

A Novel Resist System for Enhanced Resist Spreading in Nanoimprint Lithography

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Abstract

Imprint lithography is a promising technology for replication of nano-scale features. For semiconductor device applications, Canon deposits a low viscosity resist on a field by field basis using jetting technology. A patterned mask is lowered into the resist fluid which then quickly flows into the relief patterns in the mask by capillary action. Following this filling step, the resist is crosslinked under UV radiation, and then the mask is removed, leaving a patterned resist on the substrate.

There are two critical components to meeting throughput requirements for imprint lithography. The first component uses a similar approach to what is already done for many deposition and etch processes. Imprint stations can be clustered to enhance throughput. The FPA-1200NZ2C is a four station cluster system designed for high volume manufacturing.

The second component is resist fill. For a single station, throughput includes overhead, resist dispense, resist fill time, exposure and separation. Resist exposure time and mask/wafer separation are well understood processing steps with typical durations on the order of 0.10 to 0.20 seconds. To achieve a total process throughput of 20 wafers per hour (wph) for a single station (or 80 wph for a four station NZ2C system), it is necessary to complete the fluid fill step in 1.1 seconds.

There are several parameters that can impact resist filling. Key parameters include resist drop volume (smaller is better), system controls (which can impact spreading after jetting), Design for Imprint or DFI (to accelerate drop merging) and material engineering (to promote drop spreading after dispense). In addition, it is mandatory to maintain fast filling, even for edge field imprinting. In this paper, we address the improvements made in DFI and material engineering. By optimizing the drop pattern layout and introducing a two component resist system that enhances resist spreading, throughputs of 80 wafers per hour or more are achieved.

Keywords: nanoimprint lithography, NIL, throughput, DFI, resist, defectivity, non-fill defects

1. Introduction

Imprint lithography is a promising technology for replication of nano-scale features.^{1,2} For semiconductor device applications, Canon deposits a low viscosity resist on a field by field basis using jetting technology. A patterned mask is lowered into the resist fluid which then quickly flows into the relief patterns in the mask by capillary action. Following this filling step, the resist is crosslinked under UV radiation, and then the mask is removed, leaving a patterned resist on the substrate.³⁻⁸

There are many other criteria besides resolution that determine whether a particular technology is ready for manufacturing. On the mask side, there are stringent criteria for imprint mask defectivity, critical dimension uniformity (CDU), image placement (IP) and imprint defectivity. The master mask blank, which consists of a thin (< 10nm) layer of chromium on the 6" x 6" x 0.25" fused silica was recently reported to have a defectivity of only 0.04/cm² as measured by a Lasertec tool with 50 nm sensitivity.⁹ Recently, Dai Nippon Printing (DNP) has exceeded the targets for both CDU and IP. DNP has fabricated master masks containing no defects, as measured by an HMI electron beam mask inspection tool with a sensitivity of < 20 nm.¹⁰

On the wafer side, an imprint tool must be capable of addressing defects and meeting device overlay specifications in order to provide high yielding results. With respect to cost of ownership, the technology must also provide sufficient throughput relative to both the cost of the tool and the floor space occupied by the tool.

There are two critical components to meeting throughput requirements for imprint lithography. The first component uses a similar approach to what is already done for many deposition and etch processes. Imprint stations can be clustered to enhance throughput. The FPA-1200NZ2C is a four station cluster system designed for high volume manufacturing.

The second component is resist fill. For a single station, throughput includes overhead, resist dispense, resist fill time (or spread time), exposure and separation. Resist exposure time and mask/wafer separation are well understood processing steps with typical durations on the order of 0.10 to 0.20 seconds.¹² Previously, a single station throughput of 15 wafers per hour (wph) was demonstrated.¹³ To achieve a total process throughput of 17 wph for a single station, it is necessary to complete the fluid fill step in 1.2 seconds. For a throughput of 20 wph (or 80 wafers per hour for a four station cluster tool), fill time must be reduced to only 1.1 seconds. The throughput budget breakdown is shown in Figure 1.

