THE USE OF A CONTRAST ENHANCEMENT LAYER TO EXTEND THE PRACTICAL RESOLUTION LIMITS OF OPTICAL LITHOGRAPHIC SYSTEMS

Daniel R. Sutton
5th Year Microelectronic Engineering Student
Rochester Institute of Technology

ABSTRACT

Resolution capability of a GCA Mann 4800 DSW Stepper was improved using a bilayer photoresist scheme consisting of CEM-420 applied on Shipley 1400-27 resist. Wall profile or contrast improvements were observed experimentally on a 1.4 micron line-space pattern by using the Scanning Electron Microscope. Perkin-Elmer Development Rate Moniter (DRM) simulations predicted the above improvements by the use of the PROSIM software applications program. The physical data and simulations were evaluated and demonstrated a contrast improvement on the order of four times for the wafer with the contrast enhancement material.

INTRODUCTION

Today in semiconductor fabrication, circuit dimensions are becoming smaller and smaller due to the demand for increased performance. This fact, along with the need for masking low selectivity plasma processes, has increased the aspect ratios needed in the resists.(2) Consequently, this puts higher demands on the exposure systems being used. Currently, optical lithography is the predominant patterning technique, even though it doesn't demonstrate the resolution capabilities of such systems as e-beam, ion-beam, and x-ray. This is due to the higher throughput, versatility and process simplicity inherent with optical systems. Therefore, new resist processing procedures have to be utilized in order to overcome the optical limitations (Numerical Aperture, Wavelength, and Depth of Focus) associated with optical projection systems. One such technique is the use of a contrast enhancement layer (CEL) on top of the resist to increase the working resolution by producing resist patterns with very steep wall profiles.

In optical lithography an aerial image of the mask actually exposes the resist. An aerial image for optical systems is shown in Figure 1.(1) For aerial images the discrimination between darker and lighter regions is a continuous one. Thus, the image obtained can be degraded due to the diffracting lower intensity light. A CEL helps to improve the ability of the resist to effect this discrimination and consequently raise the contrast level of the aerial image. In other words the CEL modifies the aerial image which the resist sees.(2)

The CEL is a high concentration photobleachable dye in the film. Initially the film is opaque, but following a dose of radiation it becomes transparent. During exposure the regions of the bleachable layer that are exposed to the highest intensities bleach through first, while those parts of the layer that receive the lowest intensities bleach through at a later time. If the exposure of the underlying resist proceeds faster than that of the CEL then the resist beneath the high intensity regions will be completely exposed before the low intensity regions in the CEL have a chance to bleach through and the underlying resist will not be exposed. The dynamics of this bleaching process are shown in Figure 1.(1)

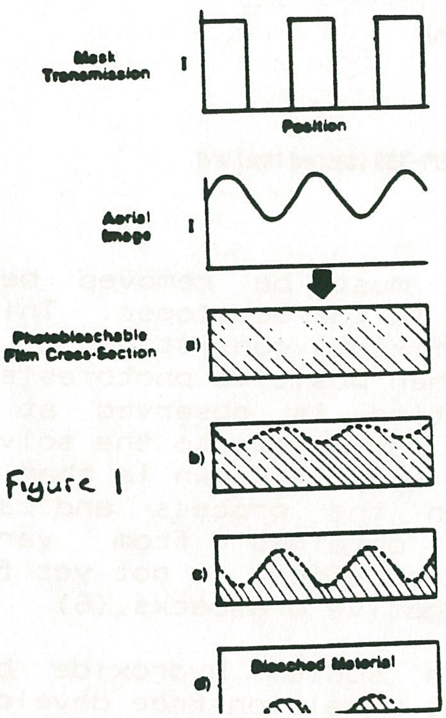

Figure 1

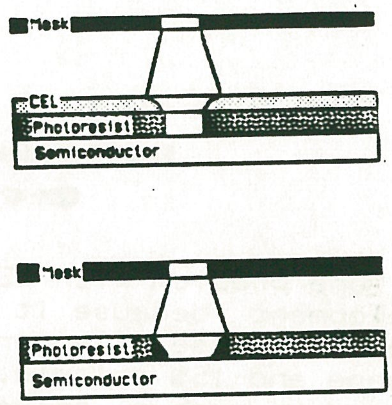

Figure 2 Comparison of contrast enhanced and non-contrast enhanced microlithography

