PROGRESS OF UV-NIL TEMPLATE MAKING

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ABSTRACT

Nano-imprint lithography (NIL) has been counted as one of the lithography candidates for hp32nm node and beyond and has showed excellent resolution capability with remarkable low line edge roughness that is attracting many researchers in the industry who were searching for the finest patterning technology. Therefore, recently we have been focusing on the resolution improvement on the NIL templates with the 100keV acceleration voltage spot beam (SB) EB writer and the 50keV acceleration voltage variable shaped beam (VSB) EB writer.

The 100keV SB writers have high resolution capability, but they show fatally low throughput if we need full chip writing. Usually templates for resolution pioneers needed just a small field (several hundred microns square or so), but recently requirements for full chip templates are increasing. For full chip writing, we have also started the resolution improvement with the 50keV VSB writers used in current 4X photomask manufacturing. The 50keV VSB writers could generate full chip pattern in a reasonable time though resolution limits are inferior to that with the 100keV SB writers.

In this paper, we will show latest results with both the 100keV SB and the 50keV VSB EB writers. With the 100keV SB EB writer, we have achieved down to hp15nm resolution for line and space pattern, but found that to achieve further improvement, an innovation in pattern generation method or material would be inevitable. With the 50keV VSB EB writer, we have achieved down to hp22nm resolution for line and space pattern.

Though NIL has excellent resolution capability, solutions for defect inspection and repair are not clearly shown yet. In this paper, we will show preliminary inspection results with an EB inspection tool. We tested an EB inspection tool by Hermes Microvision, Inc. (HMI), which was originally developed for and are currently used as a wafer inspection tool, and now have been started to seek the application for mask use, using a programmed defect template.

Key words : NIL, template, resolution, defects inspection

1. INTRODUCTION

NIL templates have 1X patterns and are required manufacturing process with higher resolution compared to that of the 4X photomasks. Table 1 shows the ITRS requirements on masks for NIL, EUV, and optical lithography. Although the patterns on the NIL templates will be made by the EB writing process which will also be used for EUV masks or advanced photomasks, the resolution should be finer, and close to 20nm in year 2013. The minimum allowed defect size on the template is also be tough and is different from other masks, and many efforts should be paid.

For the NIL template pattern making, we have been evaluating two different processes, one with the 100keV SB EB writer, and the other with the 50keV VSB EB writers[1-5]. The 100keV SB writer has high resolution capability. But it has a fatally low throughput for full field writing. On the other hand, the 50keV VSB writer is actually used in today's photomask manufacturing, and can write full field in a reasonable time as is showed figure 1. However, they are designed for 4X pattern, and show relatively low resolution capability compared to the 100keV SB writer.

Photomask and Next-Generation Lithography Mask Technology XVI, edited by Kunihiro Hosono
Proc. of SPIE Vol. 7379, 73792S · © 2009 SPIE · CCC code: 0277-786X/09/$18 · doi: 10.1117/12.824342

2. EXPERIMENTAL

Figure 2 shows our manufacturing process flow of imprint templates. A thin chrome film was coated between the EB resist and the quartz substrate. The thin chrome enabled us to make the resist thickness thinner compared to the 4X photomask resists, and made the resolution remarkably finer. The thin chrome might also reduce charge up problem during EB writing, and decrease resist peeling caused by poor adhesion between resist and quartz.

A similar process to that for chromeless mask was used to make the fine pattern on the quartz substrate. The substrate dimension was of a 6" square, 250 mil thick format, which have been familiar in conventional photomask, and we could use the same tools as we were using in the photomask manufacturing line. Usually a 65mm square format, as was introduced by Molecular Imprints, Inc., was used in the imprint process, and for this format, we added a back-end process of template manufacturing, where the 6" substrates were cut and polished into 65mm square. A pedestal was also formed during the back-end process.

The back-end process is described in figure 3. First we formed a resist pattern for the pedestal making by alignment writing on a re-coated resist layer. The pedestal was made by wet etch of the surroundings using the resist pattern. Next, the dicing and polishing process cut the 6" plate into four 65mm square plates. Until this process, the chrome and the secondly coated resist remained. After stripping the resist and chrome, the templates were coated with anti-sticking coatings, if needed.

Table 2 shows the experimental tools and material. We used the "JBX9300" (JEOL) as the 100keV SB EB writer. As the 50keV VSB EB writers, machines used in current 4X photomask manufacturing were used. A positive tone non-CAR (non-chemically amplified resist) was used as the resist material. For measurement tools, we used "LWM9000" (Vistec) CD-SEM, "LMS IPRO" (Vistec) image placement measurement tool, "Dimension X3D" (Veeco) AFM, "ULTRA" (Carl Zeiss) cross sectional SEM, and "H-7650" (Hitachi High-Technologies) TEM. Imprint performance test was done by an "Imprio250" (Molecular Imprints Inc) tool.

