



# ASML

## **EUV Mask flatness compensation in writing and exposure tools relating to total overlay**

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# Presentation contents

- ITRS roadmap and overlay for EUV Lithography
- Overlay errors from reticle blank and clamping
- Representative overlay budget for 32nm node
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# ITRS Roadmap for Overlay and Mask flatness differs ASML analysis and requirements

Table 78c EUVL Mask Requirements—Near-term Years **UPDATED**

| Year of Production                                 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
|----------------------------------------------------|------|------|------|------|------|------|
| DRAM ½ pitch (nm) (contacted)                      | 57   | 50   | 45   | 40   | 36   | 32   |
| Flash ½ pitch (nm) (un-contacted poly)             | 51   | 45   | 40   | 36   | 32   | 28   |
| DRAM/Flash CD control (3 sigma) (nm)               | 5.9  | 5.3  | 4.7  | 4.2  | 3.7  | 3.3  |
| MPU/ASIC Metal 1 (M1) ½ pitch (nm)(contacted)      | 59   | 52   | 45   | 40   | 36   | 32   |
| MPU gate in resist (nm)                            | 38   | 34   | 30   | 27   | 24   | 21   |
| MPU physical gate length (nm)                      | 23   | 20   | 18   | 16   | 14   | 13   |
| Gate CD control (3 sigma) (nm) <a href="#">[A]</a> | 2.3  | 2.1  | 1.9  | 1.7  | 1.5  | 1.3  |
| Overlay                                            | 10   | 9    | 8    | 7    | 6    | 6    |

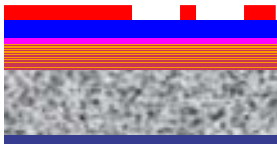
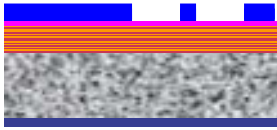
| EUVL-specific Mask Requirements                                           |       |       |       |       |       |       |
|---------------------------------------------------------------------------|-------|-------|-------|-------|-------|-------|
| Substrate defect size (nm) <a href="#">[L]</a>                            | 38    | 36    | 35    | 33    | 31    | 30    |
| Mean peak reflectivity                                                    | 65%   | 66%   | 66%   | 66%   | 67%   | 67%   |
| Peak reflectivity uniformity (% 3 sigma absolute)                         | 0.69% | 0.58% | 0.47% | 0.42% | 0.37% | 0.33% |
| Reflected centroid wavelength uniformity (nm 3 sigma) <a href="#">[M]</a> | 0.08  | 0.07  | 0.06  | 0.05  | 0.05  | 0.05  |
| Absorber sidewall angle tolerance (± degrees) <a href="#">[P]</a>         | 1     | 1     | 0.75  | 0.69  | 0.62  | 0.5   |
| Absorber LER (3 sigma nm) <a href="#">[N]</a>                             | 3.2   | 2.8   | 2.5   | 2.2   | 2     | 1.8   |
| Mask substrate flatness (nm peak-to-valley) <a href="#">[O]</a>           | 75    | 60    | 50    | 41    | 36    | 32    |

[\[O\]](#) Mask Substrate Flatness—Residual flatness error (nm peak-to-valley) over the mask excluding a 5 mm edge region on all sides after removing wedge, which may be compensated by the mask mounting and leveling method in the exposure tool. The flatness error is defined as the deviation of the surface from the plane that minimizes the maximum deviation. This flatness requirement applies to each of the front and backsides individually.

