

Layer-to-Layer Alignment for Step and Flash Imprint Lithography

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ABSTRACT

The Step and Flash Imprint Lithography (SFIL) process is a low-cost, high-throughput patterning technique with a sub-100 nm resolution capability. Investigation by this group and others indicates that the resolution of replication by imprint lithography is limited only by the size of the structures that can be created on the template. It has also been demonstrated that the SFIL process is capable of eliminating contaminants from the template (master) during a step and repeat imprinting process. The low pressure, room temperature nature of SFIL and the transparent imprint templates make it particularly attractive for high-resolution layer-to-layer alignment. Another aspect of SFIL that assists in the layer-to-layer alignment is the presence of a thin layer of low viscosity liquid between the template and wafer prior to UV curing. The liquid maintains a small gap (~0.2 μm) and acts as lubrication and damping agents, which allows for accurate *in situ* error measurement and compensation.

In this paper, we present results from overlay alignment experiments using the SFIL process. A Canon mask aligner was modified to implement a layer-to-layer alignment scheme for SFIL. The objective of this research was to achieve alignment accuracy of about 0.5 μm , which is the practical limit of the X-Y stage in the mask aligner. The overlay alignment error measurements and the corresponding corrections in X, Y, and Theta were performed using the modified mask aligner. In its current state, the alignment resolution appears to be limited by the resolution of the mask aligner stage. It is expected that other high-resolution alignment techniques that have been developed for optical projection lithography and X-ray lithography processes can be adapted to the SFIL process to significantly improve the alignment resolution.

Keywords: Step and Flash Imprint Lithography, Alignment, Overlay

1. INTRODUCTION

Recent research has shown that imprint lithography techniques can replicate sub-50 nm features, and these techniques have the potential to replace optical projection lithography as the preferred method of

patterning for semiconductor manufacturing in the sub-100 nm regime [1-3]. Several imprint lithography processes have been introduced during the 1990s [1-3]. However, most of them have limitations that preclude them from being a practical substitute for optical projection lithography because of distortions caused by the high temperature and high pressure demanded by their processes or the use of flexible templates. It is expected that these distortions will lead to major practical challenges during layer-to-layer alignment. Such problems do not exist for Step and Flash Imprint Lithography (SFIL) since the patterning is performed using low viscosity UV curable materials [4]. Therefore, overlay alignment is expected to be simpler for SFIL as compared to other imprint processes.

The SFIL process steps are shown in Figure 1. An organic transfer layer is spin-coated on a silicon substrate. A low viscosity, photopolymerizable, organosilicon solution is dispensed on the wafer in the area to be imprinted. A surface-treated, transparent template bearing patterned relief structures is aligned over the coated silicon substrate. The template is lowered against the substrate, thereby displacing the etch barrier to fill the imprint field and trap the photopolymerizable liquid in the template relief structures. Irradiating with ultraviolet light through the backside of the template cures the photopolymer. The template is then separated from the substrate leaving an organosilicon relief image on the surface of the coated substrate that is a replica of the template pattern. A short halogen etch is used to break through the undisplaced etch barrier material, called the “base layer”, exposing the underlying transfer layer. Oxygen RIE is used to amplify the aspect ratio of the imprinted image. The process is simple in concept, but every step in the process presents interesting challenges in engineering and materials science.

Overlay errors for lithography processes can include X, Y, and Theta placement errors, magnification

