

A Comparison of New Thick Photoresists for Solder Bumping

Warren W. Flack, Ha-Ai Nguyen

Ultratech, Inc.
San Jose, CA 95134

Mark Neisser, Ernesto Sison, Ping Hung Lu, Bob Plass,

AZ Electronic Materials USA Corp.
Somerville, NJ 08876

Toshimichi Makii, Yoshio Murakami

AZ Electronic Materials (Japan) K.K.
Tokyo 160-0023, Japan

The performance requirements for ultra-thick photoresists are rapidly increasing with the dramatic growth in lithographic applications that require electroplating processes. Two of the main applications for ultra-thick photoresists are advanced packaging and nanotechnology (MEMS). 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.

The requirements of thick photoresists for solder electroplating are significantly different from typical thin photoresists used in front end of line applications. As the photoresist becomes thicker, processing times increase for many process steps. Photospeed gets slower due to the requirements for more chemical reactions per area of coating. Coating uniformity and edge bead control also become more difficult as photoresist films get thicker and time delay issues between process steps can arise. This result has led to the requirement for special photoresist formulations for thick photoresist films. These are traditionally positive tone DNQ-Novolak materials such as AZ 50XT. Such materials can be designed to work for a particular range of thicknesses, but as the desired thicknesses increases the processing times can become very long for high volume manufacturing.

Many new bumping schemes require photoresists in a 60 to 70 μm thickness range. While DNQ-Novolak chemistry can work, there is a desire for faster alternatives to improve total cost of ownership (COO) of the lithography cell. In order to have fast photospeeds and reasonable processing times a chemistry that is very photo efficient is needed. Negative tone cross linking chemistries, which can give tens of thousands of chemical events for one photochemical event, provide excellent photospeed and process times. Positive tone chemically amplified photoresist provide hundreds or thousands of chemical events per photochemical event. They are somewhat slower in photospeed than free radical materials, but still provide reasonable photospeeds.

This paper compares the lithography and processing performance of these two newer types of thick film chemistries with the performance of a state of the art DNQ-Novolak thick film photoresist. The lithographic performance of these three ultra-thick positive photoresists were optimized to control critical dimensions (CD), sidewall angles and aspect ratios. The experimental results includes process latitude studies, electroplating performance and stripping performance. The general result is that negative free radical chemistry has the edge in photo-speed and processing times, but positive photoresist is better for stripping and perhaps for process integration.

Key Words: advanced packaging, thick photoresist, solder bumping, plating, process optimization

1.0 INTRODUCTION

Applications for thick photoresist films continue to gain importance for MEMS giant magneto-resistive (GMR) read write head manufacture, and wafer bumping for flip chip applications [1,2,3,4]. The advanced packaging market is growing at a compound annual rate of thirty percent as shown in Figure 1 [1]. The solder bump area is the largest component of this market. For these applications, thick photoresists need to offer vertical sidewalls, excellent adhesion to the substrate, and resistance to stress-induced cracking and underplating [4]. When used for wafer bumping processes, thick photoresist layers have to act as an effective photoresist mold as well as offer resistance to photoresist deformation during electrodeposition to ensure the precise location and geometry of the pillars interconnecting the parts of the finished device. Today there is a rapid increase in the pin counts of most solder bump applications. The corresponding reduction in bump pitch is making conventional “mushroom” type over plating impractical for high bump count devices as shown in Figure 2. Elimination of the umbrella requires even thicker photoresist layers since the entire solder volume buildup is contained in the stud defined by the photoresist mold.

This demand for increased resolution and high aspect ratio leads to great lithographic challenges. For example, the photoresist aspect ratio for thin film heads (greater than 10:1) is actually larger than the aspect ratio used in chip making [2]. The photoresist films can be so thick that substantial residual solvent remains after baking, and the amount of residual casting solvent in the photoresist film is known to affect many lithographic properties such as photospeed, contrast, critical dimension, and thermal behavior. The solvent also acts as a plasticizer and can affect the glass transition temperature (T_g) of polymers [5]. Dissolution rates of photoresist films also depend greatly on the amount of residual casting solvent [6]. So, even though the required resolution is typically not limited by optics, these thick films pose a processing challenge that is different from but no less demanding than that of leading edge sub-quarter micron lithographies.

The bulk of the photoresists used currently for thick film applications are positive-tone diazonaphthoquinone (DNQ)/Novolak photoresists. Compared with front end processing requiring much thinner photoresists, processing thicker photoresists is a substantially more challenging; they require longer bake and development and exhibit slower photospeeds. In addition, coating uniformity and control of the size of the edge bead become more difficult to achieve. To address these problems new materials are coming to the market that are based on different types of chemistry, either free radical negative polymerization or chemically amplified positive tone materials. They each have their strengths and weaknesses.