ASML removes bow before calculating flatness



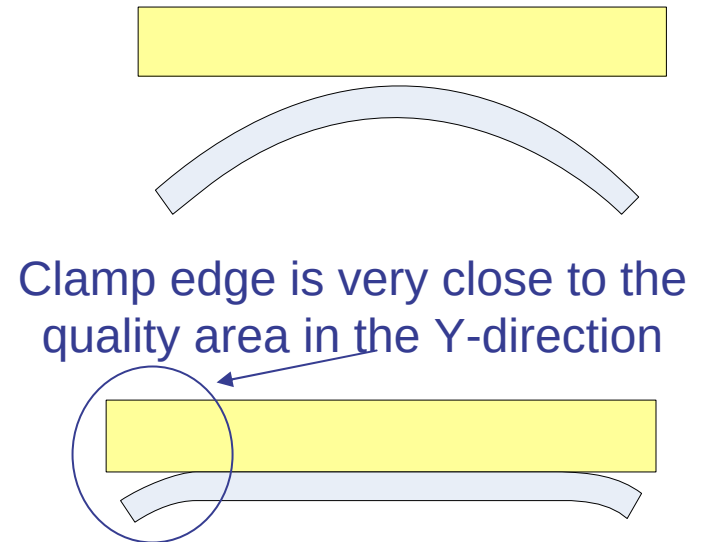
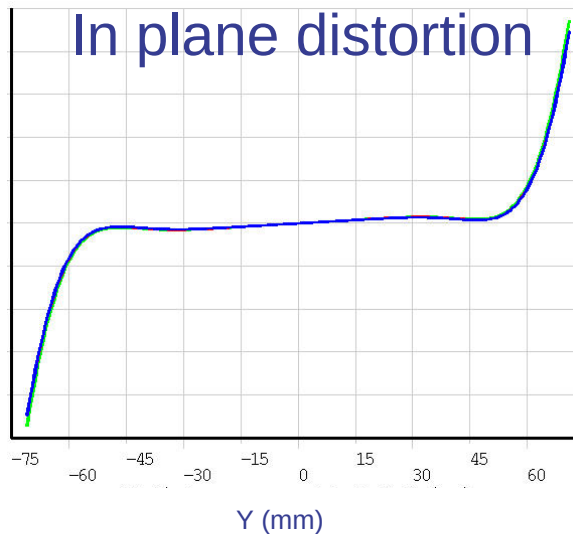
# The reticle bow is resultant of multilayer stress and relaxation due to absorber etch

|                                       | Reticle/blank<br>layer structure                                                   | Reticle/blank<br>freeform                                                            |                                                         |
|---------------------------------------|------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|---------------------------------------------------------|
| Polished flat<br>LTEM substrate       |   |    | Polished flat substrate                                 |
| Multilayer mirror<br>+ absorber stack |   |    | + compressive stress from<br>ML mirror + absorber stack |
| Backside layer                        |   |    | + (partial) stress compensation<br>by backside layer    |
| Resist apply &<br>patterning          |   |    | Reticle is written chucked on<br>a flat clamp           |
| Absorber<br>stack etch                |  |  | Stress relaxation leading to<br>unflatness/bow change   |

Bow = Range[ $a_{20}x^2 + a_{02}y^2$ ] x,y in quality area

Where  $a_{20}$  and  $a_{02}$  are defined  $Z = \sum a_{ij}X^iY^j$

# When clamped, reticle bow adds primarily in plane distortion (IPD)



- Reticle bow does not lead to a fully linear distortion due to edge effects of the clamp
- Current specification, reticle bow less than  $1\mu\text{m}$ , might have to be reduced once the full optimization of the clamp is made

# Exposure system overlay top level specification is taken from the ITRS roadmap

- Overlay specification from ITRS 2006

→ 32nm node : overlay on product 5.7nm

| Year of Production                     | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
|----------------------------------------|------|------|------|------|------|------|------|------|------|
| DRAM ½ pitch (nm) (contacted)          | 80   | 70   | 65   | 57   | 50   | 45   | 40   | 36   | 32   |
| DRAM and Flash                         |      |      |      |      |      |      |      |      |      |
| DRAM ½ pitch (nm)                      | 80   | 70   | 65   | 57   | 50   | 45   | 40   | 35   | 32   |
| Flash ½ pitch (nm) (un-contacted poly) | 76   | 64   | 57   | 51   | 45   | 40   | 36   | 32   | 28   |
| Contact in resist (nm)                 | 94   | 79   | 70   | 63   | 56   | 50   | 44   | 39   | 35   |
| Contact after etch (nm)                | 85   | 72   | 64   | 57   | 51   | 45   | 40   | 36   | 32   |
| Overlay [Å] (3 sigma) (nm)             | ◆15  | ◆13  | ◆11  | 10   | 9    | 8    | 7.1  | 6.4  | 5.7  |

- Critical level wafer exposures are done on dedicated tools, thus the 32nm overlay budget assumes that there is a single exposure tool and two reticles written on the same mask writer

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# EUVL has unique overlay budget contributions