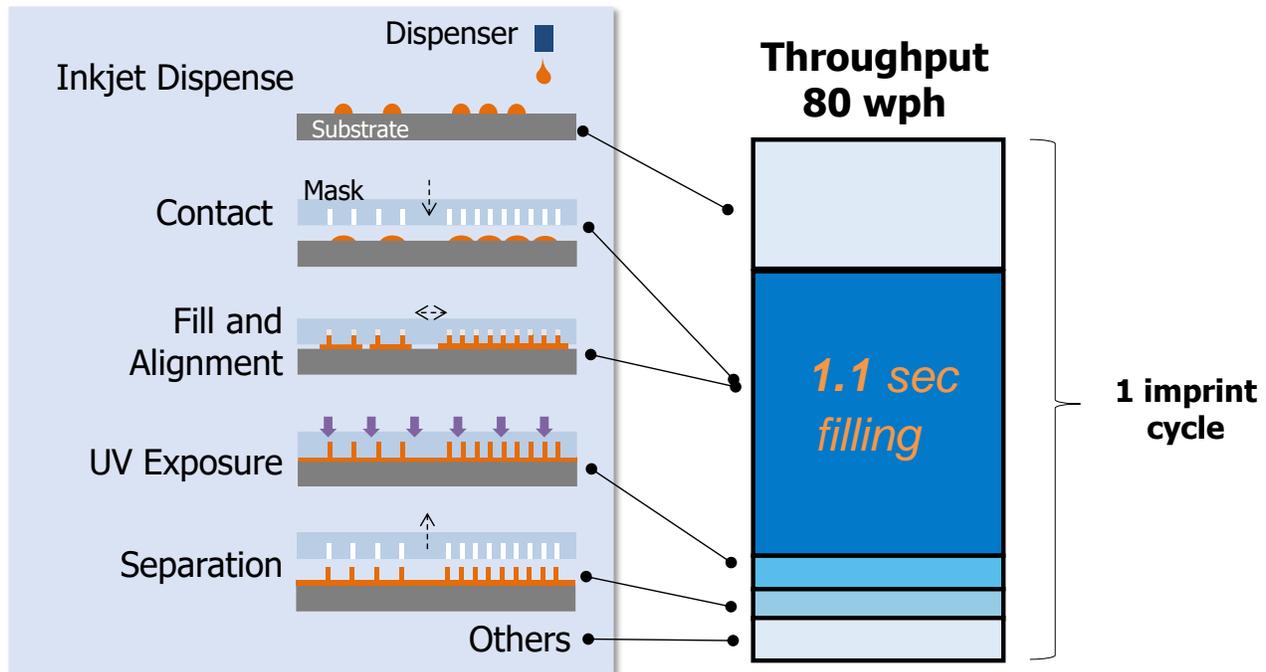


Figure 1. Throughput budget breakdown. To achieve a throughput of 80 wafers per hour, a resist filling time of 1.1 seconds is required.

There are several parameters that can impact resist filling. Key parameters include:

- Resist drop volume (smaller is better)
- Material engineering (to promote drop spreading after dispense)
- Design for Imprint or DFI (to accelerate drop merging and address different pattern types)
- System controls which address drop merging after jetting for both full fields and partial fields.
- Drop pattern optimization

In this paper, we address the improvements made in DFI and material engineering. By optimizing the drop pattern layout and introducing a two component resist system that enhances resist spreading, throughputs of 80 wafers per hour or more are achieved.

2. Experimental Details

To generate the inspection test masks, patterns were exposed using a shaped beam pattern generator and positive tone e-beam resist. After development, the chromium and fused silica were etched using Cl_2/O_2 and fluorine-based chemistry, respectively. Mesa lithography and a mesa etch process were employed to create a master imprint mask for the imprint tool.

Several pattern types were evaluated. Included were line/space arrays down to 28nm, logic type patterns and dummy fill patterns. Several of the masks also included peripheral structures such as align marks and metrology marks.

Imprinting with the replica mask was performed on a single station imprint tool. A Drop-On-Demand method was employed to dispense the photo-polymerizable acrylate based imprint solution in field locations across a 300 mm silicon wafer. The template was then lowered into liquid-contact with the substrate, displacing the solution by capillary force and filling the imprint field. UV irradiation through the backside of the template cured the acrylate monomer. The process was then repeated to completely populate the substrate. Details of the imprint process have previously been reported.¹⁴

Resist filling was visually observed with a large field of view camera that is capable of imaging the entire 26mm x 33mm field. Defectivity was measured with KLA-Tencor 2800 and 2905 wafer inspection tools. Inspections were performed in array mode for the line space patterns and in random mode for other patterns.

3. Throughput Results

a. Design For Imprint

Optimized resist patterns are necessary for the formation of a continuous and uniform resist film across the NIL stepper field. The typical sequence for defining a drop pattern includes:

- Access to the GDS/OASIS mask layout
- Conversion of the layout into a PNG image file
- Drop generation algorithm that converts the PNG density map into a drop pattern. Device levels often consist of unique regions, each having its own particular set of features.

