Step and flash imprint lithography: Defect analysis

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Step and flash imprint lithography (SFIL) is a promising, low cost alternative to projection printing. This technique has demonstrated very high resolution and overlay alignment capabilities, but it is a contact printing technique so there is concern about defect generation and propagation. A series of experiments has been carried out with the goal of quantifying the effect of defect propagation. To that end, each unit process in SFIL was studied independently. The number of particles added during handling and transportation and due to SFIL machinery was deemed acceptable, and the added particles should not complicate the inspection of process defects. The concept of a "self-cleaning" process in which the imprint template becomes cleaner by imprinting was revisited. Inspection of an imprint template before and after imprinting revealed that the template actually becomes cleaner with imprinting. Visual inspection of multiple imprints did not reveal any systematic generation or propagation of defects. The inspection area used in this study was limited, however, since the inspection was both manual and visual. Imprinting for this defect study was performed at the University of Texas in a Class 10 cleanroom, and inspection was performed at International SEMATECH. © *2001 American Vacuum Society.* [DOI: 10.1116/1.1420203]

I. INTRODUCTION

Step and flash imprint lithography (SFIL) is a novel, high throughput, low cost approach to generating relief patterns with sub-100 nm linewidth. SFIL uses no projection optics, no lenses, and operates at room temperature. The process relies largely on chemical and low pressure mechanical processes to transfer patterns. SFIL is related to other micromolding or imprint processes[1–5] in that all of these use the topography of a template to define the pattern created on a substrate. The two key differences between SFIL and other imprint lithography techniques are that this process is based on a low viscosity, photocurable liquid and a transparent, rigid template. The low viscosity of the photocurable liquid eliminates the need for high temperatures and pressures that can be a problem for accurate overlaying of the successive layers of a device. The rigid imprint template is UV transparent allowing flood exposure of the photopolymer to achieve cure. This combination of rigidity and transparency also enables layer-to-layer alignment.

We have previously described results of patterning experiments based on the SFIL process. Careful tailoring of the chemistries allowed faithful replication of the smallest features that can be generated on an imprint template. Lines/spaces as small as 60 nm,[6] high and low pattern density areas, and high aspect ratio images have been patterned. A functional micropolarizer array with 100 nm Ti lines/spaces[7] has been produced, and SFIL has been used to pattern directly over a nonflat substrate,[7] including curved surfaces.[8] The feasibility in overlay alignment was recently reported,[9] and work toward the first short channel metal–oxide–semiconductor devices made with this technology has begun.

