Compensating for Image Placement Errors during the Fabrication of EUVL Masks

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Introduction

- Tolerance on image placement (IP) errors is becoming increasingly severe as lithography technology drives the minimum IC feature sizes below 65 nm.
- Goal of this research is to investigate the IP errors induced during mask fabrication and chucking for EUV lithography.
- Basic concept is that if repeatable errors (due to fabrication and chucking) can be predicted to a reasonable accuracy, it may be possible to correct for these errors when the mask is initially patterned in the e-beam writer.
- Finite element (FE) models have been developed to simulate the response of the reticle during these processes.
- The FE predictions provide a basis for the "Correction Tables" to be used when patterning.

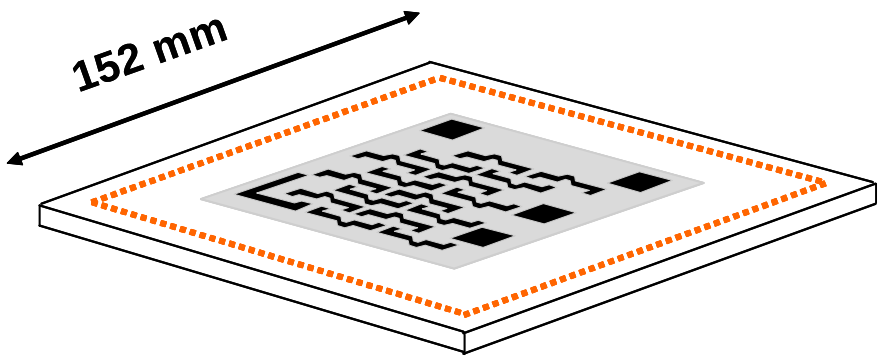
Presentation Outline

- EUV Mask Fabrication
  - flatness requirements
  - typical process flow
  - description of example case
- FE Models to Predict EUV Mask Response
  - thin film deposition
  - e-beam tool mounting
  - thin film etching
  - exposure tool chucking
- Telecentric Errors in EUV Lithography
- Summary and Conclusions

EUVL Mask Flatness Requirements
SEMI Standard P37

- **The flatness of the EUVL mask is a key issue to minimize IP errors due to nontelecentric illumination.**
- **SEMI Standard P37 specifies the flatness of the frontside (FS), backside (BS), and the thickness variation of the substrate in terms of Class A, B, C, or D.**

Freestanding Substrate Flatness



Quality Area = 142 mm × 142 mm

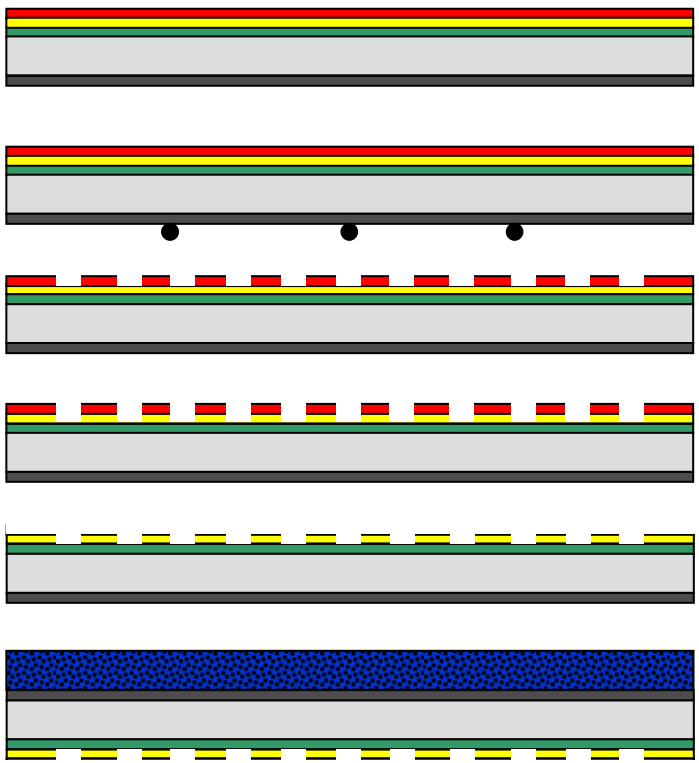
Frontside and Backside in Quality Area:

~ 30 - 100 nm *p-v* flatness

Low Order Thickness Variation (LOTV) in Quality Area:

~ 30 - 100 nm *p-v* flatness

EUV Mask Fabrication Process Flow



LS 1. Deposition of Multilayer Stack, Absorber Stack, Photoresist, and Backside Layer

LS 2. E-beam Tool Chucking and Writing in 3-Point Mount

LS 3. Resist Development

Etching of Absorber Stack

Resist Removal

LS 4. Electrostatic Chucking in Exposure Tool

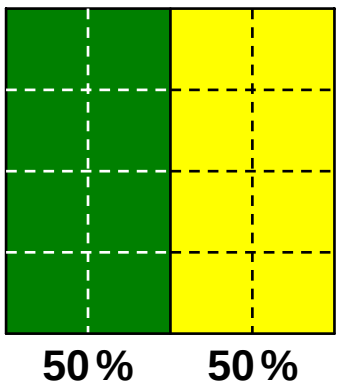
Layer	Thickness (nm)	Stress (MPa)
Multilayer Stack	280	400 (Compressive)
Absorber Stack	70	100
Photoresist	250	10
Backside Layer	60	150

Fabrication Example

- Full 3-D, FE structural models have been developed to predict the response of the EUV reticle under the Load Steps (LS) given the fabrication process flow.

