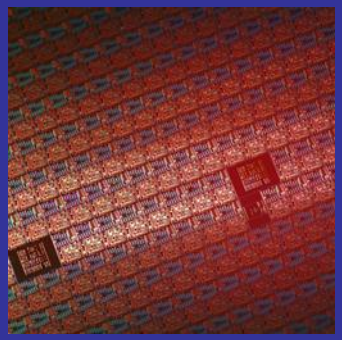
Accelerating the next technology revolution

EUV mask cleaning challenges for 16 nm and 11 nm HP nodes

IEUVI update



Abbas Rastegar
SEMATECH Albany
October 2011

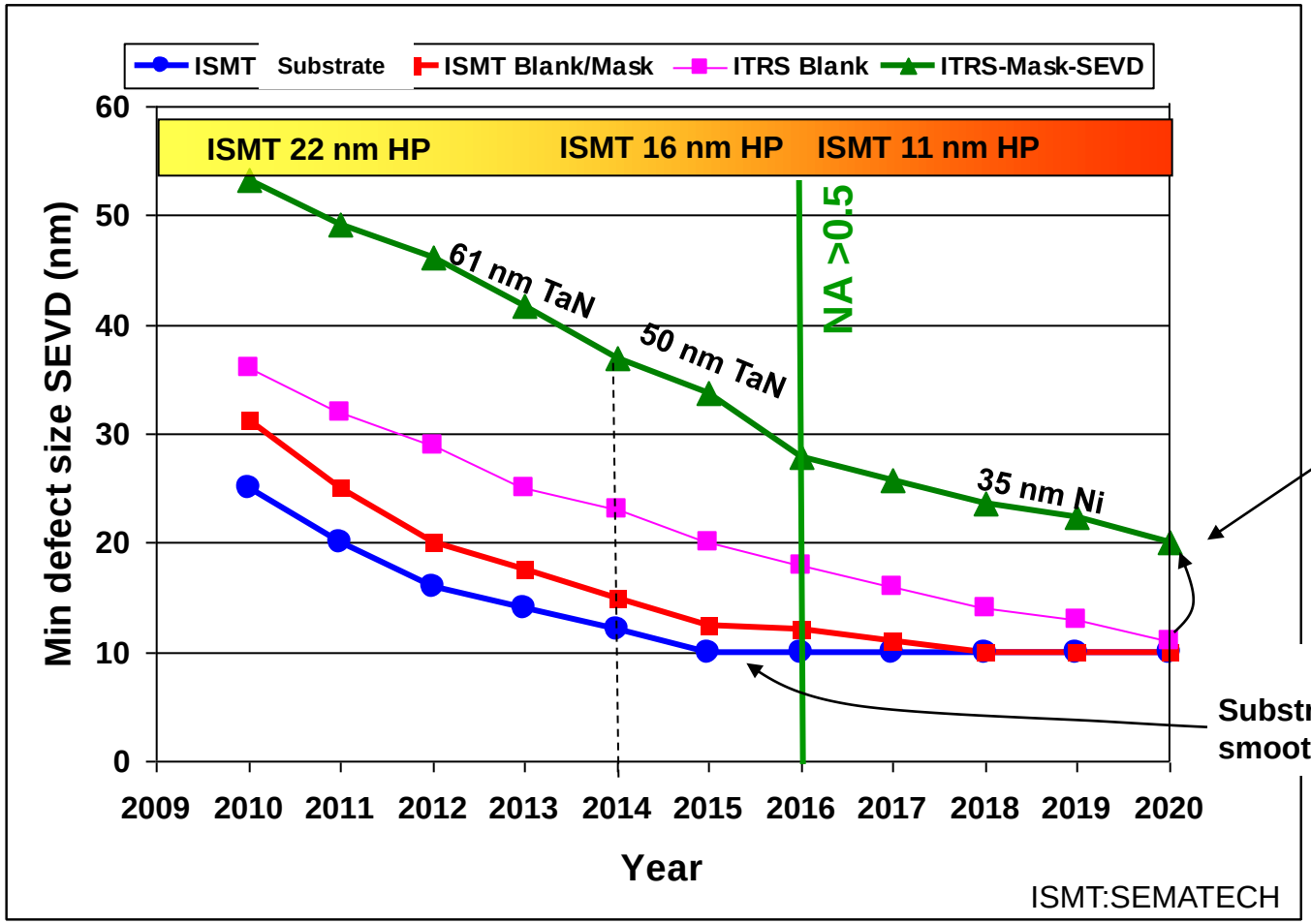
Outline

- Global issues of mask cleaning
- Cleaning Challenges of EUV masks for 22-16 nm HP
  - Mask structure for 16 nm HP
  - Choice of chemistries
  - Cleaning technologies
  - Material issues
  - Particle removal issues
- Cleaning Challenges of EUV masks for 11 nm HP
  - EUV options for 11nm HP node
  - Mask structure for 11 nm HP
  - Choice of materials
  - Material issues
- Summary and conclusions

Global issues of mask cleaning

- **Mask cleaning suffers from general issues of the mask industry concerning lack of resources**
  - Demands for solutions for near time problems
- **Lack of inspection capability**
  - Needed for end users (patterned masks in the fab)
  - Needed for tool development (substrate, blank and patterned)
  - Needed for process development (substrate, blank and patterned)
- **Lack of understanding of a printable particle**.
  - Particle removal depends on size, shape, composition and location of defect
- **EUV surface materials not well established**
  - Absorber, Arc and Capping layer composition and height changes
- **Few suppliers for mask cleaning tools**
  - Small market size limit contribution of large clean tool suppliers
- **Lack of innovative solutions for the mask cleaning**

Mask cleaning roadmap (long-term)



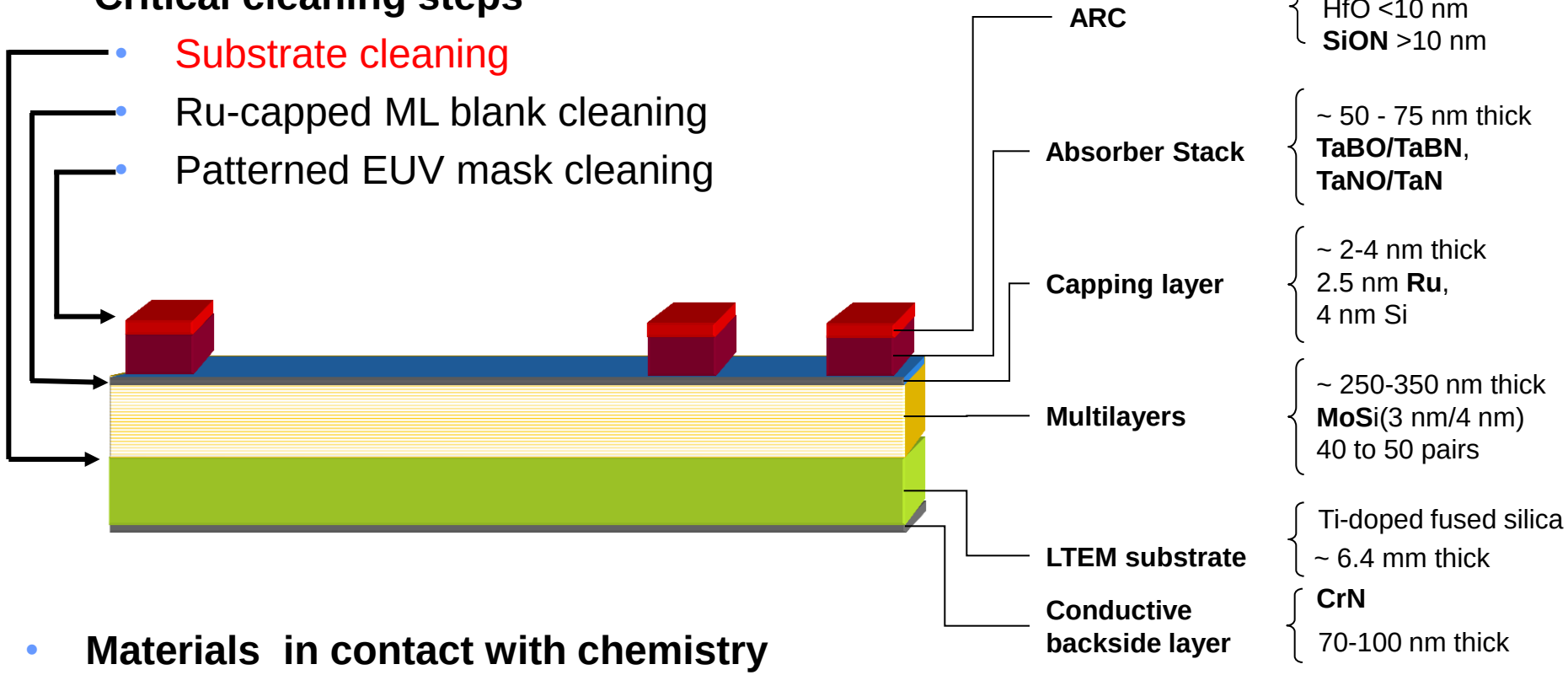
SEVD for spherical defect calculated from absorber defect area

Substrate defects will be smoothed by ML deposition

- Cleaning tools and processes should be able to remove sub-10 nm particles

EUV mask structure and materials for 16 nm HP (64 nm lines on mask)

