Impact of Multi-Layer Deposition Method on Hole/Scratch Type Defects on Photomask Blanks

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Abstract

Mask defects continue to be one of the critical issues for EUV technology development. While the more visible problem of particle defects has received the majority of scrutiny so far, the impact of holes and scratches on mutli-layer EUV mask substrates has been largely ignored. To study the impact of hole or scratch type defects, 3 mask substrates were prepared using an AFM mask repair tool to make 20, 40, 60, 80, and 100nm deep scratch defects. These masks then had 40 EUV Mo/Si multi-layer pairs deposited using Magnetron, IBD (Ion Beam Deposition), and IBD with smoothing. After the deposition TEM samples were taken of the individual defects and the impact of the deposition method on the multi-layers was examined.

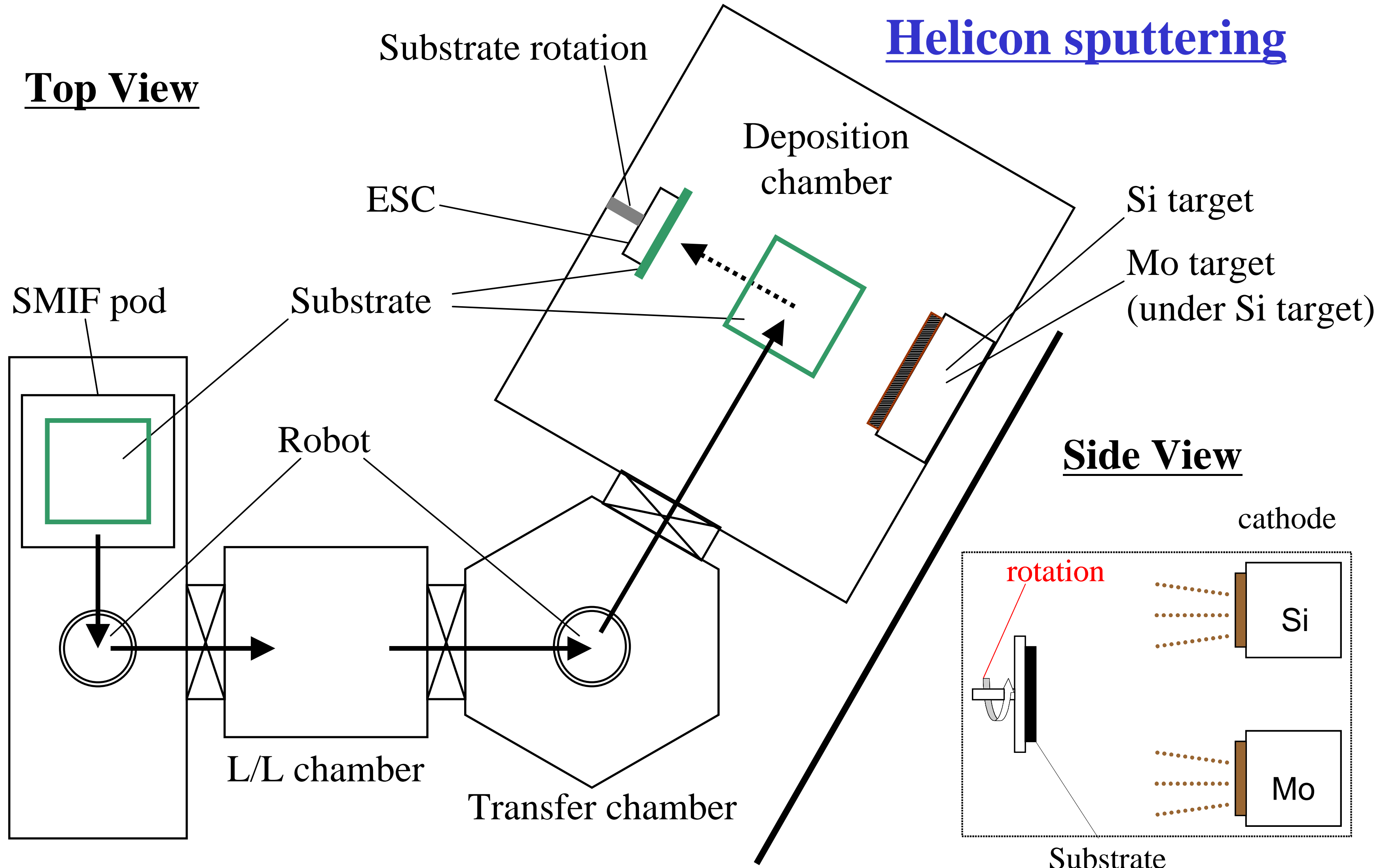
Experimental Procedure

- Pattern Mask Substrates
  - Makes it possible to find defects even when coated with multi-layers.
  - Provides an easy frame of reference for both AFM work and TEM Sampling.
- Make AFM scratches
  - AFM scratches were made using a RAVE repair tool at Dai Nippon Printing.
  - 5 depths were made on each mask starting at ~20nm and going to ~100nm. Side wall profiles and defect width were a function of the AFM tip and not as controllable as depth.
- Deposition of Multi-Layers
  - Magnetron and IBD Multi-Layers were deposited at ASET.
  - IBD with Smoothing was deposited courtesy of Veeco Instruments.
- Deposition of Protective Layer (for TEM Sampling)
  - 200nm of Si was deposited to protect the Multi-Layer stack from FIB damage during the sampling process.
- TEM Sampling and Imaging