As an example, a memory level may have dense feature regions, peripheral circuitry regions, and kerf regions that may include larger features such as align and metrology marks. Shown in Figure 2 is a mask layout containing the pattern elements described above and the resulting drop pattern, along with a magnified view of the drop pattern within the stepper field.

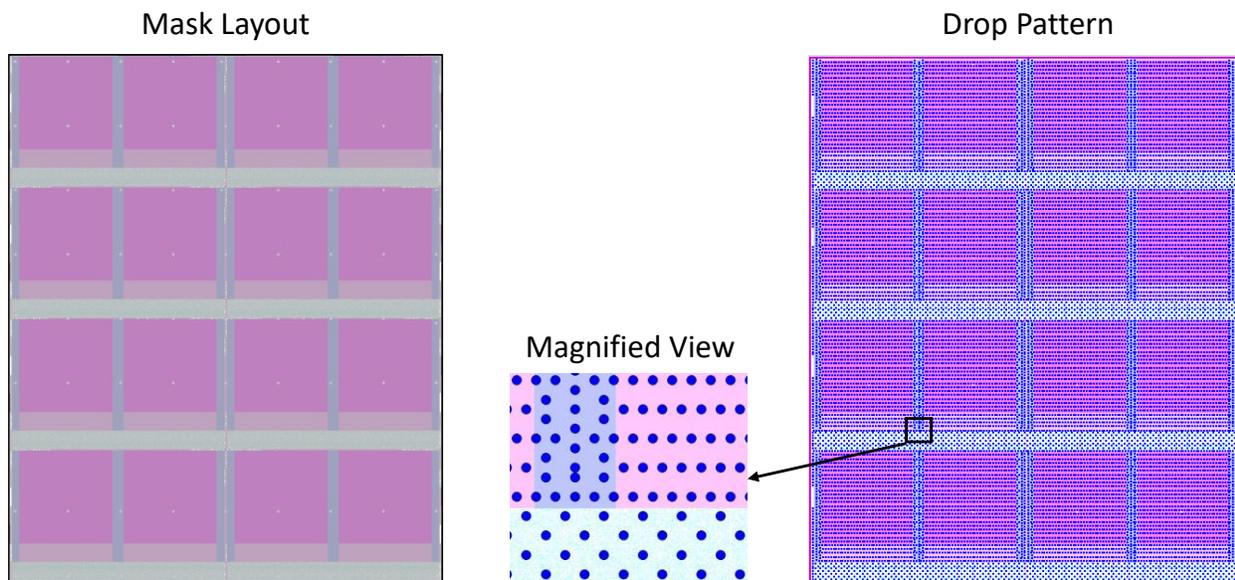


Figure 2. Mask layout containing various pattern elements and the resulting drop pattern, along with a magnified view of the drop pattern within the stepper field.

It is important to note that different pattern types require different drop pattern designs. As an example, to achieve fast resist filling of lines and spaces, a diamond like drop pattern is required, since resist filling is typically faster in the direction of the lines.¹⁵ To achieve the fastest fill times, however, drop distances in both the x and y directions must be optimized. An example illustrating line and space filling is shown in Figure 3. In this example, three cases are illustrated. In order to demonstrate the problem, the resist was cured prior to complete filling of the lines and spaces. In Figure 3a, the drop distance in the x-direction is too small, and the drops tend to merge in the x-direction first thus forming long horizontal gas voids that are slow to dissipate. In Figure 3b, the drop distance in x is too wide, and trapped gas accumulates adjacent to the drops. Finally, in Figure 3c, the drops merge in both the x and y directions at the same time and a minimum amount of trapped gas voids are observed.

