IMAGE REVERSAL OPTIMIZATION AND A POSITIVE TONE LIFT-OFF PROCESS WITH AZ5214-E PHOTORESIST

Robert C. Lindstedt
5th Year Microelectronic Engineering Student
Rochester Institute of Technology

ABSTRACT

An optimum reversal process utilizing AZ5214-E photoresist has been defined with respect to profile angle along with statistical modeling of critical variables on the resulting resist profile. A novel positive tone lift-off process was also attempted with AZ5214-E with limited success.

INTRODUCTION

As semiconductor geometries approach the submicron regime, there exists the need for an imaging technique which is capable of printing submicron features with a wide process latitude and better film properties [1]. Methods that are capable of printing in the submicron range include X-ray and direct write E-beam exposure tools, high numerical aperture and shorter wavelength steppers, and image reversal techniques of positive working photoresists. With the exception of image reversal techniques, all the methods mentioned involve using an exposure tool that is not commonly found in high volume semiconductor manufacturing. Image reversal techniques have the advantage over conventional positive resist schemes in that they exhibit greater resolution, a wider process latitude, higher thermal stability, and higher contrasts [1],[2],[3]. These benefits are however at the expense of increased processing time due to the steps necessary to obtain a reversed image.

Early image reversal techniques were not manufacturable due to the increased number of processing steps significantly impacting device throughput. The reversal method fitting this category involves treating a positive working photoresist with heat and an alkali amine after the normal exposure step. The exposed regions form indene carboxylic acid and when treated with the amine in the presence of heat form indene, which is insoluble in aqueous base and photofunctionally inactive. The unexposed regions are not affected by the amine, and a subsequent blanket exposure converts the photoactive compound to the aqueous base soluble indene-carboxylic acid. Development in an aqueous base solution removes the indene carboxylic acid, leaving the initially exposed region in place [2]. The disadvantages of this approach include the increased processing steps involved with the amine treatment and flood exposure.

AZ5214 photoresist can produce a positive or negative image depending upon the processing conditions [1],[2],[3],[4]. Under normal processing conditions, the AZ5214 functions as a high resolution positive working photoresist sensitive in the near (365 - 405nm) and mid-ultraviolet (310 - 365nm) spectrums. It is also sensitive at the commonly used G-line (436nm), but a penalty in terms of photospeed must be paid [2]. In order to obtain a negative tone image it is not necessary to treat the exposed resist to an alkali amine. Two documented methods to obtain a reversed image with AZ5214 are to treat the exposed resist to a post-exposure bake (PEB) prior to development and to treat the exposed resist with a PEB and flood exposure prior to development. [1],[3]. Thus, the complexity and the time penalty of the amine step is removed from processing.

Using the above technique, the most important variables in obtaining a reversed image are the temperature of the PEB, PEB time, developer concentration and type, and development time [1]. Manipulation of these variables allows for the optimization of the reversal process. Upon exposure of the AZ5214 the photoactive compound generates a very strong acid, much stronger than conventional positive resists. The PEB causes the acid to diffuse through the resin system and causes acid catalyzed crosslinking. Submicron geometries can be obtained by controlling the amount of acid generated via exposure, and controlling the temperature and duration of the PEB [4]. A negative image is obtainable with this method, or a flood exposure before development can be added to increase the solubility of the unexposed regions. This image reversal process may be used to obtain profiles that are sufficient for metal lift-off processes. Proper selection of the variables mentioned makes it possible to obtain an image wider at the top than at the base, ideal for a lift-off technique. Figure 1 illustrates the processing steps to obtain a reversed image.

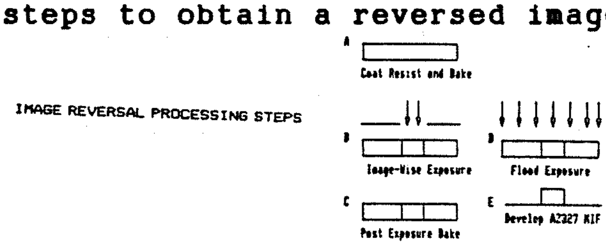

Figure 1: Image Reversal Processing Steps

AZ5214 can also be processed in the positive tone to obtain metal lift-off profiles, without any chemical treatments to modify the resists surface [4]. The use of the resist in this mode involves a novel processing approach. The steps necessary to obtain the positive tone lift-off profile are illustrated in Figure 2.