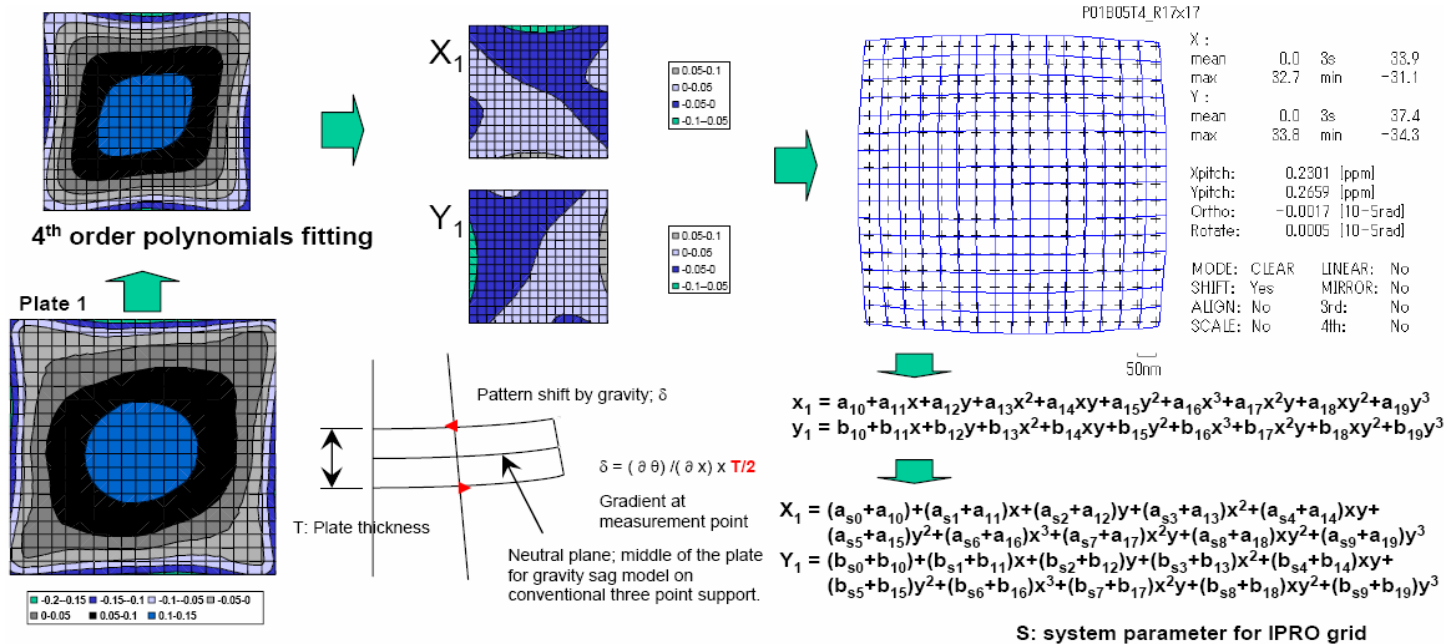
- EUV systems are not telecentric at the reticle, which means that the flatness of the clamped reticle is a component of overlay
  - Shifts in z (focus) at the reticle introduce telecentricity (lateral x,y shifts) errors at the wafer
- From an overlay budget and manufacturing specification perspective, the reticle and the reticle clamping are treated separately
- For the reticle, SEMI Standard P37 – mask flatness – assures that the reticle errors are within acceptable limits
- For the clamp or mask mounting, SEMI Standard P40 – the three rules – assures that mounting errors are within acceptable limits

# SEMI P40 guides reticle clamping for all tools, but it should be revised to allow for flexibility in meeting requirements

- Although not explicitly stated, P40 assumes that all systems are using electrostatic clamps
- Of the “three rules” (chuck flatness, pressure, stiffness), not all are necessary, nor are they sufficient to assure that the mounted reticle distortion requirements are met
- For a kinematic clamp to meet the requirements, an agreed to metrology standard would need to be added to P-40 to show compliance with the requirements
  - The standard should be revised to show that empirically matching the requirements is allowed
  - A reference reticle blank and an interferometric test could be a possibility

# IPD error budget allocation will depend on the type of reticle clamping

- NuFlare has reported<sup>1</sup> an alternative to electrostatic clamping using kinematic clamping and software compensation plus a specially designed stiff chuck in the pattern placement metrology tool



1. Correction technique of EBM-6000 prepared for EUV mask writing, Yoshitake et. al, Photomask Technology 2007 SPIE Vol 6730-105