This paper will examine the performance of three types of thick photoresists based on different types of chemistry. The AZ[®] 50XT is a traditional positive tone diazide naphthoquinone (DNQ) novolak photoresist which is cost effective, robust and compatible with most currently used processes. The AZ[®] 100nXT is a negative-tone photoresist, utilizing cross linking chemistries which provide excellent profiles, photo speeds, and process times. The AZ[®] Exp 100XT is a high performance chemically amplified photoresist which provides excellent profiles, photo speeds and process times for customers desiring a positive tone material. This paper will compare the lithographic and solder electroplating performance of these three photoresists.

2.0 EXPERIMENTAL METHODS

2.1 Lithography Equipment

Lithography for the photoresists evaluated in this study was performed on an Ultratech Saturn Spectrum 300e² Wafer Stepper[™]. The optical specifications for the Saturn Spectrum 300e² is 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 [7].

Broadband exposure is possible due to the unique design characteristics of the Wynne-Dyson lens system. This symmetric catadioptric lens system can be corrected for chromatic aberrations and chromatic variation of other aberrations such as astigmatism and spherical aberrations, over an unusually wide spectral range. The low NA and broadband illumination spectrum of the Saturn Spectrum 300e² provides a more uniform aerial image through the depth of the ultrathick photosensitive materials in contrast to reduction steppers with larger NA's and much narrower bandwidths [8]. In addition, the Spectrum 300e² is equipped with a filter changer, which allows ghi-line (350 to 450 nm),

g-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. The Spectrum 300e² stepper is configured to run both 300 mm and 200 mm wafer sizes. The stepper is also configured with WEP (Wafer Edge Protection) and WEE (Wafer Edge Exposure). The WEE unit uses a Hg arc lamp light source at the prealigner to expose the edge of the wafer coated with positive photoresist. In case of negative photoresist, the WEP ring blocks out the exposure at the edge of the wafer. The purpose of the WEE and WEP features is to create a photoresist free area around the edge of the wafer as a requirement at electroplating.

Multiple Si wafers were exposed in a focus/exposure pattern as illustrated in Figure 3. Focus and exposure latitudes were determined by cross section examination of 60 μm contact patterns for all photoresists with a 4200L Amray SEM metrology tool. All electroplating was done on wafers with Cu seed layer 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 four fields, two for each polarity. Field 1 and 2 contains round, square and octagon contact patterns of 50 μm to 100 μm for 1:2, 1:1 and 2:1 pitches whereas fields 3 and 4 include only 100 μm contacts for consistent bump height at the electroplating operation.

2.2 Photoresist Processing

SEMI standard 200 mm Si and Si with Cu seed wafers were used for this study. The photoresists used were AZ 50XT, AZ Exp 100XT, and AZ 100nXT from AZ Electronic Materials Corporation. These photoresists were selected because of the diversity of their photo-chemistries. The three photoresists were coated to the 65 μm target thickness as measured with the Dektak V300 Si and Tencor profilometers. This thickness was chosen since it is frequently used for mushroom free, solder bump applications.

AZ 50XT is a positive DNQ-novolak material most commonly used for thick photoresist application. Compared with the other two photoresists, the photospeed is slower and requires much longer processing time due to the longer bake and development times. A rehydration time is also necessary after softbake and before exposure. AZ 50XT usually work better with inorganic developers like AZ[®] 400K. The processing conditions for AZ 50XT are shown in Table 2.

AZ Exp 100XT is a new thick positive photoresist with a chemically amplified system. Compared with standard DNQ photoresists, the photospeed is much faster and provides excellent profiles. The processing of AZ Exp 100XT requires a short post exposure delay and a post exposure bake (PEB). AZ Exp 100XT is designed to work in both inorganic and organic developers. The processing conditions for AZ Exp 100XT are shown in Table 3.

AZ 100nXT is a TMAH developable negative photoresist with a free-radical chemistry. The photospeed is much faster even at thicknesses greater than 65 μm . It provides excellent sidewall profiles and processing times are much shorter. AZ 100nXT usually works better with MIF developers like AZ[®] 300 MIF. The processing conditions for AZ 100nXT are shown in Table 4.

2.3 Electroplating

Wafers using Cu as a seed layer were processed with AZ 50XT, AZ 100nXT and AZ Exp 100XT. The processed wafers were sent to Ebara Corporation in Japan for electroplating using lead-free solder (Sn-Ag). The photoresist was stripped at the AZ Electronic Materials facility in New Jersey using AZ[®] 400T as the stripper. The AZ 50XT and the AZ Exp 100XT photoresists, which are both positive photoresists, stripped very easily and required only 5 minutes stripping time with AZ 400T heated at 80°C. The AZ 100nXT material, due to its crosslinking chemistry, required approximately 50 minutes to strip.

2.4 Data Analysis

After photoresist exposure, one set of wafers were cleaved for cross section on an AMRAY 4200L metrology SEM to show depth of focus and exposure latitude of 60 μm contacts for all three photoresists. A second set of wafers was electroplated, photoresist stripped and then cleaved for cross sectional SEM analysis. The results from the data analysis are discussed in Section 3.0.