- Example case includes:
  - -- nonflatness of the EUV substrate due to polishing
  - -- stress nonuniformity of the multilayer stack

Stress Nonuniformity Assumed in Multilayer Stack



Worst Case Scenario

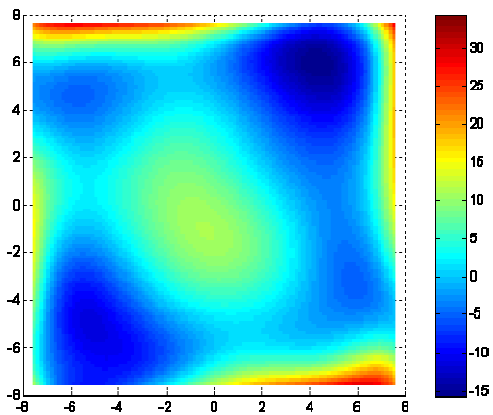
Green: 480 MPa
Yellow: 400 MPa
(compressive)

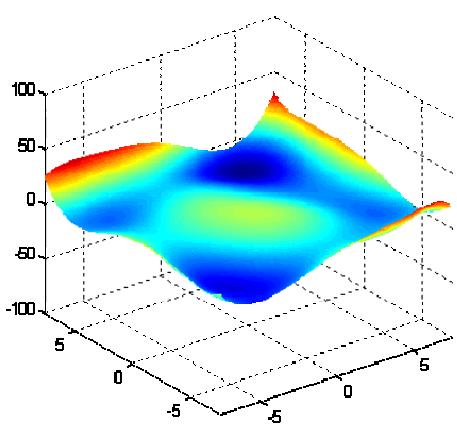
Initial Nonflatness of Reticle Substrate

Interferometric measurements of the Frontside and Backside surfaces of the substrate are represented by an 8 $\times$ 8 matrix of Legendre polynomials which are used as input into the FE models.

Polishing Nonflatness - Example Case

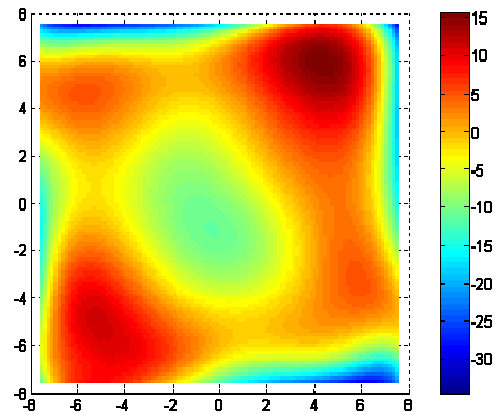
Frontside (FS)

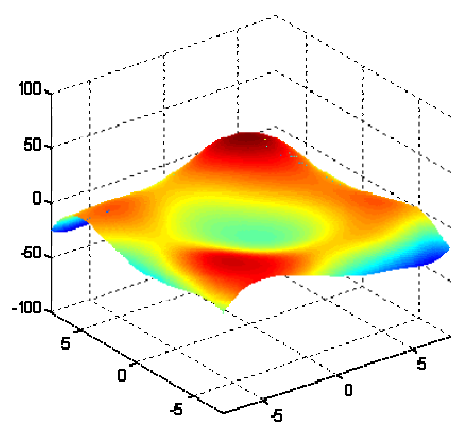




p-v **= 50 nm**

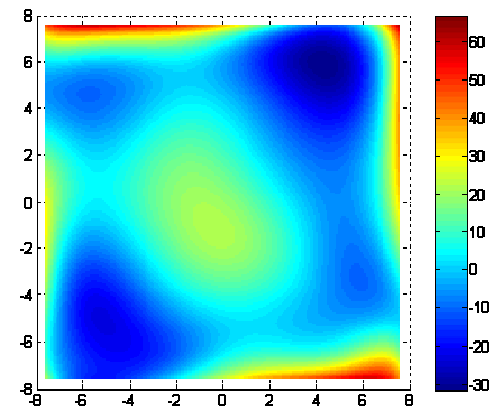
Backside (BS)





p-v **= 50 nm**

Thickness Variation



Max = 100 nm

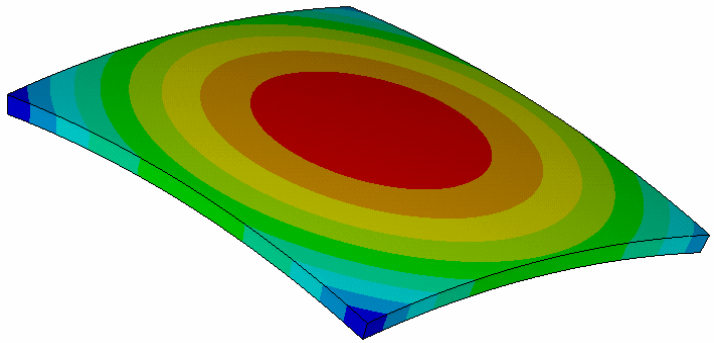
- **Thickness variation was calculated by subtracting the backside flatness data from the frontside flatness data.**