- **Critical cleaning steps**
  - Substrate cleaning
  - Ru-capped ML blank cleaning
  - Patterned EUV mask cleaning



- **Materials in contact with chemistry**
  - Ti-doped fused silica, Ru, MoSi, CrN, TaNO/TaBO, SiON
- **Surface requirements**:
  - Substrate : roughness 80 pm, flatness 50 nm PV
  - MoSi Ru-capped blank: roughness 100 pm, flatness 50 nm PV

Current challenges of cleaning EUV masks

During mask manufacturing

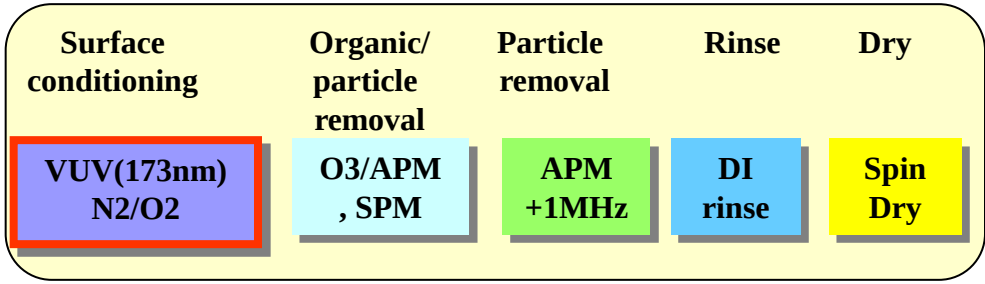
- Post CMP cleaning
- Substrate cleaning
  - Removal of 10 nm particles
  - Cleaning-induced pits
  - Sub-10 nm particle adders
- Ru-capped ML blank cleaning
  - EUV reflectivity loss
  - Cleaning induced pits
  - Sub-30 nm particle adders
  - Surface contamination
- Patterned EUV masks
  - Sub-30 nm particle removal from contacts and trenches
  - Ru oxidation/removal
  - Absorber and ARC etch

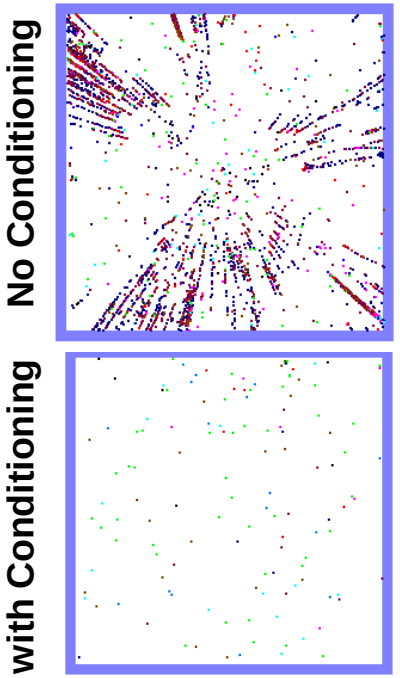
During mask repetitive use

- Material challenges
  - Ru cap oxidation and etch
  - Ru contamination
  - Absorber etch and change of CD
  - CrN durability
- Particle removal challenges
  - Sub-30 nm particle removal from contacts and trenches
  - Sub-30 nm particle adders
  - Cleaning-induced pits
- Lifetime and storage challenges
  - Progressive defects
  - EUV reflectivity loss
  - Surface contamination

Cleaning technology choices for EUV masks

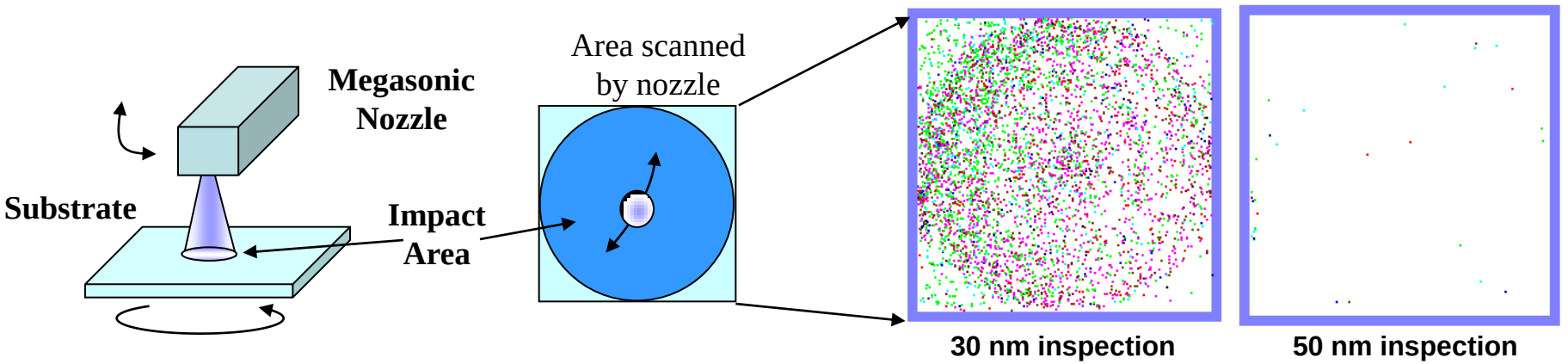
- Surface conditioning
  - Optical
    - VUV (172 nm) in gas atmosphere
    - In situ UV in solution
  - Chemical
    - SPM
- Particle removal
  - Megasonic (~ 900 KHz → 4 MHz)
    - Used by all mask and wafer cleaning tools
    - Nozzle configuration or proximity flat transducers
  - Spray (low speed to high speed jets)
    - Used by all mask and wafer cleaning tools
    - Liquid or gas/liquid sprays
  - Cryogenic (CO_2, Ar)
- Drying
  - Spin dry
  - Marongoni-based

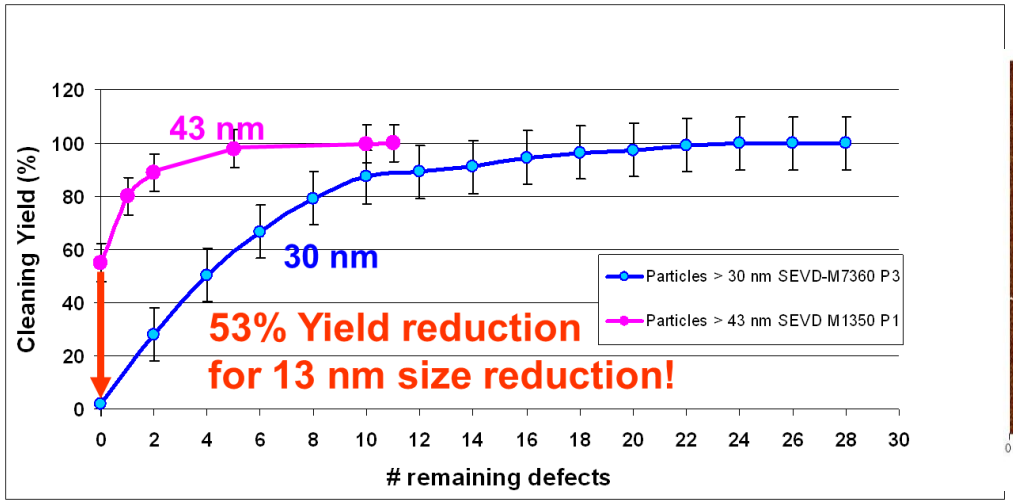


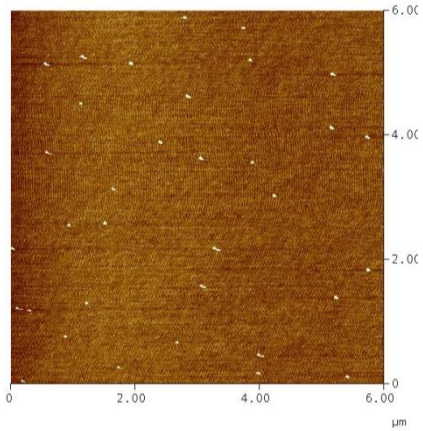


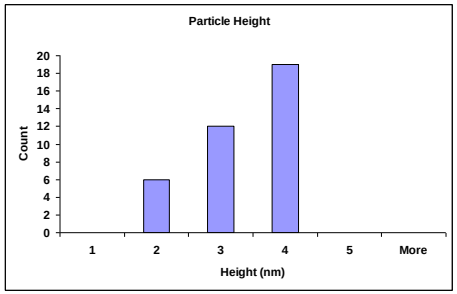
Out of box cleaning ideas are needed for EUV
No new chemistry has been introduced for EUV

Challenges of substrate cleaning: Pits, PRE, adders









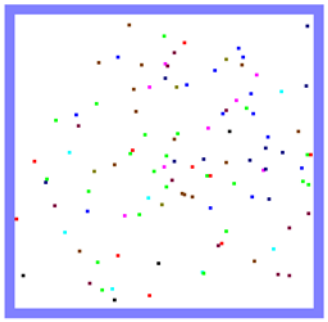
- **For sub-30 nm defects current cleaning processes have low PRE, create pits, and generate non-detectable particles (~ 4 nm high)**

