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Effect of TMAH cleaning solution for removal of contaminants from EUV mask surface

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Outline

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- Issues on contaminants on EUV mask

02 Research Objective

03 Experimental Procedure

04 Results and Discussion

- Particle removal on EUV mask surface
- Carbon contamination removal on EUV mask surface

05 Summary

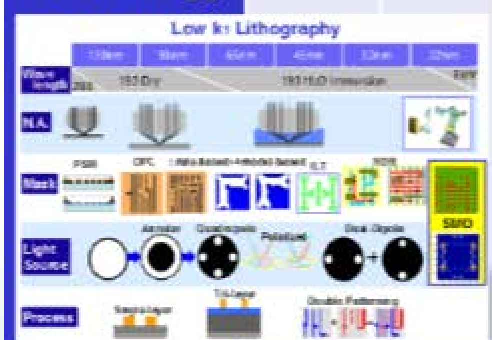
Scaling Scenario : Lithography

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
MPU	32nm	22nm			16nm					11nm	
Logic	32nm		22nm			16nm				11nm	
DRAM	2Xnm			2Ynm / 1Xnm			1Ynm or Emerging Memory				
NAND	2Xnm	1Xnm		1Ynm or 3D		3D		3D or New			

Technology

- ArF Immersion
- ArF Immersion DP(SADP, LELE, LLE), NTD, SMO
- ArF Immersion Low-k1 Lithography DP Multiple SADP(1/4) , Spacer & Cut
- EUV Lithography → EUV Extended (DP…)
- Direct Writing / EB, Nano Imprint & Directed Self Assembly

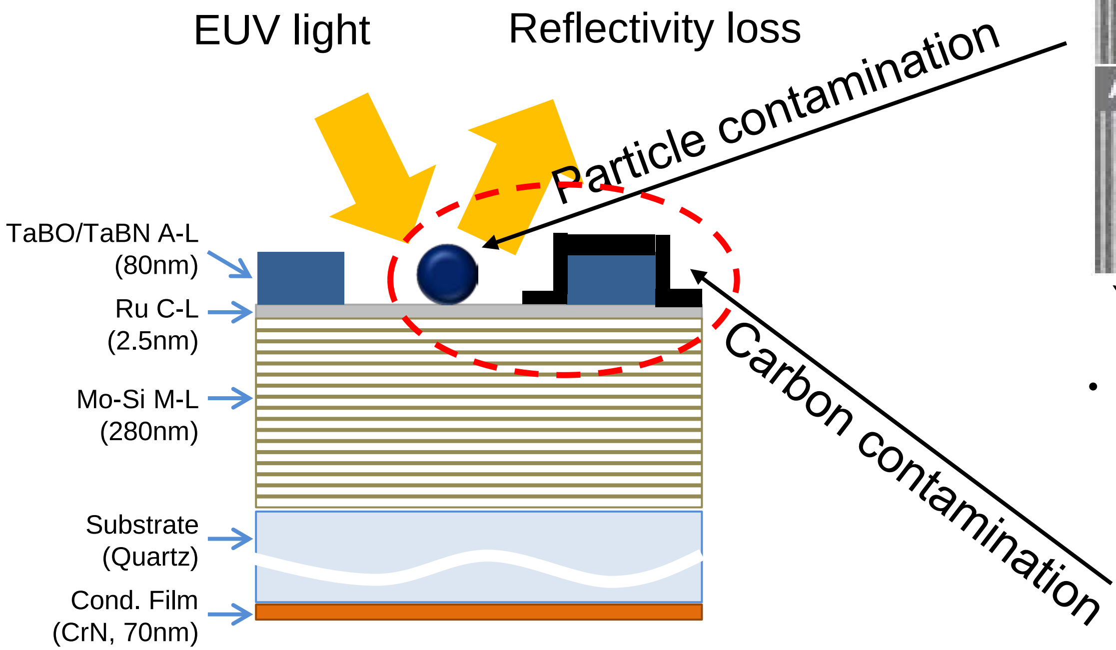
*DP Double Patterning
*SADP Self-Aligned Double Patterning
*LELE Litho Etch Litho Etch
*LLE Litho Litho Etch
*NTD Negative Tone Development
*SMO Source and Mask Optimization
*MP Multiple Patterning



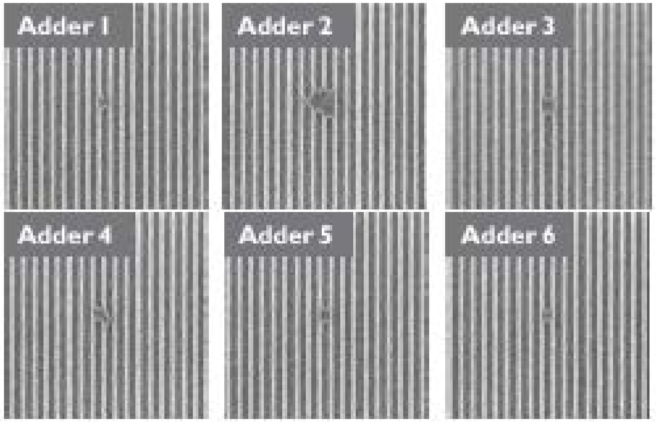
G. Chung, “Partnership to build a better future, and leading edge collaboration”, SPCC (2012)