3.0 RESULTS AND DISCUSSIONS

3.1 AZ 50XT

AZ 50XT is a positive tone, DNQ novolak based, broad spectral sensitivity photoresist. This traditional type of chemistry is cost effective, robust and compatible with most electroplating processes. Wafers were imaged on the Spectrum 300e² stepper with exposure energies ranging from 2100 mJ/cm² to 2900 mJ/cm² and the focus offsets varied from -20 μm to +0 μm . The 50 μm contacts on the test reticle cleared. However, 60 μm test reticle contacts were evaluated since this size is less than the anticipated bump size requirements for the next three years. Cross sectional SEM micrographs of 60 μm contacts in 65 μm of AZ 50XT are shown in Figure 4. The nominal exposure condition is 2500 mJ/cm² with a -20 μm focus offset. There was no significant dark film loss and the full photoresist height remains after development for the contact hole features tested. All the cross section SEM photos exhibit a slightly curved sidewall that is roughly vertical on average. A novolak photoresist film this thick typically has some residual solvent at the bottom of the film, resulting in a slightly faster development rate at the bottom of the film than at the top of the film. If the film had a uniform solvent content throughout the depth of the film, one would see the typical slightly tapered profile of thinner novolak photoresists where the bottom of a contact hole is a little smaller than the top. The combination of this “normal” taper and of faster development at the bottom of the film gives the observed “milk bottle” shape.

The complex profiles observed in this photoresist do not lend themselves to the linear analysis generally used to model photoresist profiles. Measured CD's are the CD's at the bottom of the contact hole. The actual CD measured at nominal exposure conditions is 70.1 μm . This is a bias of +10.1 μm from the reticle feature size.

While AZ 50XT has the advantage of being an industry standard chemistry and a cost effective material, it has the disadvantages of high exposure dose and long development time. It also requires a re-hydration time delay between soft bake and exposure. In our experience, plating compatibility and stripping are excellent, as would be expected for a DNQ novolak chemistry.

3.2 AZ Exp 100XT

AZ Exp 100XT is a positive tone, high performance chemically amplified photoresist. Wafers were imaged on the Spectrum 300e² stepper with exposure energies ranging from 1300 mJ/cm² to 2500 mJ/cm² and the focus offsets varied from -40 μm to +0 μm . The 50 μm contacts on the test reticle cleared. However, 60 μm test reticle contacts were evaluated since this size is less than the anticipated bump size requirements for the next three years. Cross sectional SEM micrographs of 60 μm contacts in 65 μm of AZ Exp 100XT are shown in Figure 5. The nominal exposure condition is 1700 mJ/cm² with a -20 μm focus offset. All cross section SEM photos exhibit excellent profiles. The sidewall profiles are straighter than those of AZ 50XT due to the higher contrast of its chemically amplified system compared to that of 50XT's novolak system. Because the intrinsic profiles are steeper than those of AZ 50XT, less of the “milk bottle” shape is observed and changes in the aerial image due to changing focus settings can be seen in the profile. The photoresist is sensitive to focus offset and shows some profile taper at 0 μm focus offset. There was no significant dark loss and full photoresist height remains for the contact hole features tested. The actual CD measured at nominal exposure conditions is 72.1 μm . This is a bias of +12.1 μm from the reticle feature size.

The AZ Exp 100XT clearly shows an advantage in reduced exposure dose and develop time in comparison to the AZ 50XT. It does require a post exposure bake since it is a chemically amplified material, but does not require a rehydration time delay.

3.3 AZ 100nXT

The AZ 100nXT is a negative tone, high performance photoresist based on free-radical chemistry. Wafers were imaged on the Spectrum 300e² stepper with exposure energies ranging from 400 mJ/cm² to 550 mJ/cm² and the focus offsets varied from -40 μm to +0 μm . The 50 μm contacts on the test reticle cleared. However, 60 μm test reticle contacts were evaluated since this size is less than the anticipated bump size requirements for the next three years. Cross sectional SEM micrographs of 60 μm contacts in 65 μm of AZ 100nXT are shown in Figure 6. The nominal exposure condition is 450 mJ/cm² with a -20 μm focus offset. There was no significant dark loss and full photoresist height remains for the contact hole features tested. The starting film is low in molecular weight with a high solvent diffusivity, so there is a smaller

solvent gradient through the film than in the other two materials. Since the material is negative tone, the intrinsic taper is retrograde. But since the material is relatively transparent at the exposure wavelength, the intrinsic taper in the profile is modest. It only shows up when the film is underexposed or when the best focus is in the middle of the photoresist film. Since these effects are small, all cross section SEM photos exhibit excellent, roughly vertical profiles. There is a slight foot at the bottom of the photoresist. This foot clears easily with standard descum processes that are often used to prepare wafers for plating. The development is fast and only track puddle development is required to clear features in this photoresist. The actual CD measured at nominal exposure conditions is 61.5 μm . This is a bias of +1.5 μm from the reticle feature size.

