An Optimized Process for Ultrathick Photosensitive Polyimide Applications

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1.0 Abstract

Photosensitive polyimides (PSPIs) have found acceptance in the IC industry as a stress buffer and α-ray shielding material in packaging applications. The use of PSPI overcoat eliminates several process steps and reduces IC packaging costs when compared to non-photosensitive polyimides (nPSPIs) or other processes.

Present packaging applications for photosensitive polyimide utilize aspect ratios of 1:1 (film thickness/minimum feature size). Marketplace trends indicate the need for smaller packages and therefore smaller features on the interconnect level of the package. Producing smaller features requires the use of polyimide films approaching 40 μm in thickness. In addition, the α-ray shielding layer application requires similar film thicknesses. These requirements are creating a demand for photosensitive polyimide processes that have excellent resolution and provide thick film protection capability.

This paper will discuss the results of an investigation of solvent developed PSPI for ultrathick PSPI applications using a high throughput g-line lithography system optimized for thick film processing. The polyimide to be investigated is DuPont Pyralin PI-2721. The required developer and rinse solutions are also discussed. Cross sectional analysis is used to determine the performance of 40 μm PSPI materials with aspect ratios in excess of 1:1.

2.0 INTRODUCTION

The thermal and dielectric characteristics of photosensitive polyimide are acceptable for a number of applications in the semiconductor industry. A wide variety of materials have been developed and are made commercially available to meet requirements of different applications, such as interlevel insulation, stress buffer layer, and α-ray shielding layers of semiconductor devices.

Stress buffer coating has been the largest application for photosensitive polyimide. A thick film of polyimide is applied between the passivation layer of the semiconductor device and the molding material of the plastic package to act as a buffer layer. Schuckert et al. [1] reported that this thick film of polyimide layer can eliminate or minimize quality problems related to stresses built up in the plastic packages. Franklin et al. [2] also reported that this polyimide buffer layer application had been proven in the industry with a very good reliability history.

In addition to its yield and quality benefits, photosensitive polyimide also offers cost savings [3] [4]. The stress buffer layer can be applied and patterned on the wafer level similar to a standard resist process. The photosensitive polyimide has another advantage over conventional polyimide. Because it does not require a photoresist film as the pattern transferring layer, several lithography steps in the manufacturing cycle can be eliminated. Rose et al. [5] reported that this simplified process offered a performance superior to the conventional polyimide application.

Several papers that characterize properties of photosensitive polyimide films of different thicknesses have been published recently. Flack et al. [6] presented the characterization methodology and results of two commercially available photosensitive polyimide films of 12 μm thick. Cheang et al. [4] reported performance results of a commercial polyimide product at three different thicknesses, 10, 15, and 20 μm. However, there is an increasing demand for thicker films (above 30 μm) for small package and α-ray shielding applications. These ultrathick film requirements together with high aspect ratios (larger than 1:1), have raised challenges to material suppliers, lithography equipment manufacturers, and process engineers.

This paper will present characterization results for a commercially available solvent developed photosensitive polyimide using standard photoresist characterization techniques. Two different film thicknesses were investigated. A high throughput gh-line stepper was used as the lithography tool. Focus exposure matrix experiments were run to study the available process latitudes. Bossung plots and a cross-sectional SEM analysis were applied to show the performance of the process.

3.0 EXPERIMENTAL METHODS

Bare silicon wafers of 150 mm diameter were used throughout the experiment. These wafers were not HMDS vapor primed, since the adhesion technique is not effective for photosensitive polyimides [7].

An Ultratech Titan Wafer Stepper® was the lithography system used throughout this process characterization. The Ultratech stepper is based upon the 1X Wynne-Dyson lens design. It provides broadband illumination consisting of the g and h lines including the wavelength continuum from 390 to 450 nm [8]. The stepper has a numerical aperture of 0.26 and partial coherence of 0.6. The Titan has a field size of 44 x 22 mm, although the full field size was not utilized for this process characterization.

A test reticle designed specifically for the thick film process was used to simplify cross-sectioning for the process characterization. As a result of the 1X lens design of the Ultratech Stepper, two unique exposure fields may be placed on a single 6 x 6 x 0.25 inch reticle. This reticle contains two exposure fields with identical test patterns, each of opposite polarity. The dark-field (mostly chrome) was used to pattern the line/space features for CD measurement. The bright-field (mostly clear) was used to pattern several contacts that are more representative of polyimide stress-buffer layers. These polarity requirements are due to the negative tone chemistry of most photosensitive polyimides.

The wafer layout consisted of an 11 x 11 focus/exposure array as illustrated in Figure 1. The dimension of each of the 121 sites was 10 x10 mm. Although the field size of the lithography system was much larger than 10 x10 mm, this field size was chosen to maximize the number of unique focus and exposure conditions on each wafer. Using this approach, wafer-to-wafer process variations were minimized and the total number of wafers required for the process characterization was greatly reduced.

