Characterization of an Ultra-Thick Positive Photoresist for Electroplating Applications

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The performance requirements for ultra-thick photoresists have increased rapidly with the dramatic growth in new lithographic applications that require electroplating processes. Two of the main applications for ultra-thick photoresists are nanotechnology (MEMS) and advanced packaging. Flipchip packaging has become widely adopted to address electrical device performance and chip form factor considerations. The growth in the nanotechnology market is driven by a wide range of products, which include accelerometers, ink jet print heads, biomedical sensors and optical switches.

Electroplating levels for these applications require a photosensitive polymer material capable of coating, exposing and plating with conventional semiconductor equipment and standard ancillary process chemicals. A single coat step to achieve the final photoresist thickness is critical to minimize the number of process steps and cycle time. The sidewall profile, aspect ratio, electroplating durability and subsequent stripability of the photoresist are all important. This study characterized a novel positive photoresist (ShinEtsu SIPR 7110M) for the use as a 65 μm thick single coat electroplating level on copper.

The lithographic performance of the ultra-thick positive photoresist was optimized using a broad band, low numerical aperture, 1X stepper to control critical dimensions (CD), sidewall angles and aspect ratios. Cross sectional SEM analysis, process linearity, and process latitude plots were used to establish the lithographic capabilities. High aspect ratio structures were then electroplated using the optimized photoresist process to demonstrate photoresist durability and stripability. A recommended process flow is described for this photoresist and stepper.

Key Words: advanced packaging, MEMS, thick photoresist, electroplating, process optimization

1.0 INTRODUCTION

Ultra-thick photoresists are used in many applications including thin film head manufacturing, fluidic chambers, electroforming molds and bump bonding [1]. These areas that can be broadly defined as nanotechnology and advanced packaging. Thin film heads (used for reading and writing data to hard disk drives) and inkjet printheads are the two largest commercial applications of nanotechnology today and are experiencing rapid growth and technological advances. Recently there has been a major acceleration in the pace of conversion from conventional ceramic and plastic based integrated circuit (IC) packaging to flipchip and advanced wafer level chip scale packaging (WLCSP). Initially driven by the need for smaller form factors for cellular telephones and other portable electronic devices, there is a growing dependency on advanced packaging for increased signal speed and very high input/output (I/O) counts in a widening range of IC parts. 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 [2].

The conversion to advanced packaging for more complex IC's is pushing to tighter solder ball pitches to accommodate higher I/O density [3]. One solution is to switch from mushroom type plating to in-via plating as shown in Figure 1. This approach uses thicker photoresists that allow sufficient solder volume buildup in the stud which eliminates the requirement for a typical mushroom bump with solder on top of the photoresist (umbrella). For in-via plating the photoresist thickness required can easily exceed 65 µm. Copper (Cu) plating for post passivation metallization requires a similar thickness of photoresist [4]. Extending the microlithographic processes into these rapidly growing areas is placing new demands on both the photosensitive materials and the lithography equipment.

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 contact printers 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 of larger geometries. 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 DOF [5].

Photoresist performance, like stepper performance, has generally been optimized over recent years to achieve the smallest geometries possible. Some newer photoresist formulations are available that have properties more tailored for making the high aspect ratio structures required for electroplating molds. 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 [6]. With thick films the concerns are centered around aspect ratios, downstream plating performance, latitudes and productivity. As spin coated photoresist films become more popular for these applications, it becomes important to study thick photoresists for optimization of performance and productivity [5,7,8,9].

Traditionally photoresists in the 50 µm to 100 µm range are challenging to formulate, especially in a positive tone. For example it is very difficult to design a positive tone chemistry to achieve the necessary transparency to obtain reasonable exposure doses with excellent sidewall angles [10]. Additionally, as the percent solid of the photoresist increases for ultra-thick photoresists the filtration and bottling become extremely difficult. Crystallization and polymer coming out of the solution becomes more of an issue. Furthermore very thick positive novalak photoresists have the characteristic of popping or forming voids after exposure as a result of the nitrogen generated during exposure. Frequently positive photoresist require as many as three coats to achieve a thickness around 65 µm. However, there are also major concerns in using negative photoresists for this application. Negative photoresists are very difficult to remove after plating or etching due to their chemical composition. Positive photoresists do not have this issue. Furthermore the photolithography community has been using positive photoresists for many years.

For these reasons we investigated chemically amplified positive photoresists for this application. Chemically amplified photoresist show excellent transparency, no voiding and can achieve 65 µm or greater in one coat. The objective of this study is to find a positive photoresist system that achieves resolution of 30 µm contact structures with relatively fast photospeed using a single coat 65 µm thick process. A critical dimension of 30 µm is currently beyond any road maps for solder bump processing [2]. Also plating performance is critical since plating such high features mean the photoresist can be exposed to very harsh plating environments for an extended time. To demonstrate durability we investigated Cu plating with this photoresist.

2.0 EXPERIMENTAL METHODS

2.1 Lithography Equipment

Lithography for the thick photoresist evaluated in this study was performed on an Ultratech Stepper Saturn Spectrum 3e Wafer Stepper®. The optical specifications for the Saturn Spectrum 3e are shown in Table 1. The stepper is based on the 1X Wynne-Dyson lens design employing Hg ghi-line illumination from 350 to 450 nm and having a 0.16 NA [11]. Broadband exposure is possible due to the unique design characteristics of the Wynne Dyson lens system. This symmetric catadioptric lens system does not suffer from serve chromatic aberrations common to other lens systems when broadband illumination is used. The low NA and broadband illumination spectrum of the Saturn Spectrum 3e 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 [5]. In addition, the Spectrum 3e 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 consisting of a seven by eight field array as illustrated in Figure 2. Focus and exposure latitude were examined by cross section of dense line and square contact patterns at the specific linewidth of interest with a Joel JSM 6340F and Hitachi S4100 SEM. Cu electroplating was done on wafers exposed at best focus and best exposure.

The Ultratech 1X reticle used for this study was designed primarily to support cross sectional SEM metrology. The reticle consists of two fields of 10 mm by 10 mm, one of each polarity to support both positive and negative acting photoresists. Each field contains staggered square contacts and line patterns from 10 µm to 100 µm. Dense and isolated line/space as well as contacts are included for all structure sizes. There was no data biasing applied to the design data and CDs were held to within ±0.25 µm of a nominal chrome line. Reticle CD information also was obtained for all line sizes on both fields to establish the process linearity in reticle fabrication.

2.2 Photoresist Processing

SEMI standard 150 mm ultra-flat silicon wafers sputtered with 1700 Å of Cu seed were used for this study. The ultra-thick photosensitive material used for this investigation was Shin-Etsu SIPR® 7110M-18. No pre-treatment of the wafers was used as good adhesion was observed on Cu. The SIPR 7110M-18 photoresist was coated to the 65 µm target thickness using the process and equipment described in Table 2. Photoresist thickness and uniformity were measured on a Nanometrics M6100A measurement system.

