CHARACTERIZATION, OPTIMIZATION, AND QUALIFICATION OF SHIPLEY 812 PHOTORESIST FOR WAFERTRAC PROCESSING

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ABSTRACT

Wafertrac processing was used to optimize the photolithographic process of Shipley 812 positive photoresist. For two, three, four, and five micron lines, it was found that optimum conditions are 30-40 seconds development time in MF-319 and about 72 mj/cm^2 exposure dose. These optimum conditions maximize the control over the size of the image being replicated into the resist from the mask. Hardbaking of the resist resulted in a 300-400 micron thickness loss as well as a rounding of the resist profile. Contrast varied from 1.42 to 1.76 with the highest contrast being in the optimum development time range of 30-40 seconds. Thickness versus spin speed was close to the manufacturer's data and uniformity of thickness was good.

INTRODUCTION

In photolithography, success is realized through a thorough understanding of exposure, development and processing effects on photoresist performance. An important aspect of this performance is how well the size of images being replicated into the resist can be controlled. A simple method for following the resist image dimension using a Nanometrics Nanoline critical dimension (CD) measuring system was developed.[1] Not only was this method much quicker than using a scanning electron microscope (SEM) but non-destructive as well.

Line and space pattern measurements were first made on the RIT exposure test mask (ETM), then on the actual wafers. The resist image dimension measurements were obtained for the islands (I) or lines and the windows (W) or

spaces by computer analysis at 50% line edge profile threshold using the substrate-appropriate software programs provided with the Nanoline system computer. The empirically generated critical dimension parameter, Δ, was obtained by subtracting the I/W dimension ratio on the photomask from that on the wafer, and is a relative measure of how well image transfer from the mask to the wafer is occuring.

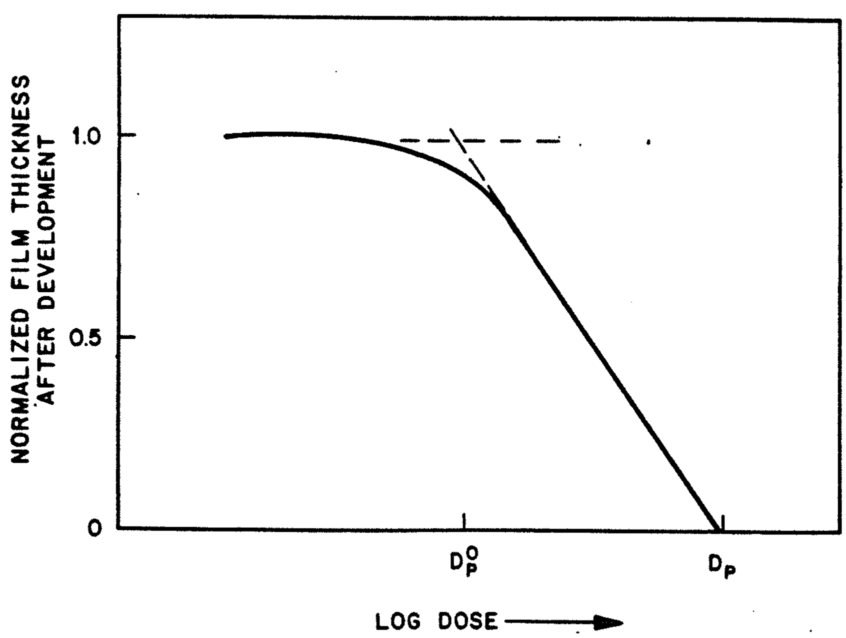
$$\Delta = I/W_{mask} - I/W_{wafer}$$

A delta of zero is the desired condition of CD transfer from the mask to wafer, and is a unique relative exposure/development equivalence point for photoresist performance comparison.

Plotting delta values versus exposure dose for various development times revealed the optimum exposure/development point. The plot with the most gradual slope indicated the best development time since changes in delta were a minimum for changes in exposure dose. The optimum exposure dose should be chosen at a delta of zero, however the exposure dose yielding a delta of zero varies according to linewidth. If several different linewidths are present in the image (usually the case) and delta for each linewidth is known, corrections can be incorporated into maskmaking.

