Advanced Mask Metrology Enabling Characterization of Imprint Lithography Templates

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ABSTRACT

Lithography costs for IC production at resolutions of 65-nm and beyond have grown exponentially for each technology node and show no sign of slowing. Step and Flash Imprint Lithography (S-FIL™), developed at the University of Texas (UT) uniquely offers IC manufacturers the potential for lower cost of ownership, because S-FIL does not require expensive optics, advanced illumination sources or chemically amplified resists (CAR). The SIA's addition of Imprint Lithography to the International Technology Roadmap for Semiconductors (ITRS) in 2003, indicates the promise to become a preferred technology and has some compelling advantages over traditional 4X optical lithography.

Advanced 90nm binary & phase shift mask processes have been altered using thin Cr (15-nm) & thin e-beam resist (<150nm) resulting in sub 100-nm geometries necessary for S-FIL, and have become the baseline for template manufacture. Commercial production of advanced 1X templates requires CD metrology capability beyond the equipment typically used in 4X mask making. Full commercialization of Imprint Lithography requires not only the ability to generate a 1X template but also a metrology solution that can characterize critical dimension (CD) parameters of the template. Previous published work on S-FIL has focused mainly on high resolution templates produced on 100keV Gaussian pattern generators (PG), and has shown that resolution is only limited by the template[1,2,3].

This work demonstrates that an advanced commercial photomask facility can fabricate templates with sub-100 nm critical dimensions, and that the CDs can be characterized using a commercially available CD-SEM metrology tool. CD metrology repeatability of 0.7nm 3s was established on a quartz only template with a 6025 form factor.

1. INTRODUCTION

Improvements in optical lithography via shorter wavelengths, improved optics, optical proximity correction (OPC), & resist processing have enabled the printing of sub 100-nm features in production. These improvements however increase the cost of ownership (CoO). The rise in CoO has been mitigated in part, by the fact that many critical material issues were transferable from the previous node. Lithography at wavelengths at or below 193-nm is likely to be more difficult and costly due to poor transmission properties, which were not encountered at previous nodes. Previous studies indicate sub 193-nm optical lithography will exceed historical growth rates for the lithography tool[4].

The Rayleigh equation (1), often used to indicate the minimum resolvable feature for a given lens numerical aperture (NA), exposure wavelength ?, and process performance constant k_1 does not apply to S-FIL, as the resolution is limited only by the pattern resolved on the template.

$$(1)\ R= k_1\ ?/NA$$

An S-FIL template is in essence a micro-mold, where the Monomat™ (resist) conforms to the mold and is solidified (cross-linked) upon the flood exposure to UV light (310nm to 365nm). Because it is a mold, the tone desired on the wafer must be reversed on the template and the mirror image of the pattern must be used in the pattern generator (PG) (see figure 1). It is interesting to also note that the template trench profile is the resist profile inverted.

Reducing the cost & complexity of the lithography tool by bypassing the material transmission & projection issues places stringent requirements on the template and its associated commercial infrastructure. Altered 90nm node commercial photomask processes were used to fabricate 1X S-FIL templates resulting in sub 100nm geometries etched in 6025 quartz photoblanks. The resultant templates now absent of conductive or semi-conductive layers such as Cr or MoSi, exacerbate charging effects commonly encountered when measuring critical dimensions (CDs) via a CD-SEM. The purpose of this work is to identify metrology methods suitable for characterizing 1X templates. New gas injected CD-SEMs reduce charging effects and may provide the means for CD characterization.

