Contrast Enhancement Materials for Thick Photoresist Applications

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The performance requirements for ultra-thick photoresists are rapidly increasing due to the dramatic growth of applications such as nanotechnology (MEMS) and advanced packaging. Commercial products such as accelerometers, ink jet print heads, biomedical sensors and optical switches are driving growth in the nanotechnology market. Advanced packaging techniques such as flip chip in package, flip chip in board and wafer level chip scale packaging have become widely adopted to address electrical device performance and chip form factor considerations.

The common lithography requirement for these applications is formation of high aspect ratio structures with sufficient process latitude to allow devices to be manufactured in production volumes. The use of a contrast enhancement material (CEM) has been shown to be effective in improving lithographic performance and process latitude for thin photoresist applications. However, CEM technology can also be used for the thick photoresist materials in MEMS and advanced packaging applications.

The lithographic performance of three representative thick photoresists was characterized with and without a top CEM. The first two materials are ultra-thick positive photoresists that are widely used for electroplated bump bonding structures. The third material is a thick negative photoresist widely used for electrical redistribution levels. All lithography was performed using a low numerical aperture, 1X stepper to control critical dimensions (CD), sidewall angles and aspect ratios. Cross sectional SEM analysis was used to establish the lithographic capabilities of the three photoresists with and without top CEM. The recommended process flow for each photoresist with top CEM is described. The advantages and disadvantages of using CEM for thick photoresist applications are also discussed.

Key Words: contrast enhancement material, CEM, thick photoresist, advanced packaging, flipchip, MEMS, aspect ratios, BCB

1.0 INTRODUCTION

Recently there has been a rapid acceleration in the pace of conversion from conventional ceramic and plastic based integrated circuit (IC) packaging to advanced wafer level chip scale packaging using both solder and gold bump technology. Initially driven by the requirement for smaller form factors for cellular telephones and other portable electronic devices, there is a growing dependency on increased signal speed and very high input/output (I/O) counts in a widening range of IC types that cannot be adapted to conventional packaging. As fabrication processes transition from 200 mm to 300 mm wafers, it is anticipated that 50 to 65 percent of the devices will be processed using advanced wafer level packaging [1]. In addition, the photoresist requirements for MEMS applications have become more challenging in terms of aspect ratios and critical dimension (CD) control [2].

The fabrication of high aspect ratio linewidths for these applications is a new and challenging use of photolithography equipment and photoresists. The photolithography requirements for thick photoresists can be addressed by using optical lithography equipment originally developed for production of semiconductor devices. Steppers, full wafer scanners and aligners are widely used in the microelectronic industry and are highly evolved production tools. Thick photoresists, however, typically require a high exposure dosage and large depth of focus (DOF) for high aspect ratio lithography. For these reasons, it is advantageous to utilize a stepper with a broad band exposure system and low numerical aperture (NA) to maximize the illumination intensity at the wafer plane and to improve photoresist aspect ratios.

Photoresist performance, like stepper performance, has generally been optimized over recent years for achieving the smallest geometries possible. The process operating conditions for thick photoresists are considerably different than for thin photoresists. In the case of thin photoresists the two issues are resolution and latitude [3]. With thick films the concerns are centered around aspect ratios, downstream plating performance, process latitude and lithography cell productivity. As the technical requirements for advanced packaging and MEMS increases it becomes important to study thick photoresists for optimization of performance and productivity [4,5,6,7].

The technique of using a Contrast Enhancement Material (CEM) was developed by General Electric in the 1980's [8]. CEM is a photo bleachable solution, which is initially opaque to the exposure wavelength(s) but becomes nearly transparent upon exposure. Figure 1a and Figure 1b shows the spectral transmission characteristics of CEM-388SS and CEM-420SS (the two CEMs used in this study), respectively for broadband exposures. The CEM is spin coated on top of photoresist and then exposed. During exposure, the aerial image from the mask hits the CEM layer, where the regions of higher intensity (clear areas of the photomask) are bleached at a faster rate than the lower intensity regions (chrome areas of the photomask). By adjusting the bleaching dynamics so that the absorption of the CEM layer is sufficiently high and the photospeeds of the CEM and photoresist layers are properly matched, it is possible to completely expose the underlying photoresist in the clear areas before the CEM is bleached through in the dark areas. Thus, during exposure an in-situ “conformal contact mask” is formed in the CEM layer. The net effect is a higher contrast level of the aerial image used to expose the photoresist (Figure 2). The enhancement of the contrast depends on the photochemical properties and thickness of the CEM and the dose required to expose the photoresist. Choosing the correct CEM is also important as each material has different blocking characteristics as a function of wavelength.

All optical systems have aberrations which degrade the printed image [9]. With the proper match of CEM and exposure parameters the CEM layer will absorb, in the dark areas, much of the light from these aberrations before they reach the photoresist surface. The benefit is a much more vertical sidewall and the elimination of rounding or pointed edges at the tops of photoresist features.

The purpose of this study is to establish the improvement in lithographic performance of using CEM on both moderate and high contrast 40 μm thick positive photoresists. CEM also has the potential to improve the performance of thick negative photoresists with compatible develop process chemistries. We will investigate the improvements of standard photoresist characteristics in both negative and positive tone photoresists with CEM.

2.0 EXPERIMENTAL METHODS

2.1 Lithography Equipment

The lithography in this study was performed on an Ultratech Saturn Spectrum 300e^2 Wafer Stepper for the two positive photoresists and an Ultratech Titan Wafer Stepper® for the negative photoresist. The optical specifications for the Saturn Spectrum 300e^2 and for the Titan are shown in Table 1 and 2. The steppers are based on the 1X Wynne-Dyson lens design employing Hg ghi-line illumination from 350 to 450 nm and having a 0.16 NA for the Saturn Spectrum 300e^2 and gh-line from 390 to 450 nm with a 0.32 NA for the Titan [10].

Broadband exposure is possible due to the unique design characteristics of the Wynne Dyson lens system. This symmetric catadioptric lens system does not introduce the chromatic aberrations common to other lens systems when broadband illumination is used. The low NA and broadband illumination spectrum of these steppers provides a more uniform aerial image through the depth of the ultrathick photosensitive materials in contrast to steppers with larger NA’s and a relatively narrow bandwidth [7]. In addition, the Spectrum 300e^2 is equipped with a filter changer, which allows ghi-line (350 to 450 nm), gh-line (390 to 450 nm) or i-line (355 to 375 nm) illumination to be selected. This approach can be used to optimize lithographic performance based on the spectral sensitivity of the photosensitive material.

Multiple wafers were exposed in a focus/exposure pattern as illustrated in Figure 3. Focus latitude and linearity were examined by cross section of dense line patterns for positive photoresists and exposure latitude of isolated spaces was investigated for negative photoresist at the specified linewidth. The metrology was performed with a Jeol JSM 6340F and Hitachi S4100 SEM for the positive photoresists and an optical microscope with a Boeckeler VIA-100 attachment for the negative photoresist.