The SIPR 7110M-18 is a chemically amplified i-line photoresist. The thickness at 700 RPM is 65 µm, but it can be easily coated between 20 and 70 µm as shown in the spin speed curve in Figure 3. The photoresist is easily patterned using conventional semiconductor processing. Potassium based developer was used in the experiment because of its fast developing rate. Broadband ghi-line illumination was selected for exposure and the softbake and post exposure bake temperature is kept constant at 130^{o}C and 80^{o}C respectively. The exposure energy range is 2500 mJ/cm^2 to 6000 mJ/cm^2 and the development time is 10 minutes immersion at room temperature, followed by a DI water rinse. The minimum delay time between coat and exposure is 1 hour while the average delay time between other process steps (expose, PEB, develop) is 15 minutes. Effect of delay time on performance was not studied, but photoresist cracking and lifting was observed when there was no delay between steps.

After determining the optimum photoresist process conditions, a set of exposed wafers was sent to Shin-Etsu Chemical in Japan for Cu electroplating and SEM analysis. These wafers were Cu electroplated to a height of 27.5 µm using the conditions shown in Table 3. Only a minimal descum is required because of the high photoresist contrast. After electroplating the photoresist can be easily stripped off by soaking in acetone which is a significant advantage when compared to a number of negative acting acryl based photoresists. The strip process chemistry was not optimized since acetone was readily available and worked easily. It is expected that solvents such as NMP would also work well to cleanly remove the photoresist after electroplating.

2.3 Data Analysis

After exposure the wafers were cleaved for cross section on a Joel JSM 6340F and Hitachi S4100 metrology SEM to show the line/space and contact linearity as well as depth of focus and exposure latitude of 30 µm contacts and lines. Bottom CD measurements were taken at 600X magnification for 30 µm dense lines and square contacts to show depth of focus at nominal exposure and exposure latitude at best focus. Cross sectional SEM photographs and best-fit plots are presented to illustrate masking linearity, exposure latitude and focus latitude for line and contact structures. The results from the data analysis are discussed in Section 3.0.

3.0 RESULTS AND DISCUSSIONS

3.1 Linearity Comparison

Figure 4 shows the process linearity for 65 µm thick SIPR 7110M photoresist at 4500 mJ/cm^2 on Cu substrates for a dense line pattern. This graph shows that the printed feature size is linear with respect to the reticle feature size. This plot was constructed using cross-sectioned SEM data for grouped lines and is a best fit plot of the data to the equation:

$$\mathbf{y} = \mathbf{x} + b \qquad (1)$$

In this equation, $\mathbf{y}$ is the measured linewidth, $\mathbf{x}$ is the reticle linewidth and b is the photomask bias. The photomask bias is +2.4 µm with an R^2 data fit of 0.998. Typically positive photoresists in this thickness range would have a larger photomask bias. Values as large as +8 µm have been measured in previous studies [7,8]. The small bias for SIPR 7110M is probably due to it being a chemically amplified photoresist. Having a small reticle bias is a significant advantage since it can simply reticle design and fabrication.

Figure 5 shows cross sectional SEM photographs of the process linearity for grouped lines exposed in 65 µm of SIPR 7110M photoresist on Cu substrates. All of the linewidths were exposed at 4500 mJ/cm^2 with a focus offset of -10 µm. The sidewall angle is excellent for all line sizes. There is some rounding at the top of the photoresist, but this is normally not a concern for most electroplating applications. There is a small foot at the base of the photoresist at the 20 µm feature size shown in figure (e). The 15 µm feature in figure (f) exhibits a more pronounced foot, but may still be acceptable depending on the application.

Figure 6 shows cross sectional SEM photographs of the process linearity for square contacts exposed in 65 µm of SIPR 7110M photoresist on Cu substrates. All of the contacts were exposed at 4500 mJ/cm^2 with a focus offset of -10 µm. The best exposure dose for the contacts is larger than the grouped lines as discussed in section 3.2. Again, the sidewall angle is excellent with some rounding at the top of the photoresist and a minimal foot at the bottom. The observed resolution of 15 µm contacts in figure (f) far exceeds the target value of 30 µm.

3.2 Exposure Latitude

The process latitude of SIPR 7110M was studied by varying the exposure dose from 3000 to 6000 mJ/cm^2. Figure 7 shows cross sectional SEM photographs of 30 µm grouped lines in 65 µm thick photoresist with a focus offset of -10 µm on Cu substrates. At 6000 mJ/cm^2 as shown in figure (a) the rounding at the top of the photoresist disappears but the slope has a slight reentrant angle near the foot. At 3000 mJ/cm^2 as shown in figure (g) the foot of the photoresist becomes quite pronounced. The dose for the optimal sidewall angle and minimum footing is between 4000 and 5000 mJ/cm^2. Figure 8 shows a plot of bottom linewidth versus exposure dose for both 40 µm grouped lines (circle) and 30 µm grouped lines (square). The dashed lines show both nominal CD's on the reticle. Both line sizes exhibit a characteristic S shape curve with a rapid decrease in size at lower doses then a plateau where the CD has minimal change in dose followed by an accelerated decrease in size at the highest doses. The optimum CD process window corresponds to the plateau region and is 4000 to 5000 mJ/cm^2 for both line sizes.

The process latitude of square contacts was also investigated since this is the most common structure for in-via electroplated bumps. Figure 9 shows cross sectional SEM photographs of 30 µm square contacts in 65 µm thick SIPR 7110M with a focus offset of -10 µm on Cu substrates. At 3000 mJ/cm^2 as shown in figure (g) the contact is not opened. A significant foot is observed at an exposure dose of 4500 mJ/cm^2 as shown in figure (d). This suggests that a higher exposure dose is required for the square contacts than the grouped lines. This exposure bias is similar to that observed in thin photoresists [12]. Figure 10 shows a plot of bottom contact size versus exposure dose for both 40 µm contacts (circle) and 30 µm contacts (square). The dashed line shows the nominal 30 µm CD on the reticle. Both curves show a gradual increase in CD with exposure dose. Even at the highest exposure dose of 6000 mJ/cm^2 the CD is smaller than the nominal CD on the reticle. Therefore, a reticle bias would be needed to obtain the correct contact CD after imaging.

