Accelerating the next technology revolution

Mechanisms of EUV reflectivity loss from the multiple cleanings

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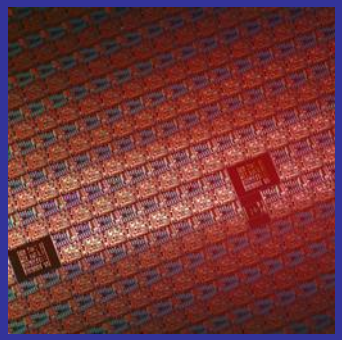
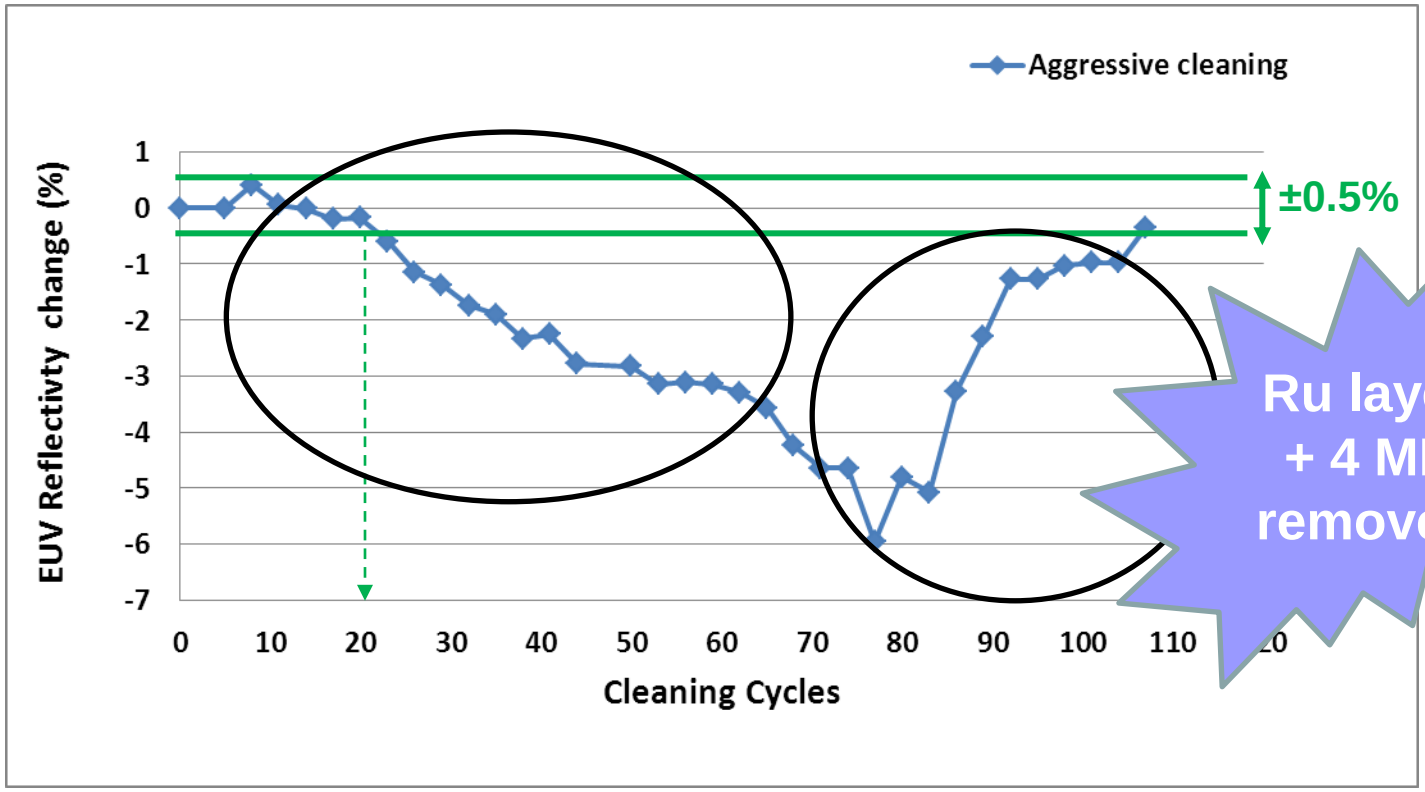


Special thanks to Thomas Laursen (ASML)

Outline

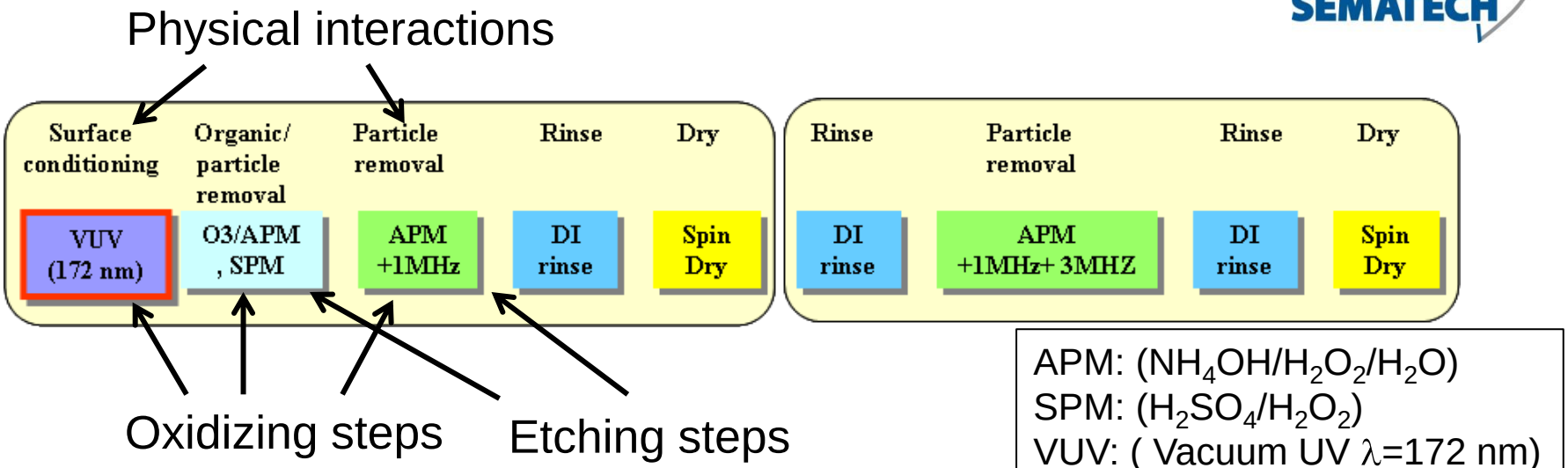
- EUV reflectivity loss from multiple cleanings
- Mask blank surface changes from cleaning
  - Si diffusion and oxidation
  - Ru oxidation
- Contribution of cleaning processes to EUV reflectivity loss
  - Radiation effects
  - Chemistry effects
  - Megasonic effects
  - Combined effects

How many times can an EUV mask be cleaned?



