Experimental Verification of Finite Element Model Prediction of EUVL Mask Flatness during Electrostatic Chucking

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Mask Flatness Issues in EUVL

- Mask nonflatness affects the image placement error (IPE) on the wafer during pattern transfer.
- The critical dimension and overlay budget dictate that this IPE be very small which in turn necessitates that the mask be extremely flat during exposure.
- An electrostatic chuck will be used to support and flatten the mask in the exposure tool.
- The SEMI Standards P37-1102 and P40-1103 describe the mask and chuck flatness in terms of the peak-to-valley (P-V), defect and roughness requirements that need to be achieved in order to enable the successful implementation of EUVL.

SEMI P37-1102, SEMI Standard Specification for EUVL Mask Substrates.
SEMI P40-1103, SEMI Standard Specification for EUV Mask Substrate Chucking.

Objectives and Introduction

- **Develop Finite Element (FE) models to simulate electrostatic chucking and predict the final pattern surface shape of an EUVL reticle.**
- **Perform experiments with an electrostatic chuck and an EUVL substrate to verify the models.**

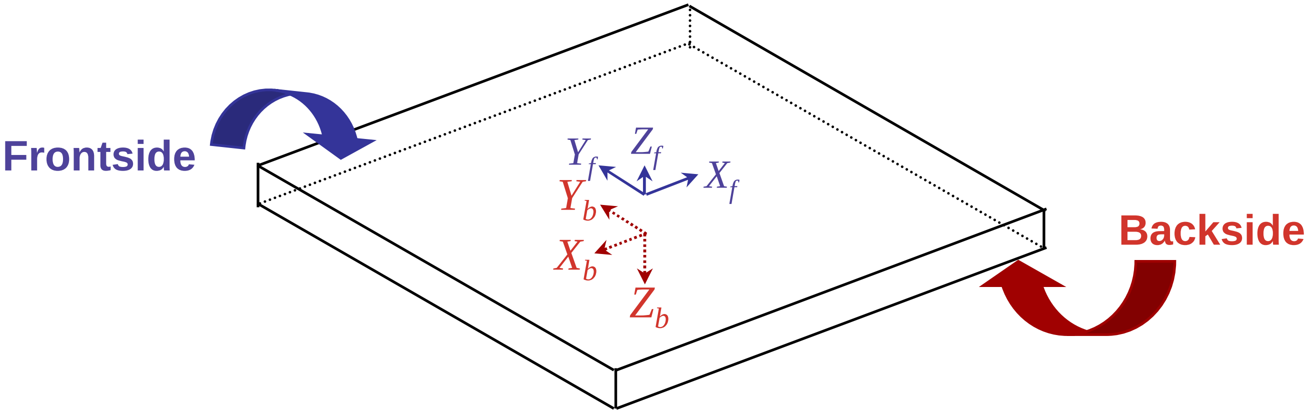
Relevant SEMI Standard Specifications

Reticle frontside and backside nonflatness: 30 nm - 100 nm P-V

Chucking surface nonflatness: < 50 nm P-V

Chucking pressure: > 15 kPa

Coordinate System used for Data Presentation



Reticle Details

Dimensions: 152 mm × 152 mm × 6.35 mm

Quality Area: 142 mm × 142 mm

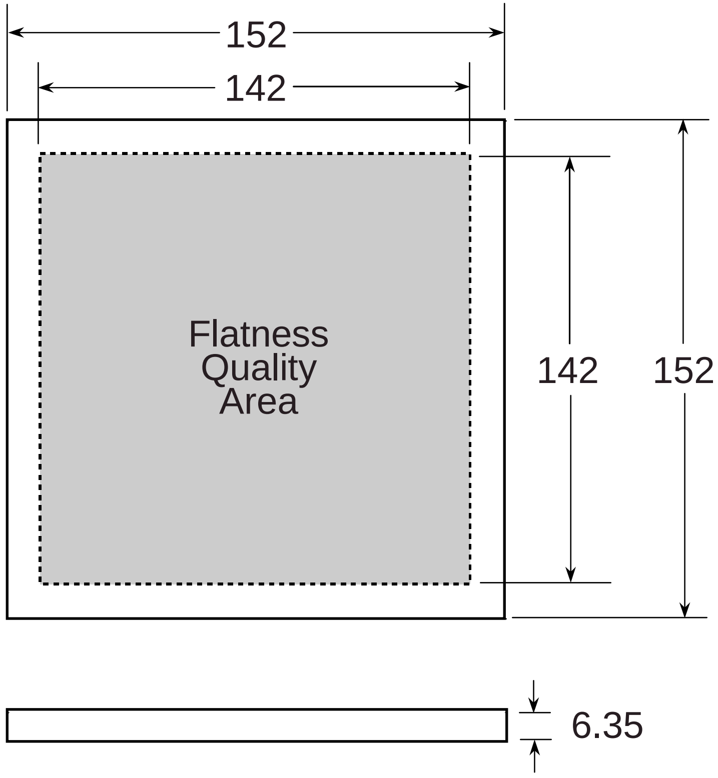
Reticle 1: Quartz Reticle

Substrate:	**Quartz**
Backside:	**Chrome**
Frontside:	**Chrome**

Reticle 2: Reticle with EUV film stack

Substrate:	**Quartz**
Backside:	**CrN:CrON**
Frontside:	**ML stack with absorber layer**