Previous studies indicate that optimal results are typically obtained with negative focus settings [4]. Correspondingly, only negative focus settings were investigated in this characterization. Focus was varied along the x-axis of the array from -21 µm to -1 µm in 2 µm increments. Exposure energy was varied along the y-axis from 1000 to 2500 mJ/cm^2 in 150 mJ/cm^2 increments. The nominal exposure dose, as recommended by DuPont, was approximately 1500 mJ/cm^2.

All coating and softbake processes were performed on a Solitec 5110C system. The coating process consisted of a static dispense, a constant acceleration spread process, and a final spin cycle. The softbake process consisted of a multistep process at two different temperatures. The conditions recommended by DuPont consisted of an initial softbake for 180 seconds at 70 °C followed by a second bake for 180 seconds at 90 °C. Several softbake temperatures were investigated to determine relative impact on adhesion. Temperatures of 110 and 115 °C were investigated in addition to the recommended temperature of 90 °C. The wafers were held in hard-contact with the hotplates and were softbaked in ambient conditions. The optimal coating and softbake parameters are shown in Table 1.

Coating Process	38.5 µm Film	35 µm Film
Spread	10 seconds @ 500 RPM	10 seconds @ 500 RPM
Spin	30 seconds @ 1000 RPM	40 seconds @ 1000 RPM
Softbake-		
Step 1	180 seconds @ 70 °C	180 seconds @ 70 °C
Step 2	180 seconds @ 115 °C	180 seconds @ 110 °C

Table 1: Polyimide Coating and Softbake Process Parameters

The film thickness was measured using a Tencor FT700 measurement system. Forty-nine sites were measured on each wafer. The Tencor provides a variety of data for each wafer including contour maps, maximum/minimum/mean thickness measurement, and standard deviation. Cauchey coefficiency for the polyimide were experimentally determined by Prometrix.

A Solitec spray development system was used for all polyimide development processing. This material requires specific developer (DE6180) and rinse solutions (RI 9180), which were supplied by DuPont. The process consisted of using a continuous spray of developer, developer and rinse overlap, rinse, and a spin dry. Develop time was optimized for the two polyimide film thicknesses investigated. The develop conditions used for both film thicknesses are listed in Table 2.

Develop Conditions	35 µm Film	38.5 µm Film
Develop	80 seconds @ 350 RPM	90 seconds @ 350 RPM
Overlap	10 seconds @ 400 RPM	10 seconds @ 400 RPM
Rinse	30 seconds @ 1000 RPM	30 seconds @ 1000 RPM
Spin Dry	30 seconds @ 1400 RPM	30 seconds @ 1400 RPM

Table 2: Photosensitive Polyimide Develop Process Parameters

The polyimide critical dimension (CD) measurements were made using a Hitachi S-7280 SEM. The 30 µm horizontal features were measured in a 7 x 7 array at the center of the total 11 x 11 matrix, for a total of 49 measurements per wafer. Measurements were taken top-down with a 50 percent threshold setting.

4.0 RESULTS AND DISCUSSION

4.1 Softbake Temperature

Initial test wafers were softbaked to the DuPont recommended process of 180 seconds at 70 °C followed by a second bake step of 180 seconds at 90 °C. Significant delamination of most features less than 40 µm were observed at these conditions. The second softbake temperature was increased to evaluate possible improvements to adhesion as well as deterioration of lithographic performance. Adhesion of the 38.5 µm film was improved at 115 °C, with partial delamination occurring for feature sizes ≤20 µm. The final spin time at the coating step was decreased from 40 to 30 seconds to compensate for the additional film thickness loss caused by the increased softbake temperature. Adhesion of the 35 µm film was also improved by increasing the softbake temperature from 100 to 110 °C. To obtain the desired film thickness, the final spin time of the coating process was left at 40 seconds.

4.2 Focus/Exposure Results

Bossung plots for 30 µm lines in both the 38.5 and 35 µm polyimide film thicknesses are shown in Figures 2 and 3. Both plots include the ±10 percent CD control limits in order to quantify process latitude.

The data for the 38.5 µm film indicates little dependence on focus setting. All 49 measurements taken are within the ±10 percent control limits. The optimal focus and exposure conditions appear to be approximately -12 µm and 1450 mJ/cm^2, respectively. At these conditions the CD is very near the desired value and variations in focus and exposure have minimal impact on the CD.

The data for the 35 µm film seems to suggest that the measured sites are overexposed. All of the CDs exceed the desired value at the lowest exposure dose. As focus is varied to less negative values, the CDs increasingly fall within the ±10 percent control limits. This would suggest that features that are overexposed have much less focus latitude than those within the correct exposure range.

4.3 SEM Results

SEM analysis for both the 38.5 and 35 µm polyimide films are shown in Figures 4-7. For the 38.5 µm film, the sidewall profile characteristics do not vary significantly with variation in exposure dose or focus. The lines exhibit a smooth top surface and a slight undercutting at the base of the feature.