Issues

- Difficulty finding the edges of the defect markers on patterned masks using SEM/FIB imaging. Solved by using a dry etch process for better side wall slope.
- Width and profile of AFM scratches were dependant on the AFM tip used while manufacturing the defect.
- Magnetron mask originally did not have protective layer and multi-layers were damaged by the FIB during TEM sampling. All sites were imaged before the error was discovered so all sites have some damage.
- Protective layer was occasionally unsuccessful in protecting multi-layers from damage during TEM sampling.
- Because a slight rotation of the defect during TEM sampling will overlap the mutli-layers (since they are no longer at 90^0 to the TEM) the multi-layers on the edges of the defects are very difficult to image clearly. This is why they appear black.

ASET Mo/Si Magnetron Sputtering System



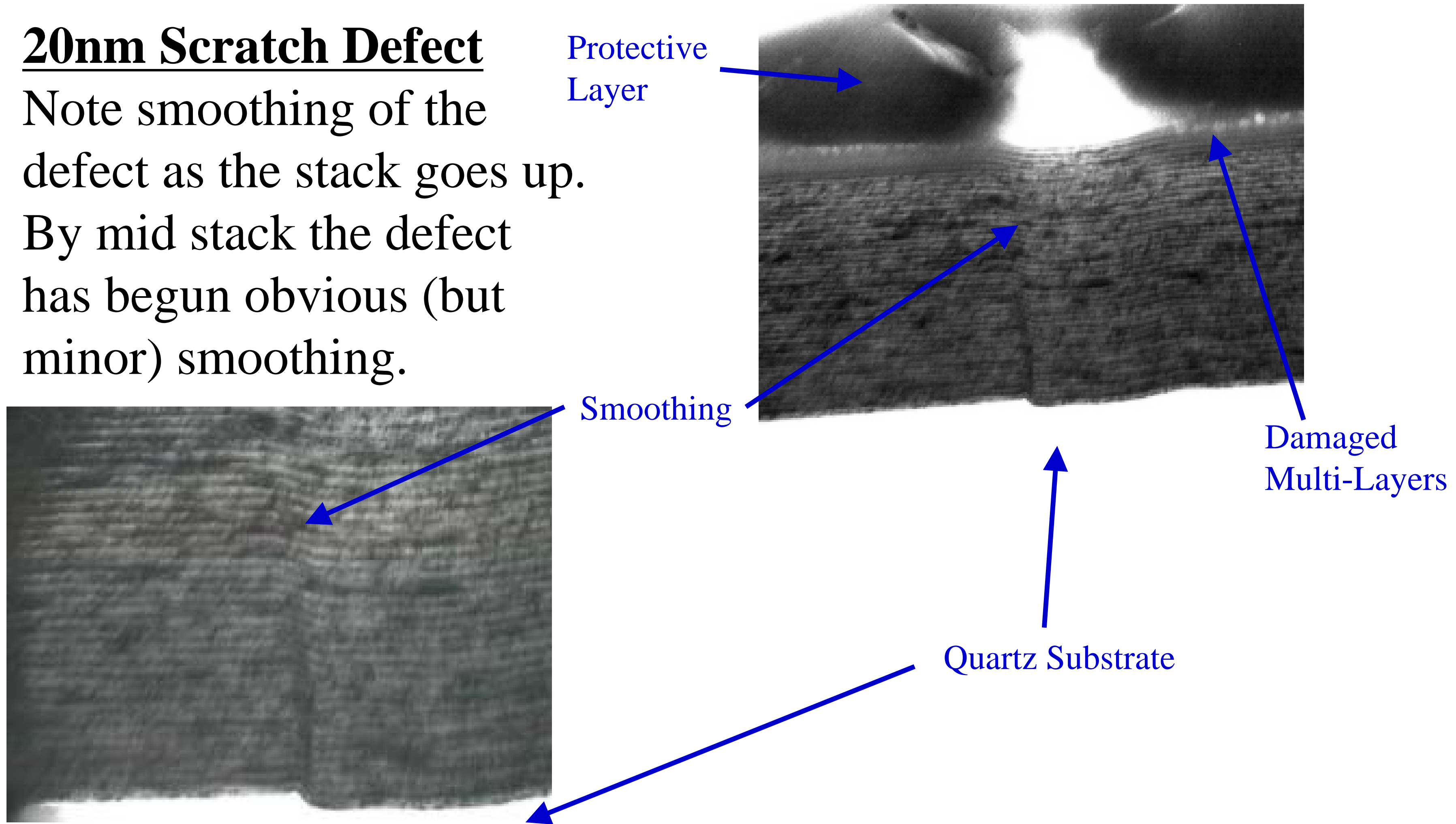
Characteristics of Magnetron Deposition

- Normally at or near 90^0 to the substrate surface.
- No physical barrier between the plasma, target material, and substrate.
- Can smooth (but is process dependant, at ASET our RF process shows smoothing, our DC process does not).
- Should not “decorate” particle defects if at or near 90^0.
- When smoothing is present, lower areas receive more deposition then higher areas.