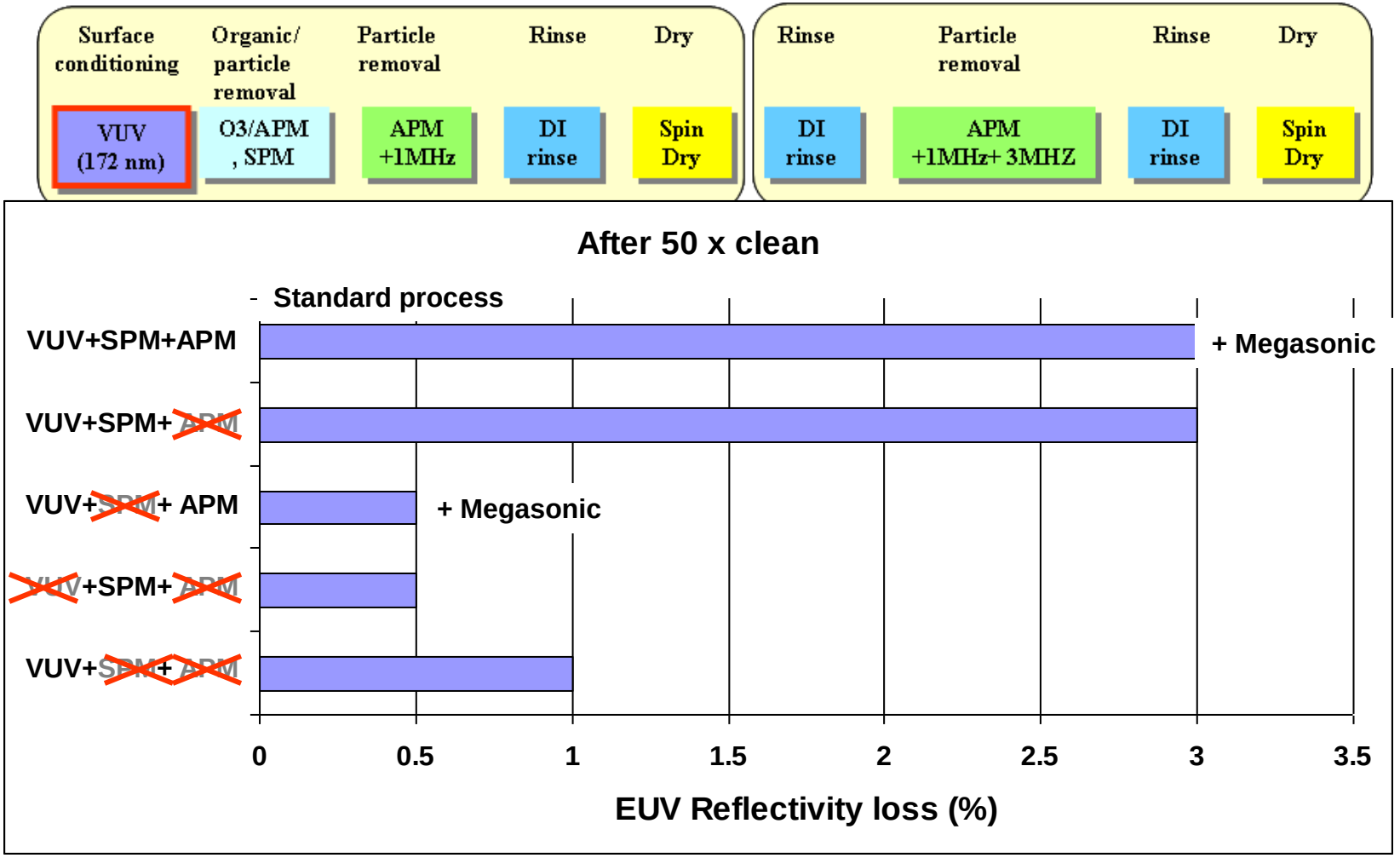
- EUV reflectivity (R_{max}) dropped below target after cleaning 20X
- **What is the mechanism of EUV reflectivity loss?**

Which cleaning steps oxidize/remove Ru?

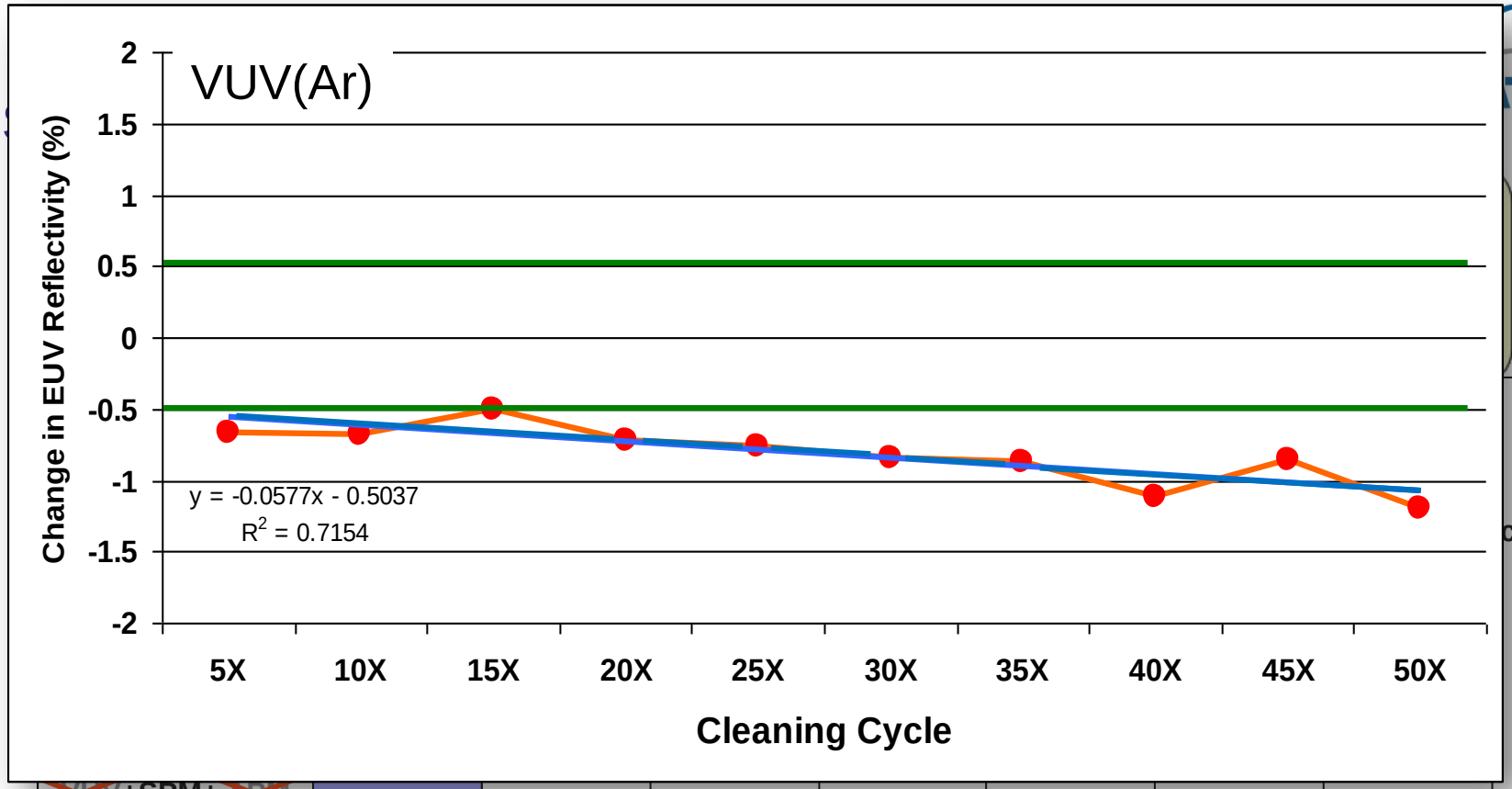


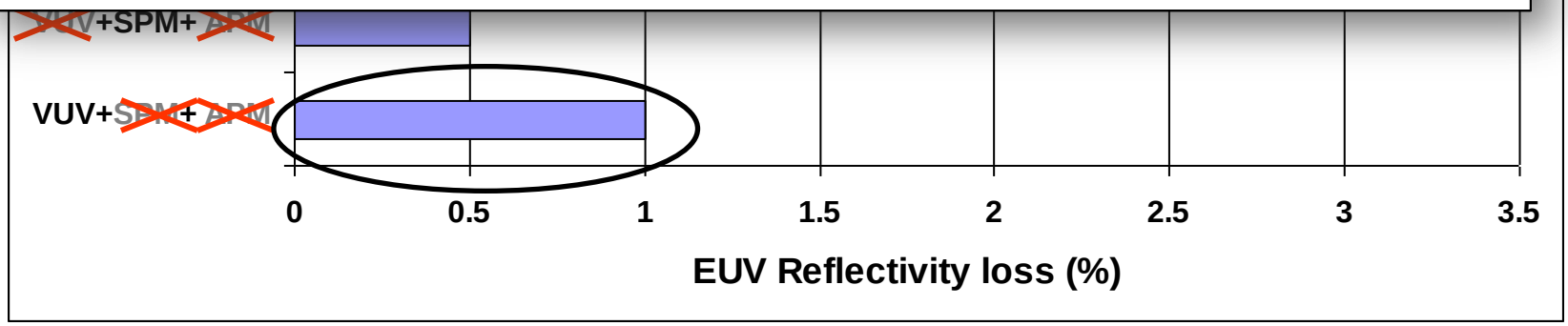
- Which steps oxidize Ru and/or Si?
- Which steps remove Ru or Si?
- Is there any combined effects?
  - (VUV+ SPM), (VUV+ APM), (SPM+APM)
- Does megasonic contribute to the chemistry effects?
- **Verification method**:
  - Change in EUV reflectivity at each step