The Ultratech 1X reticles used for this study were designed primarily to support cross sectional SEM metrology. The reticle used for positive photoresist consists of a 10 mm by 10 mm field containing line patterns from 1 µm to 50 µm. Dense and isolated line/space are included for all structure sizes. The reticle used for negative photoresist has a 44 mm by 26 mm field size and contains round and octagon vias, as well as lines and spaces patterns from 5 µm to 150 µm.

2.2 Photoresist Processing

SEMI standard 200 mm ultra-flat silicon wafers were used for this study. The photoresists used for this investigation were Clariant AZ P4620®, Shin-Etsu SIPR® 9740M-13, and Dow Chemical BCB® 4026. The CEM® (Contrast Enhancement Material) are Shin-Etsu MicroSi 388SS and 420SS for ghi and gh-line wavelength ranges respectively. The CEM materials were chosen to match their bleaching characteristics to the spectral output of the stepper. These photoresists were selected because of the diversity of their photo-chemistries as discussed in section 3.0. The Shin-Etsu SIPR 9740M-13 and Clariant AZ P4620 photoresists were coated to a target thickness of 40 µm using the process and equipment described in Table 3 and 4 and the Dow Chemical recommended process conditions for 17 µm thick BCB is described in Table 5. Photoresist thickness and uniformity for the positive photoresists were measured on a Nanometrics 8300X measurement system. The BCB thickness was measured using Foothill KT-22 measurement system.

The Shin-Etsu MicroSi CEM is a photo-bleachable material that acts as an in-situ contact mask and increases the illumination contrast. The exposure dose increases approximately 20 to 40% when CEM is applied on top of the photoresist. The CEM is removed after exposure by a DI water rinse. A barrier coat (BC7.5) was used between the CEM and photoresist to prevent intermixing of the two materials. Both the CEM and barrier coat are water soluble and removed with DI water prior to the photoresist development.

Clariant AZ P4620 photoresist is a broadband positive photoresist widely used for wafer bumping applications. The AZ P4620 is a KOH developable, positive photoresist. It can coat up to 50 µm thick in two spin applications. Potassium based AZ400K(1:3) developer is used for the experiment. Both ghi-line and gh-line wavelengths were selected for exposure. The development flow is DI water rinse for the CEM, followed by immersion develop at room temperature, followed by a final DI water rinse. The minimum delay time between coat and exposure and between exposure and develop is 1 hour (Table 4). This photoresist is considered to be a mid-range contrast photoresist. This is evident by the results in Section 3.2 with regards to resolution and sidewall profile.

Shin-Etsu SIPR 9740M-13 photoresist is a TMAH developable, positive, broadband photoresist with high contrast and resolution. It uses a bonded DNQ in order to enhance resolution and minimize unexposed photoresist loss. The thickness at 3000 RPM is 13 µm and it can easily coat up to 40 µm thick in a single application. Both ghi-line and gh-line wavelengths were selected for exposure. The development method is DI water for the CEM followed by immersion at room temperature, followed by a DI water rinse. The minimum delay time between coat and exposure and between exposure and develop is 1 hour (Table 3).

Dow Chemical BCB® 4026 is a negative acting photosensitive polymer used in wafer level applications where a dielectric layer is required for isolation or protection. The organic solvent developer used is DS3000. Gh-line wavelength was used for exposure. The development method is a DI rinse to remove the CEM and then immersion in DS3000 at elevated temperature, followed by a spin dry. The wafers were cured and descummed before inspection (Table 5). The final thickness of the BCB after develop, cure and descum is reduced by 10 to 20% from the initial coated thickness. The BCB is left on the wafer and becomes a permanent part of the device

2.3 Data Analysis

After exposure the wafers were cleaved for cross section on a Jeol JSM 6340F and Hitachi S4100 metrology SEM to show the line/space linearity and depth of focus of 10 µm lines for both Shin-Etsu SIPR9740M-13 and Clariant AZ P4620 photoresist with and without the top CEM material. Bottom CD measurements were taken at 1300X magnification for 10 µm dense lines to show depth of focus at nominal exposure and linearity at nominal exposure and focus. Cross sectional SEM photographs are presented in Section 3.0 to illustrate masking linearity and depth of focus at nominal exposure dose.

The BCB wafers were cured, descummed, and cleaved for cross section using an optical microscope to show exposure latitude at best focus for 50 µm isolated space with and without the CEM coating. The results from the data analysis are discussed in Section 3.0.

3.0 RESULTS AND DISCUSSIONS

3.1 Shin-Etsu 9740

Shin-Etsu SIPR 9740M-13 is a high contrast photoresist that is frequently used for electroplating applications requiring large aspect ratios in thick films [11]. This material was evaluated to determine if CEM could further enhance the thick photoresist performance. Cross sectional photographs were used to determine the impact of top CEM on resolution and photoresist profiles. Figure 4 shows line and space linearity of 40 µm thick Shin-Etsu 9740 photoresist exposed in ghi-line with and without top 388SS CEM. It is clear that the CEM has a dramatic impact on overall lithographic performance. For the features larger than 10 µm significant corner notching is observed without CEM (Figures 4a and 4b) compared to CEM (Figures 4e and 4f). For features smaller than 10 µm without CEM there is major photoresist top loss and more pronounced footing at the base of the photoresist (Figures 4c and 4d) compared to CEM (Figures 4g and 4h). For electroplating applications where no photoresist top loss is allowed the CEM dramatically extends the maximum aspect ratio from 4:1 (10 µm feature) to 8:1 (5 µm feature). In addition the straighter profiles allow plating to a higher portion of the film stack. This can allow a reduction in the photoresist thickness which in turn can improve the practical resolution even further.

Figure 5 shows the focus latitude of 10 µm line and space features in 40 µm thick Shin-Etsu 9740 photoresist exposed in ghi-line with and without top 388SS CEM. It is apparent that the CEM has a dramatic impact on the focus latitude of the photoresist. At a focus of -20 µm the non CEM case shows significant rounding of the photoresist top (Figure 5a) compared to the CEM (Figure 5e). At a focus of +15 µm the non CEM case shows significant slope and footing at the photoresist base (Figure 5d) compared to the CEM (Figure 5h). The CEM provides a tighter CD control and effectively increases the focus process window of the photoresist allowing it to be used with larger topography and non-flat substrates.

However, the top CEM does increase the nominal exposure dose since the CEM must photo bleach before the photoresist is exposed. For the Shin-Etsu 9740 photoresist the nominal exposure is 2800 mJ/cm^2 without CEM versus 3800 mJ/cm^2 with CEM (35% increase). The higher exposure dose of the CEM would require longer exposure times which might impact the overall throughput of the lithography exposure tool. However in production, the ratio of exposure with and without CEM may be smaller since without the CEM, to reduce the top loss and notching, the softbake time is often increased which will reduce the required exposure dose.