Another aspect of performance is contrast. Contrast was determined by the following equation[2]:

$$\gamma_p = 1/(\log D_p - \log D_p^o) = \left[\log \frac{D_p}{D_p^o}\right]^{-1}$$



There was some thickness loss of unexposed resist due to development and also to hardbaking. By taking thickness measurements throughout the process, these losses could be measured. Hardbaking also caused slight flowing of Shipley 812 due to thermal plasticity. SEM photography was used to demonstrate how much flowing actually occurred.

EXPERIMENT

The first part of the experiment was to determine the best volume of photoresist to apply to the bare 3" silicon wafers. Since the wafertrac in RIT's cleanroom uses Kodak 820 resist, it was necessary to apply the Shipley resist by hand with pipets. In order to do this, the cover of the resist spinner had to be removed. The custom wafertrac programs may be found in the appendix in the notebook.

Next, twelve wafers were coated at various spin speeds in order to generate a thickness versus spin speed graph, which was compared to that provided by Shipley in their resist literature. Wafers were treated with HMDS.

Wafers were then stripped and all coated at 4000 RPM (1.2 μm) for exposure in increments of four mj/cm^2 using the RIT Exposure Test Mask (ETM) and a GCA MANN 4800 stepper. The ETM contains linewidths ranging from .6 μm to 10 μm. These wafers were then used to generate data for contrast curves and delta versus exposure curves.

Thickness measurements were taken with a Nanospec at the appropriate times to monitor thickness loss after development and after hardbake. Contrast curves were generated with thickness measurements made after hardbake. Zero exposure thickness before hardb[illegible]rmalized one so that thickness loss due to hardbake could be seen on the contrast curve plots.

Linewidth measurements for delta plots were taken using a Nanoline, and the formula for delta was used with the data to generate plots of delta versus exposure for two, three, four, and five μm linewidths. An attempt to combine all three variables into a single three dimensional graph proved to be too confusing and not very helpful.

Development for these wafers was performed on the trac with Shipley MF-319 developer. Since the trac development is difficult to reproduce on a manual spinner and because the developer in RIT's trac is not MF-319, it was necessary to purge the line and replace the developer each time wafers needed to be developed. Wafers were also hardbaked on the trac hotplate at 120° C for 45 seconds.

Finally, wafers were developed by immersion as well as on the trac, and SEM photographs were taken to compare the differences. SEM photos were also taken before and after hardbake to detect any flowing of the resist.

RESULTS

The optimum volume for hand application on the trac was 2 milliliters applied with two pipets from either side for puddle uniformity. This gave a slightly thicker coat than reported by the manufacturer. A plot of thickness versus spin speed, both for measured values and reported values, is found in figure 1. Thickness uniformity was good, ranging from 12216 Å to 12674 Å for 33 thickness measurements on 11 wafers coated at 4000 RPM.

Values for gamma and thickness losses are tabulated below in table 1.

development time (sec.)	γ	thickness loss (due to development)	thickness loss (due to hardbake)
60	1.66	307 Å	388 Å
50	1.42	306 Å	330 Å
40	1.75	145 Å	312 Å
30	1.76	170 Å	405 Å
20	1.47	85 Å	374 Å

table 1

Contrast curve plots may be found in the appendix.

Delta versus exposure plots for different linewidths may be found in figures 2 through 5. The optimum development time was found to be 30-40 seconds, and the optimum exoposure time averaged out to be about 72 mj/cm^2. Equations of the fitted lines are found beneath each graph. Tabulated data values may be found in the appendix.

SEM photos revealed that the 812 resist does flow due to hardbake. Figure 6a shows 5 µm lines before hardbake with good steep sidewall profiles. Figure 6b shows the same size lines from the same wafer after hardbake have rounded their edges and flowed, no longer displaying the steep side walls. This could create problems in plasma etching, as the thinned regions near the edge may etch away leaving the underlying layer exposed to the plasma.

