

# CHARACTERIZATION AND PROCESS DEVELOPMENT FOR THE MEBES I ELECTRON BEAM LITHOGRAPHY SYSTEM

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## ABSTRACT

Characterization of a MEBES I electron beam lithography tool was done to investigate electron beam writing errors induced by electrical and mechanical interactions of the system. Process development of SAL603 a negatively working chemically amplified resist, which is required to provide a high sensitivity repeatable resist film, was also done.

## INTRODUCTION

The move to electron beam as a viable option to optical lithography is becoming apparent as the technology approaches the optical resolution limits. These limits result from the diffraction effects as the light passes through the narrow openings in the mask. The resolution possible by optical lithography is defined by Rayleigh as:

$$\text{Resolution} = k * \text{wavelength} / \text{NA}$$

In this formula, k is a manufacturing constant usually around .5-.8 and NA is the numerical aperture of the lens system, which can be as high as .6 for state of the art systems. From this equation, optical manufacturers are forced to produce systems with larger numerical aperture lens systems that can handle shorter wavelength light. The limits of optical lithography prevent dimensions that are sub 0.5 micron. Electron beam lithography conquers these obstacles by having a wavelength that is short enough to largely remove the diffraction effects produced by optical lithography. Electron beam uses a finely focused beam of electrons and deflects the beam over a sensitive resist material to create sub-half micron images. The MEBES I is an electron beam lithography tool developed by ETEC to accomplish high resolution lithography for maskmaking and low end direct write applications.

The MEBES I has a column which consists of three electromagnetic lenses to focus the electrons as they travel down its length. These lenses can be thought of as optical lenses. The electrons are emitted from the tip of the tungsten source filament and accelerated through a 10KeV potential to give an initial trajectory down the column. A condenser lens is used to

demagnify the beam to the desired size. Between the condenser lens and the objective lens is the beam blanking aperture, which is responsible for blanking the beam off during the writing of patterns. This is done by deflecting the beam away from the aperture opening when the unexposed portions of the pattern are being written. The condenser lens controls the size and focuses the electron beam on the substrate. Figure 1 is a simple diagram showing the electron optics of a similar electron beam lithography column. The only difference is that there is only 1 condenser lens after the beam blanking aperture to focus and shape the beam.

#### ROUND BEAM INSTRUMENTS

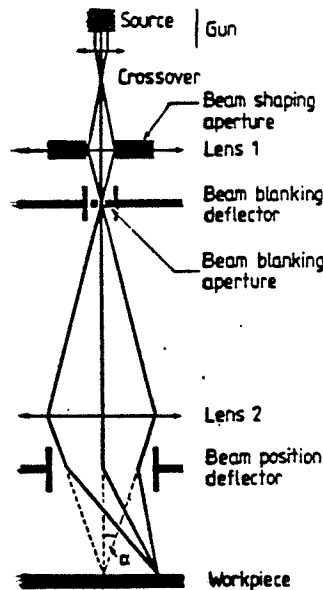
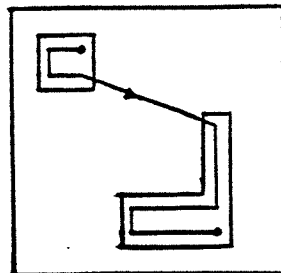


Figure 1: Simple Electron Optics Column with Two Lenses [1].

The method that the MEBES I uses to write the mask patterns is known as raster scan. This method scans the beam in the y direction and moves the stage in the x direction, blanking the beam where needed. The other method of electron beam writing is known as vector scan which directs the beam vectorially only to the areas that are to be exposed therefore saving time by avoiding the areas that do not need exposure. Figure 2 shows the two types of writing strategies.

#### • Vector



#### • Raster

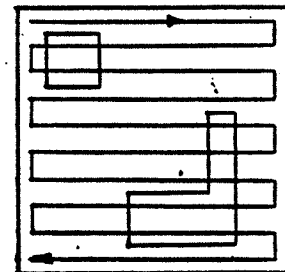


Figure 2: Possible Electron Beam Writing Strategies [1].

