Critical Dimension Analysis on the RIT Canon i-line Stepper

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Abstract - This project involved the simulation and analysis of critical dimensions (CD) using the RIT Canon 2000i1 i-line stepper. This was accomplished by optimizing the stepper parameters for specific resist feature widths. There are many tools and methods that lithography engineers have at their disposal for use in optimizing current and future lithography processes. The focus-exposure (F-E) matrix and resulting plot are integral parts of standard IC processing. It is one of the most important plots used in lithography since it demonstrates how exposure and focus work together to affect critical dimension, sidewall angle, and resist thickness loss data. This data is then analyzed to determine the process capability or useable limits for both focal depth and exposure latitude values for a given lithography process.

1. INTRODUCTION

The experiment performed focused in on three common substrates that are used in IC processing. These substrates included oxide, polysilicon on oxide and aluminum on oxide at typical thicknesses for the RIT 6" CMOS process. To begin this analysis, E_O (dose-to-clear) for each material was determined by using a full field exposure of the resist. With that data, a focus-exposure matrix was setup and run for each of the corresponding substrates to determine the optimal settings to generate 0.5μm, 0.7μm, and 1.0μm features that were then measure by a KLA-Tencor 8100XP CD SEM. The CD data was then plotted against the corresponding focus and exposure settings to create the Bossung plot, as shown in Figure 1. [1] This plot was then used to graphically represent the data for ease of analysis in determining the potential exposure latitude and focal depth needed to maintain image fidelity. With the analysis of multiple feature sizes, the optimum parameters were determined by overlapping the process windows and examining the common area, as shown in Figure 2. [2] The effects of a bottom anti-reflective coating (BARC) was also investigated to determine the amount of process improvement that was gained when revolving the same features.

Figure 1 ProDATA Focus-Exposure Matrix

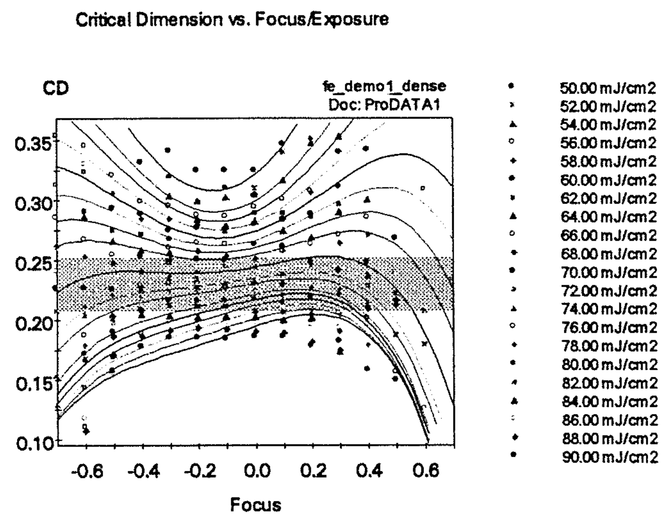
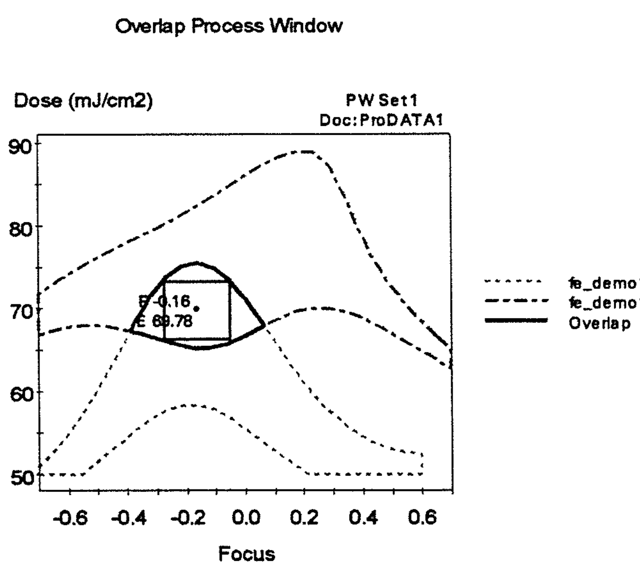