3.3 Focus Latitude

The process latitude of SIPR 7110M was studied by varying the focus from -20 µm to +10 µm from the surface of the photoresist. Figure 11 shows cross sectional SEM photographs of 30 µm grouped lines in 65 µm thick photoresist with an exposure dose of 4000 mJ/cm^2 on Cu substrates. The -20 µm focus offset in figure (a) shows a small foot but rounding at the top of the photoresist. In contrast the +10 µm focus offset in figure (g) shows a large foot and vertical sidewalls at the top of the photoresist. The best compromise between the footing and the top rounding is a focus offset of -10 µm. Figure 12 shows a plot of bottom linewidth versus exposure dose for both 4500 mJ/cm^2 (circle) and 4000 mJ/cm^2 (square) grouped lines. Both expose doses exhibit a bell shaped curve with a maximum CD near 0 µm focus. The flat part of the CD curve occurs at a large negative focus offset. The -10 µm focus condition is a compromise that provides the best sidewall angle while giving a reasonable CD process window. Also at this optimum exposure and focus condition the photomask print bias is fairly small.

Figure 13 shows cross sectional SEM photographs of 30 µm square contacts in 65 µm thick SIPR 7110M with an exposure dose of 4000 mJ/cm^2 on Cu substrates. At the -20 µm focus in figure (a) the contact shows rounding at the top of the photoresist. A large foot is observed with the +10 µm focus as shown in figure (g). The best compromise between the top and bottom of the photoresist is around -10 µm focus. Figure 14 shows a plot of bottom contact size versus focus offset for both 4500 mJ/cm^2 contacts (circle) and 4000 mJ/cm^2 contacts (square). The curve for 4000 mJ/cm^2 shows a gradual decrease in CD size as the focus offset increases. In contrast, the 4500 mJ/cm^2 curve shows essentially a flat response of CD versus focus offset. This 500 mJ/cm^2 increase in exposure dose provides a major increase in focus latitude by reducing the CD sensitivity. Again, a rather small photomask print bias was observed.

3.4 Electroplating

The electroplating performance of SIPR 7110M was also investigated since this is the most common application for ultra-thick photoresists. Figure 15 shows tilt SEM photographs of 27.5 μm thick Cu electroplated grouped lines formed using 65 μm thick photoresist. The resolution and sidewall are excellent down to 15 μm lines as shown in figure (d). However, the lines consistently show wing features in the corners of the structure. The wings are the same size for all of the linewidths which suggests that the photoresist cracked in the corners of the pattern. Figure 16 shows tilt SEM photographs of 27.5 μm thick Cu electroplated square contacts formed using 65 μm thick photoresist. The resolution and sidewall are excellent down to 15 μm contacts as shown in figure (d). However, the contacts show the same wing features in the corners of the structure as the lines. This cracking could have occurred before or during the electroplating operation. A two week time delay between the photoresist patterning and electroplating operations may be the cause of the cracking. Shin-Etsu Chemical is currently investigating modifications in the photoresist to overcome this issue.

4.0 CONCLUSIONS

This study has shown the feasibility of processing the SIPR 7110M photoresist at 65 μm thick with a one coat process on an Ultratech Saturn Spectrum 3e stepper. SIPR 7110M is a positive acting, acid catalyzed material that can be easily processed using conventional semiconductor processing equipment and ancillary process chemicals. Full process characterization was shown for coating, patterning and Cu electroplating.

Linearity, exposure analyses and depth of focus analysis were performed to investigate CD process latitude. It was determined that SIPR 7110M far exceeded the initial resolution goal of 30 μm. Near vertical sidewalls were observed for all feature sizes which meets electroplating requirements. The 15 μm resolution indicates that SIPR 7110M has the capability of supporting future generations of flipchip and WLCSP processes as feature sizes decrease. Depth of focus was shown to be more than adequate for thick film processing. Throughput in regards to wait times and exposure times was determined to be acceptable and far exceeds the performance of standard novalak based photoresists at the same thickness.

Electroplating performance was checked on Cu seed wafers processed at best resolution and exposure. All plating work was done in Japan at Shin-Etsu Chemical. Unfortunately due to the long time delays between developing and plating, cracking occurred in the corners of the structures. The cracking translated into Cu plated wings after stripping. Further modification on the photoresist is currently being investigated to overcome this issue. Also, the photoresist removed cleanly and easily with acetone after electroplating, showing further advantages of a positive photoresist as compared to a negative photoresist. Overall the SIPR 7110M with the Ultratech Saturn Spectrum 3e stepper provided a stable process with very good process latitudes and process extendiblity for devices requiring thick coatings in the range of 65 μm.

5.0 ACKNOWLEDGEMENTS

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Parameter	Spectrum 3e
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 3e stepper used in this study.

Process Step	Parameters	Equipment
SIPR 7110M-18 Coat	Dynamic dispense: 500 RPM for 12 seconds Spread: 1000 RPM for 5 seconds Spin: 700 RPM for 30 sec	ACS200 track
Softbake	Hotplate, 0.1mm proximity 300 seconds at 130^{o}C Delay time: 60 minutes	ACS200 track
Post Exposure Bake	Contact hotplate: 120 seconds at 80^{o}C Delay time: 15 minutes	ACS200 track
Develop	10 minutes immersion in AZ400K 1:3 Room temperature Constant and aggressive agitation Refresh developer after 5 minutes DI water rinse	

Table 2: Process conditions for Shin-Etsu SIPR 7110M-18 for 65 µm thickness on Cu substrates.

Process Step	Parameters	Equipment
Photoresist Descum	Reactive Ion Etch 100 W x 30 seconds 50 Pa, O_2 flow: 200 sccm	ANELVA DEM451
Cu Electroplating	250 mA x 80 minutes room temperature	EEJA MICROFAB Cu200
Photoresist Stripping	Acetone, 10 minutes, room temperature	

Table 3: Process conditions for Cu electroplating.

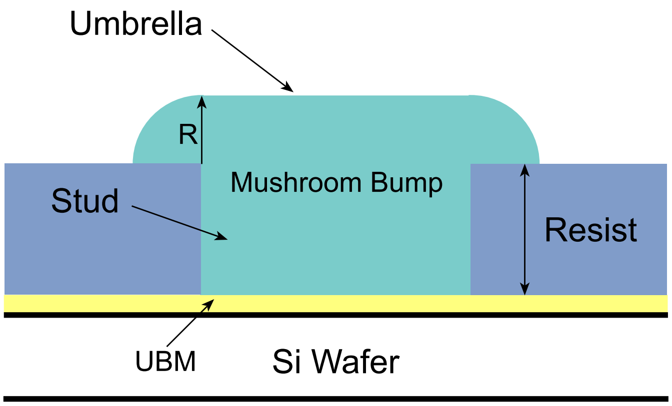


Figure 1: Cross section of a typical mushroom shaped bump. An ultra-thick photoresist allows sufficient solder volume buildup in the stud to eliminate the requirement for an umbrella.