3. RESULTS AND DISCUSSION

3-1. Resolution improvement results with 100 keV SB EB writer

We optimized the process parameters and conditions with the 100keV SB EB writer process. Figure 4 shows the results of line and space pattern and Figure 5 shows results of the dense holes and dots pattern of our improved and released process. The resolution limit is hp16nm for line and spaces, hp20nm for dense holes pattern, and hp26nm for dense dots pattern. Figure 6 is the resist images of our latest improvements for further resolution improvement trial by changing the development condition which is not yet released. We can see that around 15nm seems to be the limitation of this process, and we are considering that whether or both of a new resist system and a new writing strategy might be necessary for further improvement.

3-2. Resolution improvement results with 50 keV VSB EB writer

Figures 7 and 8 show templates made by a 50keV VSB EB writer. As a result of having improved writing condition, process condition, and material thickness, we could achieve hp22nm (partially resolved) for lines and space pattern and hp26nm for dense holes pattern. In terms of stability as well as uniformity (short range), this high resolution process with the 50keV VSB EB writer is not yet sufficient and we are on the way of fixing.

To improve the resolution of the 50keV process, we are planning to test the newest EB writer which will be used for the 32nm node 4x photomasks in the coming years. We have to match the requirements for full field NIL templates, and are planning to collect initial sets of data.

3-3. NIL template performance results

Figure 9 shows the critical dimension (CD) uniformity results in the active area (30x26mm) of NIL templates. The CD was measured at hp32nm dense space patterns. The CD uniformity results were 1.7nm and 1.2nm in 3σ with 50keV VSB EB writer and 100keV SB EB writer, respectively. These values met the ITRS requirement of 3.1nm.

Figure 10 shows the quartz depth uniformity result in the active area. The quartz depth was measured at 32nm trench pattern, where the average trench depth was 81.6nm. The quartz depth uniformity was 0.8nm in 3 σ and met the ITRS requirement of 2.1nm.

Figure 11 shows the image placement accuracy results in the active area. The image placement accuracy (3σ) results were X: 2.9nm, Y: 4.2nm, and X: 6.0nm, Y: 6.0nm with 50keV VSB EB writer and 100keV SB EB writer, respectively. These values did not meet the ITRS requirement of 3.7nm. We believe the image placement accuracy result with 50keV VSB EB writer show a sufficient value for the time being, and will be improved along with the coming technology nodes 4X photomask manufacturing.

Figure 12 shows the line edge roughness (LER) results. The LERs were measured both at hp24nm and at hp32nm line and space pattern. The 100keV SB template showed better results, because of the higher resolution capability. These performances should be improved to match with the future ITRS requirements, but at this stage of the development, we believe the values are acceptable.

Figure 13 shows the profiles of the template patterns observed with an AFM. An InSight 3D system of Veeco Instruments Inc. was used. A sharp tip made of high density carbon material was used to observe the fine template patterns. We can see that with a commercially available SS-ISC-3D tip, we can reach the bottom of a 23.2nm space. This could make the future assurance of the template possible, not only for the 2D-CD but also for the 3D profile of the template pattern.

Figure 14 shows the hp22nm line and space pattern profile observed with a TEM. The TEM photo was taken with the thin chrome on top of the template. From TEM image, we could get accurate profile of the template pattern. The AFM profile should be calibrated with whether the SEM or TEM photo, and our next step should be the discussion of how to do the metrology to assure the template CD, by verifying with the imprint result, taking the profile into account.

3-4. NIL template EB-inspection trial results

We preliminarily have tried template defect inspection with an EB inspection method. As first step of EB inspection evaluation, we have made a programmed defect template. Figure 15 shows parts of the SEM images of defects on the programmed defects template made by 100keV SB EB writer. We could make small defects including both excessive and missing defects on the line and space pattern, and hole pattern.

Using the programmed defect template, we tried defect inspection with an EB mask inspection system being developed by Hermes Microvision, Inc. (HMI). Figure 16 shows the SEM images of defects on the template defects detected by the HMI EB inspection system. Preliminary evaluation with HMI EB inspection system showed promising results.

We will continue to evaluate the EB inspection system for NIL templates and will report on our next paper.

3-5. NIL imprinted pattern results

Figure 17 shows the UV-NIL process flow and Figure 18 shows the imprinted wafer patterns. The imprint was done with a Molecular Imprints, Inc. NIL tool with their materials. The template patterns were well printed onto the wafer down to hp22nm with excellent fidelity.

4. SUMMARY

We have been developing NIL templates using and modifying current photomask manufacturing technology.

Line and space test pattern down to hp15nm was resolved with a 100keV spot beam EB writer. With a 50keV variable shaped beam EB writer, we could resolve line and space pattern down to hp22nm. Full field pattern generating technique compatible with high resolution with a 50keV VSB EB writer should be developed, focusing on CD controllability and stability over the full field.