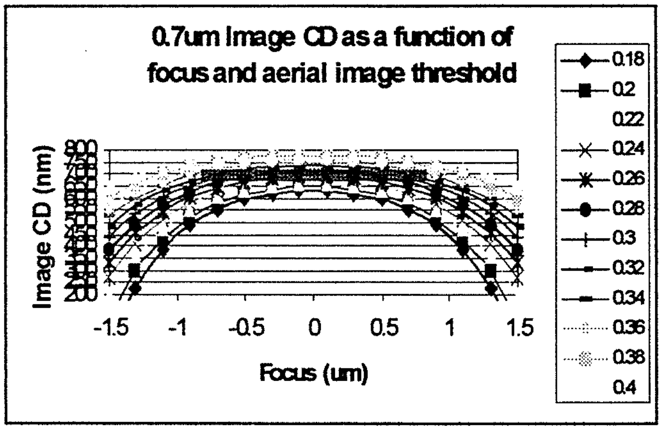
Figure 2 ProDATA Overlap Process Window



2. SIMULATIONS

Before beginning the lab portion of this experiment, the boundary conditions for focal depth and exposure latitude had to be theoretically calculated. Since no previous baseline has been performed on this process, simulations and initial lab testing was performed to determine a suitable starting point. This was accomplished with the help from the ProLITH 6.0 software package. To theoretically determine the useable focal depth, the Canon 2000i1 stepper parameters were obtained and entered into the modeling software to determine their effect on the aerial image of various feature sizes. The Figure 3 below represents the optimum aerial image for this given system and feature size. [3] From each graph of the simulated aerial image, a theoretical focal depth (TDOF) was

Figure 3 ProLITH Aerial Image CD Graph



extracted to later compare to that of the useable focal depth (UDOF) obtained from the experimental lab data. From each TDOF value the k1 factor for each feature width was calculated using Rayleigh's equation (i) and is represented in the table 1 below.

$$UDOF = k2\frac{\lambda}{NA^2} \Rightarrow k2 = \frac{UDOF \times NA^2}{\lambda} \quad \text{(i)}$$

Table 1 Simulated TDOF and k1 values

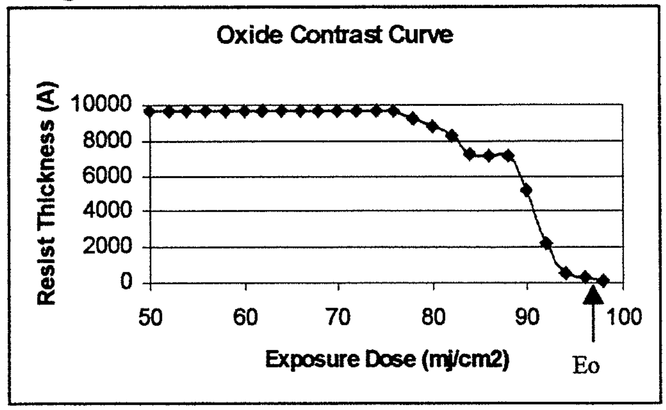
Feature Width	TDOF	k2
500nm	1.5μm	1.111
700nm	1.8μm	1.333
1000nm	3.0μm	2.222

These k1 factors were then later compared to that of the k1 factors calculated from the experimental UDOF values.

3. EXPERIMENT

Once the theoretical focal depth for each feature size was calculated, the next step of determining a minimum exposure dose or dose-to-clear (Eo) was completed. Again, due to the fact that this was a completely new and previously untested process there was no baseline to use as a reference point for the exposure dose. To begin this analysis, E_O (dose-to-clear) for each material was

Figure 4 Contrast Curve



determined by using a full field exposure of the resist for each substrate material as seen in Figure 4. Once calculated, these values were used as initial exposure doses for each of the subsequent focus-exposure matrices.

To run each of the F-E matrices, the substrate material was first grown or deposited depending upon the type needed. For this project, three substrates and one bottom anti-reflective coating were chosen for this project for their use in current RIT CMOS processing. The substrates and corresponding thickness are shown in table 2.

Table 2 Substrate Type and Thickness

Substrate Type	Target Thickness	Actual Thickness
Aluminum*	5000Å	5123Å
Oxide	1000Å	1015Å
Polysilicon*	3000Å	2943Å
BARC**	1800Å	1819Å

* *The aluminum and polysilicon substrates were deposited onto 1000Å-oxide film.*

** *The BARC thickness was chosen for the maximum i-line absorptive characteristics between 1700Å – 2000Å.*

With the E_O and TDOF range data along with substrates, each F-E matrix was then setup on the Canon stepper using the standard Canon F-E job with modified parameters for each of the substrates. The initial and increment values for both exposure and focus were setup as seen in table 3. The wafers were exposed in an 8x8 array with focus increasing by column and exposure

increasing by row. The reticle used was the standard resolution reticle that is send along with each tool. This mask has a series of resolution bars ranging from 2μm down to 0.2μm.