EUV reflectivity loss from individual cleaning steps (50X)



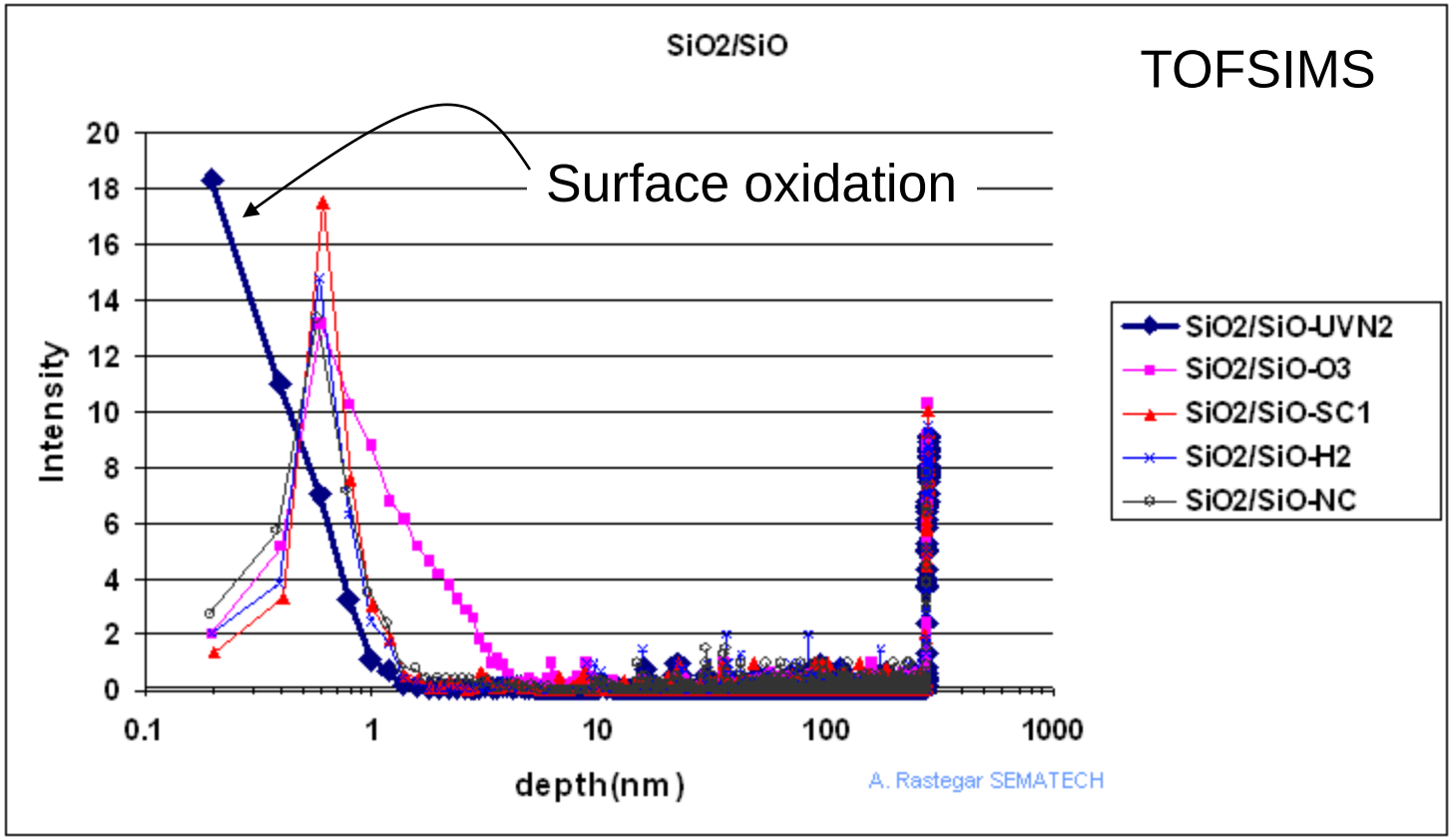
- EUV reflectivity loss is maximum when SPM follows VUV exposure





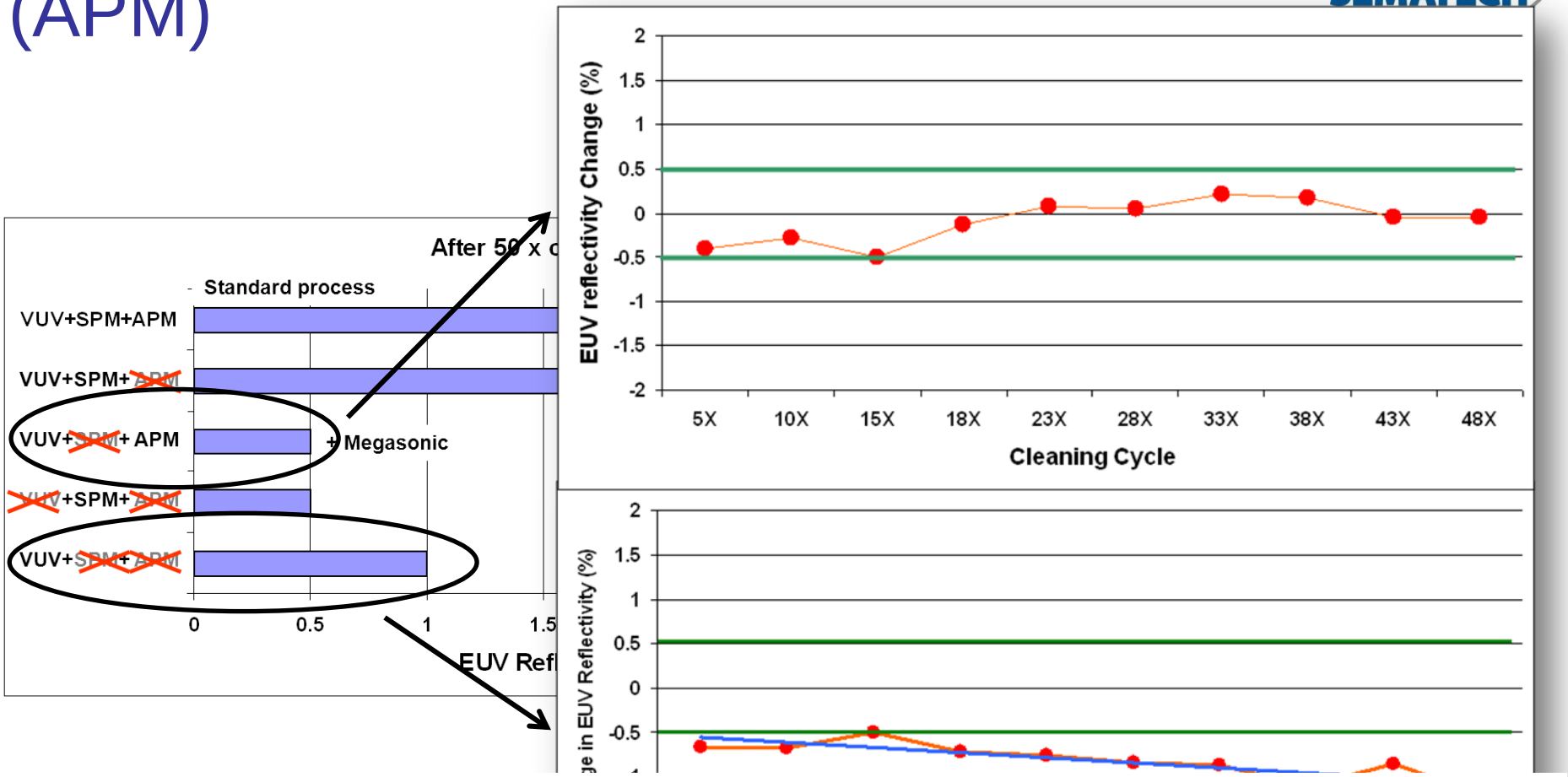
- EUV reflectivity drops linearly with exposure time