We have preliminarily tested template defect inspection with an EB inspection method using a programmed defect template. With an HMI EB inspection system we have seen promising results.

ACKNOWLEDGEMENT

The authors would like to thank Shusuke Yoshitake (NuFlare Technology, Inc.) for discussion and assistance in EB writing, Andrew Lopez and Sean Hand (Veeco Instruments, Inc.) for sharing AFM results, Jack Jau, Hong Xiao and Chiyan Kuan (Hermes Microvision, Inc.) for sharing inspection results, and MII (Molecular Imprints, Inc.) for sharing imprint results.

We also express our thanks to DNP members involved in this work

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Table 1 The requirements on masks from ITRS2008

Year of Production	**2013**		
DRAM 1/2pitch	32		
Flash 1/2pitch	25		
MPU Gate in resist	25		
DRAM/FRASH CD control (3σ)	3.3		
Gate CD control (3σ)	1.9		
Overlay (3σ)	6.4		
MASK (template) requirement	**NIL**	EUVL	Optical
Magnification	1	4	4
MASK nominal image size	25	100	70
Image placement (nm, multipoint)	3.7	3.8	3.8
CDU Isolated lines (MPU gates)	1.8	2.8	1.4
CDU Dense line DRAM/FRASH(half pitch)	3.1	4.6	2.4
CDU Contact/vias	3.5	3.5	1.3
Etch depth uniformity	2.1-3.2		
Trench width roughness (3σ)	2.2		
Defect size impacting CD x,y	2.5	25	25
Defect size impacting CD z	5.1		

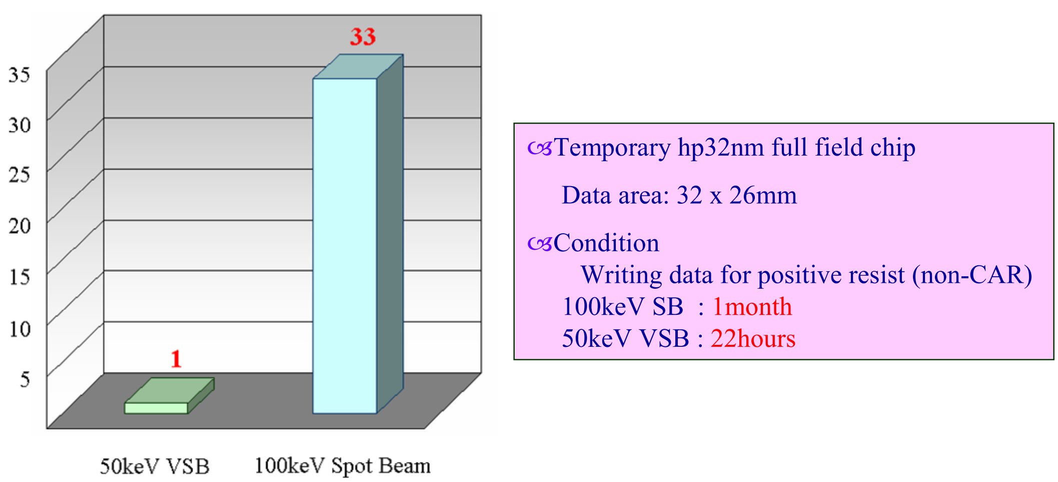


Figure 1 Writing time comparison with 50keV VSB writer and 100keV SB writer

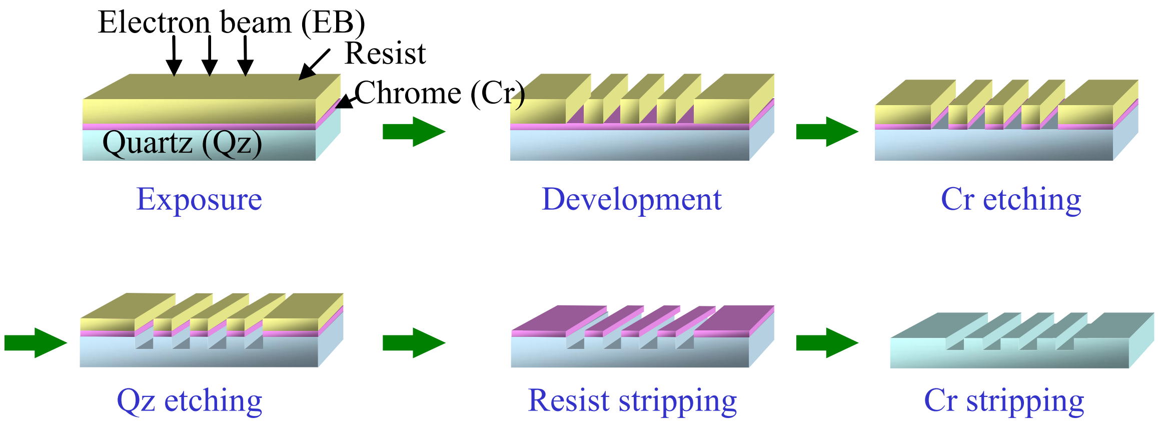
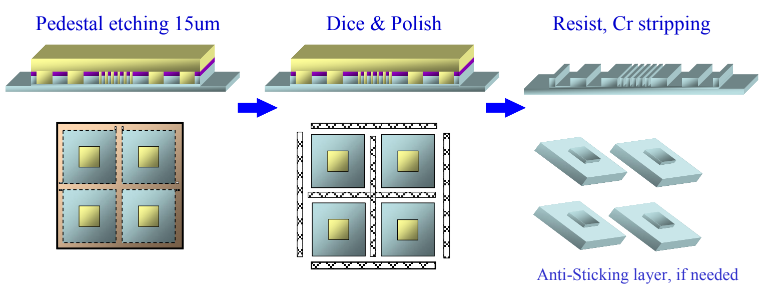