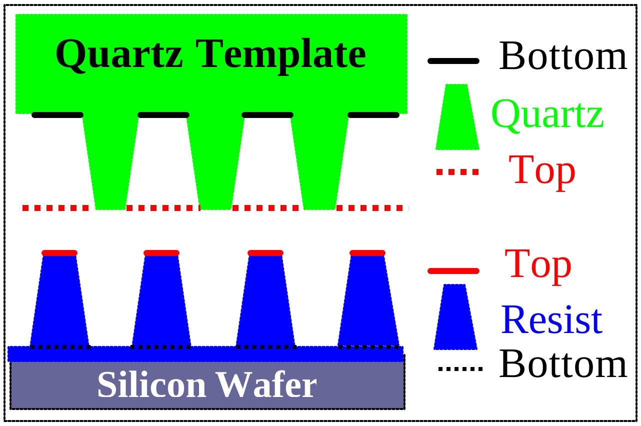


Figure 1. Template and imprinted wafer diagram

2. EXPERIMENTAL

Four 1X templates were fabricated on a standard fused silica quartz 6025 blank (6" x 6" x 0.25") with a 15nm Cr layer. A common positive tone chemically amplified electron beam resist (FEP-171) was coated (<150nm) and exposed using a JBX-9000 MVII 50keV electron beam PG, using a LaB_6 source. A modified chromeless phase shift mask (Cr-less PSM) process route was used in a commercial 90-nm node capable production photomask facility. Recipes and process conditions were changed to accommodate thinner Cr & resist thicknesses. As Cr-less PSMs and S-FIL templates have comparable process steps, standard production equipment was used (see figure 2). The Cr is used as an etch block for the quartz etch, both of which were dry etched using a production tool.

In both the Cr-less PSM and S-FIL template route, the second level lithography step is exposed using an Alta 3700 i-line laser PG. This step for Cr-less PSM is designed to expose the active area such that the Cr can be readily removed, however in the case of S-FIL templates it must protect the active area, in order to form the 15µm mesa or pedestal. The mesa is formed by etching the non-active areas in a wet buffered oxide etch (BOE) solution.

A dark-field pattern was exposed on the positive tone e-beam resist on the template, which resulted in spaces and trenches etched into the quartz plate. These spaces and trenches, when immersed into the Monomat, form the resist lines on the wafer, as shown in figure 1. As a result, when comparing the line CDs of the wafer to the template spaces that formed them, we compare the top resist line CD to the bottom of the template space and the bottom resist line CD to the top of the template space.

After patterning was completed, the 6025 plate was sent to Applied Materials for CD-SEM measurements using an Environmental Gas Injection enabled RETicleSEM tool. After measurements were completed, it was sent back for a protective resist coat and the plate was diced, thereby forming four imprint templates (see figure 3).

The RETicleSEM is a CD-SEM tool customized for reticle applications. The tool uses a narrow electron beam to scan the reticle at high magnification. One of the major issues using SEM technology on reticles, is the isolating nature of the quartz/glass blank, which results in surface charging. Charging causes a deceleration of the electron beam that changes the landing energy, and deflects the beam. By injecting nitrogen into the system, the primary &

secondary electrons produce positive ions from the injected N_2 gas which compensate for the negative charge buildup on the sample.

