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# UV NIL template making and imprint evaluation

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## ABSTRACT

UV NIL shows excellent resolution capability with remarkable low line edge roughness, and has been attracting pioneers in the industry who were searching for the finest patterns.

We have been focused on the resolution improvement in NIL template making with a 100keV acceleration voltage spot beam EB writer process, and have established a template making process to meet the requirements of the pioneers. Usually such templates needed just a small field (several hundred microns square or so).

Now, for several semiconductor devices, the UV NIL is considered not only as a patterning solution for R&D purpose but eventually as a potential candidate for production, and instead of a small field, a full chip field mask is required. Although the 100kV EB writers have excellent resolution capability, they are adopting spot beams (SB) to generate the pattern and have a fatally low throughput if we need full chip writing.

In this paper, we are focusing on the 50keV variable shaped beam (VSB) EB writers, which are used in current 4X photomask manufacturing. The 50keV VSB writers can generate full chip pattern in a reasonable time, and by choosing the right patterning material and process, we achieved resolution down to 28nm.

Keywords: UV NIL, template, EB writing, photomask

## 1. INTRODUCTION

NIL templates have 1X patterns and require patterning process with higher resolution compared to that of the 4X photomasks. Table 1 shows the 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 or photomasks, the resolution should be finer, and close to 20nm in 2013. The defect size requirements are also be tough and are different from other masks, and many efforts should be paid. In this paper we are focusing on the mask resolution, and discussion of defects on mask patterns will be taken up at another papers.

For the NIL template pattern making, we have been evaluating two different processes with 100keV SB EB writer and 50keV VSB EB writer[1-4]. The 100keV SB writer is for R&D purpose, and 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 advanced photomask manufacturing, and can write full field in a reasonable time. However, they are designed for 4X pattern generation and show relatively low resolution capability compared to the 100keV SB writer.

| Year of Production | 2013 | | |
|---|---|---|---|
| DRAM 1/2pitch | 32 | | |
| Flash 1/2pitch | 25 | | |
| MPU Gate in resist | 21 | | |
| DRAM/FRASH CD contol(3 sima) | 2.6 | | |
| Gate CD control (3sigma) | 1.3 | | |
| Overlay (3 sigma) | 6.4 | | |
| MASK Requirement | NIL | EUVL | Optical |
| Magnification | 1 | 4 | 4 |
| MASK nominal image size | 21 | 85 | 85 |
| Image placement (nm, multipoint) | 3.7 | 3.8 | 3.8/2.7 |
| CDU Isolated lines (MPU gates) | 1.2 | 1.9 | 1 |
| CDU Dens line DRAM/FRASH(half pitch) | 3.1 | 3.7 | 1.9 |
| CDU Contact/vias | 3.5 | 2.8 | 1 |
| Etch depth uniformity | 2.1-3.2 | | |
| Trench width roughness (3 sigma) | 1.9 | | |
| Defect size impacting CD x,y | 2.5 | 25 | 25 |
| Defect size impacting CD z | 5.1 | | |

Table 1 The requirements on masks

Photomask Technology 2008, edited by Hiroichi Kawahira, Larry S. Zurbrick,
Proc. of SPIE Vol. 7122, 71223P · © 2008 SPIE · CCC code: 0277-786X/08/$18 · doi: 10.1117/12.802746

## 2. EXPERIMENTAL

Fig. 1 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.

In general, though the thicknesses are different, the processes are already used in current photomask manufacturing, for example in the manufacturing of alternating PSMs. Only the conditions and parameters are modified to achieve higher resolution.

Table 2 shows the experimental tools and materials. We used the "JBX9300" (JEOL) and "ELS-7000" (Elionix) as the 100keV SB writer. As the 50keV VSB EB writer, 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, and "ULTRA" (Carl Zeiss) SEM. Imprint performance test was done by an "Imprio250" (Molecular Imprints Inc) tool.