thickness vs. spin speed

manufacturer's data and measured data

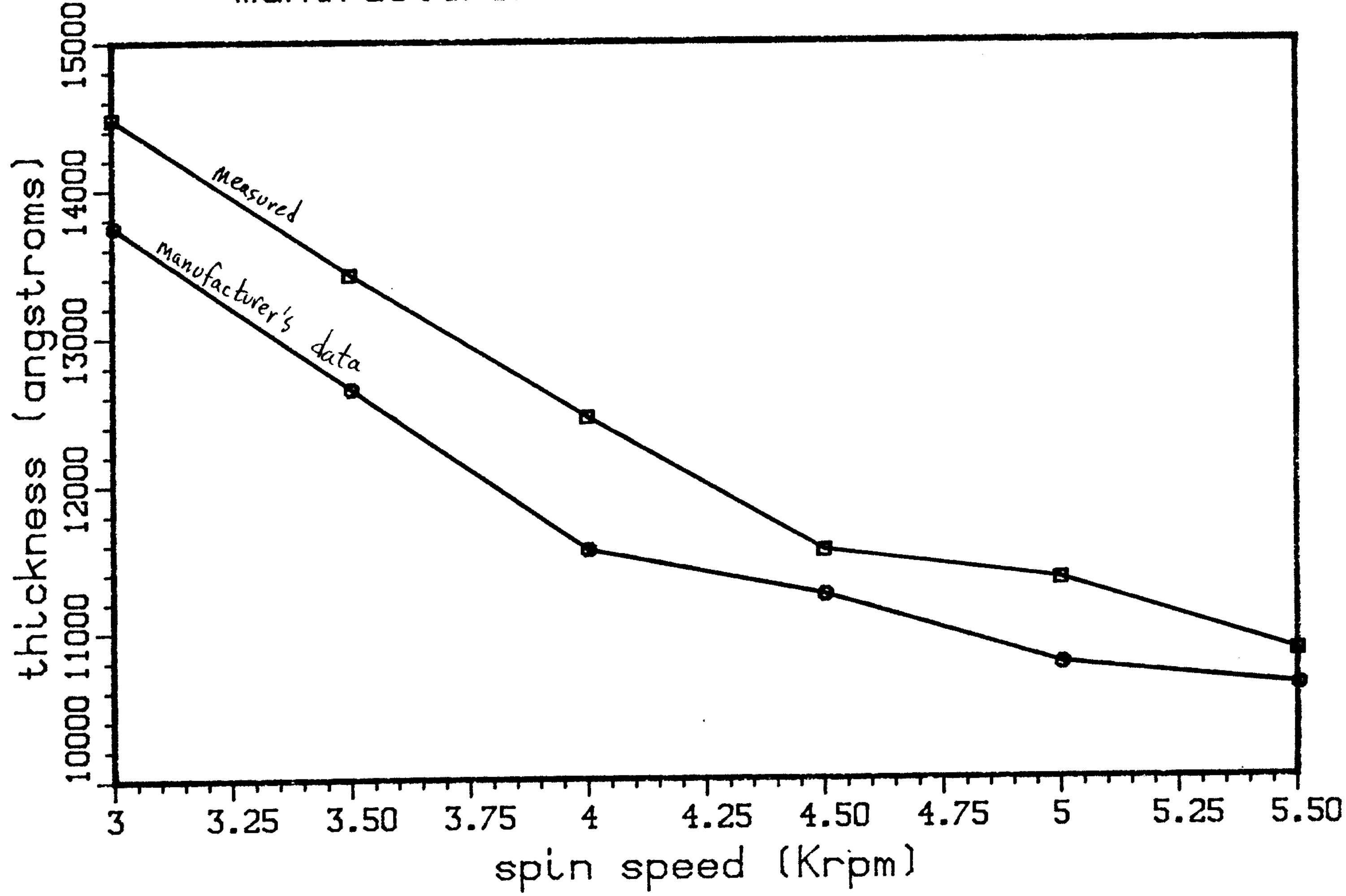


figure 1

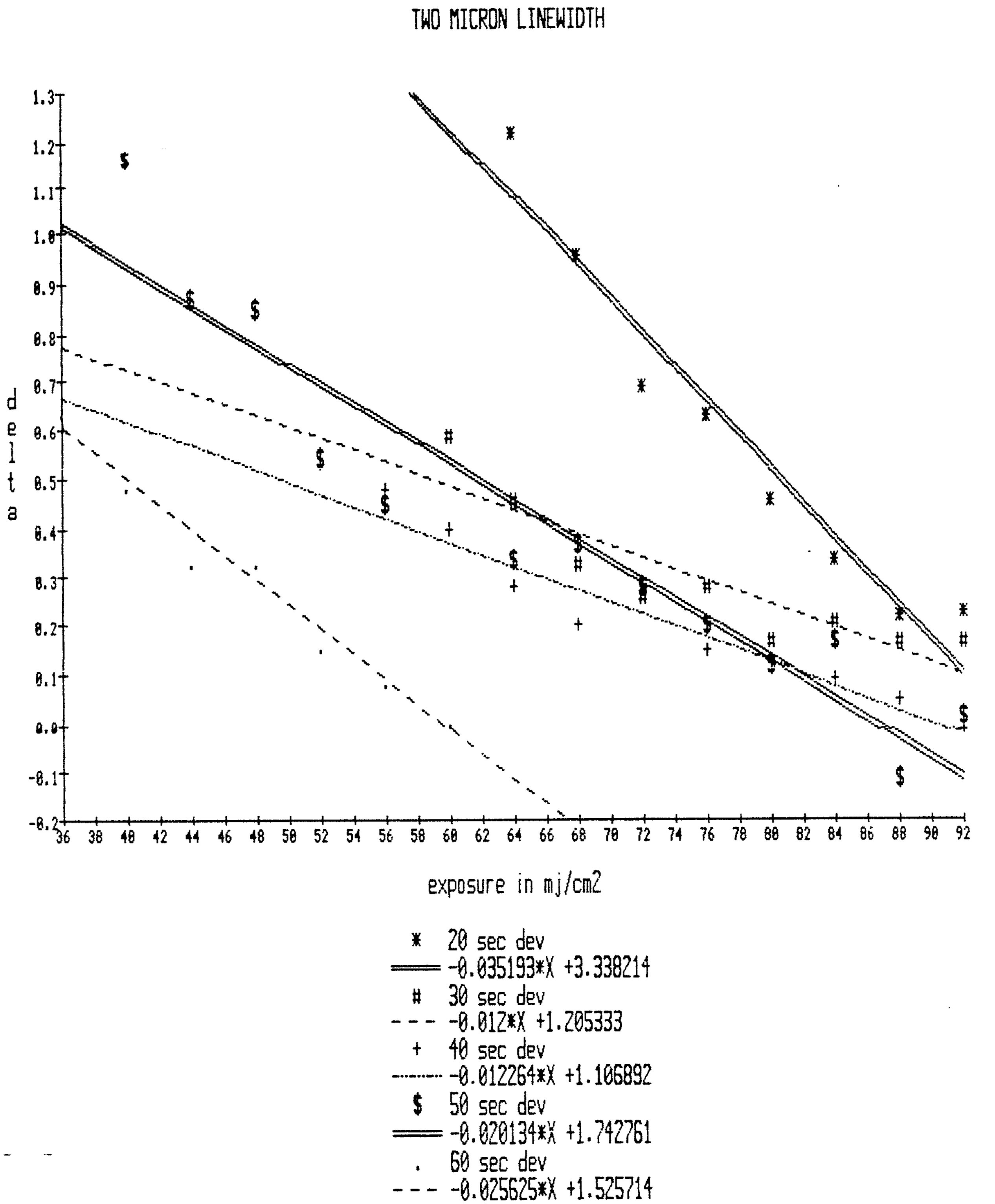

TWO MICRON LINEWIDTH
delta
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88 90 92
exposure in mj/cm2
* 20 sec dev
-0.035193*X +3.338214
30 sec dev
-0.012*X +1.205333
+ 40 sec dev
-0.012264*X +1.106892
$ 50 sec dev
-0.020134*X +1.742761
. 60 sec dev
-0.025625*X +1.525714