Issues of EUV mask contamination

❖ **EUV mask contamination**

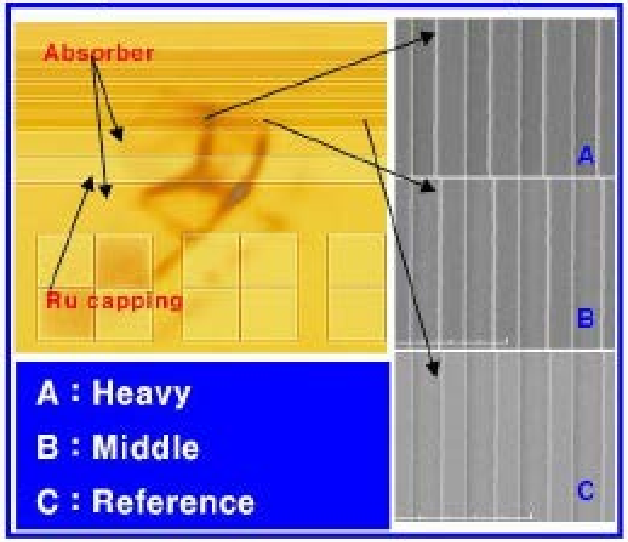


- Pattern defect on wafer by particle on EUV mask



Y. Hyun, et al., Proc of SPIE 9422, 94221U1 (2015)

- CD change by carbon contamination on EUV mask

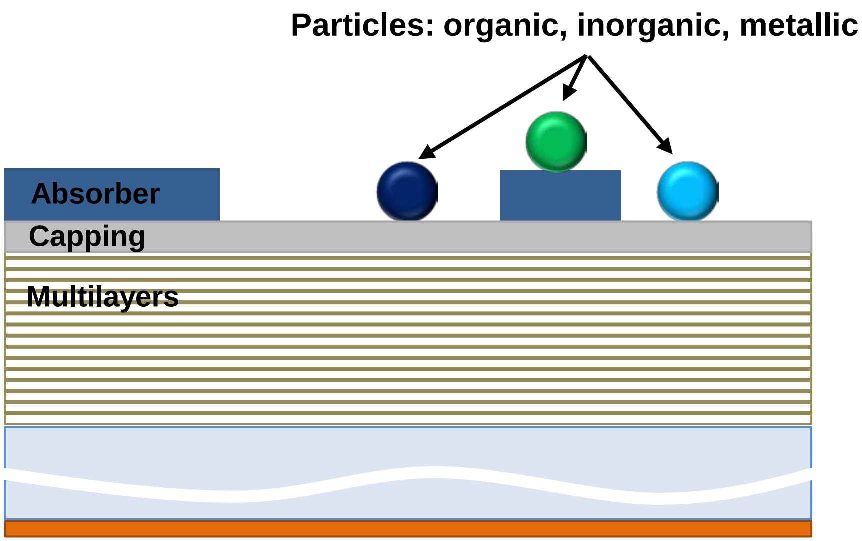


H.S. Lee, et.al, Proc. of SPIE Vol.7748, 774804 (2010)

- **Particles: pattern defects on Si wafer**
- **Carbon contaminant: pattern CD change**

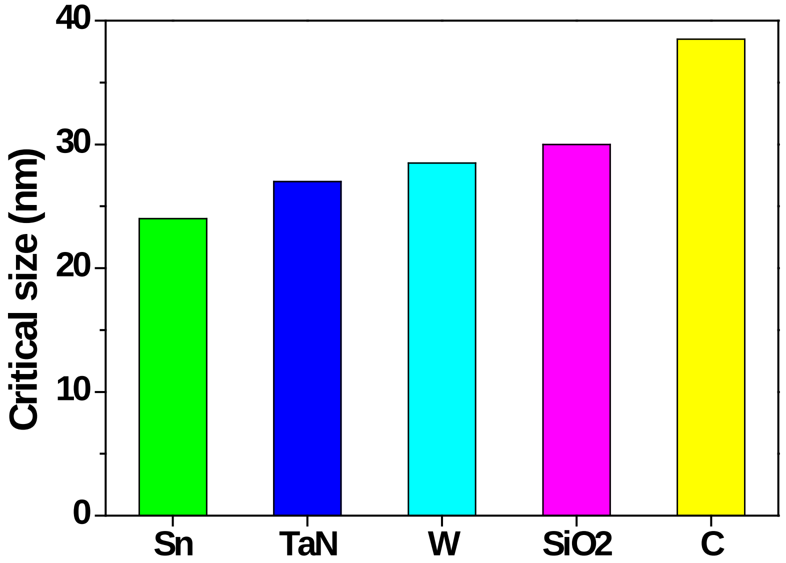
Particle contamination on EUV mask

❖ **Schematic of particle contamination on EUV mask**



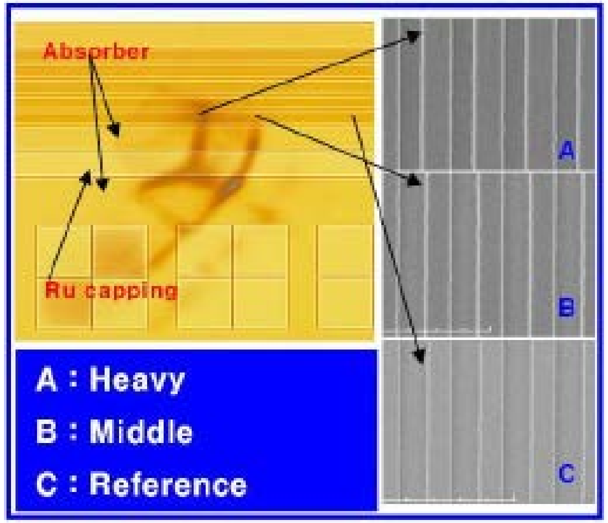
❖ **Critical particle size w/ various materials on 16 nm HP node**

Simulation condition
- Fast Litho tool
- Pseudo-Spectral Time Domain (PSTD) method
- Parameters: n, k, thickness