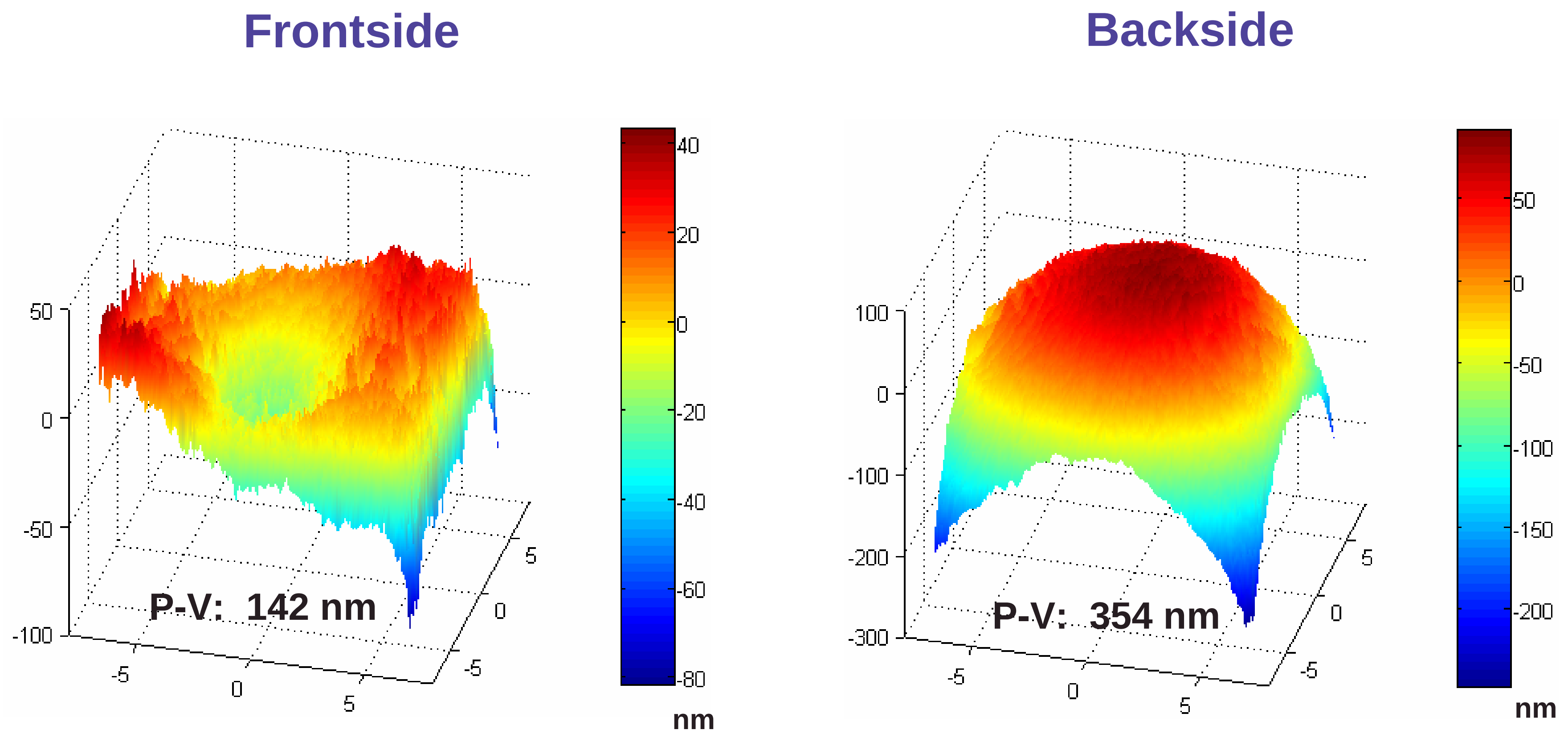
Reticle Layout



All dimensions in mm.

Reticle 1 Flatness Measurements

Interferometric Maps



Frontside

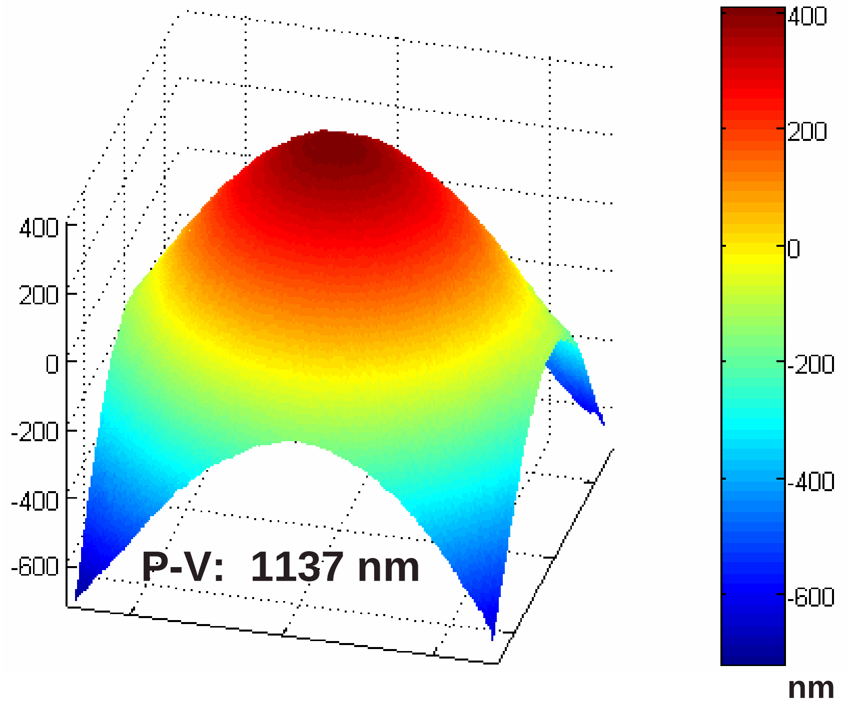
Backside

- **Flatness measurements were made using a Zygo interferometer.**
- **Plots are shown for the Quality Area (142 mm × 142 mm).**