5.0 CONCLUSIONS

A very thick photosensitive polyimide process was successfully developed and characterized. Two thick polyimide films were analyzed using standard photoresist characterization techniques. Bossung plots and cross-sectional SEM analyses were used to illustrate relative lithographic performance and process latitude.

Results suggest a slightly higher softbake temperature than the manufacturer's recommended temperature is required to improve adhesion of the thick photosensitive polyimide investigated. Optimal focus and exposure conditions for the 38.5 μm film appear to be -12 μm and 1450 mJ/cm^2, respectively. However, significant process latitude is exhibited for the conditions investigated. The feature sizes are within the desired control limits throughout all of the focus and exposure conditions.

Results for the 35 μm film suggest that the range of exposure conditions investigated was not optimal. While many of the combinations of focus and exposure yield features within the desired control limits, all features measured appear to be over exposed. At 1300 mJ/cm^2, the lowest exposure energy investigated, all CDs have dimensions larger than the targeted 30 μm.

6.0 REFERENCES

1. Schuckert, C. et al., IEEE/SEMI Advanced Semiconductor Manufacturing Conference, (1990) pp.72.

2. Franklin, C. et al., “Polyimide Evaluations for Controlled Collapse Chip Connection and Passivation Stress Buffer Technologies,” OCG Microlithography Seminar, Interface ‘94 Proceedings, (1994) pp. 91 -104.

3. Newman, G, “Lithography Requirements for Photosensitive Polyimide Processing,” SEMICON Taiwan ‘95.

4. Cheang, P. et al., “Optimization of Photosensitive Polyimide Process for Cost Effective Packaging,” Surface Mount Technology Seminar, 1996.

5. Rose, John D., “A Practical Comparison of Photosensitive and Non-Photosensitive Polyimide Used as a Buffer Coat,” OCG Microlithography Seminar, Interface ‘94 Proceedings, (1994) pp. 269-287.

6. Flack, W. et al., “An Investigation of the Properties of Photosensitive Polyimide Films,” SPIE Vol 27-261, Optical Microlithography (1996), pp. 169-185.