Si oxidation on top of Ru from exposure to VUV(λ=172 nm)



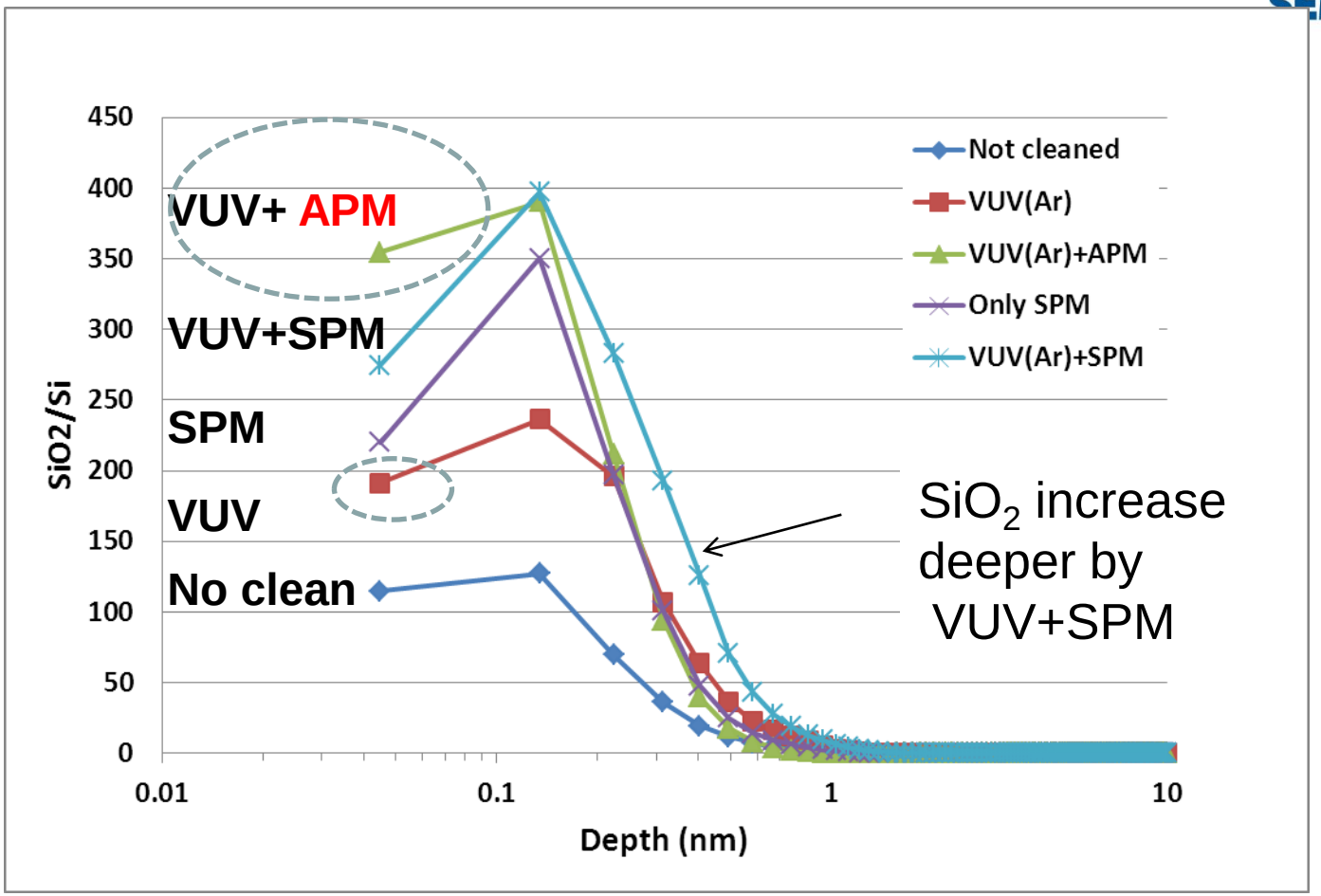
- Diffused Si on top of Ru is further oxidized by VUV radiation (ratio of SiO_2 / SiO increases)

VUV(172 nm)+ $NH_4OH/H_2O_2/H_2O$ (APM)



- VUV + APM is more aggressive than VUV alone.
- Why EUV reflectivity loss is less for (VUV+APM)?

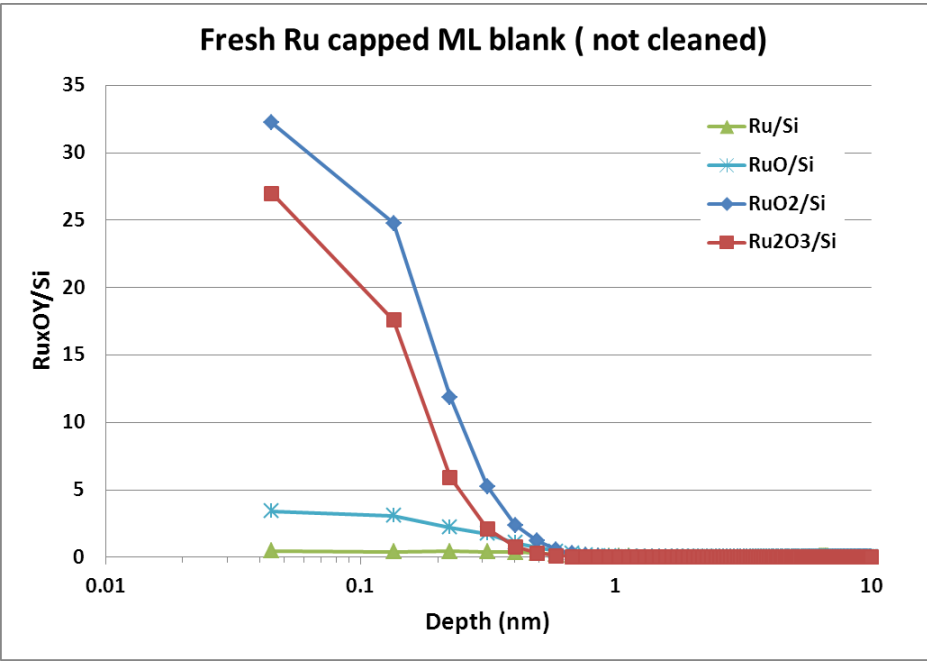
Si oxidation from cleaning process



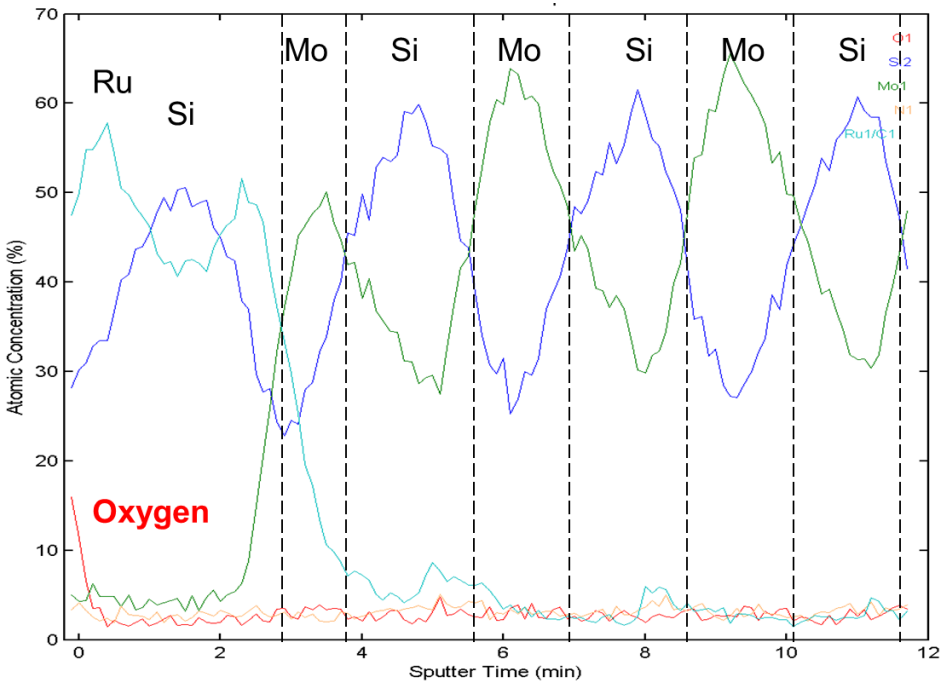
- Greater Si oxidation from (VUV+ APM) than VUV
- APM oxidizes Si and etches SiO_2