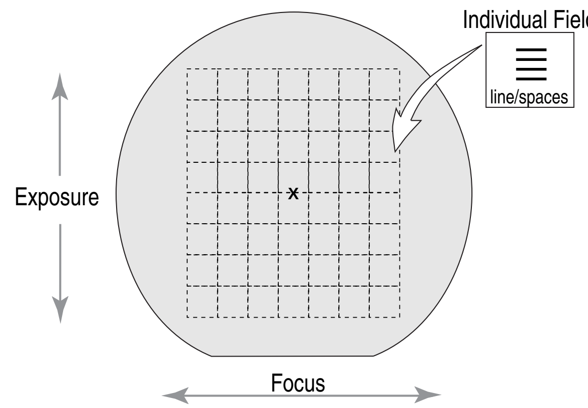


Figure 2: Wafer layout for the focus and exposure matrix. A seven by eight field array was exposed with focus varying in the horizontal axis and exposure dose varying in the vertical axis.

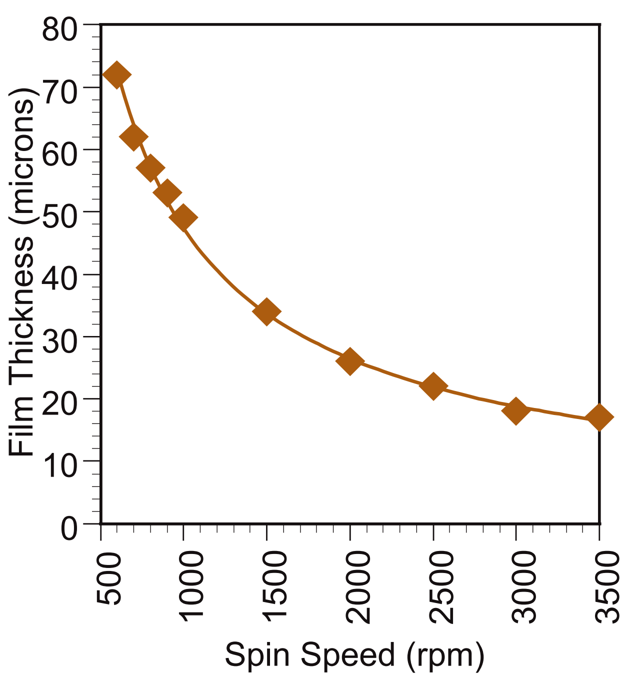


Figure 3: Spin speed curve for SIPR 7110M photoresist on silicon.

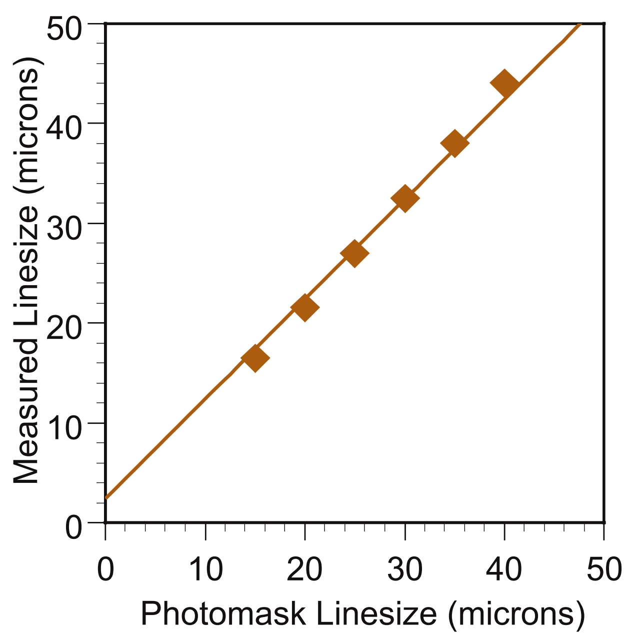
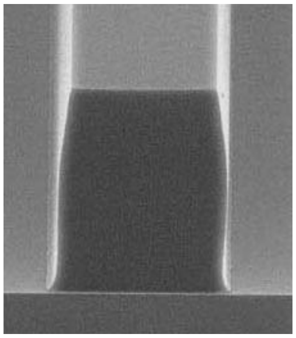
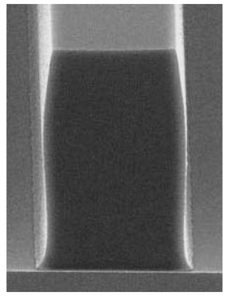
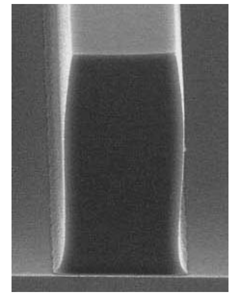
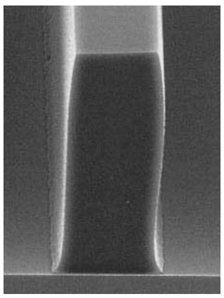


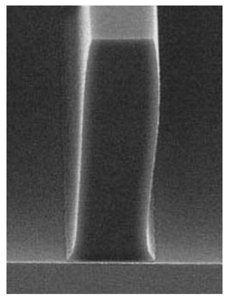
Figure 4: Mask linearity plot of 65 µm thick SIPR 7110M for lines. The exposure dose is 4500 mJ/cm^2 on Cu substrates.


(a) 40 μm line


(b) 35 μm line


(c) 30 μm line


(d) 25 μm line


(e) 20 μm line

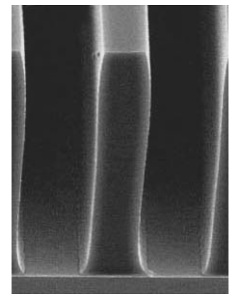
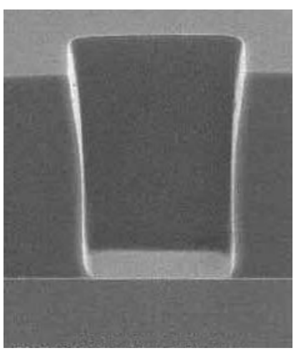
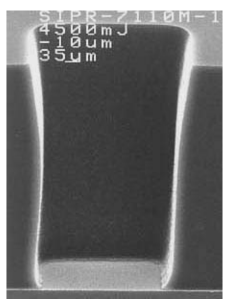
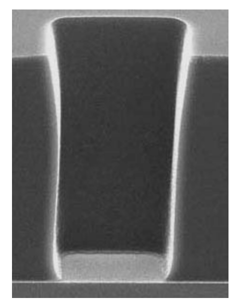

(f) 15 μm line

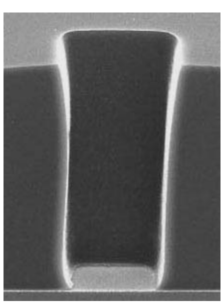
Figure 5: SEM photographs showing linearity for 65 μm thick SIPR 7110M lines exposed at 4500 mJ/cm^2 and a focus offset of -10 μm on Cu substrates. The magnification is 600X in all pictures.