7. DuPont Electronic Materials, “Pyralin PD Polyimide Coatings_PI2700 Processing Guidelines,” pp. 4.

8. Hershal, R., “Characterization of the Ultratech Wafer Stepper,” SPIE Vol. 334 Optical Microlithography, 1982.

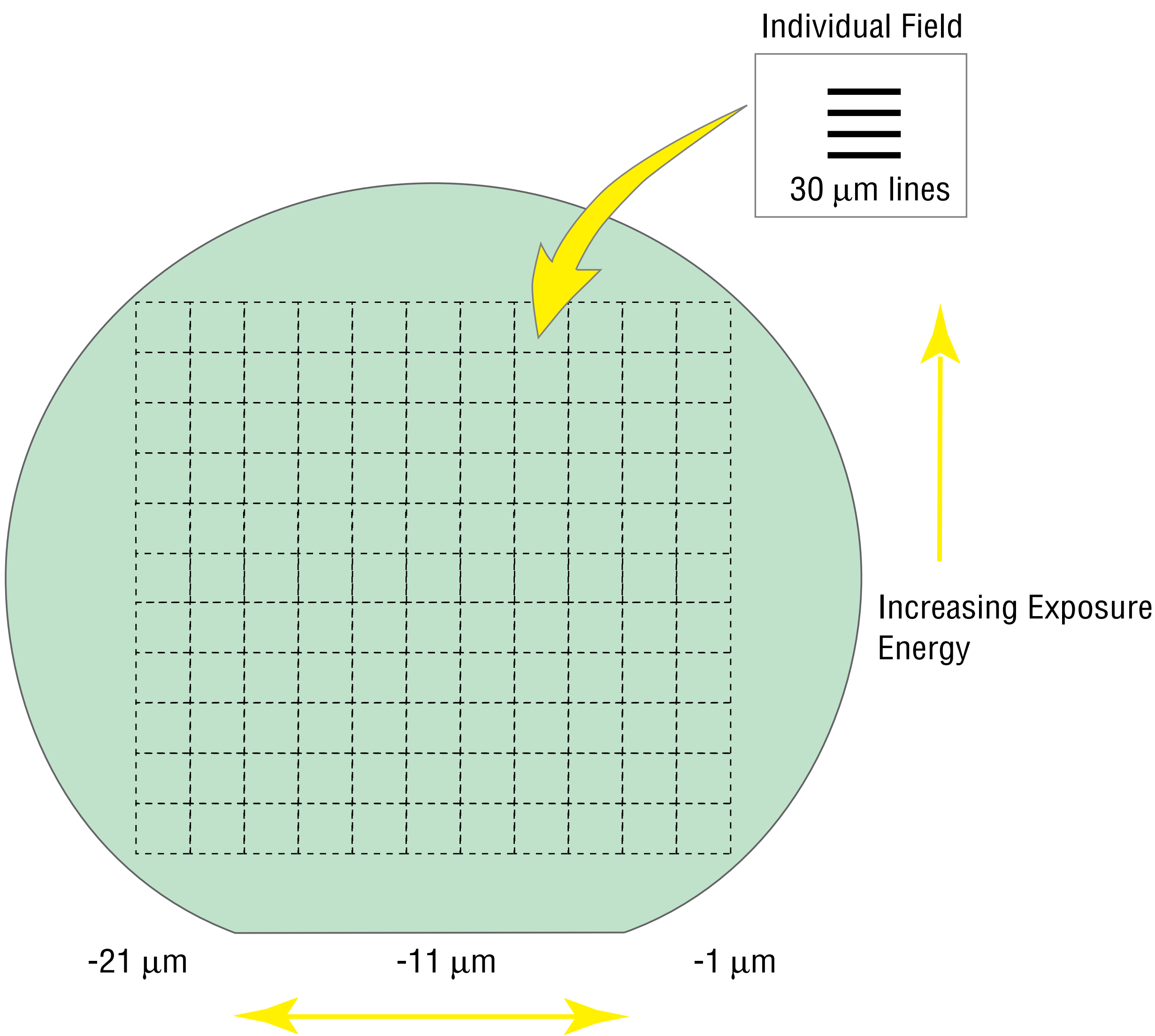


Figure 1: Wafer map showing the focus exposure matrix.

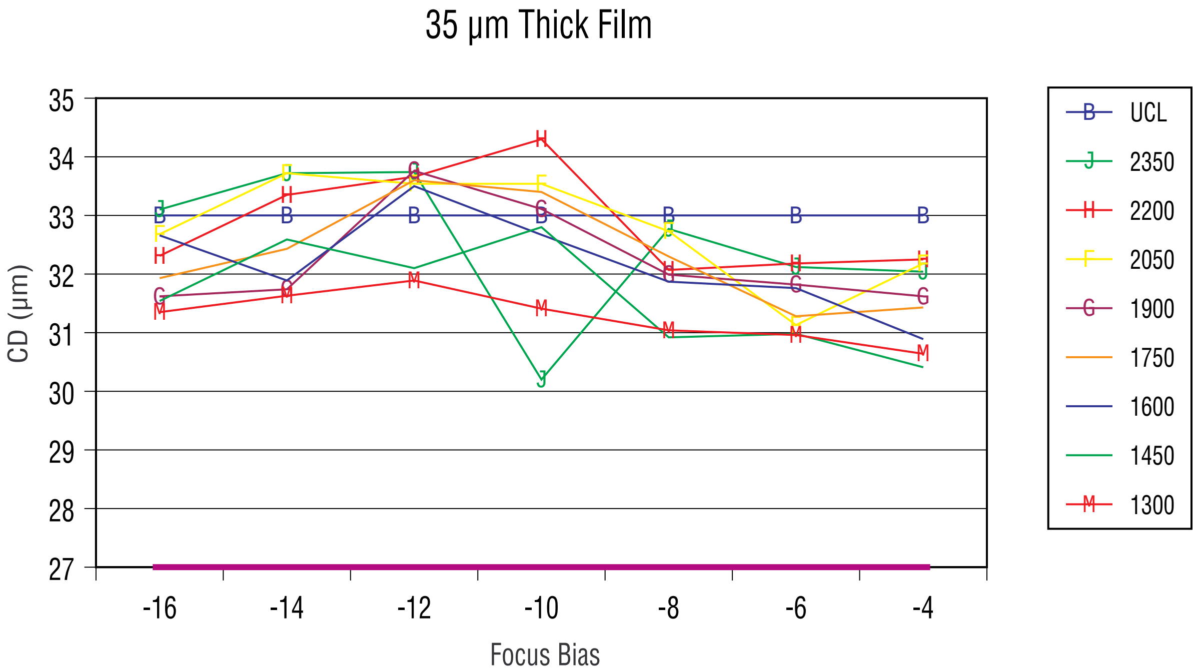


Figure 2: Bossung plot for the 35 µm polyimide (the nominal size is 30 µm with ±10 control limits).