Study of Ru oxidation by TOFSIMS and Auger (freshly deposited Ru cap multilayer)

TOFSIMS



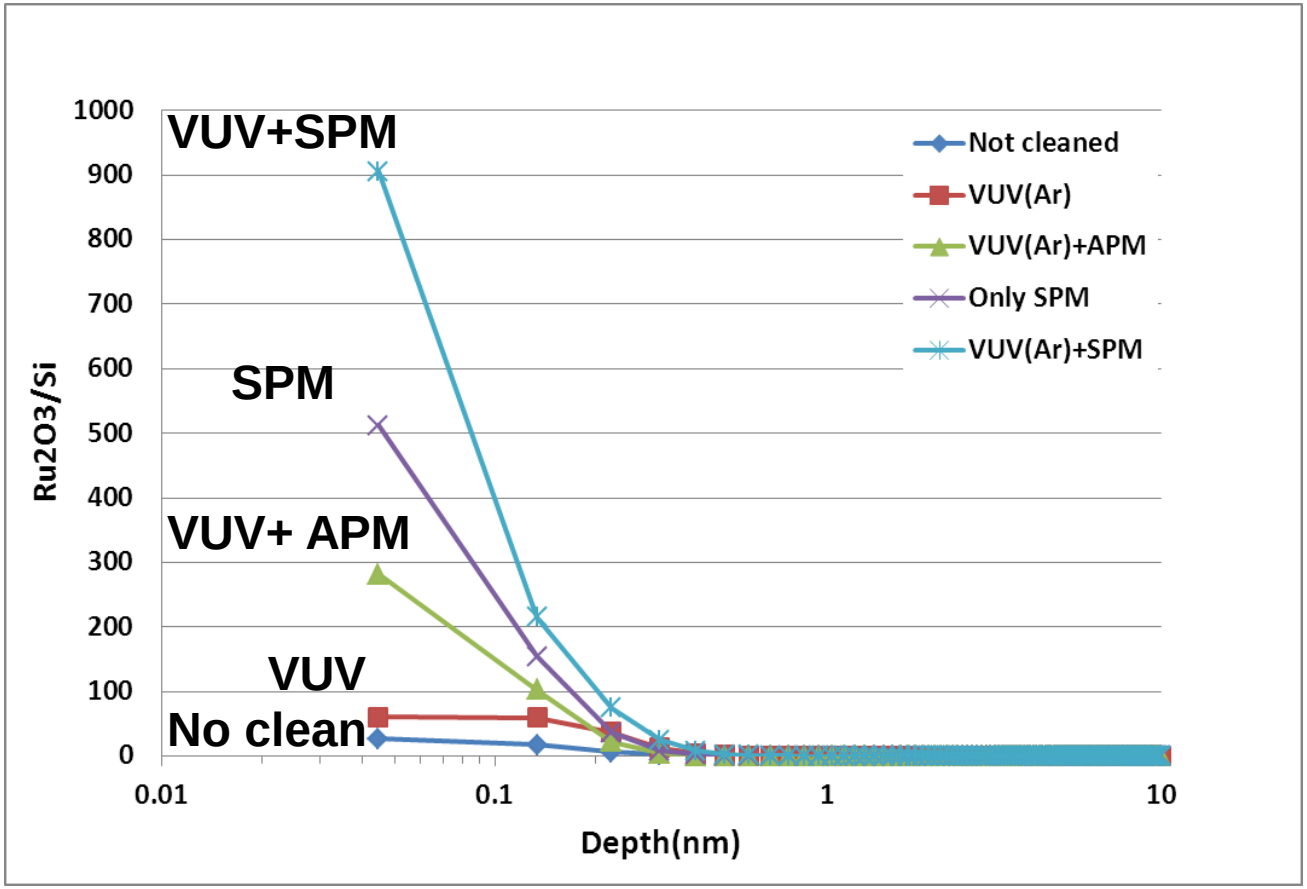
Auger



- Auger depth profile analysis shows Ru, Si, and O on the surface, indicative of both Ru and Si oxides
- Ru oxide in all 3 oxidation valances is found on surface of the fresh Ru blank after deposition (RuO_2>Ru_2O_3>RuO): (9.5:8:1)

