Design and Performance of a Step and Repeat Imprinting Machine

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Abstract

Molecular Imprints, Inc. (MII) has developed the Imprio™ 100, which is the first commercial step and repeat imprint lithography system with field-to-field alignment (Figure 1). This system is designed to implement the UV curable nano-replication capability of the Step and Flash™ Imprint Lithography (S-FIL™) process. To-date, the Imprio 100 system has demonstrated:

1) Full 200 mm wafer coverage with lithographically useful patterning
2) Full wafer residual thickness control to enable practical etching (thickness variation < 50 nm, 3σ)
3) Field edge control compatible with 50 um kerf regions.
4) Multi-day CD uniformity measured on an analytical SEM < 2 nm, 3σ with no process adjustments
5) Etch pattern transfer including break-through etch of residual material, followed by a bi-layer etch through thick planarization layers
6) Initial level-to-level alignment target acquisition with accuracy of better than 100 nm.
7) Low air borne particle counts in tool microenvironment consistent with Class 0.1 while imprinting.

Introduction

Previous work in the area of Step and Flash Imprint Lithography and other forms of imprinting have demonstrated multiple examples of imprinting showing the ability to resolve very small features [1-6] [§]. There are 2 different imprint strategies, room temperature UV cure imprinting and thermal imprinting. In thermal processing, the material is taken above its glass transition temperature, the mold is pushed into the liquid under high pressure and then the mold and substrate is cooled below the glass transition temperature to create the pattern [2]. It is believed that maintaining alignment between the template and substrate in thermal imprinting will be very challenging due to the presence of differential thermal expansion and unpredictable distortions due to imprint pressures.

The attraction of UV imprinting is that the complete operation is done at room temperature. There are two versions of material deposition during UV imprinting; spin on, and field-to-field liquid dispense. The spin on material must form a stable layer of a liquid that remains “wet”[6]. To form a stable wet layer requires low molecular weight polymers that inevitably have a high viscosity. Imprinting of high viscosity materials requires correspondingly high pressure.

Colburn et al [1] developed Step and Flash Imprint Lithography (S-FIL) that uses UV imprinting with field-to-field dispense of UV crosslinkable monomer mixtures (Figure 3). S-FIL™ is a replication technique (Figure 2) that has the potential to lead to a low cost, high throughput process. It has been shown previously that the resolution of the replication process is only limited by the resolution of the template fabrication techniques and can be as good as 10nm. Imprint lithography techniques are essentially micromolding processes in which the topography of a template defines the patterns created on a substrate. S-FIL is an imprint lithography technique that operates at room temperatures and low pressures (<5 psi)

Emerging Lithographic Technologies VII, Roxann L. Engelstad, Editor,
Proceedings of SPIE Vol. 5037 (2003) © 2003 SPIE · 0277-786X/03/$15.00

since it is based on a low-viscosity, UV-curable liquid approach delivered field-to-field in a drop-on-demand manner. This approach is particularly suited for high-resolution layer-to-layer alignment. It is also insensitive to variations in pattern density, which could be a problem for thermal, high-pressure molding and spin-on UV imprinting. The challenges in designing and building a practical imprinting system include the need to maintain the relative position and orientation of the template with respect to the substrate, while applying modest imprint forces through a lubricated liquid contact.

MII has developed the first commercial tool implementing the S-FIL process. This paper describes process data which demonstrates that S-FIL can deliver “lithographically useful” patterning.

Imprint Process

Step and Flash Imprint Lithography (S-FIL) is a bi-layer approach using a low viscosity, UV-curable imprint solution deposited on an underlying organic planarization layer. The quartz template is rigid and transparent, allowing for UV curing of the imprint solution.

Figure 2 shows the process in cross-section, and Figure 3 shows the step and repeat process. With S-FIL, an organic planarization layer is spin-coated onto the substrate. Then a low viscosity, UV photo-polymerizable imprint solution is dispensed on the wafer to form an etch barrier in the area to be imprinted (step 1). A surface-treated, transparent template bearing patterned relief structures is aligned over the coated substrate. The template is lowered onto the substrate, thereby displacing the solution, filling the imprint field, and trapping the photo-polymerizable imprint solution in the template relief (step 2). Irradiation with UV light through the backside of the template cures the solution (step 3). The template is then separated from the substrate leaving an organo-silicon relief image on the surface of the coated substrate that is a replica of the template pattern (step 4). The wafer is then stepped and the process is repeated on the next field.