Challenges of Ru cap multilayer cleaning: Adders, pits, PRE,

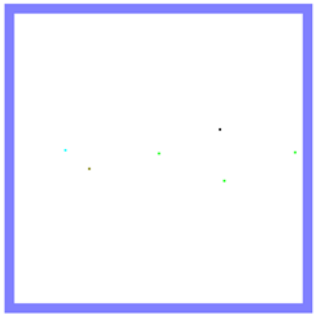
Frontside

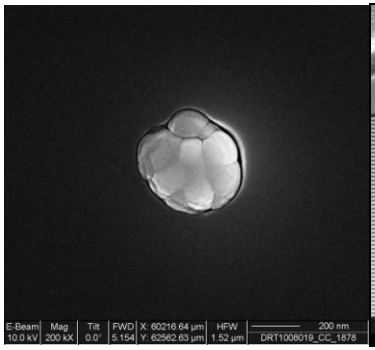
Before cleaning

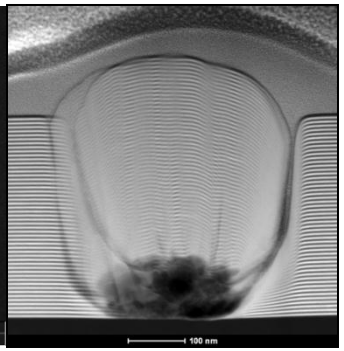
After cleaning



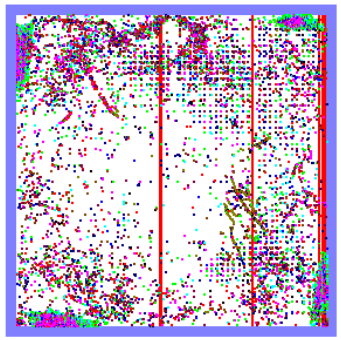
Added by cleaning

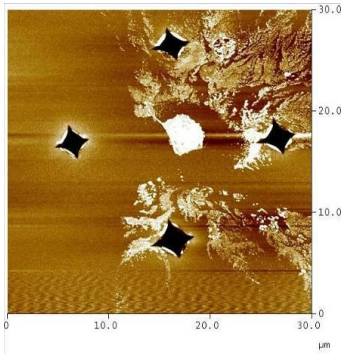


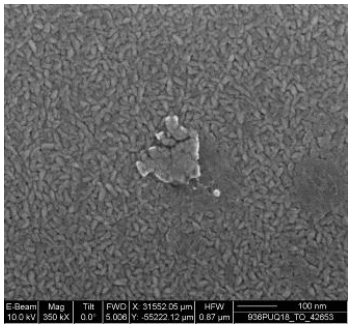


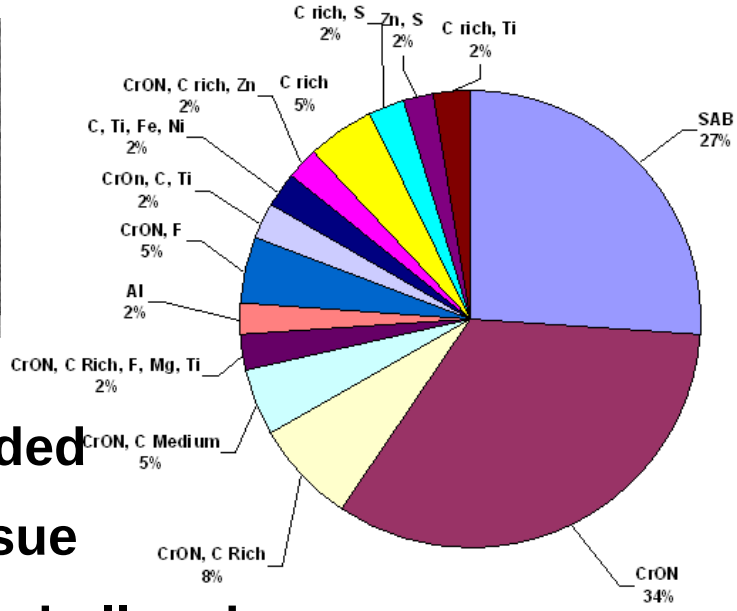


Backside



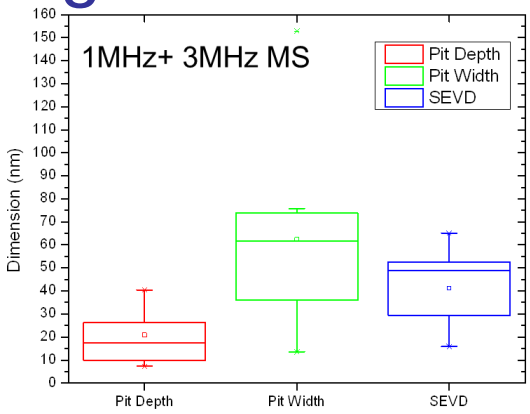


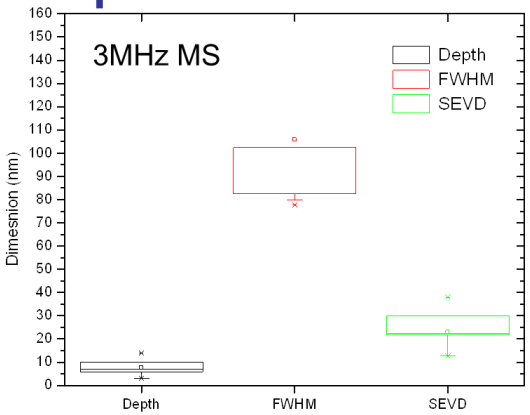




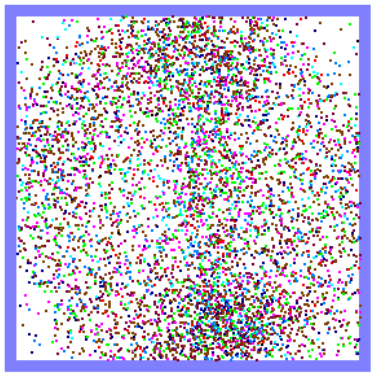
- **Many particles on top surface are embedded**
- **Particles added by the cleaning are an issue**
- **Removal of backside metallic particles is challenging**

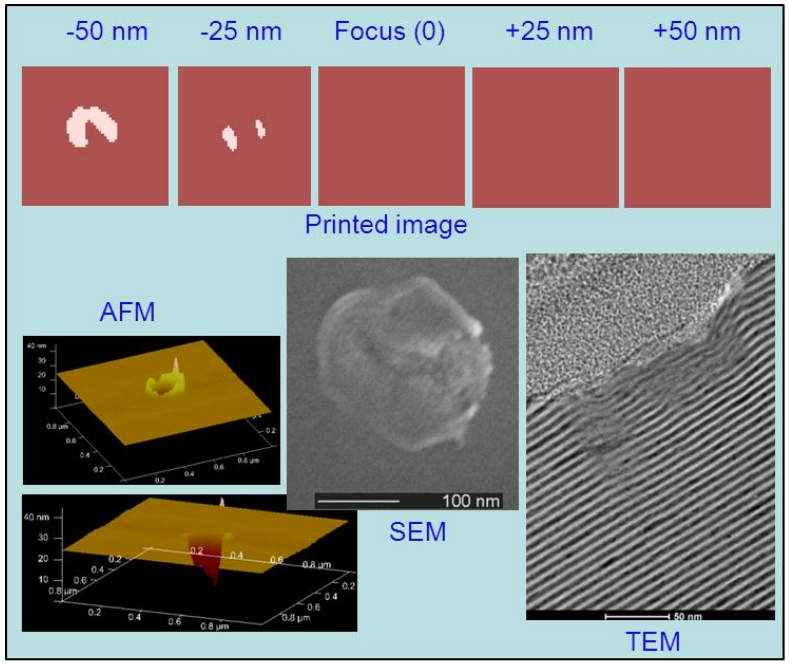
Particle removal challenges: Megasonic induced pits on Ru

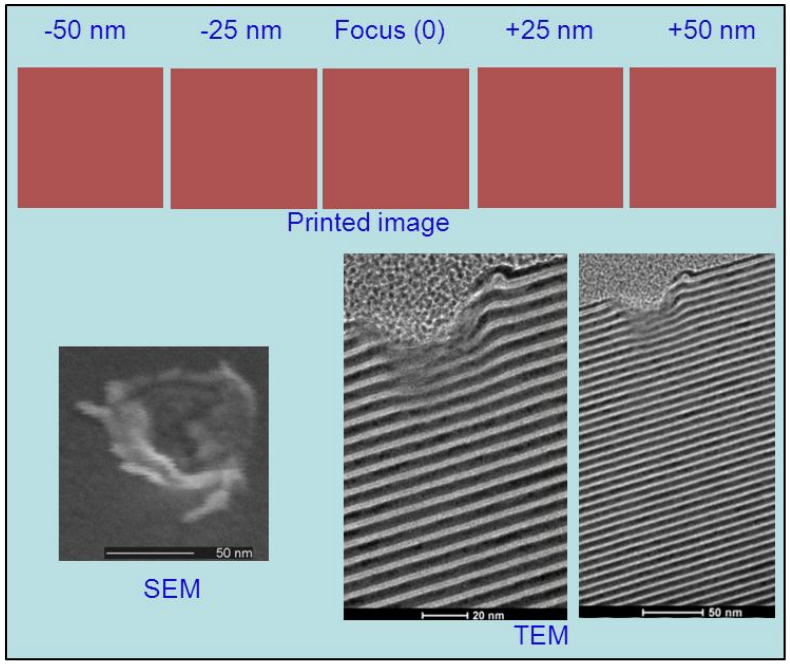




After 40X cleaning (1 MHz,3MHz)