The AZ 100nXT shows a dramatic reduction of exposure dose in comparison to both the AZ 50XT and 100XT. It lends itself to moderate track develop times using standard TMAH developer. It does not require a post exposure bake or a rehydration time delay. However, it is negative tone which may be a concern for defects on the reticle [9]. Stripping of the photoresist will require more aggressive strippers and a longer time than required for either of the two positive tone photoresists.

3.4 Electroplating

Wafers with each photoresist type were electroplated using lead-free solder (Sn-Ag). All three photoresists demonstrated durability in the electroplating bath with no cracking or adhesion failure. After electroplating the wafers were stripped using AZ400T at 80°C. The stripping time for the AZ 50XT and AZ Exp 100XT photoresists was five minutes. However, the stripping time for the AZ 100nXT photoresist was fifty minutes. The longer strip time is due to the cross linking the material by free radicals making it much harder to remove.

Cross sectional SEM micrographs of 100 μm contacts before and after electroplating are shown for all three photoresists in Figure 7. Plating height of the solder posts were measured and are listed under each photoresist. The electroplated post profile closely matches the photoresist profile for both the AZ 50XT and AZ 100nXT materials. However, the height and shape of the post profile for AZ Exp 100XT appears to be different. It is hypothesized that since the wafers for all three photoresists were electroplated under the same conditions that the height of the solder bumps would be a function of the open area on the wafer. The AZ Exp 100XT had the largest positive CD bias (+12.1 μm) which means that more wafer area is open for electroplating than at nominal CD. As a result the AZ Exp 100XT bumps will shorter than the bumps defined by the other photoresists. This emphasizes the point that the electroplating process needs to be optimized for different size features and different photoresist materials.

4.0 CONCLUSIONS

This paper examined the performance of three types of thick photoresists based on different types of chemistry. A summary of the key performance parameters is shown in Table 6. While AZ 50XT has the advantage of being an industry standard chemistry and cost effective material, it has the disadvantage of high exposure dose, long development time and a complex profile shape. It also requires a rehydration time delay between softbake and exposure. The AZ Exp 100XT clearly shows an advantage in exposure dose and develop time in comparison to the AZ 50XT. It does require a post exposure bake since it is a chemically amplified material but does not require a rehydration time delay. The AZ 100nXT shows a dramatic advantage in terms of exposure dose in comparison to both the AZ 50XT and AZ Exp100XT. It lends itself to track develop using standard TMAH developer. It does not require a post exposure bake or a rehydration time delay. However, it is negative tone which raise concerns about defects on the reticle.

All three photoresists demonstrated durability in the electroplating bath with no cracking or adhesion failure. However, the stripping time for the AZ 100nXT photoresist was fifty minutes versus five minutes for the AZ 50XT and AZ Exp 100XT. The longer strip time is from the cross linking the material by free radicals making it much harder to remove.

5.0 ACKNOWLEDGEMENTS

The authors would like to thank Dr. Kiumi Rei from Ebara for electroplating support and as well as Hai Nguyen from Ultratech for photoresist process support.

6.0 REFERENCES

1. M. Ranjan and S. Kay, "Lithography for Advanced Packaging", *Advanced Packaging*, August 2002.
2. Chris A. Mack, Gary E. Flores, Warren W. Flack, Elizabeth Tai, "Lithographic Modeling Speeds Thin-Film-Head Development", *Data Storage*, 55-58, May/June 1996.
3. Katherine Derbyshire, Ed Korczynski, "Giant Magnetoresistance for Tomorrow's Hard Drives", *Solid State Technology*, 57-66, (Sept. 1995).
4. Stanley Ficner, James Hermanowski, Ping-Hung Lu, Elaine Kokinda, Yvette Perez, and Ralph Dammel, "The Development of Two New Thick Film Photoresists", *Advances in Resist Technology and Processing XIII Proceedings*, SPIE **2724**, 654-665, (1996).
5. Bernhard T. Beauchemin, Jr., Charles E. Ebersole, Ivan Daraktchiev, "The Influence of Retained and Absorbed Solvent on Novolak and Resist Film Dissolution and Thermal Behavior", *Advances in Resist Technology and Processing XI Proceedings*, SPIE **2195**, 610-622, (1994).
6. Allen B. Gardiner, Anwei Qin, Clifford L. Henderson, Sanju Pancholi, William J. Koros, C. Grant Willson, "Diffusivity Measurements in Polymers II: Residual Casting Solvent Measurement by Liquid Scintillation Counting", *Advances in Resist Technology and Processing XIV Proceedings*, SPIE **3049**, 850-860 (1997).
7. W. Flack, A. Nguyen, E. Capsuto, "Process Improvements for Ultra-Thick Photoresist Using a Broadband Stepper", *Optical Microlithography XIV Proceedings*, SPIE **4326**, 2001.
8. B. Todd, W. Flack, S. White, "Thick Photoresist Imaging Using a Three Wavelength Exposure Stepper", *Micromachining and Microfabrication Process Proceedings*, SPIE **3874**, 1999.
9. D. Schurz, W. Flack, G. Newman, "The Printability of 1X Reticle Defects for Submicron Design Rules", *Symposium on Photomask Technology and Management Proceedings*, SPIE **3236**, 1997.
10. Reports prepared by Tech Search International and E&G Technology Partners.