Once the wafer is fully imprinted using S-FIL, the pattern transfer is achieved using a bi-layer etch process. A halogen etch is used to clear the undisplaced, cured imprint solution so that the underlying planarization layer is fully exposed in the recessed regions of the pattern. A subsequent oxygen reactive ion etch into the planarization layer amplifies the aspect ratio of the imprinted image.

System Design

The key features of the Imprio 100 system include:

- Step and repeat approach
- Self contained Class 0.1 micro-environment
- Through-the-template (TTT) field-by-field alignment
- Advanced graphical user interface
- Built-in diagnostics
- High throughput wafer stage
- Semi-automatic wafer / template loader

The unique design challenges associated with Imprio 100 included providing liquid dispense, leveling, mechanical stiffness to Z forces, and TTT alignment microscope access. The liquid is dispensed on a field-to-field basis as shown in Figure 3. The tool design is based on a vacuum preloaded XY air bearing stage that has nano-resolution motion characteristics, excellent flatness of motion, and suitable stiffness to Z loads. Leveling is achieved in 3 steps: the template is leveled to the stage plane using an upward air gauge. Then, the wafer is leveled to the stage plane using a downward air gauge. Finally, the unique passive self-correcting flexure design described in [7] takes out any local substrate non-planarity to generate imprints with residual material layers of uniform thickness. The mechanical degrees of freedom are shown in Figure 4. The wafer support sub-systems, the wafer leveling stage, the template support sub-system, the template leveling and Z motion stage for the imprint head were designed by MII to provide exceptional mechanical stiffness and low particle generation. A moving TTT alignment microscope is used to view the wafer and template through the back of the template.

Templates

Templates for the Imprio 100 are 65 x 65 mm quartz squares as shown in Figure 5. They are fabricated four at a time on a standard 6" mask blank. The imprint pattern is placed on a 25 x 25 mm raised mesa that is 15 um high. The template is fabricated by first patterning the fine features in a chrome coated mask blank using a conventional pattern generator. The chrome is used to mask the dry etch of the quartz and then removed. The patterned blank is coated with second layer of photoresist and the mesa patterned using a low resolution laser pattern generator. A 15 μm mesa is etched, and the chrome is stripped. Finally, the blank is diced into four 65 x 65 mm templates [8].

Experimental details

The wafers were coated with a planarization layer of BARC material "DUV 30" from Brewer Science. All of the imprints were run on an Imprio 100 located at the Molecular Imprints application laboratory. The film thickness measurements were made on a Filmetrics measurements attachment on a Nikon Optical Microscope. The SEM's micrographs of Figure 9 were obtained on a JEOL analytical SEM operating at 5KV on gold coated samples. For CD measurements reported in Figure 8, a single line scan was superimposed over the top down image of the lines. The line width was set at the 50% intensity point of the line scans.

The alignment measurements were made on previously imprinted Si wafers. The first layer imprints were bilayer etched to transfer the pattern into Silicon and dry stripped. The wafers were then stripped in piranha and rinsed clean. The etched wafers were then coated with 350 nm of BARC before imprinting the second layer. The second layer alignments were manually targeted using the TTT microscope.

Process Performance

For imprinting to find an application in semiconductor manufacturing, the technology needs to demonstrate "lithographically useful" imaging. This includes resolution, critical dimension control, full field liquid filling with small kerf regions between the fields, pattern transfer, layer-to-layer align, and particle management.

MII has focused its early efforts on fluid control to deliver high quality thickness and field edge control. Figure 6 shows a 200 mm wafer with well defined streets between the fields, and uniform imprints with less than 50 nm, 3σ of thickness variation (2 colors). The example shows 1 mm gaps between fields, and recently gaps as small 50 um have been printed. The control chart for layer uniformity is shown in Figure 7 as better than 50 nm, 3σ for the most recent imprints. This thickness control is quite sufficient for etch pattern transfer through sub-100nm films as shown in Figure 10.