Figure 2

3.0 MICRON LINEWIDTH

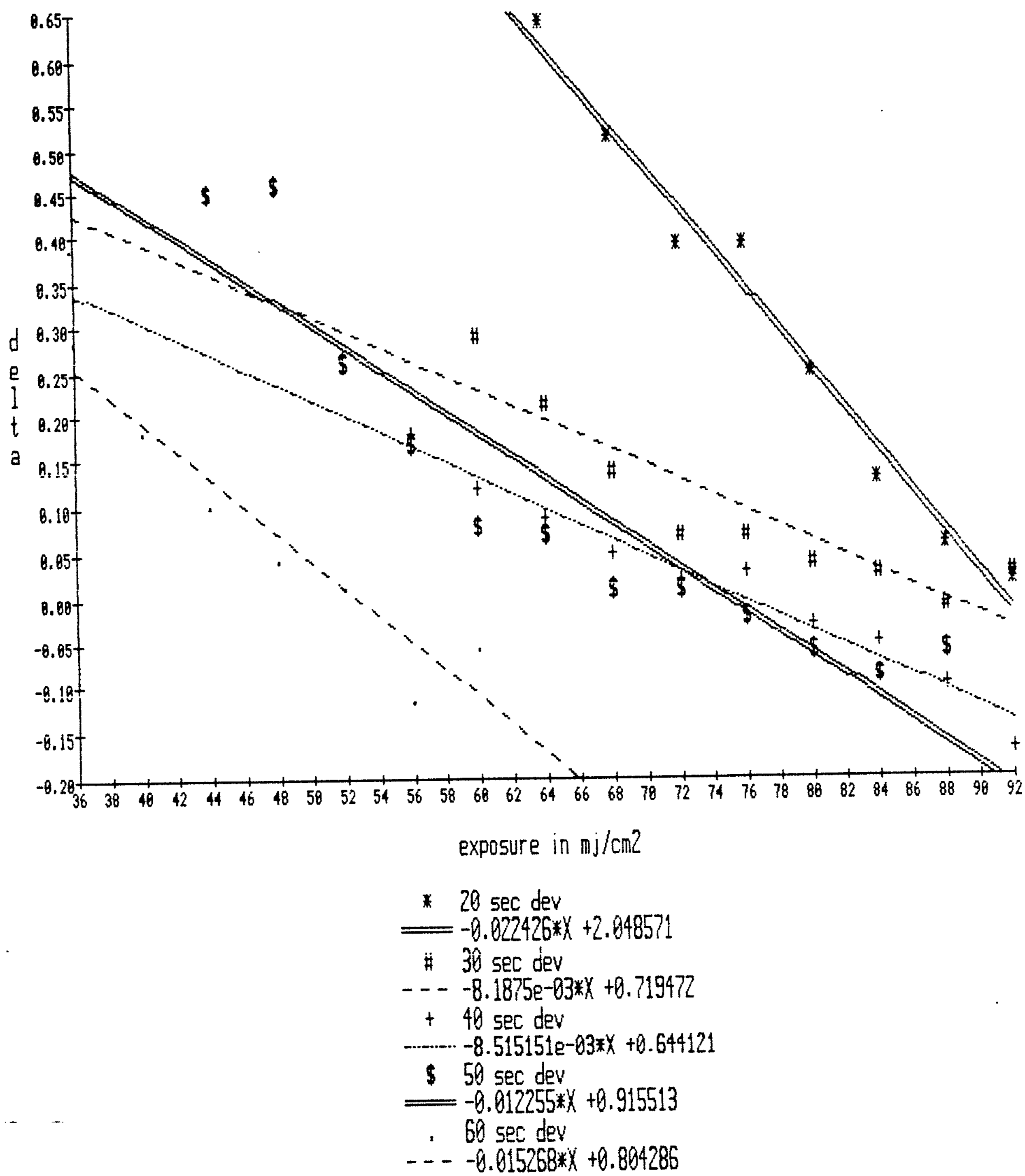


figure 3

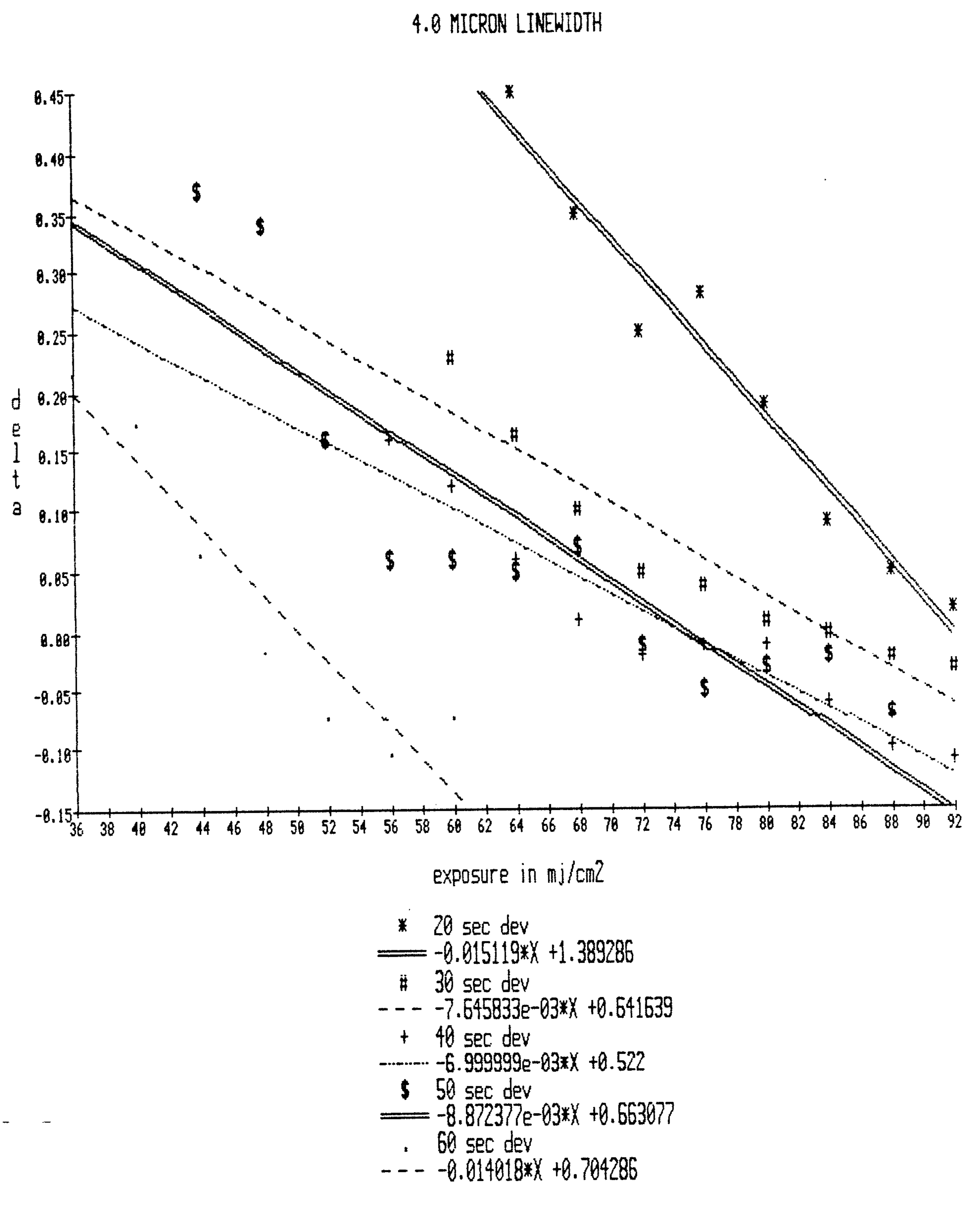

4.0 MICRON LINEWIDTH
delta
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88 90 92
exposure in mj/cm2
* 20 sec dev
-0.015119*X +1.389286
30 sec dev
-7.645833e-03*X +0.641639
+ 40 sec dev
-6.999999e-03*X +0.522
$ 50 sec dev
-8.872377e-03*X +0.663077
. 60 sec dev
-0.014018*X +0.704286