Table 3 F-E Parameter Settings

Substrate Type	Initial Exposure	Exposure Increment	Initial Focus	Focus Increment
Aluminum	100mj/cm^2	10mj/cm^2	-0.8μm	0.2μm
Oxide	250	10	-0.8	0.2
Polysilicon	120	10	-0.8	0.2
BARC	240	10	-0.8	0.2

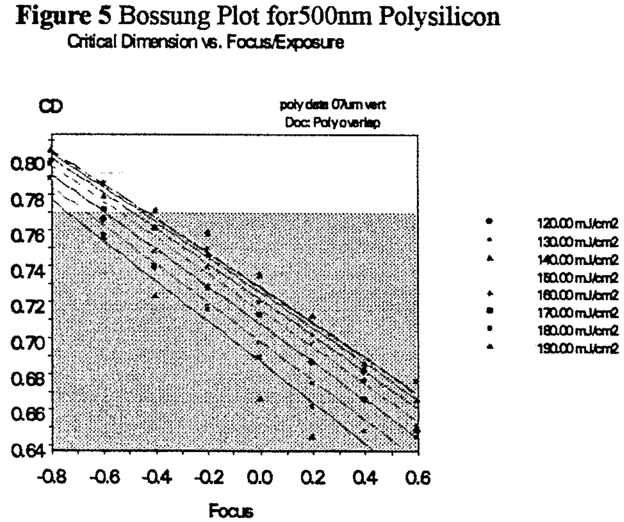
Once the wafers were exposed, each was reviewed optically for image fidelity. The wafers were then sent to KLA-Tencor, in San Jose, California for measurement on the 8100XP CD SEM using recipes setup up for this mask design previously. Returned was the raw data and images for each substrate for analysis.

The raw data was first organized into the proper input file format needed by the ProDATA software for analysis.

4. ANALYSIS

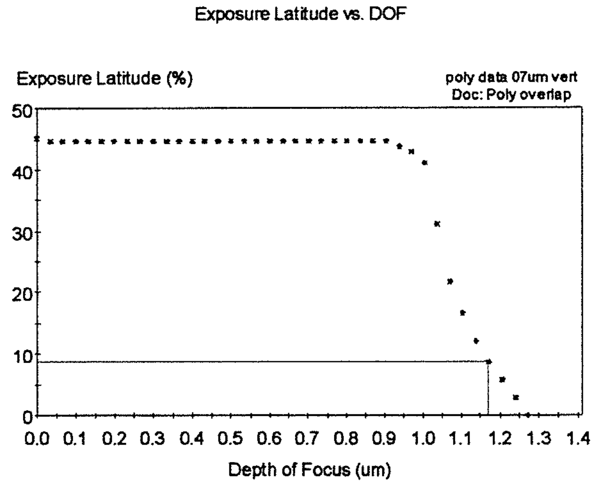
Each substrate was analyzed for the three feature sizes 500nm, 700nm, and 1000nm dense resist lines. As demonstrated earlier each set of raw data was entered into the ProDATA software for analysis. Output by this software was a contrast curve and Bossung plot for each corresponding substrate and feature as seen in Figure 5.

Figure 5 Bossung Plot for500nm Polysilicon



There was 10% exposure latitude and a 10% critical dimension tolerance set as boundary conditions for analyzing the CD data. For each Bossung plot the software analyzed the data and extracted the potential process window for exposure and focus target values as well as the useable focal depth. Depending on the strictness of a given exposure latitude will determine the useable focal depth for that same system, as seen in Figure 6. A corresponding process window was calculated for

