Motivation

Aim: achieve adequate stamp uniformity. Structured stamps offer short residual layer thickness uniformity. The use of backside grooves etched into a silicon stamp [1] can provide longer flexibility to conform to stamp topography, 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.

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

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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 topography, 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. 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]. Stamps with 500 µm; wgroove that would occur with a uniformly thick stamp are superimposed on wgroove, an approximation to the additional stamp deformation afforded by the grooves.

Simulation results

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 thick stamp, under identical loadings.

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: 2×10^12 Pas. sg = 2 mm.

Region of stamp: stripes of mesas with protrusion-density contrast from 20% to 67%. Stamp-average pressure 0.35 MPa; imprint time 5 min. Simulations for ranges of initial wafer thicknesses and groove widths and depths.

4. Preliminary experimental results

Optical micrographs of imprinted resist, after using a stamp with initial wafer thickness ρ = 67%. Step-change in ρ 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 thick stamp.
• Structured stamps could therefore offer faster imprinting times.
• Our simulation model allows these benefits to be quantified and stamp geometries selected.

References