3.2 Clariant AZ P4620

Clariant AZ P4620 photoresist is a moderate contrast photoresist that is widely used for wafer bumping applications requiring thick photoresist. This material was evaluated to determine if CEM could provide a major increase in overall thick photoresist performance. Once again cross sectional photographs were used to determine the impact of top CEM on resolution and photoresist profiles. Figure 6 shows line and space linearity of 40 µm thick Clariant AZ P4620 photoresist exposed in ghi-line with and without top 388SS CEM. It is clear that the CEM has a dramatic impact on overall lithographic performance. Even at the largest feature of 20 µm significant top rounding and footing is observed without CEM (Figure 6a) compared to CEM (Figure 6e). For both the 15 µm and 10 µm features without CEM there is major photoresist top loss and significant footing at the base of the photoresist (Figures 6b and 6c) compared to CEM (Figure 6f and 6g). For 8 µm features without CEM the photoresist is almost completely eroded away (Figure 6d) compared to full thickness retention with CEM (Figure 6h). For electroplating applications where no photoresist top loss is allowed the CEM dramatically extends the maximum aspect ratio from 2:1 (20 µm features) to 5:1 (8 µm feature). In addition the straighter profiles allow plating to a higher portion of the film stack. This can allow a reduction in the photoresist thickness which in turn can improve the practical resolution even further.

Figure 7 shows the focus latitude of 10 µm line and space features in 40 µm thick Clariant AZ P4620 photoresist exposed in ghi-line with and without top 388SS CEM. It is apparent that the CEM has a dramatic impact on the focus latitude of the photoresist. Over the entire focus range of -20 µm to +15 µm significant photoresist loss is observed without CEM (Figures 7a to 7d). For the case with CEM full photoresist thickness and sidewall control is maintain for a 20 µm focus window centered at -10 µm (Figures 7e to 7g). This focus process window with top CEM is large enough to allow 4:1 aspect ratios to be used.

As in the case of Shin-Etsu 9740, the top CEM increases the nominal exposure dose of the Clariant AZ P4620 photoresist from 3100 mJ/cm^2 without CEM to 3900 mJ/cm^2 with CEM (25% increase). The same observations concerning lithography tool throughput and overall productivity apply for both the Shin-Etsu 9740 and Clariant AZ P4620 photoresists.

3.3 Wavelength Comparison for Shin-Etsu 9740

Previous studies have shown that very thick novolak photoresist exhibit better resolution with gh-line exposure than ghi-line exposure [12]. At i-line the bulk absorption of novolak photoresists are so large that they requires higher exposures in order to clear out the base of the photoresist. Such extremely high exposures causes photoresist top loss and general profile degradation. Since the CEM is highly effective at eliminating photoresist top loss it is anticipated that CEM would eliminate this phenomenon and allow the user to determine the optimum exposure wavelength based on other criteria such as process window and lithography system throughput.

Cross sectional SEMs were used to determine the impact of the exposure wavelength on resolution and photoresist profiles. Figure 8 shows line and space linearity of 40 µm thick Shin-Etsu 9740 photoresist exposed in ghi-line with top 388SS CEM and gh-line with 420SS CEM. There is no noticeable difference between the ghi-line performance (Figures 8a to 8d) and the gh-line performance (Figures 8e to 8h) over the entire feature size range. For this case the exposure energy at ghi-line is 3800 mJ/cm^2 (1.69 seconds) versus 3400 mJ/cm^2 (2.27 seconds) for the gh-line. In this case exposure times (based on the measured dose and wafer plane irradiance) are shown in order to provide insight into relative performance of the exposure wavelengths. It is apparent that exposing with broadband ghi-line increases the overall throughput of the stepper by reducing the expose time for the photoresist.

3.4 Dow Chemical BCB 4026

Dow Chemical BCB 4026 is a low contrast negative acting photosensitive polymer. It is typically used in a thickness range of 12 to 18 µm. In most advanced packaging applications the majority of the exposure field is clear and via openings will be defined by chrome, thus allowing the BCB in the unexposed areas to be removed during develop. This material was evaluated to determine if CEM could provide an increased exposure latitude. Once again cross sectional photographs were used to determine the impact of top CEM on exposure latitude and sidewall profiles.

Figure 9 shows the exposure latitude of 50 µm wide spaces in 17 µm thick Dow Chemical BCB 4026 exposed in gh-line with and without top 420SS CEM. The photographs show that there is no evidence of an interaction between the water developable CEM and the organic developable BCB. This indicates that it is feasible to use the aqueous based CEM with a solvent developer system. Focus offsets of -3 µm, -8 µm and -13 µm were initially evaluated, but no significant differences were observed. The focus offset shown in Figure 9 is fixed at –13 µm. Without CEM the spaces begin to “scum” at 1800mJ/cm^2 (Figure 9c) and are totally closed at 2000mJ/cm^2 (Figure 9d). This indicates the total exposure latitude is less than 400mJ/cm^2. The slope on the BCB without CEM is 40 to 50 degrees, which is typical after completion of the curing operation. The BCB wafers exposed with CEM show clearly resolved openings at exposure doses from 2300mJ/cm^2 (Figure 9e) to 3100mJ/cm^2 (Figure 9h), an exposure latitude of greater than 800mJ/cm^2. The wall profile on the CEM wafers shows a steeper slope at the top of the opening, which may impact metal step coverage depending on the deposition technique. Again the higher exposure dose of the CEM would require longer process times and may impact the overall throughput of the lithography exposure tool. Additional work will be necessary to characterize the impact of using CEM coating with Dow Chemical BCB photo polymers on packaging characteristics.

4.0 CONCLUSIONS

This study has shown the feasibility of processing moderate and a high contrast positive photoresists at 40 µm thickness with a top CEM. Full process characterization was shown for Shin-Etsu 9740 and Clariant AZ P4620 photoresists with and without CEM through the use of linearity and depth of focus analysis. The use of CEM dramatically improves the lithographic performance for both photoresists. With CEM there is no difference in the profiles performance between gh-line and ghi-line, which allows the stepper to use its full band width and to reduce exposure times. It was determined that the resolution goal for advanced packaging processing and most MEMs applications was far exceeded with both positive photoresists. Near vertical sidewalls were observed with CEM, suggesting plated features will meet or exceed expectations. Depth of focus was shown to be more than adequate for thick film processing.

Negative photoresists have traditionally had very low contrast and hence poor image fidelity. The CEM improves the performance of Dow Chemical BCB 4026 photopolymer dramatically. The exposure latitude doubled which allows a significantly more robust process. This work has also shown the feasibility of using an aqueous based CEM with a solvent based development system. Process and packaging characteristics such as metal step coverage with the BCB photopolymer require further study.