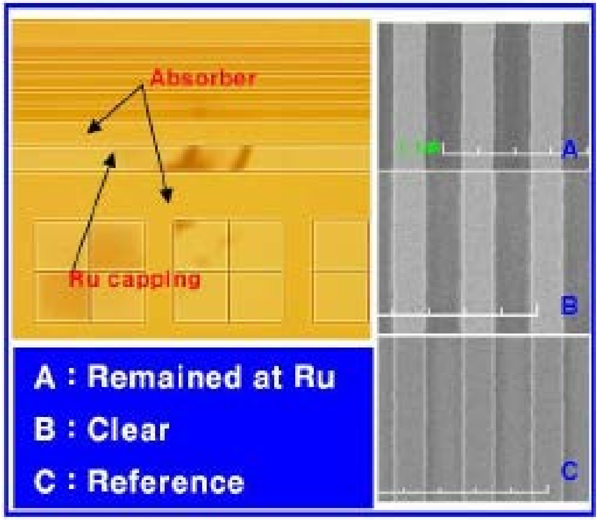


- **Various type of particle can be deposited on the capping or absorber layer**
- **All types of particles should be removed from EUV mask surface (Capping, Absorber)**

Issue of carbon contaminant removal



Contamination



Cleaning

H.S. Lee, et.al, Proc. of SPIE Vol.7748, 774804 (2010)

Carbon contaminant was removed from ARC surface but not from Ru surface

Why carbon contaminant not removed from Ru surface ?

- **Carbon contaminants on Ru surface have higher density and thickness than on ARC surface ?**
- **Carbon contaminants have higher adhesion with Ru than ARC surface ?**

H. Lee et al., ECS Transactions, **58** (6), 93 (2013)

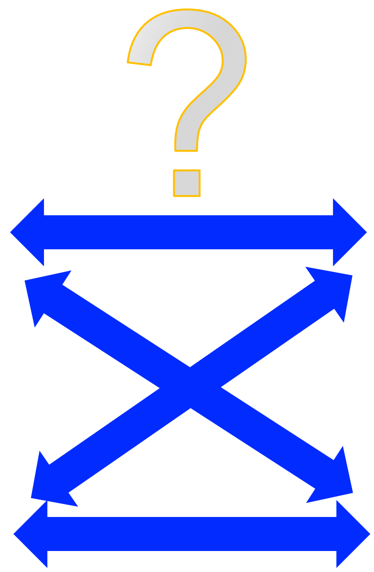
Research objective

Surface interactions between contaminants and EUV mask surfaces

Contaminants

Particles
(inorganic, organic)

Carbon contaminant



EUV mask surface

Ruthenium
(Capping layer)

Tantalum nitride
(Absorber layer)

Experiments

❖ Particle removal test

- 2 kinds of particles
  - Silica, PSL standard particles (100 nm, Corpuscular, USA)
- 3 kinds of surfaces
  - Si wafer, TaN and Ru coated wafer (2 cm x 2 cm)
- Particle deposition (spin method, particles in DIW)
- Akrion 0.84 MHz megasonic cleaning with DIW, dNH_4OH and dTMAH

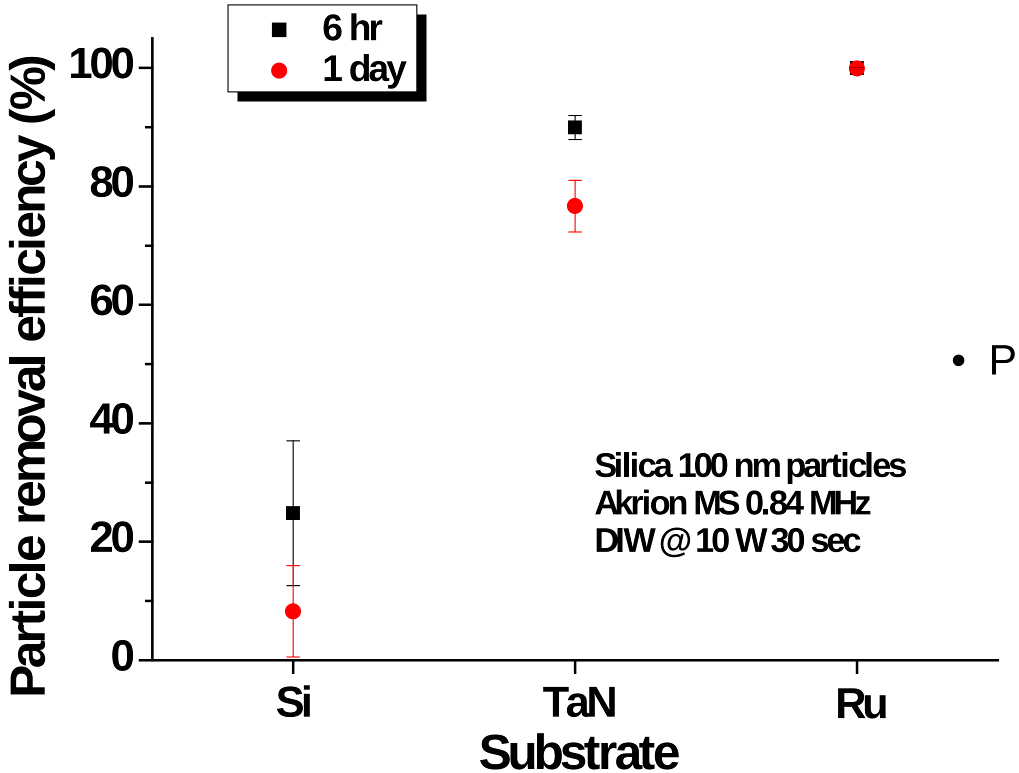
❖ Carbon contaminant removal test

- Hydrocarbon film deposition on TaN and Ru surface
  - Using PECVD, 40 nm thickness
- Hydrocarbon removal using solvent based cleaning solution
  - Dimethyl sulfoxide (DMSO) 80% with NH_4OH or TMAH (0.1M), 65 ℃, 20min (dipping)

