Determining Critical Defect Size for EUV Mask Substrates and Blanks

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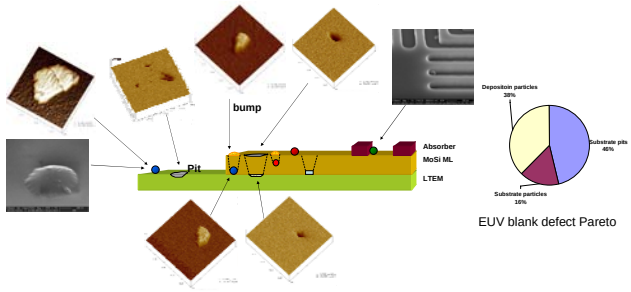
EUV Mask Defects

Substrate Defects + Blank Defects + Pattern Defects

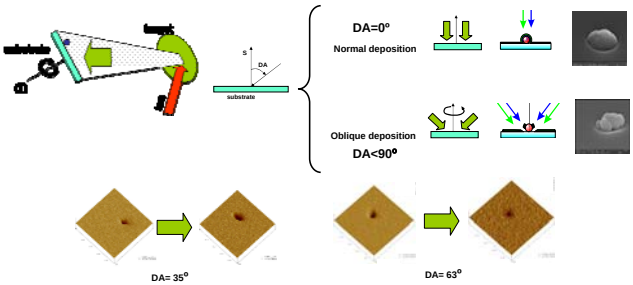


EUV blank defect Pareto

Many factors contribute to determining critical EUV defect size. Main contributors are;

- **Optical size** (How defect inspection tools size the defects?)
- **Defect shape**
- **AFM size** (How AFM can be used to measure defect size?)
- **Electron/ion size** (Size measurement with SEM)
- **Defect size change by Multilayer (ML) deposition**
- **Defect size change due to number of bilayers**
- **Defect deformation by ML stress**
- **Defect printability (on wafer)**

Size Change by Multilayer Deposition



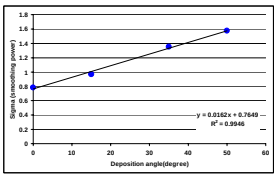
Smoothing power

Smoothing power defined as (Aspect ratio on substrate)/ (Aspect ratio on ML)

$$\sigma = \frac{(AR)_S}{(AR)_{ML}}, \quad AR = \frac{h}{(FWHM)}$$

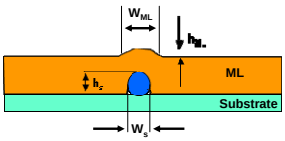
σ=1 no smoothing
σ >1 high smoothing

Smoothing power for pits linearly increases with increase of deposition angle



Simple model

$h_{ML}=\alpha_d\, h_S$
$W_{ML}=\beta_d\, W_S$

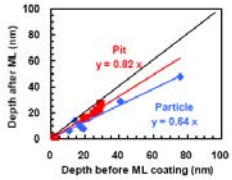


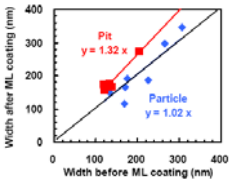
α_d and β_d are a function of deposition parameters; deposition angles, number of bilayers ,etc

For a typical deposition parameters;

α_d =(0.64 for particles),(0.82 for pits)
β_d =(1.02 for particles),(1.32 for pits)

W is width and defined as FWHM



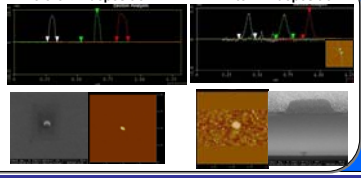


Defect Deformation

Under compressive force of MoSi multilayers some defects will deform and their dimensions changes

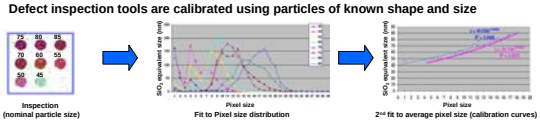
20 nm PSL Height reduced to~ 5 nm after ML deposition