figure 4

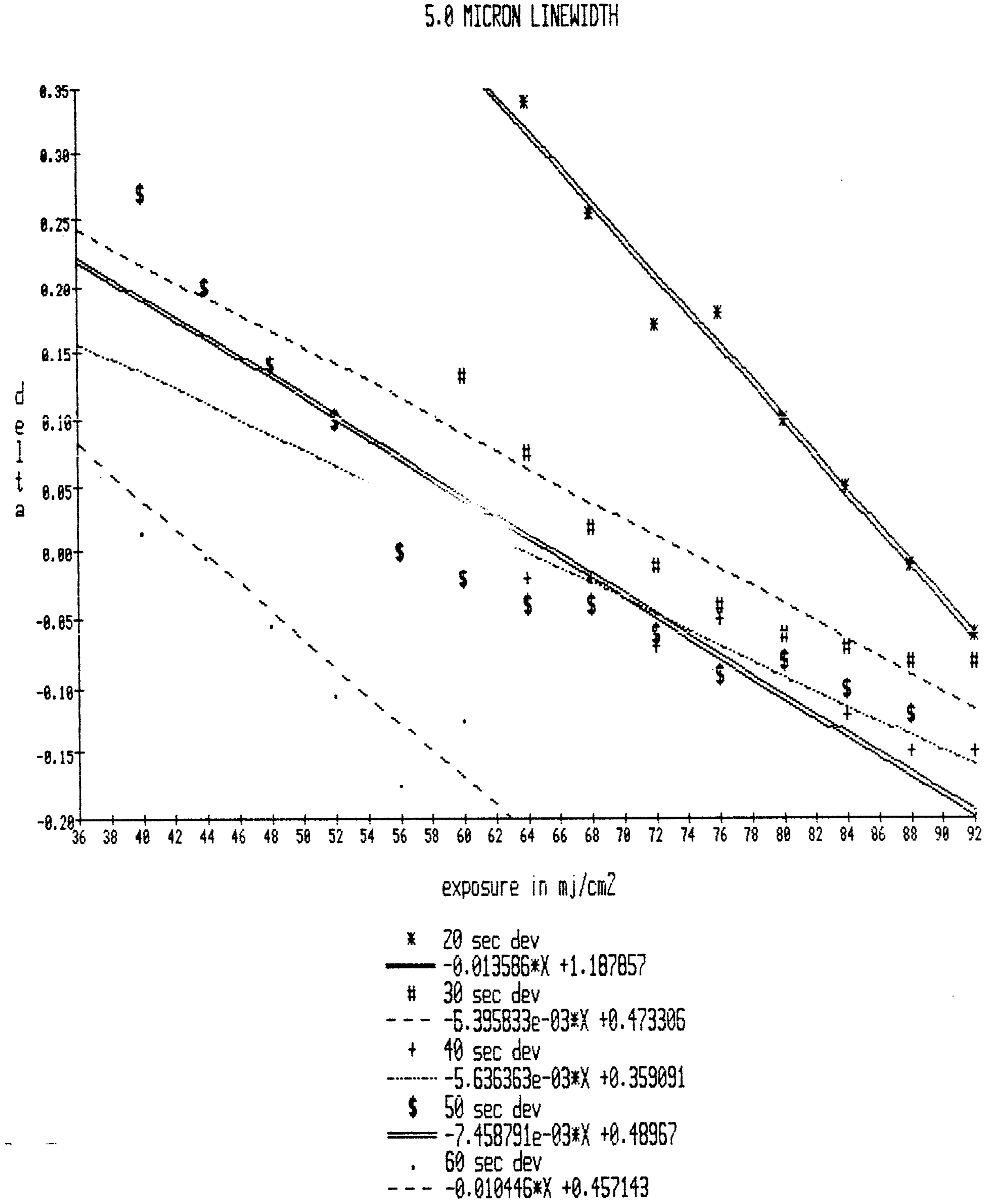

5.0 MICRON LINEWIDTH
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
delta
36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88 90 92
exposure in mj/cm2
* 20 sec dev
-0.013586*X +1.187857
30 sec dev
-6.395833e-03*X +0.473306
+ 40 sec dev
-5.636363e-03*X +0.359091
$ 50 sec dev
-7.458791e-03*X +0.48967
. 60 sec dev
-0.010446*X +0.457143