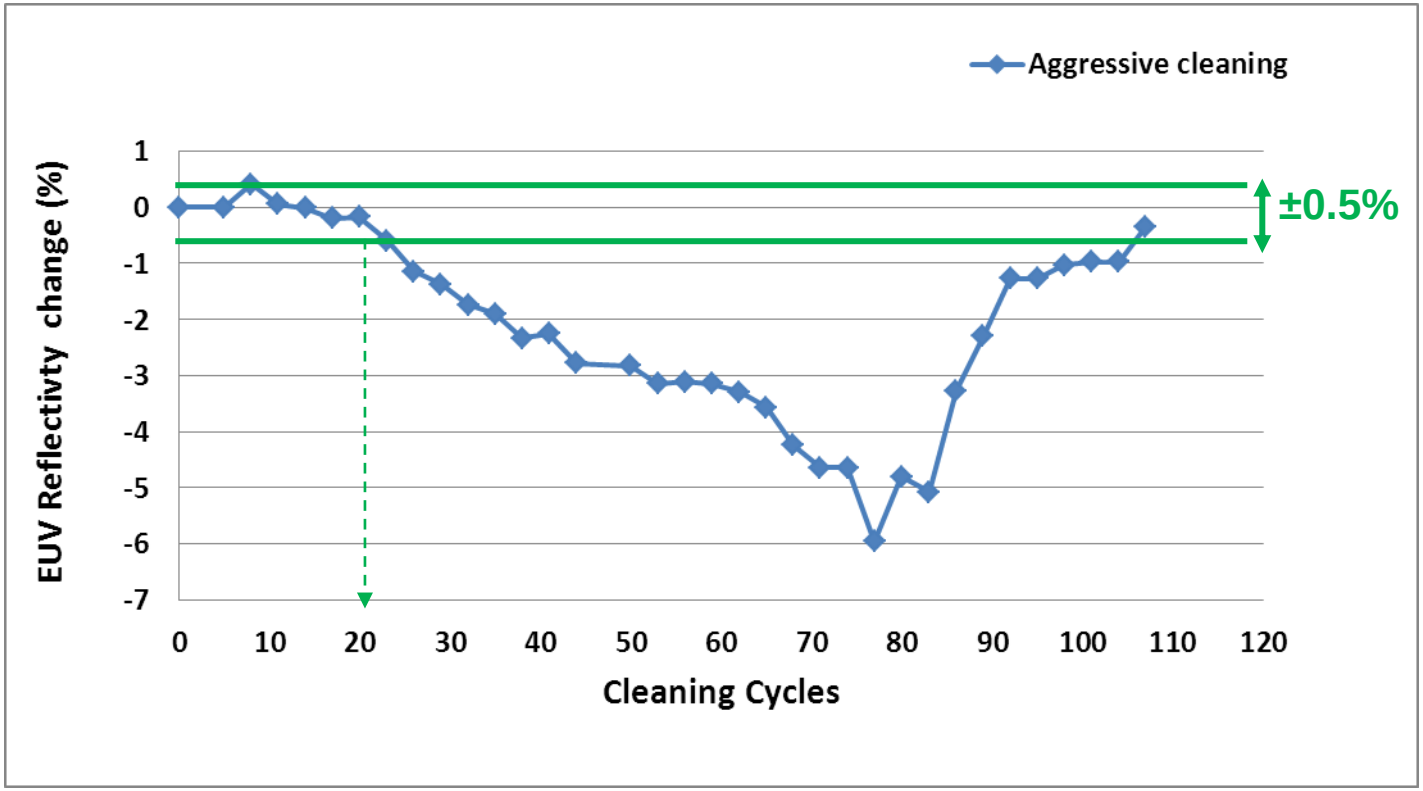






- Some megasonic induced pits are printable (H. Kwon- BACUS 2011)

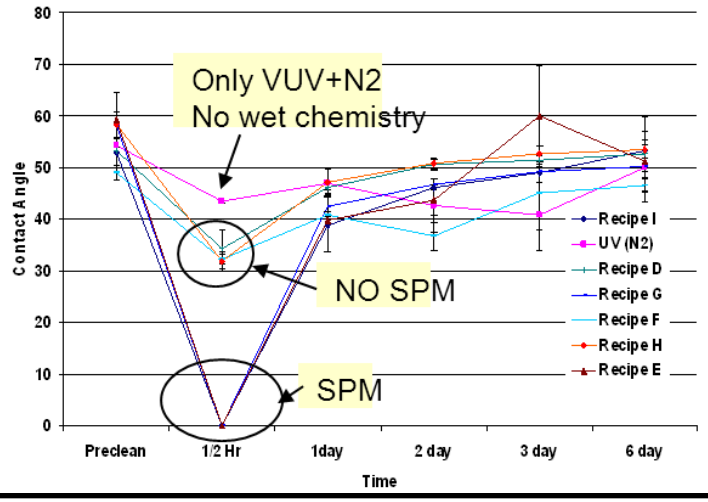
How many times an EUV mask be cleaned?

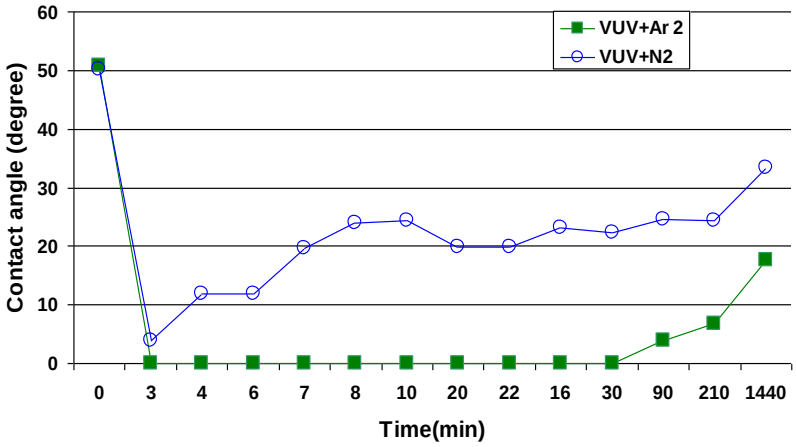


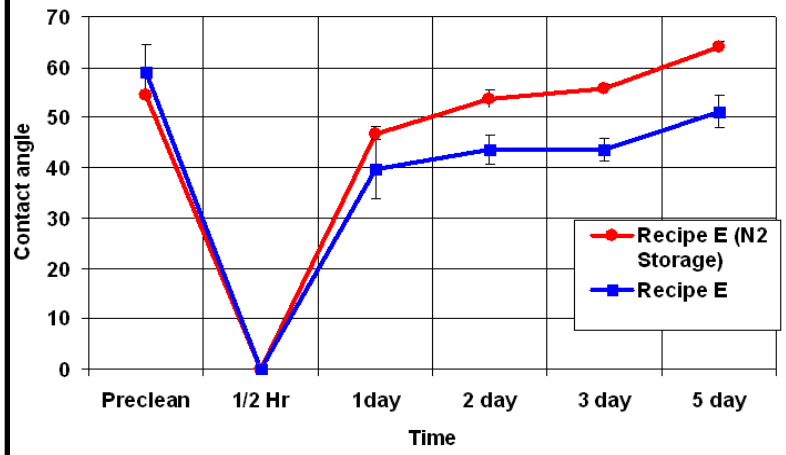
- EUV reflectivity (R_{max}) dropped below spec after 20X cleaning
- What is the mechanism of EUV reflectivity loss?