# Proposed changes to P-40 that would allow more design flexibility in mounting EUV reticles

| Parameter                                                 | Current P-40  | Proposal     |
|-----------------------------------------------------------|---------------|--------------|
| Mean clamping pressure (kPa)                              | $15 \pm 1.5$  | Delete       |
| Max clamping pressure in contact area (kPa)               | Not specified | $\leq 3,000$ |
| P-V flatness-quality area (nm)                            | 48            | $\leq 32$    |
| P-V flatness-sub aperture (nm)<br>75mm, etc               | 24, etc       | Delete       |
| Local slope error ( $\mu\text{rad}$ )<br>(over 20mmx20mm) | Not Specified | $\leq 1$     |
| Stiffness (Nm)                                            | $> 30,000$    | Review       |
| Pin Pitch (mm)                                            | $< 10$        | Delete       |

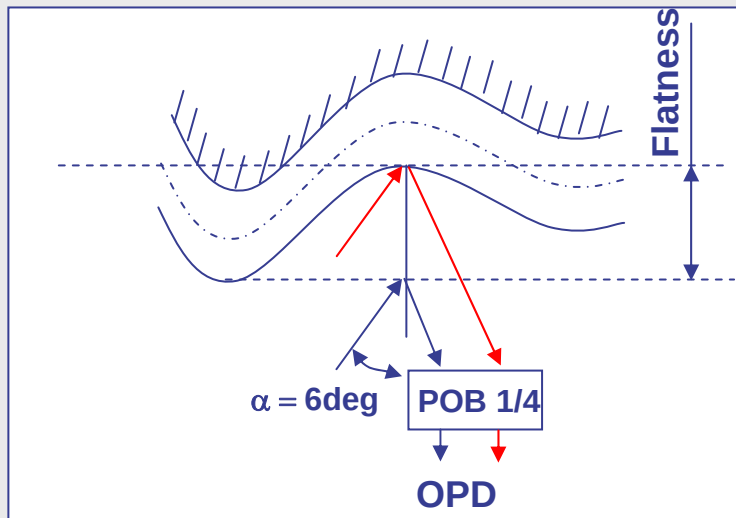
Note that the suggested values are consistent with a 32nm overlay budget and that various quality levels would have to be added for subsequent nodes

# Reticle blank and clamp non flatness leads to out of plane distortion (OPD)

## Out of Plane Distortion (OPD)

$$\text{OPD} = 1/4 \cdot \text{Flatness} \cdot \tan(\alpha)$$

$$\text{OPD} \approx \text{Flatness} / 40$$



## Example :

Flatness  $\rightarrow$  32nm

**Resulting OPD  $\approx$  0.8nm**

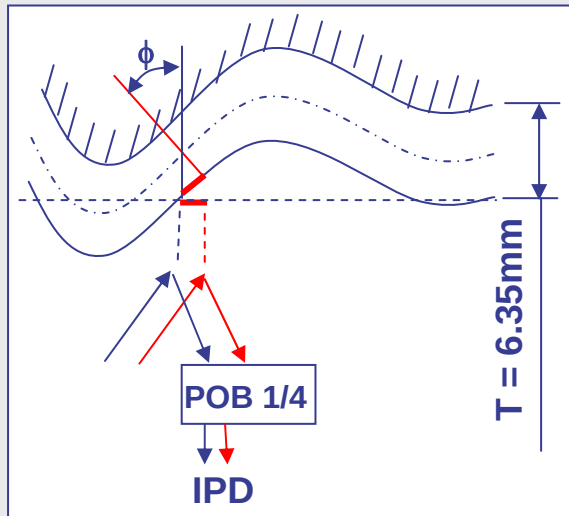
Error budget allocation is less since exposure tool reticle alignment determines a best focus that offsets some of the error

# Reticle blank and clamp non flatness leads to in plane distortion (IPD)

## In Plane Distortion (IPD)

$$\text{IPD} = 1/8 \cdot T \cdot \phi$$

$$\text{IPD} \approx 0.8 \cdot \phi$$



## Example :

Spatial period  $\sim 32\text{mm}$   
and

Flatness of  $32\text{nm}$

Local Slope  $\rightarrow 1\mu\text{rad}$

**Resulting IPD  $\approx 0.8\text{nm}$**

Error budget allocation is more since exposure tool and pattern generation tool clamping will not exactly match even if meeting the P40 rules