Figure 2 Manufacturing process flow of UV-NIL template



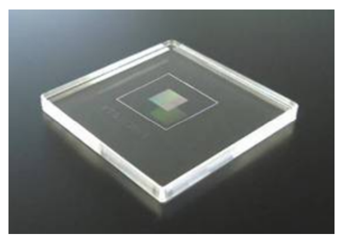


Figure 3 Manufacturing process flow for back-end process of 65mm templates

Table 2 Experimental tools and material

EB writing tool	100keV Spot Beam writer : JBX9300 50keV Variable Shaped Beam (VSB) writer : photomask production tool
Resist material	Non-CAR (positive-tone)
Measurement tools	CD-SEM (LWM9000) Image placement (LMS IPRO) AFM (Dimension X3D) Cross sectional SEM (Ultra) TEM (H-7650)
Imprint tool	Imprio 250

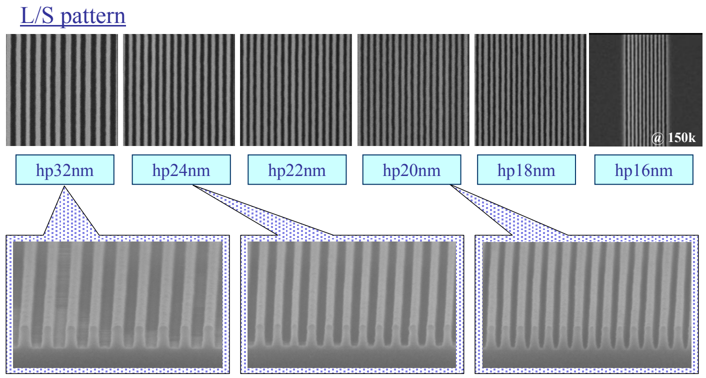


Figure 4 Quartz SEM images for line and space pattern with the 100keV SB writer

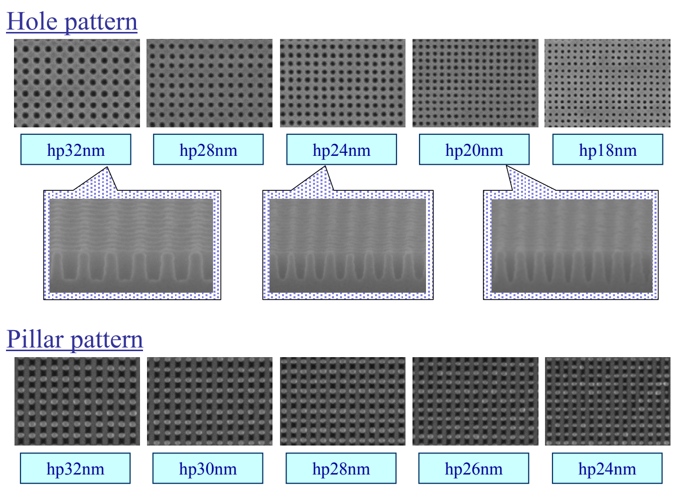


Figure 5 Quartz SEM images for dense holes and dots pattern with the 100keV SB writer