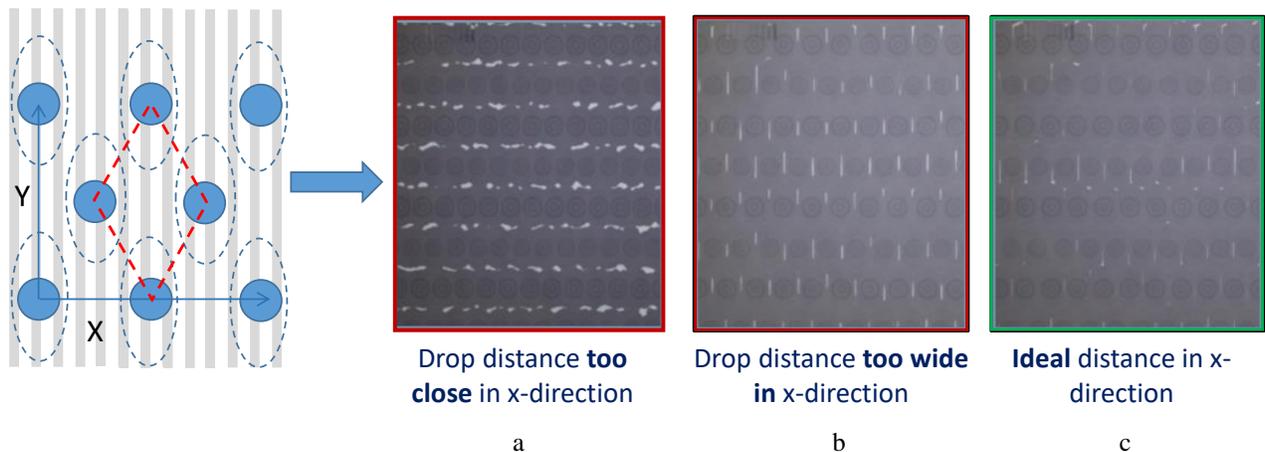


Figure 3. An example illustrating line and space filling. In Figures 3a and 3b, drop distances in x are incorrect, resulting in excess trapped gas between the resist droplets. In Figure 3c, drop spacing is optimized.

The resultant effect on resist fill time is significant. With a non-ideal diamond like drop pattern, fill times as long as 4.6 seconds have been observed. With an optimized pattern, fill times can be reduced to as little as 1.4 seconds.

b. Enhanced Drop Spreading

Resist filling, after the imprint mask makes contact with the liquid resist is significantly influenced by the drop diameter prior to mask contact. The effect is illustrated in the simple schematic shown in Figure 4. In Figure 4a, a smaller drop diameter means more gas must be expelled once the mask makes contact with the resist. In Figure 4b, a larger drop diameter means less trapped gas, and therefore faster filling times.

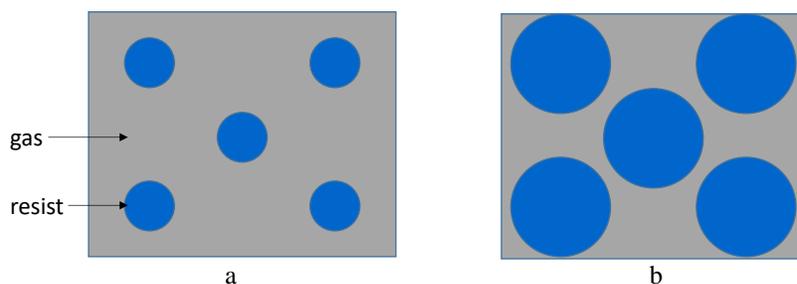


Figure 4. In Figure 4a, a smaller drop diameter means more gas must be expelled once the mask makes contact with the resist. In Figure 4b, a larger drop diameter means less trapped gas, and therefore faster filling times.

To enhance drop spreading after dispense, but to prior to mask contact, we have used a two component resist system, which creates a surface tension gradient to drive resist flow. The approach is similar to Marangoni flow, which is driven by surface tension gradients.¹⁶ The process consists of three basic steps:

- In the first step, the first component of the imprint resist is spin coated with a pre-determined surface tension.
- In the second step, the second resist component is jetted and has a lower surface tension than that of the first component.
- In the final step, the second resist component quickly spreads along the surface while intermixing with the first component, thereby forming a new resist film.

The process is schematically illustrated in Figure 5.

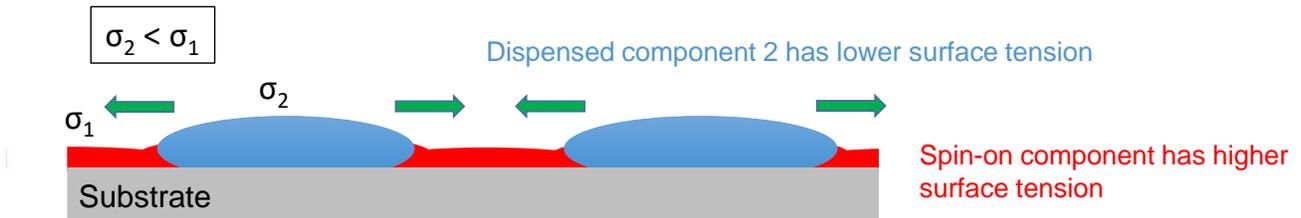


Figure 5. The two component resist system enhances resist spreading as a result of a difference in surface tension between the two components.