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.

Process Step	Parameters	Equipment
HMDS Vapor Prime	20 minutes at 150°C	YES Oven
AZ 50XT Coat	Dynamic dispense for 30 rpm for 10 seconds Spread: 1800 RPM for 1 seconds Spin: 700 RPM for 20 seconds Backside rinse: 450 rpm for 10 seconds Dry: 1000 rpm for 3 seconds	Suss ACS 200
Softbake	Hotplate, 0.5 mm proximity 2 minutes at 85°C 12 minutes at 115°C	Suss ACS 200
Exposure	Delay Time before exposure: 60 minutes Focus/Exposure matrix Delay Time after exposure: None	Spectrum 300e ²
Develop	8 minute immersion in AZ 400K (1:3 dilution) Room temperature Constant and aggressive agitation DI water rinse	

Table 2: Process conditions for AZ 50XT for 65 μm thickness.

Process Step	Parameters	Equipment
AZ Exp 100XT Coat	HMDS Vapor Prime Dynamic dispense for 50 rpm for 30 seconds Spread: 1000 RPM for 1 seconds Spin: 600 RPM for 30 seconds Flash Spin: 1000 RPM for 0.2 seconds	TEL Mark 8
Softbake	Hotplate, 0.1 mm proximity, 600 seconds at 115°C	TEL Mark 8
Edge Rinse	800 RPM for 120 seconds	TEL Mark 8
Exposure	Delay Time before exposure: None Focus/Exposure matrix Delay Time after exposure: 30 minutes	Spectrum 300e ²
Post Exposure Bake	180 seconds at 40°C, contact hotplate	Suss ACS 200
Develop	4 minute immersion in AZ303 (1:6) Room temperature Constant and aggressive agitation DI water rinse	

Table 3: Process conditions for AZ Exp 100XT for 65 μm thickness.

Process Step	Parameters	Equipment
AZ 100nXT Coat	Dynamic dispense for 30 rpm for 10 seconds Spread: 1700 RPM for 1 seconds Spin: 800 RPM for 10 seconds Backside rinse: 450 rpm for 10 seconds Dry: 1000 rpm for 3 seconds	Suss ACS 200
Softbake	Hotplate, 0.5 mm proximity, 360 seconds at 115°C	Suss ACS 200
Exposure	Delay Time before exposure: None Focus/Exposure matrix Delay Time after exposure: None	Spectrum 300e ²
Develop	Developer: 2.38% TMAH 4 puddles for 60 seconds each Room temperature DI water rinse	Suss ACS 200

Table 4: Process conditions for Clariant AZ 100nXT for 65 µm thickness.

Process Step	Parameters	Equipment
Solder Electroplating	Lead-free Eutectic Sn-Ag Alloy 3.5 µm/minute, 25 °C	Ebara UFP-300M
Photoresist Stripping AZ400T	AZ 50XT, AZ Exp 100XT: 5 minutes at 80 °C AZ 100nXT: 50 minutes at 80 °C	

Table 5: Process conditions for Lead Free solder electroplating.

Photoresist	Profile	Exposure Dose (mJ/cm ²)	Develop Type/ Time (Min.)	Stripping Time (Min.)
AZ 50XT	Milk Bottle	2500	Immersion / 8	5
AZ Exp 100XT	Vertical	1700	Immersion / 4	5
AZ 100nXT	Vertical	450	Puddle / 4	50

Table 6: Photoresist Performance Comparison.

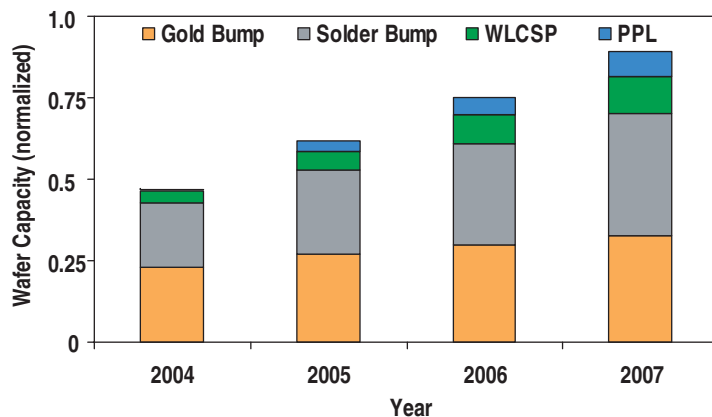


Figure 1: Wafer capacity forecast of 30% annual compound growth rate of the advanced packing market [10].