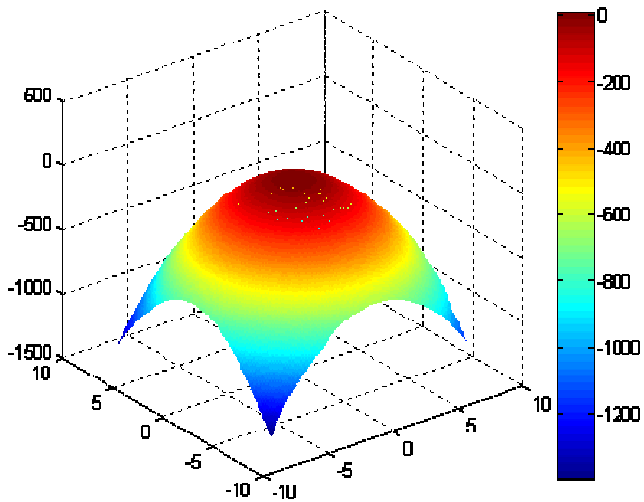
Simulating Thin Film Deposition

Load Step 1

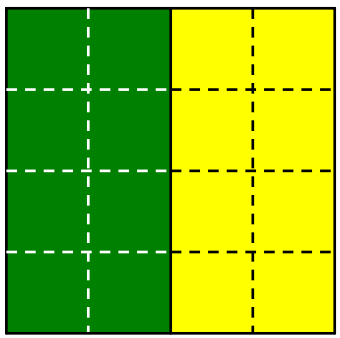
- **After generating the FE model of the EUV substrate with the FS and BS nonflatness, the deposition of the nonuniform stressed layers is simulated.**

- **For the example case, the out-of-plane distortion (OPD) of the FS is 1400 nm *p-v*. The shape is convex due to the net compressive stress.**





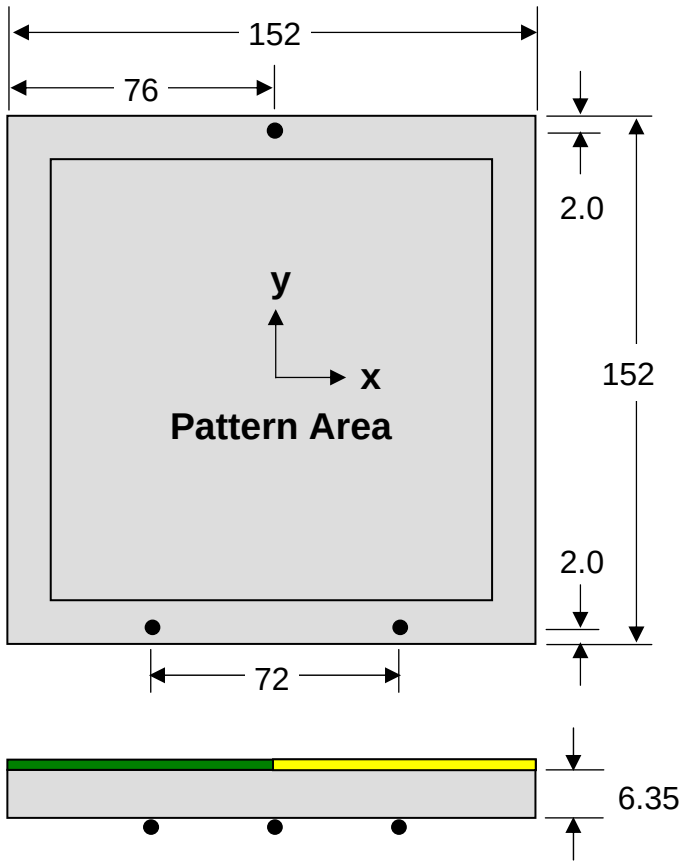
OPD Frontside (*p-v* = 1400 nm)



Green: 480 MPa
Yellow: 400 MPa
(compressive)

Chucking in the E-Beam Writer

Load Step 2

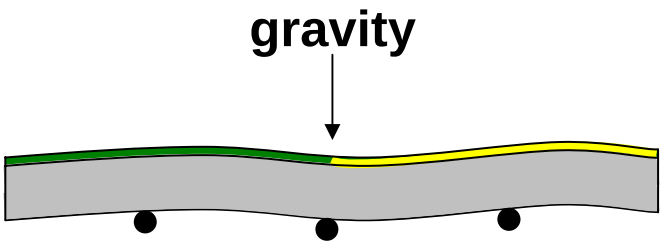


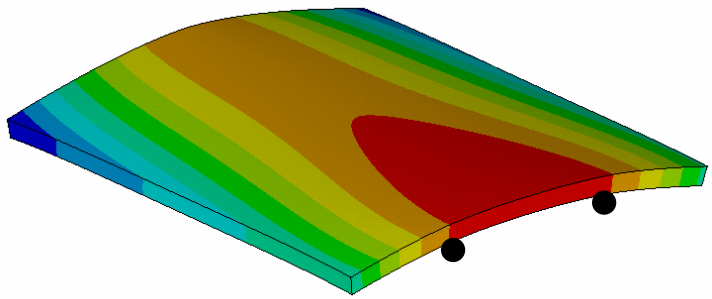
Units in mm.