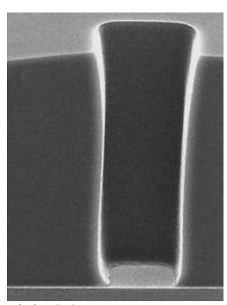

(a) 40 μm contact



(b) 35 μm contact


(c) 30 μm contact


(d) 25 μm contact


(e) 20 μm contact

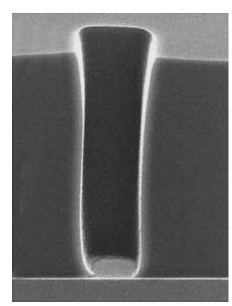
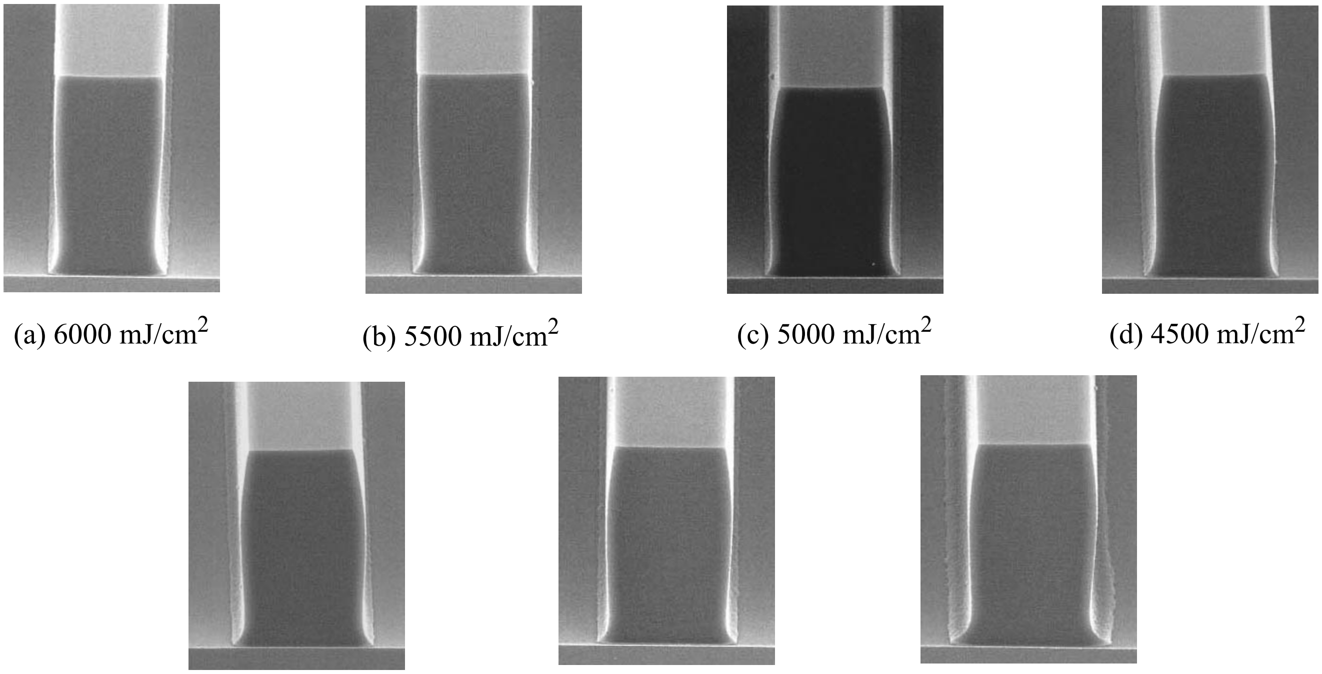

(f) 15 μm contact

Figure 6: SEM photographs showing linearity for 65 μm thick SIPR 7110M square contacts exposed at 4500 mJ/cm^2 and a focus offset of -10 μm on Cu substrates. The magnification is 600X in all pictures.



(a) 6000 mJ/cm^2 (b) 5500 mJ/cm^2 (c) 5000 mJ/cm^2 (d) 4500 mJ/cm^2

(e) 4000 mJ/cm^2 (f) 3500 mJ/cm^2 (g) 3000 mJ/cm^2

Figure 7: SEM photographs showing exposure latitude of 30 µm linewidths in 65 µm thick SIPR 7110M on Cu substrates. The focus offset is -10 µm in all pictures. The magnification is 600X in all pictures.

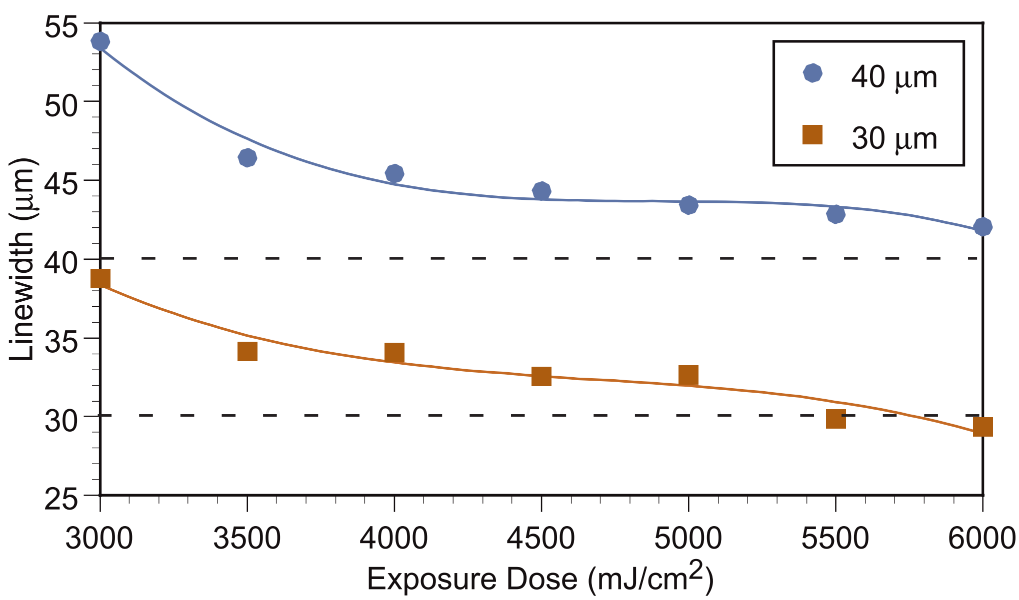
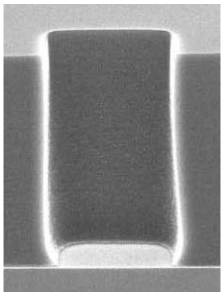
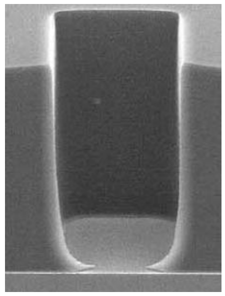


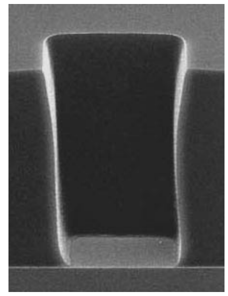
Figure 8: Exposure latitude for 30 and 40 µm lines in 65 µm thick SIPR 7110M on Cu substrates. The focus offset is -10 µm. The CD is measured at the bottom of the photoresist.