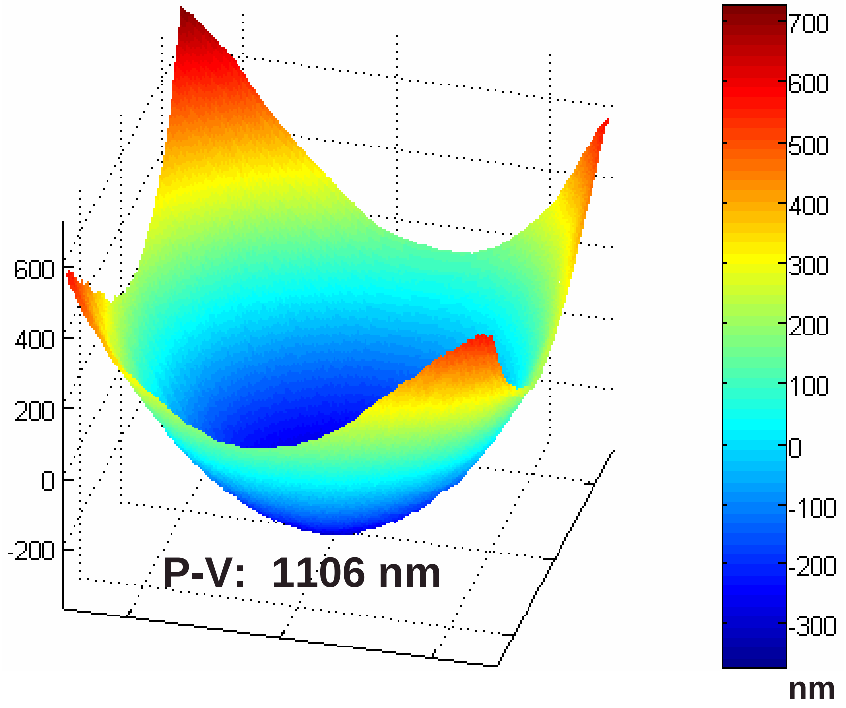
Reticle 2 Flatness Measurements

Interferometric Maps

Frontside



Backside

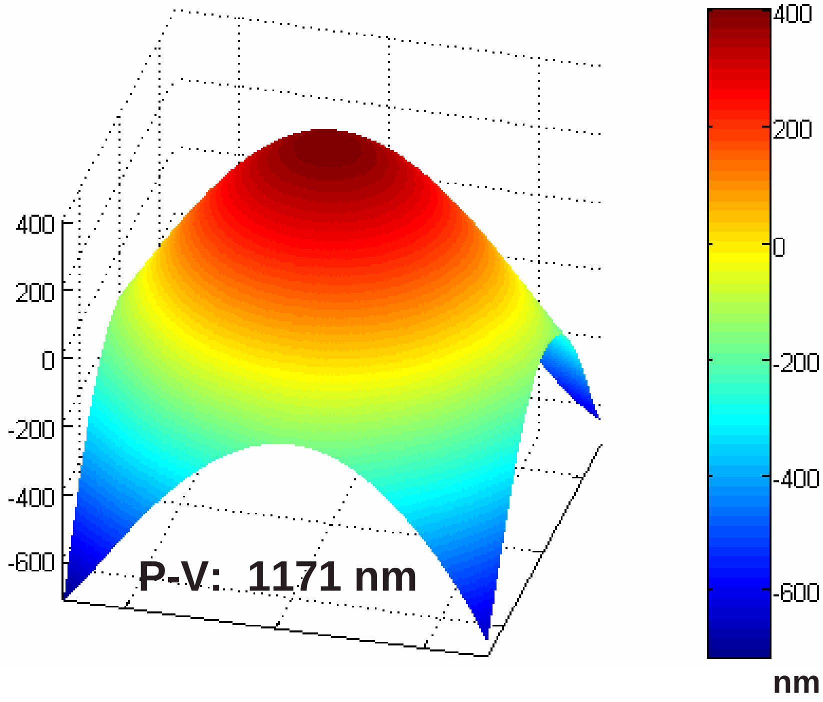


- **Flatness measurements were made using a Zygo interferometer.**
- **Plots are shown for the Quality Area (142 mm × 142 mm).**

Example of Legendre Fit Data

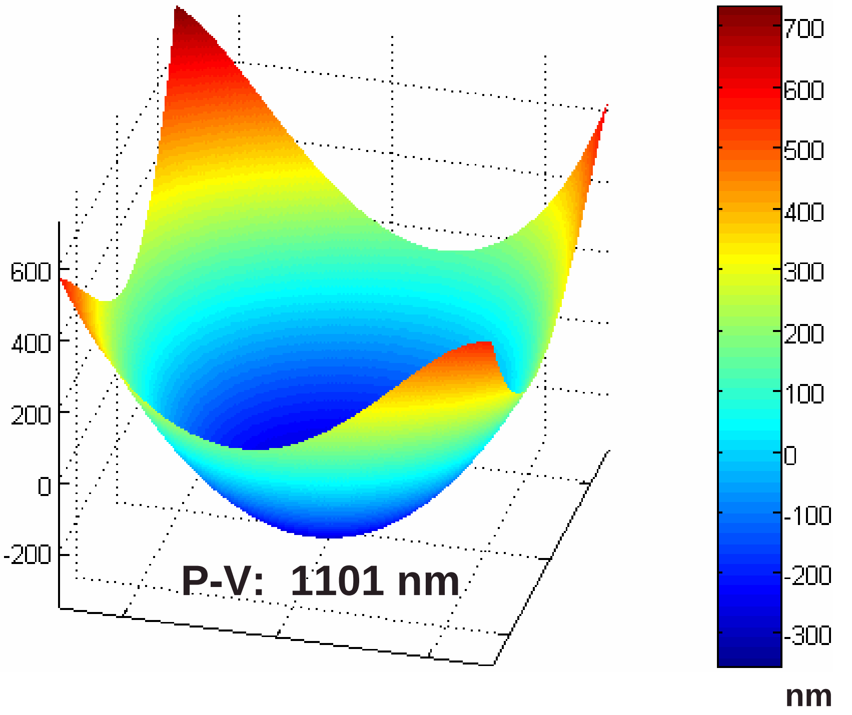
Reticle 2 Flatness Data

Frontside



P-V: 1171 nm

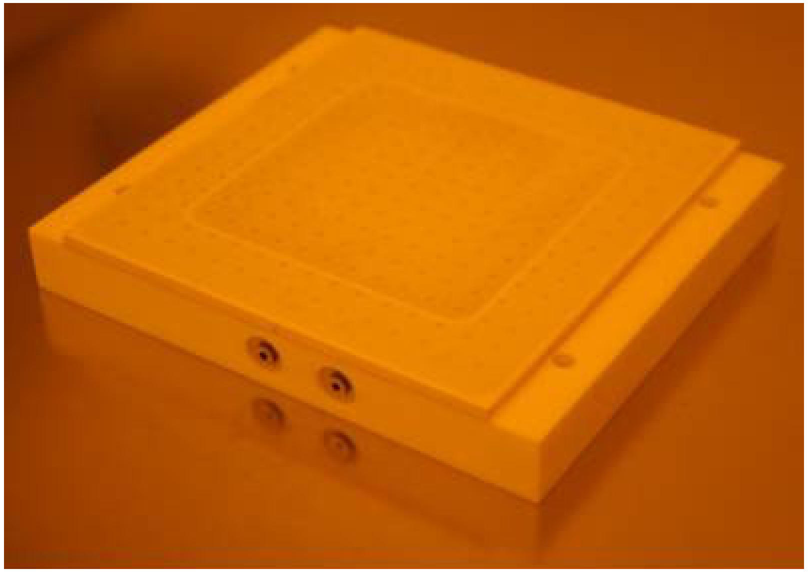
Backside



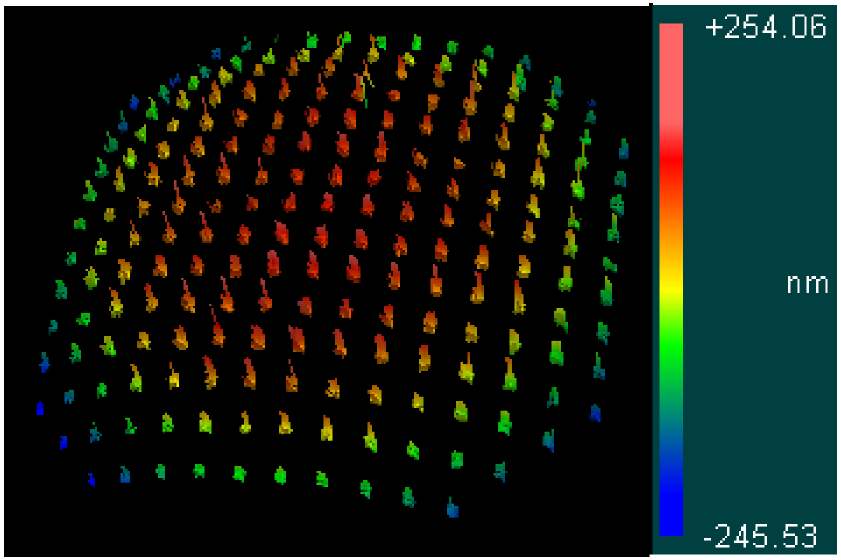
P-V: 1101 nm

- Legendre polynomials up to the 7th order were used.
- These were used as input to the FE models.