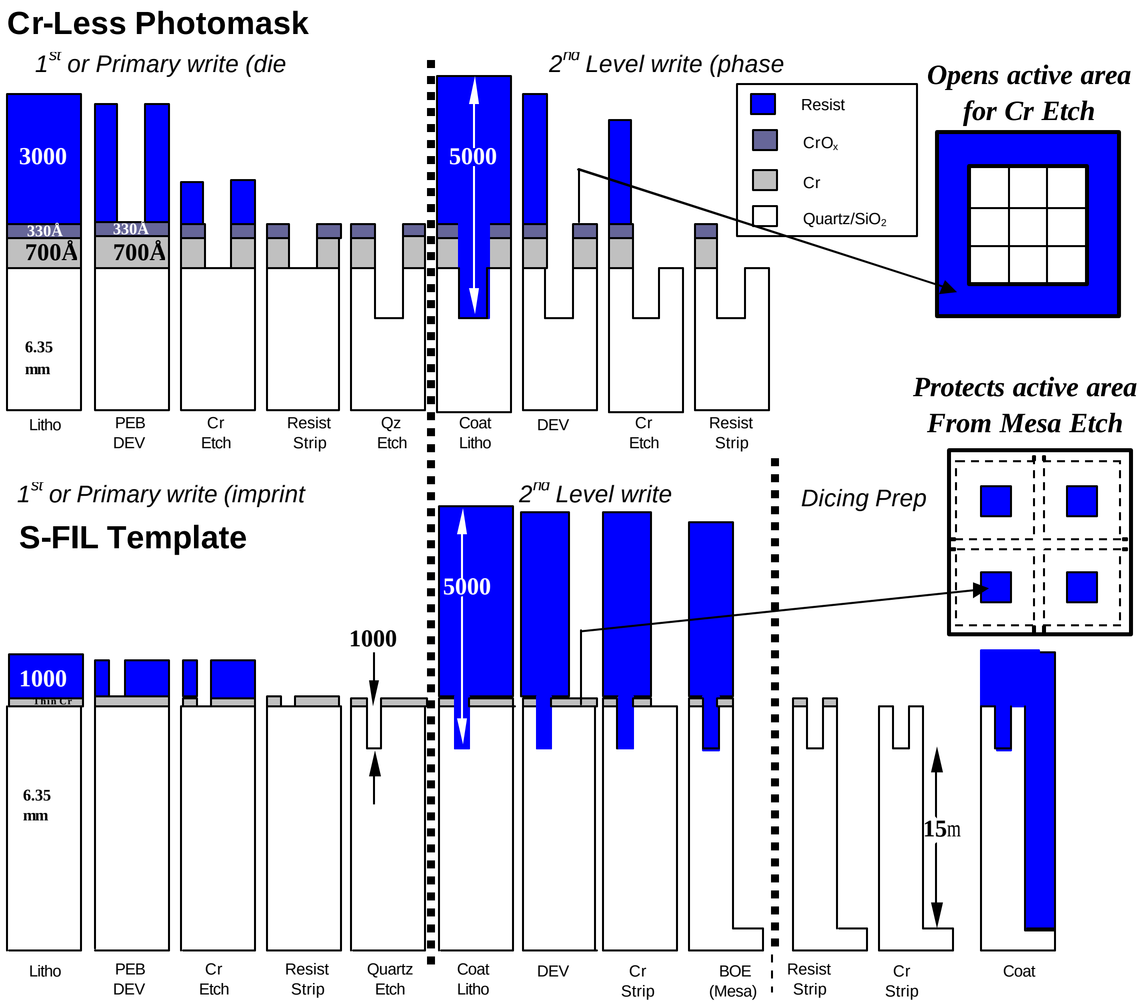
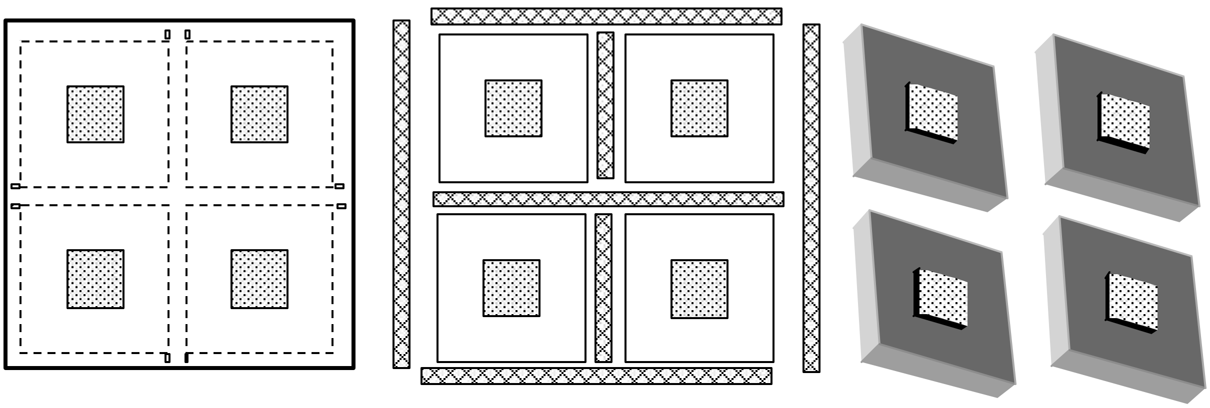


Figure 2. S-FIL analogous process route compared to a typical Chromeless PSM route



a. b. c.

Figure 3 a) 6025 plate layout of four S-FIL pedestal templates. b) diced 6025 plate resulting in four templates and discarded quartz. c) four S-FIL templates, 65mm x 65mm x 6.35mm, with 25mm square raised (15µm) active (center) area.

After dice, one of the templates was cleaned and imprinted using an Imprio 100 nano-imprint tool, on 200mm wafers coated with 60nm of DUV30J, an inorganic bottom anti-reflective coating (BARC). A non-silicon containing low viscosity Monomat material (resist) was dispensed, and cross-linked with UV light, exposed through the back of the transparent template. Process details and mechanics of S-FIL has been described thoroughly elsewhere[5,6,7]. The imprinted wafers were then measured on the same CD-SEM from Applied Materials (RETicleSEM), in the same locations, and the results were compared.

The CD-SEM was calibrated using an OPAL calibration wafer/reticle using the appropriate beam conditions for the wafer and template, 900V and 2000V respectively. The repeatability of the template measurements were carried out using two static within 5 dynamic runs on 60nm isolated and nested spaces/trenches (see table 1). Each of the 3σ and its associated means came from 10 measurements. The average 3σ variation was excellent, measuring 0.7nm.