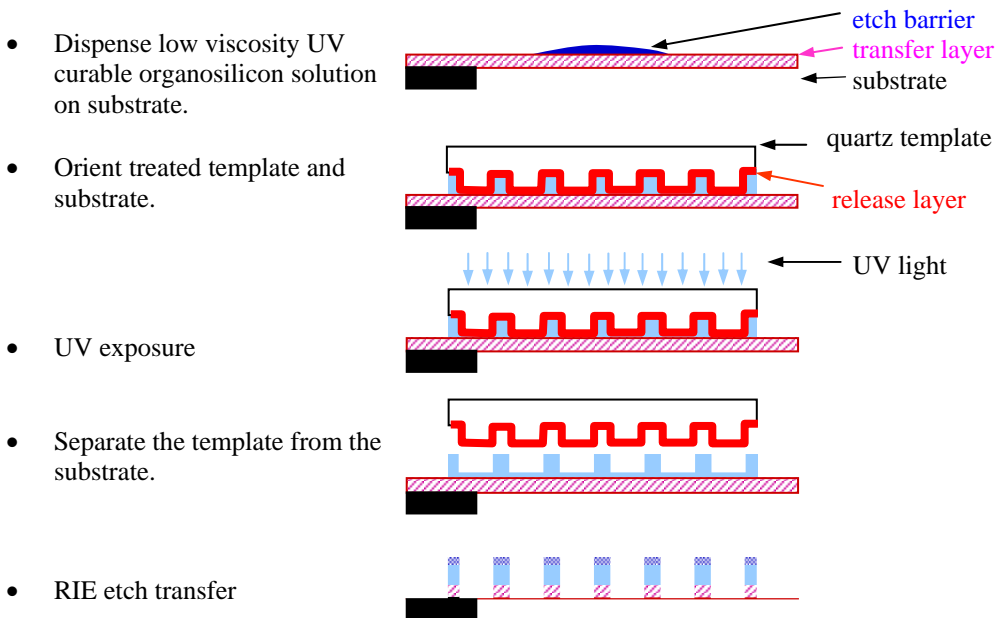


Figure 1. The Step and Flash Imprint Lithography (SFIL) process

error, and mask distortion errors. In this work, overlay correction for the X, Y, and Theta placement errors is investigated. Since SFIL is a room-temperature and low pressure process, it is less likely to be susceptible to distortions of the template and wafer. Further, templates are made of relatively thick quartz plates, which have no significant pattern dependent template distortions. This is an advantage as compared to NGL processes that employ membrane masks such as X-ray lithography. Further, unlike photo masks used in optical lithography, the entire area of the SFIL template is transparent to the exposing light, which results in no thermal gradients in the template.

Another unique aspect of SFIL is the fact that fine α and β orientations (see Figure 2) may need to be performed more frequently than in other lithography processes if surface variations exist on the substrate. Other processes are less sensitive to small surface variations and hence typically need only one orientation alignment (one-time α and β alignment for the entire wafer). If orientation alignments are coupled with the X-Y positioning of the template and substrate, field-to-field placement error compensations are necessary. An orientation stage that can perform orientation alignment without inducing lateral errors was presented in [6].

In this research, an existing Canon 501 mask aligner has been adapted with appropriate modifications to implement a multi-layer SFIL process. The overlay alignment error measurements; corresponding corrections in X, Y, and Theta; and UV exposure were performed using this modified mask aligner. Zhang and Chou have presented results of overlay alignment using high temperature and pressure imprints [8]. They performed alignment and patterning steps using a mask aligner and a separate high pressure imprinting machine, respectively.

2. ALIGNMENT METROLOGY

Figure 3 shows overlay mark configurations for three lithography processes. Figure 3(a) illustrates the overlay mark configuration for optical projection step and scan lithography, Figure 3(b) for optical proximity printing, and Figure 3(c) for the SFIL process.

In optical step-and-scan lithography tools, alignment is performed i) to align the mask relative to the mask stage, ii) to align the wafer relative to the wafer stage, and iii) to align the mask and the wafer relative to each other using multiple reference mirrors. Calibration of these step and scan tools essentially involves proper alignment of all of these reference mirrors with respect to the mask and wafer stages. In order to maintain the calibration, the tool must be carefully monitored for thermal, vibrational and mechanical