- The SEMI Standards Committee on EUV Mask Chucking originally recommended the development of an electrostatic chuck for use in the e-beam tool (SEMI P40).
- Industry prefers to retain the use of a 3-point mount during e-beam patterning.
- Gravitational distortions can be significant and will need to be corrected.

Simulating E-Beam Tool Chucking

Identifying Correction Table A

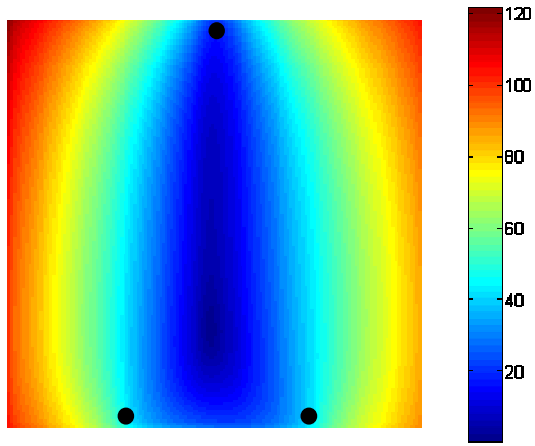




OPD Frontside (*p-v* = 1477 nm)

- FE models predict the OPD due to the initial nonflatness of the substrate, nonuniform stress distribution, and gravitational distortions on a 3-point mount.

- The corresponding in-plane distortion (IPD) is to be used as Correction Table A.

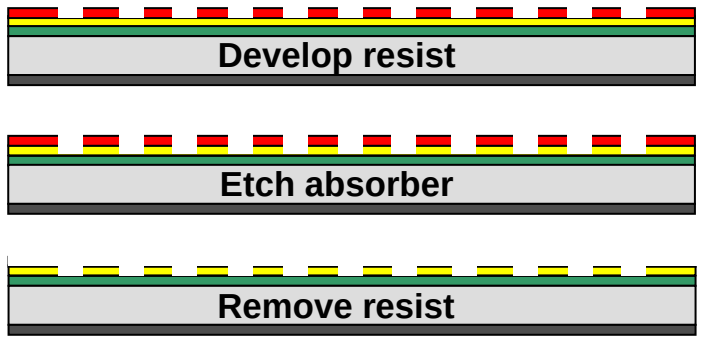


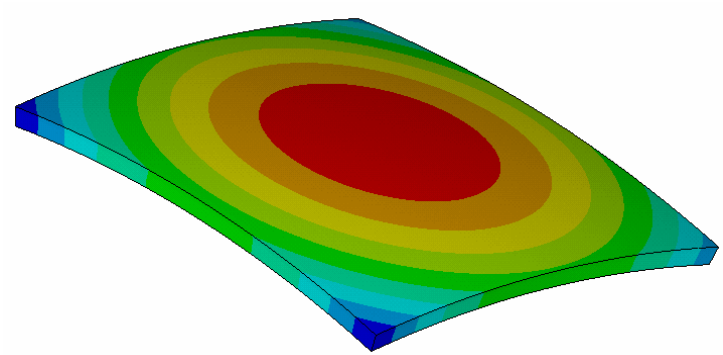
IPD Frontside (max = 122 nm)

Simulating Thin Film Etching & Developing

Load Step 3

- In the current example case, the resist is developed, the absorber stack is etched and the resist is removed.
- The change in the OPD and IPD of the reticle will be relatively small (i.e., ~1.0 nm) for this case and can be neglected.
- Previous analyses show that if the multilayer is etched, it should be included in the simulations.
- When simulating etching, pattern-specific distortions can be predicted using submodeling and equivalent modeling techniques.





Change in OPD and IPD is neglected.

Chucking in the Exposure Tool

Load Step 4

E-Chuck

Electrostatic chuck will be "pin" type to minimize the effects of particles.