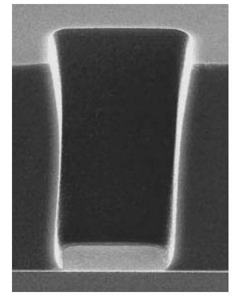
(a) 6000 mJ/cm^2



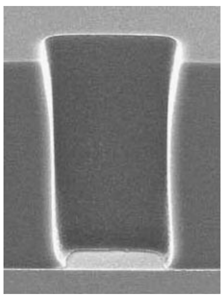
(b) 5500 mJ/cm^2



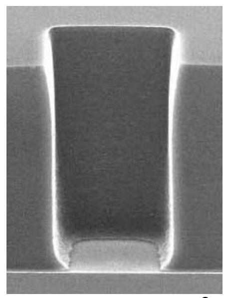
(c) 5000 mJ/cm^2



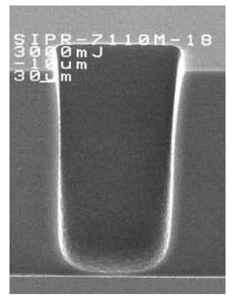
(d) 4500 mJ/cm^2



(e) 4000 mJ/cm^2



(f) 3500 mJ/cm^2



(g) 3000 mJ/cm^2

Figure 9: SEM photographs showing exposure latitude of 30 µm square contacts in 65 µm thick SIPR 7110M on Cu substrates. The focus offset is -10 µm in all pictures. The magnification is 600X in all pictures.

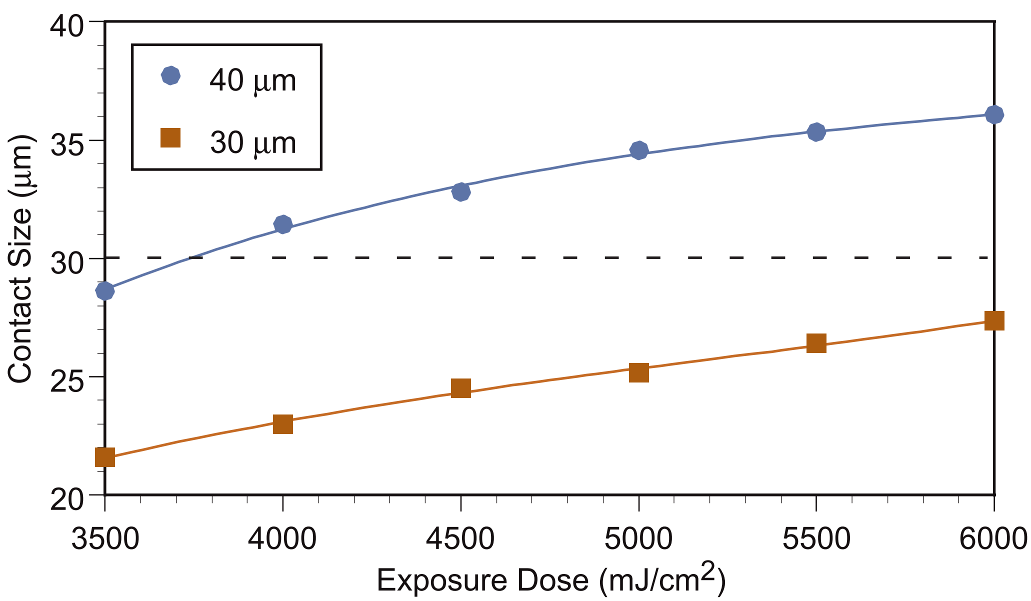
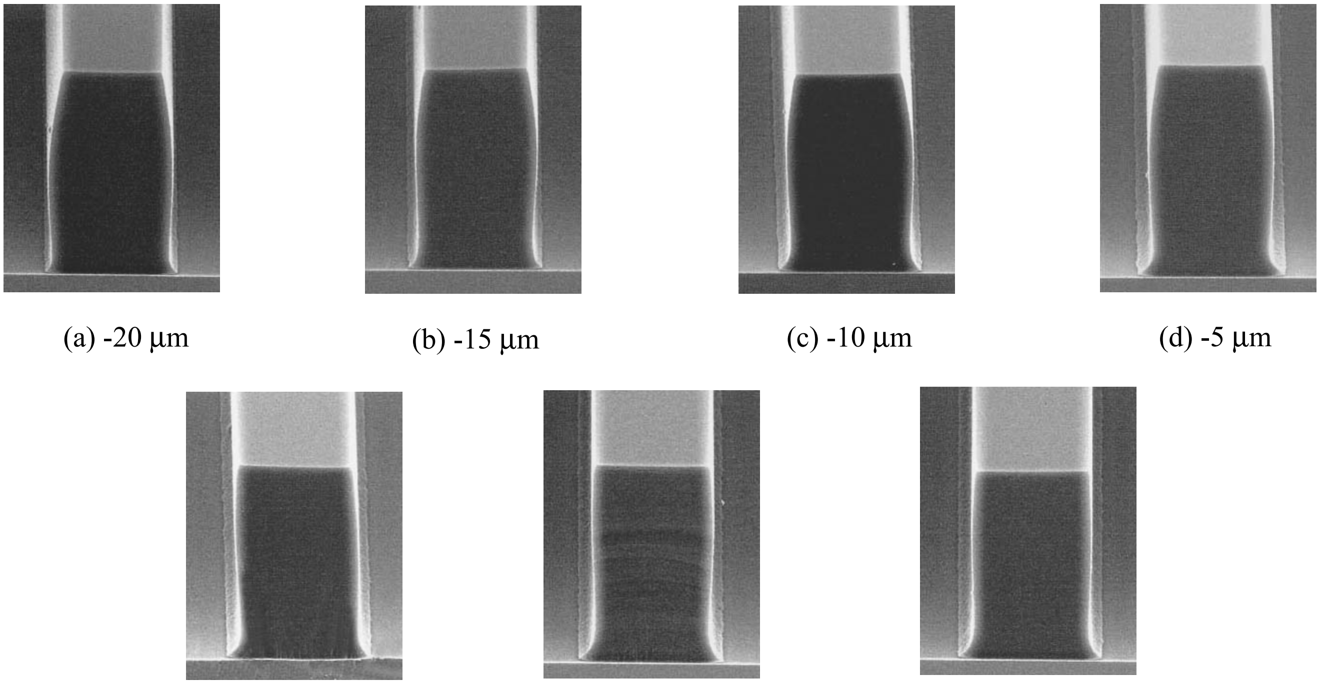


Figure 10: Exposure latitude for 30 and 40 µm square contacts in 65 µm thick SIPR 7110M on Cu substrates. The focus offset is -10 µm. The CD is measured at the bottom of the photoresist.