# Reticle clamps must meet two flatness specifications to adhere to overlay budget allocations

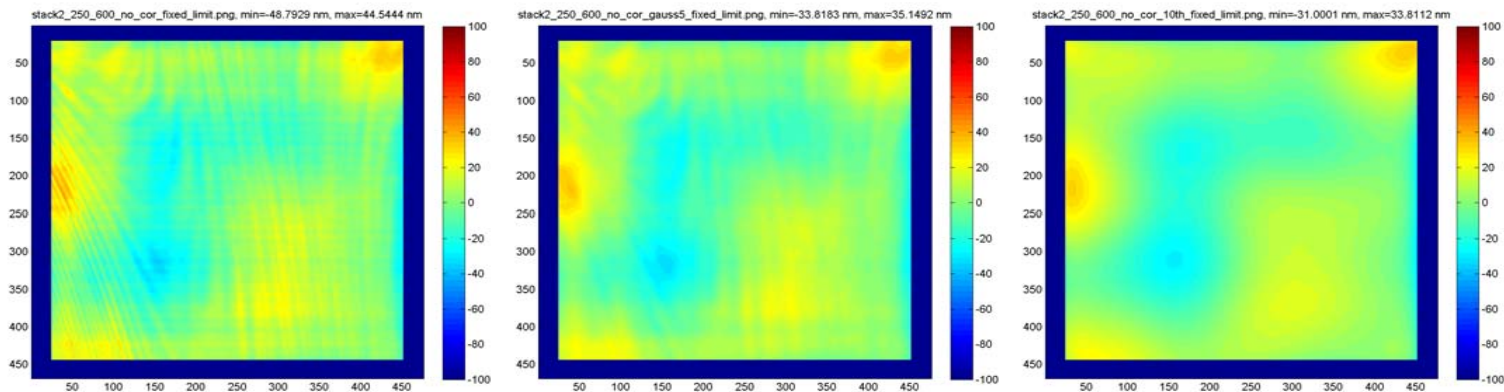


Clamp surface



Reticle blank

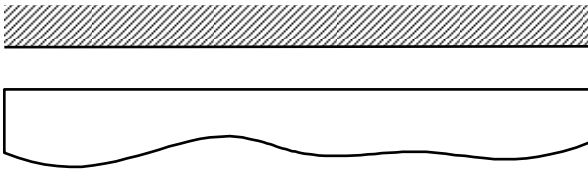
- ASML requirements for electrostatic clamps have local slope and global p-v flatness specifications
- E-clamps are qualified interferometrically as used in the exposure tool - mounted and holding a mask blank – in a “stack test”



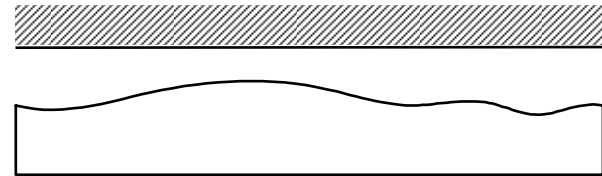
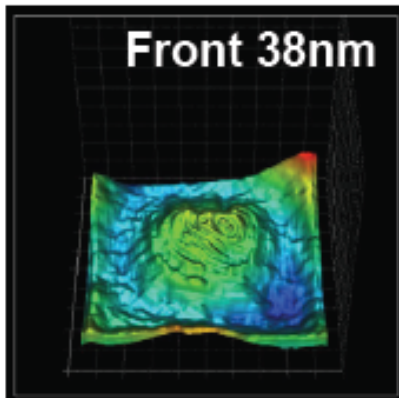
Results from a recent Alpha stack test show P-V 70nm flatness for the stack which is ~55nm P-V for the clamp



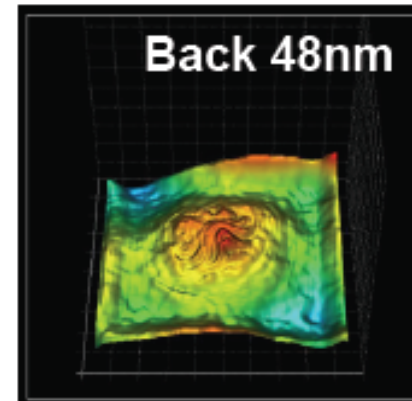
# Front and backside reticle flatness adds to overlay error but blanks are almost at the required flatness