In essence, the CEL forms an in situ contact mask for the resist, thus taking advantage of contact printing without mask degredation. A comparison of contrast enhanced and non-contrast enhanced imaging is demonstrated in Figure 2.(4) All of this giving rise to a lower contrast threshold for projection systems. It must be noted that the exposure doses for resist covered with a CEL are typically twice as much as that of resist alone, due to the bleaching which must occur.

The contrast enhancement material used in this experiment was Altilith CEM-420, optimized for use with G-line (436nm) illumination systems. A graph of the optical transmission properties is shown in Figure 3.(5) This shows a high initial absorption at the G-line, which is necessary for optimum contrast enhancement. Therfore, the GCA Mann 4800 DSW Stepper, which has optimum focus at the G-line, was used to expose the resist.

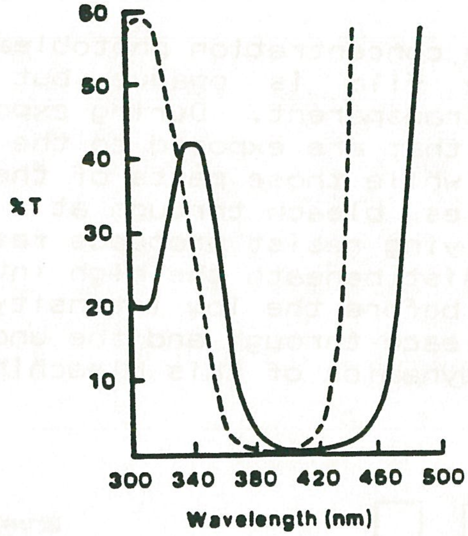

Figure 3. Spectral transmission curves for CEM-388 (dashed line) and CEM-420 (solid line) [15]

One problem with CEM is that it must be removed before development because it is not soluble in the developer. This is done by the use of an organic solvent mixture consisting of 85% toluene and 15% anisole.(3) However, when positive photoresist is exposed to such a solvent an inhibition is observed at the surface of the resist. This effect may be due to the solvents involved and/or interlayer diffusion. What is known is that the inhibition is strongly dependent on the process and can be adjusted from experimental results obtained from various processing techniques. This inhibition effect is not yet fully understood, but the results show no negative drawbacks.(6)

Development was carried out with a sodium hydroxide based developer. The reason for this is that metal ion free developers typically have more resist loss and lower contrast than the sodium based developers. Development rate data was obtained from the Perkin-Elmer DRM 5900. I refer the reader to the RIT DRM operation instructions document for information pertaining to theory, procedure and the application software Dreams and Prosim.

EXPERIMENT

Using 4-inch wafers an adhesion promoter (HMDS) was applied via static dispense and a 4000 rpm spin for 20 seconds utilizing a manual spin coater. Subsequently, Shipley 1400-27 resist was dynamically dispensed at 800 rpm with a manual ramp to 4000 rpm for a total time of 40 seconds. One of the most important factors in obtaining a desired resist thickness, in this case 1.2 microns, is the ramping. The wafers were pre-baked on the GCA Wafertrac 9000 hotplate for 100 seconds at 90 c. After the wafers had been coated and prebaked two wafers were coated with the Altilith CEM-420. To obtain the desired film thickness of 6000A-7000A the material was dispensed at 500 rpm and then ramped to 4000 rpm for 25 sec.