Electrostatic Chuck Details



- **Bipolar Coulombic pin chuck.**
- **Pin Area: 127 mm × 127 mm**
  Pin Size: 2.5 mm × 2.5 mm × 20 µm
  Pin Pitch: 8.85 mm
- **The pin chuck was placed on a 3-point mount in a horizontal configuration during flatness measurement.**
- **Chuck surface was convex with a bow of about 340 nm across the diagonal.**

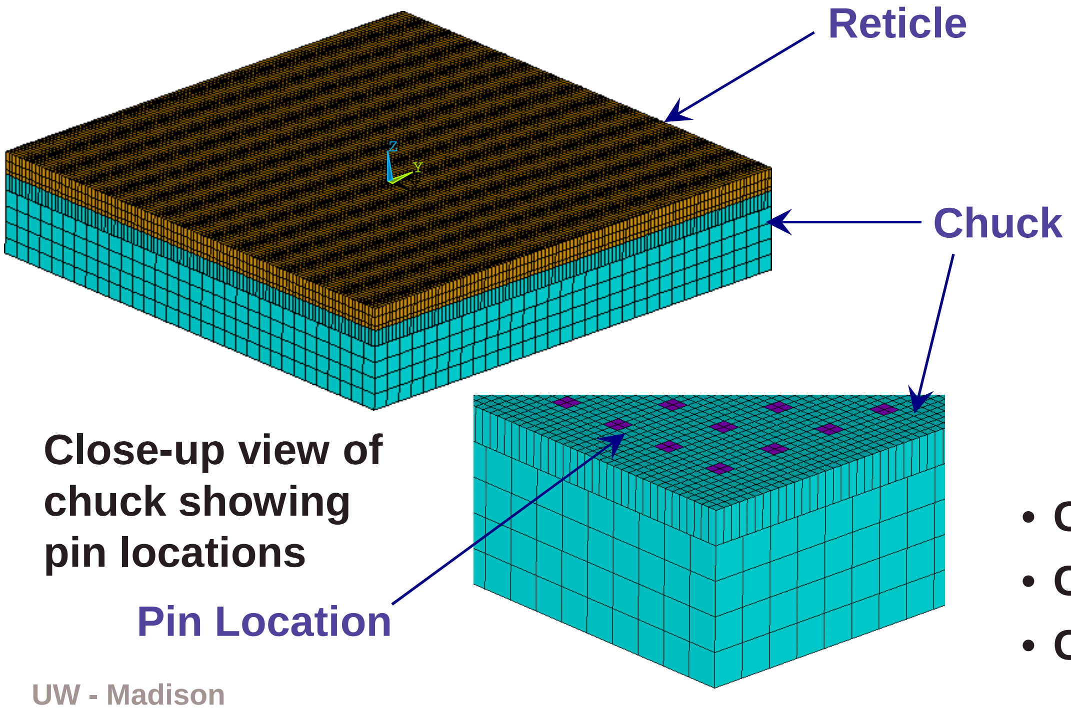


FE Modeling Details

- **Interferometric flatness data for the reticle and the chuck was fitted with Legendre coefficients and input to the FE models. The top surface of the chuck was modeled as a continuous surface with contact allowed only at pin locations.**

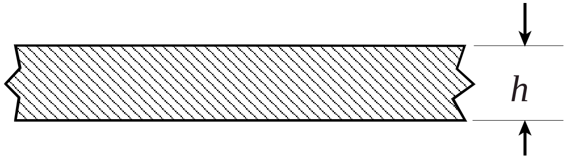
- **Pressure was applied to simulate electrostatic chucking. The pressure at the pins was higher than between the pins.**

- **The thickness of the chuck was adjusted to match the effective flexural stiffness value of the chuck.**



Close-up view of chuck showing pin locations

Chuck Bending Stiffness, *D*



$$D = \frac{Eh^3}{12(1-\nu^2)}$$

E **= elastic modulus**
h **= thickness**
ν **= Poisson's ratio**

- **Chuck flexural stiffness: 383 kN-m**
- **Clamping pressure: 0.8 kPa - 3.1 kPa**
- **Coefficient of friction: 0.2**

Electrostatic Force Calculation

Coulombic Bipolar Chuck

Pressure at the Pins

$$P = \frac{V^2 K^2 \varepsilon_0}{8(d + K\delta)^2}$$

V = applied voltage (1000 V)
K = relative permittivity of dielectric (~8)
ε_o = permittivity of free space (8.85×10^{-12} F/m)
d = dielectric thickness (~150 μm)
δ = gap height (0 at the pins)

P at the pins: ~3.1 kPa

Pressure between the Pins

$$P = \frac{V^2 K^2 \varepsilon_0}{8(d + K\delta)^2}$$

V = applied voltage (1000 V)
K = relative permittivity of dielectric (~8)
ε_o = permittivity of free space (8.85×10^{-12} F/m)
d = dielectric thickness (~130 μm)
δ = gap height (20 μm between pins)

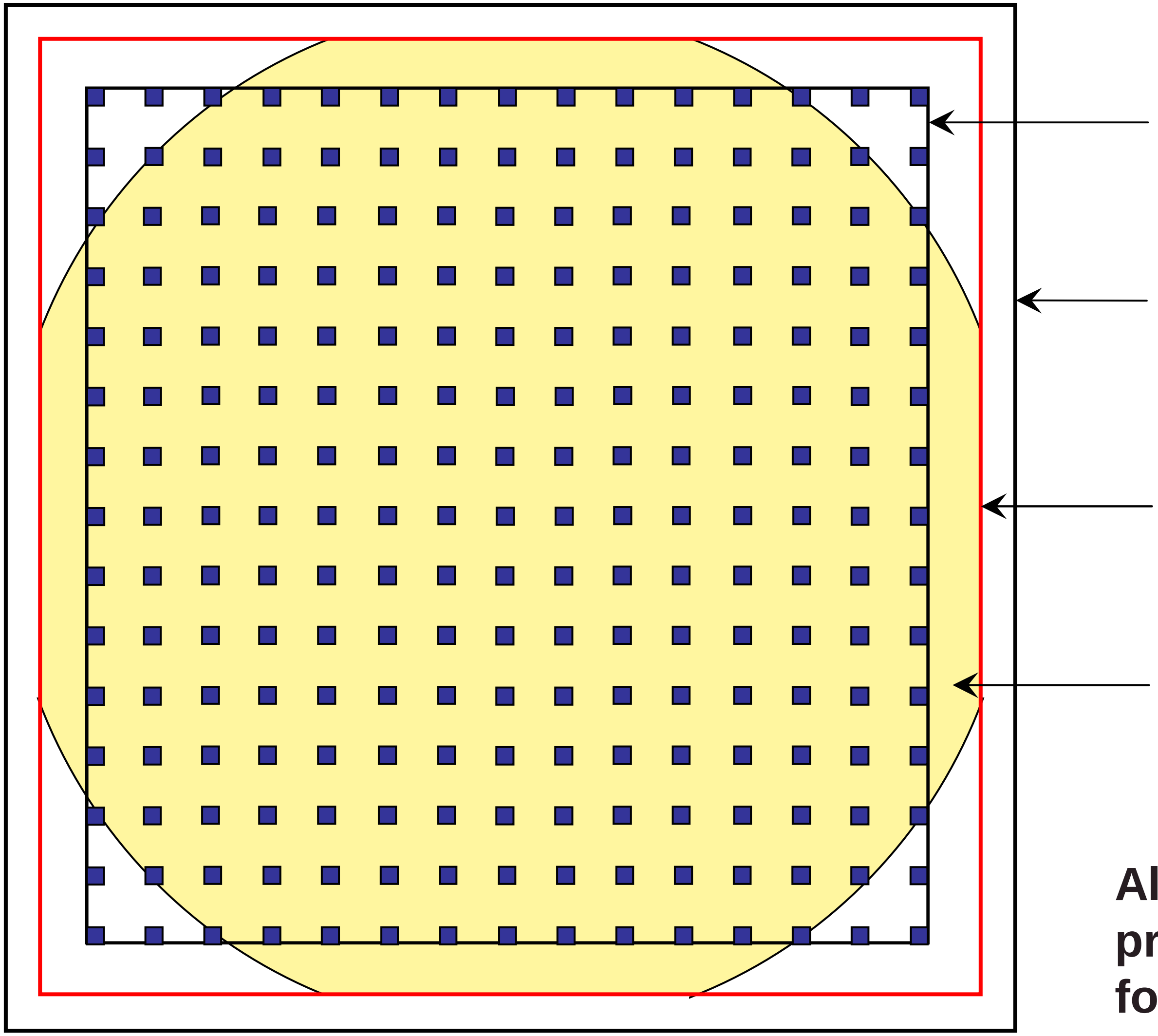
P between the pins: ~0.8 kPa

$$P_{avg} = P_{pin}\left(\frac{A_{pin}}{A_{entire}}\right) + P_{between\_pins}\left(1 - \frac{A_{pin}}{A_{entire}}\right)$$

