SPCC 2018

Hanyang University NEMPL

Acidic Cleaning Solutions for Post InGaAs CMP Cleaning

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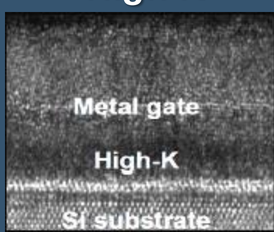
High mobility semiconductor for Logic Device

Technology development trend of semiconductor industry

- ✓ **Demand of high speed**
- ✓ **Decreasing the power consumption**
- ✓ **Shrinking device size (high density of integration)**

Logic Devices Roadmap

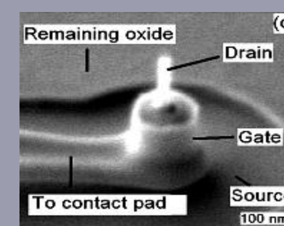
Material — **Metal gate High K**



Structure — **FIN FET**

Material — **High mobility channels**

Structure — **Vertical nano wire / Tunnel FETs**



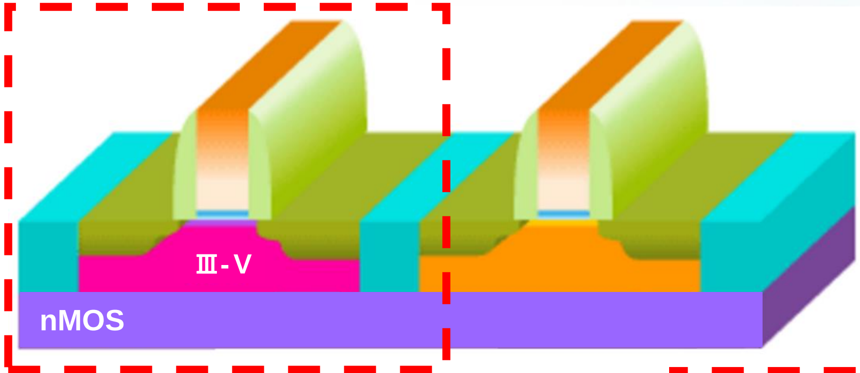
45 nm | 32/28 nm | 22/20 nm | 14 nm | 7 nm | 5 nm | …node

Recently new material is required for high mobility channels

Babu, Suryadevara. *Advances in Chemical Mechanical Planarization (CMP)*. Woodhead Publishing, 2016.

Properties of semiconductor materials

CMOS Structure



Material	Si	III / V				
		GaAs	InP	InGaAs	InAs	InSb
Electron mobility (cm^2/Vs)	1,600	9200	5400	**11,200**	40,000	77000
Hole mobility (cm^2/Vs)	430	400	200	**300**	500	850
Lattice constant (Å)	5.43	5.65	5.86	**5.87**	6.06	6.48
Band gap (eV)	1.11	1.42	1.34	**0.74**	0.36	0.17

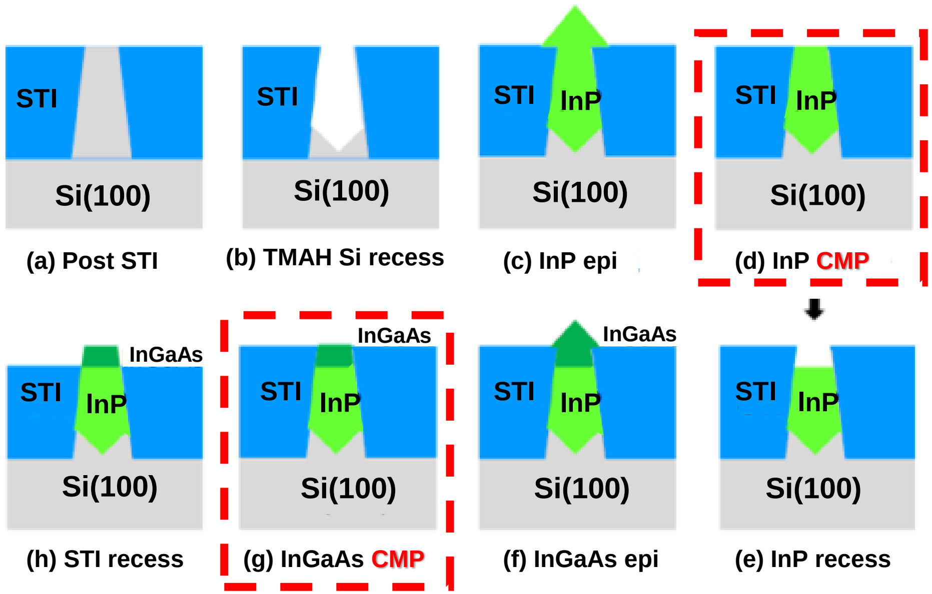
➢ **Combined elements from group III and V** shows higher electron mobility and it is considered as an **alternative to Si as a channel material**, specifically for nMOS.