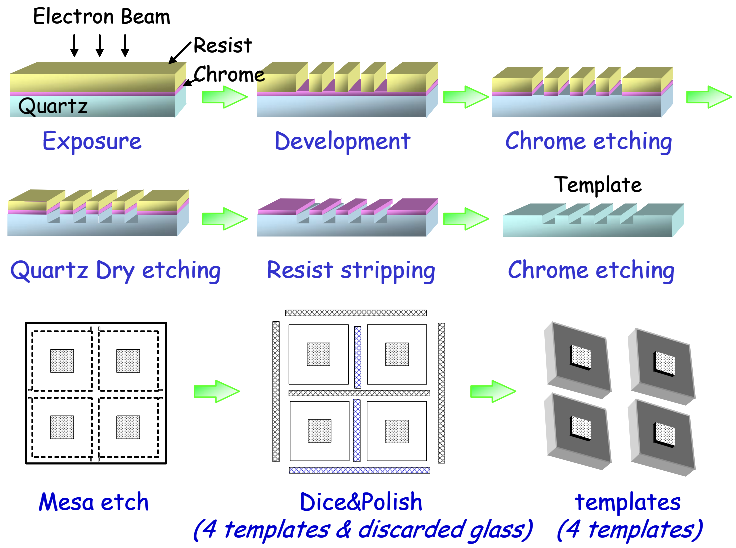



Fig. 1. Manufacturing process flow of imprint templates

| | |
|---|---|
| Exposure tool | 100keV spot beam EB writer (JBX9300, ELS-7000)<br>50keV VSB EB writer (4X photomask manufacturing tool) |
| Resist materials | Non CAR (Positive tone) |
| Measurements tool | CD-SEM (LWM9000)<br>Image placement measurement (LMS IPRO)<br>Cross section-SEM (Ultra) |
| Imprint tool | Imprio 250 |

Table 2 The experimental tools and materials

## 3. RESULTS AND DISCUSSION

We optimized the process parameters and conditions with the 100keV SB EB writer. Fig. 2 shows the line and space patterns and Fig. 3 shows the dense hole and dots. The resolution limit is hp16nm for line and spaces, hp20nm for dense holes, and hp26nm for dots. Fig. 4 is the resist images of our latest improvements, and shows further resolution for line and spaces, but 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.