❖ Analysis

- Particle removal efficiency measurement
  - Optical microscope (dark field mode, LV-100D, Nikon, Japan)
- Chemical bonding analysis using FTIR (Nicolet iS50, Thermo Scientific, USA)
  - Multiple internal reflection (MIR) and attenuated total reflection (ATR) method
- Contact angle analyzer (Phoenix, SEO, KOREA)

Silica particle removal with various surfaces



- PRE of silica particles @ various surfaces

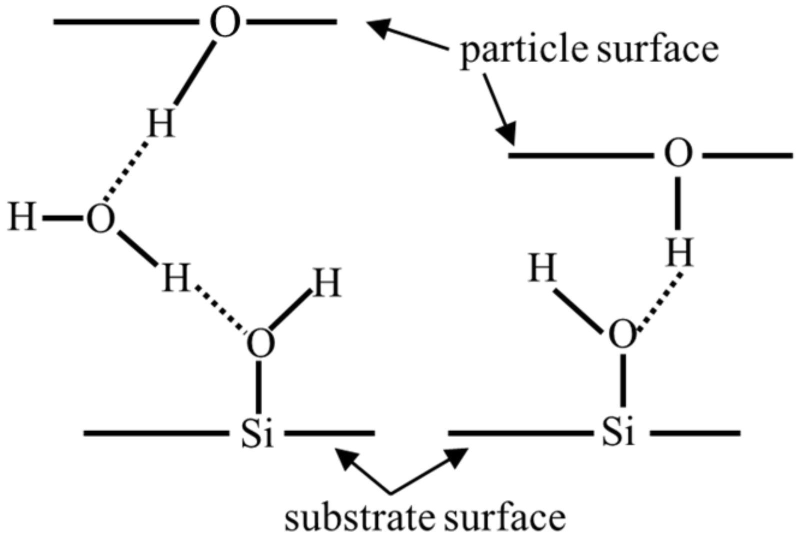
Si ⟪ TaN ⟨ Ru

- **Silica particle removal efficiency was very lower @ Si surface even 6hr aging time**
- **Silica particle was easily removed from Ru surface**

→ Why PRE is different with surface materials?

Surface interaction (hydrogen bonding)

❖ **Hydrogen bonding between Si surface and oxide particle**



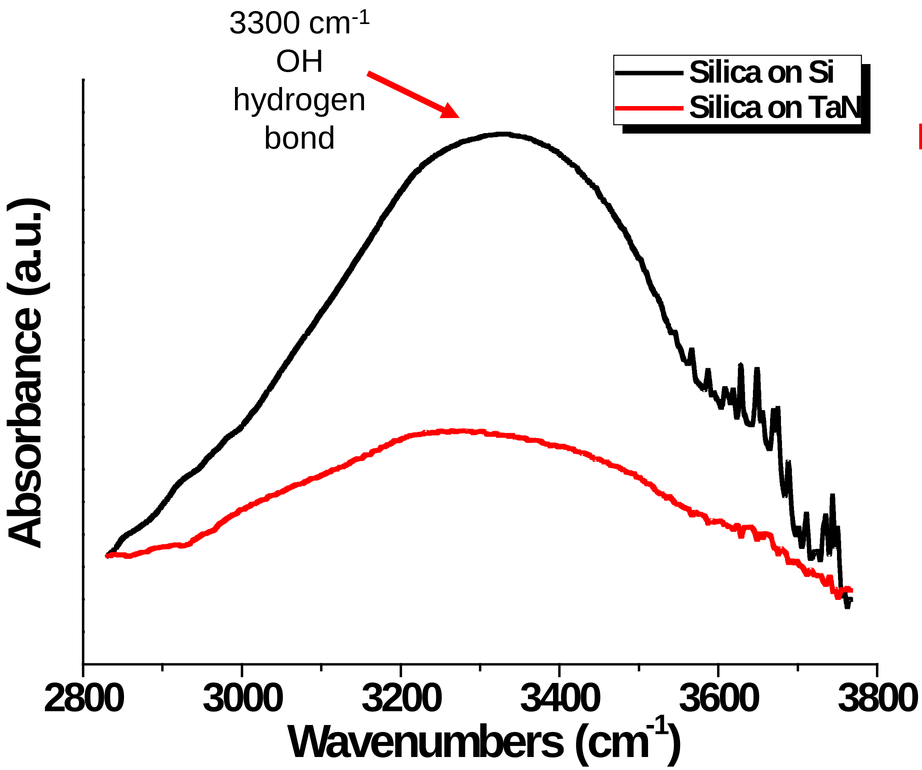
Hydrogen bonding with silica ($F_{H\text{-}bond}$)	600 nN
Van der Waals force with silica (F_{vdW})	30 nN