The resolution obtained is mostly dependent upon the resist system being used and its parameters such as sensitivity, contrast, and ability to withstand future processing. The dose that the electron beam uses to expose the resist can be determined by

$$\text{Dose} = I * t / \text{Area}$$

where  $I$  is current density,  $t$  is exposure time, and area is the scan area of the beam.

The MEBES system has a certain amount of error inherent in its writing capabilities. These errors can be induced by the stage with the x-y motors or the electron beam lens control system. The system therefore needs to be monitored on a frequent basis to determine the amount of error and to feed data back into the system so that it can correct for them. This is done by writing a set of patterns that contain structures to determine the induced error. After writing these patterns the mask is processed and inserted back into the MEBES. The MEBES is then used as a diagnostic tool to measure the error by measuring the actual location and positioning of the marks compared to the desired placement of these marks.

There are three patterns that are used to measure the error in the tool. The first is an 11x11 array of crosses placed evenly over the 5" mask. This is used to determine the mirror orthogonality which is a correction for the errors in the stage control mirrors. The second is a checkerboard structure which also determines the write scan length. This measurement determines if the electron beam is writing equal amounts in both the x and y directions. The last structure is a staircase of 126 crosses. The MEBES measures the location of each of these crosses and gives a value for write scan linearity or how linear the beam deflection is as it writes the staircase of crosses.

Process development of a chemically amplified resist. This resist is made by Shipley SAL603 with sensitivity around  $2\text{uC}/\text{cm}^2$  and has the ability to resolve submicron features. The resist is chemically amplified which requires a post exposure bake to activate the acid generated by the e-beam exposure. This activated acid will cause crosslinking in the exposed areas. This resist also has the benefit of being aqueously based instead of organic based.

## **EXPERIMENT**

For this project, one must be fluent with the various software packages that are required to be able to comfortably operate the MEBES I system. The first is called AESOP which is used to automatically or manually set the beam up to the correct the spot size and current density. This must be done each time before writing a mask. This program will adjust the lens voltages and emission currents to obtain the desired beam parameters. When the column is correctly set up, the pattern is written using the

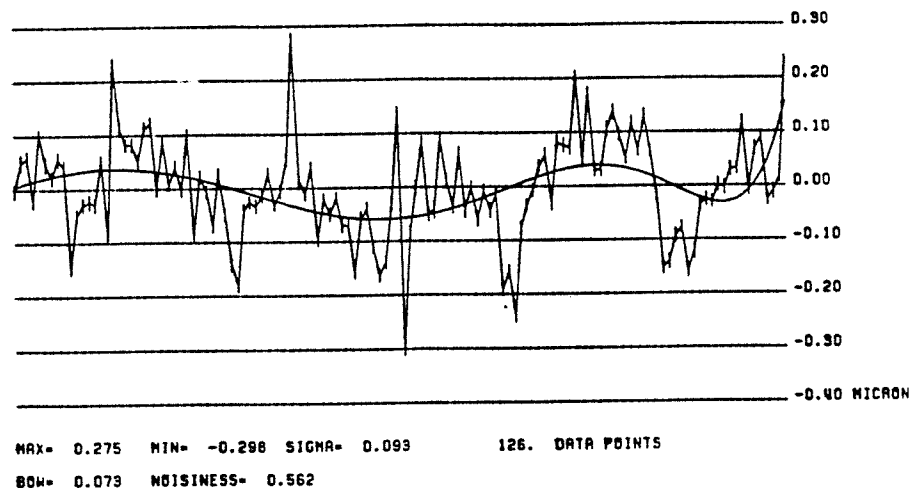
program called MEBES. As a protection, MEBES will check the job deck and check the column setup for any errors before it starts writing. To do the error measurement, the software MARKET was used to turn the MEBES into a diagnostic tool and to measure the location of resist images on the substrate.