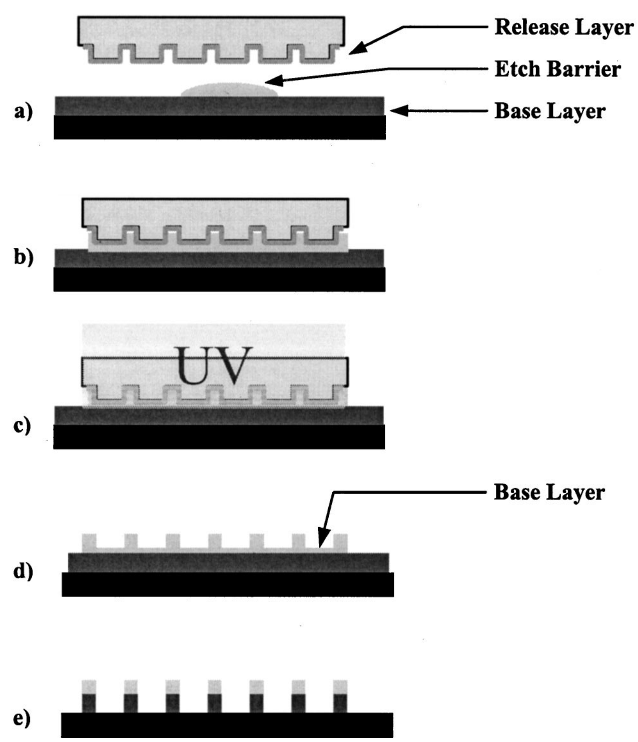

FIG. 1. Step and flash imprint lithography process. The process employs a template/substrate alignment scheme to bring a rigid template and substrate into parallelism (a), trapping the etch barrier in the relief structure of the template (b). The gap is closed until the force that ensures a thin base layer is reached. The template is then illuminated through the backside (c) to cure the etch barrier. The template is withdrawn (d), leaving low-aspect ratio, high resolution features in the etch barrier. The residual etch barrier (base layer) is etched away with a short halogen plasma etch, after which the pattern is transferred into the transfer layer with an anisotropic oxygen reactive ion etch (e), creating high-aspect ratio, high resolution features in the organic transfer layer.

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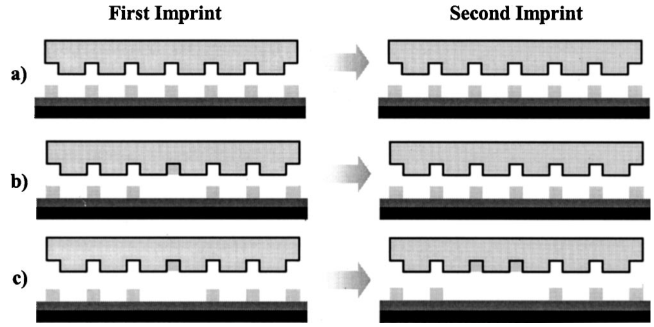

FIG. 2. Three hypotheses for defect generation and propagation. Perfect imprints (a) yield no defects and perfect pattern transfer. Defect generation without propagation (b) yields a random appearance of defects, which may be tolerable in very low numbers. Generation and propagation of defects (c) yields a case where the imprint template becomes dirtier over time and would result in a geometric rise in defects with time.

As with any next generation lithography (NGL) being considered, the manufacturability of SFIL depends on the ability to transfer patterns from the master, in this case an imprint template, to the substrate without generating pattern defects. Since imprint lithography is a contact process, there is concern about defect generation and propagation. Fortunately, the imprint process is self-cleaning for contamination on the imprint template.[10] This article describes the next level of defect analysis.

II. BACKGROUND

The SFIL process is shown in Fig. 1 and has been detailed previously.[6] For the purpose of this analysis, it is assumed that the propensity for the process to create or propagate defects can be seen by analyzing steps 1(a)–1(d), that is dispensing of etch barrier, imprinting, exposure, and template/substrate separation. The transfer layer shown in Fig. 1 can be spin coated using standard techniques employed for coating photoresist or antireflection coatings. The aspect ratio-enhancing etch steps, shown in Fig. 1(e), are standard etch processes and are presumed to be well characterized.

The fundamental question to be answered is, does the imprint process create and/or propagate defects simply by its contact nature. There are three extreme hypotheses illustrated in Fig. 2. Figure 2(a) shows the case in which no defects are generated, and so no defects propagate; this is the perfect imprint process. Figure 2(b) shows the case in which some defects are generated during an imprint cycle, but the defects do not propagate through multiple imprints. These defects may exist for a few imprints, but they eventually disappear, regenerating the original defect-free imprint pattern. This case may be acceptable if the number of generated defects is very small and the number of steps required to clean the template is very low. The third case [Fig. 3(c)] is that in which defects are generated, and most of these new defects propagate through multiple imprints, possibly even for the lifetime of the template, leading to catastrophic loss of pattern transfer fidelity. The initial investigation is based on the effect of multiple imprints on the transfer fidelity using patterns comprised of features with dimensions on the order of 1 μm. If there exists catastrophic defect generation processes, they should appear in patterns of such features. Future work may involve similar experiments using features of smaller dimensions.

III. EXPERIMENTAL PROCEDURE

Imprinting for this experiment was done at the University of Texas, and most of the inspection was done at International SEMATECH. It was necessary to characterize the SFIL cleanroom and to establish the number of defects introduced by all process steps in the absence of imprinting in order to establish the lower limit of analysis designed to identify ‘‘adders.’’