20nm ASET Mo/Si Magnetron Sputtering

20nm Scratch Defect

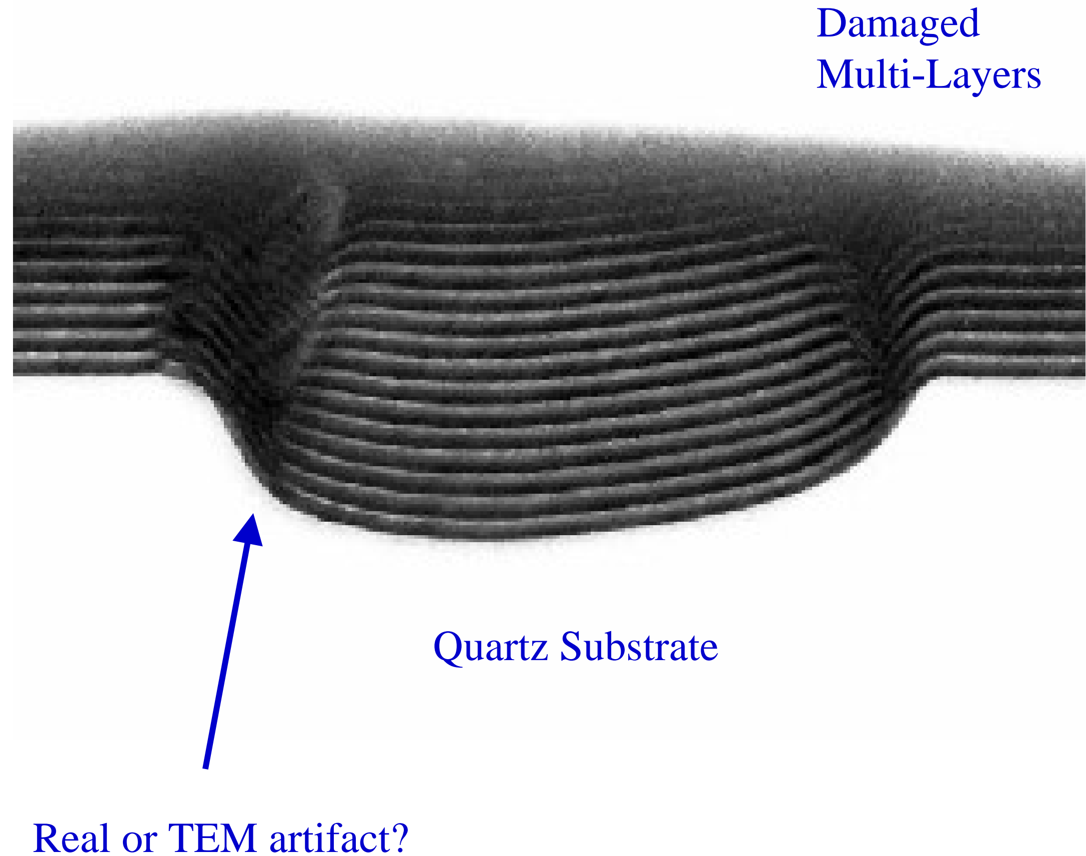
Note smoothing of the defect as the stack goes up. By mid stack the defect has begun obvious (but minor) smoothing.