- **Backside layer used to facilitate electrostatic chucking.**
- **Specifications of e-chucks in SEMI Standards on EUV Mask Chucking (SEMI P40):**

  -- flatness ≈ 50 nm (*p-v*)

  -- clamping pressure ≥ 15 kPa

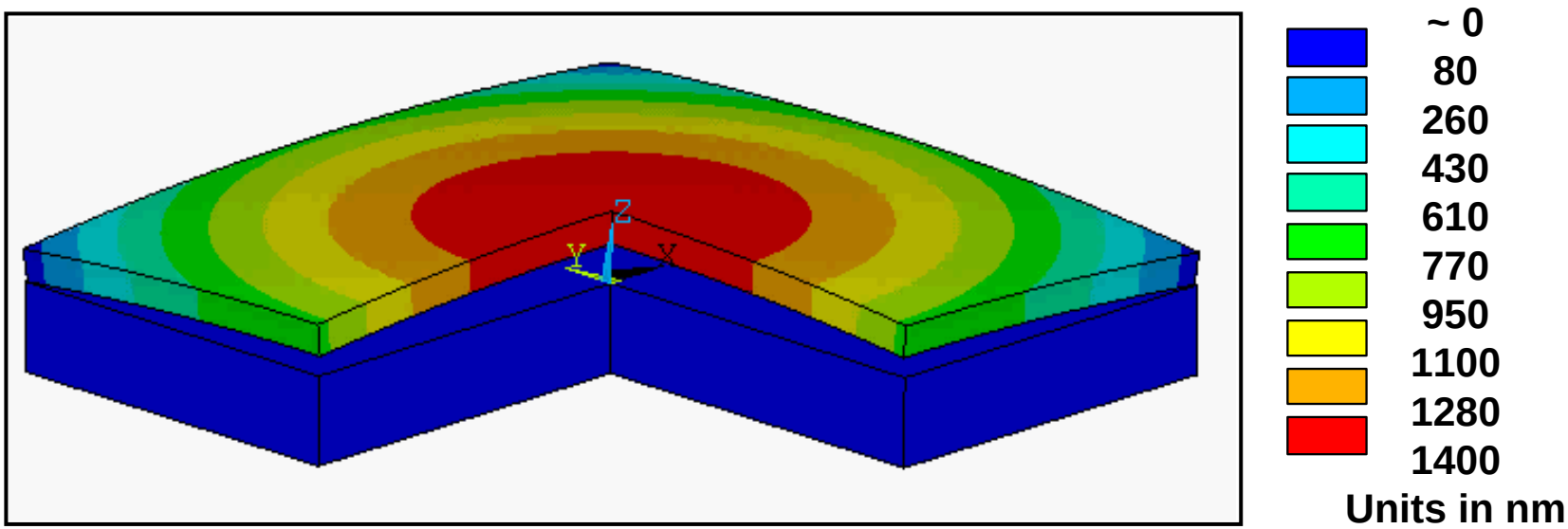
  -- stiffness ≥ 30 kN-m

Simulating Electrostatic Chucking

- **Full 3-D, FE models have been developed to simulate electrostatic chucking of the EUV mask. Model capabilities include:**
  - nonflatness of the top surface of the chuck (interferometric measurement is represented by an 8 $\times$ 8 matrix of Legendre polynomials which is used as input into the FE model)
  - gap-dependent pressures, contact friction, and the actual stiffness of the chuck, as well as any constraints (or boundary conditions)
  - a prediction of the final shape of the reticle FS and BS surfaces, the deformation of the chuck, and the remaining gap
- **For the simulations shown here, the models assumed a relatively stiff chuck (so chuck deformations could be neglected).**
- **Clamping pressures of 15 kPa were employed to ensure negligible gaps between chuck and reticle.**