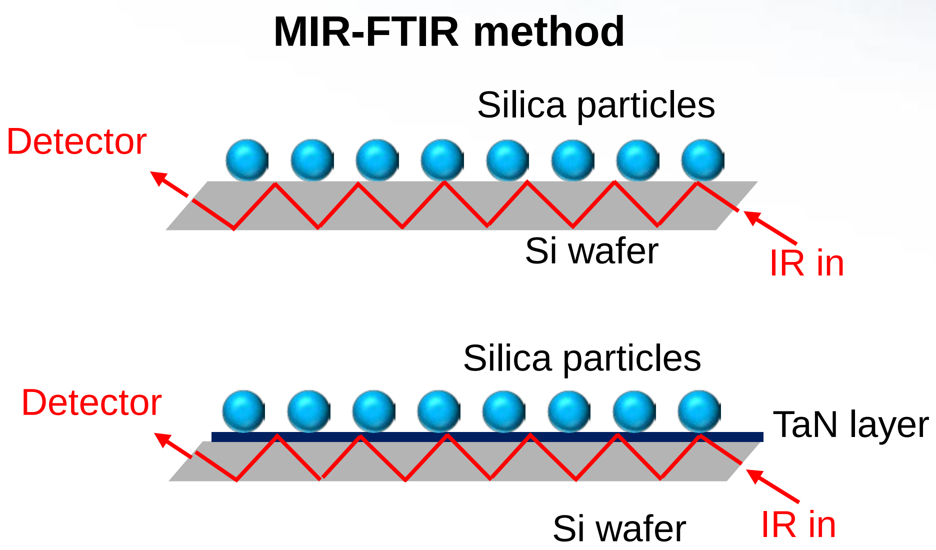
Hydrogen bonding ≫ van der Waals force

X. Wu, et al., *J. of Appl. Phys.* **86** (3) (1999)

- **Si surface and inorganic oxide particles can interact to form hydrogen bonds**
- **Adhesion force of hydrogen bonding is much larger than van der Waals force**

Hydrogen bonding analysis (MIR-FTIR)



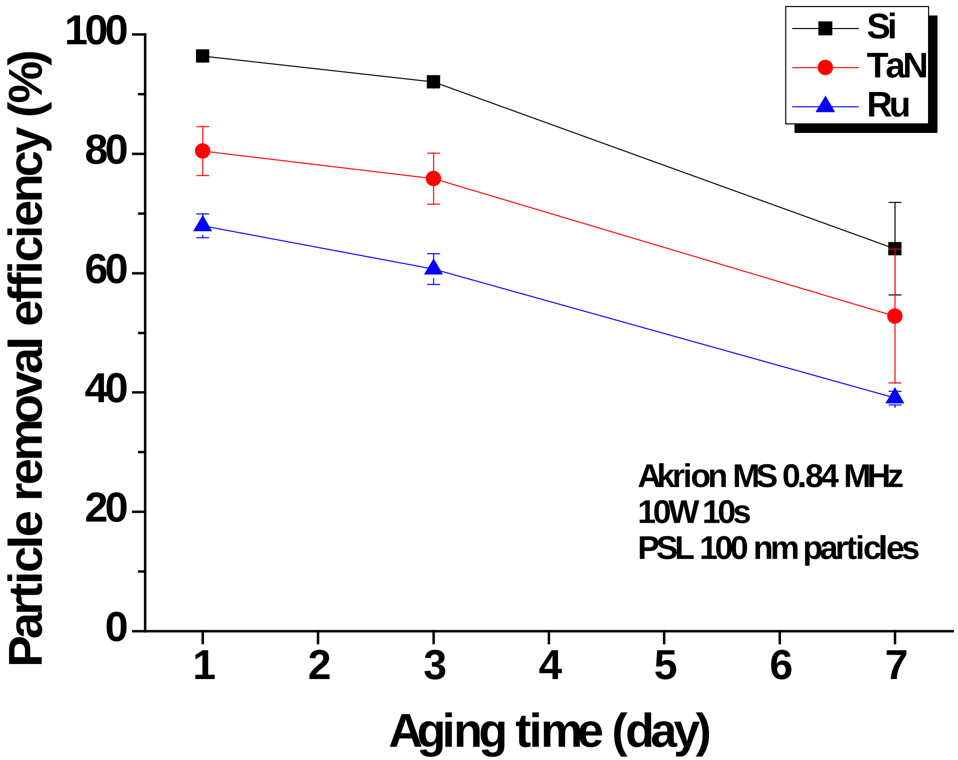


Surface	Hydrogen bonding with silica
Si	Strong
TaN	Weak
Ru	None (only F_{vdW})

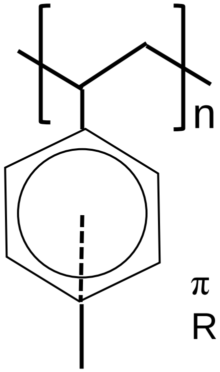
- **Hydrogen bond peak (3300 cm^{-1}) was measured using MIR-FTIR method**
- **OH peak is much higher @ Si than TaN surface**