60nm ASET Mo/Si Magnetron Sputtering

<u>60nm Scratch Defect</u>

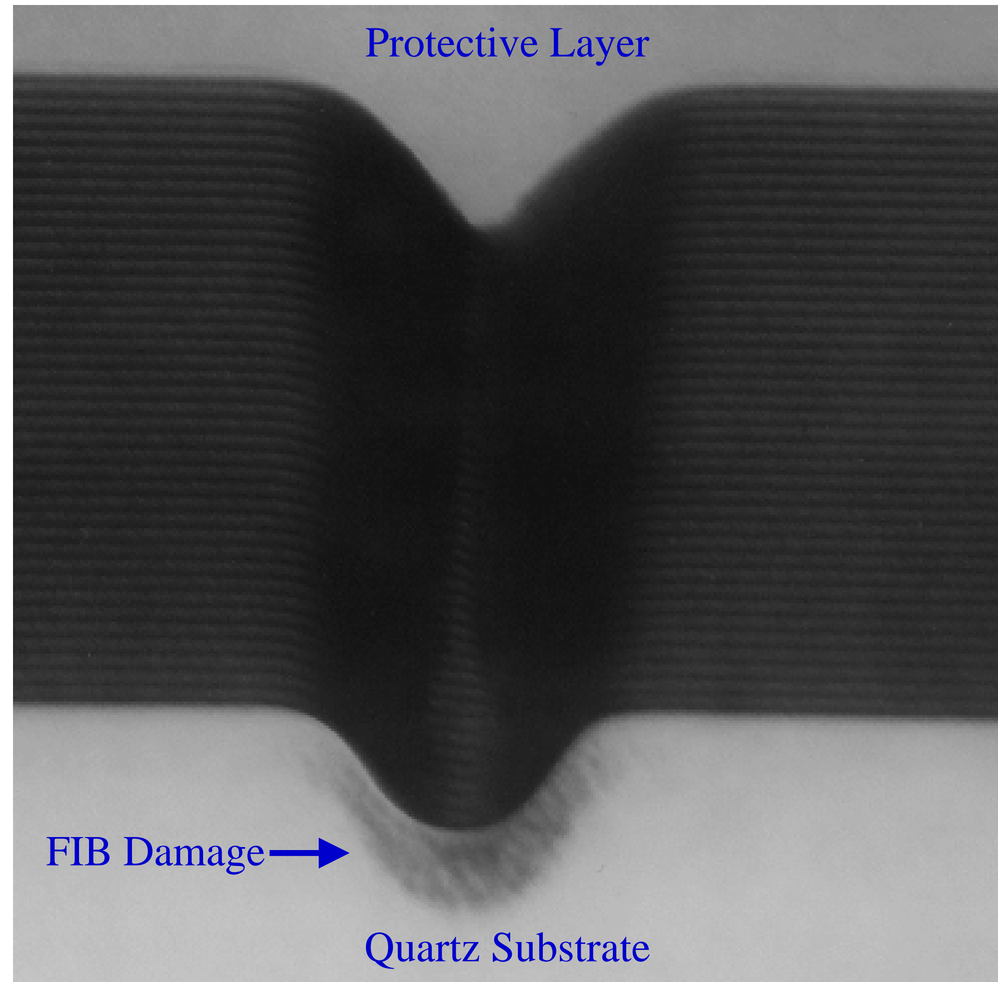
Limited value due to multi-layer damage during TEM sampling. Of interest is whether there is "shading" on the sides since the ASET magnetron process is not at 90^0 but has a slight angle to it or whether this is a TEM artifact.