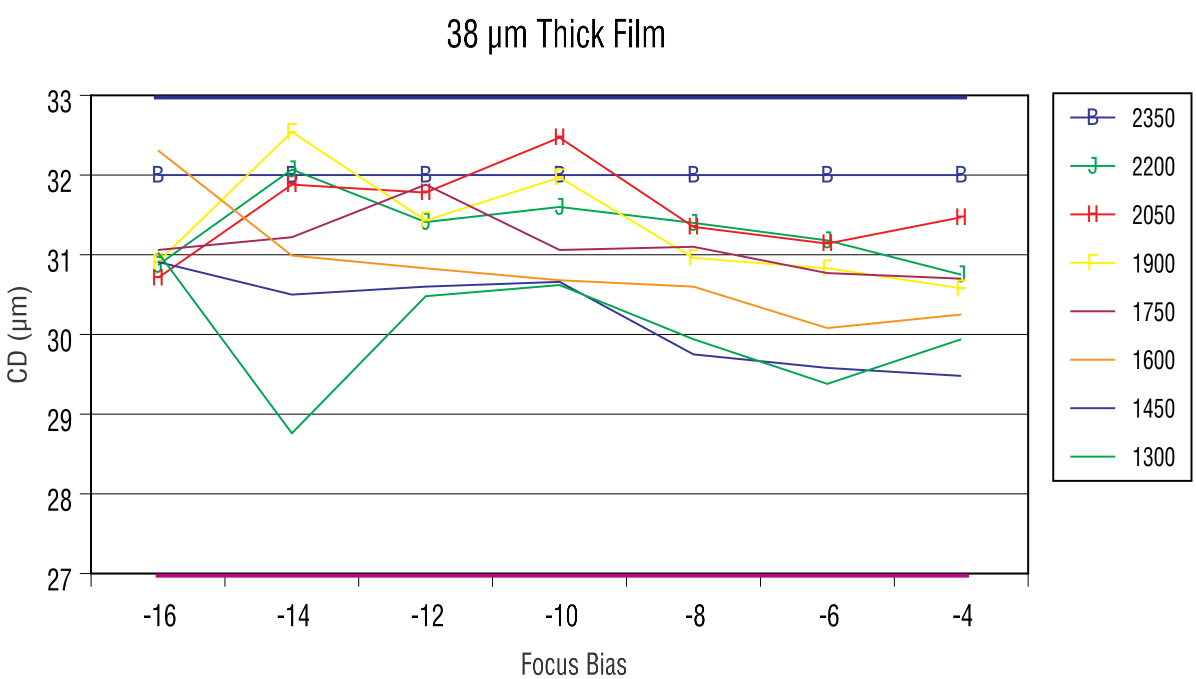
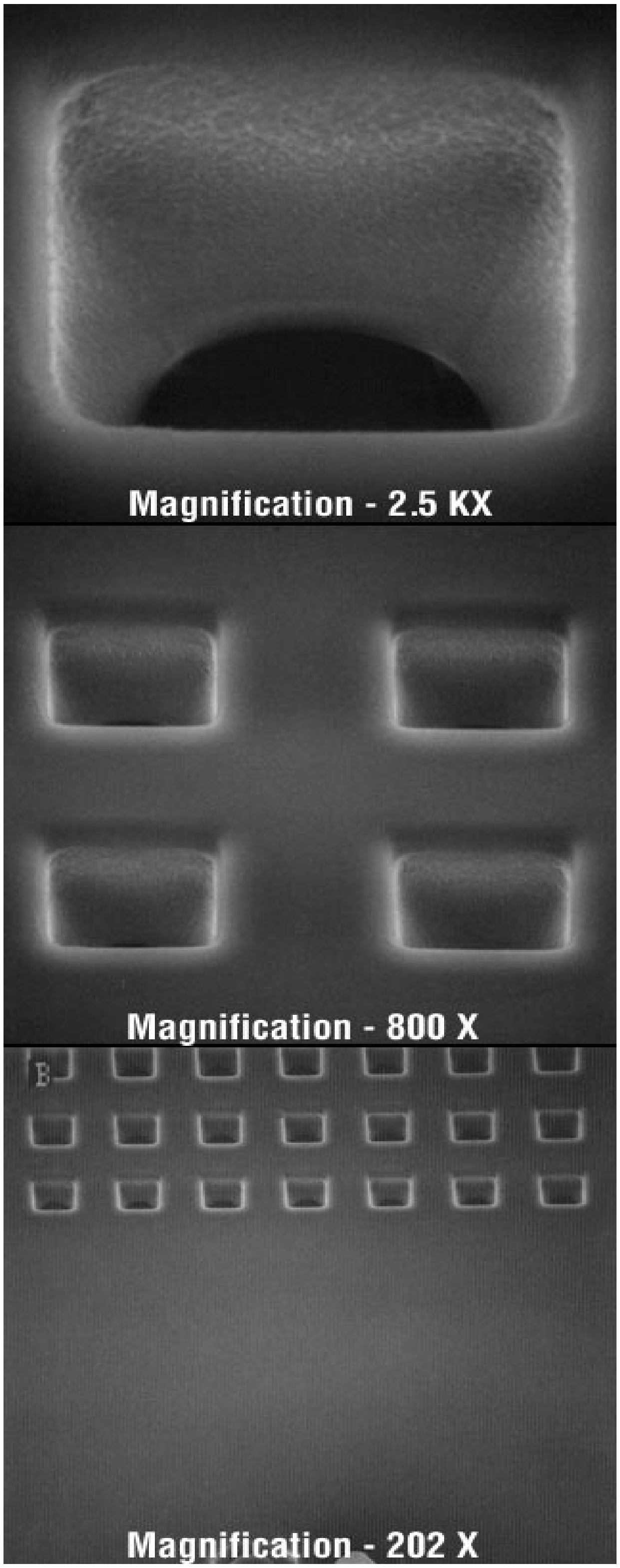