The ability of the imprinting process to faithfully replicate the template with minimal line edge roughness is one of its most attractive features. The data in Figure 8 shows, for the first time, CD uniformity over multiple days of operation with no process adjustments used to target the CD. The JEOL analytical SEM described earlier was used to measure the same location on 3 lines in 4 groups in each field. The template manufacturer measured the CD on the template at about 5 nm, 3σ. The same template was used for each day's run, so the results in each field could be averaged to minimize the effect of measurement noise. The data is plotted as the mean and 3σ for each field. The mean variation within a field was 7 nm, 3σ. The mean for the fields are all within 2 nm, 3σ. The majority of this error is residual measurement error.

The high resolution features typically associated with S-FIL imprinting are shown in Figure 9. The SEM's include examples of printing of small spaces, a situation that is particularly challenging for conventional optical lithography.

The align system in the Imprio 100 uses a relatively low resolution microscope objective (0.14 NA) to look through the back of the template and image the template and wafer simultaneously. The use of a low viscosity UV curable liquid interface allows in-situ relative motion of the template and substrate immediately prior to UV exposure. Based on studying video images of the TTT alignment procedure, it was observed that less than 100 nm target acquisition was possible using Moiré targets. Further, the tool possesses sufficient mechanical stiffness to support relative motion between the template and substrate with a resolution of less than 100 nm.

Defects and particle generation during imprint is a particular concern because of the fact that the template and wafer make lubricated contact and the whole machine is put under mechanical stress. Figure 9 shows > 0.1um air-borne particle counts of 3 per cubic foot per min inside the tool microenvironment during imprinting. This low particle count level is equivalent to a Class 0.1 environment.

The etch pattern transfer process is discussed next. As shown in Figure 10, a halogen rich etch is used to etch through the residual layer in the recessed regions of the features. The mixture is then changed to a halogen free oxygen gas to etch through the planarization layer. The images in Figure 6 show a highly anisotropic etch achieved using a LAM 9400SE dual frequency etcher [9].

Conclusions

Molecular Imprints, Inc. believes that the data presented in this article shows that room temperature, low pressure UV imprinting can be used to generate well controlled lithographically useful fine features on a 200 mm wafer. In addition, the feasibility of etch pattern transfer, alignment, and the maintenance of a clean environment in the tool during imprinting have been demonstrated.

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Figure 1: Imprio™ 100 from Molecular Imprints, Inc.