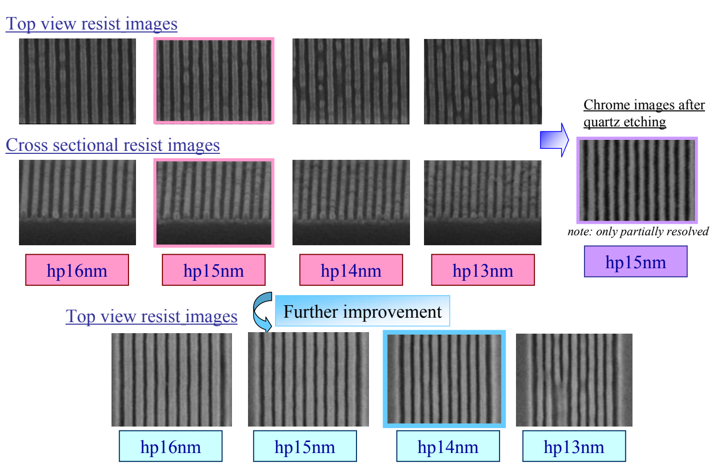


Figure 6 Resist SEM images of our latest improvements with 100keV SB writer

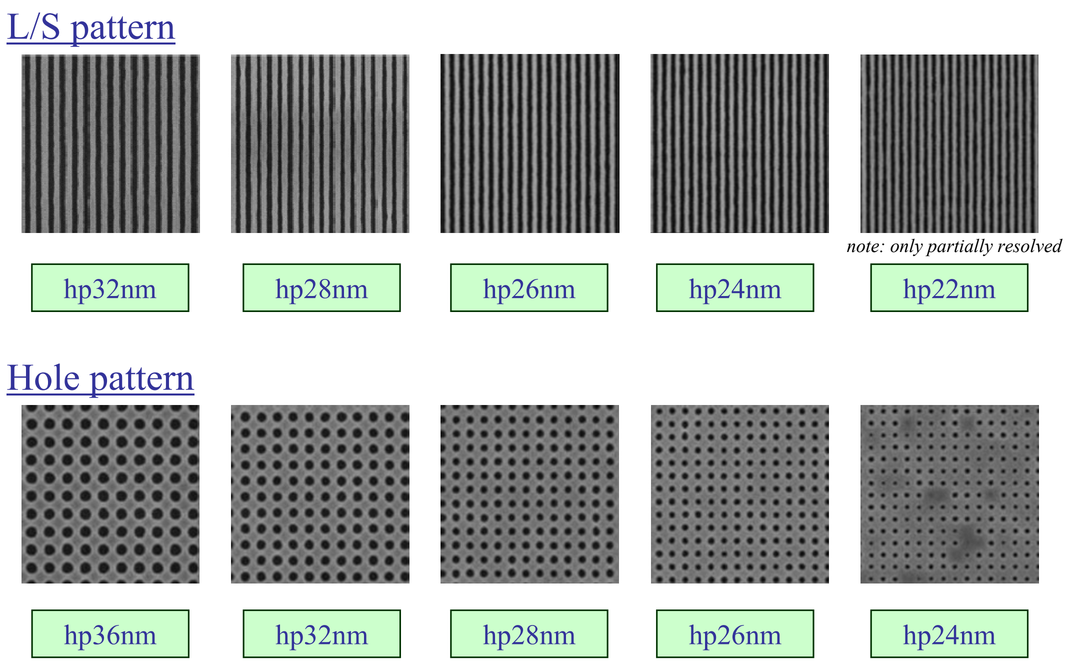


Figure 7 Quartz SEM images with 50keV VSB writer

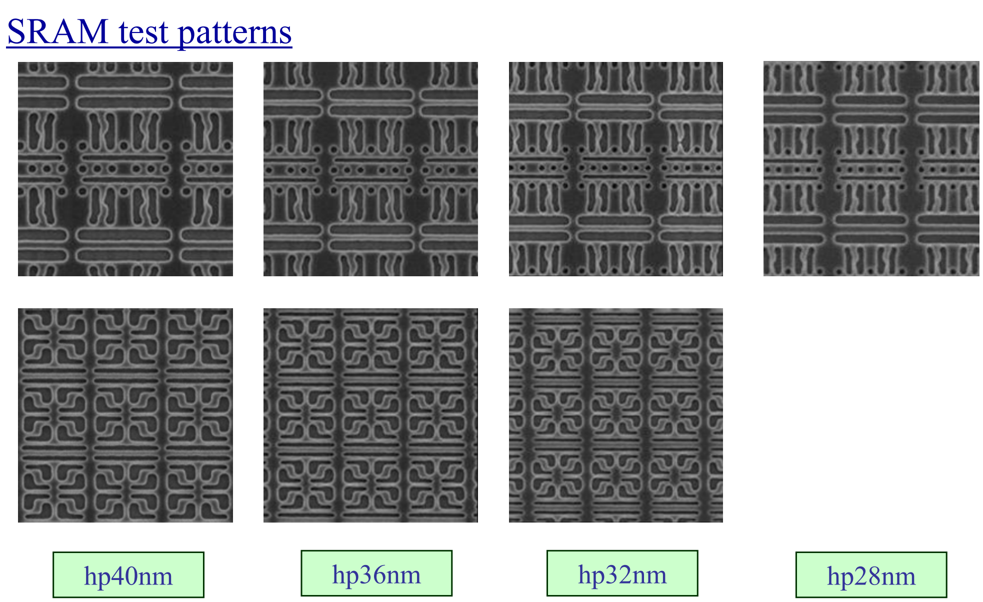
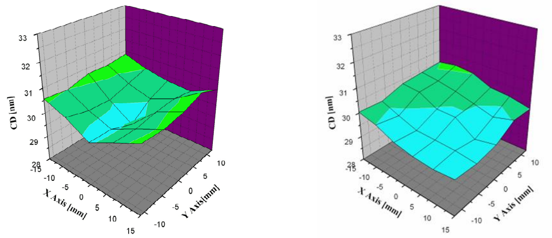