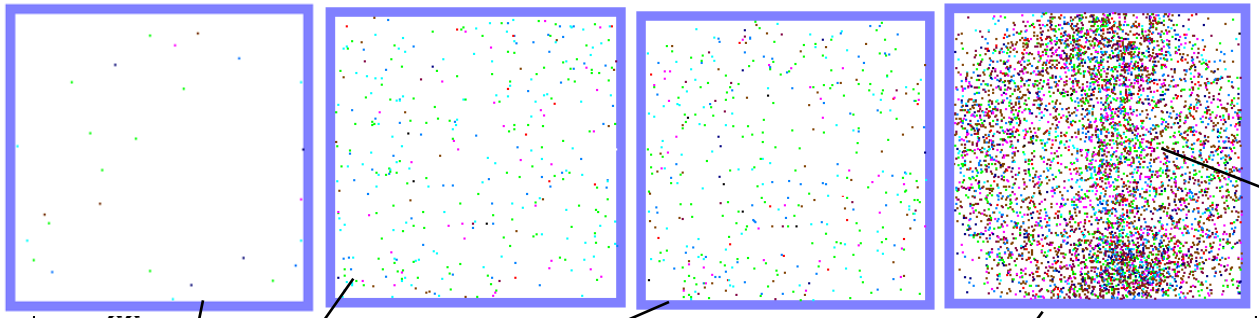
With c contribution of Thomas Laursen

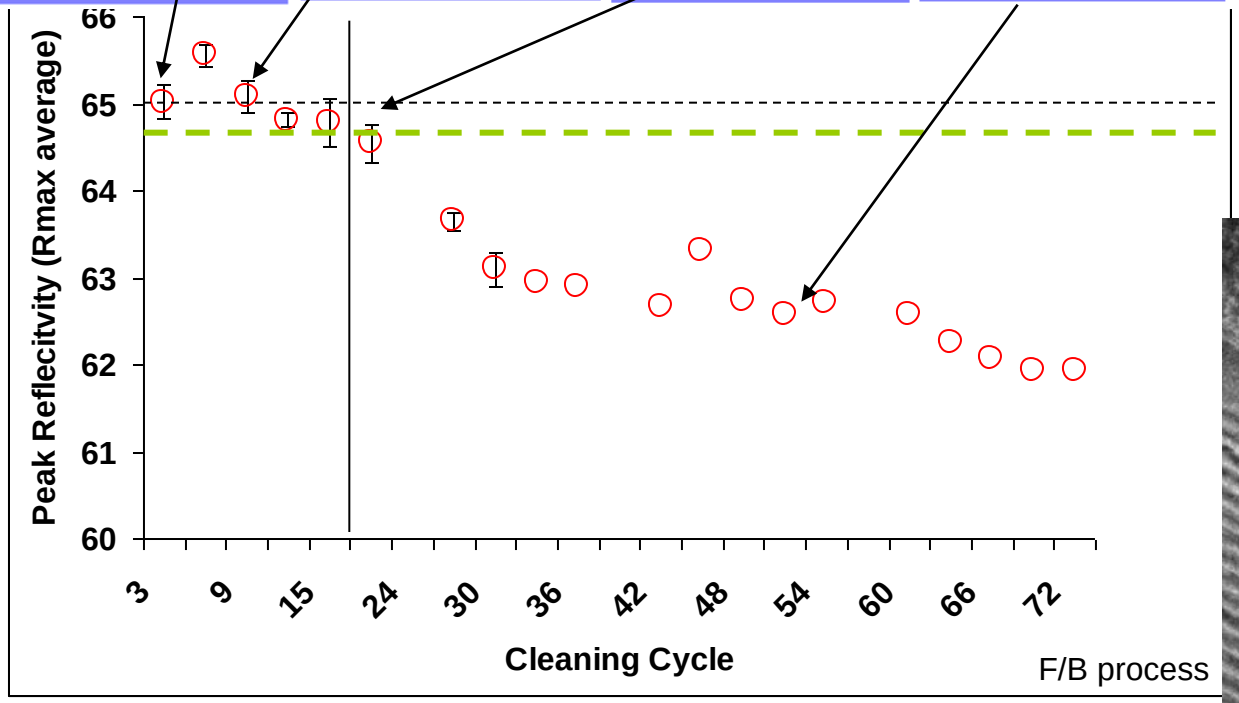
Ru oxidation from the cleaning process

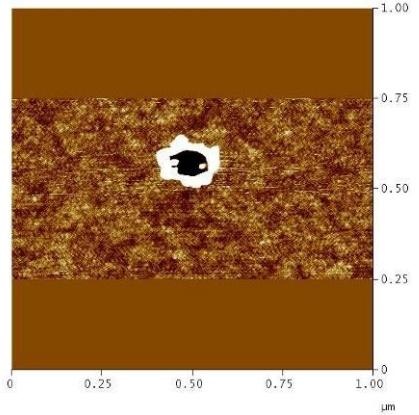


- (VUV+ SPM) leaves the most Ru_2O_3 on the surface
- All steps with wet chemistry oxidized the Ru surface
- VUV in Ar atmosphere has a small contribution to Ru oxidation

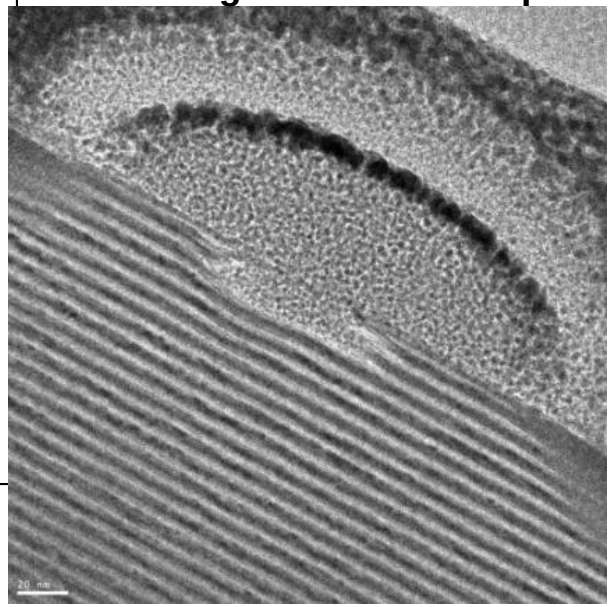
Megasonic contribution to EUV reflectivity loss