P_{avg} (at 1000 V) = ~1 kPa

The gaps between the mask and the chuck due to the nonflatness of the mask have been neglected for this calculation.

Schematic of Measurement Area



Pin Area (127 mm × 127 mm)

**Substrate
(152 mm × 152 mm)**

**Quality Area
(142 mm × 142 mm)**

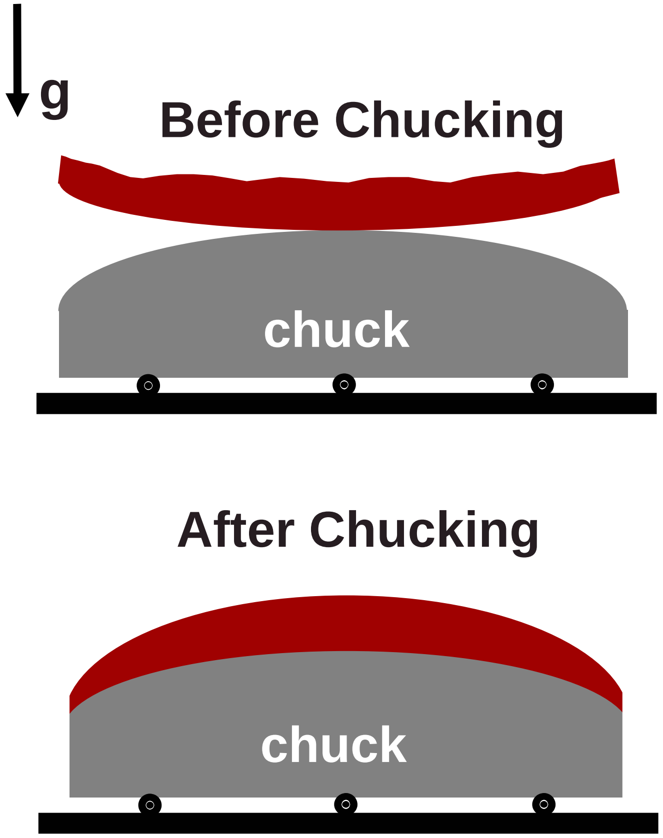
**Measured Data (Circular
area of 6 in. diameter)**

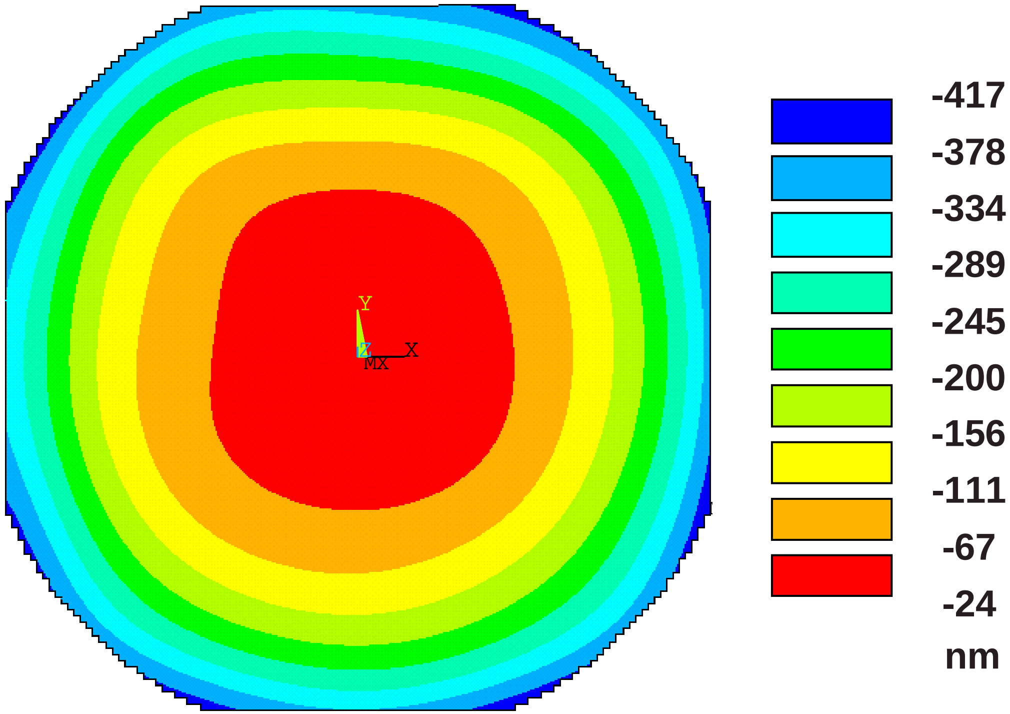
All further plots in this presentation are shown for the yellow area.

FE Simulation Results

Reticle 1

- FE prediction of the pattern surface shape after chucking.
- Pressure applied was 0.8 kPa between the pins and 3.1 kPa at the pins.