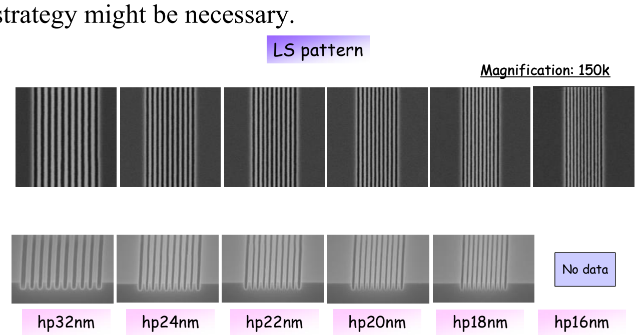



Fig. 2. Resolution images of the line and space patterns

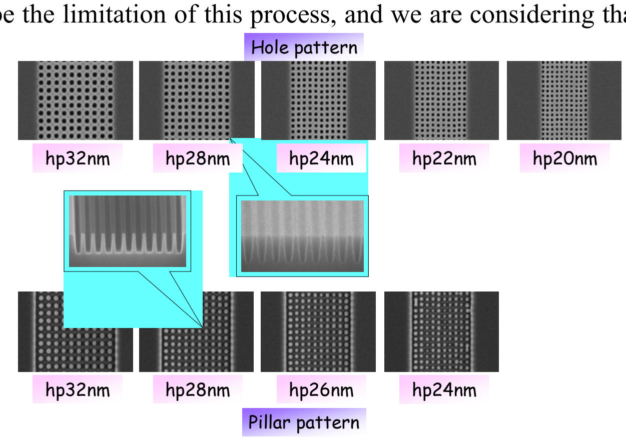



Fig. 3. Resolution images of the dense hole and dots

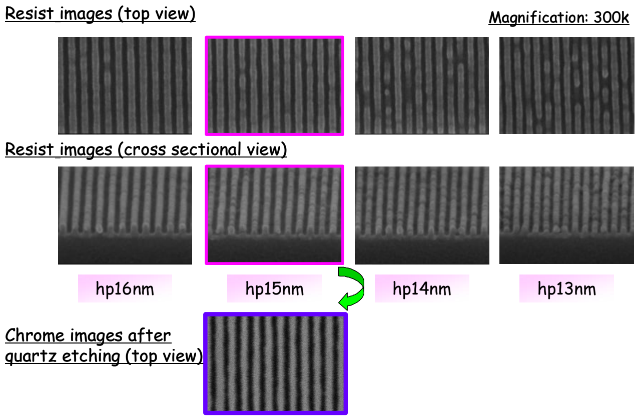



Fig. 4. The resist images of our latest improvements

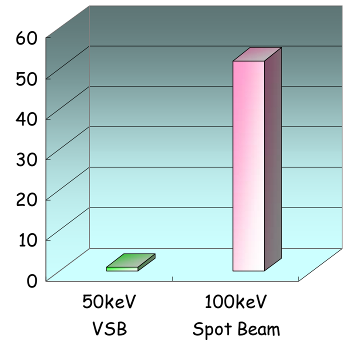



Fig. 5. EB writing time comparison

Figs. 6 and 7 are templates made with the 50keV VSB writer. The resolution is limited down to hp28nm, but as we can see in Fig. 5, the throughput of the 50keV VSB tool enables to make a larger field. Taking into account that the NIL does not need high load optical proximity correction pattern, the 50keV VSB tool has the potential of NIL template manufacturing.

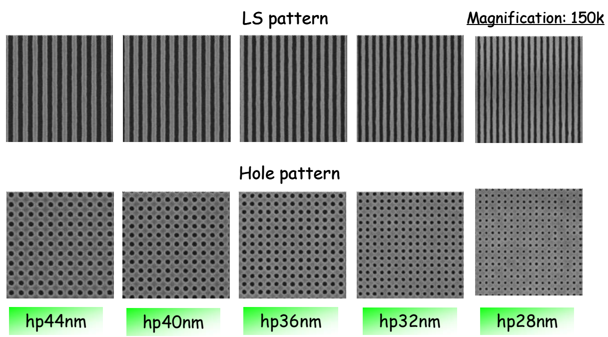



Fig. 6. Resolution images of the line and space patterns using 50keV EB writer

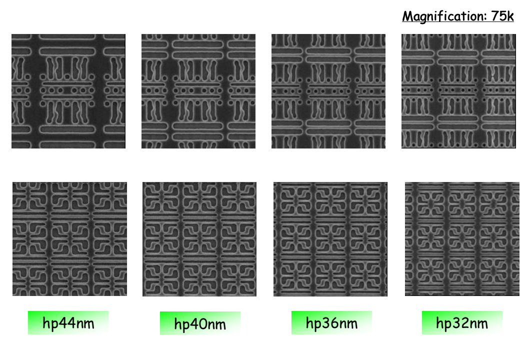



Fig. 7. Resolution images of the SRAM patterns using 50keV EB writer

Figs. 8, 9, and 10 show the critical dimension uniformity (CDU), image placement accuracy, and pattern fidelity of both 50keV VSB and 100keV SB process. CDU and pattern fidelity was evaluated with an hp32nm line and space pattern, so the 100keV SB template shows better results, because of the resolution capability (note that hp32nm is close to limit for the 50keV VSB, while the 100keV SB has still a margin). These performances should be improved to match with the future ITRS requirements, but at this stage of the development, we believe the numbers are acceptable.

To improve the resolution of the 50keV process, along with the CD and image placement accuracy, 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 NIL template process, and are planning to collect initial sets of data in the coming months.

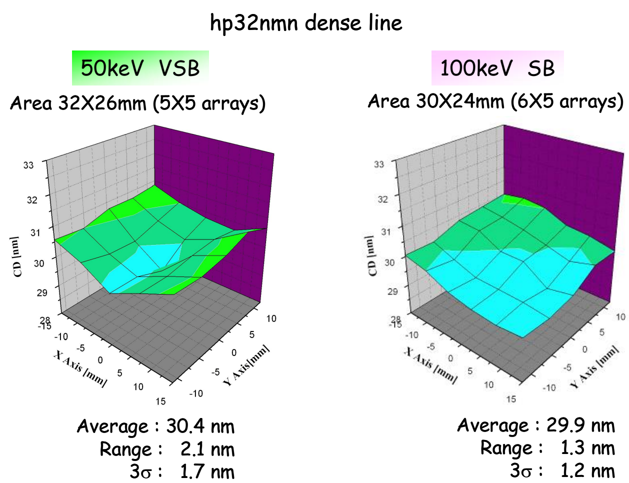



Fig. 8. The critical dimension uniformity of both 50keV VSB and 100keV SB process.