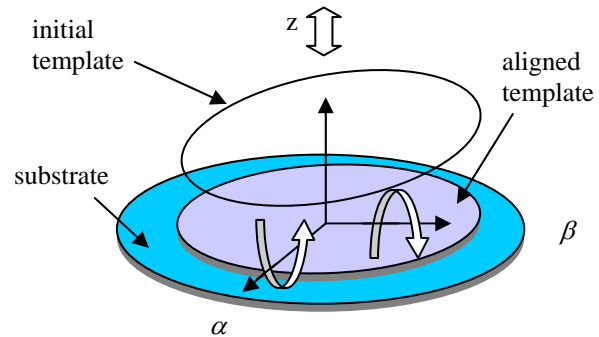


Figure 2. Two flats representing template and wafer

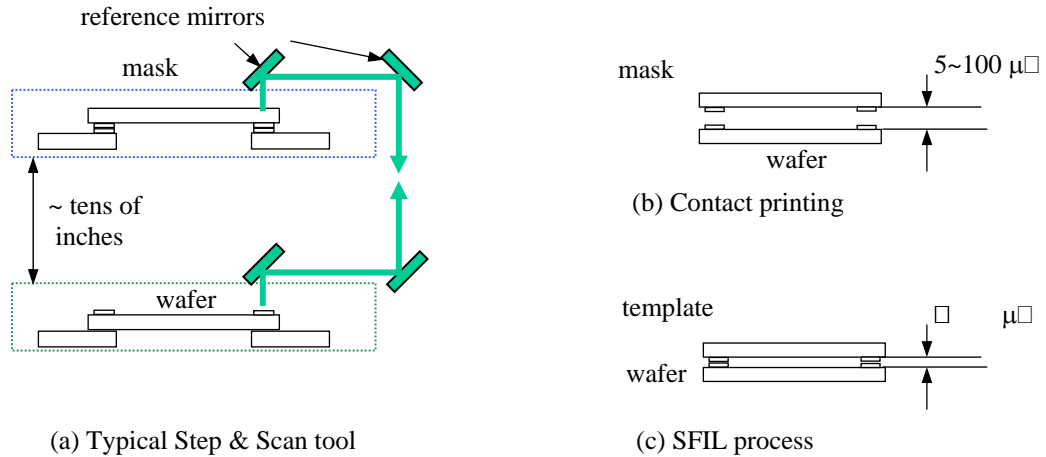


Figure 3. Mask (template) and wafer configurations for various lithography processes.

contributions to pattern distortions. The SFIL process has the advantage of not requiring mirror and/or calibration of this sort.

The SFIL process has a thin layer of liquid between the template and substrate. The thin fluid layer prevents the template from directly contacting the substrate and it acts both as lubricant and a damping agent. Therefore, both the overlay measurement and correction can be performed with a small gap ($\sim 0.2 \mu\text{m}$) between the template and wafer. This small gap also provides well focused images of the alignment marks and minimal optical error.

The liquid layer between them template and wafer prevents the two surfaces from sticking to each other. The lateral damping forces increase as the gap size decreases and as the correction velocity increases. A rough correction (of the order of microns) was done with a large gap ($\sim 2 \mu\text{m}$) and the final correction was done with a small gap ($\sim 0.2 \mu\text{m}$). For the fine resolution correction, the correction velocity was of the order of $\mu\text{m/s}$. During the fine alignment motion, the lateral damping force acting on the template is estimated as,

$$F = \mu (v/h) A_{\text{template}} \quad (1)$$

where, μ is the viscosity of the UV curable liquid, v is the relative velocity of the template and substrate, h is the gap and A_{template} is the template surface area. For $\mu = 1 \text{ cp}$, $v = 10 \mu\text{m/s}$, $A_{\text{template}} = 10 \text{ cm}^2$ and $h = 0.2 \mu\text{m}$, $F = 5 \times 10^{-5} \text{ N}$.

Overlay marks and the overlay error measurements can be readily developed for SFIL by adapting existing techniques. It is expected that the overlay measurement techniques developed and demonstrated for X-ray proximity printing can be adapted to SFIL [9]. When the gap between the template and wafer is small, two layers of overlay patterns, such as box-in-box or cross-in-box, can be simultaneously acquired without difficulty using conventional microscopes.

