Modeling the enhancement of NIL stamp-bending compliance by backside grooves: mitigating the impact of wafer nanotopography on residual layer thickness

Hayden Taylor[1*], **Kristian Smistrup**[2+], and **Duane Boning**[1]

[1] Microsystems Technology Laboratories, Massachusetts Institute of Technology
Room 39-328, 77 Massachusetts Avenue, Cambridge, MA, 02139, USA
* hkt@mit.edu
[2] NIL Technology, Diplomvej 381, DK-2800 Kongens Lyngby, Denmark
+ks@nilt.com

Abstract

We describe a model for the compliance of a nanoimprint stamp etched with a grid of backside grooves. We integrate the model with a fast simulation technique that we have previously demonstrated, to show how etched grooves help reduce the cross-wafer residual layer thickness (RLT) variations caused by random undulations of the stamp and substrate wafer topographies.

1. Motivation

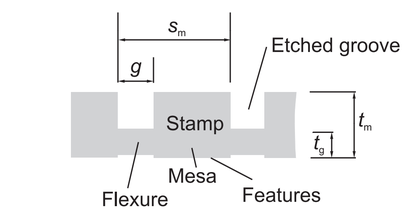
- Wafer-scale nonuniformity of residual layer thickness (RLT) remains a challenge in thermal nanoimprint lithography (TNIL).
- The use of backside grooves etched into a silicon stamp [1] can provide long-range flexibility to conform to stamp nanotopography, while retaining short-range stamp rigidity to limit pattern-dependencies.
- The compliance of such stamps needs to be modeled to enable selection of groove geometries.
- Aim: achieve adequate stamp compliance without making fabrication unnecessarily difficult or consuming a great deal of silicon area with unnecessarily wide flexures.

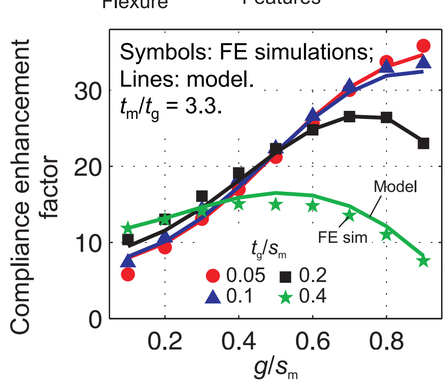
2. Modeling grooved stamp deflections

Our semi-analytical model for the elastic deflections of a structured stamp captures local indentation, transverse shearing, and bending. The model has been calibrated against finite-element simulations for ranges of initial wafer thicknesses and groove widths and depths.

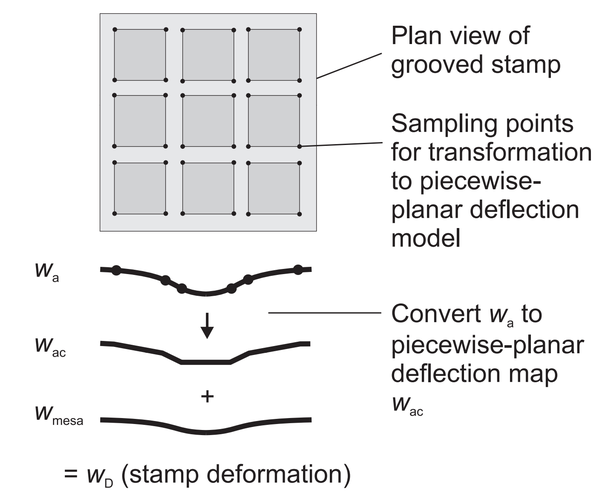
Right: geometry of NIL stamp with backside grooves. Each square chip sits on a 'mesa' which protrudes ~ 1 μm from the stamp.

Stamp compliance is considerably increased by backside grooves. 'Compliance enhancement factor' is the ratio of peak-peak deflection of the structured stamp to that of a uniformly t_m-thick stamp, under identical loadings.