5.0 ACKNOWLEDGEMENTS

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Parameter	Spectrum 300 e^2
Reduction factor	1X
Wavelength (nm)	350 - 450
Numerical aperture (NA)	0.16
Partial coherence (σ)	1.0
Wafer plane irradiance (mW/cm^2)	2250

Table 1: Optical specifications of the Saturn Spectrum 300e2 stepper used in this study.

Parameter	Titan
Reduction factor	1X
Wavelength (nm)	390 - 450
Numerical aperture (NA)	0.32
Partial coherence (σ)	0.5
Wafer plane irradiance (mW/cm^2)	1400

Table 2: Optical specifications of the Titan stepper used in this study.

Process Step	Parameters	Equipment
HMDS Vapor Prime	20 minutes at 150^{o}C	YES Oven
SIPR 9740M-13 Coat	Static dispense for 8 seconds Spread: 1000 RPM for 3 seconds Spin: 850 RPM for 30 seconds	ACS200 track
Softbake	Hotplate, 0.1 mm proximity, 360 seconds at 110^{o}C Delay Time After Softbake: 60 minutes	ACS200 track
CEM Coating (If applicable)	Refer to Tables 6 and 7	ACS200 track
CEM Removal (if applicable)	Delay Time after exposure: 60 minutes DI water rinse for 60 seconds Dry using Nitrogen	
Develop	10 minute immersion in Arch OPD262 Room temperature Constant and aggressive agitation DI water rinse	

Table 3: Process conditions for Shin-Etsu SIPR 9740 for 40 μm thickness.

Process Step	Parameters	Equipment
HMDS Vapor Prime	20 minutes at 150°C	YES Oven
AZ P4620 Coat	First Coat: Static dispense for 5 seconds Spin: 650 RPM for 60 seconds Hotplate Bake: 0.1mm proximity 300 seconds at 110°C Second Coat: Static dispense for 5 seconds Spin: 700 RPM for 60 seconds	ACS200 track
Softbake	Hotplate, 0.1 mm proximity 300 seconds at 110°C Delay Time After Softbake: 60 minutes	ACS200 track
CEM Coating (If applicable)	Refer to Tables 6 and 7	
CEM Removal (if applicable)	Delay Time after exposure: 60 minutes DI water rinse for 60 seconds Dry using Nitrogen	
Develop	6 minute immersion in AZ400K 1:3 Room temperature Constant and aggressive agitation DI water rinse	

Table 4: Process conditions for Clariant AZ P4620 for 40 µm thickness.

Process Step	Parameters	Equipment
Adhesion Promoter	Apply AP3000 Final Spin Speed: 3000 rpm	ACS200 track
Coat	Apply BCB 4026 Final Spin Speed: 1600 rpm	ACS200 track
Softbake	Hotplate at 80°C	ACS200 track
CEM Coating (If applicable)	Refer to Tables 6 and 7	ACS200 track
CEM Removal (if applicable)	DI water rinse for 60 seconds Dry using Nitrogen	Semitool
Develop	Dow DS3000 Immersion Spin Dry	Constant Temperature bath
Cure	Ramp to 225 to 250°C In Nitrogen	Blue-M Oven
Descum	O_2/CF_4 chemistry Remove 1500 Angstroms	Parallel Plate Etcher

Table 5: Process conditions for Dow Chemical BCB 4026 for 17 µm thickness.

Process Step	Parameters	Equipment
Barrier Coat CEM BC7.5	Static dispense for 3 seconds Spread: 2000 RPM for 3 seconds Spin: 4000 RPM for 30 seconds	ACS200 track
CEM Coat 388SS	Static dispense for 3 seconds Spread: 2000 RPM for 3 seconds Spin: 2000 RPM for 30 seconds	ACS200 track

Table 6: Process conditions for Shin-Etsu MicroSi 388SS for 1.5 µm thickness.

Process Step	Parameters	Equipment
Barrier Coat CEM BC7.5	Static dispense for 3 seconds Spread: 2000 RPM for 3 seconds Spin: 4000 RPM for 30 sec	ACS200 track
CEM Coat 420SS	Static dispense for 3 seconds Spread: 2000 RPM for 3 seconds Spin: 4000 RPM for 30 sec	ACS200 track

Table 7: Process conditions for Shin-Etsu MicroSi 420SS for 1.5 µm thickness.

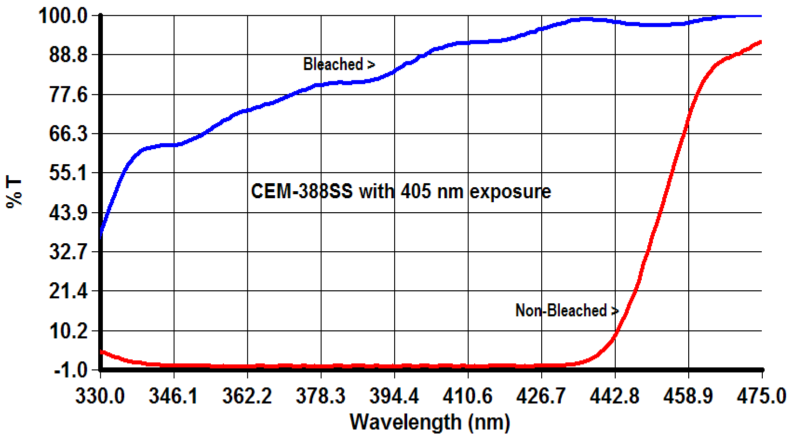


Figure 1(a): Shin-Etsu MicroSi CEM-388SS spectral transmission characteristics.

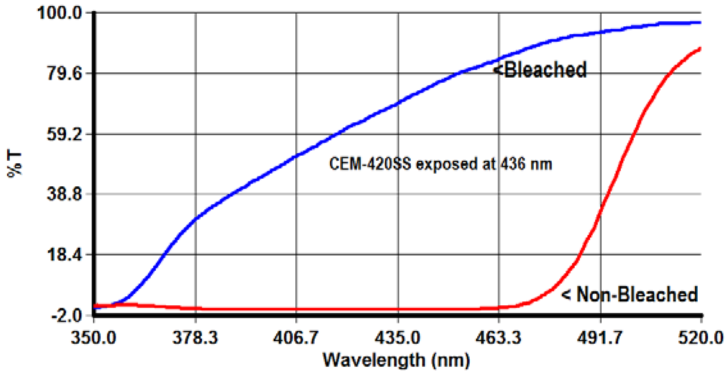


Figure 1(b): Shin-Etsu MicroSi CEM-420SS spectral transmission characteristics.