The difference in drop diameter can be very significant, as shown in Figure 6. Pictured in Figure 6a is a resist droplet which has been cured after sitting on the substrate surface for 1 second. The drop diameter is 70 microns. In Figure 6b, the experiment is repeated with the spin coated resist component in place. The resulting drop diameter is increased by ~3x to 215 microns.

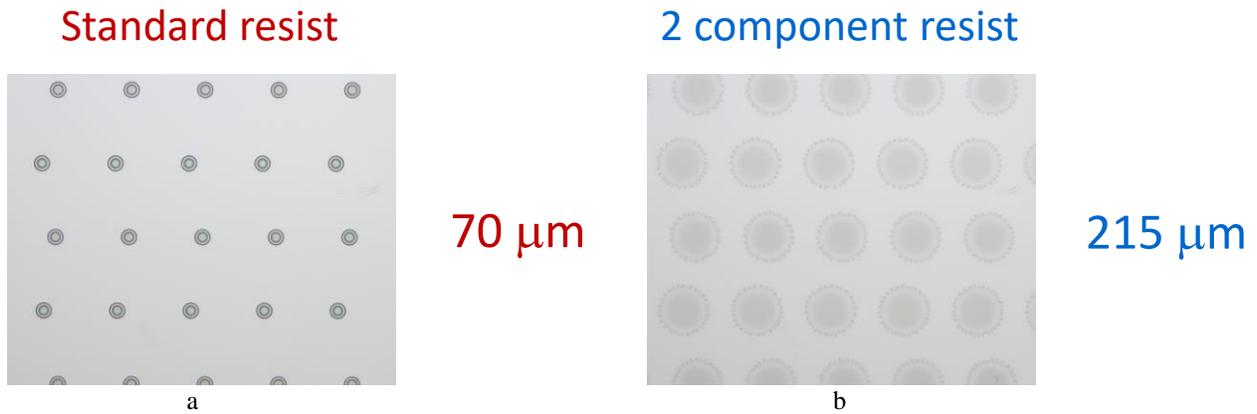


Figure 6. Difference in drop diameter between the standard jetted resist, and the two component resist system.

The difference in surface tension between the two resist components is critical for optimizing spreading and minimizing fill time. If the surface tension is too small, there is insufficient drop spreading and the improvement in resist filling is minimized. If the surface tension difference is excessive, both intermixed resist components will be moved to the drop boundaries, creating large voids at the centers of the original drop locations. These effects are shown in Figure 7. The latter is not desired as the goal is to reduce the amount of gas voids. The optimal spreading is achieved at ~ 3.1 dyn/cm of surface tension difference. These effects are shown in Figure 7.

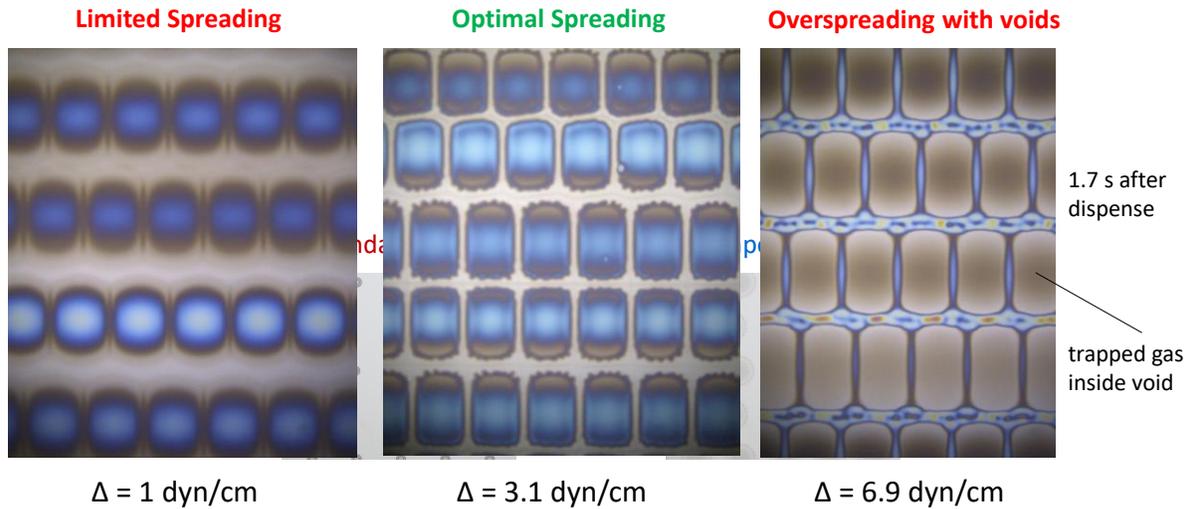


Figure 7. Drop spreading with various surface tension differences. When the surface tension difference is optimized (center image), drop spreading prior to the mask making contact with the resist, is maximized.