  → PRE was much lower @ Si surface

PSL particle removal with various surfaces



Particle	Bonding with Ru surface
Silica	F_{vdW}
PSL	Metal-carbon bond

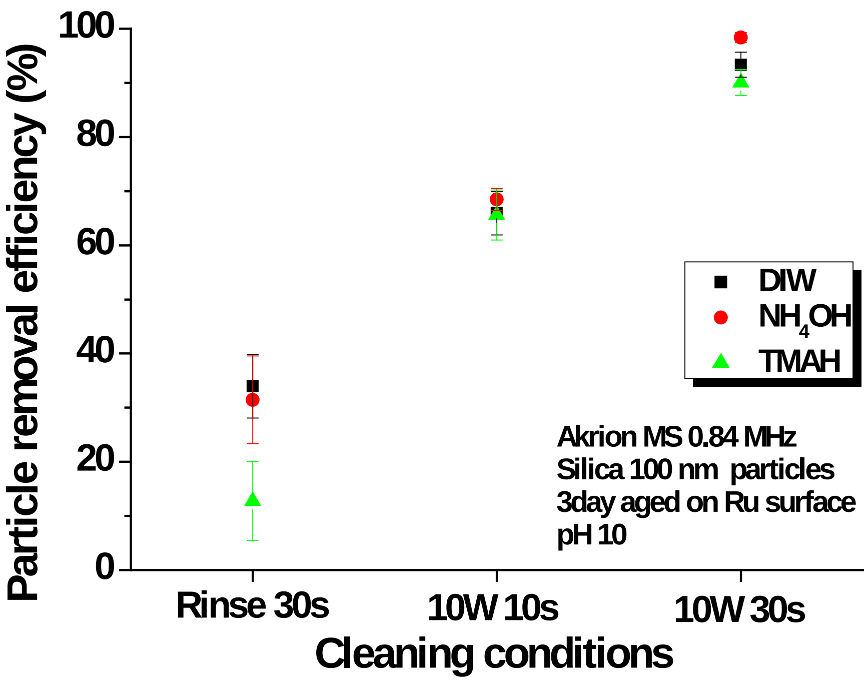


R. A. Zelonka, et al., Can. *J. Chem.* **50** (1972)

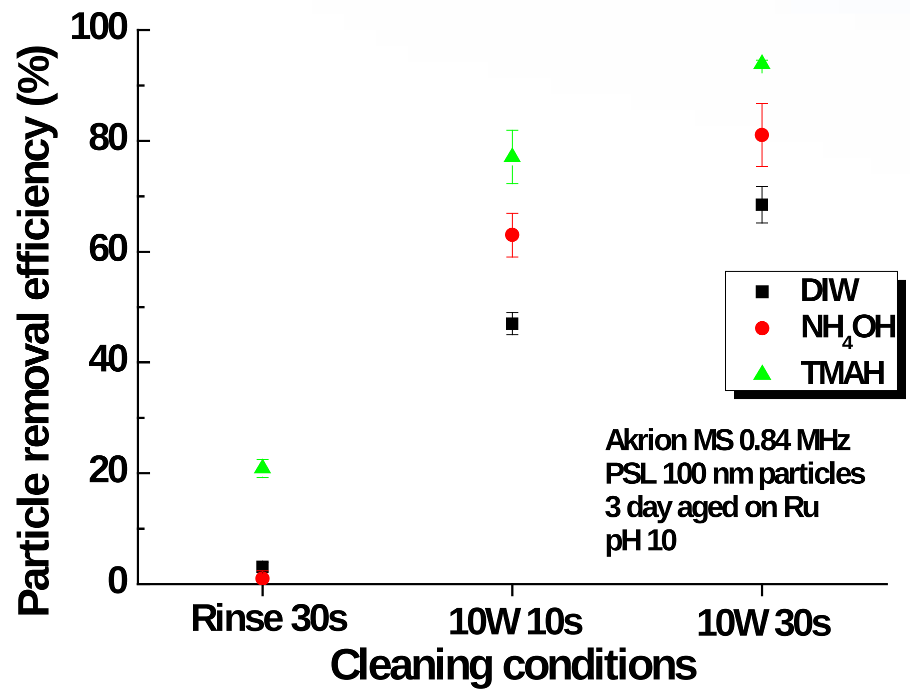
- **In case of PSL particle, PRE was lower @ Ru surface than Si and TaN surface**
- **Ru (transition metal) can form chemical bonding with aromatic ring of PSL particle**
  → Increase adhesion force

Effect of TMAH on PSL particle removal

❖ PRE of silica on Ru surface



❖ PRE of PSL on Ru surface



- No effect of cleaning solution on silica particle removal @ Ru surface
- TMAH cleaning with megasonic showed higher PRE on PSL particle from Ru surface

  → TMAH can break the metal-carbon bonding as solvent

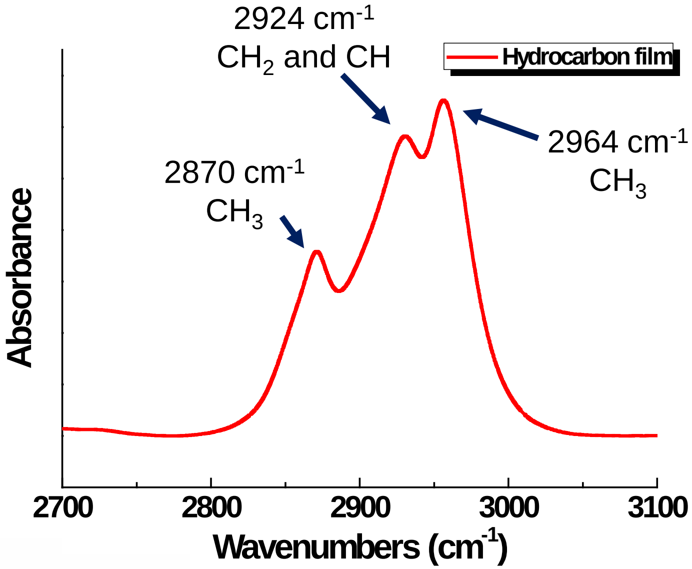
TMAH is very effective to remove organic particle from Ru surface