Figure 8 Quartz SEM SRAM pattern images with 50keV VSB writer

*Measurement feature : hp32nm dense line

50keV VSB
Area 32 x 26 mm (5 x 5 arrays)

100keV SB
Area 30 x 24 mm (6 x 5 arrays)



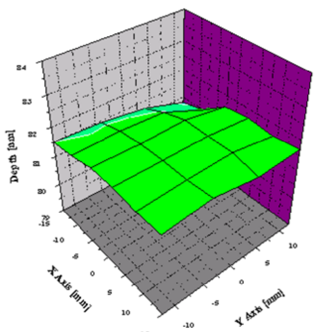
	50keV VSB	100keV SB
Average	30.4 nm	29.9 nm
Range	2.1 nm	1.3 nm
3σ	1.7 nm	1.2 nm

ITRS 3σ : 3.1nm

Figure 9 Critical dimension uniformity results with 50keV VSB and 100keV SB EB writer

*Measurement feature : 32nm iso space

Area 30 x 24 mm (6 x 5 arrays)



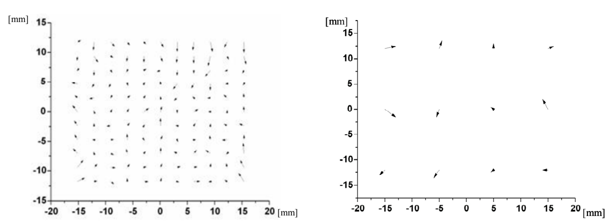
Average : 81.6nm
Range : 1.2nm
3σ : 0.8nm

ITRS 3σ : 2.1nm

Figure 10 Quartz depth uniformity result

50keV VSB
Area 30 x 26 mm (11 x 11 arrays)

100keV SB
Area 28 x 24 mm (4 x 3 arrays)



50keV VSB:

	X	Y
3σ	2.9	4.2
Min	-2.0	-3.0
Max	2.0	4.0

100keV SB:

	X	Y
3σ	6.0	6.0
Min	-2.0	-3.0
Max	4.0	4.0

ITRS 3σ : 3.7nm

Figure 11 Image placement accuracy results with 50keV VSB and 100keV SB EB writer

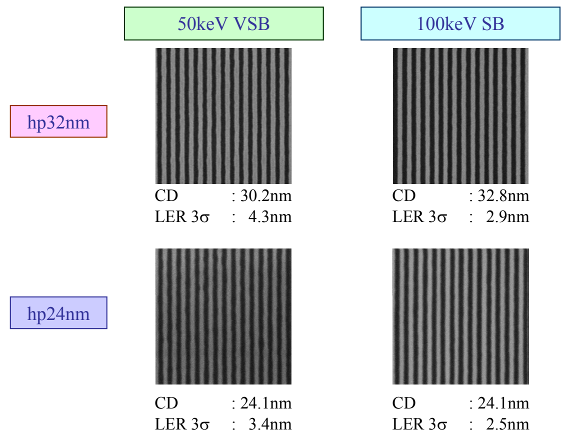


Figure 12 Line edge roughness results with 50keV VSB and 100keV SB EB writer

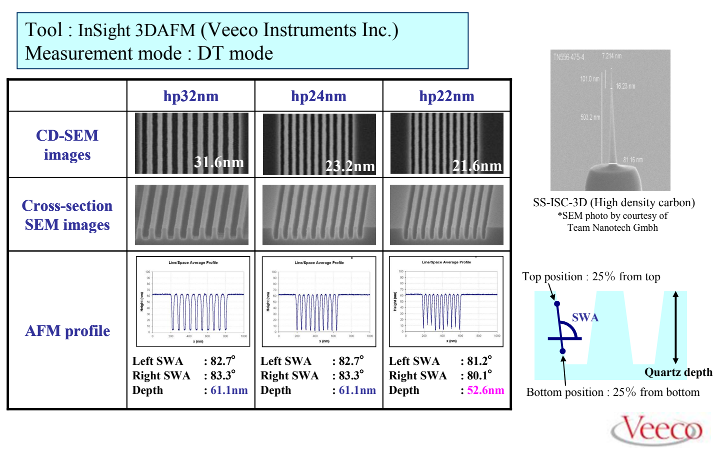
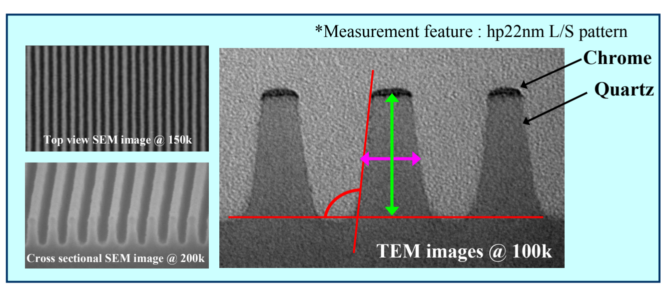