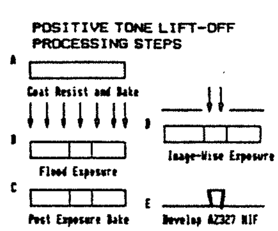

Figure 2:
Positive Tone Lift-off Process

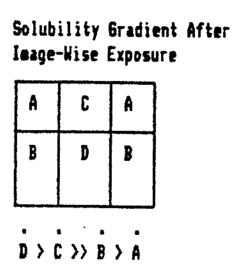

Figure 3:
Solubility Gradient

The initial flood exposure must be low enough to induce acid generation only in the upper surface of the film. A PEB then induces cross-linking at the surface, reducing the photsensitivity of the upper resist regions. A high energy image-wise exposure consequently changes the resists solubility gradient. Figure 3 illustrates the resulting solubility gradient, with the order of maximum to minimum solubility regions given by D, C, A, and B. Thus when developed, an undercut profile can be achieved.

The main objectives of this experiment were to obtain and characterize a workable image reversal process with a wide process latitude using AZ5214-E photoresist and to investigate the feasibility of using AZ5214 for metal lift-off applications.

EXPERIMENTAL

Since AZ5214 is designed for use in the wavelength range from 310 nm to 405 nm, it was necessary to expose wafers on both a GCA stepper (wavelength = 436nm) and Kaspar aligners (wavelengths 365 - 436nm) to determine the potential of using either tool. Six wafers were processed for an initial investigation. The starting wafers' substrates were silicon with 4600 angstroms of SiO_2. The wafers were prebaked and HMDS was handspun on the wafers. AZ5214-E was handcoated at 4000 RPM for 45 seconds (1.25 micron thickness) and softbaked for 60 seconds at 100 degrees Celsius on a hotplate.

An exposure test mask/reticle was used in both cases. This test mask consisted of various size line and space arrays along with test structures, such as focus stars and Murray daggers, that allow for the evaluation of imaging conditions. Three wafers were exposed on a Kaspar aligner at exposure energies of 30,45, and 60 mJ/cm2, while three wafers were exposed with the GCA 4800 stepper. The stepper exposure energies ranged from 20 to 220 mJ/cm2 utilizing an exposure matrix job program. All wafers received a Post-Exposure Bake on a hotplate at 125 degrees Celsius for 30 seconds. A 175 mJ/cm2 flood exposure was performed on the Kaspar aligners, and the wafers were developed in prediluted AZ327 MIF developer until visually clear. The PEB temperature and time were selected from literature [2].

Found in this initial investigation was that both exposure tools yielded a reversed image in the range of conditions selected. An interesting detail that was observed with the wafers exposed with the stepper was that for exposure energies below 80 mJ/cm2, no image remained after development. Since the stepper proved adequate in obtaining a reversed image, all further image-wise exposures were performed on it, while the flood exposure step was performed on the Kasper aligners because of its ease of use. The purpose of using the stepper as the exposure tool was due to its ability to yield data quicker than the aligners, and steppers of the wavelength 436 nm are commonly found in production environments.

The software package RSDiscover (RS/1) was then used to generate an Inscribed Central Composite (CCI) Experimental Design of the factors exposure energy, PEB temperature and time, and development time, with responses of resolution and resist profile angle. This design type was selected as it allows for five levels of each factor to be investigated while determining response surfaces which best model the obtained results. From this model, predictions can be made as of the effect of the variables on the selected response and also give insight on different variable combinations. The RSDiscover generated design was then ran (experimental trial runs can be found in Figure A in the appendix).

Summarized in Table 1 is the range of levels for each factor used in the design.

FACTOR NAME	RANGE	UNITS
Exposure Energy	150 to 190	mJ/cm^2
PEB Temperature	120 to 140	Degrees Celsius
PEB Time (HOTPLATE)	20 to 60	Seconds
Develop Time (AZ 327 MIF)	45 to 105	Seconds

Table 1 Variables and Ranges Investigated

Cross-sectional analysis of the resist sidewall profiles was then performed with an International Scientific Instruments scanning electron microscope. The responses of resolution and profile angle were then modeled with RSDiscover. For comparison purposes AZ5214 was processed in the positive mode and compared to the optimum condition of the reversed mode. Positive tone processing consisted of identical coating and softbaking steps as the reversal mode, with the exception of no flood exposure or PEB. For the positive mode, a focus-exposure matrix was performed on a GCA 4800 stepper, development was with Microposit 351 in a (3.5:1) solution for 3.5 minutes, and microscopic inspection yielded the maximum resolution. A Nanometrics Nanospec yielded thickness information necessary for determination of the characteristic curves for both modes.