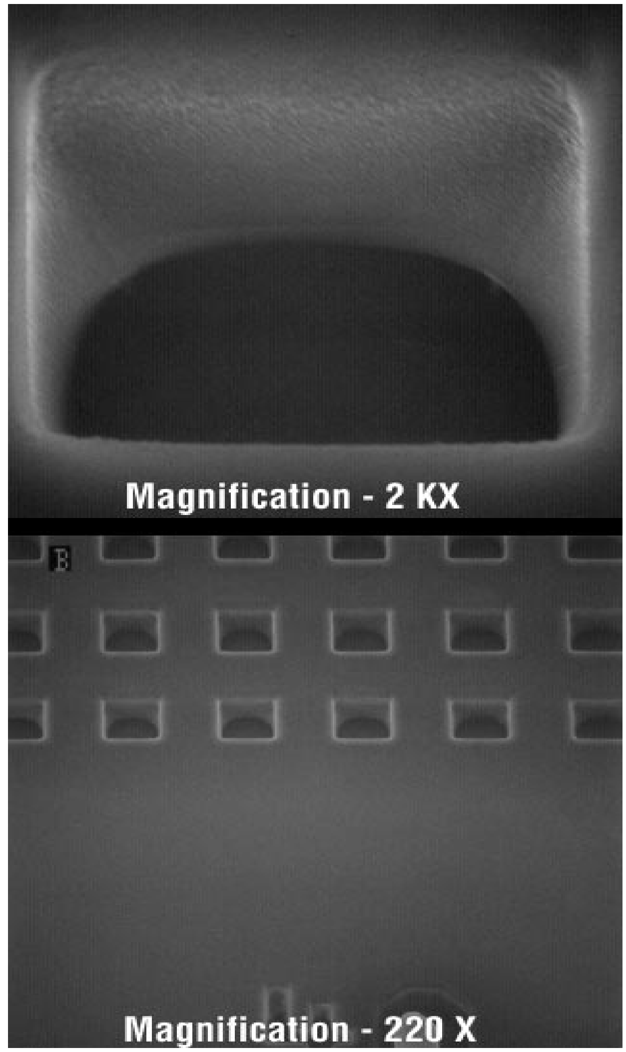


