Modeling and simulation of stamp deflections in nanoimprint lithography: exploiting backside grooves to enhance residual layer thickness uniformity

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 systematic residual layer thickness (RLT) variations that occur when different patterns lie in close proximity on the stamp.

1. Motivation

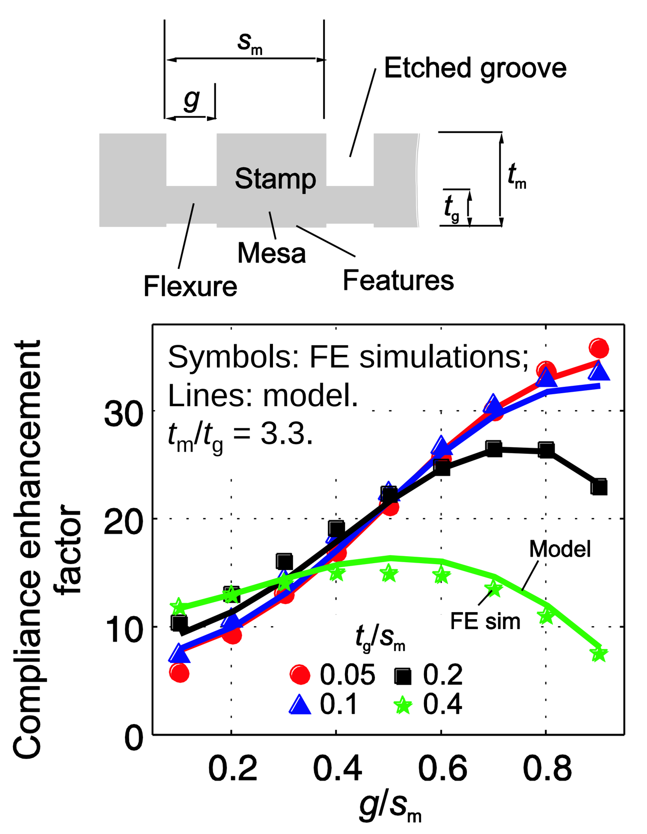
- Wafer-scale nonuniformity of residual layer thickness (RLT) remains a challenge in thermal nanoimprint lithography (TNIL).
- The use of backside grooves etched into a silicon stamp [1] can provide long-range flexibility to conform to stamp nanotopography, while retaining short-range stamp rigidity 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

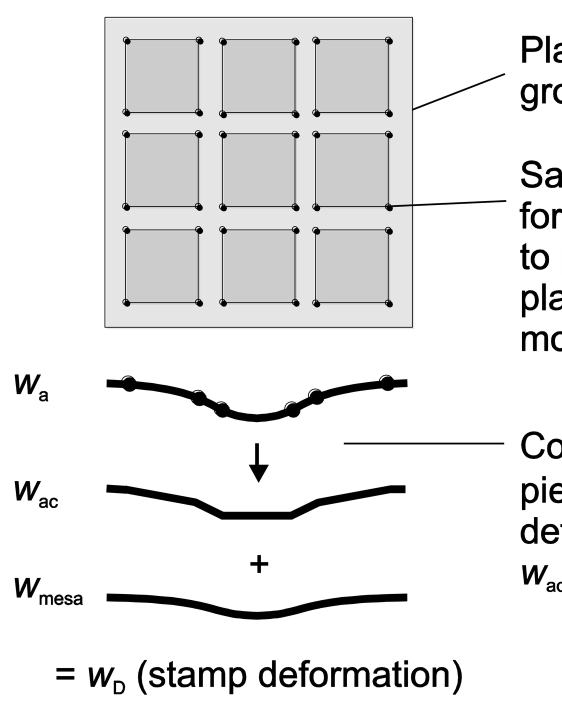
Our semi-analytical model for the elastic deflections of a structured stamp captures local indentation, transverse shearing, and bending. The model has been calibrated against finite-element simulations for ranges of initial wafer thicknesses and groove widths and depths.

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.