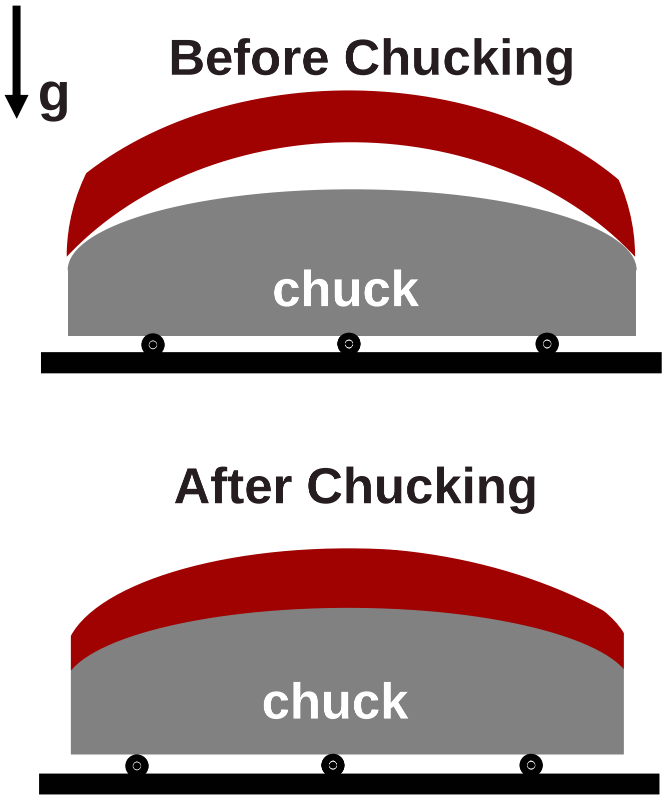


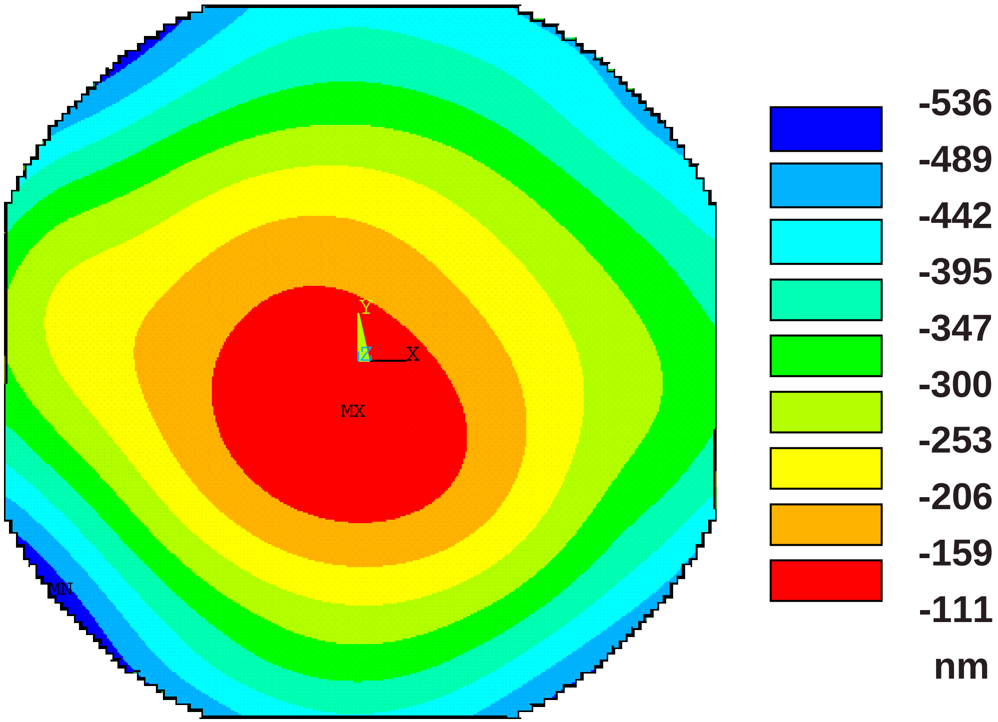
P-V: 393 nm

FE Simulation Results

Reticle 2

- FE prediction of the pattern surface shape after chucking.
- Pressure applied was 0.8 kPa between the pins and 3.1 kPa at the pins.





P-V: 425 nm

Experimental Set-Up

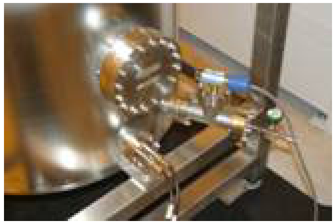
Chamber and Interferometer

Zygo interferometer

vacuum chamber

3 ft. x 4 ft.
vibration
isolation cradle

top viewport

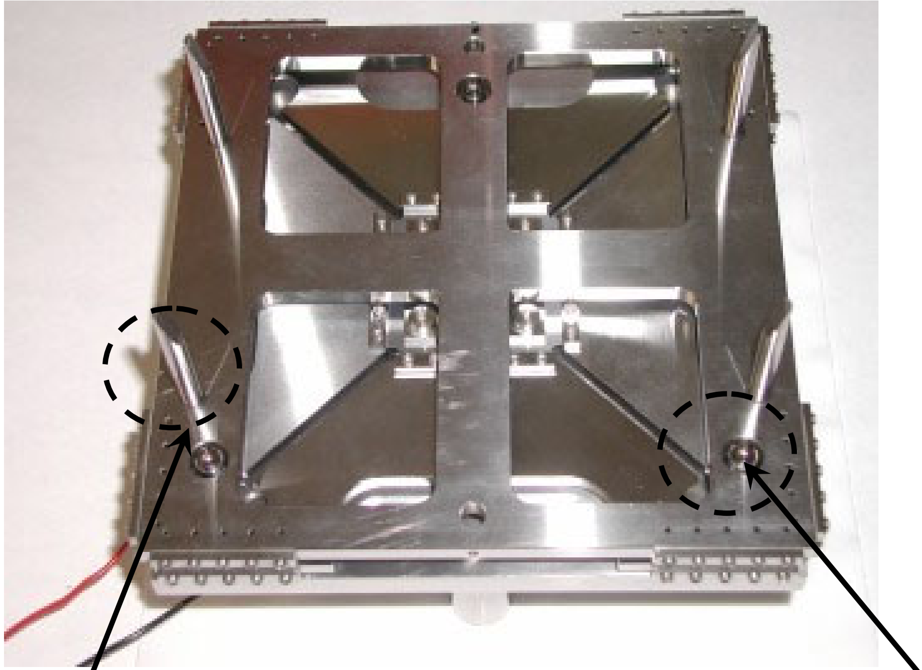


high voltage feedthrough
and pressure sensors

Experimental Set-Up

Lift / Lower Mechanism

Mask Lifter System



Chuck placed on the Lifter System

Four pins used to raise and lower the mask onto the chuck

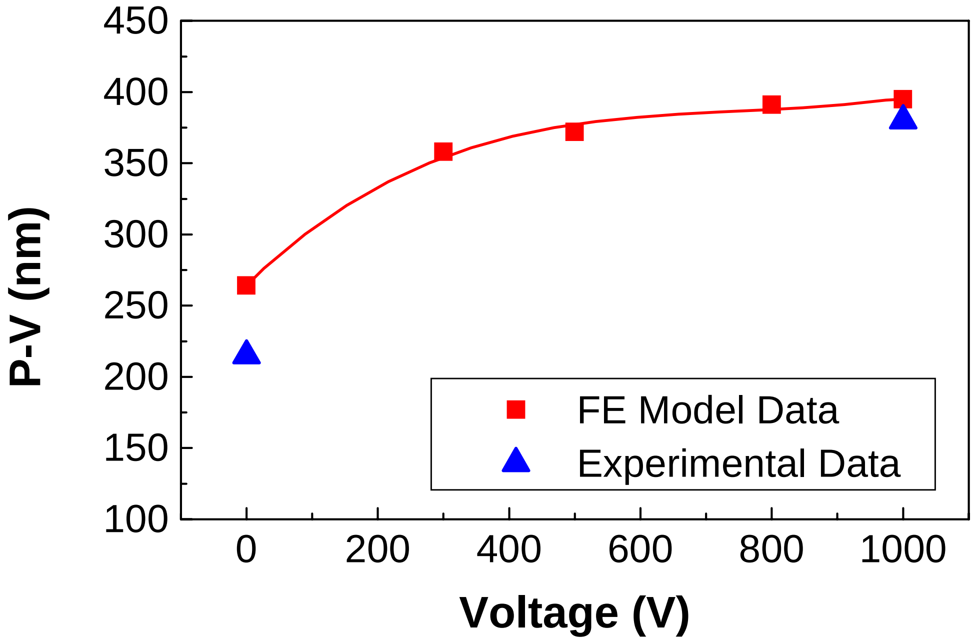
3-point mount on which the chuck is placed