Five wafers were processed in the positive tone lift-off mode. Table 2 illustrates the variables investigated and the levels of each.

Trial	Flood Exp. mJ/cm^2	Image-Wise Exp. mJ/cm^2	Develop Time Minutes
1	30	280	1.0
2	30	240	1.5
3	25	280	1.5
4	25	240	1.5
5	20	280	2.0

Table 2: Positive Tone Lift-Off Variables

Specific processing steps included a 40 second spin coating at 4000 RPM (1.25 micron thickness), a softbake at 95 degrees celsius for 90 seconds, a reversal bake at 115 degrees celsius for 90 seconds, and development with Microposit 351 in a dilution of (5:1). The samples were examined with the SEM to determine the processes success.

RESULTS/DISCUSSION

All combinations performed in the CCI design resulted in reversed images. Some combinations however exhibited slight under development. The reversal process was determined to resolve equal line-space pairs of approximately 2.0 microns. Resolution test structures (Murray Daggers) resolved features down to 0.7 microns, indicating submicron capability with AZ5214. Cross-sectional analysis revealed sidewall profiles exceeding 80 degrees could be obtained at the 2.0 micron level. However, no combination yielded a negatively sloped profile as as desired. Figure 4 illustrates a 2.0 micron line-space pair cross-section with a sidewall profile of approximately 82 degrees.

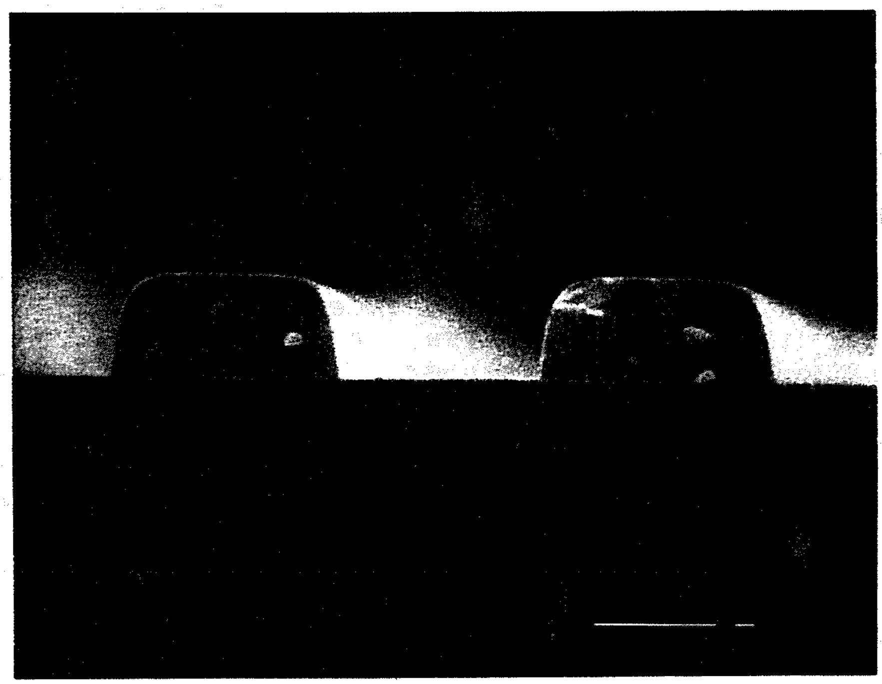

Figure 4: 2.0 micron Line/space 82 Degree Profile

The RSDiscover modeling yielded mixed results. The surface fitted to the response of sidewall profile fit extremely well with an R-squared value of 0.97. This value indicated that 97 percent of the variation exhibited in the experiment was explained by the model. The optimization function was performed for the sidewall profile angle. The greatest angle the model predicted that could be obtained was 86 degrees, which would

occur at an exposure of 168 mJ/cm2, a PEB of 126 degrees for 33 seconds, and development time of 71 seconds. Contour plots of PEB time versus temperature at the optimum exposure energy and develop time revealed that the PEB temperature could vary from 120 to 131 degrees, and the PEB time could vary from 25 to 45 seconds and still maintain profiles of 80 degrees or better. Thus there is a wide process latitude for the PEB temperature and time variables at the optimum exposure and develop time.