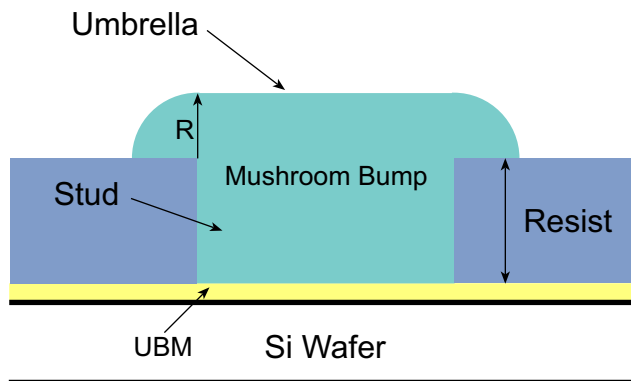


Figure 2: Cross section of a typical mushroom shaped bump. An ultra-thick photoresist allows sufficient solder volume buildup in the stud to eliminate the requirement for an umbrella.

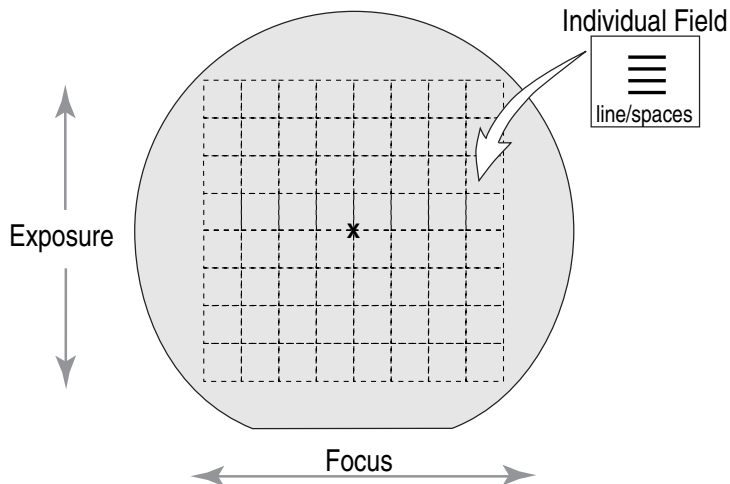
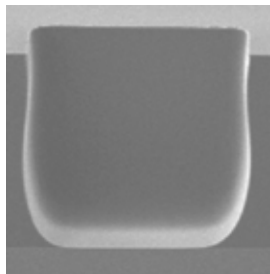
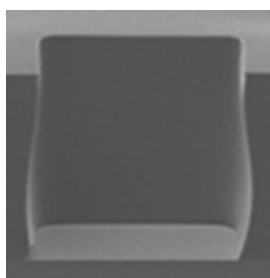


Figure 3: Wafer layout for the focus and exposure matrix. An eight by eight field array was exposed with focus varying in the horizontal axis and exposure dose varying in the vertical axis.

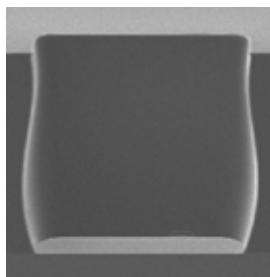
Exposure Latitude



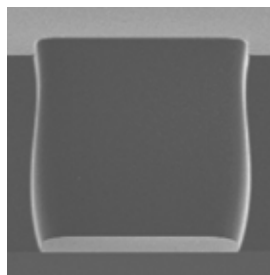
(a) Exposure = 2100 mJ/cm², Focus= -20 μm



(b) Exposure = 2500 mJ/cm², Focus= -20 μm

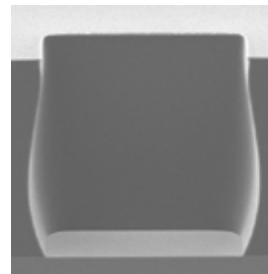


(c) Exposure = 2700 mJ/cm², Focus= -20 μm

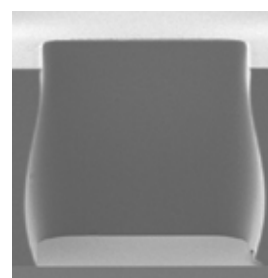


(d) Exposure = 2900 mJ/cm², Focus= -20 μm

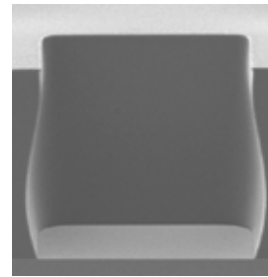
Focus Latitude



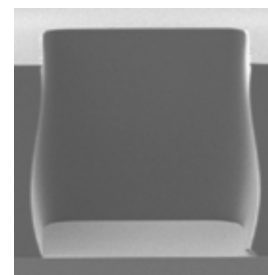
(e) Exposure = 2500 mJ/cm², Focus= 0 μm



(f) Exposure = 2500 mJ/cm², Focus= -10 μm



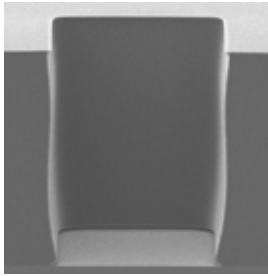
(g) Exposure = 2500 mJ/cm², Focus= -15 μm



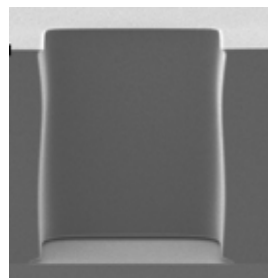
(h) Exposure = 2500 mJ/cm², Focus= -20 μm

Figure 4: SEM Photographs illustrating process latitude of 60 μm contacts in 65 μm thick AZ 50XT, ghi-line exposure, The nominal condition is -20 μm focus and 2500 mJ/cm².