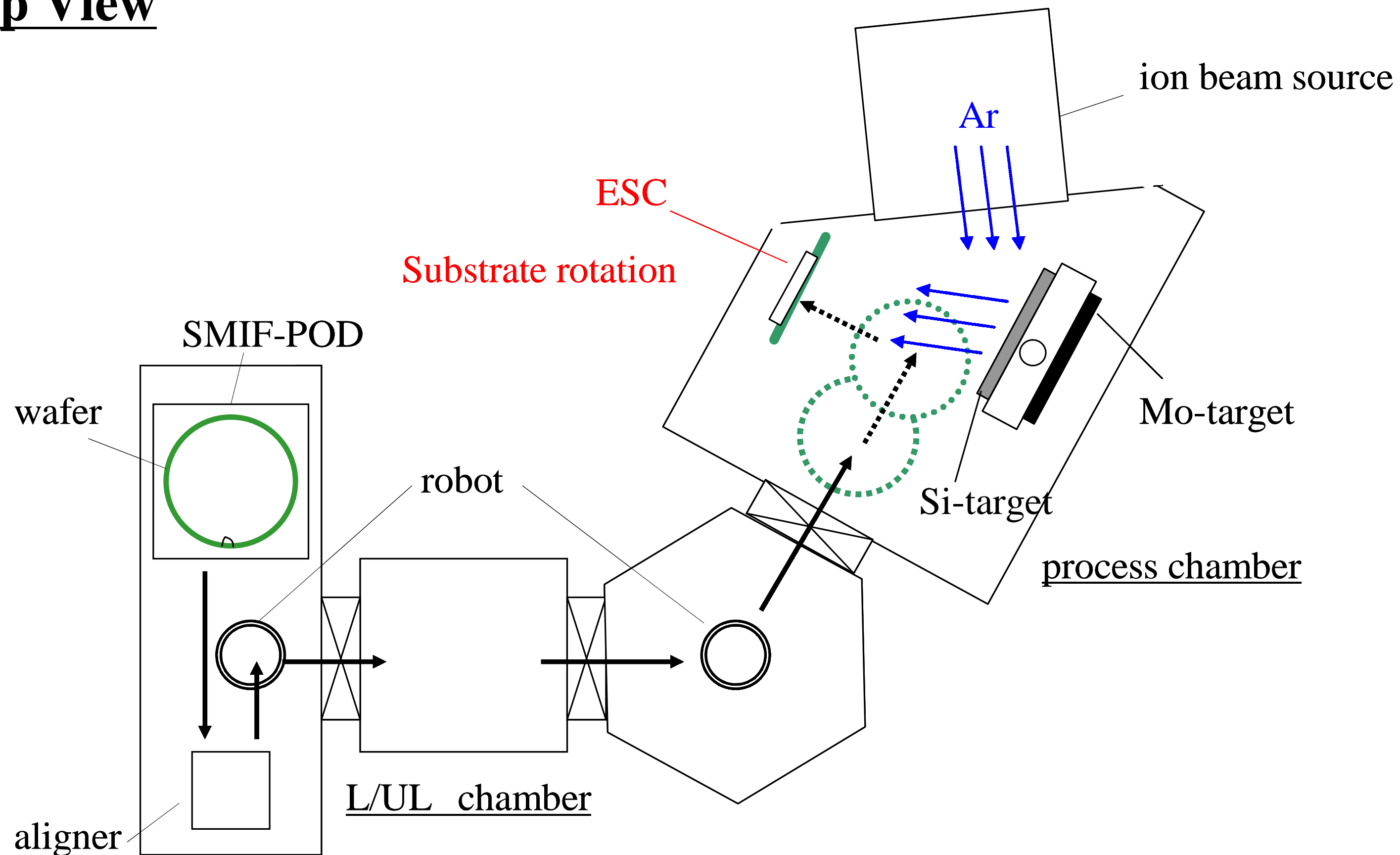
80nm ASET Mo/Si Magnetron Sputtering

<u>80nm Scratch Defect</u>

Defect was created using an FIB rather then an AFM (Which accounts for the damage to the substrate under the defect). Defect is narrowing (probably due to angle of ASET Magnetron Deposition not being 90^0). If there is smoothing the effect is relatively minor.



ASET Mo/Si Multilayer Ion Beam Sputtering System



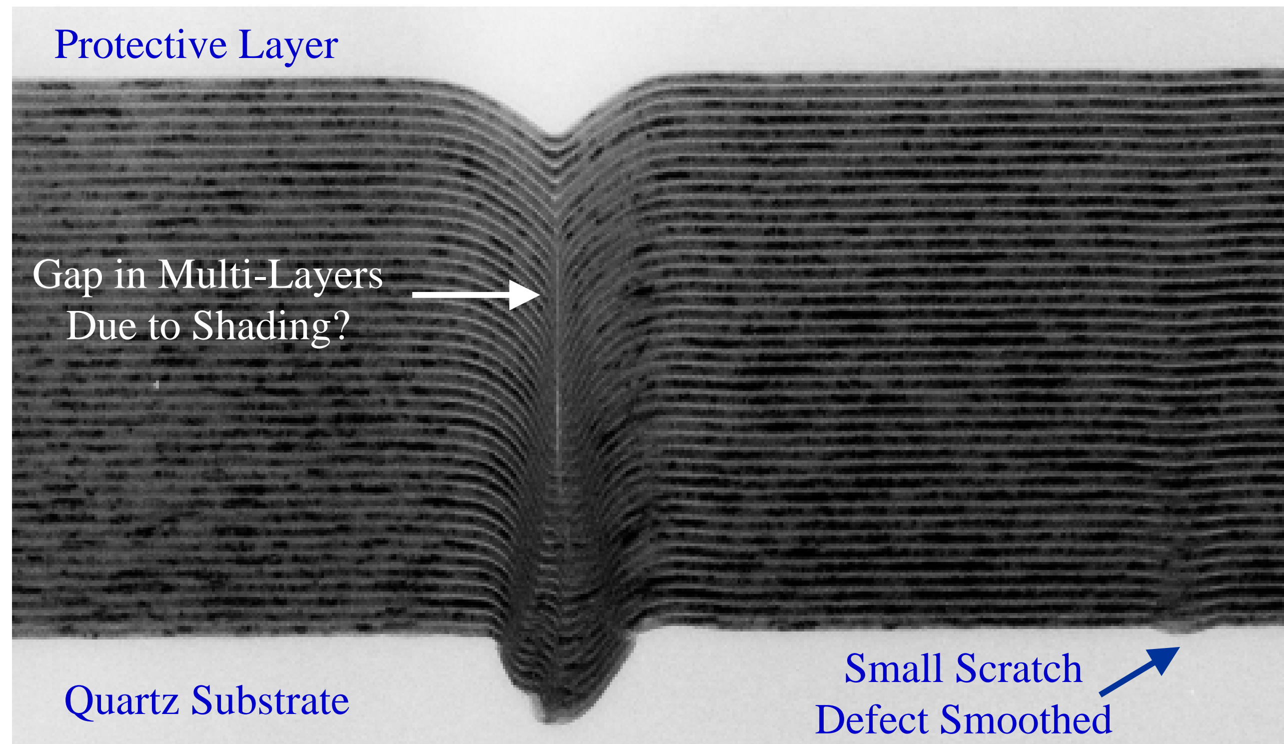
Characteristics of Ion Beam Deposition

- Normally done with the substrate at an angle relative to the target material for uniformity.
- Has a Mo grid between the plasma and the target material to create a potential to accelerate the plasma to the target. This grid is sputtered along with the target material potentially causing particle defects.
- Should smooth scratch defects. Since the flux of material is higher to surfaces close to 90^0 the side walls should receive close to normal amounts of material deposited (since the substrate is rotated.
- This should eventually close the defect. However, as the side walls grow to have an angle greater then the deposition angle the bottom of the defect no longer sees deposition and a hole will form between the side walls. This should close if the width of the defect is small enough.
- This same deposition on sides will deposit additional material on the sides of bump or particle defects causing them to grow.

40nm ASET Mo/Si Ion Beam Sputtering

40nm Scratch Defect

Defect's shape is not ideal but does show excellent smoothing as it moves up the stack. Of particular interest is whether the "line" in the middle of the defect is real or a TEM artifact. Due to the line's appearance in all other IBD defects seen we suspect this is a real phenomena and a result of the sidewall steepening as the defect closes causing shading at the bottom of the defect. Eventually this hole closes near the surface.