Front side reticle non flatness adds OPD



Back side reticle non flatness adds OPD

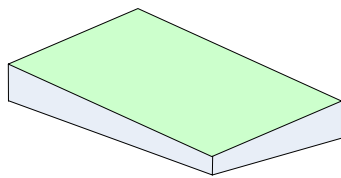


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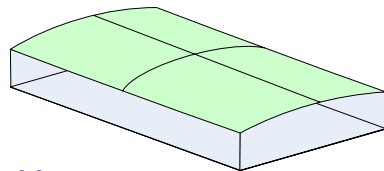
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# ASML's advanced scanners can compensate for some of the reticle induced OPD and IPD errors

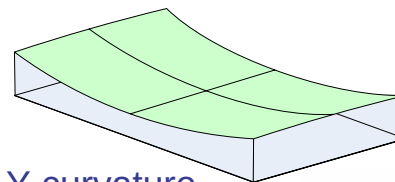
- Data on the reticle is obtained in the scanner and used for compensation
  - Reticle alignment is done every time a reticle is loaded
  - Reticle shape correction is measured once and parameters applied each time a reticle is used
- OPD is compensated via reticle leveling
- IPD is compensated via magnification and skew corrections
- Note that only low order distortions can be compensated by the exposure tool



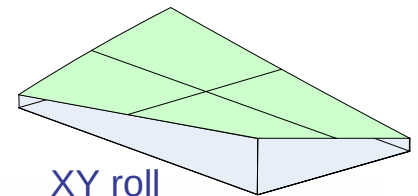
Wedge



X curvature



Y curvature



XY roll

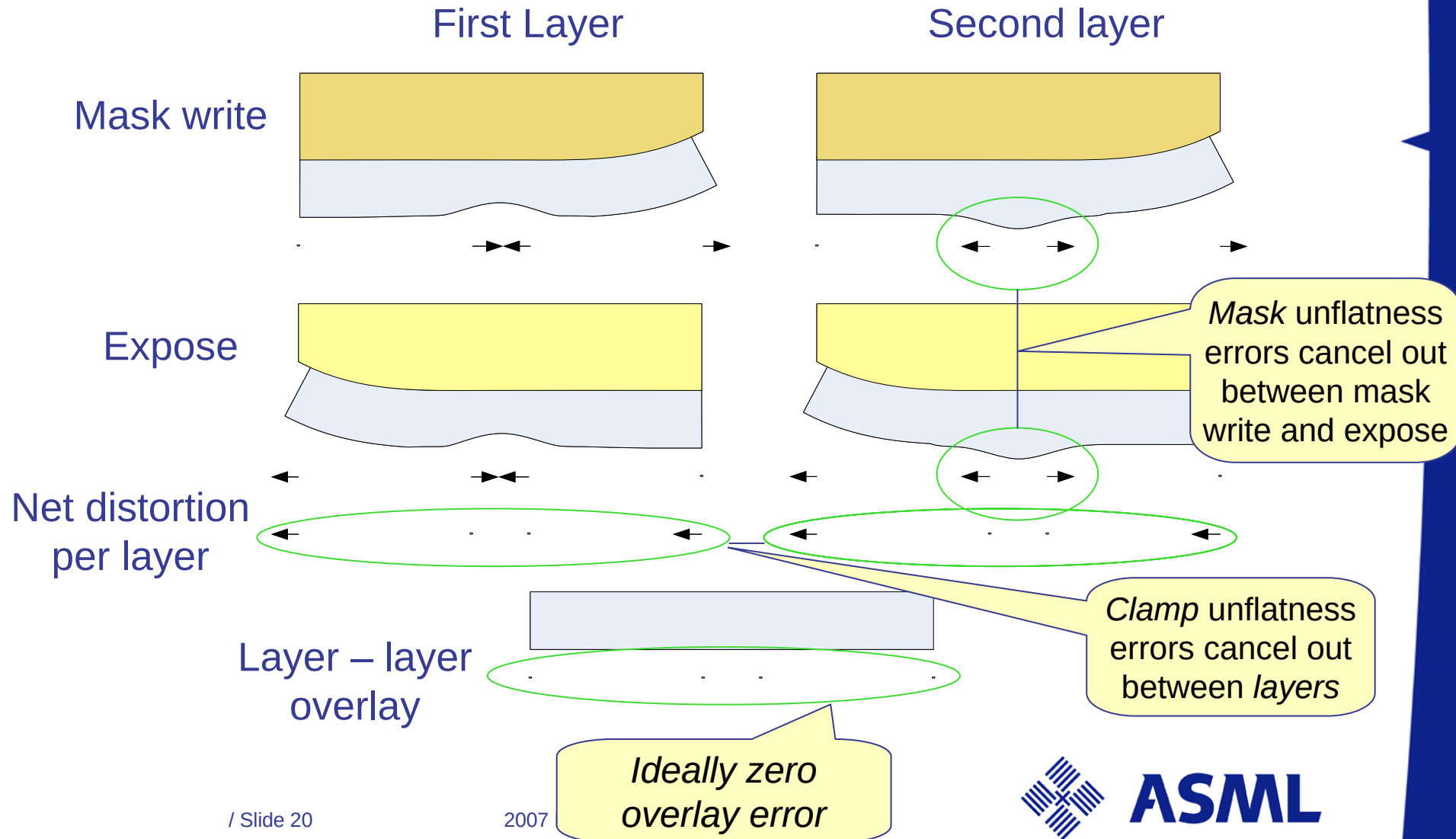


# Reticle blank, clamp and scanner requirements for 32nm node overlay have been identified

- Reticle blank requirements have been determined consistent with ITRS guidelines, SEMI Standards, and exposure tool compensation techniques
  - Front and back side global flatness  $\leq 32\text{nm p-v}$
  - Bow  $< 1.0$  micron (to be confirmed)
  - Local angle  $\leq 1 \mu\text{rad}$  over any 20mm x 20mm area
- Clamping requirements based on a proposed revision to SEMI P-40 that includes a global flatness and local slope error
  - Additionally, there is some low order scanner compensation of the clamped reticle
- Errors for thermal (reticle and wafer and optics) distortion, optics distortion, reticle alignment, and stage positioning have been allocated in the scanner budget



