exposure was performed on the Karl Suss contact aligner with i-line filter in place. The measured irradiance from the lamp for calculating sample exposure dose was 1.7mW/cm^2 for samples 1 through 5 and 1.4mW/cm^2 for samples 6 through 9. The post exposure bake step was at 65°C for 0.5min and 95°C for 1min, 65°C for 1min and 95°C for 2min, and 65°C for 1.5min and 95°C for 3min correspondingly (See fig. 2 for treatment combination table). Development was done by puddle method and by agitated immersion in SU-8 developer, PGMEA for 3min. Hard bake was performed at 150°C for 7min. The aforementioned process steps used the MicroChem recommended processing step parameters and procedures as a baseline. Inspection of developed features was performed via SEM analysis for line width CD and sidewall angles, step height profilometry for resist thickness and optical microscopy for visual inspection of features.

Sample#	Dose (mJ/cm^2)	Total PEB time (min)
1	200	3
2	250	4.5
3	150	1.5
4	250	1.5
5	200	1.5
6	150	4.5
7	200	4.5
8	250	3
9	150	3

Fig.2: Treatment combination table

IV. RESULTS AND ANALYSIS

The average resist thickness at the designated spin speed of 1000 RPM across the 9 samples measured via step height profilometry was 18.7 ± 0.9 μm. Figure 3 shows the different treatment combination and the corresponding responses data. According to Microchem's Dose versus Resist thickness graph and as confirmed by earlier screening experiment, the center point treatment combination was using a dose of 200mJ/cm^2, and PEB time of 3 min. From the 3^2 full factorial experiment centered on the above treatment combination, statistical analysis showed a large residual error and thus unexplained variation in the process as it pertains to controlling line width CD. Statistical analysis of the sidewall response to the factors also showed a large residual error and thus unexplained variation in the process as it pertains to controlling the sidewall angle.

FACTORS		RESPONSES		
Dose [mJ//cm2]	PEB time [min]	8 micron line CD [µm]	Sidewall angle [°]	Minimum line CD resolved [µm]
150	1.5	11.8	91	8*
200	1.5	7.1	92	6*
250	1.5	8.1	91.5	6*
150	3	8.7	92.5	6
200	3	8.6	99.5	8
250	3	7.3	91.5	5
150	4.5	7.9	92.5	6
200	4.5	7.4	92.5	4*
250	4.5	8.3	92	6

Fig. 3. Treatment combinations and corresponding response data

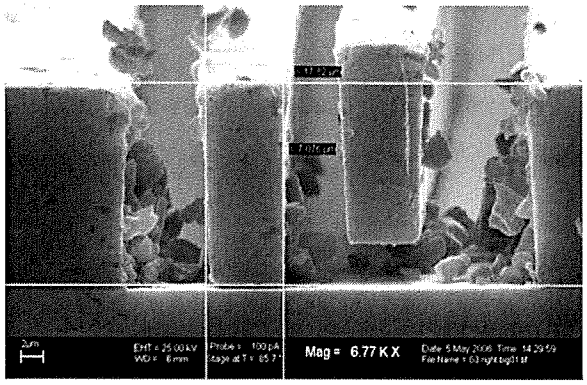

Fig. 4 SEM micrograph of best aspect ratio of approximately 3:1 using 8µm line width CD

Looking at the 8 micron line width CD which was the minimum line CD resolved across all treatment combinations, the treatment combination with the smallest 8 micron CD was dose of 200 mJ/cm^2, PEB time of 1.5 min and the measured feature width was 7.1 microns to give an aspect ratio of approximately 3:1(see Figure 3 for SEM micrograph).

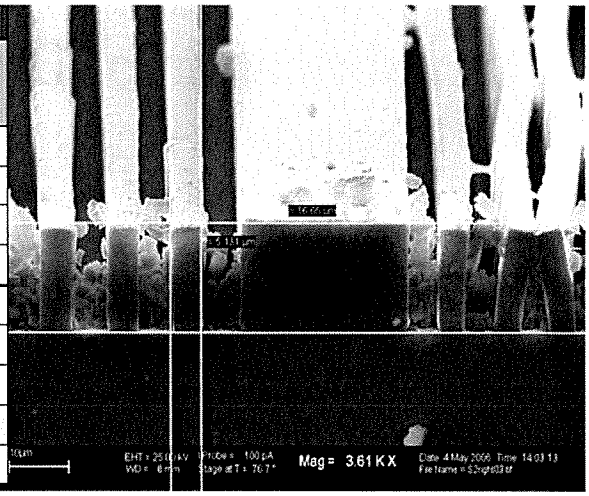

Fig. 5 SEM micrograph of best aspect ratio of approximately 4:1 using 6µm line width CD.

Across all treatment combinations, dose of 250 mJ/cm^2, PEB time of 4.5 min gave the smallest line width CD resolved with a CD of 5.1 microns giving approximately 4:1 aspect ratio (see Figure 5 for SEM micrograph)

V. CONCLUSIONS

The project's target was to image SU8 structures with aspect ratio was 10:1 with line width CD of 1 to 2µm. The best aspect ratio yielded: was approximately 4:1 with a minimum line width CD of 4µm. Due to the large residual errors in the statistically analyzed response data, further study is needed to identify and control the source of variability in the process and hence reduce source of residual error in the process.

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