Figure 3: Bossung plot for the 38 µm polyimide (the nominal size is 38 µm with ±10 control limits).

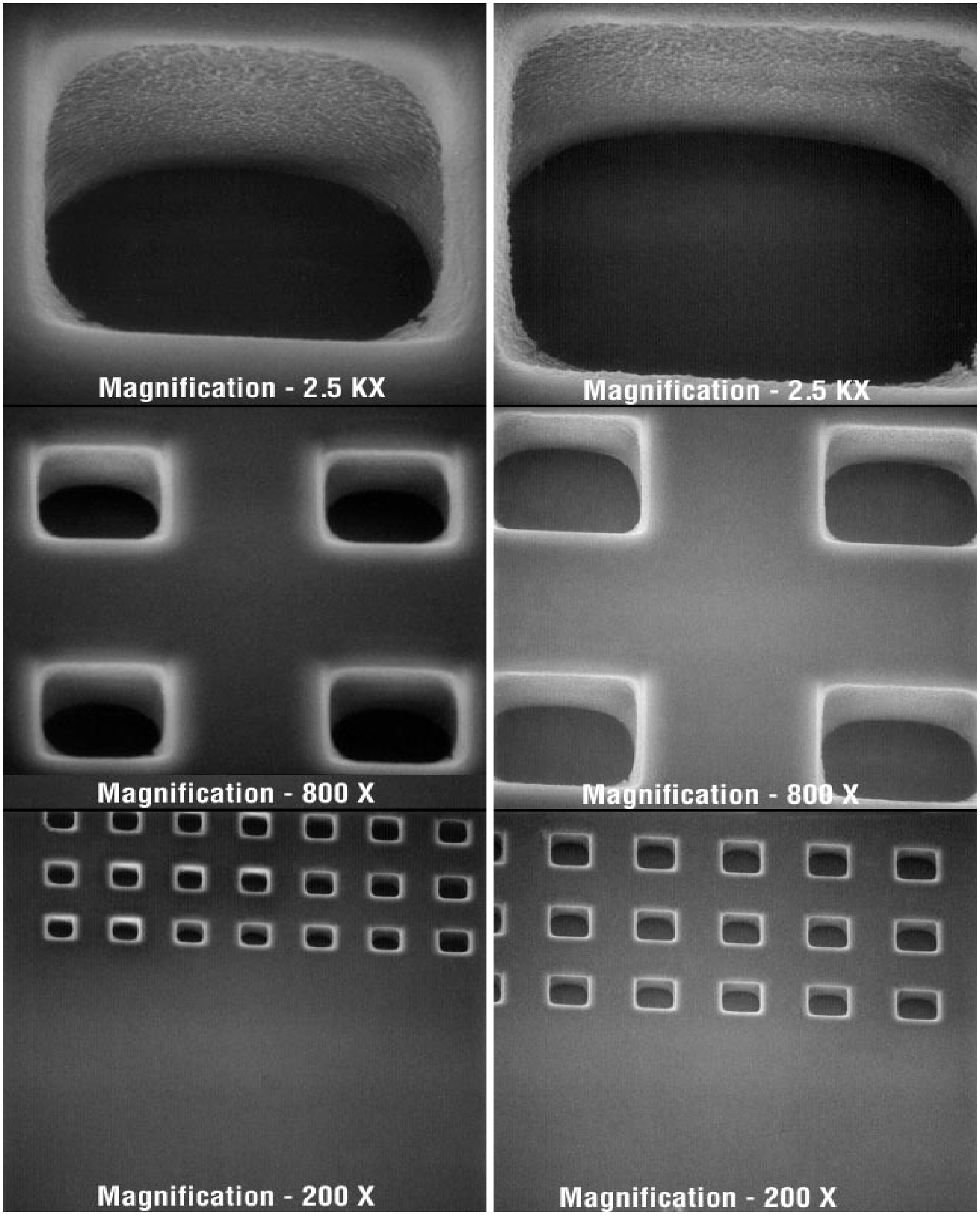


30 µm contacts



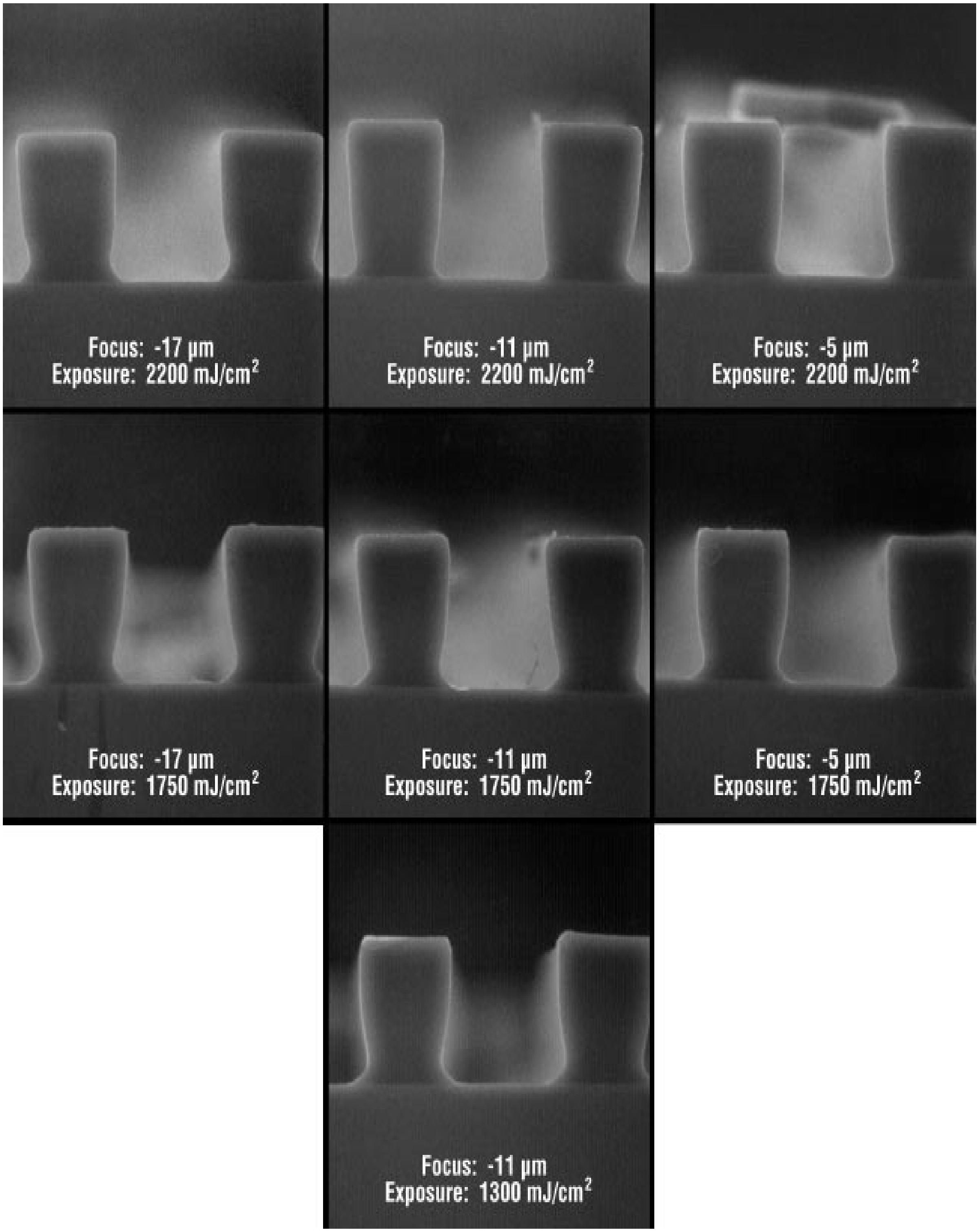
40 µm contacts

Figure 4: 30 and 40 µm contacts in 38 µm photosensitive polyimide.