3. MODIFIED MASK ALIGNER

An imprint machine with overlay capability has been developed by modifying a Canon PLA501 mask aligner. Modifications to the original machine include (i) the replacement of the mask holder with a template orientation stage, (ii) replacement of the original grooved wafer chuck with a pin-type wafer chuck, and (iii) replacement of the original split-view microscope with a single object lens microscope.

As shown in Figure 1, the template and wafer need to be parallel with a uniform gap to imprint using SFIL. During the overlay error correction step, it is also necessary to ensure that the template and wafer surfaces are parallel in order to allow controlled motion between the two surfaces. Figure 4 shows a two degrees-of-freedom flexure stage that can perform the required orientation alignment. The torsional stiffness of the cross-flexure joints of the template orientation alignment stage was designed so that the template can self-correct its orientation in the case of an initial tilt error. The vertical stiffness is designed to support the imprinting force with a low vertical displacement [10].

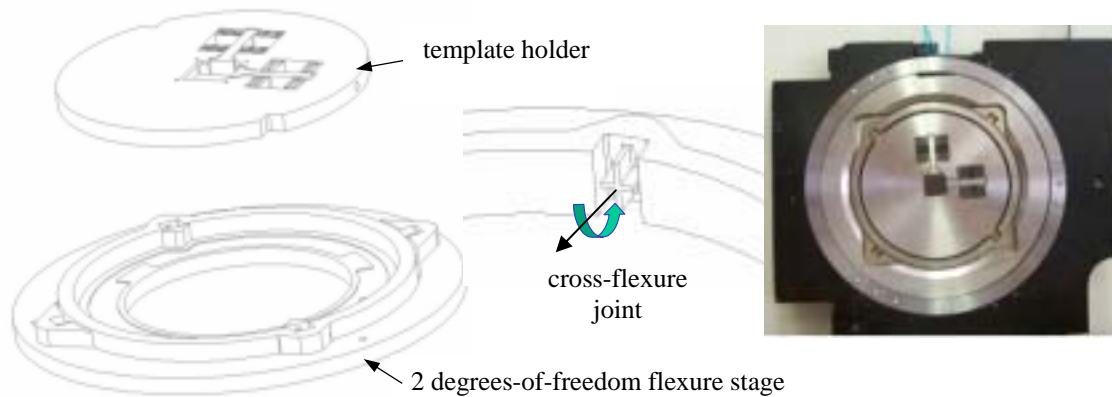


Figure 4. Flexure based template orientation stage and its assembly to the existing mask holder. Template holder can be modified according to the template size.

The flatness requirement on the substrates for the SFIL process is stringent. The original grooved wafer chuck produced undesirable topography variations on the substrate surface. A pin-type wafer chuck, therefore, replaced the grooved wafer chuck. The pin spacing and geometry were chosen carefully to avoid excessive deflection of the wafer between the pins and gross deflections of the pins themselves. For a given pitch, if the spacing between the pins is made too small, the likelihood of trapping a particle on the pin increases. Such particles are undesirable for SFIL, and therefore an optimal pin spacing was chosen that minimizes wafer deflections and the particle effects.

The template is smaller (1 inch by 1 inch) than a typical optical mask, so it is difficult to find room to include two object lenses above the template. Therefore, the Theta alignment error correction was

performed by consecutive measurement and correction at the two sites of alignment marks using a single object lens that was translated to the two sites.

The wafer handling tool and the X-Y-Theta stage were used without any modification. The overlay error measurement resolution for the Canon 501 mask aligner is better than the minimum step size of the X-Y stage (resolution $\sim 0.5 \mu\text{m}$). The overlay alignment resolution is, therefore, expected to be no better than that of the stage.

4. RESULTS

One inch square templates, made from 0.25 inch thick optical flat quartz, were used for the imprinting experiments. The templates were produced by the Reticle Technology Center in Round Rock, Texas using conventional phase-shift reticle technology. The template has four identical sites with multiple overlay marks, as is illustrated in Figure 5(a). The distance between two such sites along an edge of the template is 0.8 inch, and the etched depth of the marks is approximately 250 nm. Using pairs of grating patterns shown in Figure 5(b), varying levels of alignment accuracy can be obtained. The largest line/space pattern is $8/8 \mu\text{m}$ and the smallest is $0.5/0.5 \mu\text{m}$. The template contains identical grating patterns oriented along X and Y directions in order to measure alignment errors in Y and X directions respectively. These grating patterns provide a simple way to obtain overlay error measurement resolution of $0.5 \mu\text{m}$.