(a) -20 µm (b) -15 µm (c) -10 µm (d) -5 µm

(e) 0 µm (f) +5 µm (g) +10 µm

Figure 11: SEM photographs showing focus latitude of 30 µm linewidths in 65 µm thick SIPR 7110M on Cu substrates. The exposure dose is 4000 mJ/cm^2 in all pictures. The magnification is 600X in all pictures.

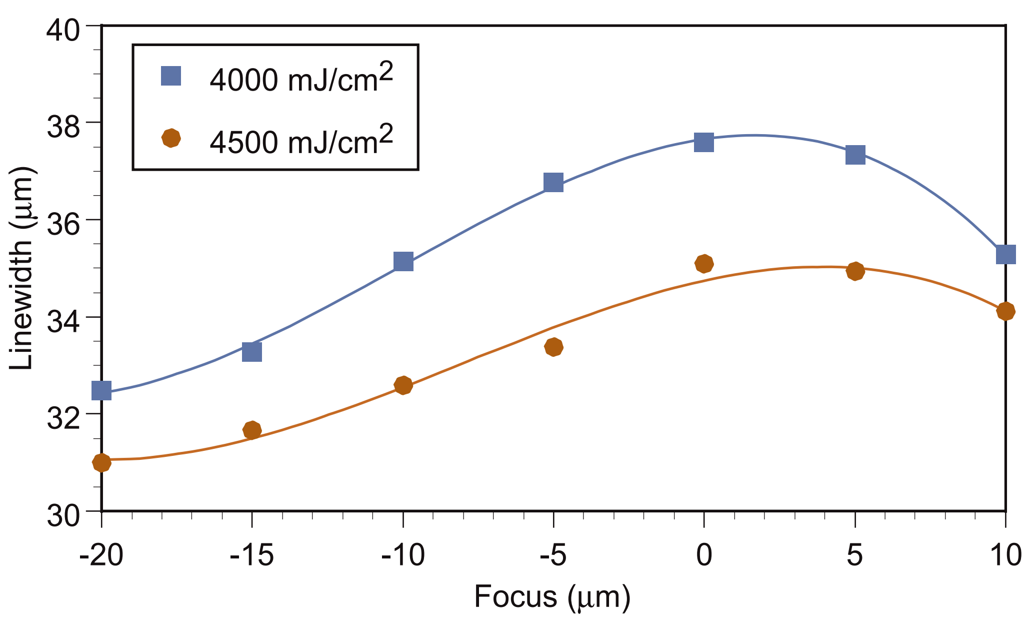
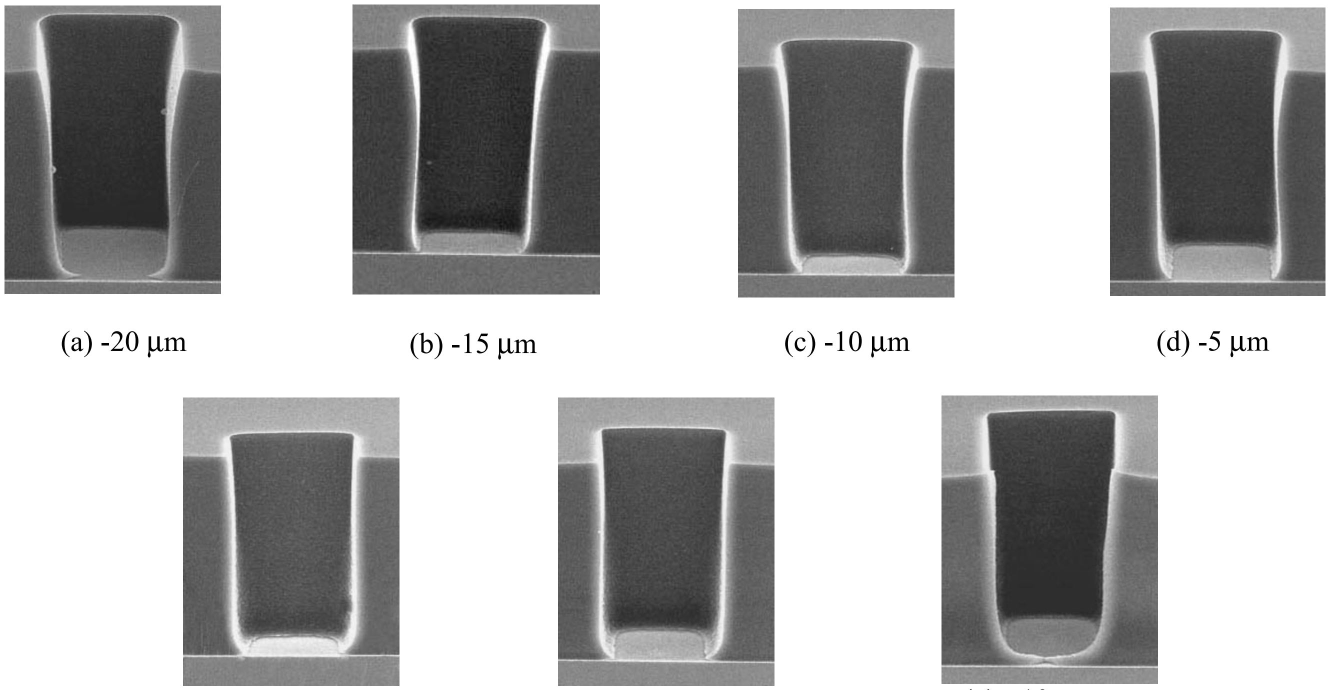


Figure 12: Focus latitude for 30 µm lines in 65 µm thick SIPR 7110M on Cu substrates. Both 4000 and 4500 mJ/cm^2 exposure doses are shown. The CD is measured at the bottom of the photoresist.



(a) -20 µm (b) -15 µm (c) -10 µm (d) -5 µm

(e) 0 µm (f) +5 µm (g) +10 µm

Figure 13: SEM photographs showing focus latitude of 30 µm square contacts in 65 µm thick SIPR 7110M on Cu substrates. The exposure dose is 4000 mJ/cm^2 in all pictures. The magnification is 600X in all pictures.