Various areas within the SFIL cleanroom were monitored using a Met One 200L laser particle counter, equipped with an isokinetic probe. The raw data from the air sampler, in the form of total particles in the sampling time, was normalized to reflect the number of particles per cubic foot of sampled air. The flow rate of the air sampled by the isokinetic probe is $1.0 \pm 0.1\ \mathrm{ft}^3/\mathrm{min}$. The number of particles added on the wafers during handling and transportation was measured on a Tencor 6200 wafer surface scanner. Twenty-five wafers were measured on the Tencor 6200, then loaded onto the SFIL stepper and ‘‘stepped,’’ but without imprinting. The wafers were then measured again on the 6200.

Wafers were prepared at International SEMATECH. A commercial bottom antireflection coating (BARC) (DUV30J-11, Brewer Science) was used as the transfer layer. The BARC was spun at 3000 rpm for 60 s and baked at 180 °C for 60 s, yielding films of thickness ~1100 Å. The films were triple-coated, yielding thicknesses in the range of

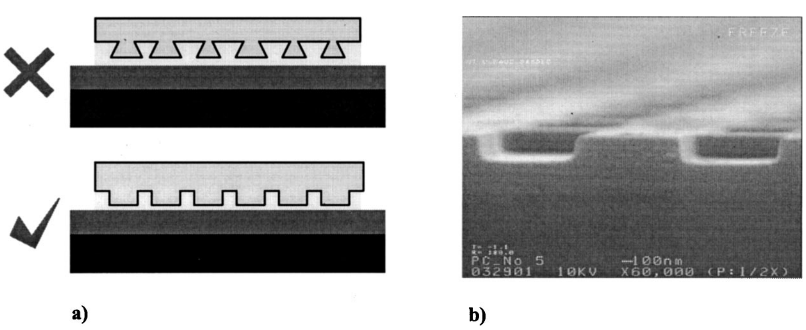

FIG. 3. Etch anisotropy and template release. Any etch undercut produced when defining the features in the imprint template results in a ‘‘dovetail’’ effect during imprinting, effectively spoiling the release step in the process. The SEM image shows a cross-section view of one of our imprint templates used for this study, showing no etch undercut; the sidewall angle is acceptable.

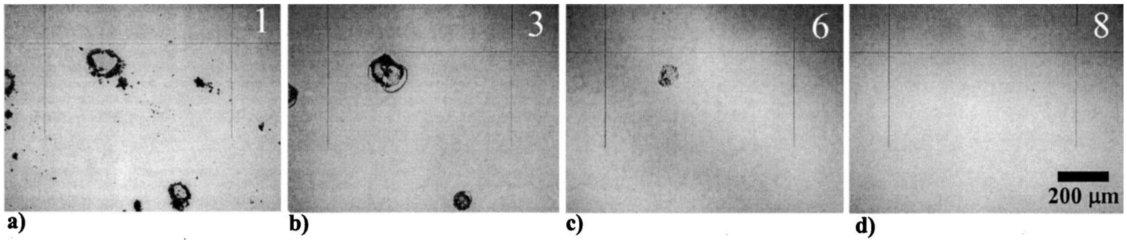

FIG. 4. Disappearance of template-bound contamination can be seen in these images. Image 1 is a micrograph of the first imprint, etc. Note the rapid disappearance of small defects. Even the very large defects shrink upon successive imprinting and completely disappear after the eighth imprint. [Adapted from Bailey *et al.* (Ref. 10).]

330 nm, approximately the thickness of our usual transfer layer.