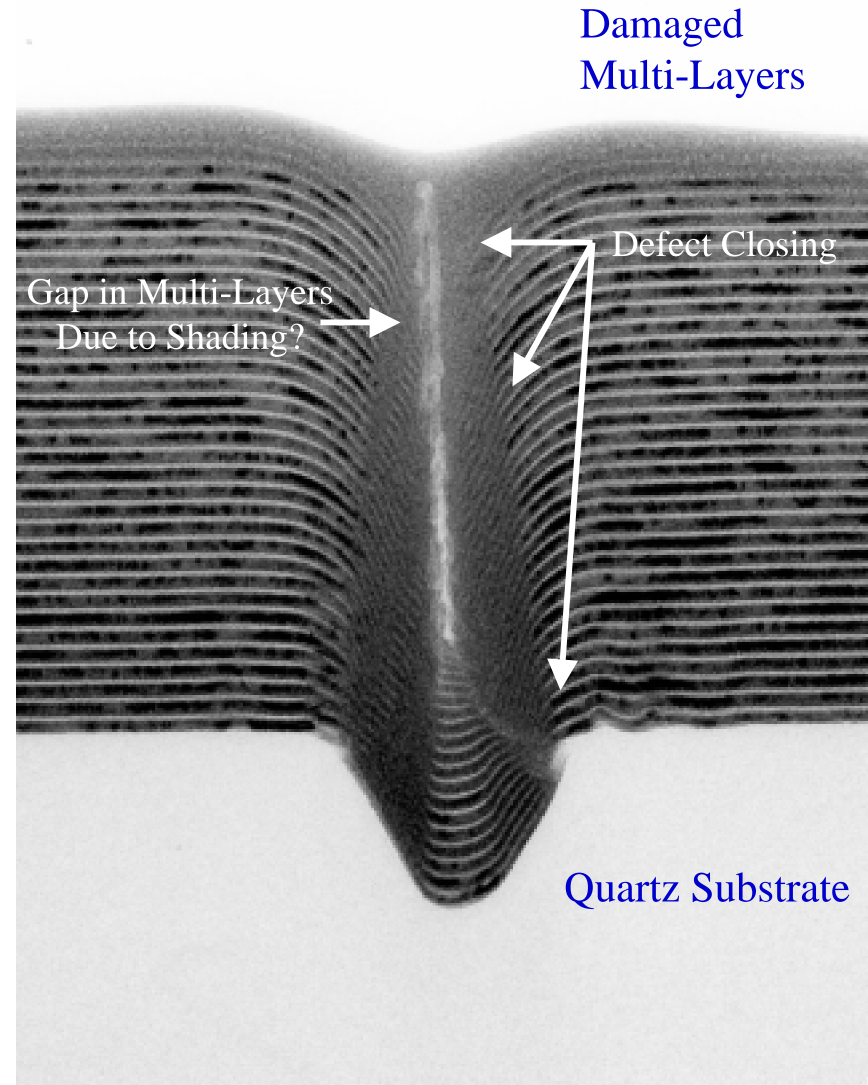
60nm ASET Mo/Si Ion Beam Sputtering

<u>60nm Scratch Defect</u>

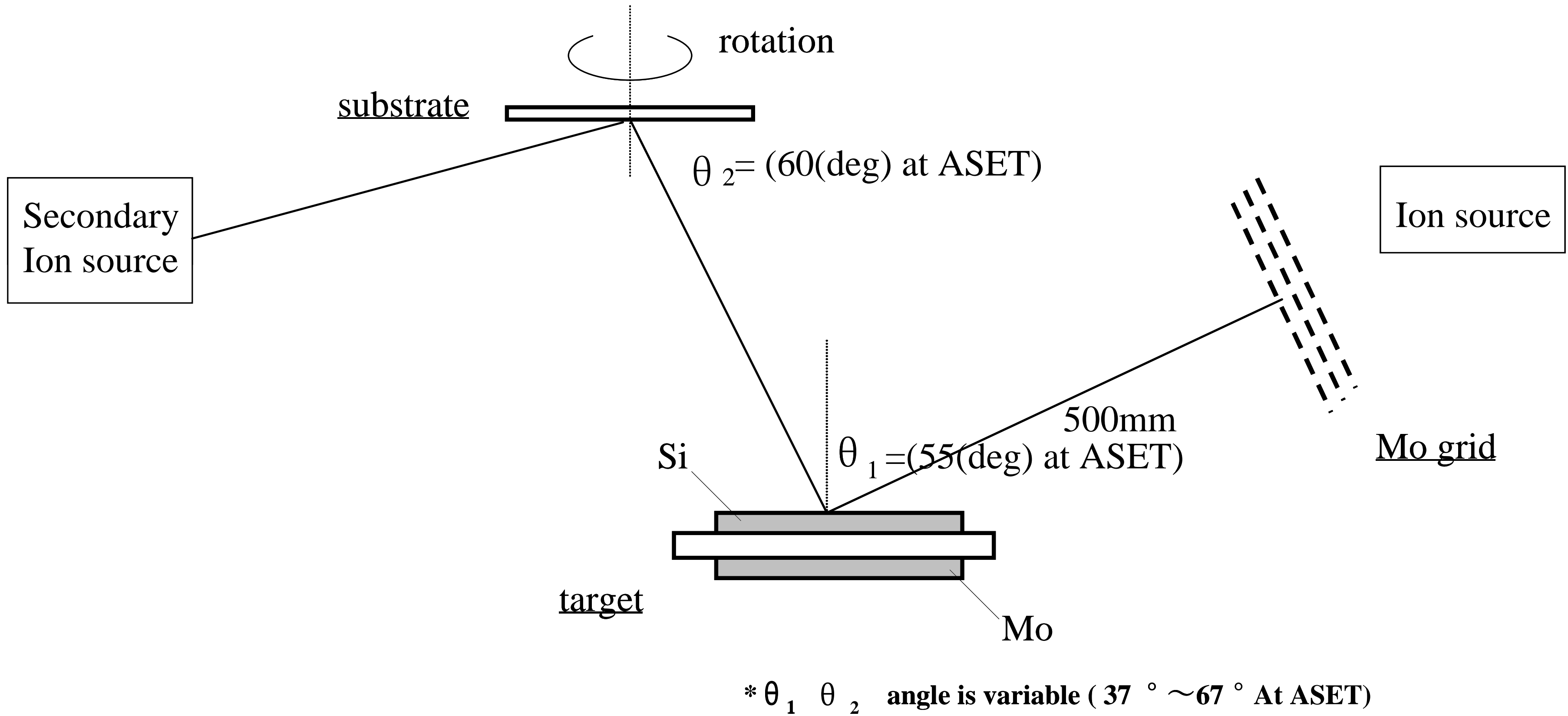
Good defect shape. This defect shows the shading effect much more clearly. It is unknown if the shading would have had time to closed as it did with the 40nm defect or if it would have continued. Clearly visible though is the change in the multi-layers as the side walls steepen and the defect closes.

A small bump/scratch to the right of the defect is smoothed over.

Unfortunately the amount of smoothing cannot be properly evaluated due to the failure of the protective layer.