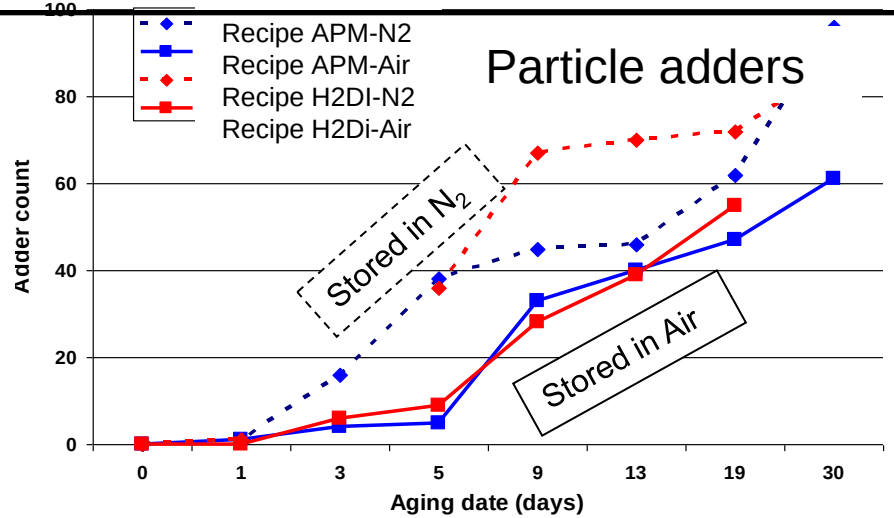
EUVL presentation on Tuesday

Material issues: Ru
Ru cap contamination



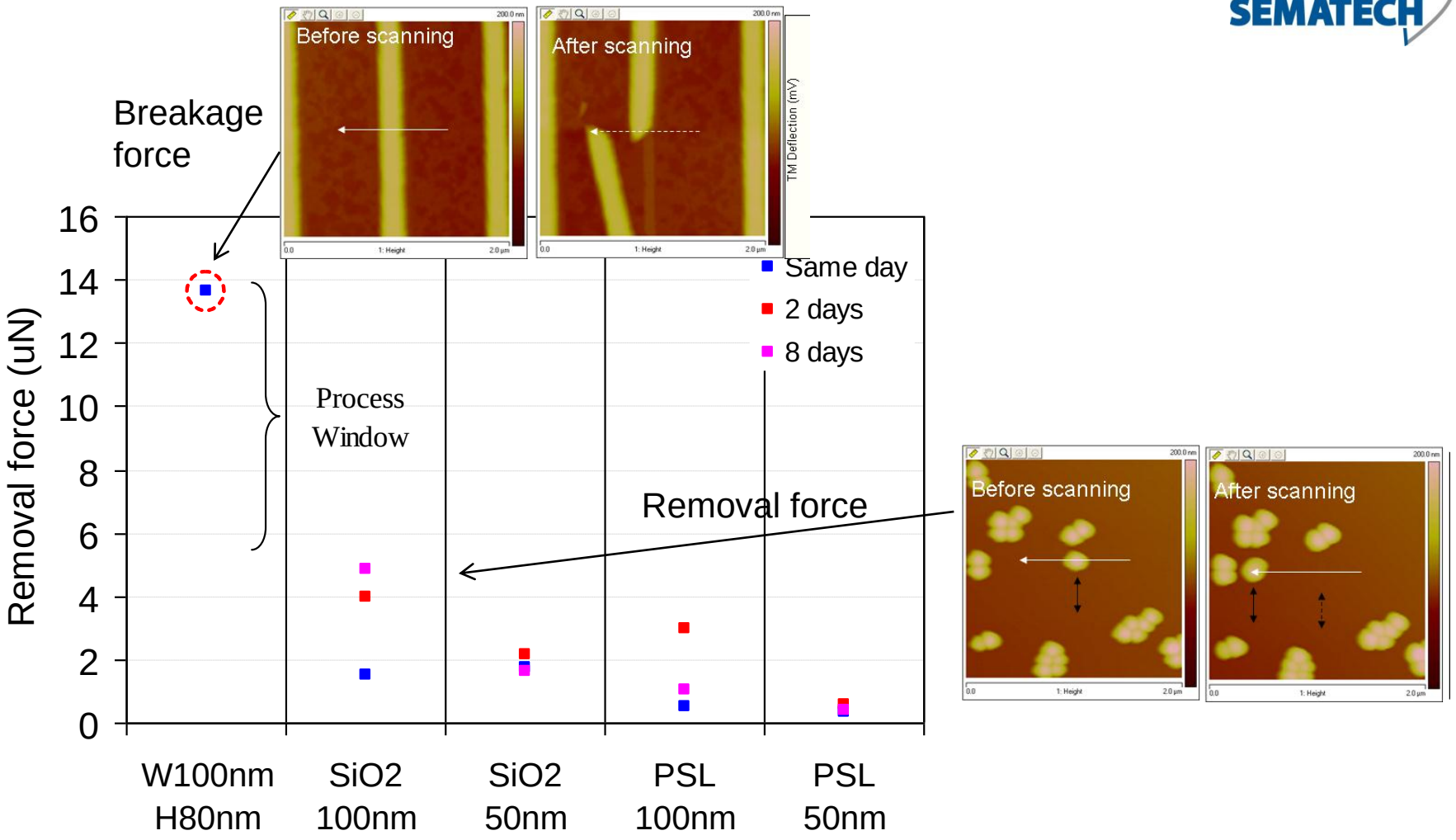






Ru act as a getter and very fast get contaminated

EUV mask durability to pattern damage

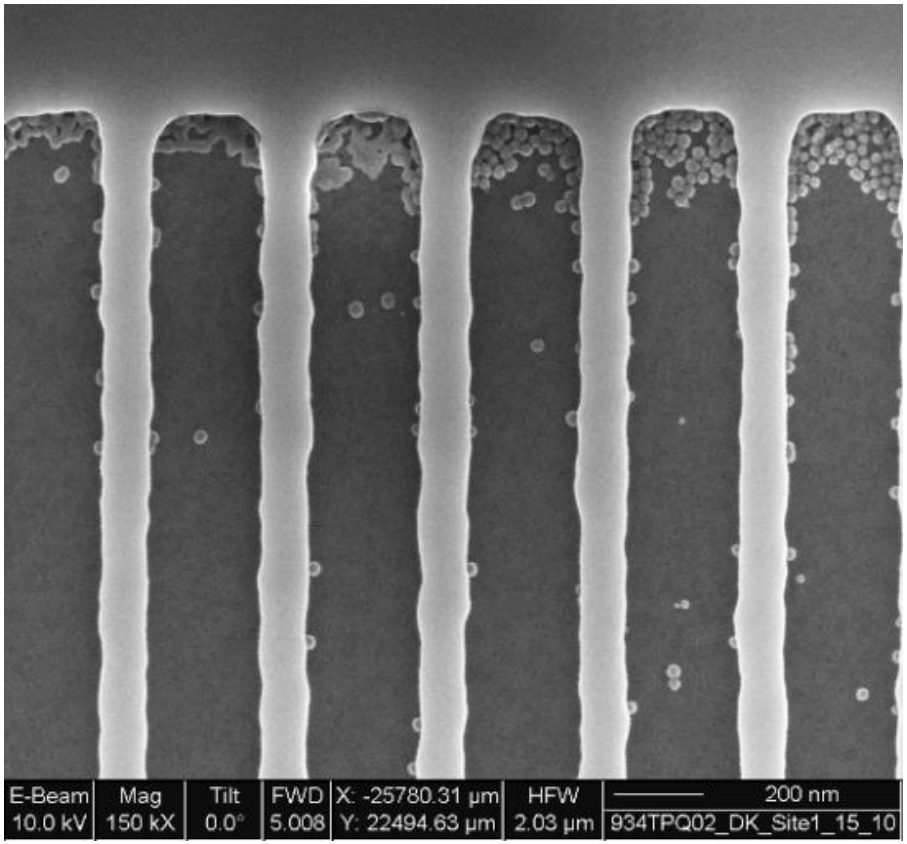


- **EUV masks are less prone to pattern damage by megasonics thantheir optical counter parts**