The next step was to transfer the resist process to the negative working chemically-amplified SAL603 resist. The resist was spin coated to a thickness of about .4um and then pre-baked on the hotplate for 90 seconds at 100C. A series of line-space patterns were written with increasing doses to determine the optimum exposure dose. The optimum dose was determined to be  $2\mu\text{C}/\text{cm}^2$ . This was determined by finding the dose when the lines and spaces are of equal size for a specific dimension. This resist requires a PEB to crosslink the image by utilizing the acid catalyst formed by the exposing electron beam. This was done at 110C for 90 seconds on the hotplate. The resist was then developed using the MF321 developer for 2 minutes. The two bake steps and the dose given were found to be the most important parameters to be able to achieve high resolution.

The last portion of the project was to characterize the errors in the MEBES system using the patterns discussed in the Introduction. These patterns are resist images that have been written with the electron beam. The location of these images is measured by using the MEBES as a diagnostic tool and running a software package called MARKET. This program scans the beam over the desired location of the resist images and can therefore determine the error by finding the delta between the known and desired resist image patterns.

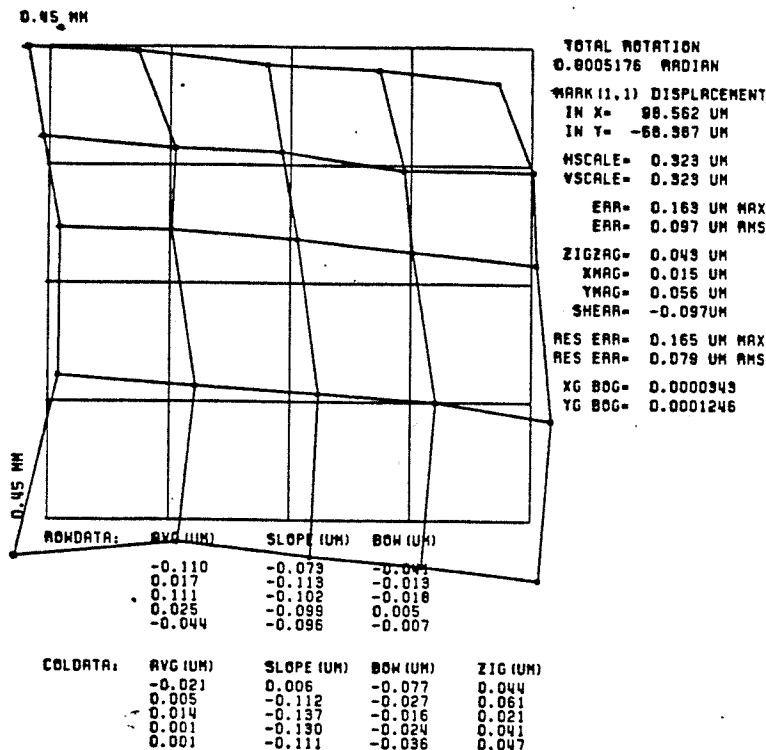
### RESULTS/DISCUSSION

The plot obtained for the staircase patterns is shown in Figure 3. This plot shows that the linearity of the electron beam deflection is  $\pm .2\mu\text{m}$  for the  $1\mu\text{m}$  spot size which is within spec for the system.