figure 5


5.0 um linewidth
MF319 trac develop 40 sec.
5000 x
NO HARDBAKE

fig. 6a

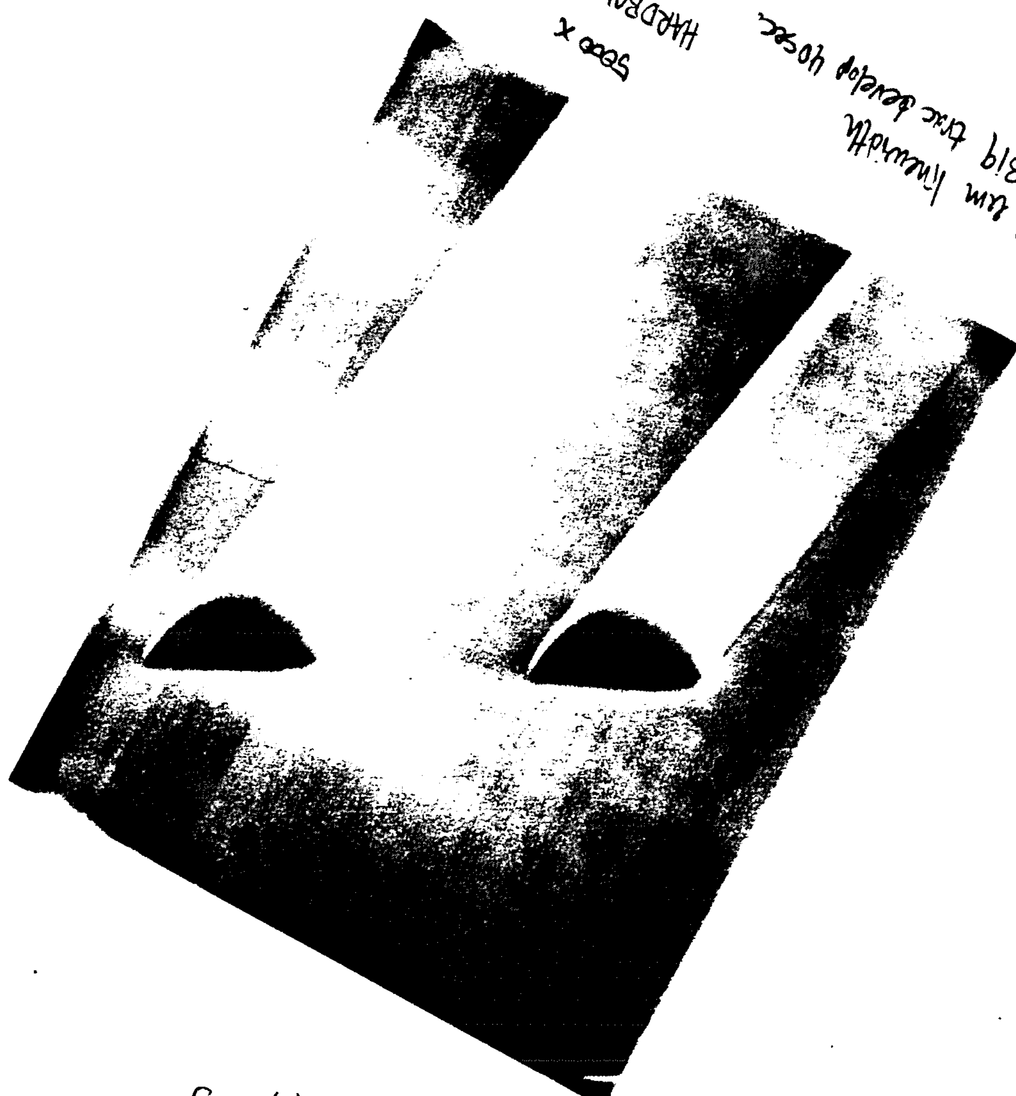

5.0 um linewidth
MF319 trac develop 40 sec.
5000 x
HARDBAKE

fig. 6b

CONCLUSIONS

The optimum exposure/development conditions for Shipley 812 with MF-319 developer are 30-40 seconds development time and about 72 mj/cm^2 exposure dose. These optimum conditions also yield the highest contrast. Hardbaking causes a loss in thickness of resist - 300-400 μm for 120° C for 45 seconds. It also causes the resist to slightly flow and thus lose its steep sidewall profile. Coating uniformity is good. SEM photos show that trac development is comparable to immersion development - no noticeable difference was seen. Standing wave effects were noticeable prior to hardbake but flowed away after hardbake. Shipley 812 positive photoresist is suitable for use on the wafertrac.

ACKNOWLEDGMENTS

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REFERENCES

1. C.C. Walker and J.N. Helbert. "Method for a Comparative Study of Positive Photoresist Lithography Performance", Polymers in Electronics, ACS Symposium Series No. 242, 1984, pp. 65-77

2. L.F. Thompson, C.G. Willson, and M.J. Bowden, Introduction to Microlithography, ACS Symposium Series No. 219, (American Chemical Society, Washington, D.C.1983) p.170.