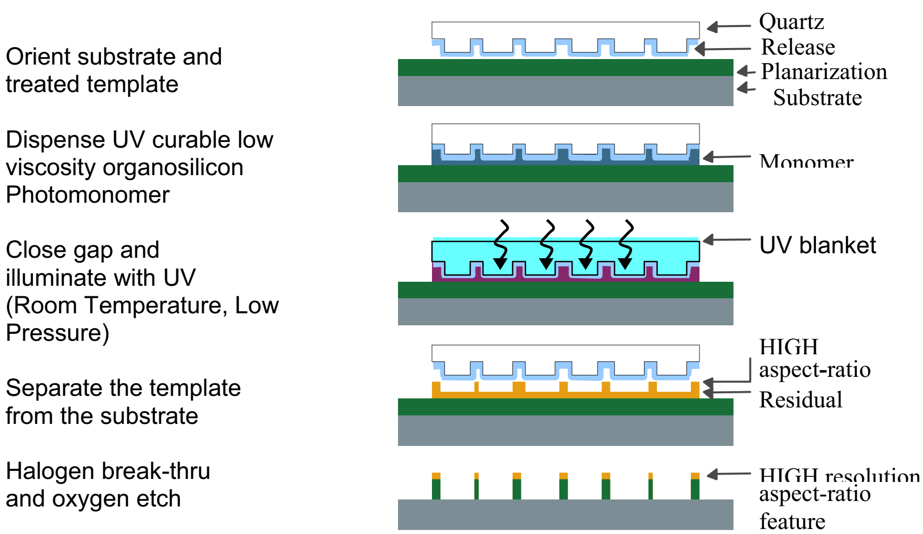

Figure 2: Step and Flash Imprint Lithography (S-FIL) process cross-section

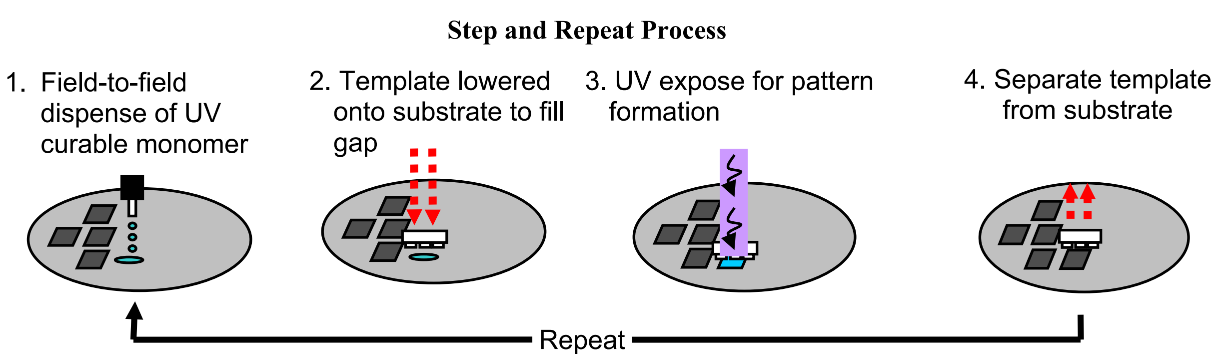

Figure 3: Step and Flash Imprint Lithography (S-FIL) step and repeat process

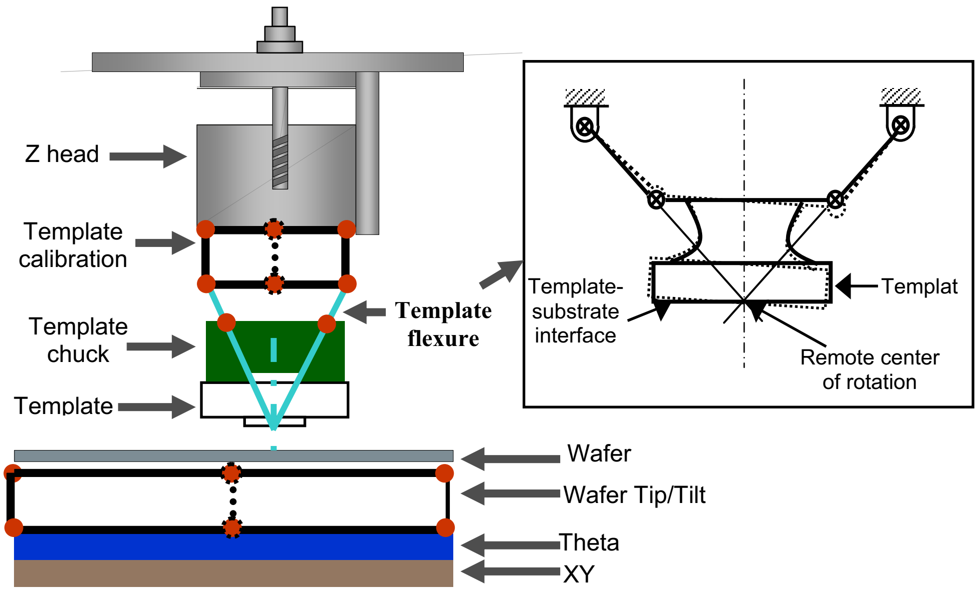

Figure 4: Mechanical degrees of freedom in the Imprio 100. Circular dots represent hinges.