**Figure 3: MARKET results of staircase of crosses.**

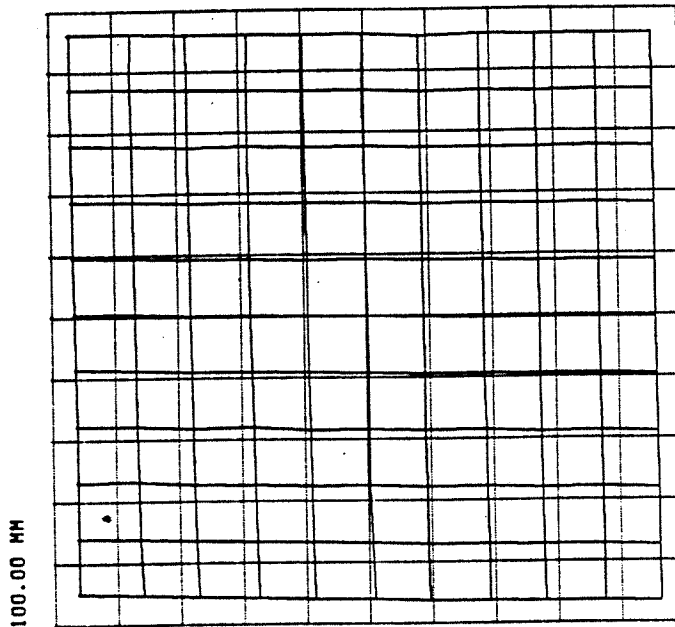
The next plot obtained is that from the checkerboard structure and is shown in Figure 4. The checkerboard structure is analyzed by measuring the location of each intersection of x and y lines composing the structure. The figure shows the desired and actual locations of the intersections of these lines. The summary shows the average deviation, slope and bow of each row and column of data points measured on the checkerboard.



**Figure 4: MARKET results of the checkerboard structure.**

The plot shown in Figure 5 is of the 11x11 array of crosses. This plot is similar to that of the checkerboard structure and but is spread out over the whole mask. This plot shows that the image is contracted with respect to the desired image. The errors in the center of the mask are under a micron but exceed a micron near the edges. The value of shear is used as feedback for the system to correct the non-orthogonality. The plot shown is for the 1 micron beam size, but the patterns are written with 1.5 and .25 micron beam sizes. Plots have been obtained of the results of those patterns as well and they show the same trends as on the 1 micron beam size writing of the pattern.

100.00 MM



TOTAL ROTATION  
-0.0044771 RADIAN  
MARK (1,1) DISPLACEMENT  
IN X= 258.249 UM  
IN Y= 639.323 UM  
HSCALE= 4.058 UM  
VSCALE= 4.058 UM  
ERR= 2.577 UM MAX  
ERR= 1.441 UM RMS  
ZIGZAG= -0.012UM  
XMAG= -3.101UM  
YMAG= -3.286UM  
SHEAR= -0.348UM  
RES ERR= 0.286 UM MAX  
RES ERR= 0.107 UM RMS

ROWDATA:	AVG (UM)	SLOPE (UM)	BOW (UM)
	1.648	-0.607	0.152
	1.305	-0.576	0.085
	0.996	-0.489	0.068
	0.649	-0.473	0.051
	0.337	-0.434	0.065
	-0.005	-0.326	0.054
	-0.332	-0.234	0.054
	-0.657	-0.204	0.041
	-0.990	-0.167	0.074
	-1.308	-0.190	0.094
	-1.642	-0.126	0.088

**Figure 5: MARKET Results From 11X11 Array**

COLDATA:	AVG (UM)	SLOPE (UM)	BOW (UM)	ZIG (UM)
	1.453	-0.341	-0.017	0.005
	1.330	-0.456	0.093	-0.033
	0.864	-0.442	0.080	-0.017
	0.680	-0.451	0.138	-0.025
	0.287	-0.407	0.072	-0.013
	0.089	-0.377	0.080	-0.008
	-0.356	-0.312	0.040	-0.010
	-0.533	-0.319	0.075	0.006
	-1.002	-0.257	0.051	-0.024
	-1.187	-0.234	0.023	-0.005
	-1.624	-0.231	0.022	-0.006

## CONCLUSION

This project has succeeded in obtaining a working negative resist process for maskmaking. Optimum resolution of the resist was obtained with 100C pre-bake, 2uC/cm\*\*2 dose, and a 110C PEB. The work in this project also investigated the method for measuring writing errors such as orthogonality, write scan length, and write scan linearity.

## ACKNOWLEDGMENTS

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## REFERENCES

- [1] Owen Geraint, "Introduction to Electron Beam Lithography," Short Course Notes in SPIE's 1991 Symposium on Microlithography
- [2] Fwdynshyn and Cronin, Vac. Sci. Technol B, 1454-1460 (Nov/Dec 1990)