# Dedicated exposure tool and mask writer eliminates clamp IPD

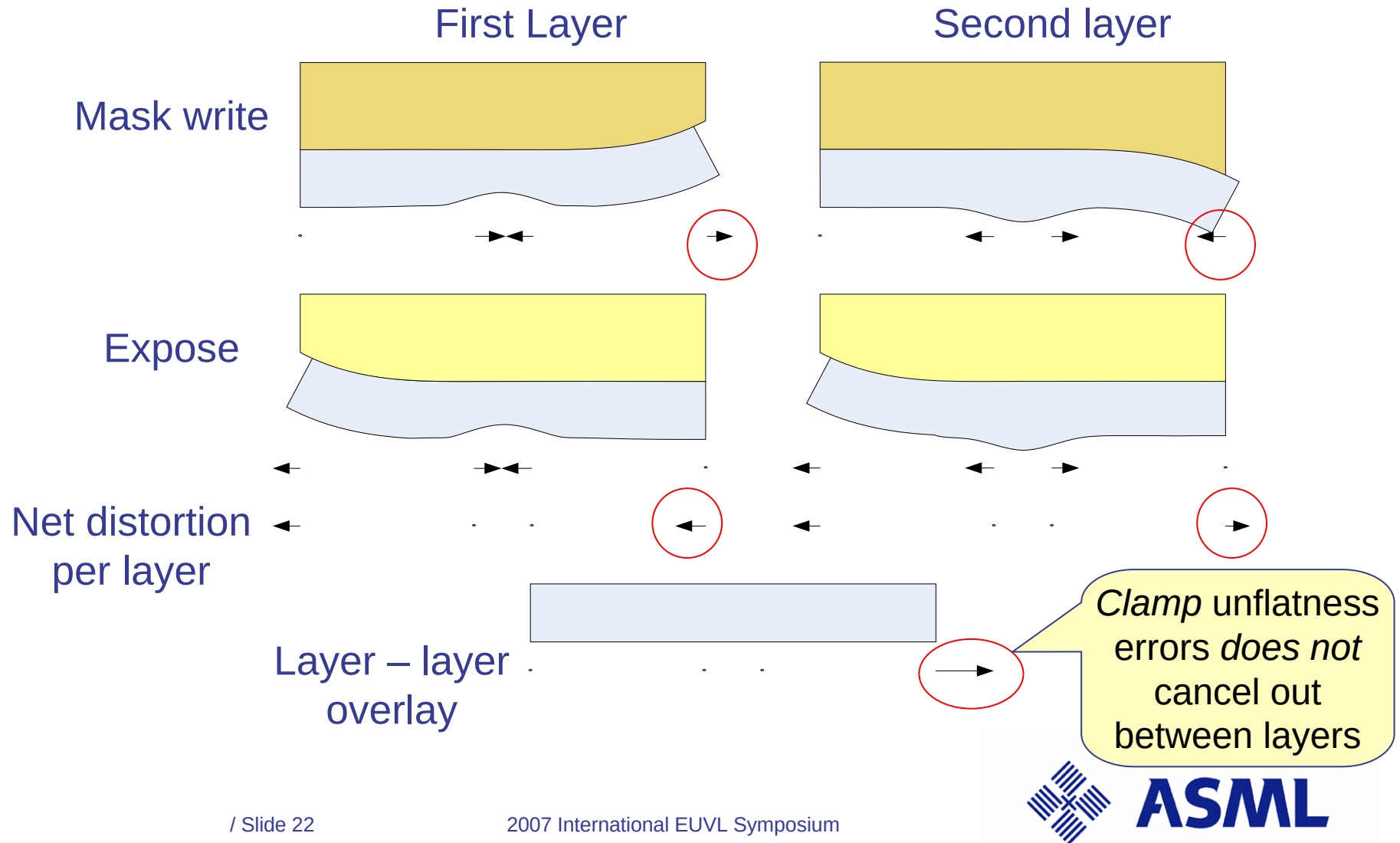


# ITRS roadmap and SEMI Standards values for reticles and clamps are necessary to meet the 5.7nm 32nm node overlay target

| Representative Budget (nm)             | ITRS + P-40 |
|----------------------------------------|-------------|
| Tool                                   | 3.2         |
| Process                                | 1.5         |
|                                        |             |
| Exposure tool reticle clamp unflatness | 0.0         |
| IPD                                    | 0.0         |
| OPD                                    | 0.0         |
|                                        |             |
| Reticle clamped in exposure tool       | 1.4         |
| Reticle writing                        | 0.9         |
| Reticle flatness                       | 0.9         |
| OPD                                    | 0.8         |
| IPD                                    | 0.2         |
| Bow                                    | 0.4         |
| CTE non-uniformity                     | 0.6         |
|                                        |             |
| Total per layer                        | 3.8         |
| Layer to layer                         | 5.4         |

A relaxation to 50nm P-V reticle flatness and a corresponding ease in the writing requirement almost meets the 32nm overlay requirements

# Different writing tools and exposure tools add to the layer-to-layer overlay error



# ITRS roadmap and SEMI Standards values for reticles and clamps are necessary to meet the 5.7nm 32nm node overlay target

| Representative Budget (nm)             | ITRS + P-40 | ITRS + P-40 & No Dedication |
|----------------------------------------|-------------|-----------------------------|
| Tool                                   | 3.2         | 4.5                         |
| Process                                | 1.5         | 1.5                         |
|                                        |             |                             |