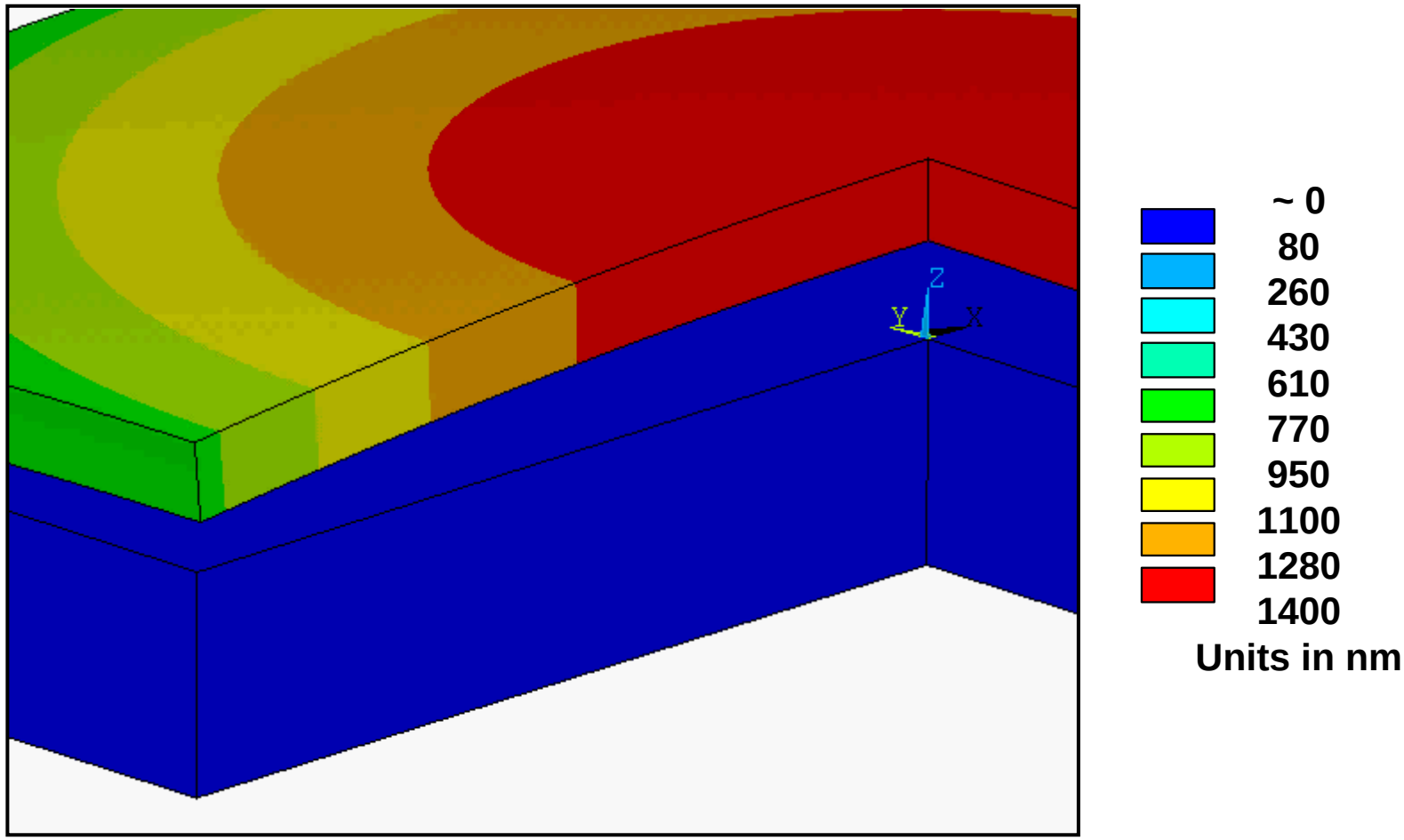
FE Model of Electrostatic Chucking

- The EUV reticle will bow roughly 1400 nm due to the net compressive stress in the thin film stacks. With electrostatic pressures reaching 15 kPa, the reticle is chucked relatively flat as shown in the FE model animation.



Close-up of FE Model

- **The final gap at the interface is only a few nanometers.**

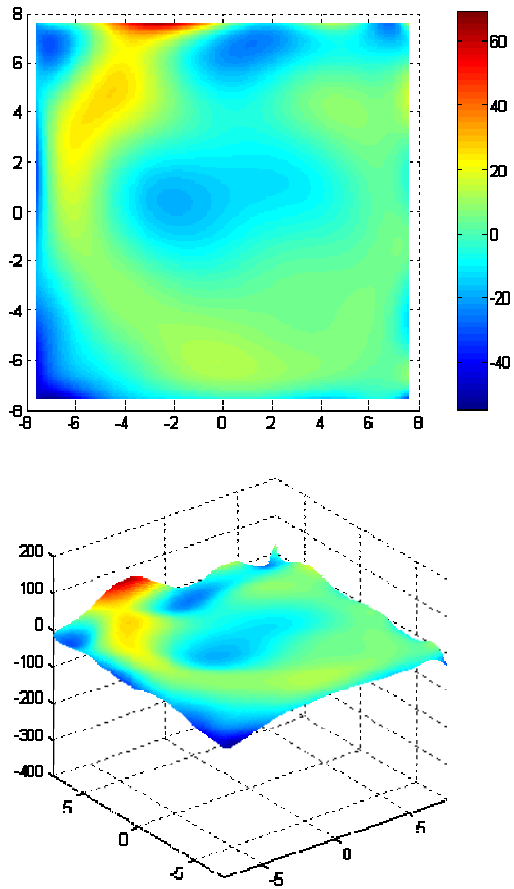


Effect of Chuck Nonflatness

- Simulation neglects any nonflatness of the chuck.
- Represents using a **"universal" mask** – it can be clamped in any exposure tool.

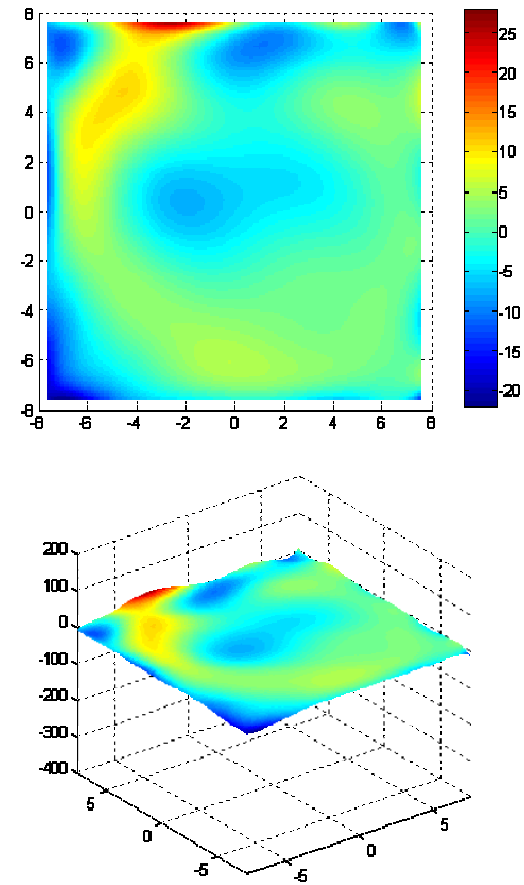
Case A
(perfectly flat)