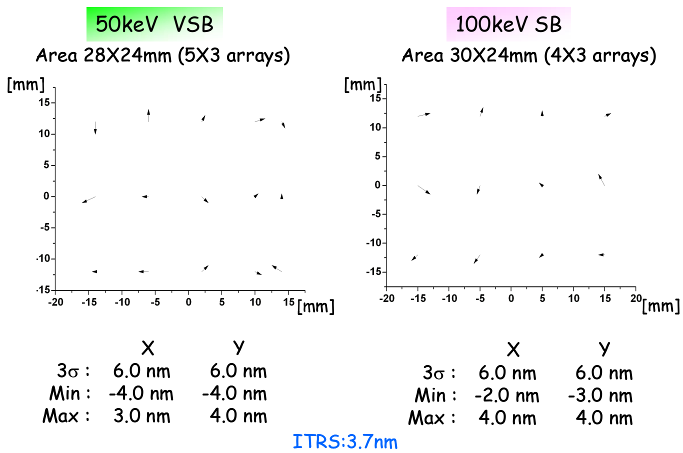



Fig. 9. The image placement accuracy of both 50keV VSB and 100keV SB process.

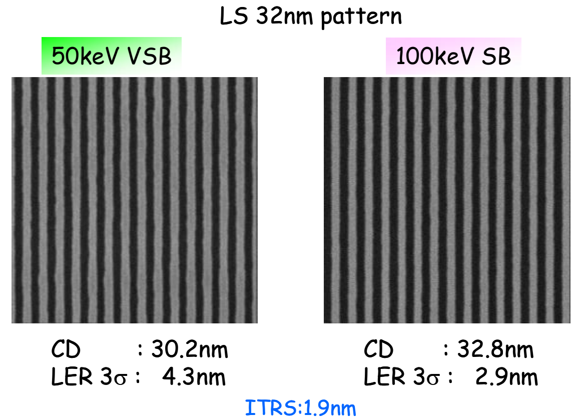



Fig. 10. The pattern fidelity of both 50keV VSB and 100keV SB process.

Fig. 11 shows the profile of the template pattern monitored 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 CDP15-150C tip, we can reach the bottom of a 27.3nm space. This could be make the future assurance of the template possible, if not only the planar CD but also the 3D profile of the template pattern have decisive impact on the imprint performance.

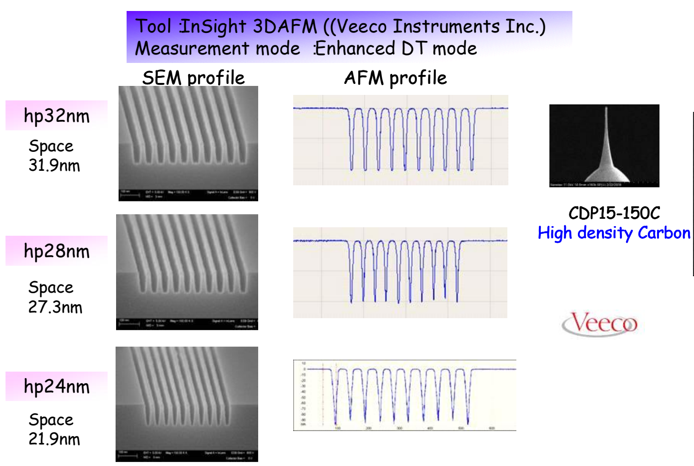



Fig. 11. The profile of the template pattern monitored with an AFM

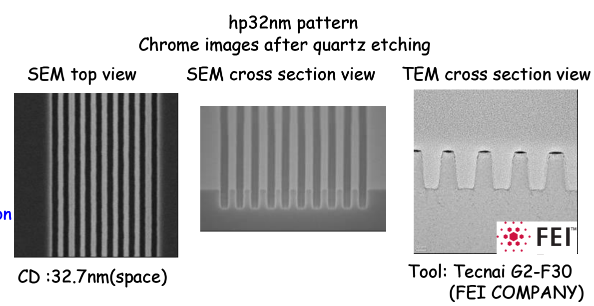



Fig. 12. The profile monitored with a TEM

Fig. 12 shows the profile monitored with a TEM. A Tecnai G2-F30 of FEI company was used. The TEM photo was taken with the thin chrome on top of the template. 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.