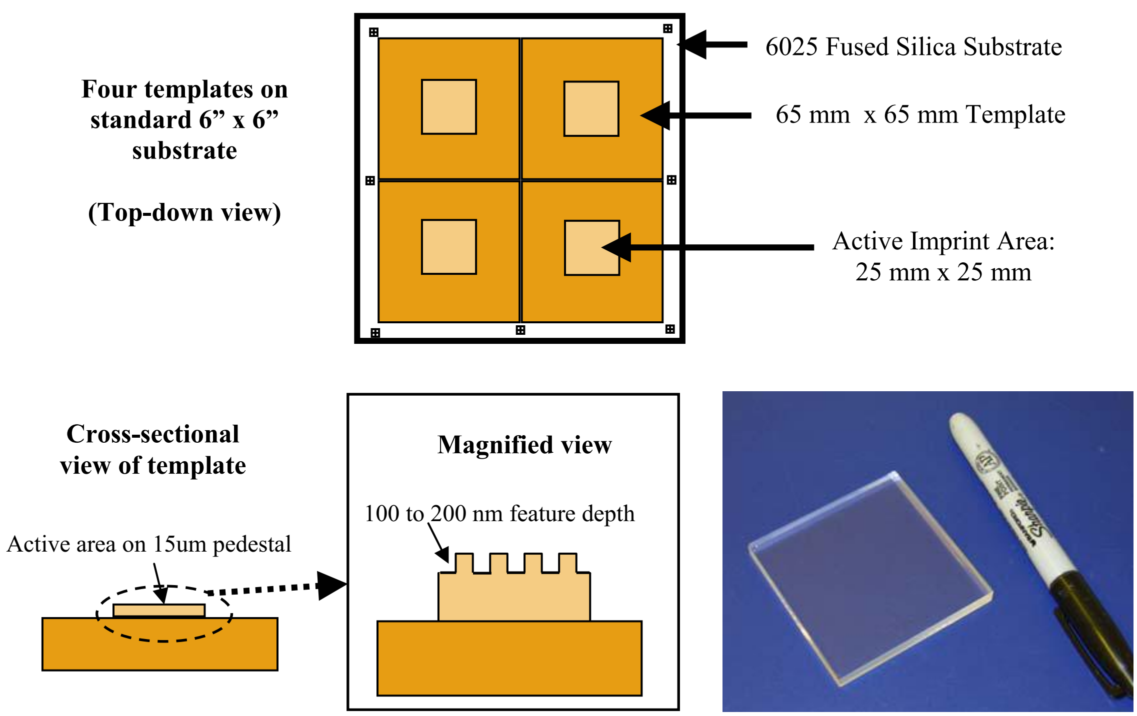

Figure 5: MII’s template design and form factor

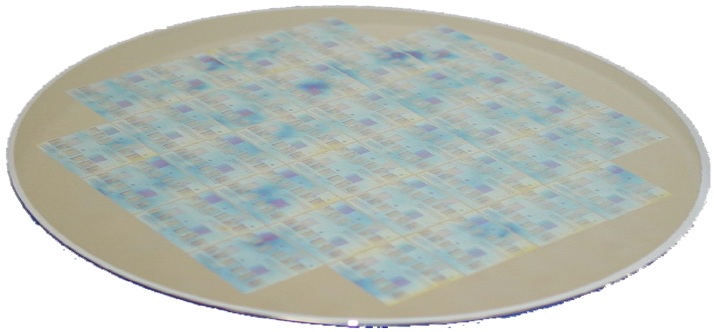

Figure 6: Full 200 mm wafer coverage with lithographically useful thickness (50 nm, 3σ) and field edge control compatible with < 250 um kerf.

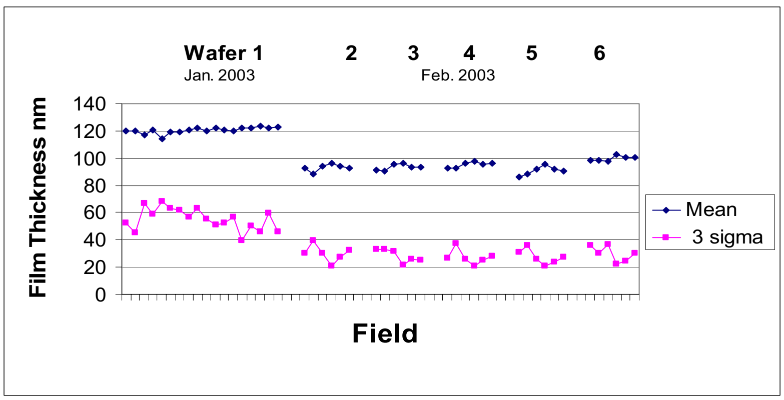

Figure 7: Control chart of film thickness showing improvements (reduction) in mean residual layer thickness and variation in thickness (3σ)