Case B
(actual chuck surface)



***p-v* = 124 nm**

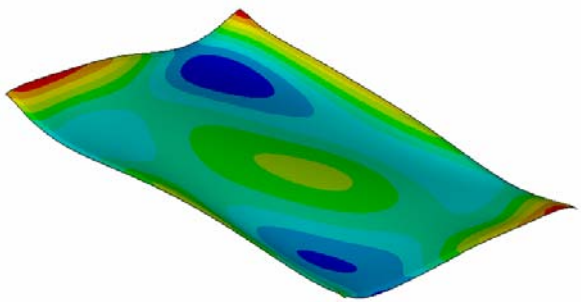
Case C
(actual chuck scaled down)



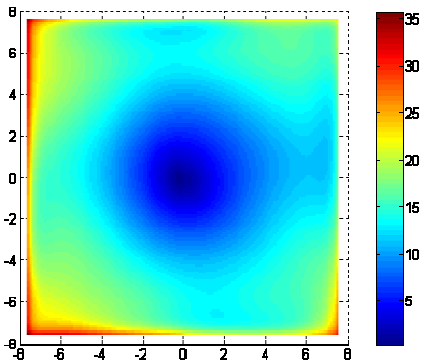
***p-v* = 50 nm**

FE Predictions after E-Chucking

Case A
(perfectly flat chuck)

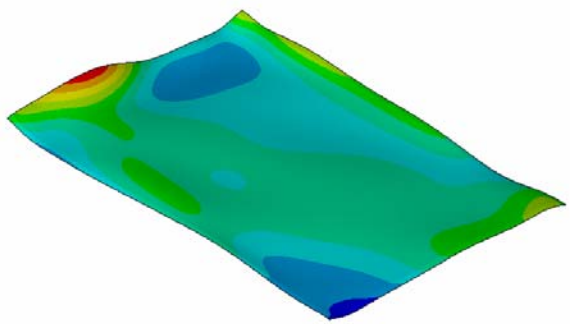


OPD Frontside
(*p-v* = 91 nm)

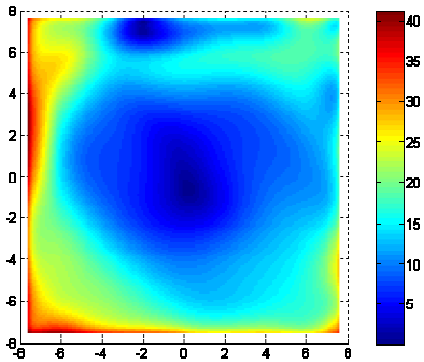


IPD (max = 36 nm)

Case B
(actual chuck surface)

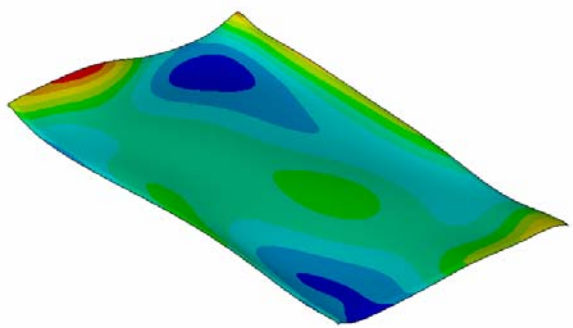


OPD Frontside
(*p-v* = 173 nm)

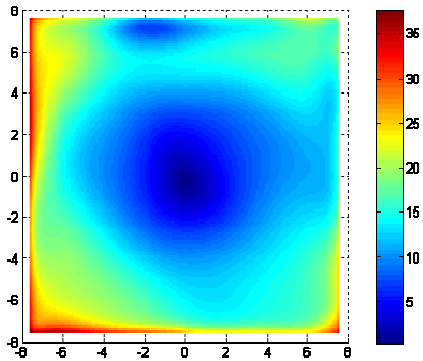


IPD (max = 41 nm)

Case C
(actual chuck scaled down)