The imprint templates were prepared on standard 6 in.×6 in.×$\frac{1}{4}$ in. mask substrates by DuPont Photomask, Inc., Round Rock, TX. A ''brick-and-mortar'' pattern design was used, consisting of recessed 1 μm×4 μm bricks, which yields raised rectangular features in the imprinted etch barrier. The patterned area is 0.6 in.×0.6 in., yielding ~23 mil features per imprint. The imprint templates were cut to 1 in.×1 in. size to fit in the stepper template holder. When etching the features in the quartz, it is important to avoid any undercut, which could lead to a ''dovetail'' effect, as in Fig. 3(a); this would seriously complicate the template/substrate separation following imprinting. Cross-sectional scanning electron microscopy (SEM) images of the templates revealed straight sidewall angles [Fig. 3(b)], so no dovetailing is expected. The templates were cleaned in an acetone ultrasonic bath, followed by O_2 reactive ion etch (RIE) at 50 W, 10 sccm O_2, 20 mTorr for 10 min. The clean templates were then treated with a release agent, tridecafluoro-1,1,2,2-tetrahydrooctyltrichlorosilane (Geleste), by vapor exposure at 1 atm total pressure (precursor plus N_2) for 90 min, and annealed at 100 °C for 15 min, yielding an ultrathin fluorocarbon film that is chemically bonded to the template surface.

Imprinting was performed on the University of Texas stepper, which has been described previously.[11] Approximately 100 nl of the etch barrier that was described previously[10] was dispensed per imprint, and the imprints were cured with ~40 mJ/cm^2 broadband UV light from an Oriel 500 W Hg arc lamp running at 300 W. Imprinting was performed with a newly treated template, and the imprint cycle of successive imprints was completed without further cleaning the template. Inspections of imprint templates and imprinted die were performed on an Olympus Vanox-T microscope and a Leica INS2000 inspection station, respectively. Defect detection using an optical microscope should resolve defects on the order of 200 nm in isolated features, and perhaps smaller defects in a regular array.

IV. RESULTS AND DISCUSSION

A. Background contamination

Particle counts were measured in different areas of our cleanroom and indicate it is operating at or cleaner than Class 10 conditions. The 25 wafers measured on the Tencor 6200 revealed that approximately 8 ± 6 particles (>0.25 μm) are added during handling (loading on the stepper, simulating an imprint cycle, and loading into the cassette) and transportation between the University of Texas and International SEMATECH.

B. Template self-cleaning

We have previously reported that particles on the imprint template were reasoned to become entrained in the etch barrier during imprinting, thus the printing process cleans the template for future imprints,[10] as shown in Fig. 4. In this study an imprint template was inspected prior to installation, and again after imprinting. The template possessed surface-bound contamination prior to imprinting. After two imprints, an area of contamination on the template [Fig. 5(a)] is clean [Fig. 5(b)]. While it is unlikely that every sort of contamination is removed by the imprinting process, it is clear that the types of contamination introduced by normal storage and handling are removed quite efficiently. Thus while SFIL does

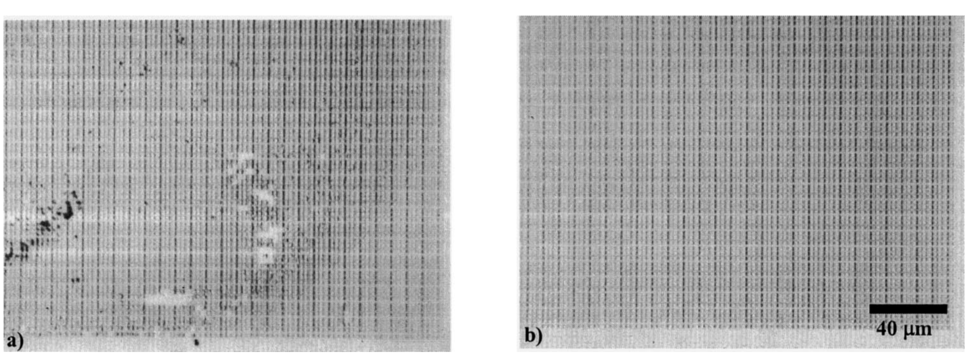

FIG. 5. Images of an imprint template before (a) and after (b) two imprints. This confirms our conclusion that the template contamination is removed during imprinting. This pattern is different from that in Figs. 3 and 6.