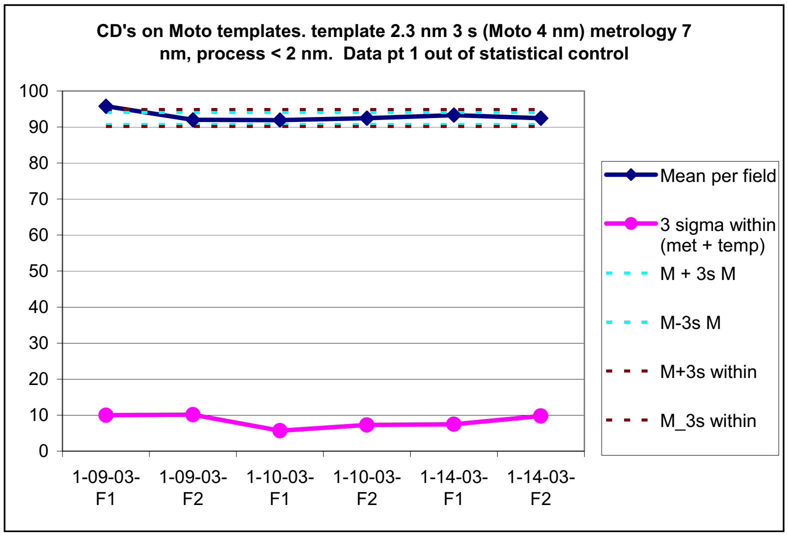

Figure 8: CD Measurement of Imprinted Features

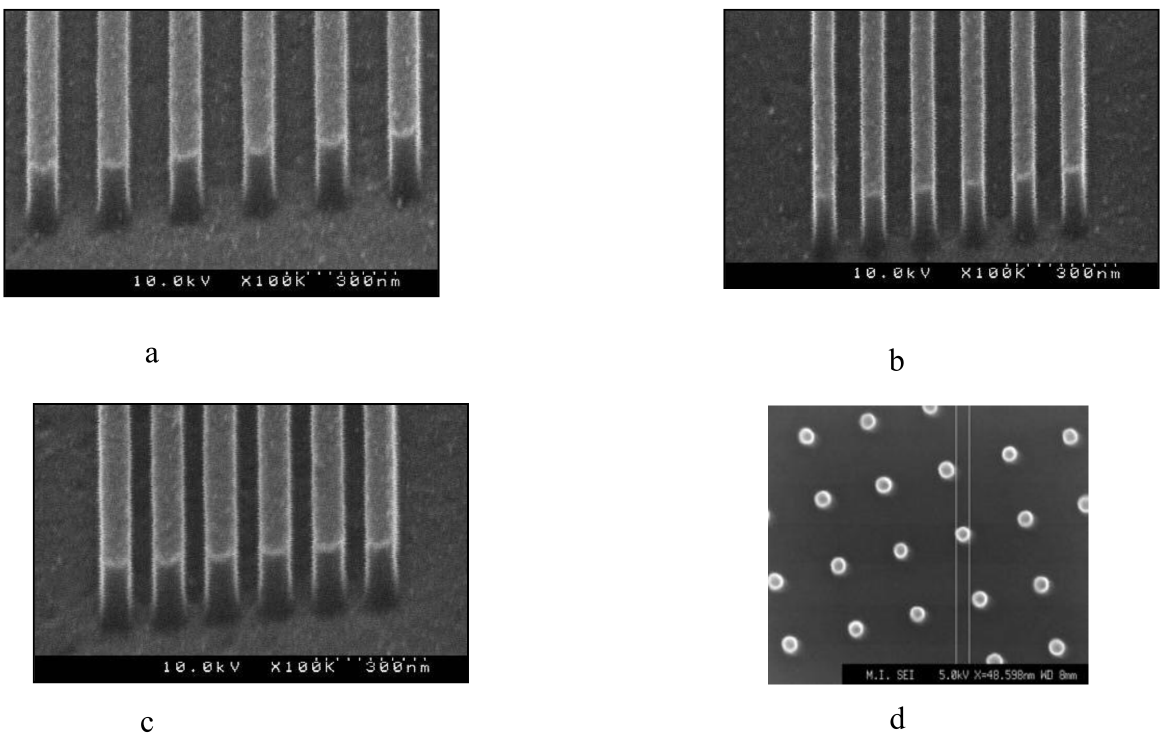

Figure 9: Imprint patterns showing a) 100 nm lines and spaces, b) 70 nm lines and spaces, c) 100 nm lines and 50 nm spaces, and d) 50nm pillars

