SEMATECH Approach to Smoothing Pit Defects on EUV Mask Blank Substrates

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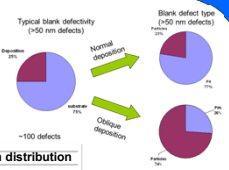
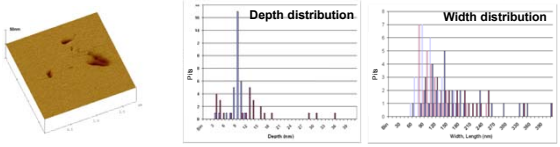
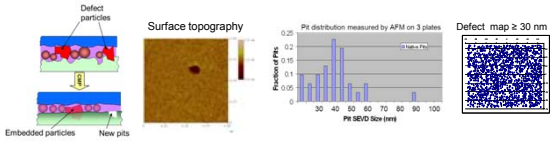
Pit Defects

- Pit defects are major contributor to the substrate defects and their removal will greatly reduce mask blank defectivity

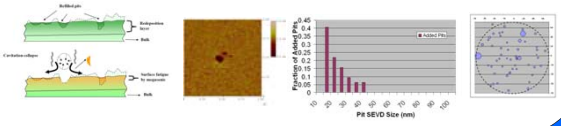




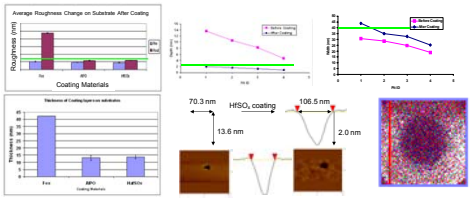
- Major mechanisms of pit creations are;
  - **CMP induced pits** and embedded particles
    - Slurry left over, embedded slurry, embedded defects

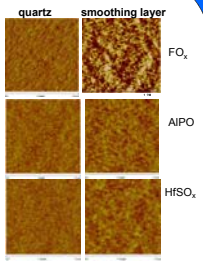


  - **Cleaning induced pits** (e.g. megasonic cavitation)



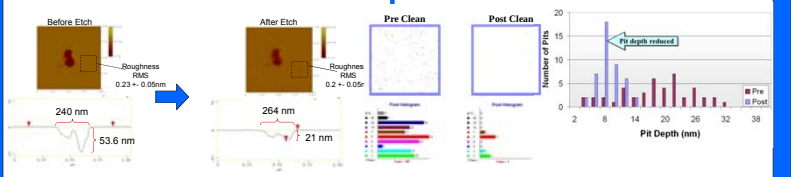
Smoothing by spin-on materials





AlPO and $HfSO_x$ from Inpria meet spec for substrate roughness but defectivity is still a challenge

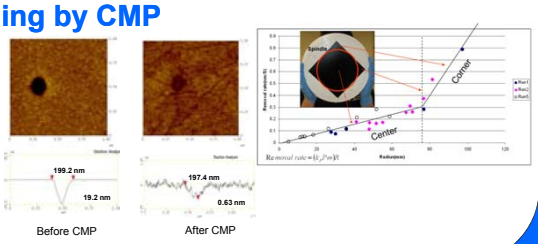
SEMATECH Smooth/Clean process



Smooth/ clean process is the cleanest smoothing process and is effective for high aspect ratio pits

Surface retouching by CMP

- Main idea is to remove 9 nm top surface of the glass by soft CMP
- Pit smoothing was demonstrated but process led to nano scratches
- Further progress requires post CMP clean development



Before CMP After CMP

Pit Smoothing Strategy

Smoothing technique should
- Reduced total defects (Pit + Particles)
- Meet roughness and flatness requirements

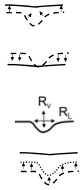
Physics of Smoothing

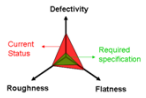
Filling pits
- Sputtering a layer
- Spin coating a layer
- Filling individual pits

Removing surrounding area
- Anisotropic etch (CMP, smooth clean)

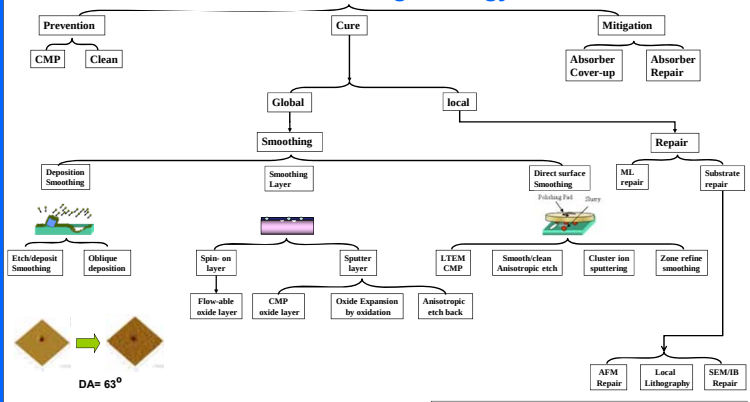
In both cases there should be a difference between vertical and lateral deposition/removal rate