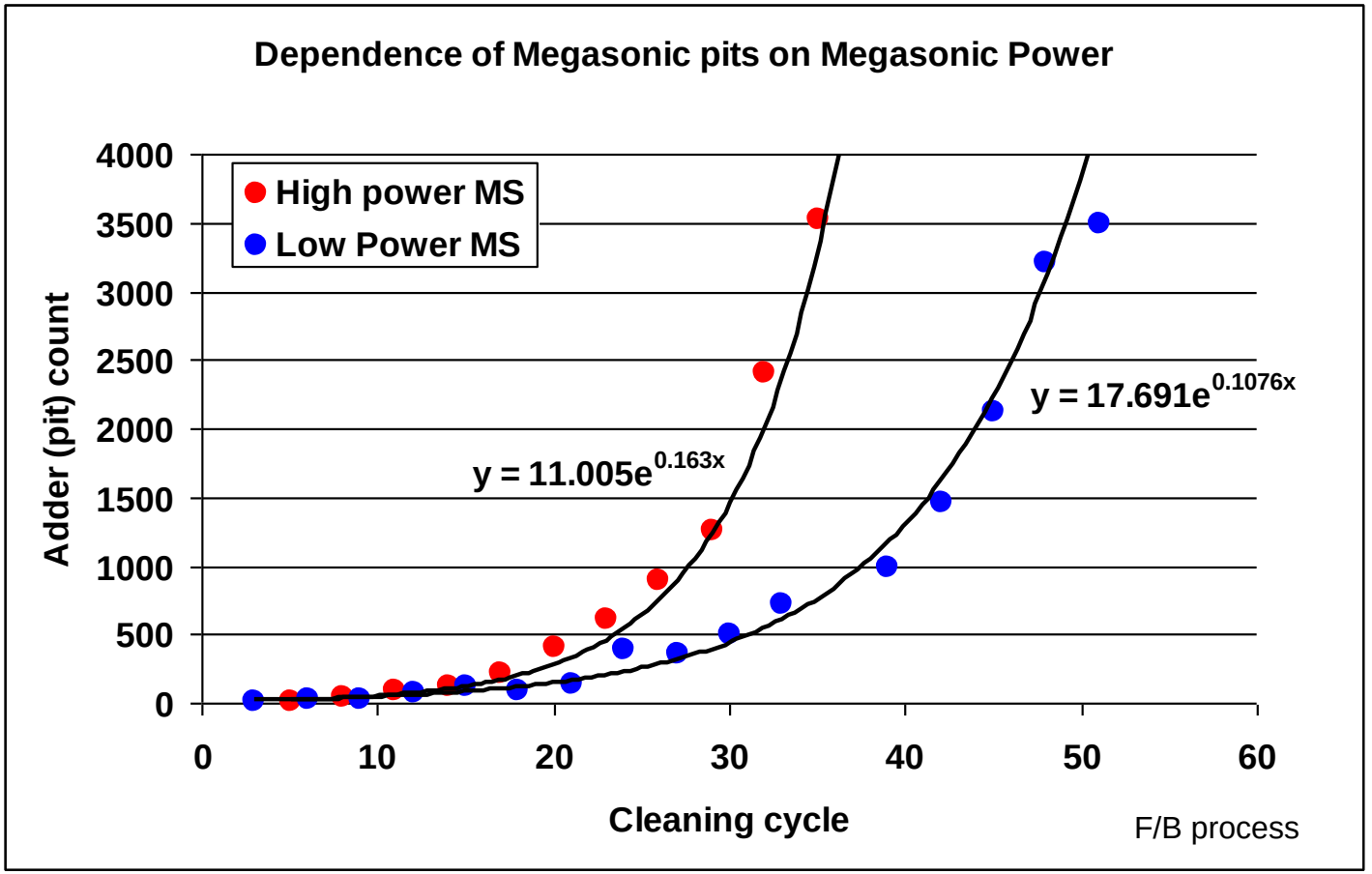
Megasonic induced pits



- Megasonic cleaning of blanks creates pits on the blank surface

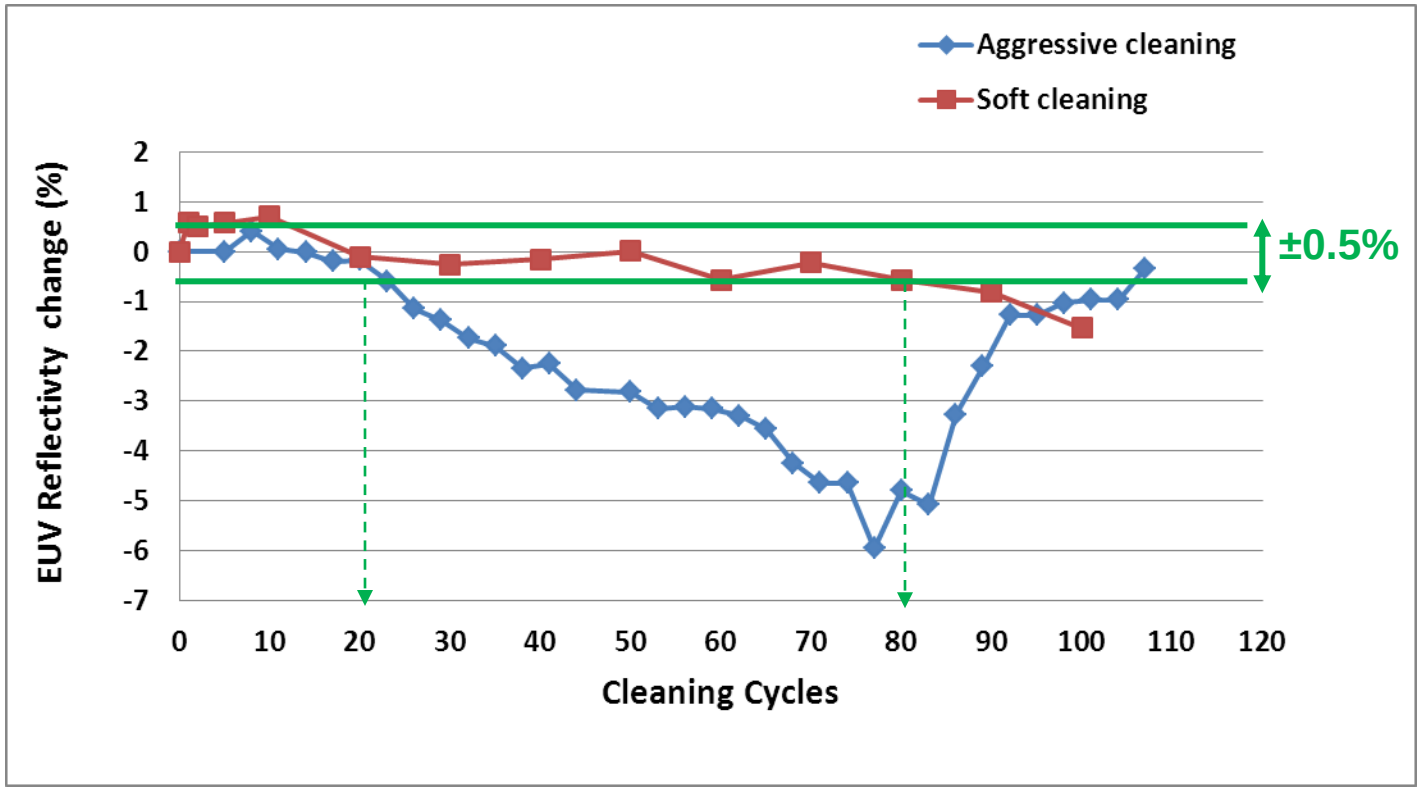
TEM: Jena Harris Jones

Cleaning-induced pit dependency on megasonic power



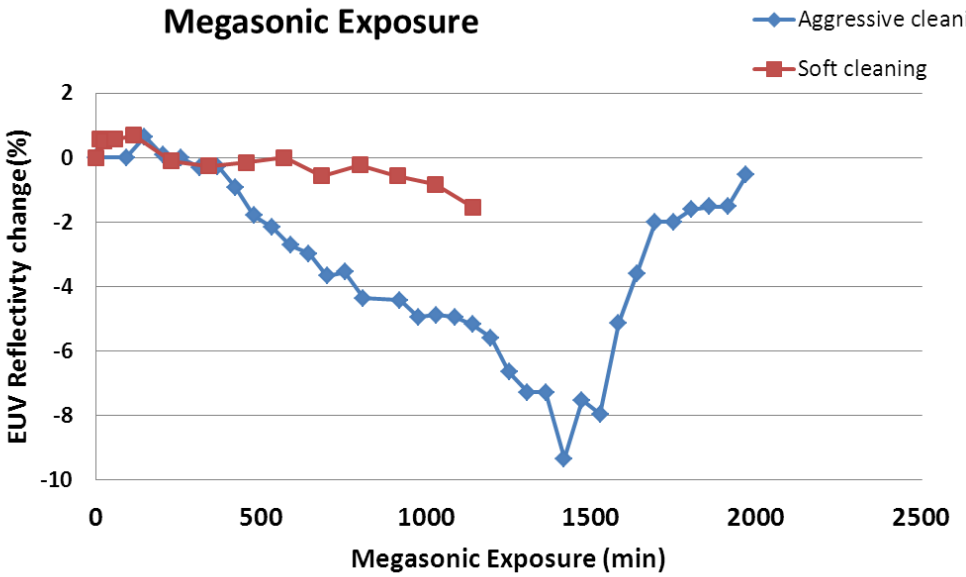
- Higher megasonic powers result in faster pit creation

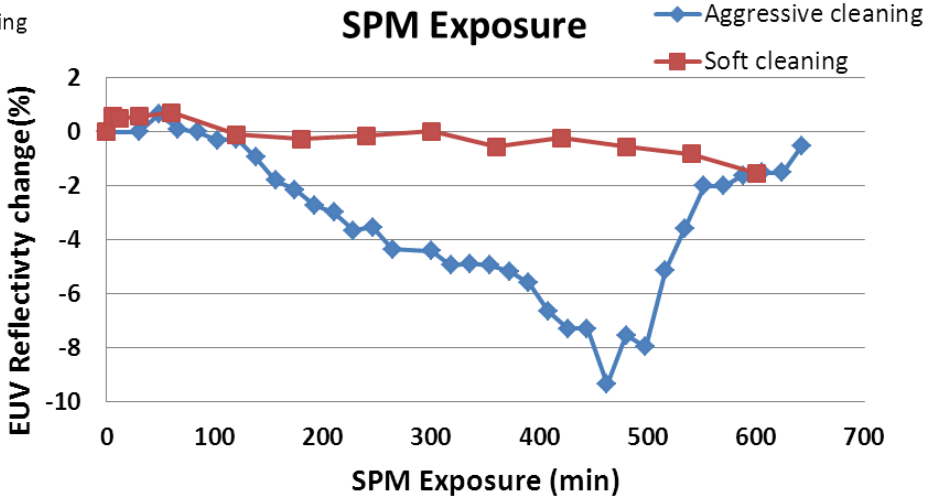
Improvement in mask lifetime using softer cleaning processes

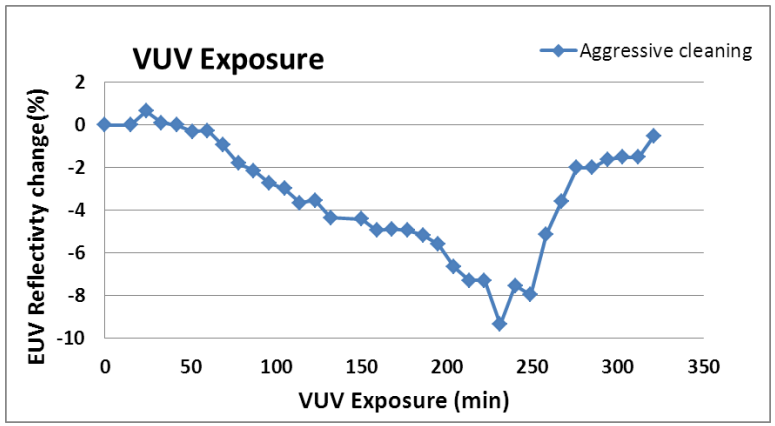


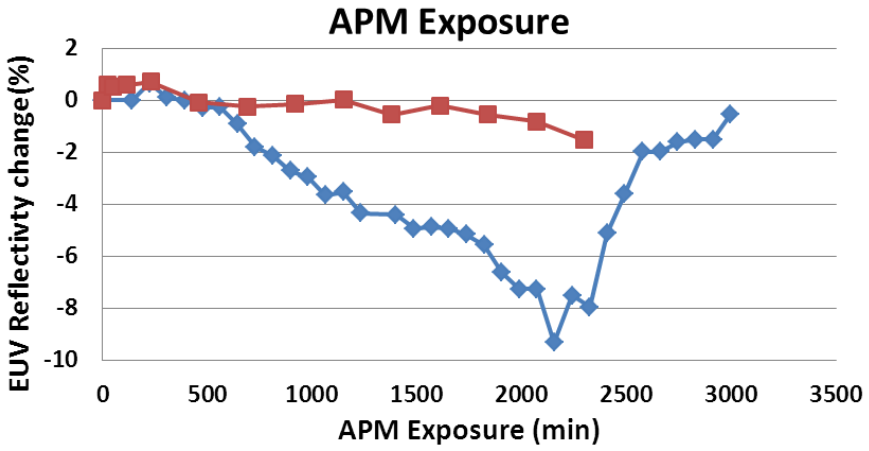
- Softer cleaning processes can clean the mask up to 80X
- Softer clean processes:(no VUV) + lower megasonic powers