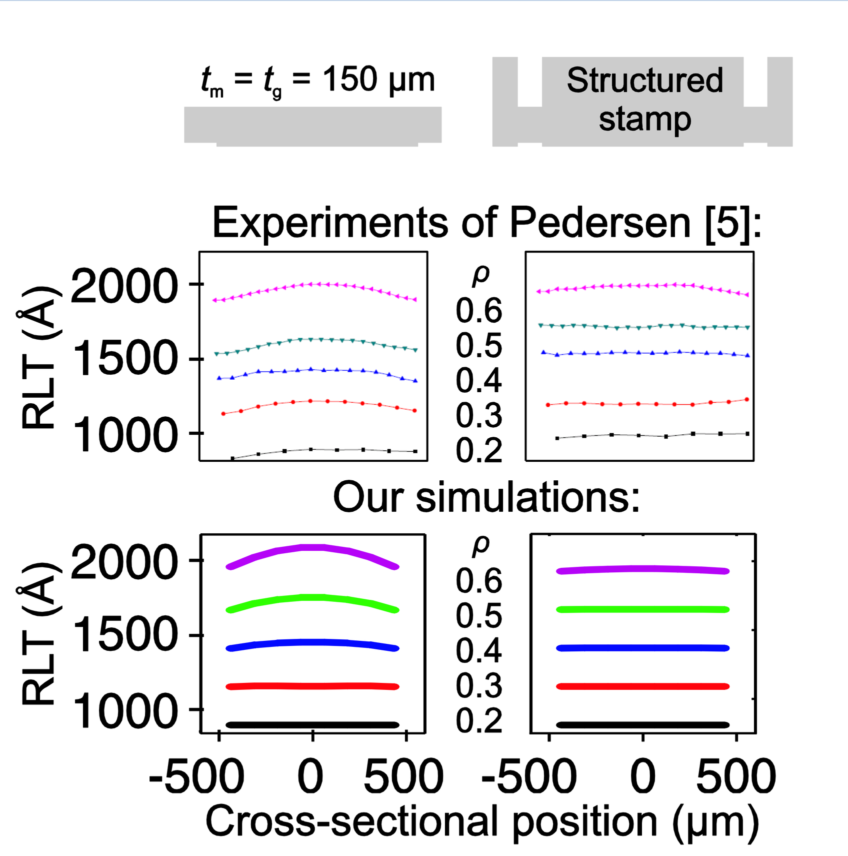


The model is integrated with our existing scheme for fast TNIL simulation [2,3]: an impulse response describes flowing resist and a point-load response encapsulates stamp flexibility [4]. Stamp deflections, w_{mesa}, that would occur with a uniformly t_m-thick stamp are superimposed on w_{ac}, an approximation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