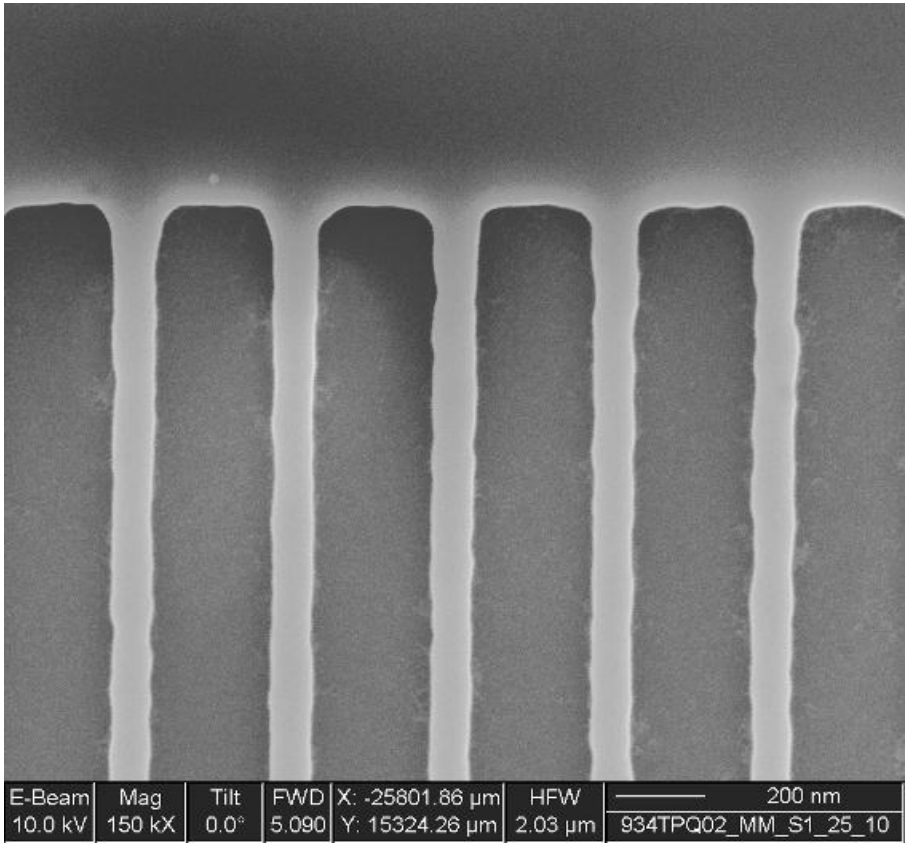
Shimomura *et al.,* SPCC11, BACUS 11

Cleaning challenges of EUV patterned masks: TaN absorber etch by SPM

After 28 nm SiO2 deposition

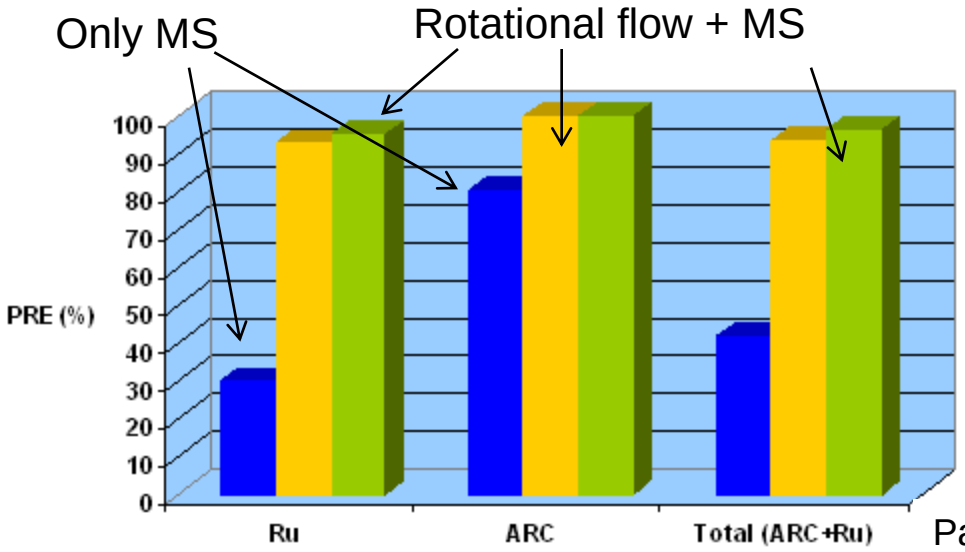


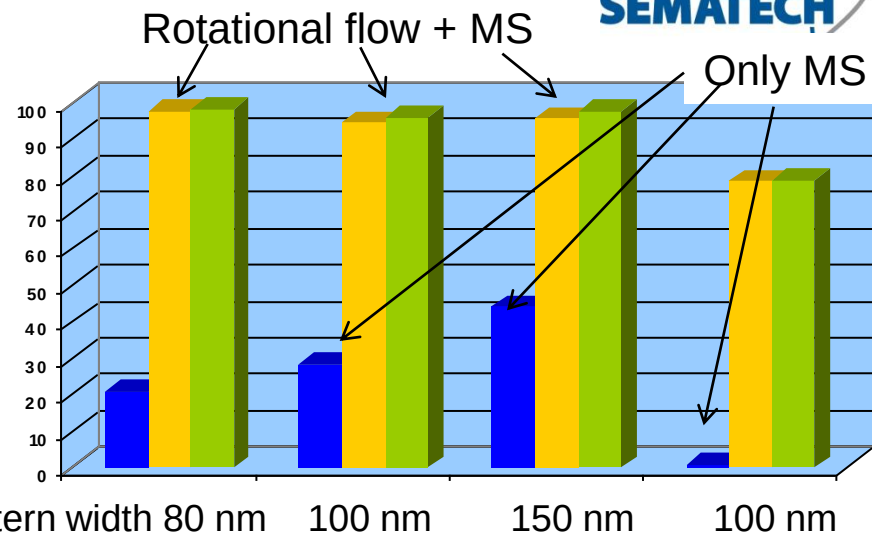
After multiple SPM+MS cleaning

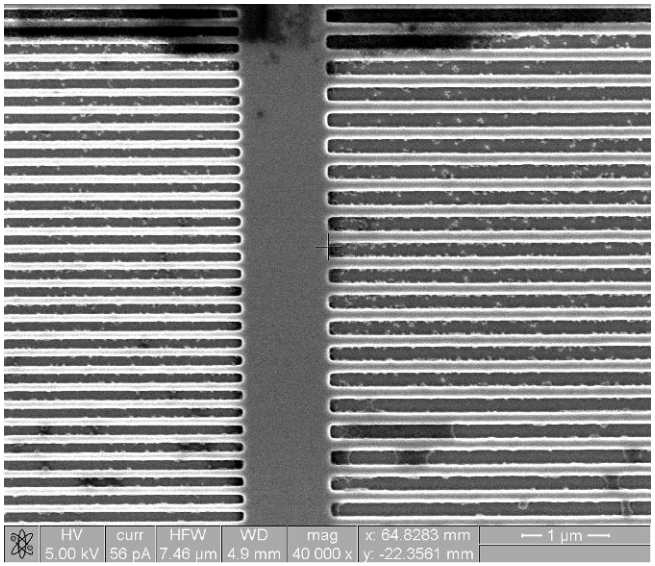


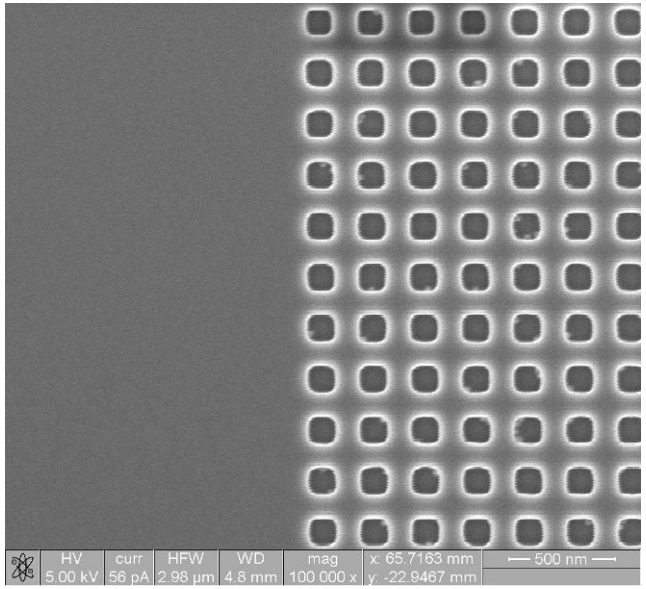
- **28 nm SiO_2 particles were removed by SPM cleaning process**
- **TaN absorber line got etched, CD increased, LER reduced**

Particle removal challenges: flow









No plate rotation

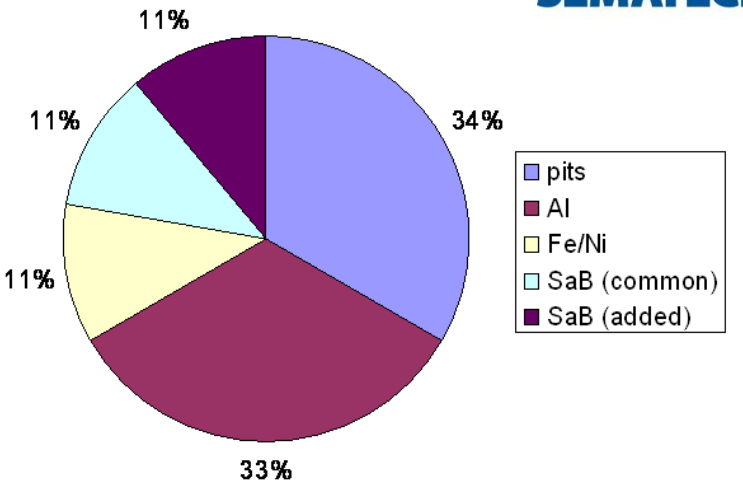
SC1

POR

Megasonics cannot remove particles without flow close to surface

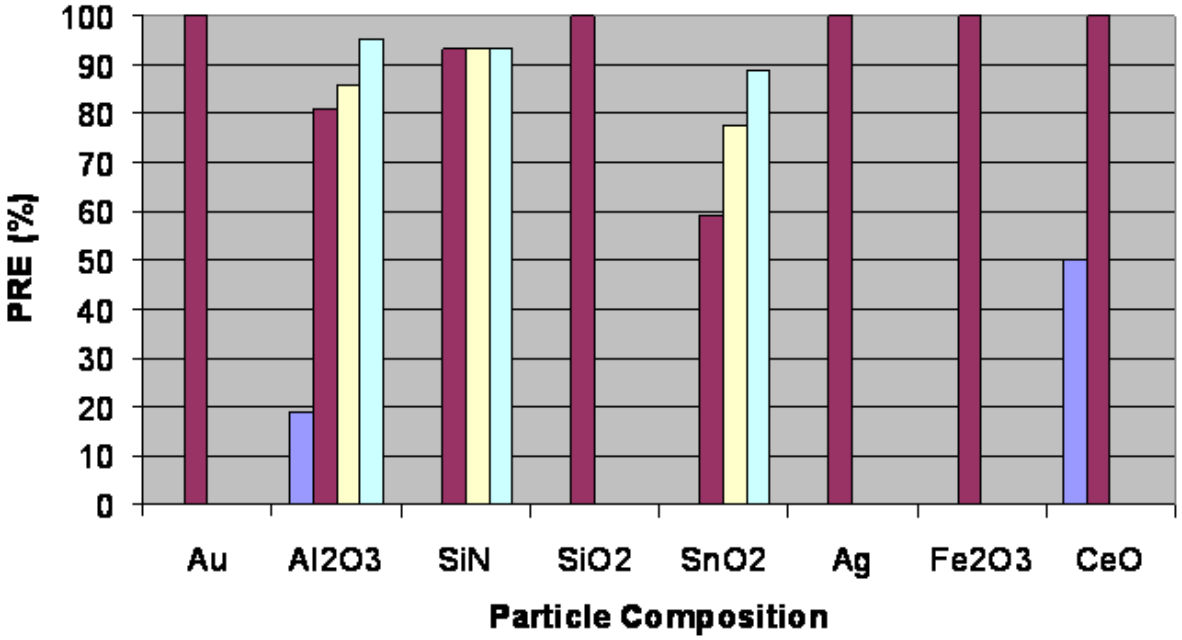
Particle removal challenges
Metallic particles