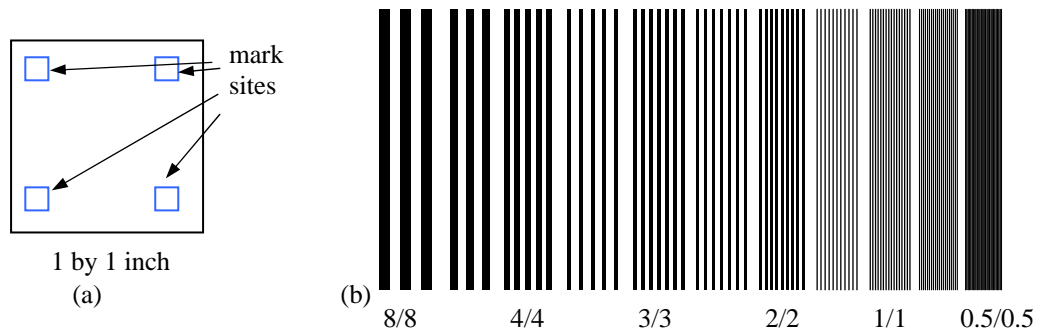
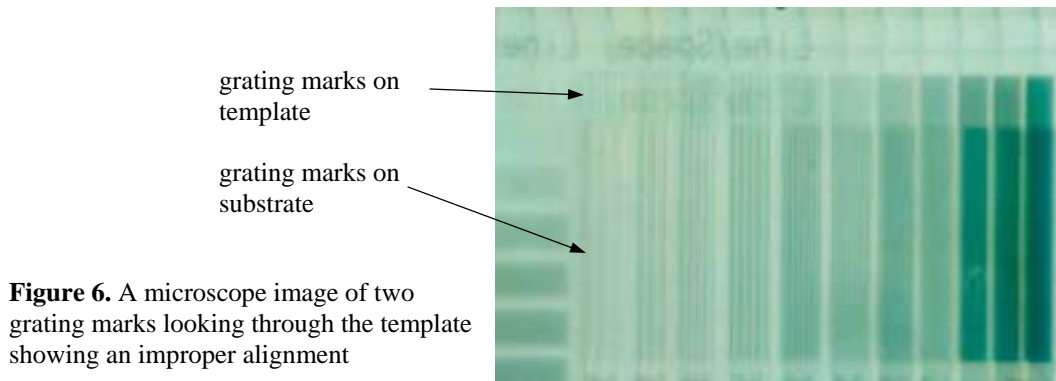


Figure 5. (a) Template with four sites of overlay marks. (b) Grating patterns with various line/space. Gratings are aligned in both X and Y directions.

An estimate of the overlay error can be obtained by identifying the darkest block of grating lines that have equal line and space widths. The overlay error is equal to the line width of the grating pattern in the darkest block. If multiple blocks have the same level of darkness, the block that has the largest lines/spaces specifies the error. While more sophisticated techniques, such as the Moiré fringe method, can significantly improve the overlay measurement resolution, we did not pursue them at this time because our stage is limited to a resolution of about $0.5 \mu\text{m}$.

Overlay alignment was performed through the quartz template using the microscope, which was connected to a CCD camera. Figure 6 shows an optical microscope image of a set of grating patterns on the



substrate overlaid with a matching set of grating patterns on the template as seen through the template. The image shows that the two sets of gratings are not properly aligned.