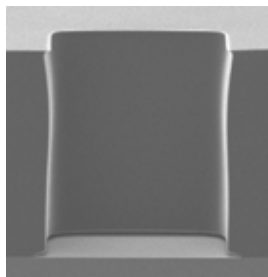
Exposure Latitude



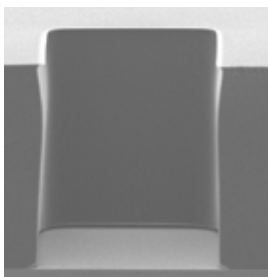
(a) Exposure = 1300 mJ/cm², Focus= -20 μm



(b) Exposure = 1700 mJ/cm², Focus= -20 μm

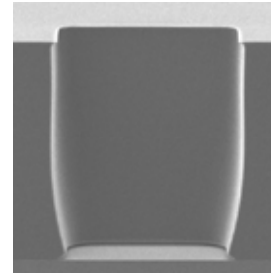


(c) Exposure = 2100 mJ/cm², Focus= -20 μm

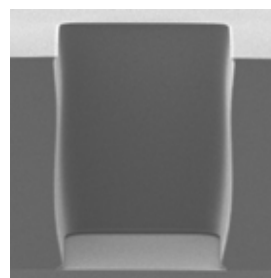


(d) Exposure = 2500 mJ/cm², Focus= -20 μm

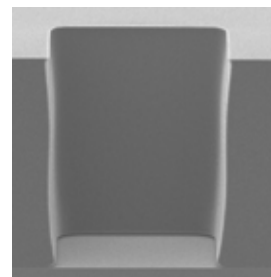
Focus Latitude



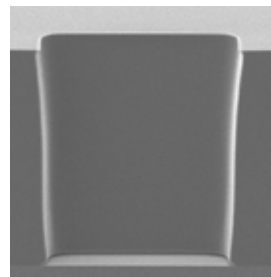
(e) Exposure = 1300 mJ/cm², Focus= 0 μm



(f) Exposure = 1300 mJ/cm², Focus= -20 μm



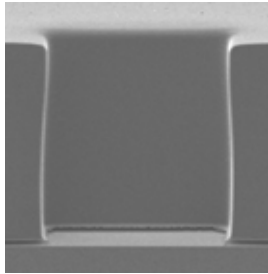
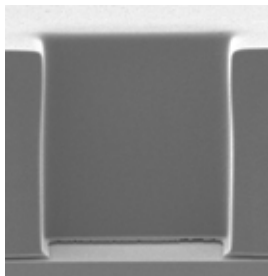
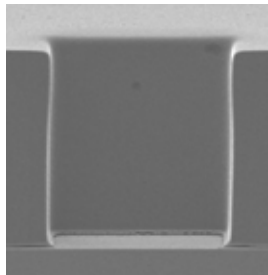
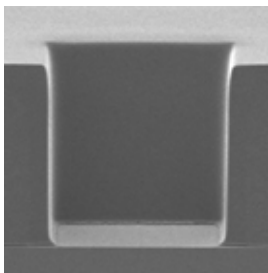
(g) Exposure = 1300 mJ/cm², Focus= -30 μm



(h) Exposure = 1300 mJ/cm², Focus= -40 μm

Figure 5: SEM Photographs illustrating process latitude of 60 μm contacts in 65 μm thick AZ Exp 100XT, ghi-line exposure, The nominal condition is -20 μm focus and 1700 mJ/cm².

Exposure Latitude

(a) Exposure = 400 mJ/cm², Focus= -20 μm(b) Exposure = 450 mJ/cm², Focus= -20 μm(c) Exposure = 500 mJ/cm², Focus= -20 μm(d) Exposure = 550 mJ/cm², Focus= -20 μm