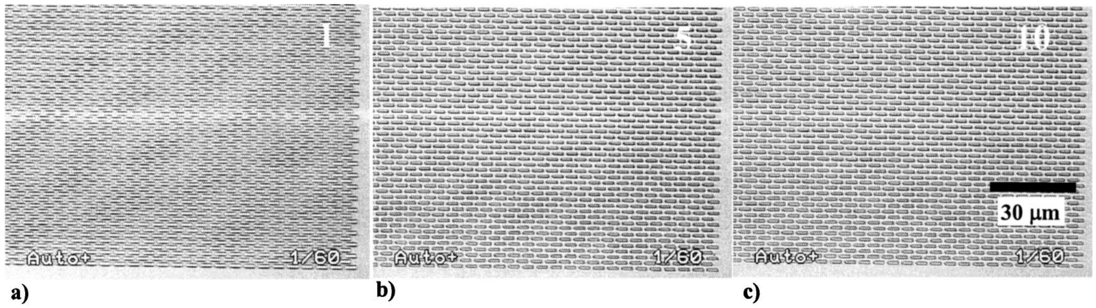

FIG. 6. Visual inspection of multiple imprints. The same area of an imprint field was visually inspected through ten imprints. No generation of defects can be seen. The diagonal fringes are a Moiré effect manifested by the pattern regularity. Any observed difference in the pattern sharpness is due to manual focusing on the Leica INS2000, and not due to pattern transfer fidelity issues. The dark spot in the middle right of the images is on the microscope optics.

not incorporate an analog of the pellicle that protects the master from contamination, contamination does not necessarily result in producing repeated defects in every die.

Considering Fig. 2(c), where defects are generated and propagate through successive imprints, the imprint template might be expected to become more contaminated or dirtier over time. Our observation that the template actually becomes cleaner with successive imprinting allows immediate rejection of that hypothesis.

C. Inspection of multiple imprints

The ultimate test of the SFIL process in terms of defect analysis requires the inspection of imprinted patterns over the course of hundreds or thousands of imprints. To that end, efforts are being made to integrate the SFIL stepper in the University of Texas cleanroom and a KLA 2132 inspection tool at International SEMATECH. An inspection recipe is being developed that will allow rapid, automated inspection of hundreds of imprints, yielding statistical data. This analysis requires resolution of certain tool compatibility issues including improvement in die placement accuracy.

Initial inspection of multiple imprints using a Leica INS2000 inspection station has been encouraging. Figure 6(a) shows the first imprint on a sample wafer, Fig. 6(b) the fifth, and Fig. 6(c) the tenth imprint. The features are 1 μm$\times$4 μm$\times$0.25 μm, and there are approximately 1100 bricks per image field. No defect generation is observed through the ten imprints. These fields represent only a small fraction of the imprint area. Quantification of the defect generation and propagation must await improvements in the orthogonality of the die array relative to the stage movement axes. Certain important characteristics of the imprint process can be gleaned from careful, manual analysis of the imprint images. These manual inspections show no pathological defect generation by, for example, release failure or feature ‘‘pull-out.’’ No such behavior has been noted during inspection of many imprints on many wafers. Random defects have been observed, but all repeating defects have been associated with flaws in the template.

It should be noted that while the template surface treatment or release layer is not presented as an integral part of this study, imprinting with untreated templates results in catastrophic loss of pattern fidelity. The effect of template surface treatment conditions on release layer durability through multiple imprints is under investigation.

V. CONCLUSIONS

The SFIL cleanroom is operating at Class 10 conditions. The number of particles added during handling and transportation of the wafers, and due to the motion of the SFIL machinery, was measured to be approximately eight particles per wafer. This number of particles should not limit the ability to characterize generation and propagation of process-related defects.

Contamination from storage and handling of the template prior to imprinting was efficiently removed during imprinting. This greatly reduces concern that the imprint fidelity would diminish over time, resulting from imprinted material becoming irreversibly adhered to the template. That case would result in the imprint template becoming dirtier over time, which is not observed.

An area of a die was visually inspected through ten imprints. There is no evidence of defect generation among the ~1100 features in the inspected area. Work directed toward automatic inspection of multiple SFIL wafers on a KLA 2132 inspection tool to yield statistical defect data continues.

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