Defect-Free LTEM Substrates for EUV Lithography: Challenges and Solutions

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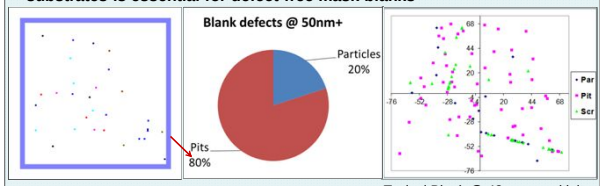
Introduction

- EUV substrate defectivity remains one of the key issues to be resolved to achieve the total defectivity goals of EUV masks
- Eighty percent of defects on a champion mask blank originate from substrates, the majority of which are substrate pits and scratches
- Scratches originate from chemical mechanical polishing of substrates and pits are generated by cleaning processes before ML deposition
- Developing damage-free polishing and cleaning processes for EUV substrates is essential for defect-free mask blanks



*Defects on a champion blank[1] @ SiO_2 50 nm+

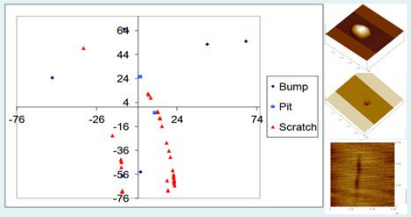
AGC SEMATECH

Typical Blank @ 42 nm sensitivity: 56 Pits, 21 Particles, 43 Scratches

*Joint work: SEMATECH/AGC

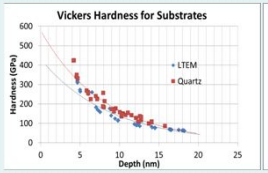
Pits and Scratches on Substrates

- Substrate defects include pits, particles, and scratches
- On good quality incoming substrate, pits and scratches constitute majority of the defects after cleaning

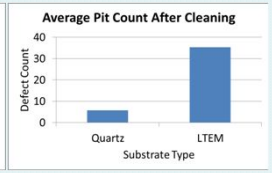


Pits and scratches on a substrate @ 42 nm+ SiO_2 equivalent size

- Formation of pits and scratches is a more severe problem in LTEM than quartz[2], probably LTEM subsurface is not as hard as quartz in the top few nanometers



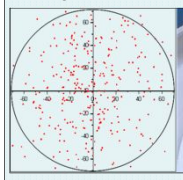
Hardness values obtained at various depths in substrate material



Average pits added on substrates by the same standard cleaning process

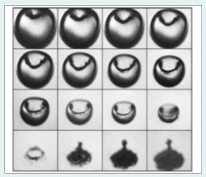
Cleaning-Induced Pits on LTEM

- Cleaning substrates using 1 MHz megasonics has been identified as the root cause of pit formation at size 40 – 60 nm SiO_2 equivalent.
- Megasonic cavitation collapse is the mechanism behind pit formation.

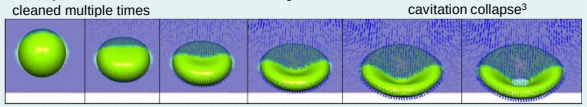


Added pits on substrate cleaned multiple times

Active area of megasonics



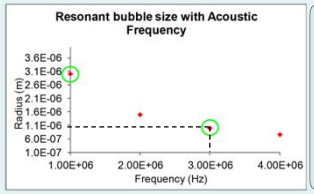
Experimental observation of cavitation collapse[3]



Simulation[4] of collapse of a 10 micron bubble in a 1 MHz field. Velocity vectors on the bubble-fluid interface and cross-section through the center of bubble are also plotted.

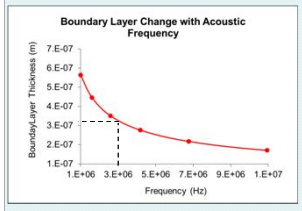
Megasonic Frequency and Cavitation Bubble

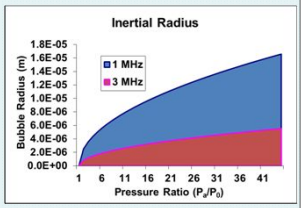
- Size of resonant cavitation decreases with increasing frequency[5]



- Size of resonant cavity for 3 MHz is ~1/3rd of 1 MHz
- Impact force from 3 MHz cavitation collapse is reduced by an order of magnitude compared to 1 MHz cavitation[6]

- Acoustic streaming increases with frequency leading to further thinning of hydrodynamic boundary layer
- Only cavitation of initial radius below the inertial radius becomes transient, leading to more stable cavitation for 3 MHz

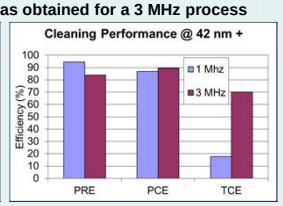




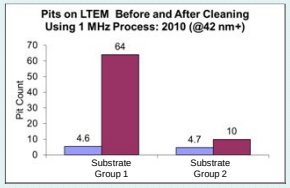
- Sweeping from stable cavitation and hydrodynamic drag force is more effective in a thinner boundary layer

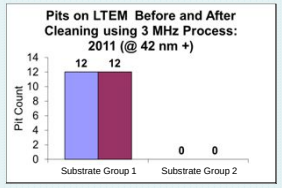
Implementation of 3 MHz Processes for LTEM Cleaning

- 3 MHz megasonics was successfully implemented at SEMATECH for LTEM substrate cleaning without pit generation at 42nm+ SiO_2 equivalent
- Pit formation was reduced 30 times for a 3 MHz process similar to 1 MHz
- Overall better cleaning efficiency was obtained for a 3 MHz process



PRE = Particle removal efficiency
PCE = Particle cleaning efficiency (includes particle adders)
TCE = Total cleaning efficiency (includes pit and particle adders)





- For the first time, SEMATECH substrate cleaning processes are shown to be independent of incoming material and to generate zero pits by cleaning

Summary and Conclusion

- Substrate pits and scratches dominate defects on a good quality EUV mask blank
- Scratches are induced on the surface by CMP processes, whereas the majority of pits are added by substrate cleaning before deposition
- Megasonic cavitation collapse is identified as the root cause of pit generation. Theoretical predictions on megasonic cavitation are successfully implemented in cleaning processes for LTEM that generate NO pits. For the first time, LTEM cleaning process at SEMATECH is shown to be independent of the quality of incoming material and to generate no pits at 42 nm and above
- Ongoing work at SEMATECH includes standardizing 3 MHz processes and evaluating higher frequency megasonics, i.e., 4 and 5 MHz. CMP processes are also being investigated to reduce scratches on substrates.

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References

[1] J. Kageyama, et al., EUVL Symposium 2011.
[2] A. JohnKadaksham, et al., *Proc. SPIE* 7969, 76369OZ1-13, 2011.
[3] O. Lindau, et al., J. of Fluid Mechanics, Vol 479, PP 327-348.
[4] ESI-ACE, Version 2006.0.28, © 1994-2005 ESI Group.
[5] F. R. Young, Cavitation, Imperial College Press, ISBN: 1-86094-198-2.
[6] P. Deymier, B. Merhab, U. Arizona, "Modeling Spin-Spray Megasonic System," SEMATECH Internal Report 2009.