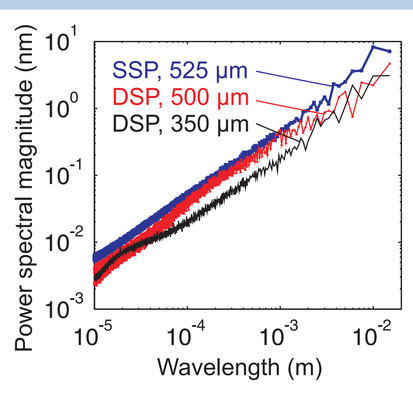




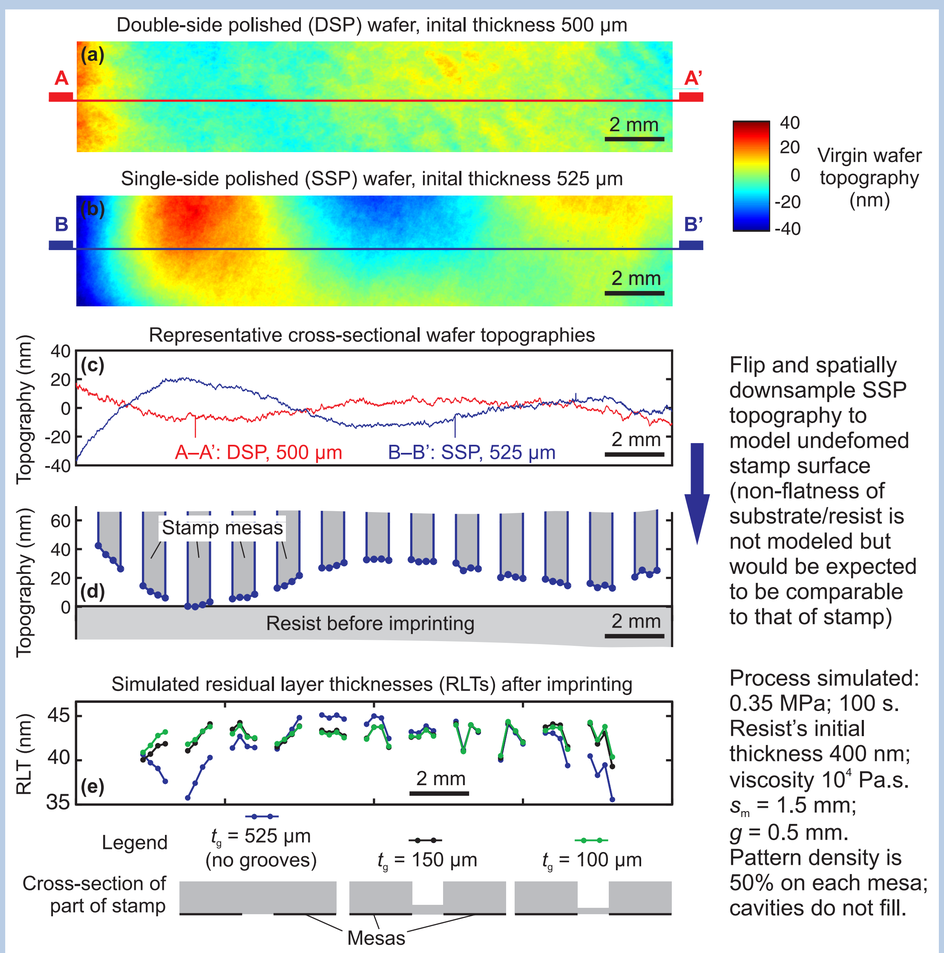
The model is integrated with our existing scheme for fast TNIL simulation [2,3]: an impulse response describes flowing resist and a point-load response encapsulates stamp flexibility [4]. Stamp deflections, w_{mesa}, that would occur with a uniformly t_m-thick stamp are superimposed on w_{ac}, an approximation to the additional stamp deformation afforded by the grooves.



3. Propagation of parasitic nanotopographies to RLT variation: simulations incorporating a measured wafer topography



- Measurements of the surface roughness of three virgin silicon wafers (above) show that the amplitude of nanotopography is approximately proportional to its wavelength up to scales of ≥10 mm.
- We simulated a thermal NIL process (right) in which the stamp was assumed to have the topography measured from the SSP wafer.
- Simulations indicate that etched backside grooves in the stamp allow the stamp to conform more easily to the substrate, enabling substantial reductions in both mesa-to-mesa and *within*-mesa RLT variation, compared to a grooveless stamp of the same original thickness.
- Meanwhile, the ability of grooves mechanically to 'decouple' adjacent mesas with differing protrusion pattern densities is investigated in our recent work [6].



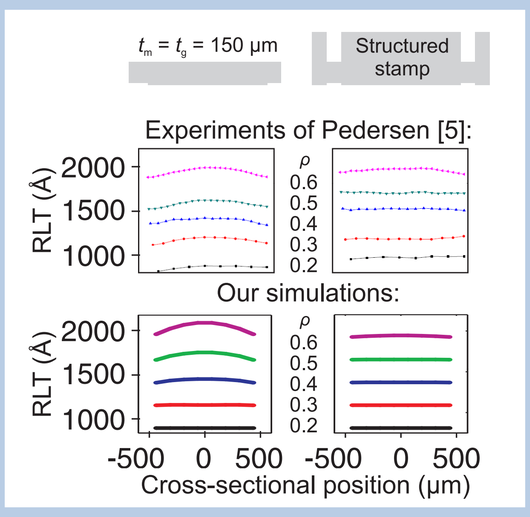
Flip and spatially downsample SSP topography to model undeformed stamp surface (non-flatness of substrate/resist is not modeled but would be expected to be comparable to that of stamp)

Process simulated: 0.35 MPa; 100 s. Resist's initial thickness 400 nm; viscosity 10^4 Pa.s. s_m = 1.5 mm; g = 0.5 mm. Pattern density is 50% on each mesa; cavities do not fill.

This table summarizes variation of the measured stamp topography, extracted from (d) above, and variation of simulated RLTs, extracted from the three cases in (e).		Mean *within*-mesa std. dev. (nm)	Mesa-to-mesa std. dev. (nm)
Undeformed stamp topography		1.8	10.4
Simulated RLTs	t_g = 100 μm	1.0	0.3
	t_g = 150 μm	1.1	0.7
	no grooves	1.3	2.3

4. Limiting systematic residual layer thickness variation

A structured stamp with narrow flexures separating thicker feature-carrying mesas gives smaller systematic RLT variation than a uniformly thin stamp.



ρ: protrusion density. Resist viscosity fit: 2×10^5 Pa.s (within the range of literature values for this 50K PMMA). t_m = 525 μm; t_g = 150 μm; s_m = 1.5 mm; g = 500 μm. Stamp-average pressure 0.35 MPa; imprint time 5 min.

5. Outlook

- Structured stamps offer short-range stamp rigidity combined with longer-range flexibility.
- Longer-range flexibility enables stamps to conform to random stamp/substrate undulations, improving wafer-scale RLT uniformity.
- Our simulation model allows these benefits to be quantified and stamp geometries selected.

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Massachusetts Institute of Technology

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