Experimental Results

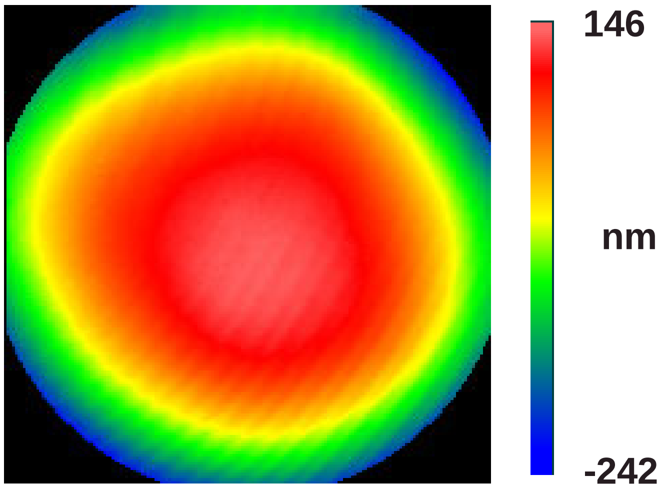
Reticle 1

The FE model was solved at various voltages (pressures) and the results are compared to the experimental results.

Nonflatness as a function of voltage



Final pattern surface shape at 1000 V

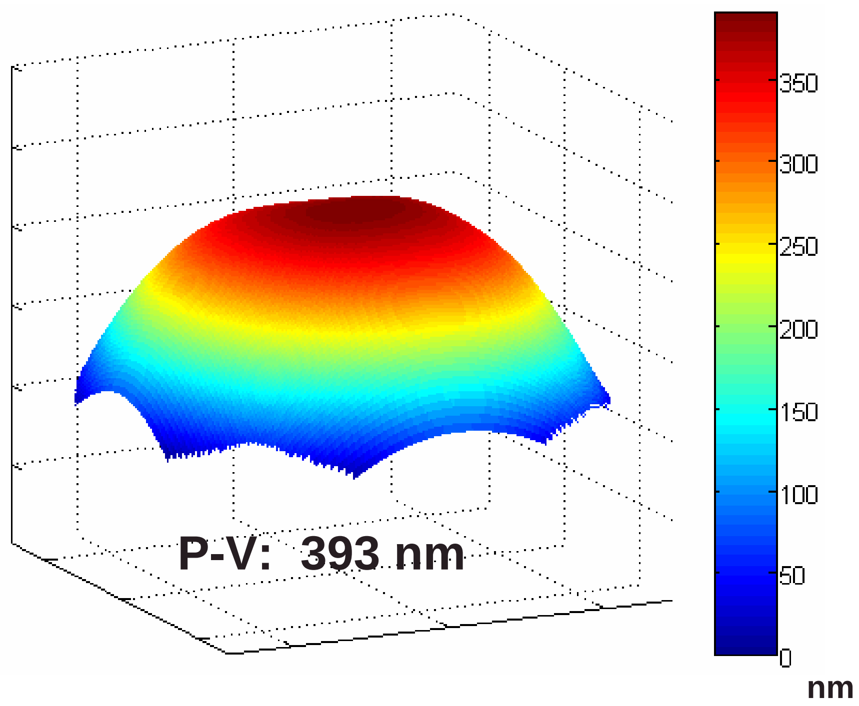


P-V = 388 nm

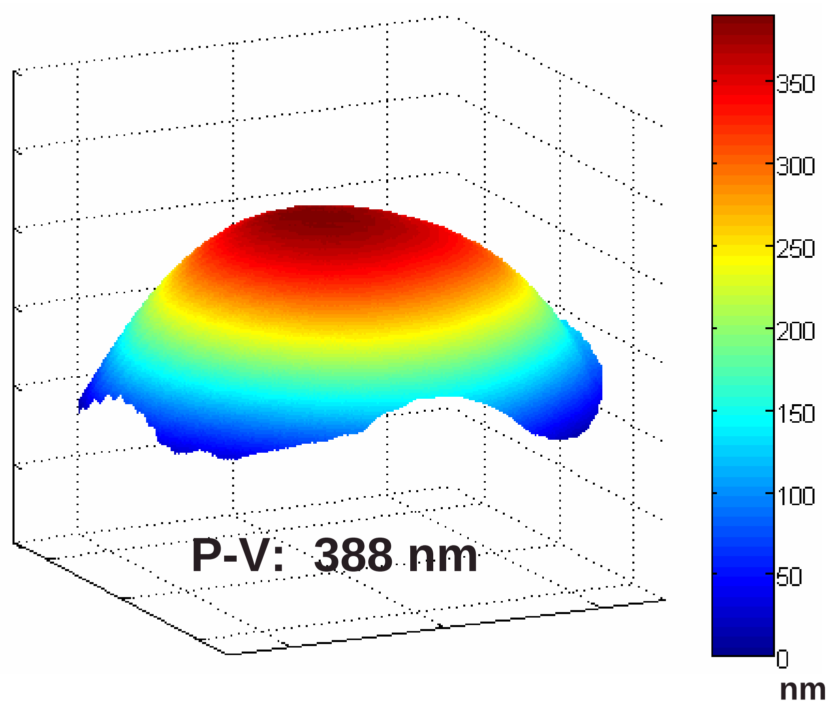
Comparison of Results

Reticle 1

FE Prediction



Experimental Data



- Basic shape predicted by FE model is consistent with the experimental data.

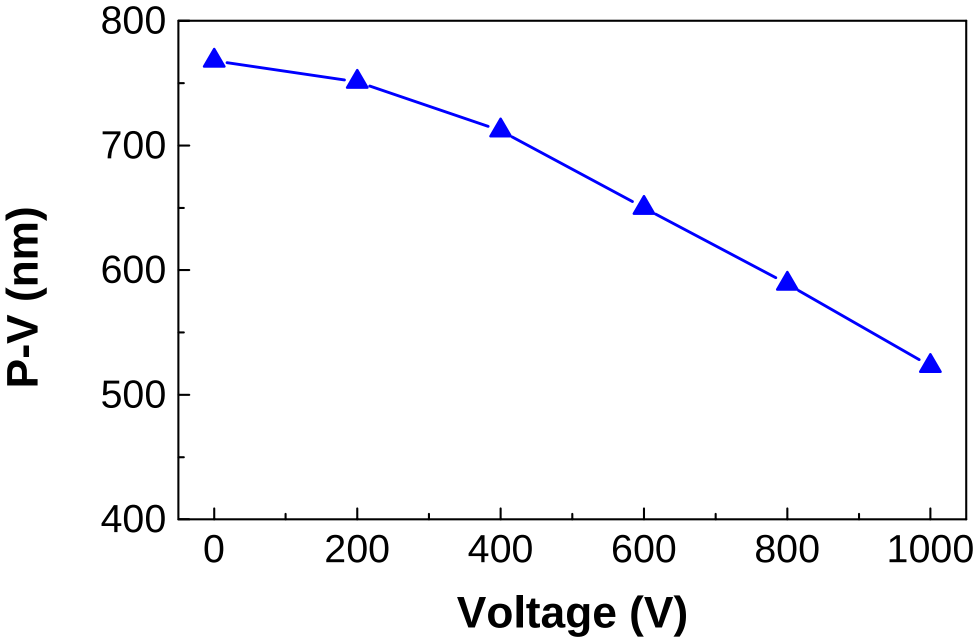
- Possible explanations for differences:
    - nonuniform forces.
    - small particles lodged between the reticle and chuck surfaces.
    - use of Legendre fits in the FE model.