Before ML deposition **After ML deposition**

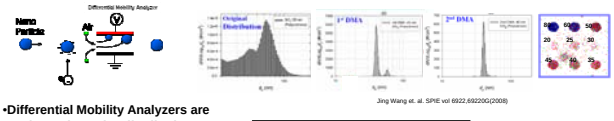


Optical Sizing

Defect inspection tools are calibrated using particles of known shape and size

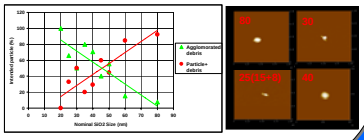


Defect sizing depends on width of the size distribution of the deposited particles



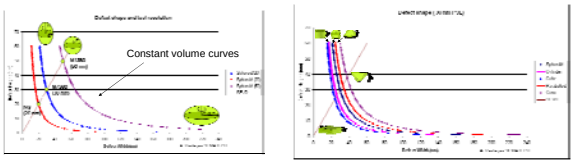
Jing Wang et. al. SPIE vol 6922,69220G(2008)

- **Differential Mobility Analyzers are used to reduce size distribution**
- **In this technique sizing is done based on charge accumulation on particles**
- **Agglomerated small particles can be sized as larger particles**
- **Not reliable below 40 nm**



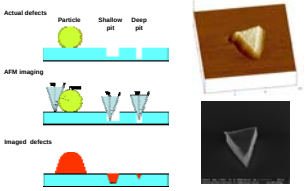
Defect Shape

Signal of optical inspection tool is proportional to defect volume
Sensitivity of an optical inspection tool is different for defects with different shape

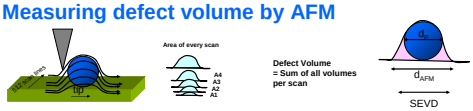


AFM Sizing

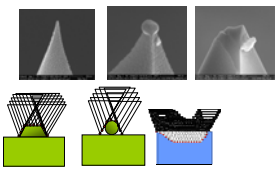
- **Signal of optical inspection tools is proportional to defect volume**
- **Defect volume should be measured precisely.**
- **AFM is an non-intrusive technique that is able to measure volume of sub 50 nm defects**
- **Special care should be taken to prevent AFM artifacts when defect size is comparable to tip size**



Measuring defect volume by AFM



- **Tip shape and size information should be obtained**
- **Side wall slope of defect determine the amount of error in width measurements**
- **There is almost no error in measurement of particle height and there is large error in measurement of particle width.**
- **Pit width can be measured accurately but pit depth can have large error**



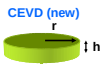
Defect Size Definitions

- **Defect Height and width are crucial for defining EUV defect properties.**
- **One dimensional SEVD can not describe EUV defects sufficiently**
- **We propose use of Cylindrical Equivalent Volume Diameter (CEVD) instead of Sphere Equivalent Volume Diameter.**
- **Defect volume and height/depth are measured by AFM. CEVD is calculated from measured volume**

SEVD (old)

$$V = \frac{4\pi}{3} r^3$$
$$SEVD = 2r$$

CEVD (new)



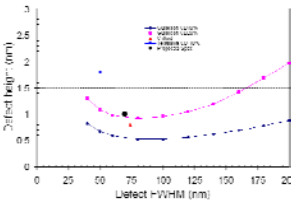
$$V = h\pi\, r^2$$
$$CEVD = 2r$$

EUV Critical Defect Size for 22 nm HP node

- **Defect dimensions on substrate changes by multilayer deposition process.**
- **Defect printability simulation studies are done by using defect dimension on top of multilayer or buried Gaussian phase defects**
- **We propose following defect sizes as the EUV critical defect size for 22 nm HP node**

On top of ML;

CEVD: (h=1 nm, 2r = 70 nm)

On top of substrate:

CEVD(h=1 nm, 2r =50 nm)