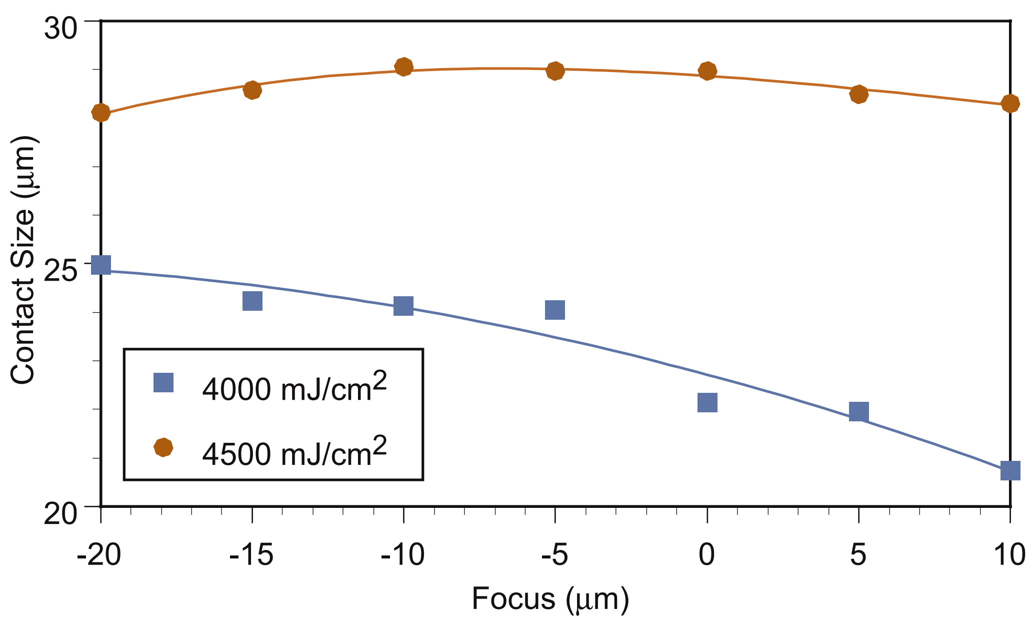
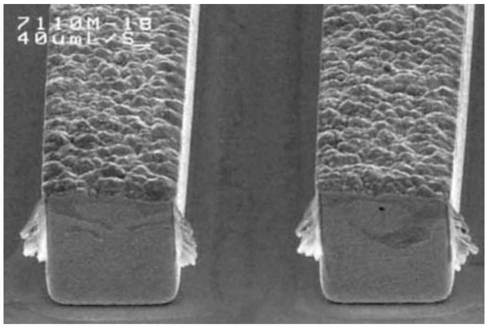
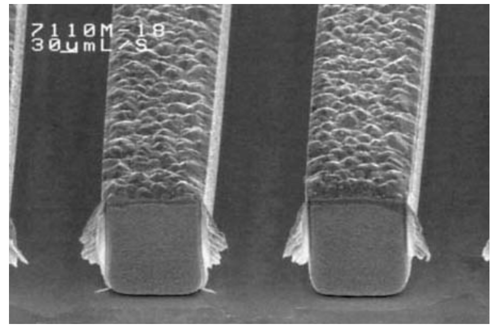


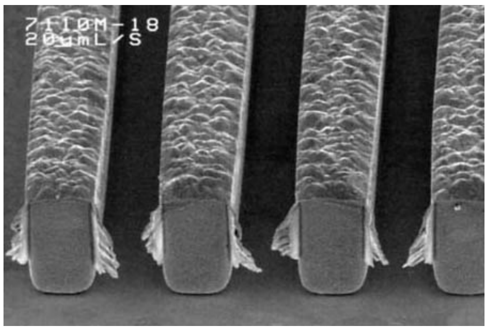
Figure 14: Focus latitude for 30 µm square contacts in 65 µm thick SIPR 7110M on Cu substrates. Both 4000 and 4500 mJ/cm^2 exposure doses are shown. The CD is measured at the bottom of the photoresist.



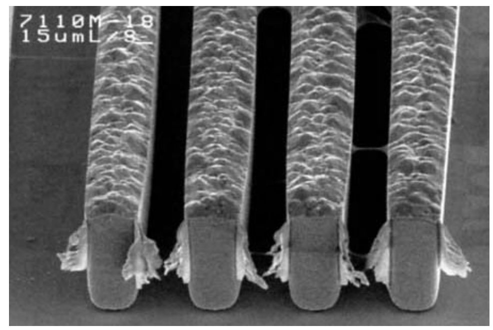
(a) 40 μm line/space



(b) 30 μm line/space

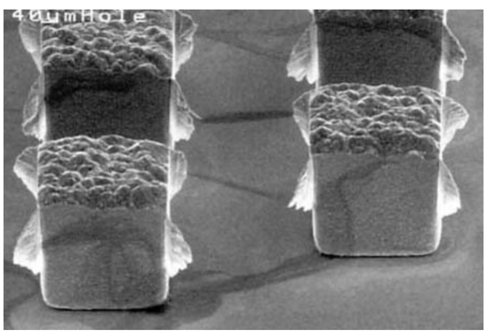


(c) 20 μm line/space

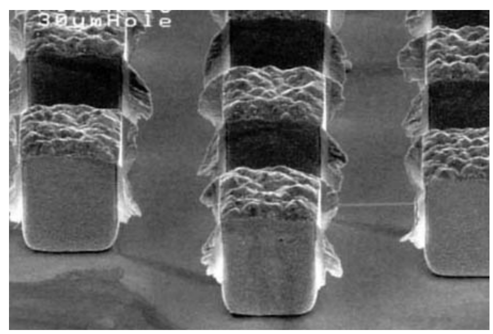


(d) 15 μm line/space

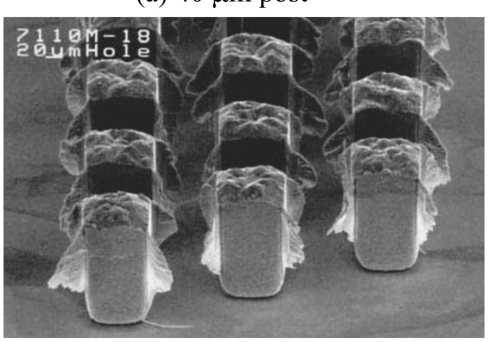
Figure 15: SEM photographs of 27.5 μm thick Cu electroplated lines formed using 65 μm thick SIPR 7110M. The magnification is 500X in all pictures.



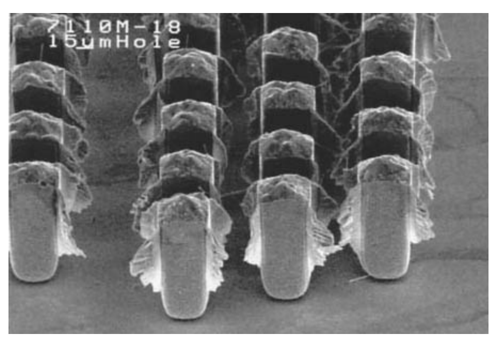
(a) 40 μm post



(b) 30 μm post



(c) 20 μm post



(d) 15 μm post

Figure 16: SEM photographs of 27.5 μm thick Cu electroplated posts formed using 65 μm thick SIPR 7110M. The magnification is 500X in all pictures.