Hydrocarbon film deposition

❖ **RF-PECVD (SRN-501, Sorona, Korea)**

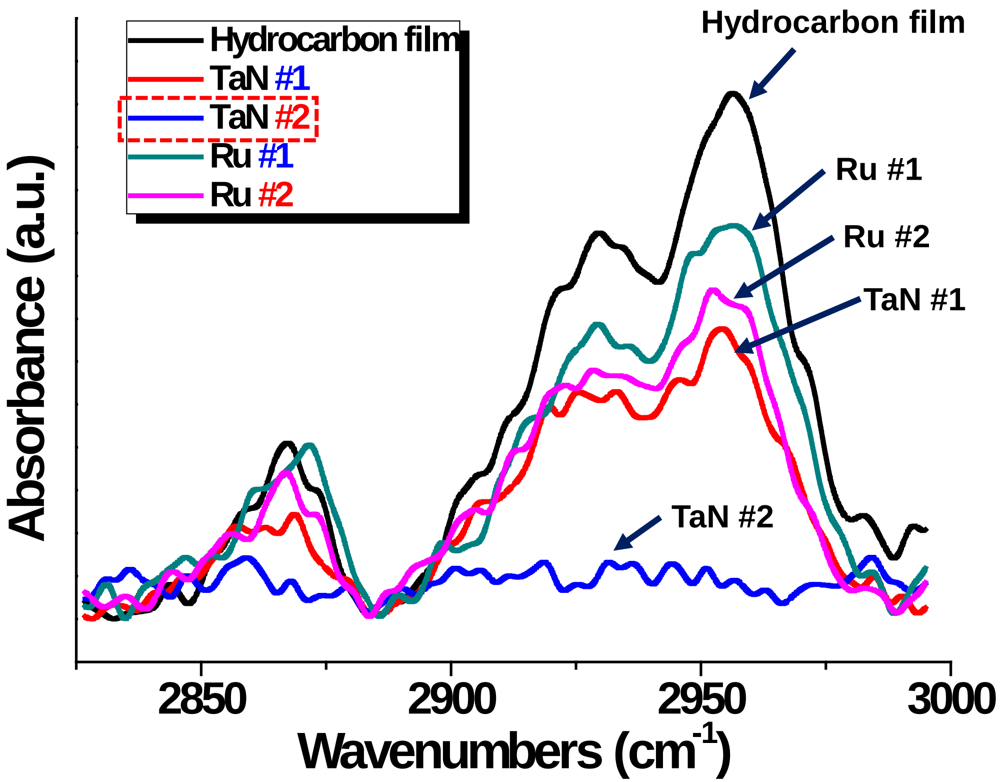
Process condition	
Gas ratio (CH_4 : Ar)	1 : 1
Plasma power	240 W
Temperature	30 ℃
Chamber pressure	0.6 torr

- Density of hydrocarbon film (1.3 g/cm^3)

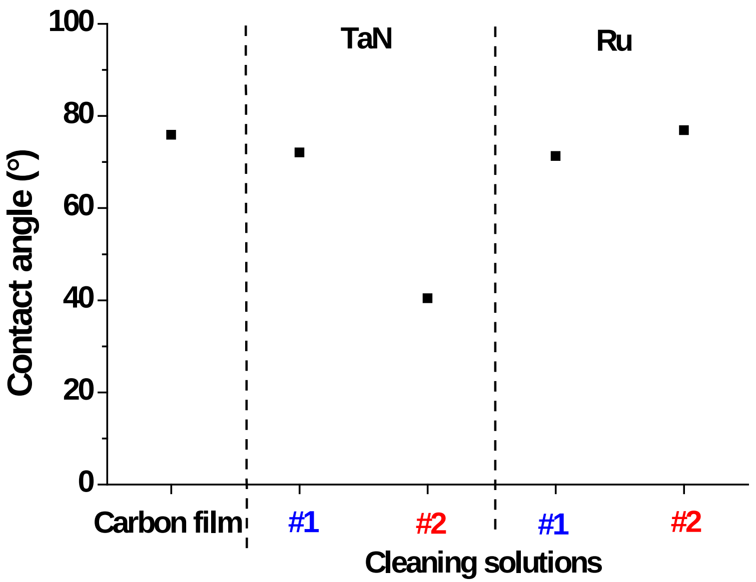


Hydrocarbon removal from TaN and Ru surface

❖ **ATR-FTIR analysis**



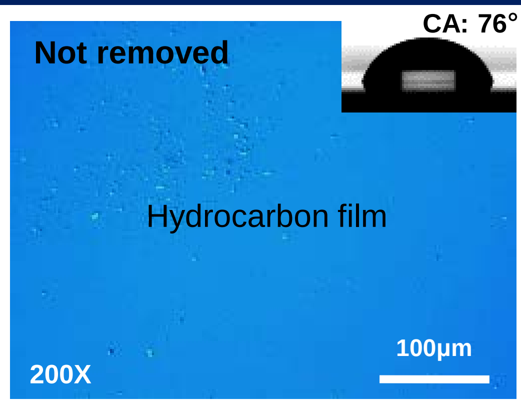
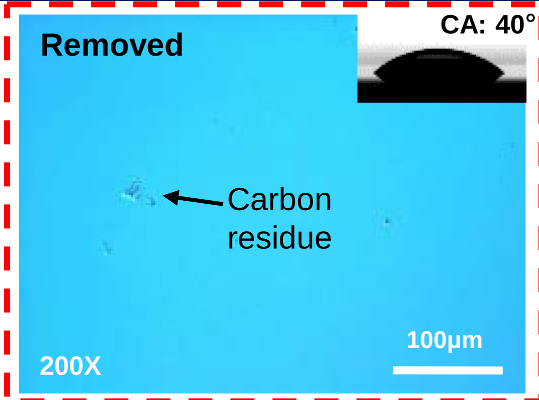
	Cleaning solution
#1	DMSO (80%) + NH_4OH (0.1 M)
#2	DMSO (80%) + TMAH (0.1 M)



- TMAH can help remove hydrocarbon with DMSO
- Carbon peaks of hydrocarbon film was removed at TMAH added DMSO cleaning solution from TaN surface
- Hydrocarbon film was not removed from Ru surface @ TMAH with DMSO cleaning solution