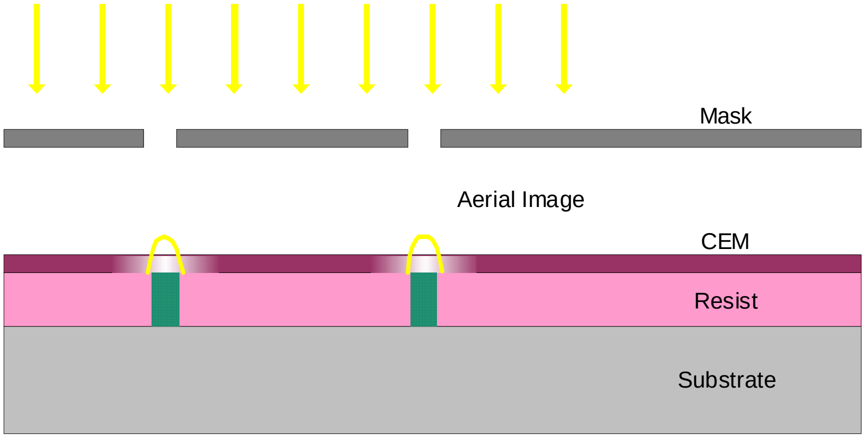


Figure 2: Cross section of a CEM coated substrate. The CEM acts like a conformal contact mask to create a higher contrast level of the aerial image used to expose the photoresist.

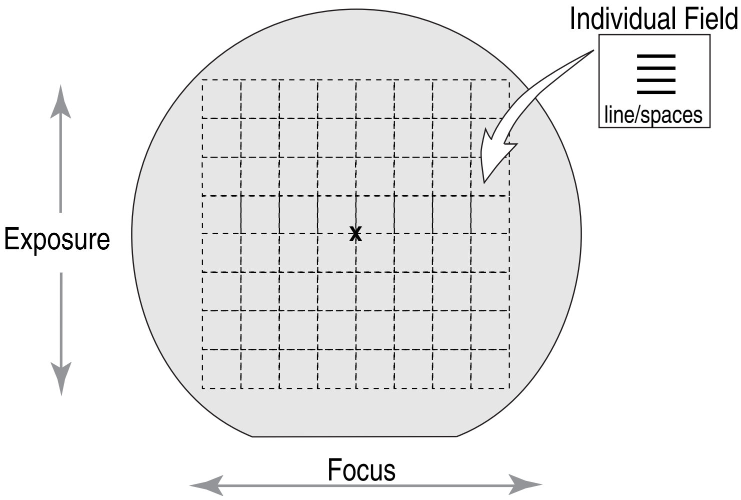


Figure 3: Wafer layout for the focus and exposure matrix. An eight by eight field array was exposed with focus varying in the horizontal axis and exposure dose varying in the vertical axis.

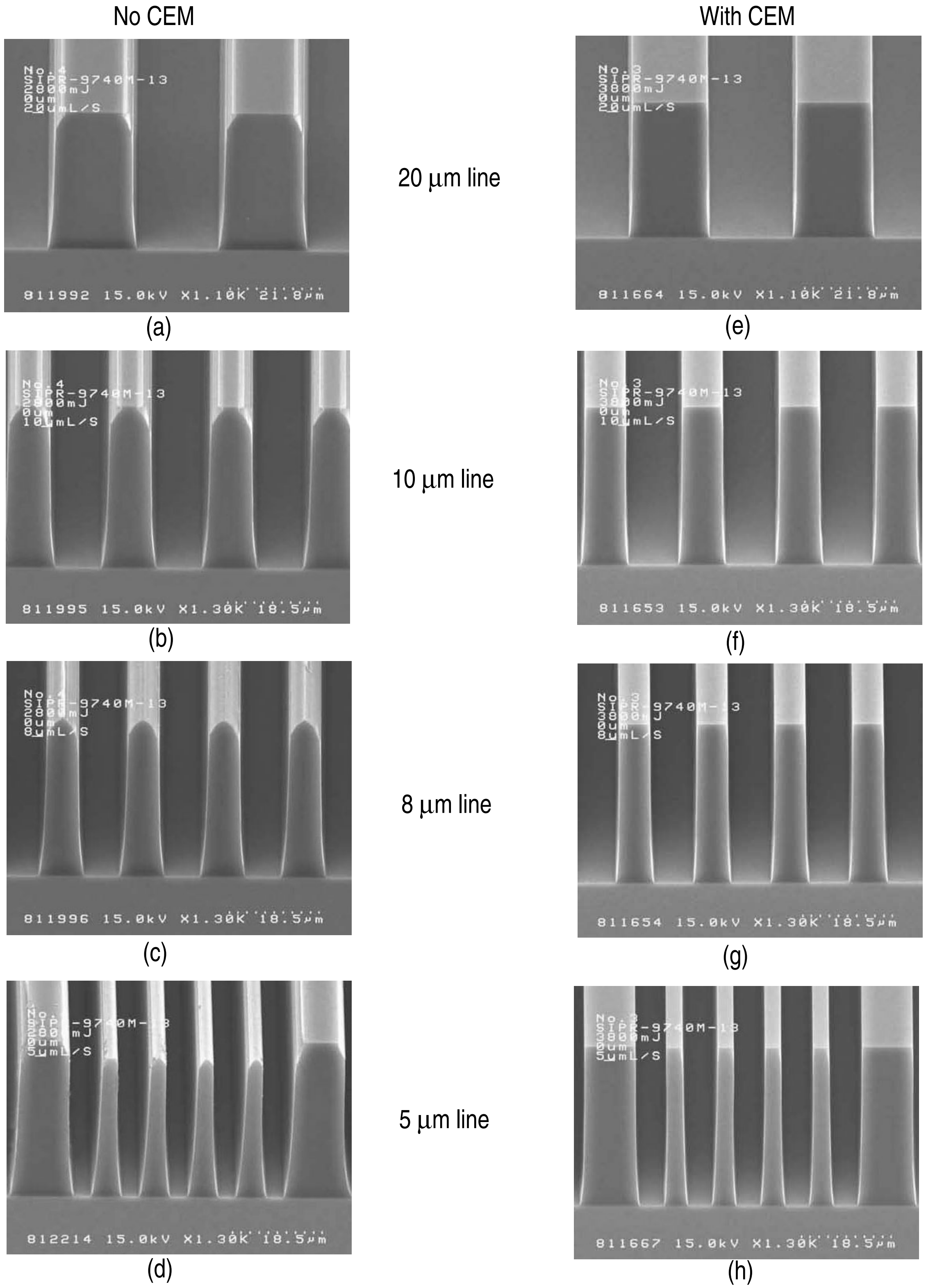


Figure 4: SEM Photographs of the linearity of 40 µm thick Shin-Etsu 9740, ghi-line exposure, 0 µm Focus, 3800 mJ/ cm^2 with CEM 388SS, 2800 mJ/cm^2 without CEM.