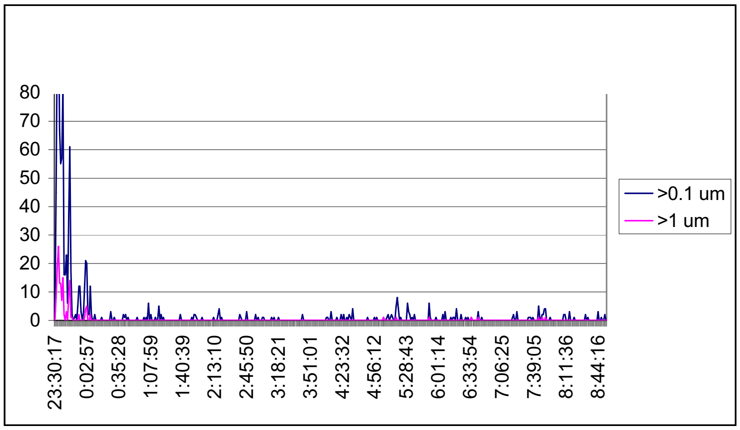

Figure 10: Low particle count consistent with Class 0.1 performance inside the tool mini-environment during imprinting

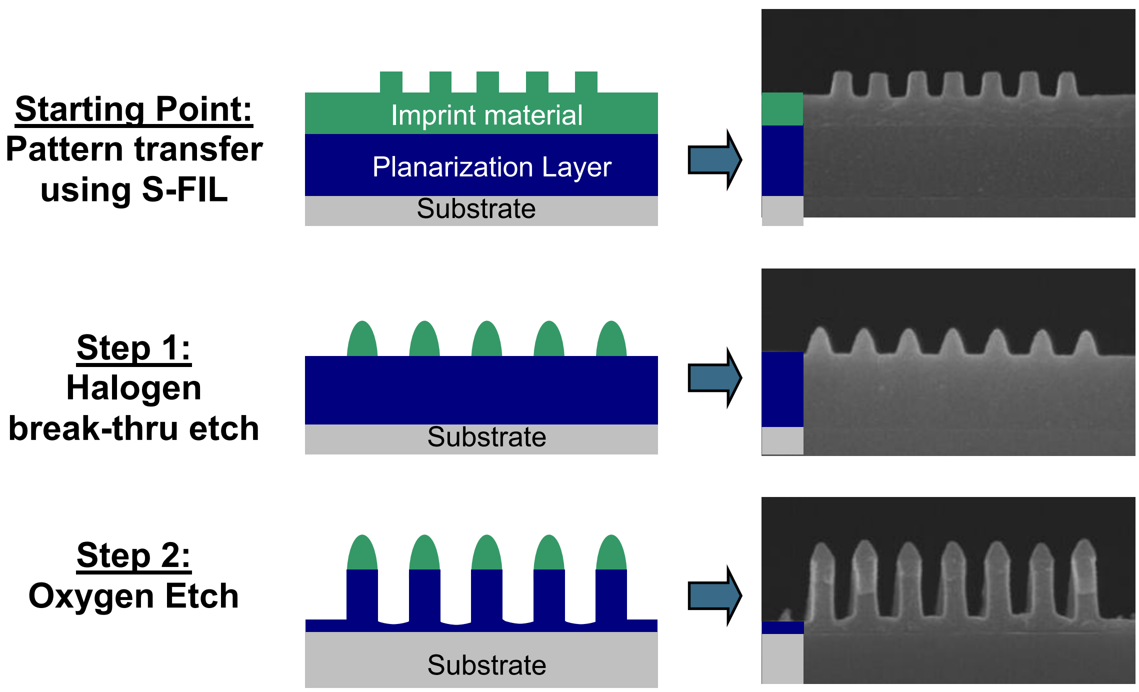

Figure 11: Etch results showing the initial imprint pattern, etched residual layer and etched planarization layer (courtesy of S.C. Johnson et al. [9])[1].

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[1] This etch work was performed at International Sematech on a Lam 9400SE etcher