Experimental Results

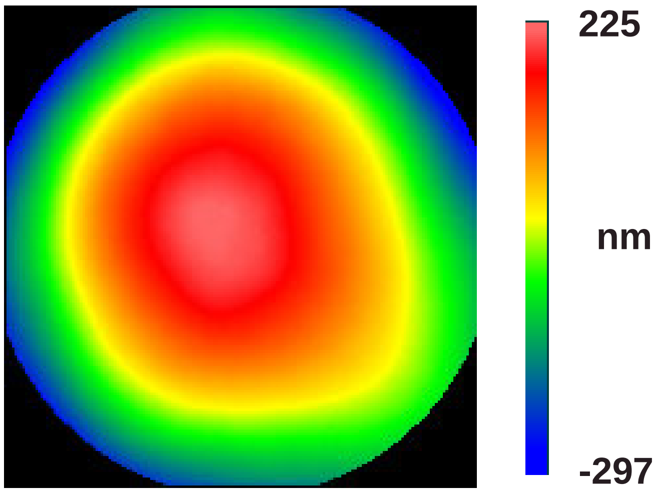
Reticle 2

The voltage was increased in steps of 200 V and interferometric maps of the frontside flatness data were recorded.

Nonflatness as a function of voltage



Final pattern surface shape at 1000 V

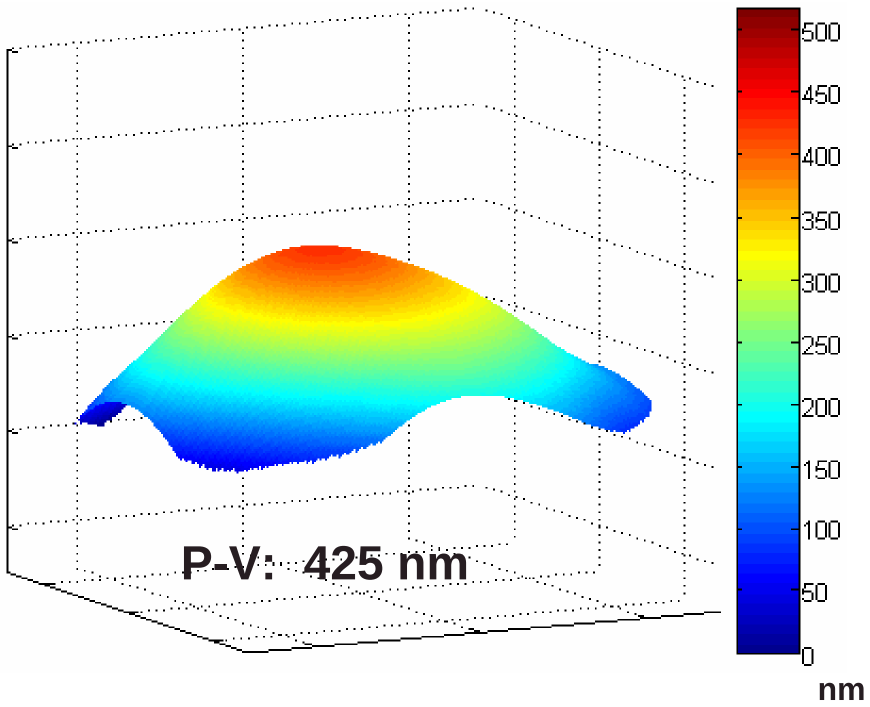


P-V: 522 nm

Comparison of Results

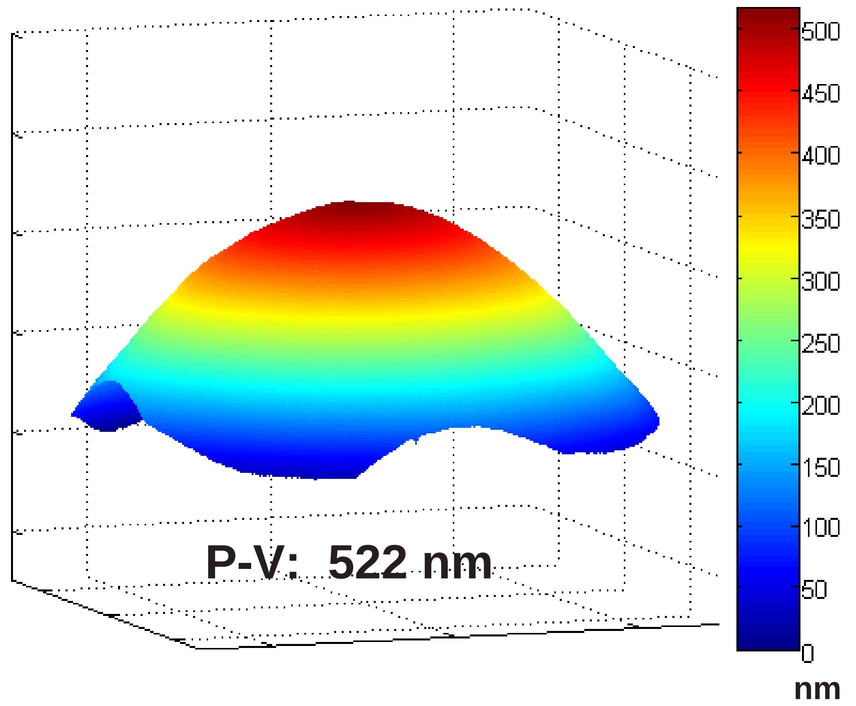
Reticle 2

FE Prediction



P-V: 425 nm

Experimental Data



P-V: 522 nm

- Basic shape predicted by FE model is consistent with the experimental data.

- Possible explanations for differences:
  - nonuniform forces.
  - small particles lodged between the reticle and chuck surfaces.
  - use of Legendre fits in the FE model.
  - the coefficient of friction may be higher than 0.2.

Summary and Conclusions

- **This is the first time that results from simulations and experiments performed to characterize the response of an EUV reticle clamped by an electrostatic pin chuck have been shown.**
- **Interferometric flatness measurements of the reticle and pin chuck were used as input to the FE model.**
- **Pressure was applied to simulate electrostatic chucking and a prediction for the chucked pattern surface shape was obtained.**
- **Chucking experiments in vacuum were performed and the final pattern surface shape was measured using an interferometer.**
- **Reasonable agreement between modeling and experiments was observed, but additional investigation of other factors is ongoing to improve the agreement.**
- **Once the validity of the FE models is well-established, they can be used to facilitate the implementation of the SEMI Mask and Chucking Standards.**