Transferring the interface
- Move pits to the surface of other layer which is easier to work with

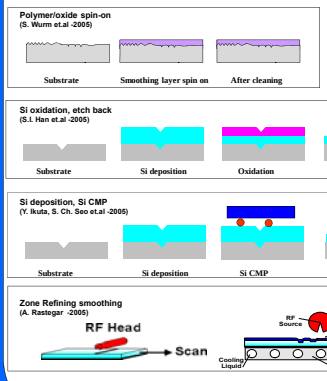


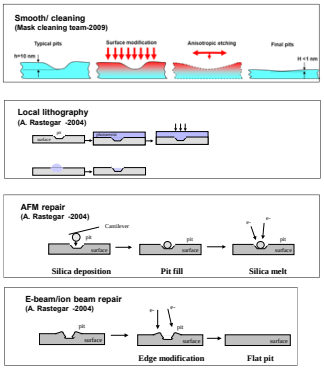


Pit Smoothing Strategy



DA= 63°





Comparison of Smoothing Techniques

Smoothing power

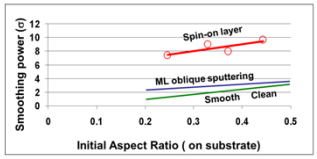
Smoothing power defined as (Aspect ratio on substrate)/ (Aspect ratio on multilayer)

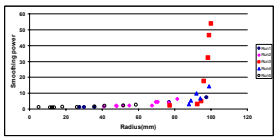
$$\sigma = \frac{(AR)_s}{(AR)_{ml}}, \quad AR = \frac{Height}{Width}$$

$\sigma = 1$ → **No smoothing**

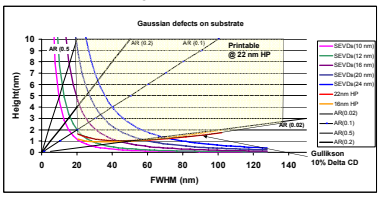
$\sigma > 1$ → **Partial smoothing**

$\sigma \to \infty$ → **Complete smoothing**

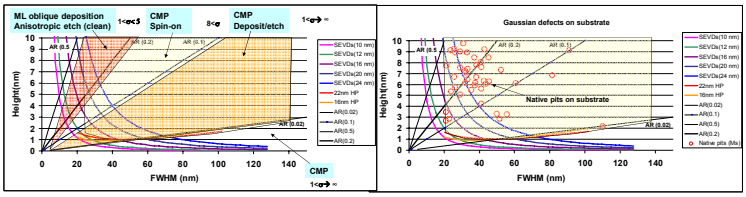




CMP has the highest smoothing power, spin –on, ML oblique deposition and Smooth cleaning have lower smoothing power and work best for pits with high aspect ratios



- Height/width defect diagrams are important for demonstrating printable defects
- Constant volume curves are used for determining defect detection and printability
- Height/width diagrams can be divided into regions with different defect aspect ratios
- Lower smoothing power techniques can be used for higher aspect ratio regions and high smoothing power technique are used for low aspect ratio regions



Conclusions

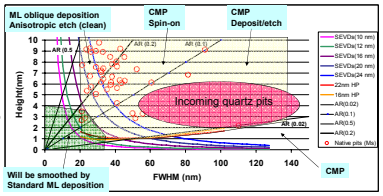
ML oblique deposition (1<σ<5)
Effective for high aspect ratio pits but will not smooth shallow pits

Smooth clean process (1<σ<3)
Effective for high aspect ratio pits and can replace current cleaning processes. Surface roughness control is necessary

Spin-on smoothing layer (8<σ)
Can smooth high aspect ratio pits. Not very effective in small aspect ratio pits. Layer contamination is a potential issue and needs further work

Pit repair
Substrate pit repair is challenging. Finding defect with repair tools requires fiducial. Clean repair process is challenging. Probably more contamination introduced by repair process. Slow process

CMP (1<σ→∞)
This is unique solution with highest chance of success
Further optimization of glass CMP process for reduction of defectivity is necessary



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