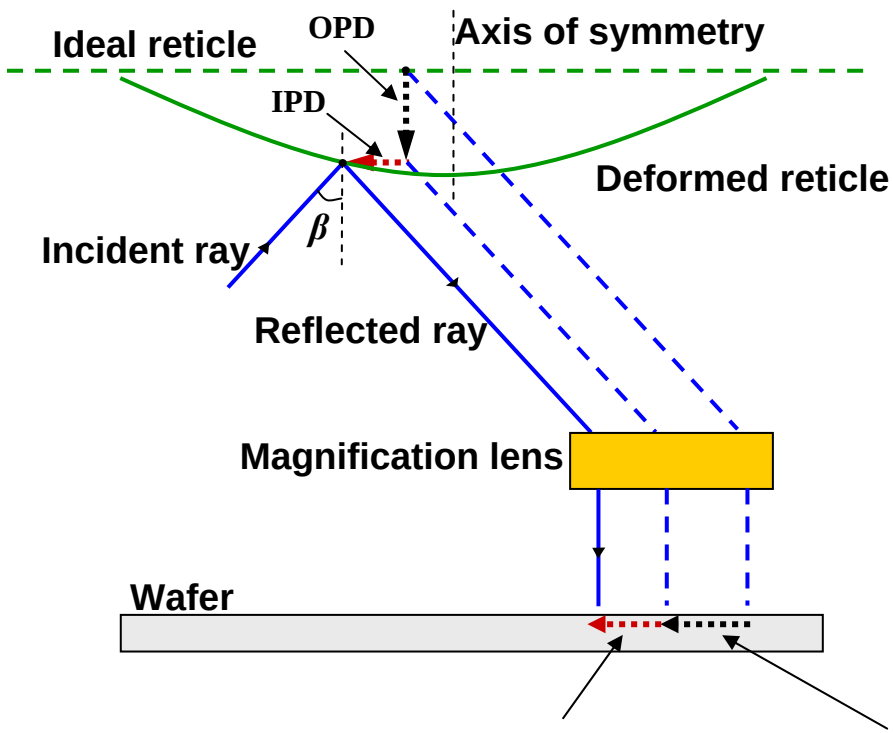
OPD Frontside
(*p-v* = 112 nm)



IPD (max = 38 nm)

Identifying Telecentric Errors

Effects from Both IPD and OPD



- **Image placement errors (IP Error) at the wafer are due to both the induced IPD and OPD on the reticle.**

$$(\text{IP Error})_{\text{IPD}} = \frac{\text{IPD}}{4}$$

$$(\text{IP Error})_{\text{OPD}} = \frac{\text{OPD} \times \tan 6^{\circ}}{4}$$

Total Error at Wafer = $(\text{IP Error})_{\text{IPD}} + (\text{IP Error})_{\text{OPD}}$

This is a vector addition.

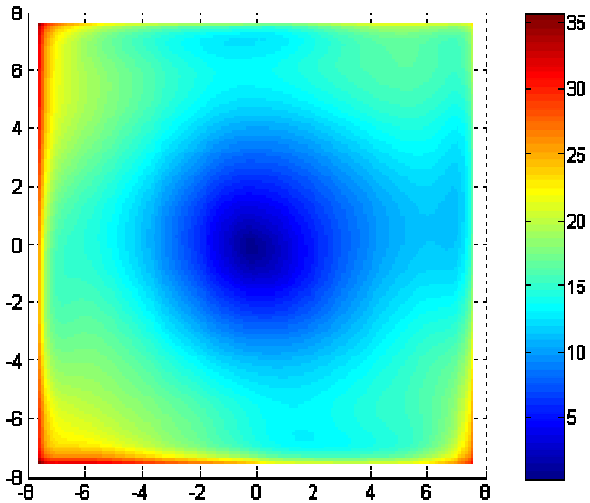
Determining Correction Table B

Effects from Both IPD and OPD

- The IPD map obtained when simulating electrostatic chucking must be modified to account for telecentric effects. The modified map becomes **Correction Table B.**

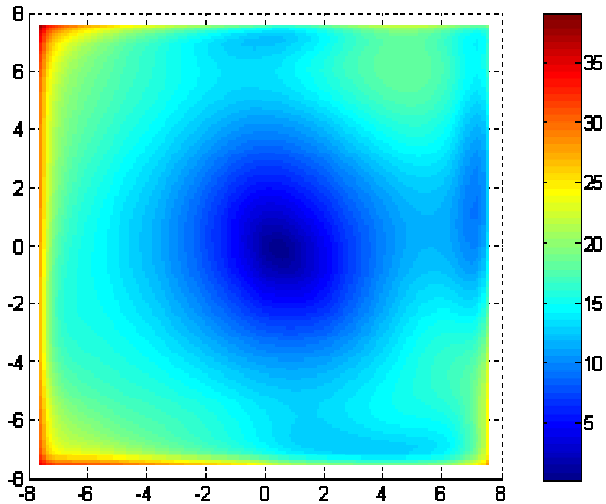
- For Case A, assuming a flat chuck:

Without Telecentric Effects



IPD_{MAX} = 36 nm

With Telecentric Effects



IPD_{MAX} = 39 nm

Summary and Conclusions

- The EUV industry prefers to continue using a 3-point mount in the e-beam tool when patterning the reticle.
- IP errors induced during fabrication and chucking will need to be corrected to meet the stringent error budget on IP accuracy.
- Full, 3-D FE models have been constructed to simulate the response of the reticle during these processes.
- The FE predictions are used to identify Correction Tables that can be used when e-beam writing to correct all repeatable distortions.
  - Table A (shape of patterned surface during e-beam writing)
  - Table B (shape of patterned surface during exposure)

Summary and Conclusions

- An experimental program has been initiated with SEMATECH / Albany.
- Goal is to verify and benchmark the FE modeling techniques associated with the individual load steps.
- The industry is encouraged to participate in this program to ensure all the necessary process steps are included and that the modeling is validated for each.

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