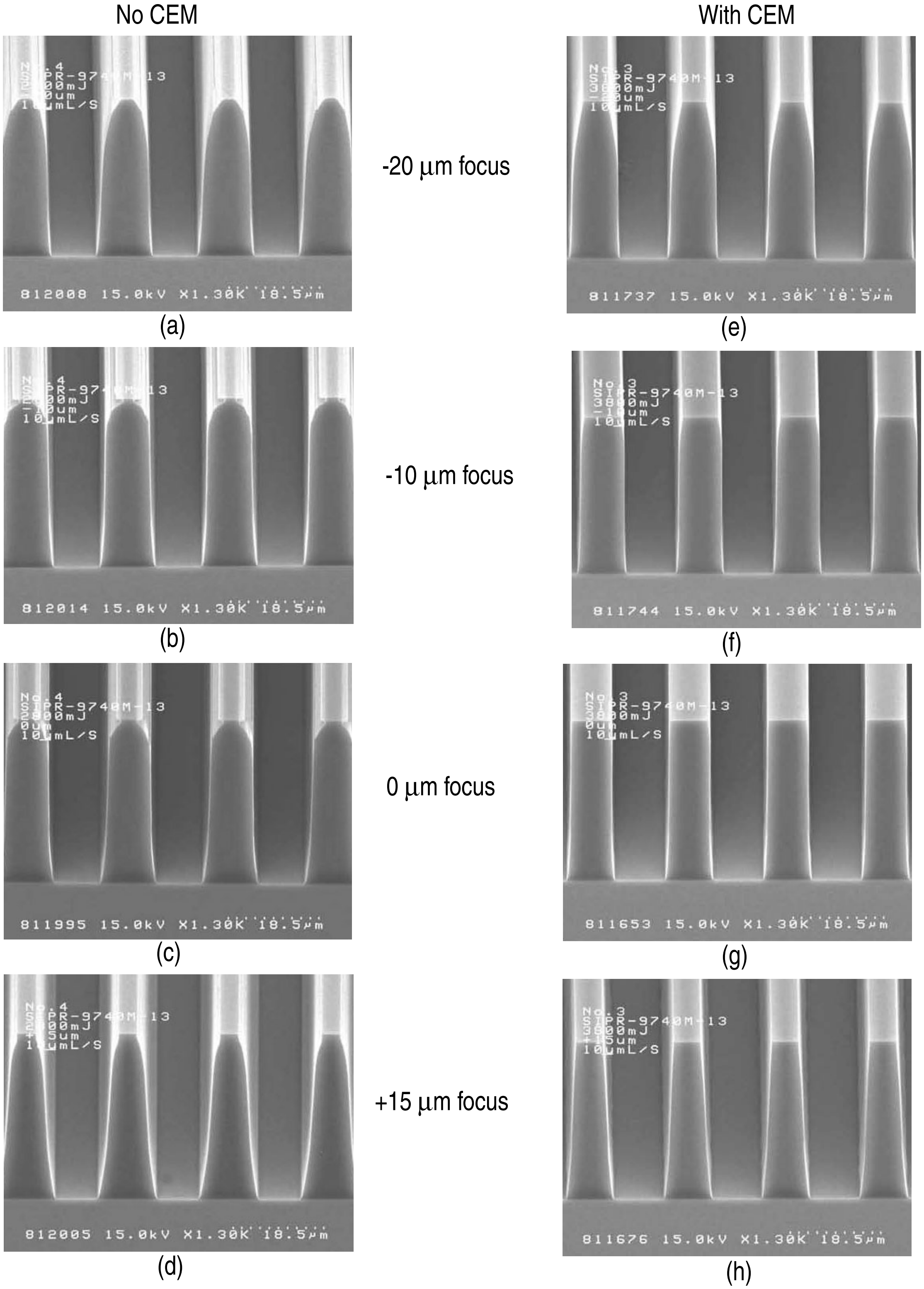


Figure 5: SEM Photographs of the depth of focus of 40 µm thick Shin-Etsu 9740, ghi-line exposure, 10 µm line, 3800 mJ/cm^2 with CEM 388SS, 2800 mJ/cm^2 without CEM.

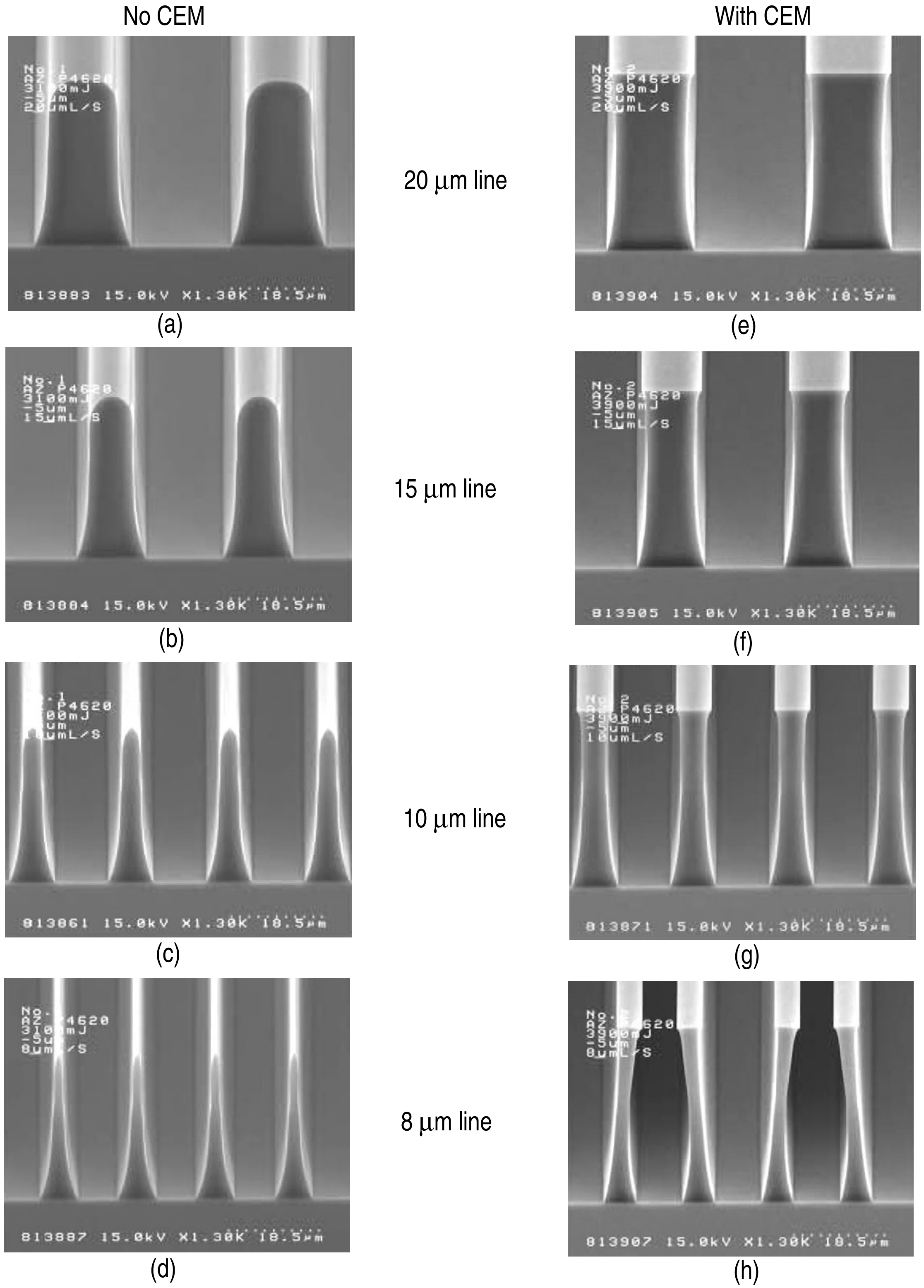


Figure 6: SEM Photographs of the linearity of 40 µm thick Clariant AZ P4620, ghi-line exposure, -5 µm Focus, 3900 mJ/cm^2 with CEM 388SS, 3100 mJ/cm^2 without CEM.