Exposure was performed on the 10:1 GCA Mann 4800 DSW Stepper. Since the Perkin-Elmer DRM 5900 was used it was necessary to first do step exposures with the DRM 5900 mask to obtain development rate data. This means that a 6x6 array was produced on the wafer with each row being a different exposure and each die representing the DRM 5900 mask. Table 1 shows the exposure dose that resulted for various times using 260 mw/cm2 intensity for wafers with and without CEL.

TABLE 1

(Itensity = 260 mw/cm2)

NO CEL		CEL	
Dose(mj/cm2)	Time(sec)	Dose(mj/cm2)	Time(sec)
3	0.01	135	0.52
47	0.18	179	0.69
91	0.35	223	0.86
135	0.52	267	1.03
179	0.69	311	1.20
223	0.86	355	1.37

Prior to development, Altilith CEM Stripper A-15 was puddled on the wafer for 45 seconds then spun dry at 4000rpm for 30 seconds. Development was carried out with the DRM using Shipley AZ351 developer diluted 2:1. Each wafer was analyzed with the Dreams and Prosim software applications programs to determine thickness vs. time, dissolution rate vs. thickness, thickness vs. log exposure, and resist profile simulations for the two processes.

Two more wafers were processed, but with the use of the RIT ETM mask. The development times for the wafer with CEM and the one without were 270 and 290 seconds, respectively. The purpose for this is to evaluate the edge profiles and resolution limits of the two processes using the Cambridge SEM. However, before they could be viewed with the SEM a thin layer of aluminum had to be deposited in order to dissipate any charging which could disintegrate the resist.

RESULTS

One advantage of CEM-420 is that it allows you to obtain much steeper side wall angles without any significant resist loss. Figure 4 shows 1.4 micron features with and without a CEL and Figure 5 shows the same features at a higher magnification. An improvement in contrast is demonstrated. However, from the SEM pictures it is difficult to see the amount of resist loss predicted by the DRM. The resist loss predicted was on the order of 0.2 microns, which was obtained from the resist profile simulation.

The DRM plot of Thickness vs. time showed the inhibition effect related with the use of a CEM. Other plots such as dissolution rate vs. thickness showed how the CEM doesn't deal with the standing wave effect and the thickness vs. log exposure plot showed an increase of gamma on the order of four times.

All of these simulations helped represent the final plot of the resist profile, which showed the increase in contrast and no resist loss for the wafer with a CEL. The one without, predicted image degredation defined by resist sidewall angle and resist loss. This was verified in the SEM pictures talked about above.

There were problems of resist adhesion on the patterned wafers, which could have been attributed to the HMDS used or the application. However, this could be remedied by patterning the resist on oxide grown wafers.

CONCLUSION

This simple bi-layer process showed how resist profiles can be improved without much added complexity. Although the fundamental optical resolution limits cannot be exceeded, the working resolution can be greatly enhanced. Also the added advantages allow the resist to be coated on thick so that some topography problems can be dealt with. Further work could be done in this area by trying to image high aspect ratio lithography.

REFERENCES

1. R.E. Williams, P.R. West, and J.Sardella, "Altilith CEM-420: A New Contrast Enhancement Material for G-line Steppers", General Electric publication.

2. E. Pavelchek, V. Valenty, R. Williams, "Application of a Contrast Enhancement Material to Broadband Projection Printing", General Electric publication.

3. P.R. West, G.C. Davis, and B.F. Griffing, "Contrast Enhanced Photolithography: Application of Photobleaching Processes in Microlithography", Journal of Imaging Science, Volume 30, No. 2, March/April 1986, p.65

4. M. McCreary, "Photoresist Schemes for Submicron Optical Lithography", Eastman Kodak Company Research Laboratories, 1986

5. D. Meyerhofer, "Process Latitude in Contrast Enhancement Layer Lithography", RCA Review, Volume 47, June 1986.

6. B.F. Griffing, P.R. West, "Contrast Enhanced Photoresists - Processing and Modeling", Signal Electronics Laboratory, Report No. 82CRD252, Sept. 1982