Characterization of Photoresist Processing by Statistical Design of Experiment (DOE)

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Abstract- SU-8 is a epoxy based photoresist designed for MEMS applications, where a thick, chemically and thermally stable image is desired. But SU-8 has proven to be very sensitive to variation in processing variables and hence difficult to use in the fabrication of useful structures. In this paper, negative SU-8 photoresist processed has been characterized in terms of delamination. Based on a full factorial designed experiment. Employing the design of experiment (DOE), a process parameter is established, and analyzing of full factorial design is generated to investigate degree of delamination associated with three process parameters: post exposure bake (PEB) temperature, PEB time, and exposure energy. These results identify acceptable ranges of the three process variables to avoid delamination of SU-8 film, which in turn might lead to potential defects in MEMS device fabrication.

***Keyword*:** SU-8, Post Exposure Bake (PEB), Statistical Design of Experiment (DOE)

1. INTRODUCTION

SU-8 is a high contrast, epoxy based photoresist designed for micromachining and other microelectronic applications, where a thick, chemically and thermally stable image is desired. It is non-conductivity and so can be used as a dielectric in electroplating. Thus, potentially, SU-8 has many of the advantages of the other thick film techniques, and few of their specific disadvantages. For these reasons, it has been widely used by MEMS devices.

Despite the advantages of SU-8, Thick layers of SU-8 experienced more stress, and the structures tended to delaminate more quickly than thin layers [1]. SU-8 has proven to be very sensitive to variation in processing variables and hence difficult to use in the fabrication of useful structures. The literature describes wide variation in values for processing parameters which reflects the different SU-8 recipes used [2]. Therefore, this paper investigates the variation of SU-8 processing, with the ultimate goal of minimizing delamination, using statistical design of experiment (DOE).

2. EXPERIMENT

2.1 Statistical designed experiment

The traditional method of collecting large quantities of data by holding each factor constant in turn until all possibilities have been tested is an approach that quickly becomes impossible as the number of factors increases. Statistical experimental design is a systematic and efficient alternative methodology for characterization and modeling using a relatively small number of experiments [3].

Full factorial experiments are suitable when there are many factors of interest in an experiment. The perfect experimental design is a full factorial, with replications, that is conducted in a random manner. The number of treatment conditions is determined by:

$$TC = k^n \quad (1)$$

where TC is the number of treatment conditions, k is the number of levels, and n is number of factors. However, a good experiment must be efficient. If the experiment is conducted on production equipment with lengthy setup times, full factorial design may be in efficient [4].

In this paper, three input factors with three level of each were considered, and they are exposure energy, and post exposure baking (PEB) temperature/time. Since cross-linking takes place after exposure, the variables in the soft baking step were later omitted. Instead, the soft baking step was performed in a consistent manner for all samples.

2.2 Fabrication

SU-8 was spin coated on 4 inch silicon wafers to a thickness of 100μm, and the samples were soft baked at 70 ℃ on a hot plate to drive off solvents. Based on the designed experiment, all possible orthogonal combinations of three parameters were applied. All samples were developed for a fixed time, and the degree of delamination was measured. The degree of delamination was quantified by the following expression:

$$Delamination = \left(\frac{(L-l)}{L}\right) \times 100(\%) \quad (2)$$

where L is the length of the original bar pattern, and l is the length of bar pattern that remained on substrate (see

Figure 1). To minimize measurement error, l was averaged over eight bar patterns in one location.

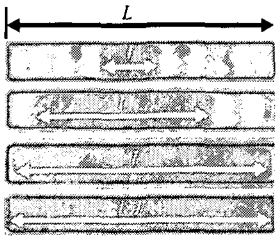

Figure 1. Different degrees of delamination.

3. RESULT AND DISCUSSION

The ANOVA table of the general linear model is presented in Table 3. We have confirmed that the main effects exist in Figure 3. and relationships between each parameter and delamination were identified. In terms of interactions, two way interactions exist in this experiment. Figure 4 shows the interactions of three parameters. The lines are not parallel, there is an interaction between these factors that influences the measured delamination.

Table 1. ANOVA table for the general linear model.

Source	DF	Seq SS	Adj MS	F	P
Exposure energy	2	2881.3	1440.6	2.96	0.090
PEB temperature	2	10688.2	5344.1	1098	0.002
PEB time	2	2153.6	1076.8	2.21	0.152
Exposure energy*PEB temperature	4	6154.0	1538.5	3.16	0.054
PEB temperature*PEB time	4	3869.5	967.4	1.99	0.161
Error	12	5869.5	486.8		
Total	26	31588.5			

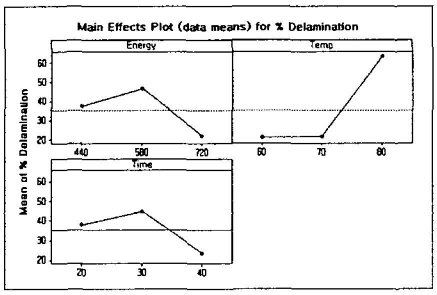

Figure 3. Main effects plot for delamination.

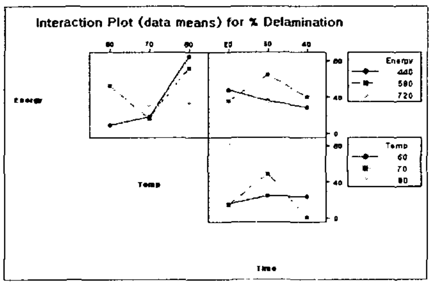

Figure 4. Interaction plot for delamination.

It is observed that the higher the temperature, the large the degree of delamination. In addition, PEB time also somewhat affects the degree of delamination at a given temperature. The shorter the PEB time, the less cross-linking, increasing the degree of delamination after a certain temperature. The high degree of delamination at temperatures above 70 ℃ is primarily due to the coefficient of thermal expansion (CTE) mismatch between SU-8 and the silicon wafer with native oxidation. As the exposure energy increases, the degree of delamination decreases, while the temperature at which the delamination starts to occur decreases. Lower exposure energy tends to decrease cross-linking of the polymer in the exposed area, and consequently, this decreases adhesion. Lake of resist adhesion leads to distorted patterns on the wafer surface. The PEB time is less than 30 minutes and the exposure energy is less than 580 mJ/cm^2, showed some degree of delamination due to incomplete cross-linking.

4. CONCLUSION

In this paper, three significant parameters associated with SU-8 delamination were investigated, and their effects on delamination determined found. Higher PEB temperatures at a fixed PEB time result in more delamination due to CTE mismatch. In addition, a greater dose of exposure energy at which cross-linking completeness to occur and decreases degree of delamination. These results identify acceptable ranges of the three process variables to avoid delamination of SU-8 film, which in turn might lead to potential defects in MEMS device fabrication.

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