Generic Mo/Si Multilayer Ion Beam Sputtering System



* θ_1 θ_2 angle is variable (37 ° ～67 ° At ASET)

Characteristics of Ion Beam Deposition With Smoothing

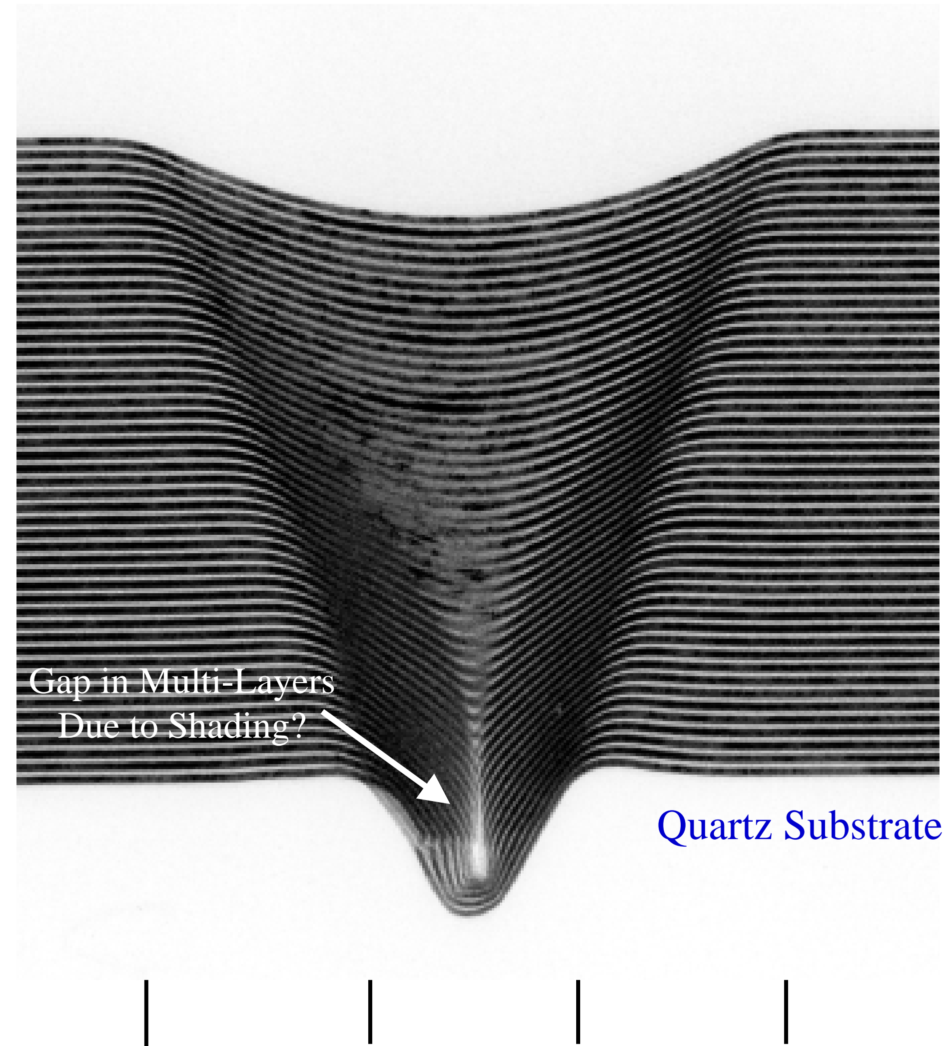
- The same as Ion Beam Deposition but with an added "smoothing" etch.
- This added step is traditionally an additional ion beam which is at a high angle of incidence to the mask substrate. The impact of this is similar to the deposition process. Any feature which is at a higher angle to the beam will receive a larger flux of the ions and will be "smoothed".
- While this method is well suited for smoothing particle defects it will also "widen" a hole/scratch type defect.