Figure 6 Exposure Latitude Plot for 0.5um Polysilicon



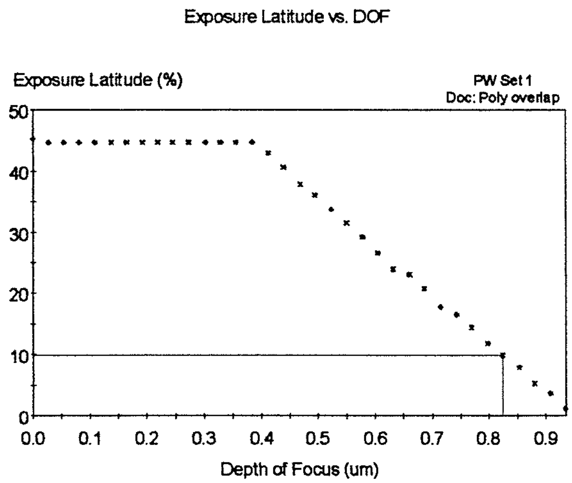
each substrate. The windows within each substrate were then overlapped to extract a common process window area. This window determined the target focus and exposure settings and useable focal depth common for all three-feature sizes, as seen in Figure 2. A second exposure latitude graph was also generated for all three features, which was analyzed similar to the Figure 6.

5. RESULTS

Each of the four substrates was analyzed using this same method above. The simulation data was analyzed first to determine an aerial image and theoretical focal depth that should be experienced by an ideal system, These values were calculated by hand on each of the simulated aerial image plots. The resulting Bossung plots that were produced from the experimental data did not seem to demonstrate the standard format for a Bossung plot as in the simulations. Each plot seemed to be only a section of the whole plot, which lead to an error that was made. Unfortunately, this error was made and the focal ranges were underestimated when calculated. Even with this issue, the plots still demonstrated a range of CD values above and below the CD tolerance, which was desired for analysis.

The polysilicon was the first set of CD data that was entered into ProDATA. Each of the three Bossung plots demonstrated a similar trend with the CD data, which seemed to show early on that the chosen focal range was not large enough. This same point was reiterated in the exposure latitude graph as seen in Figure 7.

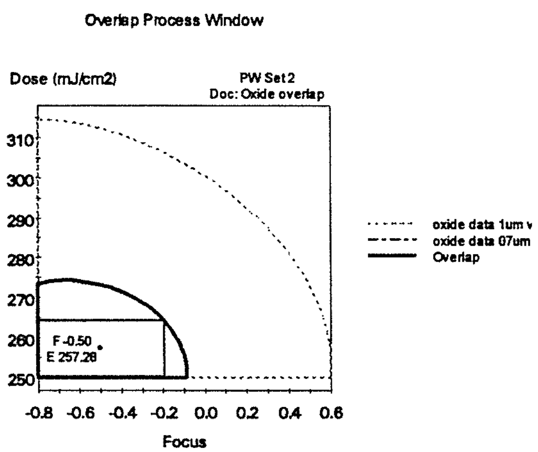
Figure 7 Exposure Latitude Plot for all Polysilicon Features



Therefore, the focal depth for many of the Bossung plots showed the same pattern.

The next CD data set analyzed was the oxide substrate. The focal range for this material showed an improved spread in CD data, though not the complete range. The limiting feature showed to be the 0.5μm feature. There was a large decrease in the process window when compared to the 1.0μm and 0.7μm window as seen in Figure 8.

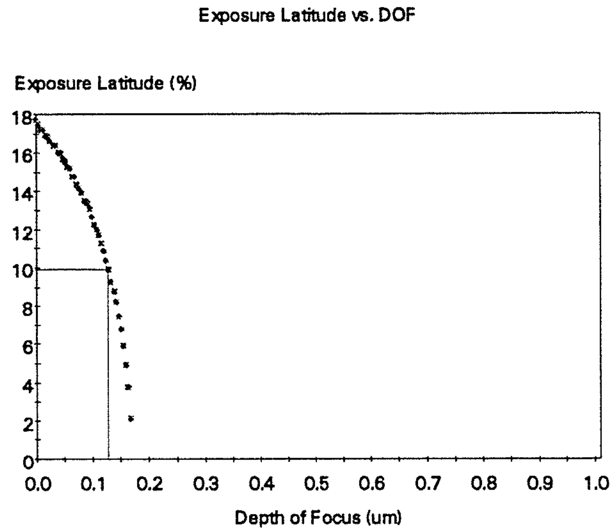
Figure 8 Oxide Process Window



Again, the resulting useable focal depth for this substrate was much lower than the expected when compared to the simulation focal depth.