Figure 13 Profiles of line and space pattern on template observed with an AFM



From TEM image･･･

- **Average of SWA : 84.0°**
- **Depth of quartz : 61.4nm**
- **Middle CD (50% from top) of central line : 22.2nm**
- **Bottom shape of quartz is rounding**

Figure 14 Profile of hp22nm line and space pattern on template observed with a TEM

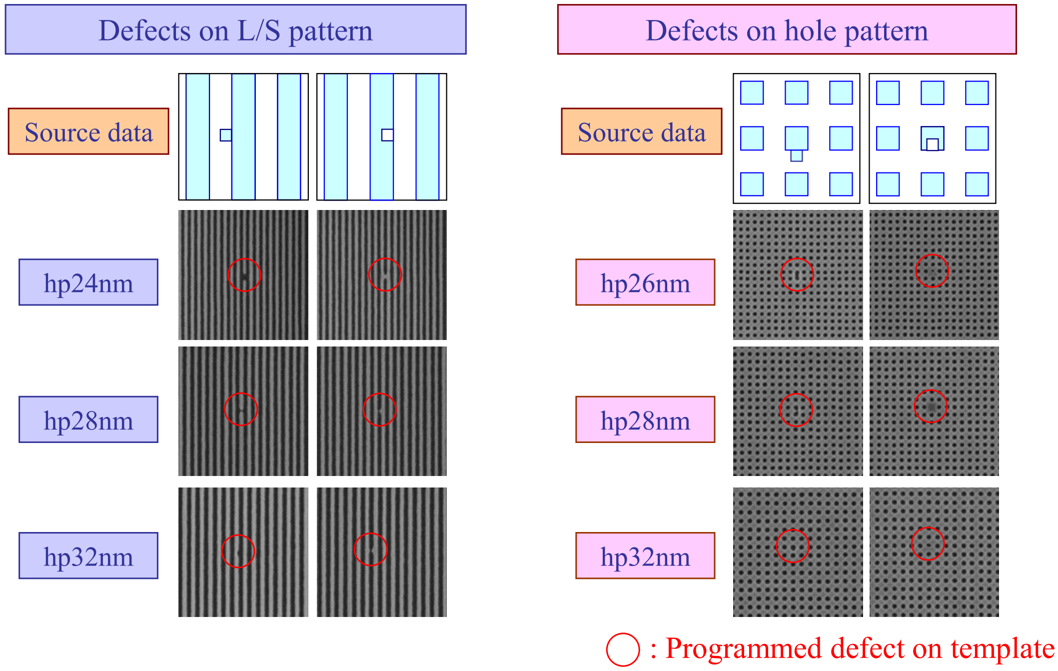