- **Current cleaning process do NOT remove metals**
- **Native metal particles are not removed**
- **Most Deposited particle metals are removable**



DI rinse
SC1 18 min
SC1 40 min
O3+SC1

Particle Composition	Size -- Advertised	Number of Particles Analyzed
Au	40 nm	12
Al2O3	40-80 nm	21
SiN	30 nm	15
SiO2	15 (80) nm	10
SnO2	60 nm	27
Ag	60 nm	26
Fe3O4	50-60 nm	18
CeO	50-100 nm	2

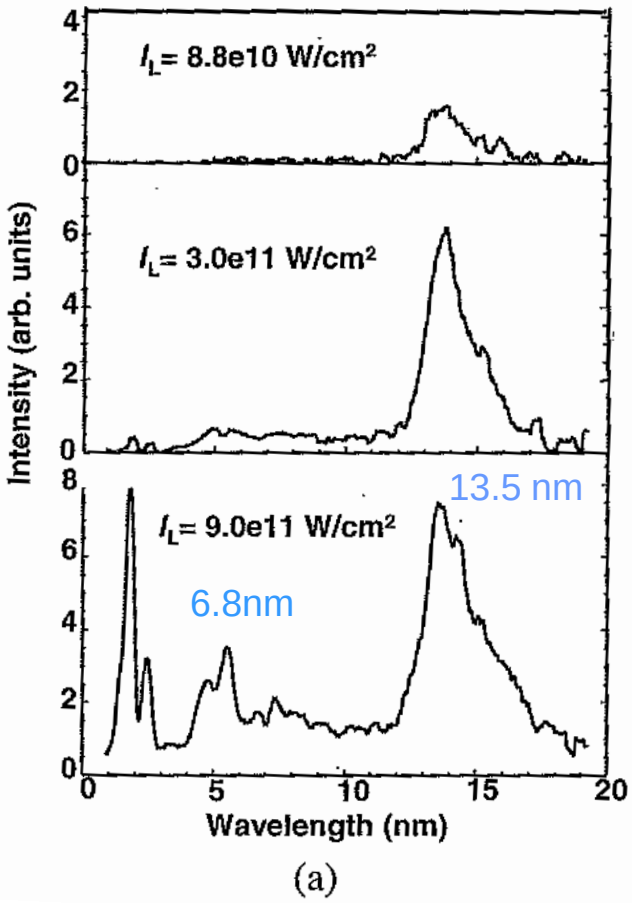


EUV options for 11 nm HP

$$Minimum\ HP = \frac{K_1\,\lambda}{NA}$$

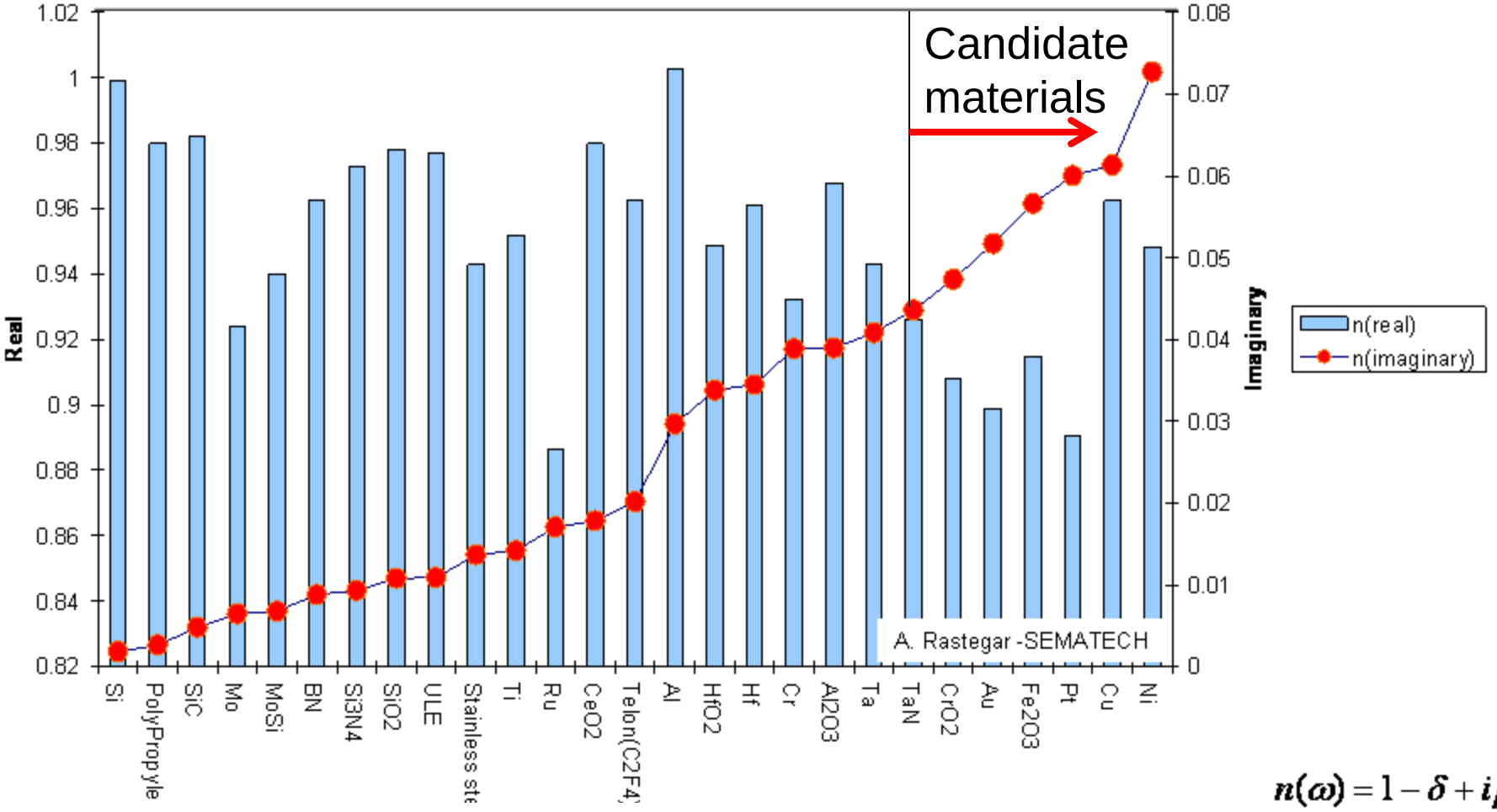
- Reduce the wavelength
  - Xe→ ~ 11 nm
    - no real advantage
  - Sn→ 6.8 nm
    - Almost ½ intensity of 13.5 nm
    - Requires high power source
  - EUV blank film structure should change(Γ)
- Increase NA
  - Impact s mask structure and materials
- Reduce the K_1
  - Tool dependent

Emission spectra of tin plasma



EUV sources by V. Bakshi

Materials choices for 11 nm HP node
Index of refraction at λ= 13.5 nm



$$n(\omega) = 1 - \delta + i\beta$$

Mask shadowing effects requires thin absorber

Thinner absorber requires higher absorption

were obtained from LBNL http://www-cxro.lbl.gov/

Challenges of cleaning for 11 nm HP EUV masks

- Assuming EUV wavelength remain 13.5 nm
  - NA→ >0.5 → 8 mirrors optics→ Chief Ray Angle → >10
  - MoSi → Multi stack with different periodicity → impacts blank defectivity
  - ML deposition processes smooth sub 10 nm substrate pits
  - There should be no megasonic induced pits >10 nm
- ARC materials
  - Actinic inspection requires new materials (Ni,Pt,Cu,..)
- Absorber layer
  - New materials (Ni,Pt,Cu,..)
- Capping layer
  - New materials (TiO2, V2O5, Ru, Ta,..)
  - Depends on choice of absorber, Arc, and availability of selective absorber etch processes

Summary and Conclusions-1

- Substrate cleaning
  - Substrate defectivity is responsible for about 80% of the blank defects
  - Lack of inspection capability below 20 nm is the most critical challenge for progress in substrate cleaning
  - No cleaning technology is available for 10 nm particle removal
  - To reduce particle adders sub 10 nm filtration of chemicals and DI water with proper flow rate is required but currently is not available
  - None of the smoothing techniques have been as successful as CMP (SEMATECH poster in EUVL)
  - LTEM CMP is the most critical step in manufacturing EUV mask substrates (impacts defects, roughness, flatness, surface hardness). Very limited resources work on EUV substrate CMP!!
  - Post CMP cleaning processes need to be optimized together with final cleaning processes.(Complementary processes)
  - Backside CrN deposition process can impact LTEM front side defectivity