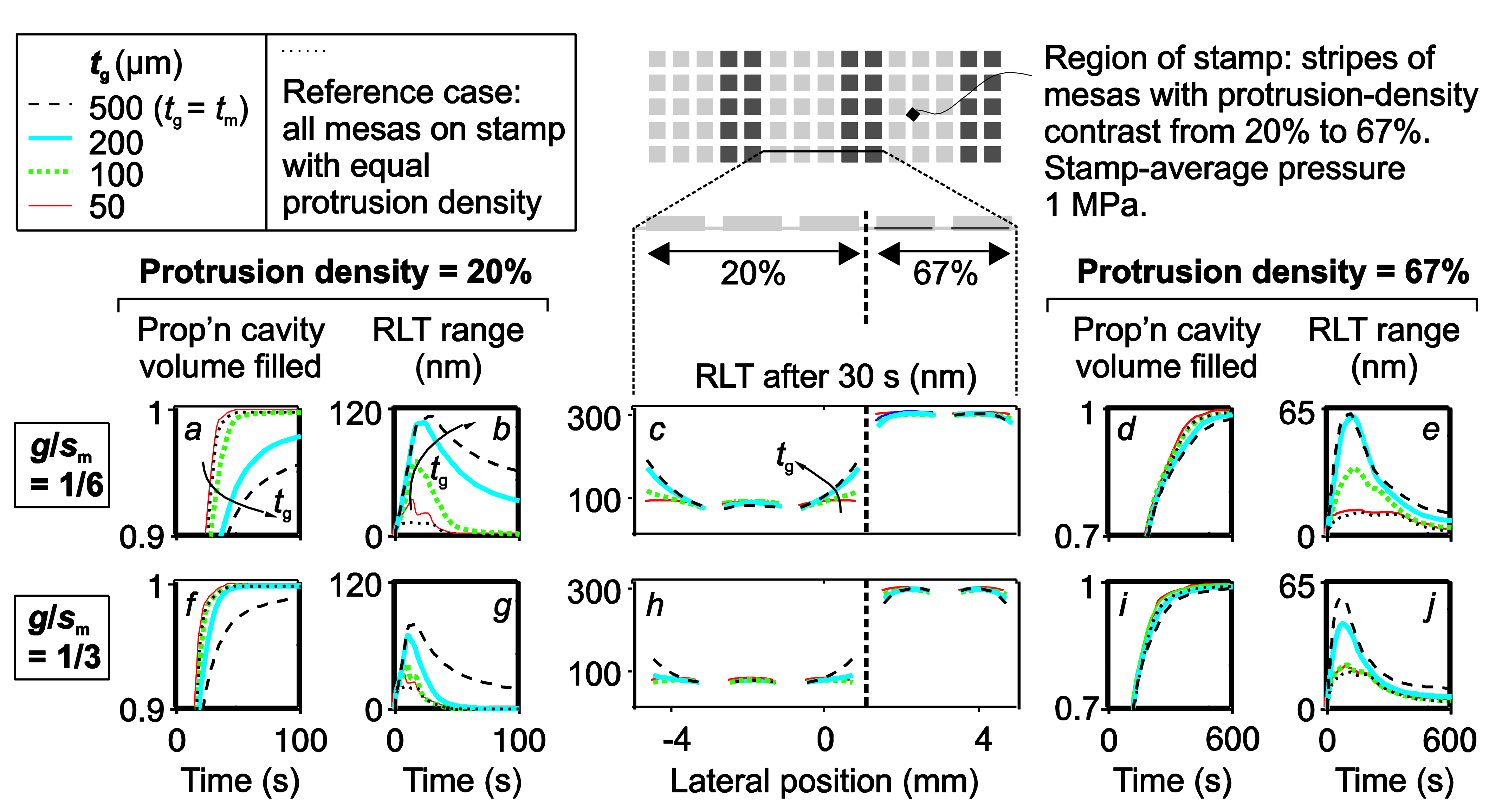


3. Simulation results

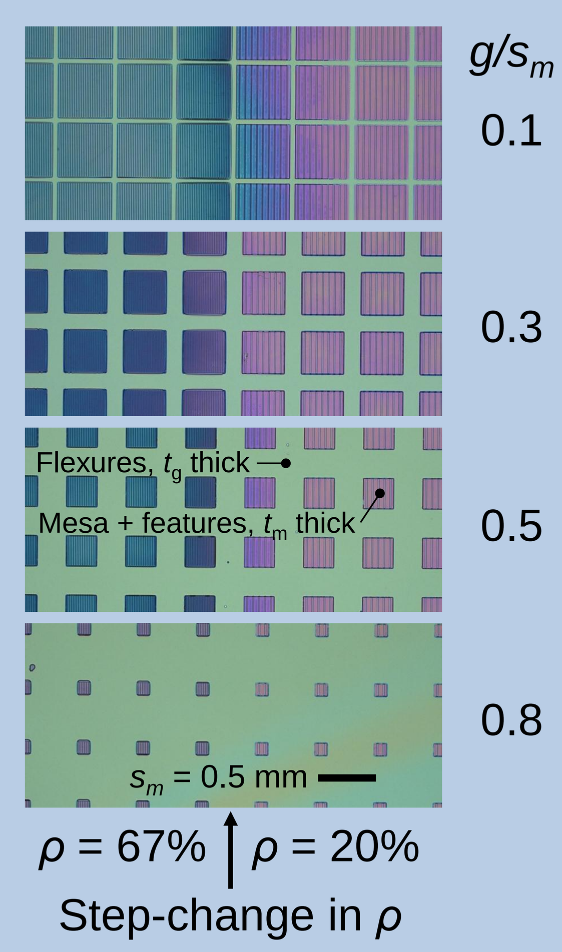
Right: A structured stamp with narrow flexures separating thicker feature-carrying mesas gives smaller systematic RLT variation than a uniformly thin stamp. ρ: protrusion density. Resist viscosity fit: 2×10^5 Pa.s (within the range of literature values for this 50K PMMA). t_m = 525 µm; t_g = 150 µm; s_m = 1.5 mm; g = 500 µm. Stamp-average pressure 0.35 MPa; imprint time 5 min.



Below: Imprinting an array of mesas with contrasting density. Thinner flexures accelerate cavity-filling and reduce peak RLT ranges by decoupling differently patterned adjacent mesas on the stamp. Longer flexures have a stronger decoupling effect. Resist viscosity: 2×10^6 Pa.s. s_m = 2 mm.



4. Preliminary experimental results



Optical micrographs of imprinted resist, after using a stamp with initial wafer thickness t_m = 500 µm and flexure thickness t_g = 240 µm.

Color gradients near step-changes in protrusion-density ρ indicate that RLT is perturbed over a distance of 0.5–1 mm from each step. Stamp-average imprint pressure was ~ 0.4 MPa.

5. Outlook

- Structured stamps offer short-range stamp rigidity and longer-range flexibility.
- Longer-range flexibility enables stamps to conform to random stamp/substrate undulations, improving wafer-scale RLT uniformity.
- Where the protrusion pattern differs between adjacent stamp mesas, simulations indicate that flexures enable earlier completion of stamp-cavity filling and a tighter range of within-mesa RLT, compared to a uniformly t_m-thick stamp.
- Structured stamps could therefore offer faster imprinting times.
- Our simulation model allows these benefits to be quantified and stamp geometries selected.

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Massachusetts Institute of Technology

NIL TECHNOLOGY

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