60nm Mo/Si Ion Beam Sputtering with Smoothing

<u>60nm Scratch Defect</u>

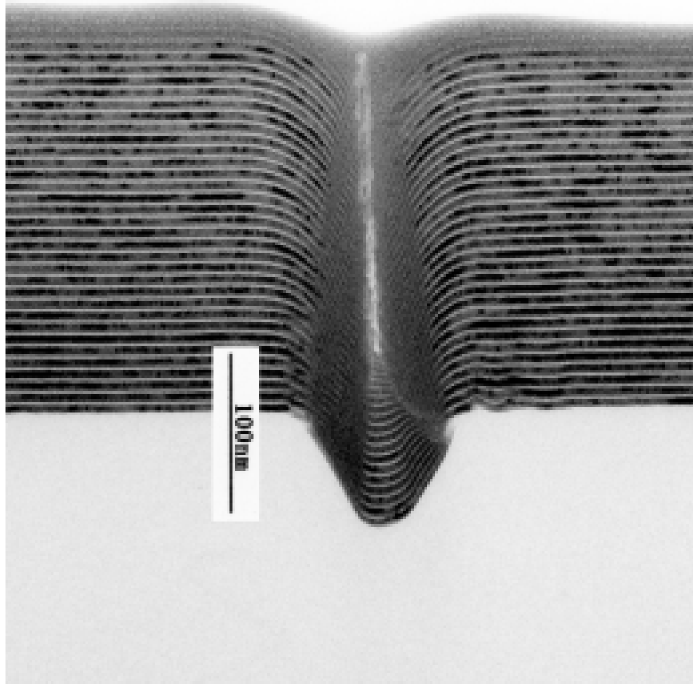
Good defect shape. This defect shows the shading effect until the secondary ion smoothing opens the defect enough that the side walls are no longer shading the bottom of the defect.

The impact of the smoothing process is very visible. The scratch has gone from a narrow defect to a very wide defect (~3x it's original width).

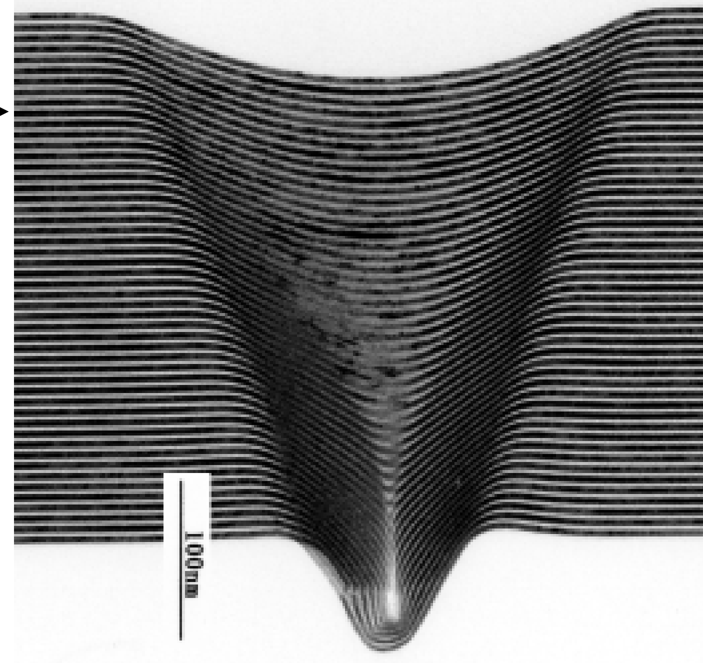


60nm IBD/IBD with Smoothing

IBD



IBD with Smoothing



40 multi-layer pairs

Summary

- All 3 processes (Magnetron, IBD, IBD with smoothing) showed smoothing.
- If shading was an issue for the Magnetron mask it was a minor issue.
- IBD showed good smoothing and closure on the 40nm defect. Due to multi-layer damage it is unknown if the defect would have closed for the 60nm defect.
- IBD with Smoothing showed good smoothing of the defect but the width of the defect grew. Shading was relatively minor due to the widening of the defect from the secondary ion etch. Defect grew by approximately 3x in width.

Acknowledgements

ASET is supported by New Energy and Industrial Technology Development Organization (NEDO).

Dai Nippon Printing for AFM work and mask patterning.

Veeco Instruments for IBD Deposition with Smoothing