Chemistry vs. megasonic contributions









- VUV(λ=172 nm) and megasonic contribute the most to EUV reflectivity loss

Summary

- The top surface of the Ru cap is a mixture of Ru, oxygen, Si and all possible combined oxides and silicides (Ru_xO_y, Si_xO_y,$Ru_xSi_yO_z$)
- **VUV radiation**
  - Oxidizes Si; therefore, EUV reflectivity drops when the Si oxide layer becomes thicker
  - Oxidizes Ru slightly
- **(VUV+APM)**
  - APM will etch the silicon oxide layer formed by VUV radiation; therefore, EUV absorption will be minimal
- **SPM**
  - Mainly oxidizes Ru
- **(VUV+SPM)**
  - Strongly oxidizes Ru and severely impacts EUV reflectivity
  - Not clear which Ru-containing compound has highest EUV absorption
- **Megasonic exposure** compromises Ru layer integrity, which results in oxidizing chemistries attacking the multilayer

Conclusions

- UV light radiation and cleaning chemistries modify the surface of the Ru-capped multilayer, increasing both the scattering and absorption of EUV light
- VUV light not only oxidizes the Si on the top surface but also modifies Ru oxides and silicides such that it will be further oxidized by strong oxidant agents such as sulfuric acid and hydrogen peroxide
- At this time, it is not clear which chemical compound (Ru oxides, Ru silicides, or a combination) severely reduces EUV reflectivity
- **Therefore, the combined effects of VUV+ chemistry and exposure to megasonic are responsible for degrading capping layer integrity**

Thank You

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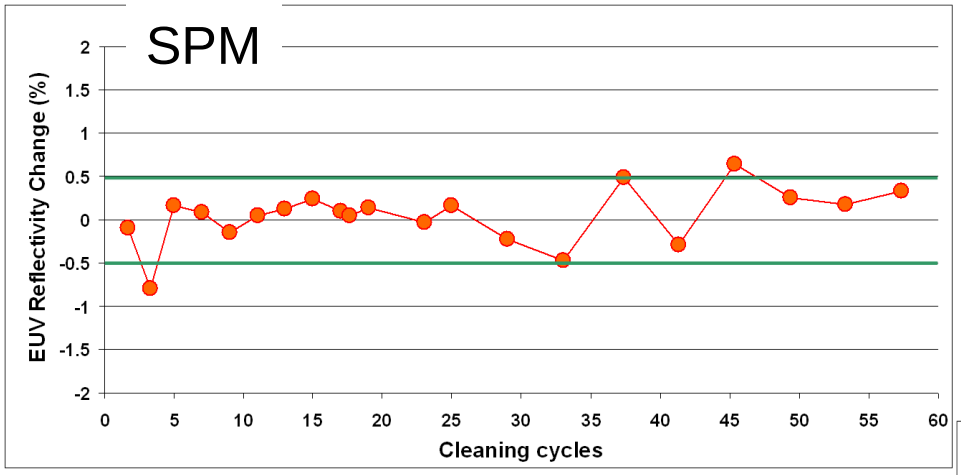
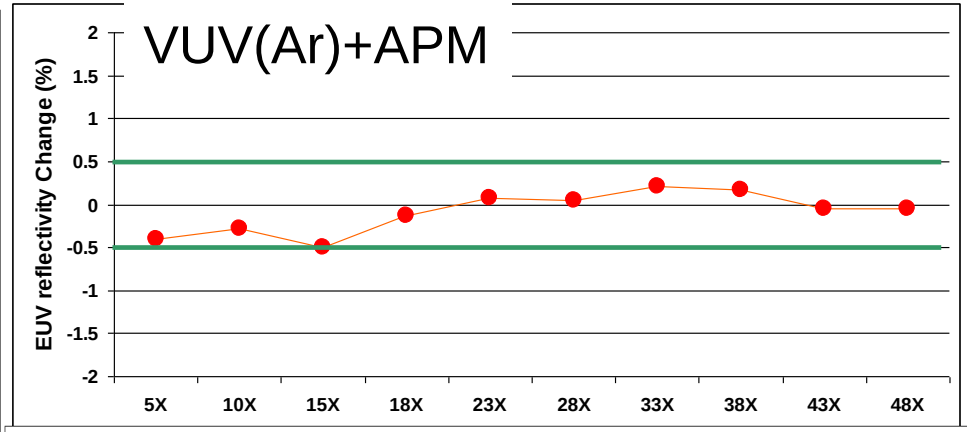
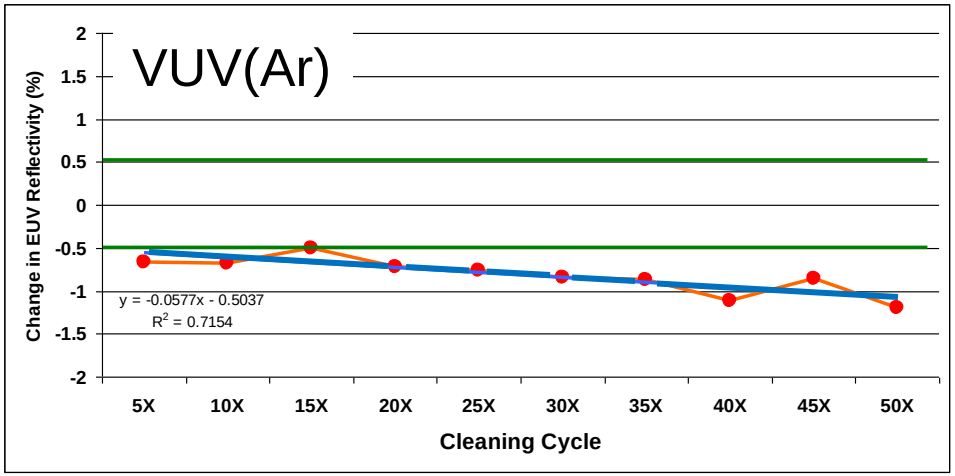
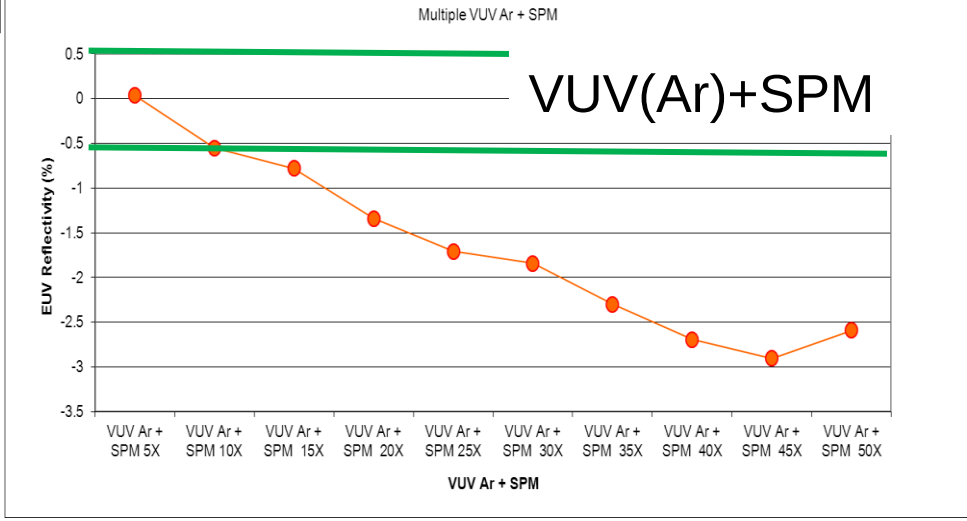
EUV reflectivity loss by individual steps









- Only VUV in Ar atmosphere and VUV+ SPM reduce reflectivity