Focus Latitude

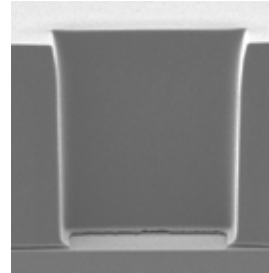
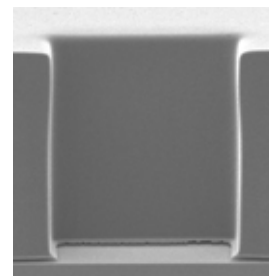
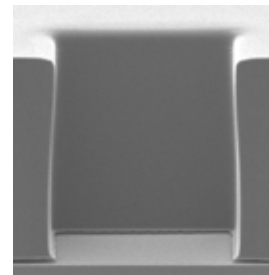
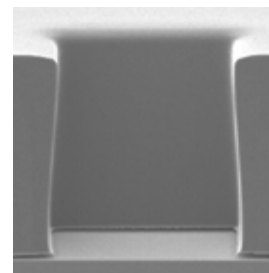
(e) Exposure = 450 mJ/cm², Focus= 0 μm(f) Exposure = 450 mJ/cm², Focus= -20 μm(g) Exposure = 450 mJ/cm², Focus= -30 μm(h) Exposure = 450 mJ/cm², Focus= -40 μm

Figure 6: SEM Photographs illustrating process latitude of 60 μm contacts in 65 μm thick AZ 100nXT, ghi-line exposure, The nominal condition is -20 μm focus and 450 mJ/cm².

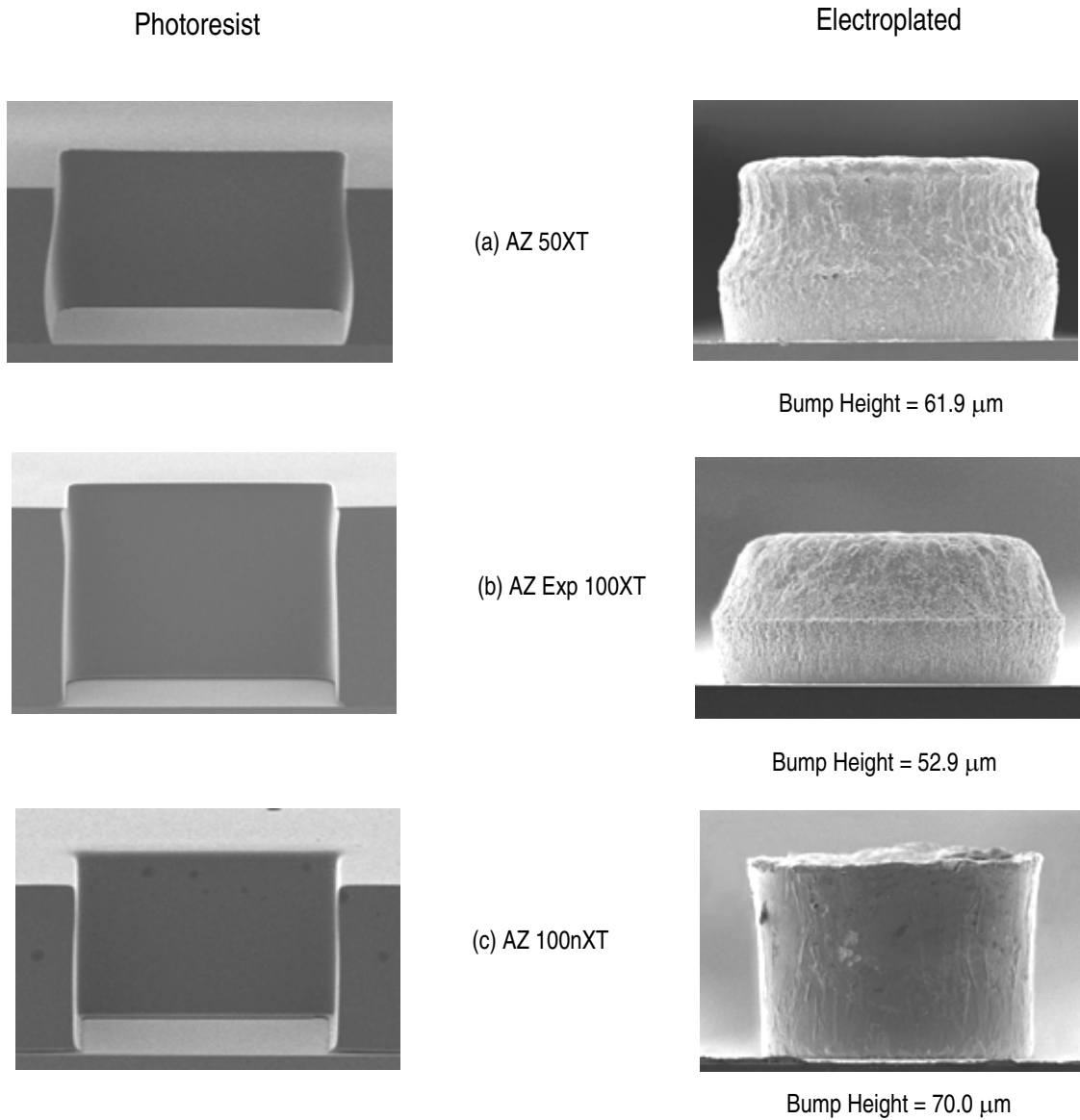


Figure 7: SEM Photographs of the three AZ photoresists before and after electroplating. The photoresist image is a 100 μm square contact and the electroplated structure is a 100 μm lead free solder bump.