	Isolated				**Nested (1:3)**				**Pitch (1:3)**			
Template	***1***	***2***	***3***	***4***	***1***	***2***	***3***	***4***	***1***	***2***	***3***	***4***
Ave CD(nm)	50.08	46.34	50.47	49.40	64.28	61.96	60.83	61.55	232.3	234.4	237.6	232.3
3s(nm)	0.73	0.68	0.37	0.71	1.04	0.77	1.31	0.97	0.49	0.54	0.45	0.39

Table 1. Template repeatability results using two static measurements, within 5 dynamic on 60nm trenches.

Several size trenches/spaces were exposed (from 50nm to 150nm), both isolated and nested (see figure 4). The space:line ratio (S:L) included 1:5 and 1:3 for all sizes, and as dense as 1:1 for 80nm structures and larger. The active area on the 65mm x 65mm templates was 25mm x 25mm. The active area is centered within the temp late and is raised above the surrounding quartz 15µm.

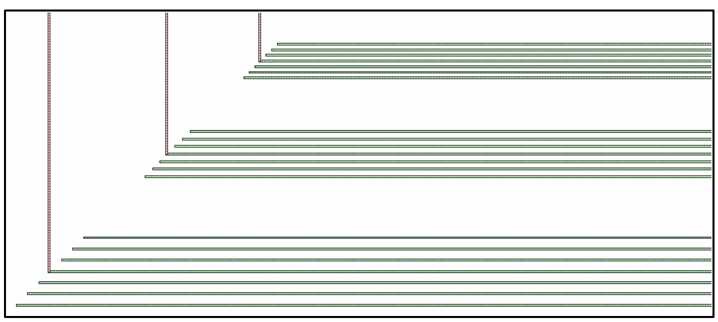


Figure 4. Isolated and nested template spaces

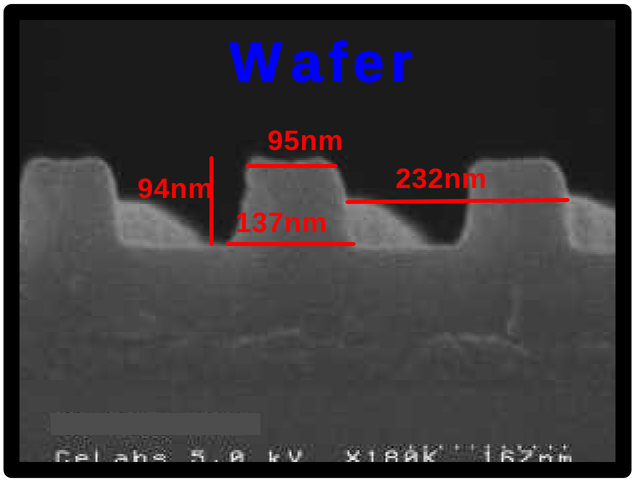
A second template was used to make an imprinted wafer in the same manner and both were sent for cross-sections of the 90nm structures in the same locations. The wafer was broken to obtain the resist cross-sections and after determining the cross-sectional location, the template was cross-sectioned in the same place using a focused ion beam (FIB) tool.

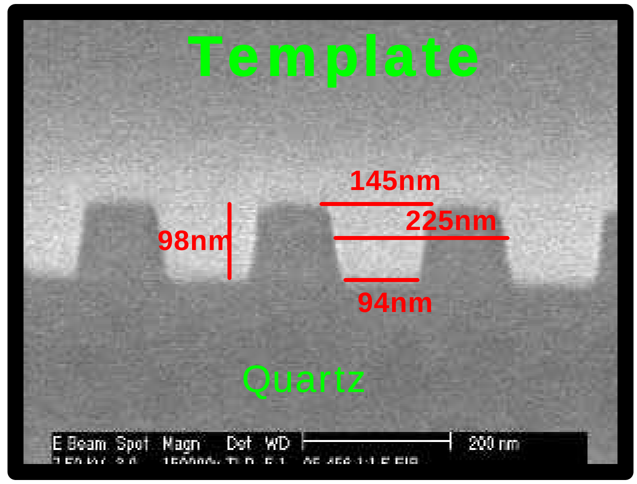
3. RESULTS AND DISCUSION

We examined the cross-sections of the second sacrificed template and its imprinted wafer and found good agreement between the wafer lines and template trenches (see figures 5 and 6, & table 2). Some of the issues noted, were:

- The side wall angle of the template trench and resist lines were less than 90 degrees
- The top of the resist profile and bottom of the template trench were not level (see figures 7 and 8)
- There was a slight foot on the imprinted lines

The bottom of the trench had a shallow micro-trenching, which when inverted through the imprint process into the resist lines produce slight ridges on the top edges. This profile is better shown in figures 7 & 8 and similar results have been reported by Motorola via transmission electron microscopy (TEM)[8].