Figs 13 to 16 are the imprint results of our templates. Imprint process and data collection were done by Molecular Imprints Inc.. We can see that the template patterns were well imprinted onto the wafer.

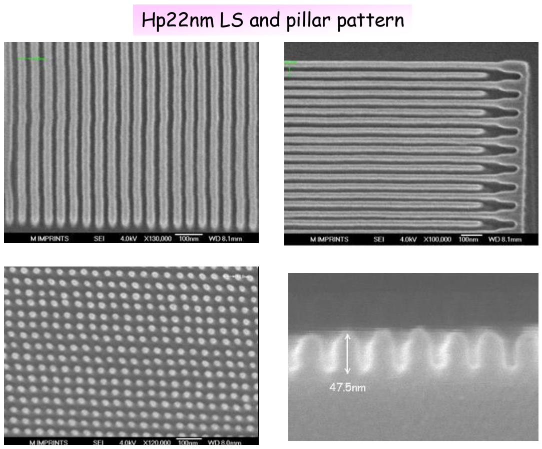
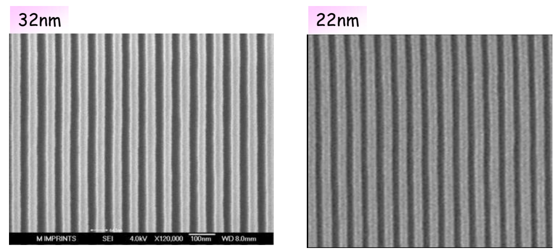



Fig. 13. Imprint results using by 100keV template.




32nm:

| Parameter | mean | standard deviation |
|---|---|---|
| Line width | 31.94 | 1.84 |
| LWR 3Ξ | 2.37 | 0.36 |
| Pitch | 64.10 | 2.08 |
| LER 3Ξ | 2.22 | 0.30 |

22nm:

| Parameter | mean | standard deviation |
|---|---|---|
| Line width | 24.51 | 0.72 |
| LWR 3Ξ | 3.13 | 0.43 |
| Pitch | 44.67 | 1.51 |
| LER 3Ξ | 3.54 | 0.36 |

[nm]

Fig. 14. Imprint results using by 100keV template

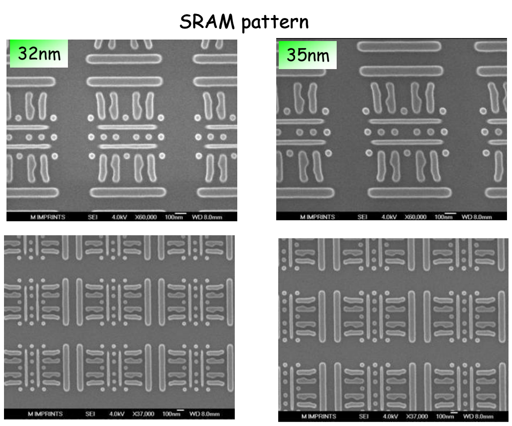
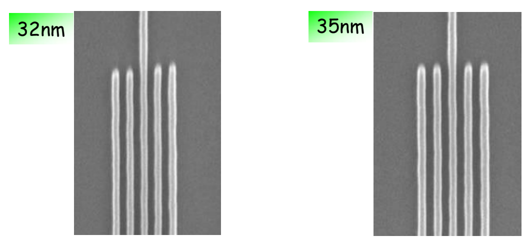



Fig. 15. Imprint results using by 50keV template




32nm:

| Parameter | mean | standard deviation |
|---|---|---|
| Line width | 33.20 | 1.70 |
| LWR 3□ | 3.02 | 0.74 |
| Pitch | 66.93 | 2.37 |
| LER 3□ | 2.26 | 0.40 |

35nm:

| Parameter | mean | standard deviation |
|---|---|---|
| Line width | 35.89 | 1.85 |
| LWR 3□ | 3.12 | 0.38 |
| Pitch | 71.55 | 2.82 |
| LER 3□ | 2.08 | 0.09 |

[nm]

Fig. 16. Imprint LER measurements using by 50keV template

## 4. CONCLUSION

NIL template process was discussed focusing on the pattern resolution.

Currently used 50keV VSB EB process has enough capability for full field template manufacturing with patterns down to around hp30nm. To achieve the requirements for the next generation lithography masks, we are beginning to test the new 50keV VSB tools designed for the 32nm node 4X photomask manufacturing.

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