Under optimized conditions, the local filling of the line/space patterns can be reduced down to 0.50 seconds. NIL throughput is determined not by localized filling, but by the filling of the entire stepper field. Total fill time is judged by a target value set for non-fill defects and the target is typically set to 0.10 defects/cm². The graph below illustrates total fill time for both the line/space areas of the field and the entire field. The target of 0.10 def/cm² for the whole field is achieved after 1.00 seconds, thereby meeting the fill time specification of 1.1 seconds, which corresponds to a tool throughput of 80 wafers per hour.

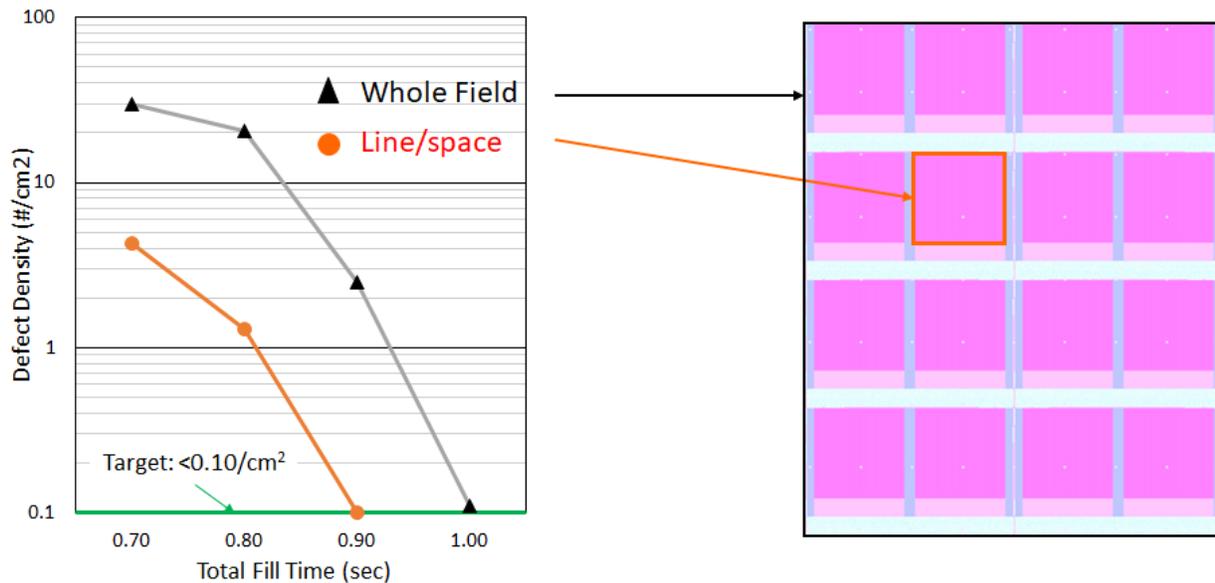


Figure 8. Non-fill defect density as a function of fill time. The target of 0.10 def/cm² for the whole field is achieved after 1.0 seconds, thereby meeting the fill time specification of 1.1 seconds, which corresponds to a tool throughput of 80 wafers per hour.

Conclusions

To achieve a total process throughput of 20 wafers per hour for a single station tool, it is necessary to complete the resist fluid fill step in 1.1 seconds. This work has demonstrated that by utilizing Design For Imprint (DFI) and by implementing a new two component resist system to enhance resist spreading prior to the mask making contact to the liquid resist, non-fill defect densities below 0.10 def/cm² can be achieved in less than 1.0 seconds. This meets the target of 1.1 seconds, necessary for a tool throughput of 80 wafers per hour when applied to a four station cluster tool.

Efforts are now underway to further increase throughput by applying additional modifications to the resist system, dispensing resist on multiple fields on the wafer and by imprinting multiple fields in a single imprint step.

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