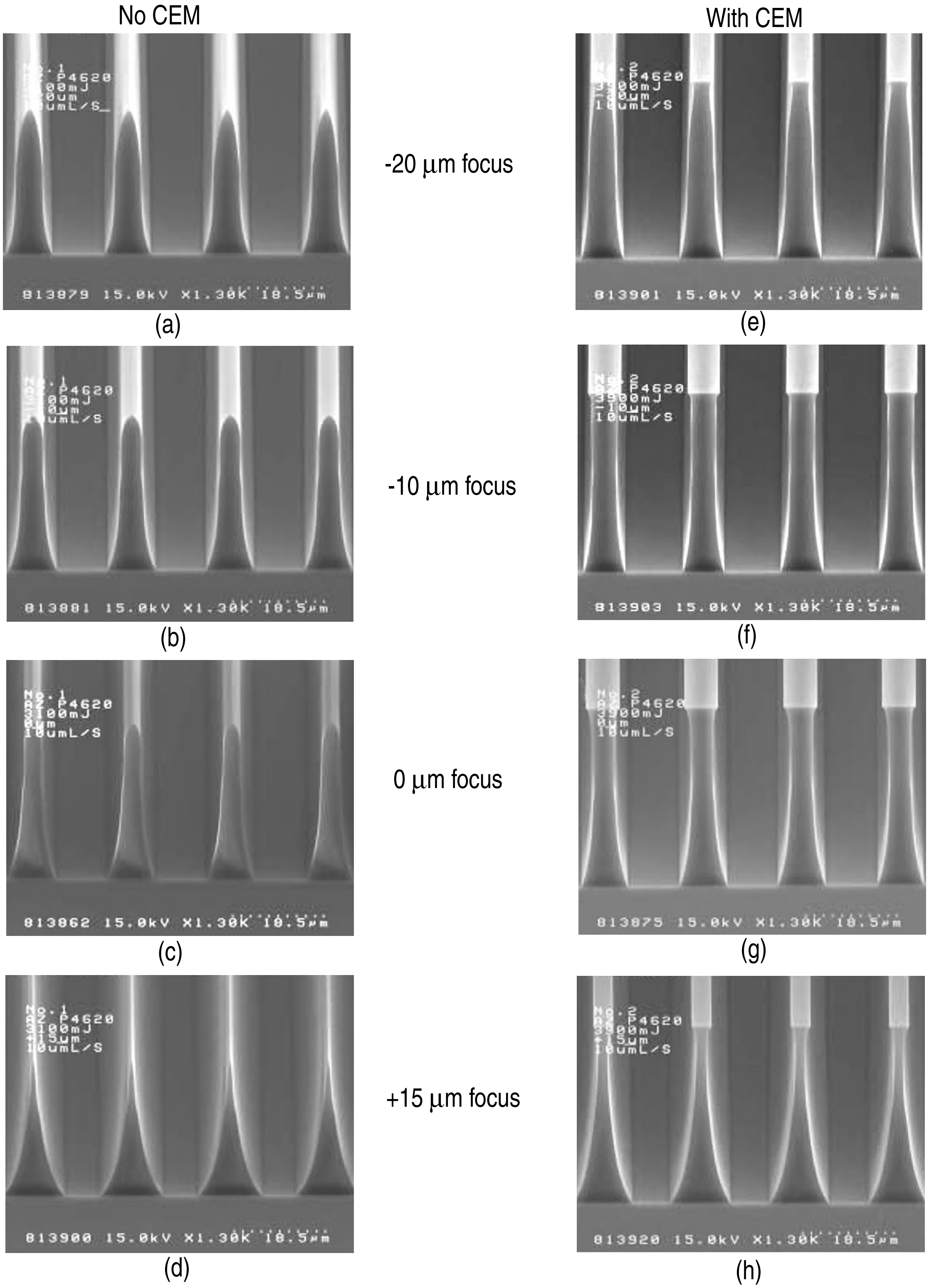


Figure 7: SEM Photographs of the depth of focus of 40 µm thick Clariant AZ P4620, ghi-line exposure, 10 µm line, 3900 mJ/cm^2 with CEM 388SS, 3100 mJ/cm^2 without CEM.