The sputtered aluminum substrate was difficult to analyze due to the absence of the 0.5μm and 0.7μm resist features at all focus settings. As seen in figure 9, even with the 1.0μm feature there was a unusually low UDOF at 0.15μm, which varied from the usual 2.5-3.0μm that is normally witnessed. Both of these issues were explained by the overexposure of the resist and the high reflectivity.

Figure 9 Aluminum Focal Depth



The final substrate that was analyzed for this experiment was the Brewers Science Inc. i-line BARC material. This material was coated to a thickness of 1800Å to utilize the optimum absorbing properties of the BARC. With such a high absorbing material, the exposure dose was increased to have complete resist exposure. The CD data, unfortunately, did not demonstrate the resolution enhancing properties that were expected in this experiment. The focal depth of oxide, also a high absorbing material, was greater than that of the BARC as seen in Figure 10. Therefore, the CD data had the effects of an unknown factor that skewed the data.

Figure 10 BARC Focal Depth

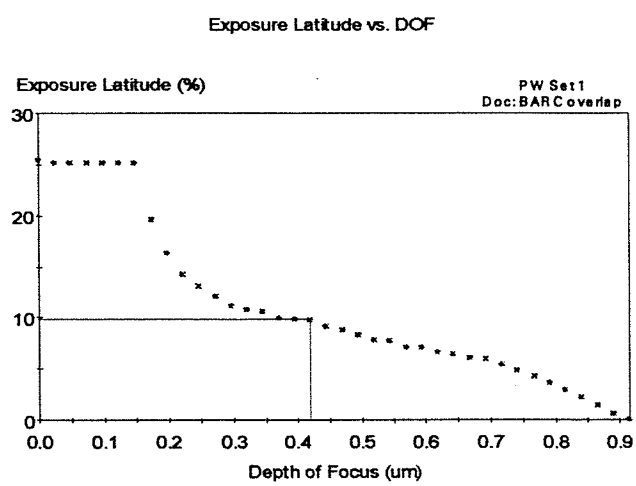


Table 4 Resulting Target Focus/Exposure, and Focal Depth Setting

Substrate Type	Target Exposure	Target Focus	UDOF
Aluminum	237	-0.54	0.15
Oxide	257	-0.54	0.60
Polysilicon	152	0.1	0.85
BARC	295	-0.59	0.42

When comparing process window for different substrates, the optimum parameter settings varied greatly for exposure and focus as seen in Table 4. This characteristic was related to the difference in the reflectivity of each substrate. Oxide and BARC, both highly absorptive, required a higher exposure dose when compared to the highly reflective substrates of polysilicon and aluminum. Except for polysilicon the optimum focus setting for each centered on -0.6μm for this experiment.

Table 5 Comparison of k2 values

Substrate Type	Sim. k2	Exp. k2
Aluminum	1.111	0.111
Oxide	1.111	0.444
Polysilicon	1.111	0.630
BARC	1.111	0.311

From k2 comparisons extrapolated from Table 5, the k2 were well under the simulated values that were gathered. A small amount of error should be seen when comparing these values due to non-ideal processing. But due to the focal range error that occurred during the simulation, only a small section of the greater process window was captured during the experiment for many of the Bossung curves and the resulting k2 values were lower than expected. This is not to say that the data was not useable, just that the full UDOF was not able to determined during this baseline test. Unlike photolithography engineers, the project only allowed for a single iteration for the F-E matrices. In industry if the optimum Bossung plot is not obtained the lithographer will just redo the experiment and re-measure the features.
Therefore, continued testing with a larger focal range will add to the data already obtained and home in on, with more confidence, the optimized process window for each substrate.

6. CONCLUSIONS

This project involved the simulation and analysis of critical dimensions (CD) using the RIT Canon 2000i1 i-line stepper. This was accomplished by optimizing the stepper parameters for specific resist feature widths. This was completed, but unfortunately due to a calculation error that was made the optimized parameter settings that were obtained were only a section of the complete process window that was desired. Overall, the experiment and procedures were a success even with the error that occurred. Further testing, with a larger focal range, these parameter settings can be realized. Besides CD values, sidewall angle and resist loss are two other parameters that may be explored when testing the effects focus and exposure settings.

7. ACKNOWLEDGMENTS

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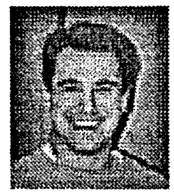

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[1] ProDATA v1.0, FINLE Technologies, 1999
[2] Ibid.
[3] ProLITH v 6.03, FINLE Technologies, 1999