Hydrocarbon removal from TaN and Ru surface

❖ **Surface images after cleaning process (OM)**

<table>
<tr><th></th><th>#1 (DMSO + NH_4OH)</th><th>#2 (DMSO + TMAH)</th></tr>
<tr><td>TaN surface</td><td>
</td><td>
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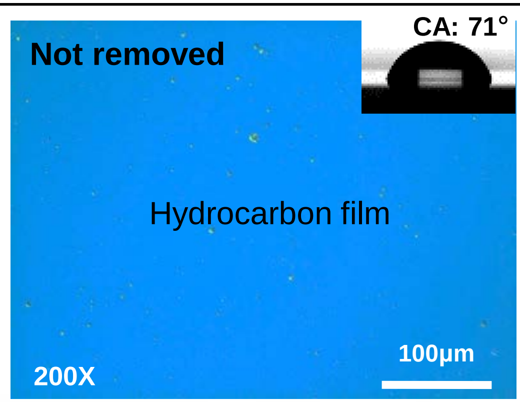
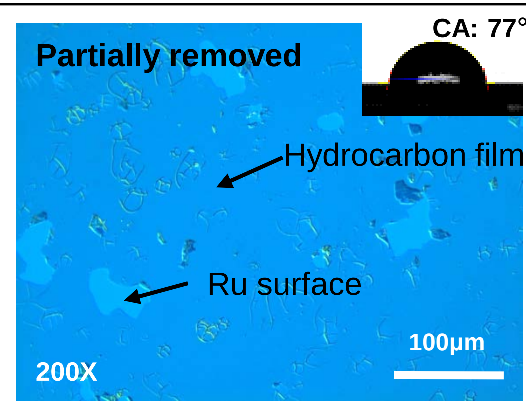
<tr><td>Ru surface</td><td>
</td><td>
</td></tr>
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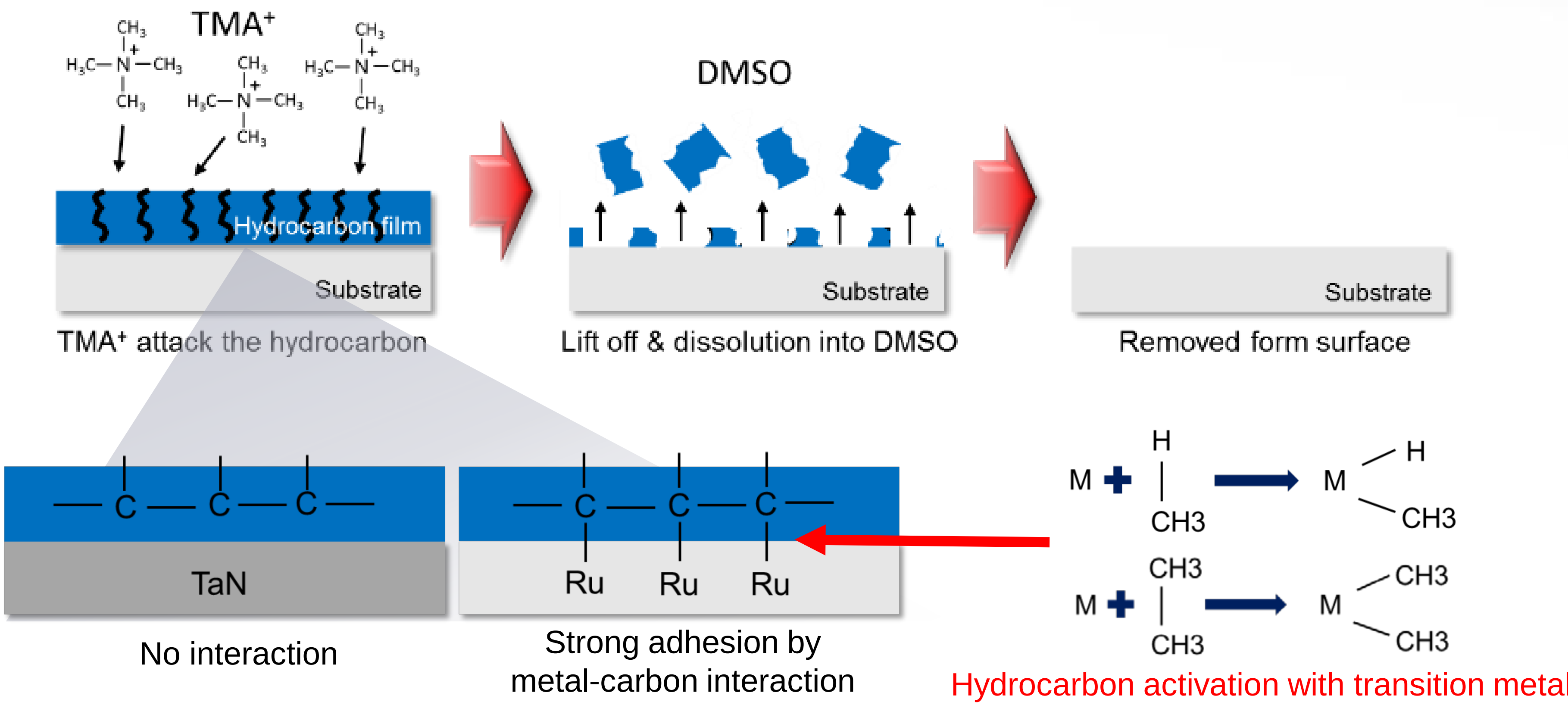
Hydrocarbon film is still remained on Ru surface (partially removed)

Mechanism of hydrocarbon removal

❖ **Hydrocarbon removal in DMSO with TMAH cleaning solution**



M. R. A. Blomberg, et al., *J. Am. Chem. Soc.*, **113** (2), 424 (1991)

More difficult to remove hydrocarbon film from Ru surface by transition metal – carbon interaction than those from TaN surface

Summary

- Need to understand the surface interaction between contaminants and substrates in EUV masks

- Silica & PSL particle removal
  - Hydrogen bonding is dominant on oxide particle removal from surface
    → PRE of silica : Si << TaN < Ru
  - PRE of PSL is lower @ Ru surface due to metal – carbon interaction
    → **TMAH is effective to enhance organic particle removal from Ru surface**

- Hydrocarbon film removal
  - DMSO with TMAH cleaning solution can remove hydrocarbon film from TaN surface
  - More difficult to remove carbon contaminant from Ru surface
    → **Transition metal – hydrocarbon interaction between Ru and hydrocarbon film**

THANK YOU FOR YOUR ATTENTION !!