Summary and Conclusions-2

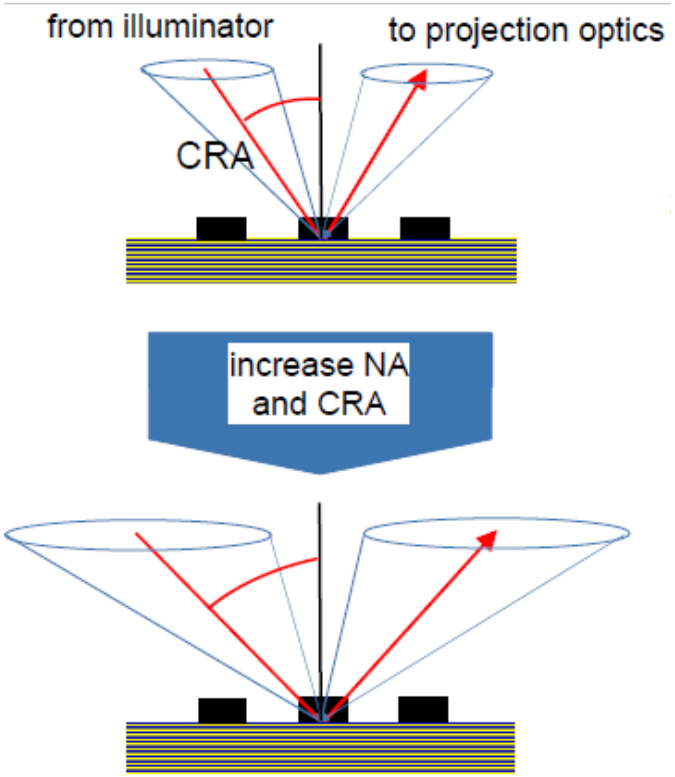
- Patterned EUV mask cleaning
  - Currently there is not enough data for the size and composition of printable particles on top of EUV masks
  - Absorber and ARC etch by oxidizing chemistries is a challenge
  - Removal of sub 30 nm particles from inside of trenches and contact holes for 16 nm HP is a challenge
  - EUV reflectivity loss by multiple cleaning is challenging
  - Pit induced by the cleaning on Ru surface is an issue but no pit defects have been detected on the patterned EUV masks (Lack of inspection capability?)
- Mask cleaning at 11 nm HP node
  - Many materials are still unknown. However SEMATECH has started cleaning feasibility studies of potential materials
  - There is a need for collaboration among all surface cleaning communities for tackling EUV mask cleaning issues. SEMATECH supports such collaborations

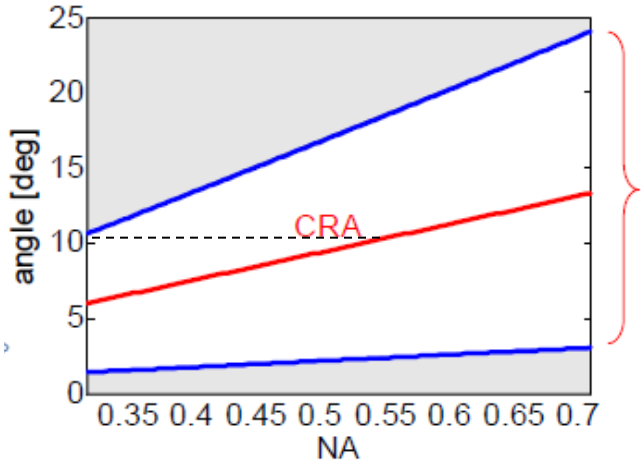
Thank You

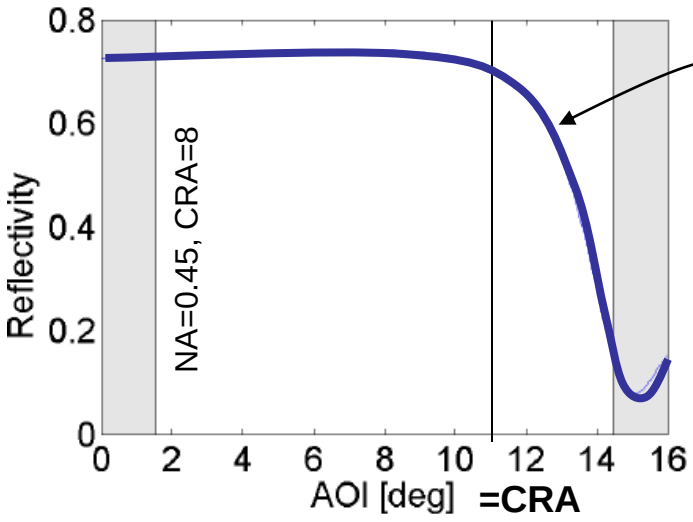
Chemistry choices for EUV masks

- Traditional chemistries are still in use for mask cleaning
  - SPM (H_2SO_4/H_2O_2) (8→5:1)
  - APM ($NH_4OH/H_2O_2/H_2O$) (1:1:5→8)
  - O_3 based (O_3/H_2O) , (O_3/APM) (O_3 :6→ 50 ppm)
  - H_2 based (H_2/H_2O) , (H_2/NH_4OH) (1→ 1.4 ppm)
  - Dilute Ammonia (H_2O/NH_4OH) (1→ 6 ppm)
  - Clustered water (H_2O/NH_4OH)
- HPM ($HCl/H_2O_2/H_2O$) , Dilute HF is NOT used due to many metallic surfaces in EUV masks
- Solvents are not used due to risk of progressive defects and (optical induced) haze observed in optical masks
- No new chemistry has been introduced for EUV

Requirement of ML structure change for NA>0.5



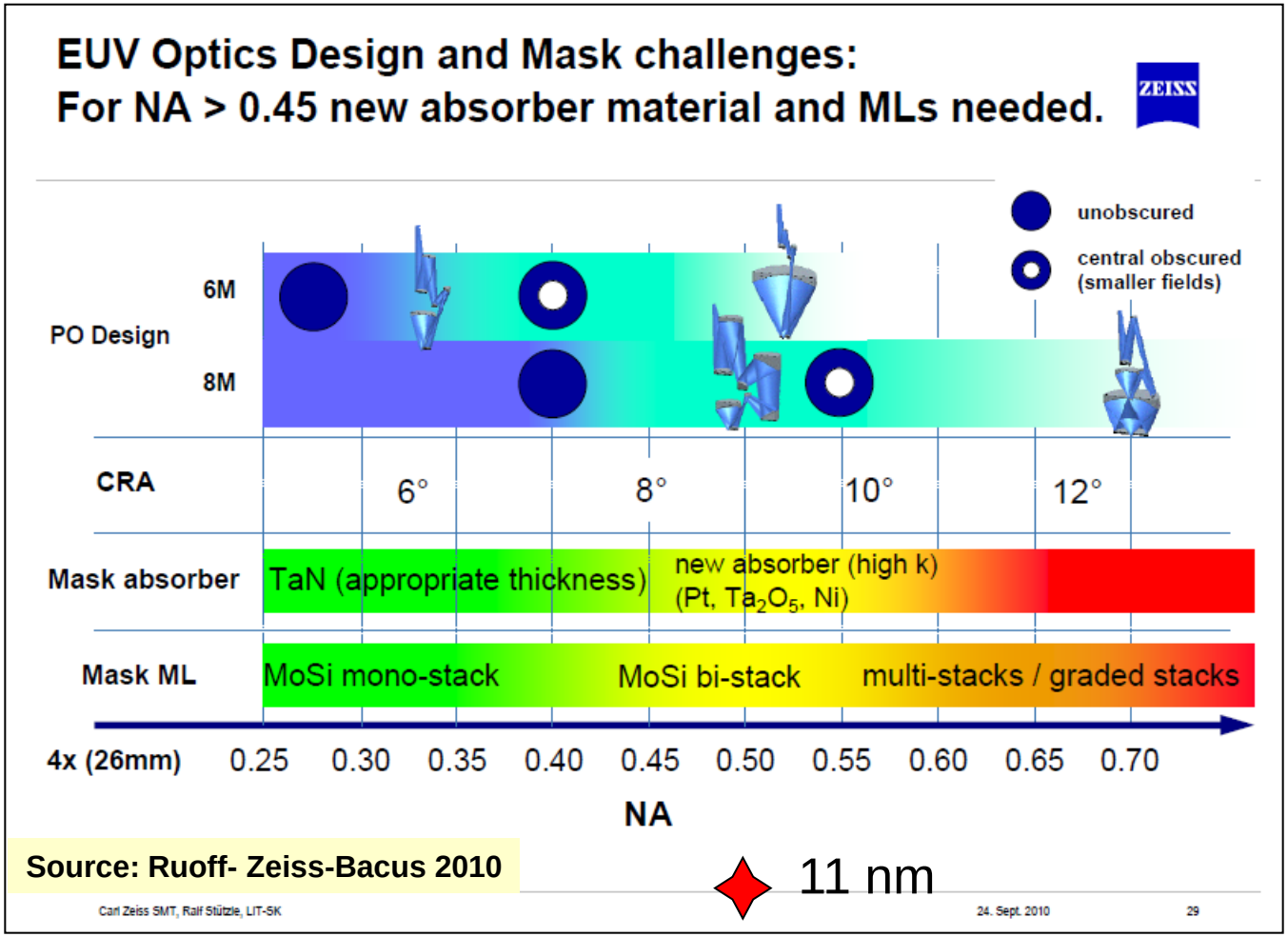




In CRA>11,Na >0.5 EUV reflectivity will drop
ML structure should change

Source Zeiss-Bacus 2010

Impact of EUV @ NA>0.5 on mask



- New absorber material and multilayer structure will have impact on choice of the cleaning chemistries