An imprint that includes two well-aligned layers is shown in Figure 7. At the resolution limit of the current alignment stage, only the block of $0.5/0.5\mu\text{m}$ grating becomes the dark as shown in Figure 7(a). Two overlay mark sites separated by 0.8 inch are used for the Theta error measurement and correction (Figure 5(a)). The image on the left of Figure 7(b) indicates that overlay of alignment accuracy of $0.5\mu\text{m}$ has been achieved both in X and Y directions at one site. The image on the right in Figure 7(b) shows an overlay alignment accuracy of about $0.75\mu\text{m}$ in X and Y directions at the second site. While performing experiments with the modified mask aligner, it was found that the need to use a single microscope to measure errors at the two sites made it difficult to achieve an overlay accuracy of $0.5\mu\text{m}$ at both sites.

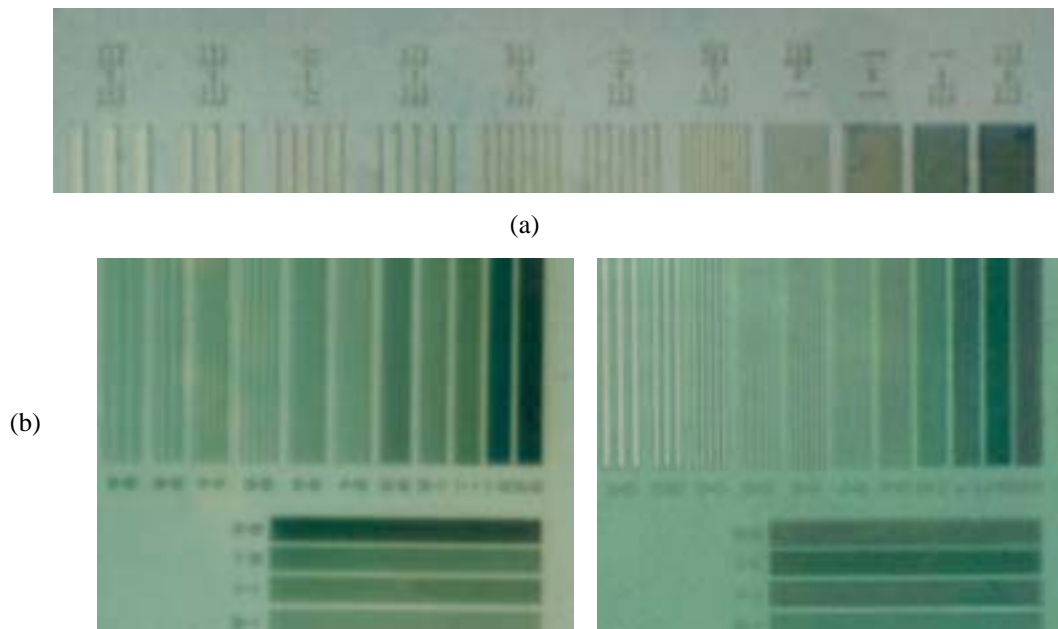


Figure 7. Top images of two grating marks: (a) Two grating marks are aligned showing no visible error in x. (b) Theta alignment has been achieved using two grating marks spaced by 0.8 inch.

Therefore, the Theta alignment accuracy is not at the resolution of the stage. This problem can simply be resolved by using a larger template that can accommodate a split-view microscope to simultaneously view the two overlay sites.

5. CONCLUSIONS

The low pressure, room temperature nature of SFIL and the use of transparent imprint templates make SFIL particularly suited for layer-to-layer alignment. In this article, we have demonstrated layer-to-layer alignment for Step and Flash Imprint Lithography using a modified mask aligner. Overlay alignment has been performed by superimposing two layers of overlay marks through a 0.25 inch quartz template. The overlay alignment resolution is limited by the resolution of the stage to approximately 0.5 μm . The presence of a thin layer of a low viscosity photopolymer between the template and substrate makes it possible to directly measure the overlay errors and perform *in situ* corrections.

The objective of this research was to develop a basic approach for performing overlay alignment using Step and Flash Imprint Lithography and to achieve alignment accuracy of about 0.5 μm , which is the practical limit of the X-Y stage in the mask aligner. By using a nano-resolution stage and adapting existing sophisticated overlay errors measurement techniques, it is believed that the overlay alignment of the SFIL process can be improved significantly beyond what is presented in this article.

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