Figure 15 SEM images of defect on the programmed defects template

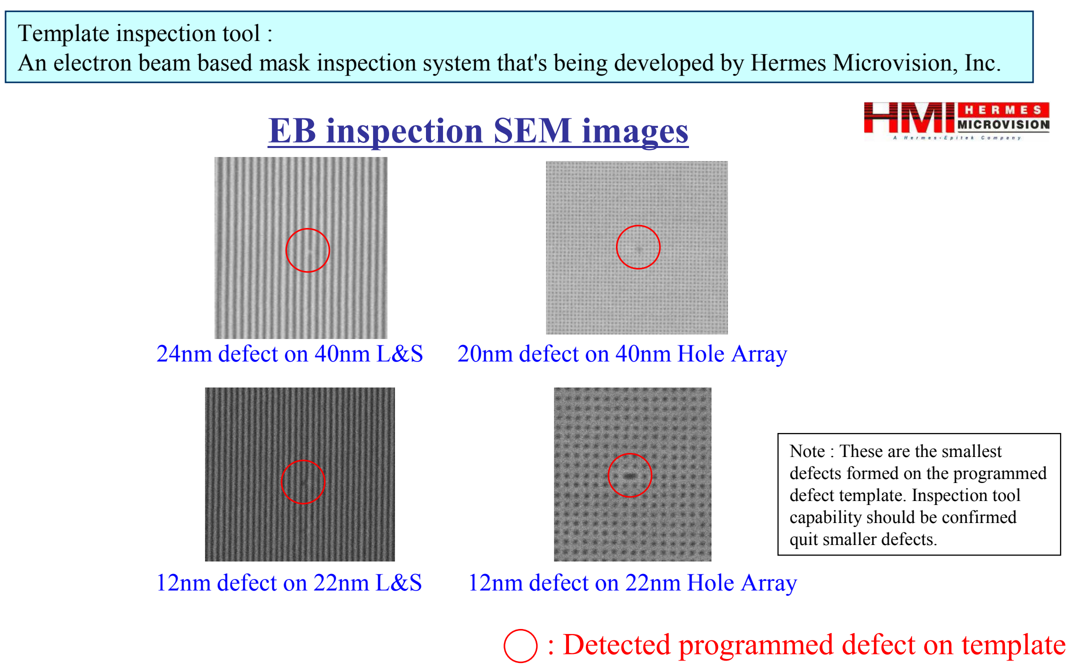


Figure 16 SEM images of programmed defects on the programmed defects template detected by EB inspection system

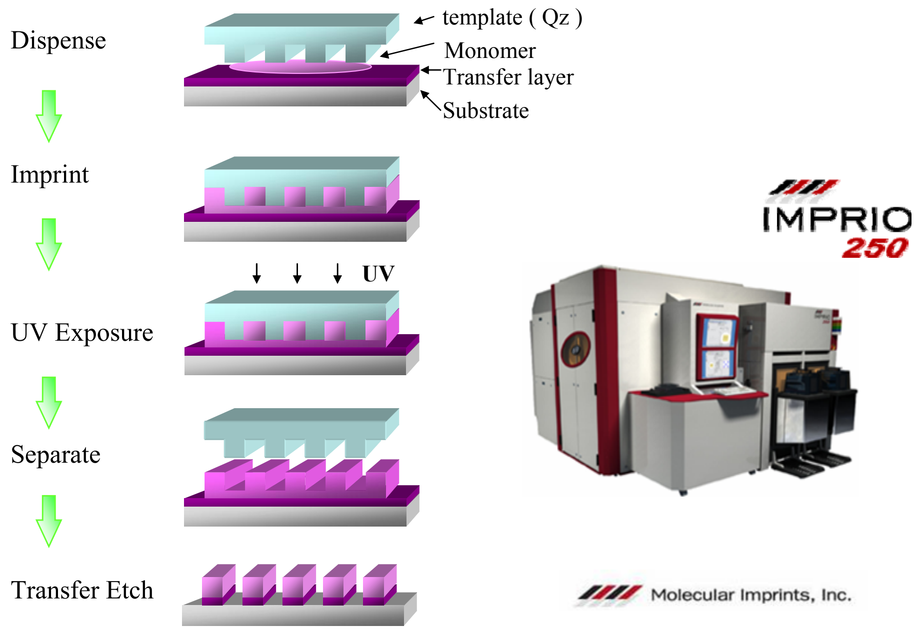


Figure 17 Process flow of nano imprint lithography and MII imprint tool

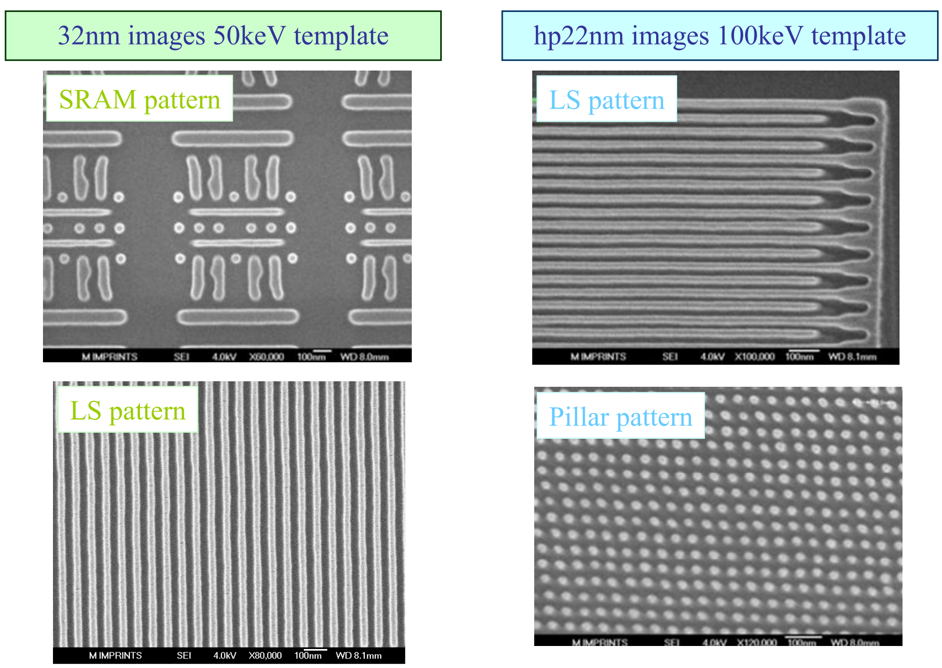


Figure 18 Imprint pattern on wafer SEM images