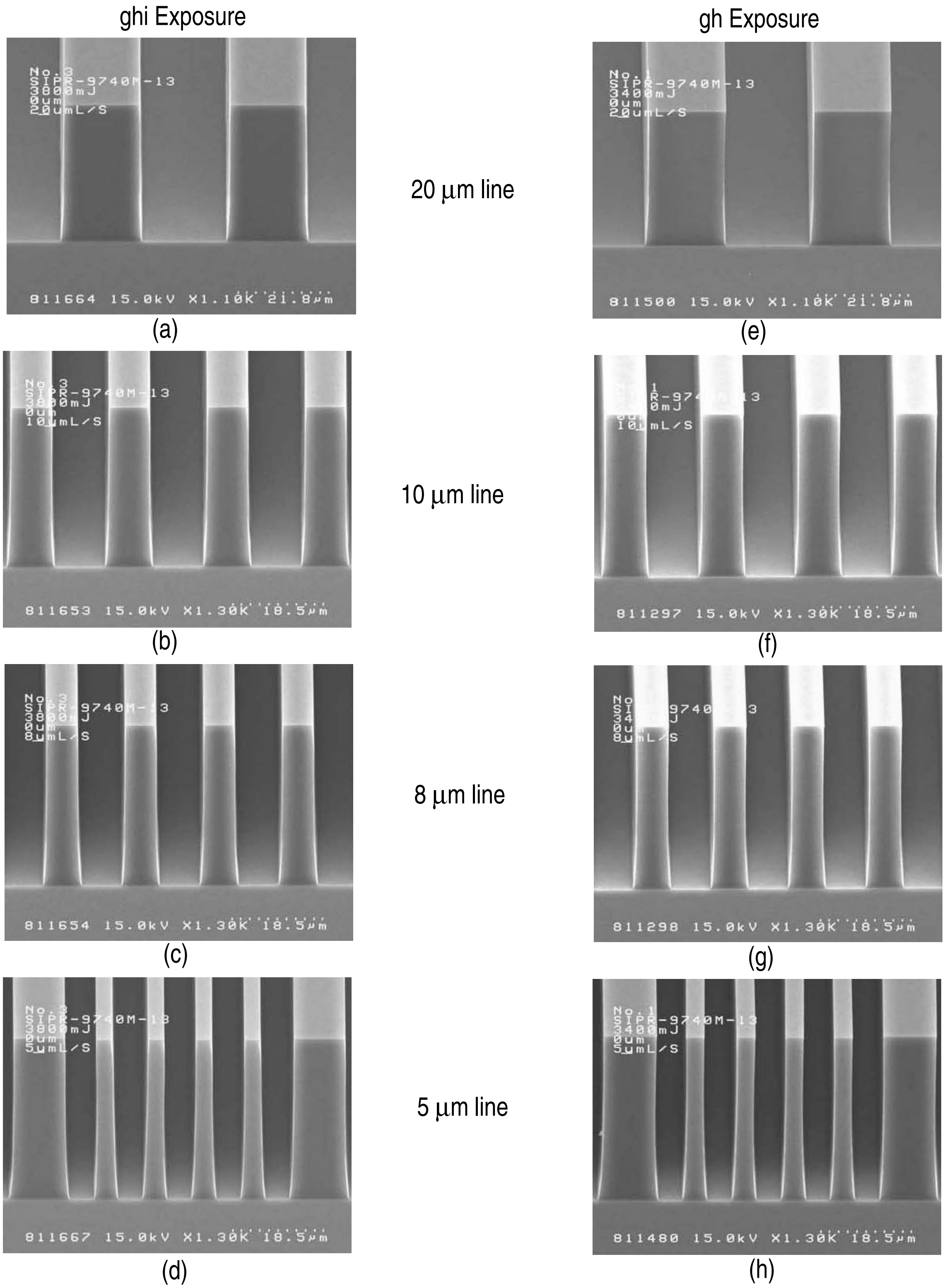
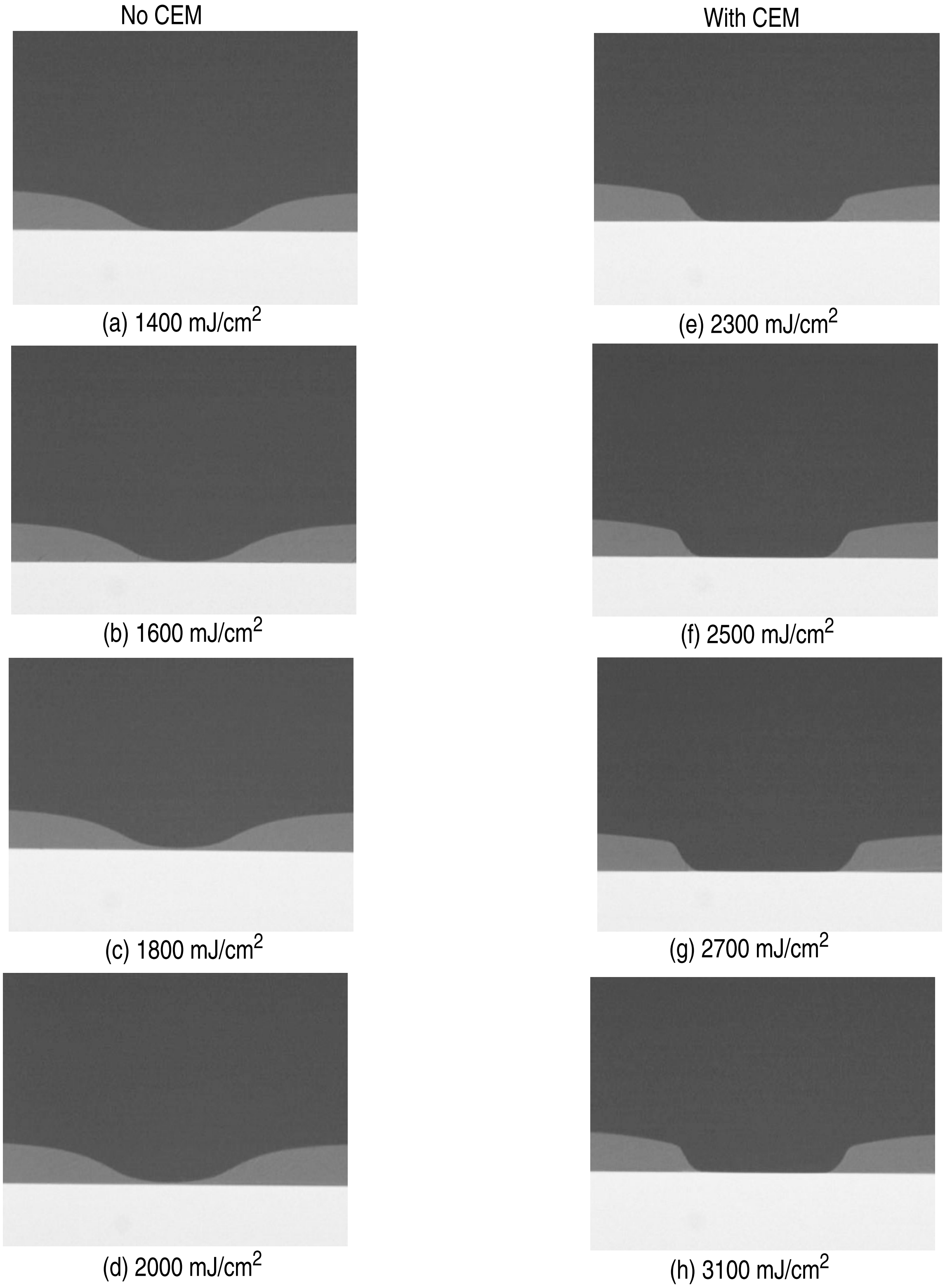


Figure 8: SEM Photographs of the linearity of 40 µm thick Shin-Etsu 9740. The ghi-line exposure is 3800 mJ/cm^2 (1.69 seconds) with CEM 388SS and 3400 mJ/cm^2 (2.27 seconds) for gh-line with CEM 420SS.



(a) 1400 mJ/cm^2

(e) 2300 mJ/cm^2

(b) 1600 mJ/cm^2

(f) 2500 mJ/cm^2

(c) 1800 mJ/cm^2

(g) 2700 mJ/cm^2

(d) 2000 mJ/cm^2

(h) 3100 mJ/cm^2

Figure 9: SEM Photographs of the exposure latitude of 17 µm thick Dow Chemical BCB 4026 in gh-line, 50 µm space pattern, -13 µm focus offset. The exposure dose is the same with and without CEM 420SS.