Cross-Sections courtesy of Cerium Labs

Figure 5. Wafer imprint x-section from a sacrificed wafer

Figure 6. Template x-section from a sacrificed template

	Resist	Template
Top	95	145
Bottom	137	94
Pitch	232	225
Z	94	98

Table 2. X-Section Critical Dimensions

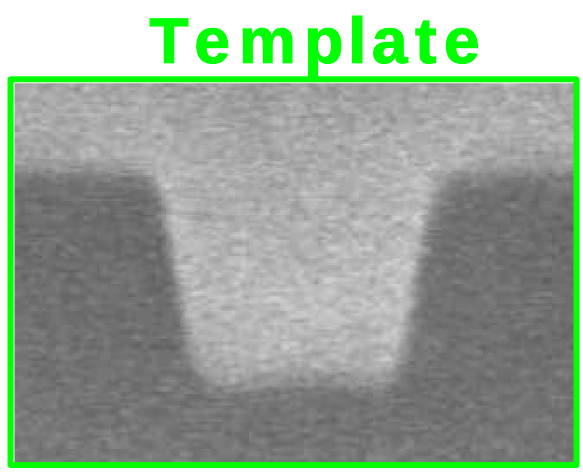


Figure 7. Wafer imprint x-section from sacrificed wafer

Figure 8. Template x-section from sacrificed template

Excellent correlation was noted between the template and resist features. As an example, the base of the template trench and the top of the resist image were nearly identical in size. In fact, for all of the feature attributes, the critical dimensions were essentially the same, to within the measurement error of the technique employed. Naturally, a non-destructive method of measurement is required to routinely characterize the fused silica templates.

Choice of the correct CD-SEM algorithm is critical for properly identifying feature profile. The CD-SEM has three available modes for determining the top of the resist and the bottom of the template trench: namely, max peak, max falling edge, and line analysis (see figure 9). We modulated the three modes on both 90nm & 150nm features. The results are reported in table 3. For the bottom of the template space, the use of different modes did not did not influence the final measurement. The top of the resist line was highly dependent on the particular algorithm, however. The max peak mode produced CDs consistent between wafer and template.

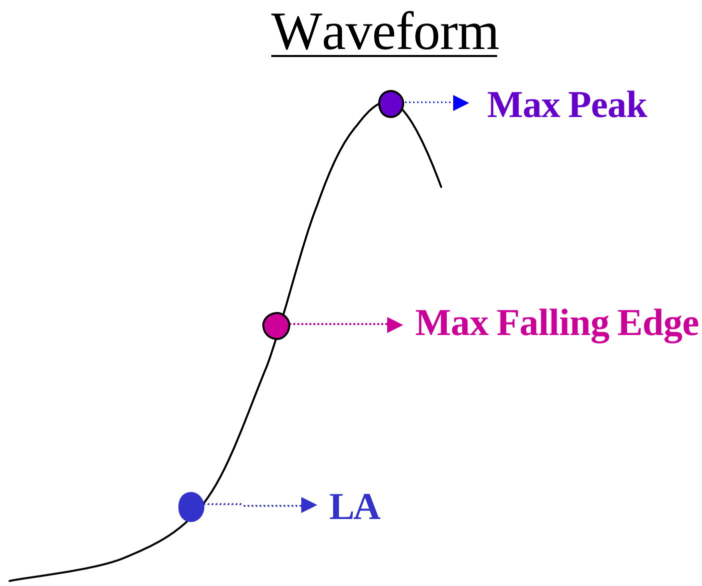


Figure 9. Available modes for topographic point detection

	90nm		**150nm**	
	Wafer *Top Line*	**Template** *Bottom Space*	**Wafer** *Top Line*	**Template** *Bottom Space*
Max Peak	84.83	80.68	149.34	145.93
Max Falling Edge	63.1	80.53	126.68	145.2
Linear Analysis	57.44	80.68	107.76	144.4

Table 3. Mode modulation for CD measurement

The top CD and the bottom CDs for both the template and wafer features have a consistent offset of approximately 47nm. This is consistent with cross section results depicted in figures 5-8. Many measurements were taken on complimentary template and resist features and the results are reported in figure 10. Because the profiles of the features are not 90 degrees, the data does not fall along the 45 degree line drawn on the scatter plot. Instead, the two data sets follow parallel paths, indicating the reversed nature of the template and resist features. It is interesting to note that data that does not fall along these two lines is generally indicative of a flyer in the data set. Two examples of flyers are depicted in figures 11 and 12.