Inconclusive results were obtained for the response of resolution. R-squared values below 0.90 were obtained when the regression model was initially fit. Because of this, several trials were removed from the experiment to obtain a model with an acceptable R-squared value greater than 0.90. The optimization function was ran and a negative resolution value was given, which led to the conclusion that something was seriously wrong and the resolution response could not be accurately modeled from the data obtained in the experiment. Figure 5 illustrates the contour plot for the response of profile angle at the optimum exposure and development time. A three dimensional plot of the response surface may be found in Figure B of the appendix.

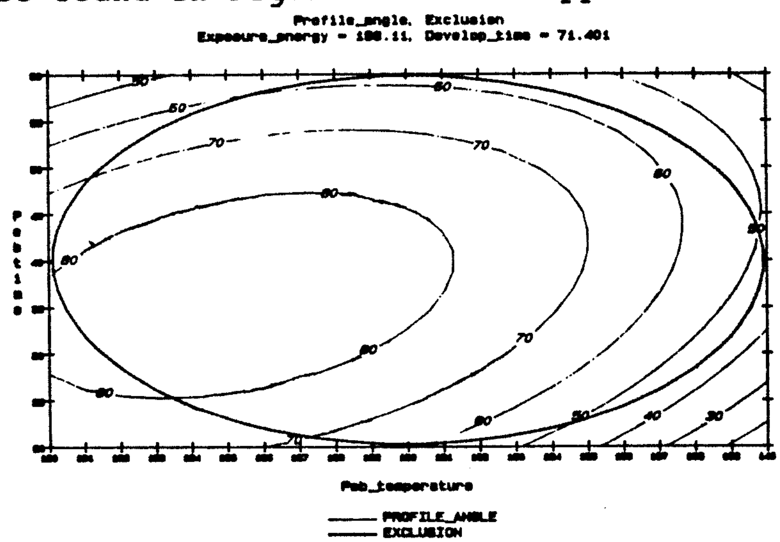

Figure 5: Contour Plot of Profile Angle Response

Table 3 illustrates the results of the comparison between the positive and reversed (negative tone) modes, with the reversal mode demonstrating superior resolution, contrast, and photospeed. The characteristic curves for both modes may be found in Figure C of the appendix.

COMPARISON OF POSITIVE AND NEGATIVE TONE (Reversal)
PROCESSES USING AZ 5214-E PHOTORESIST

Tone	Resolution in Microns	Contrast	Photospeed mJ/cm^2
Reversal	≈ 2.2	- 5.57	90.3
Positive	≈ 2.4	4.28	157.0*

Table 3: Positive/Reversal Comparison

The positive tone lift-off process was of little success. The combinations ran resulted in near vertical sidewall profiles. This leads to the conclusion that the variable combinations were not correct, or the developer type, concentration or time should have been different. However, the near vertical profiles warrants a future investigation with a stronger developer, such as AZ400K, or a stronger dilution of Microposit 351 to H2O.

CONCLUSIONS

A range of process conditions and a optimum condition for vertical profiles have been defined which result in image reversal of AZ5214-E photoresist. Resolution of 2.0 micron equal line-space pairs was obtained with resolution test structures indicating submicron capability. Resist profiles exceeding 80 degrees can also be obtained without sacrificing resolution. Variable effects were successfully modeled on the response of resist profile angle with the software package RSDiscover. The reversed mode demonstrated superior resolution, contrast, and photospeed compared to the positive tone process. The positive tone lift-off experimentation exhibited vertical profiles, which are not adequate for a repeatable lift-off process.

In summary, a successful image reversal process has been defined while the use of AZ5214-E for lift-off profiles needs further experimentation.

ACKNOWLEDGMENTS

I would like to acknowlege the great amount of inputs and assistance that I received on the project from Katherine Hesler and Bruce Smith of the Microelectronic Engineering faculty and Dr. Thomas Frederick for his assistance with the SEM.

REFERENCES

[1] Marriott, V, C.M. Garza, and M. Spak, "Image Reversal: A Practical Approach to Submicron Lithography", SPIE Advances in Resist Processing and Technology, 1987.

[2] Balch, E.W., S.E. Weaver, R.J. Saia, "Characterization of a Submicron Image Reversal Process", SPIE, 1988.

[3] Spak, M., D. Mammato, S. Jain, and D. Durham, "Mechanism and Lithographic Evaluation of Image Reversal in AZ 5214 Photoresist", VII Int. Tec. Photo Polymer Con., 1985.

[4] Dunbobbin, D.R., and J. Fagnet, "Single-Step, Positive-Tone, Lift-Off Process Using AZ 5214-E Resist", 1988.