| Exposure tool reticle clamp unflatness | 0.0         | 1.0                         |
| IPD                                    | 0.0         | 0.8                         |
| OPD                                    | 0.0         | 0.6                         |
|                                        |             |                             |
| Reticle clamped in exposure tool       | 1.4         | 1.6                         |
| Reticle writing                        | 0.9         | 0.9                         |
| Reticle flatness                       | 0.9         | 1.2                         |
| OPD                                    | 0.8         | 0.8                         |
| IPD                                    | 0.2         | 0.8                         |
| Bow                                    | 0.4         | 0.4                         |
| CTE non-uniformity                     | 0.6         | 0.6                         |
|                                        |             |                             |
| Total per layer                        | 3.8         | 5.1                         |
| Layer to layer                         | 5.4         | 7.2                         |

Without tool dedication, the target overlay cannot be met



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# Summary

- For EUV lithography, the mask blank adds some unique overlay error contributions due to the projection optics being non telecentric on the object side
- The ITRS roadmap gives appropriate guidance on required reticle flatness but the treatment of bow needs to be addressed too
- Recommendations for changes to P-40 are made so that the required mounted reticle distortion is assured
- Error budget allocations have been made for system contributors and mask blank errors, assuming single exposure tool using two different reticles written on the same pattern generator
- Today's manufacturing capability for mask blanks and reticle clamps is close to meeting a 5.7nm on product overlay, though clearly more work will be needed to meet the expected industry demands for overlay