30 µm contacts 40 µm contacts

Figure 5: 30 and 40 µm contacts in 35 µm photosensitive polyimide.



Figures 6 : 30 µm lines/spaces at 38.5 µm thick film (600 X magnification).

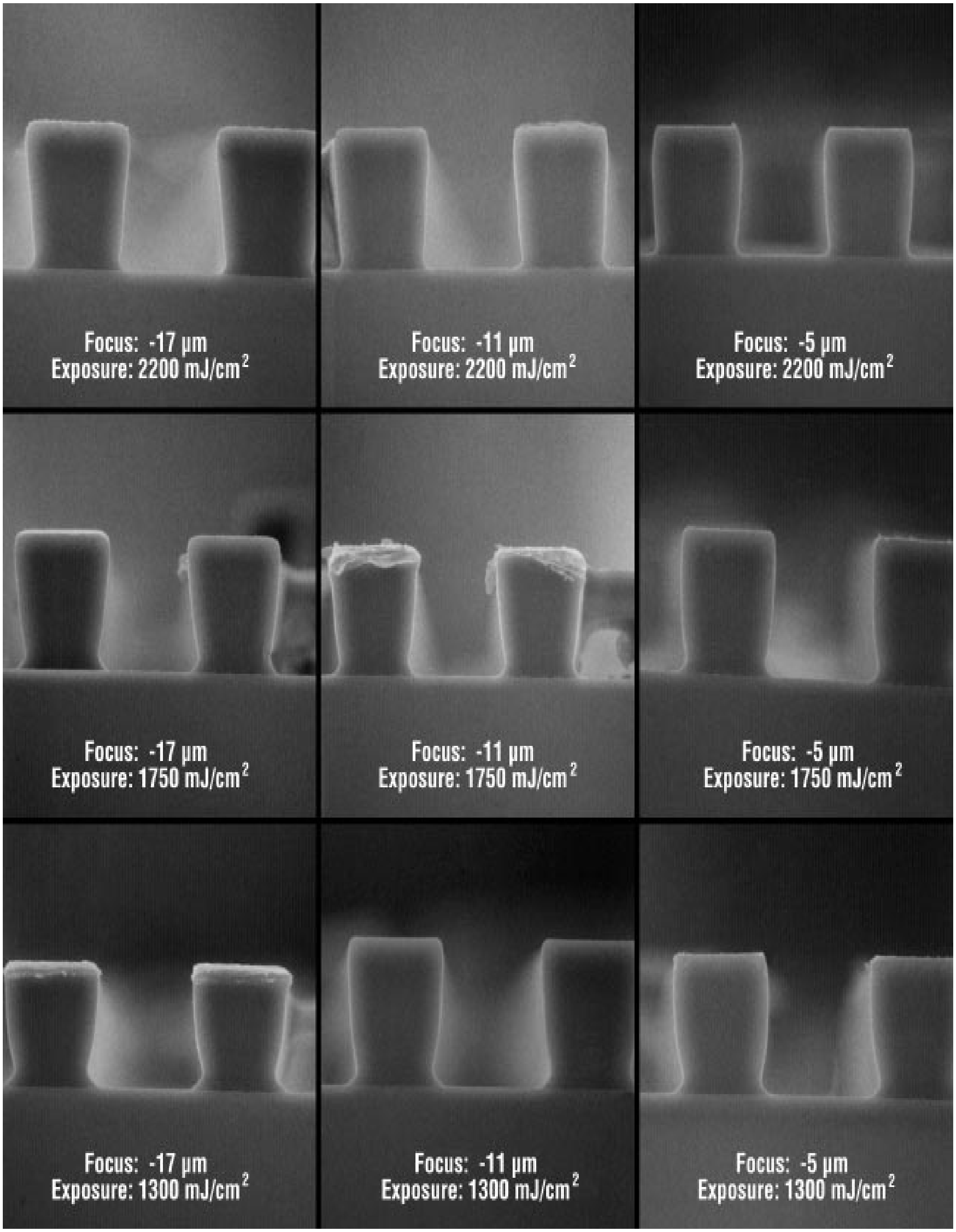


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Figure 7: 30 µm lines/spaces at 35 µm thick film (600 X magnification).