Previous work has indicated that feature profiles approaching 90 degrees are possible, and that optimization is still required on the current fabrication process [3].

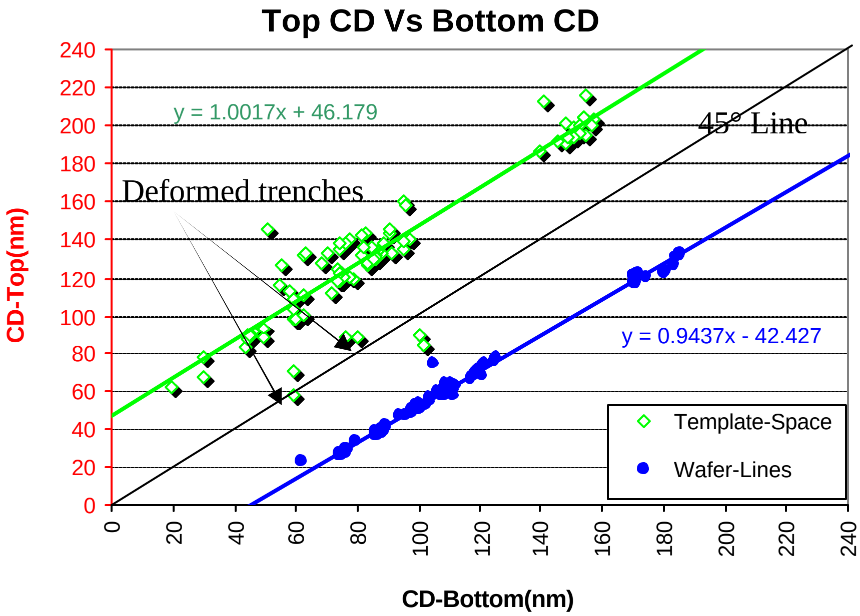


Figure 10. Top CD vs. Bottom CD scatter plot

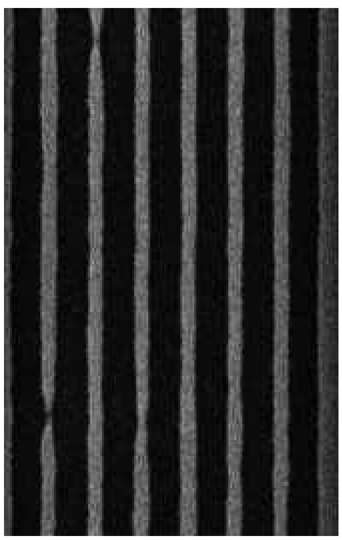


Figure 11. Template: 80nm 1:1 Spaces

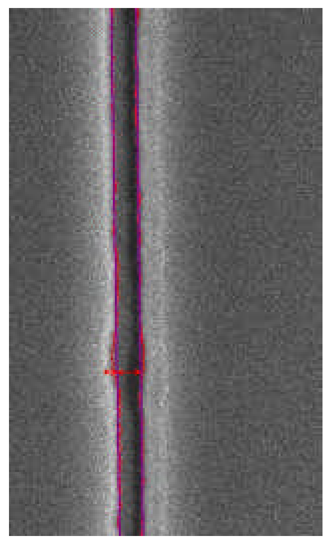


Figure 12. Template unresolved 70nm Isolated Space

4. SUMMARY & CONCLUSIONS

Sub 100nm S-FIL templates can be fabricated with existing commercial 90nm node photomask production equipment. The process flow is analogous to the existing Cr-less PSM routes and critical dimensions on the templates can be characterized using an environmental gas injection enabled CD-SEM. Further work is necessary to optimize the template fabrication process in order to achieve the dimensional control suitable for the 65nm node. The path forward is known and work will include:

- improved proximity effect correction (PEC)
- improvements in commercial e-beam PG resolution
- improved resists
- improved dry etch processes (Cr & quartz)

Environmental gas injection CD-SEM metrology is effective for charactering quartz templates fabricated in a commercial setting and will be useful as merchants mask makers continue to optimize template processes..

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