➢ Considering the lattice mismatches and band gap, **InGaAs** may consider as a promising material for nMOS.

http://www.yokoyama-gnc.jp/english/research/cmos.html

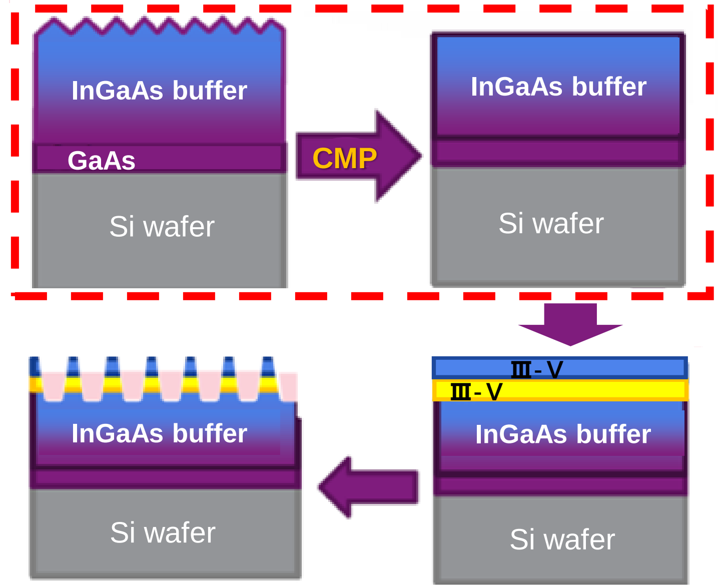
CMP process for III-V Fins

❖ STI first



- ✓ ART (Aspect-Ratio Trapping) :
  Trapped defects in the III-V layer
- ✓ **CMP is needed to reduce the overburden post epitaxial growth**

❖ STI last



- ✓ SRB (Strain Relaxed Buffer):
  Reduced lattice mismatch with Si
- ✓ **CMP is needed before epi growth of new layer**

In both approaches, InGaAs requires at least 1 CMP step using silica slurry

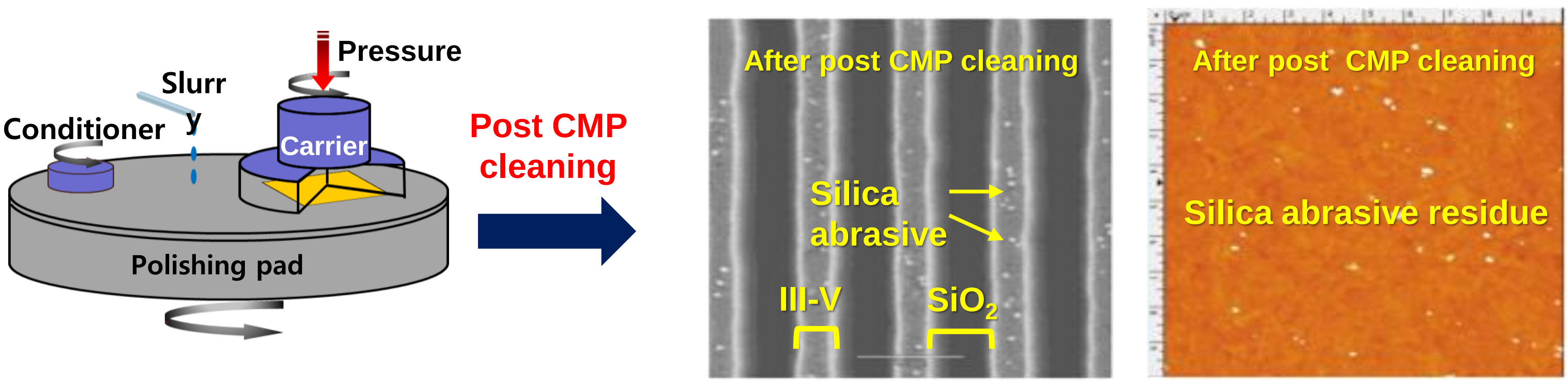
Lieve Teugels et al., Semicon Korea 2015, 4-6 February 2015

Motivation

- After CMP process, **post InGaAs CMP cleaning** process was performed using megasonic, brush and **diluted ammonia solutions** to remove slurry contaminants.

❖ **Issues of post InGaAs CMP cleaning**

- The **conventional post InGaAs CMP cleaning process is not effective** for removing nano silica slurry particles from InGaAs surface.



➢ **Development of new cleaning chemical is required for post InGaAs CMP process**

✓ **High cleaning efficiency**

✓ **Minimal material loss with less oxidized surface**

Lieve Teugels et al., Semicon Korea 2015, 4-6 February 2015

Experiments for etch rate and oxidation

❖ Materials & Experimental condition

- **Substrate : Polished InGaAs ($In_{0.53}Ga_{0.47}As$; ~75nm thickness)**
- **Cleaning Chemicals: HCl** (0.001 M, 0.005 M, 0.01 M, 0.05 M)

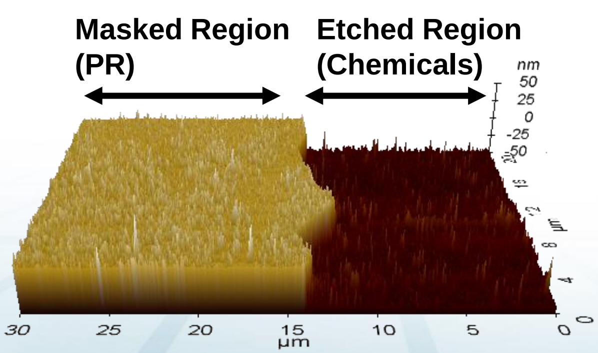
  H_2O_2 (0.001 M, 0.005 M, 0.01 M)

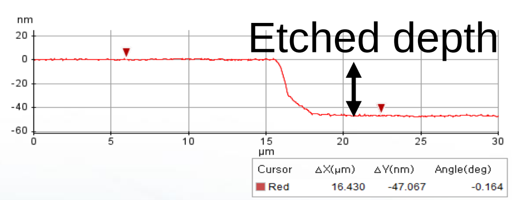
Etch Rate (Material Loss)

- **Photoresist (PR) line patterns of 110 μm**
  - Selective Etching
- **AFM (**XE 100, Park System, Korea**)**
  - Etched step height

Composition Analysis (Oxidation)

- **XPS (**Sigma Probe, Thermo, UK**)**
  - Oxide percentage

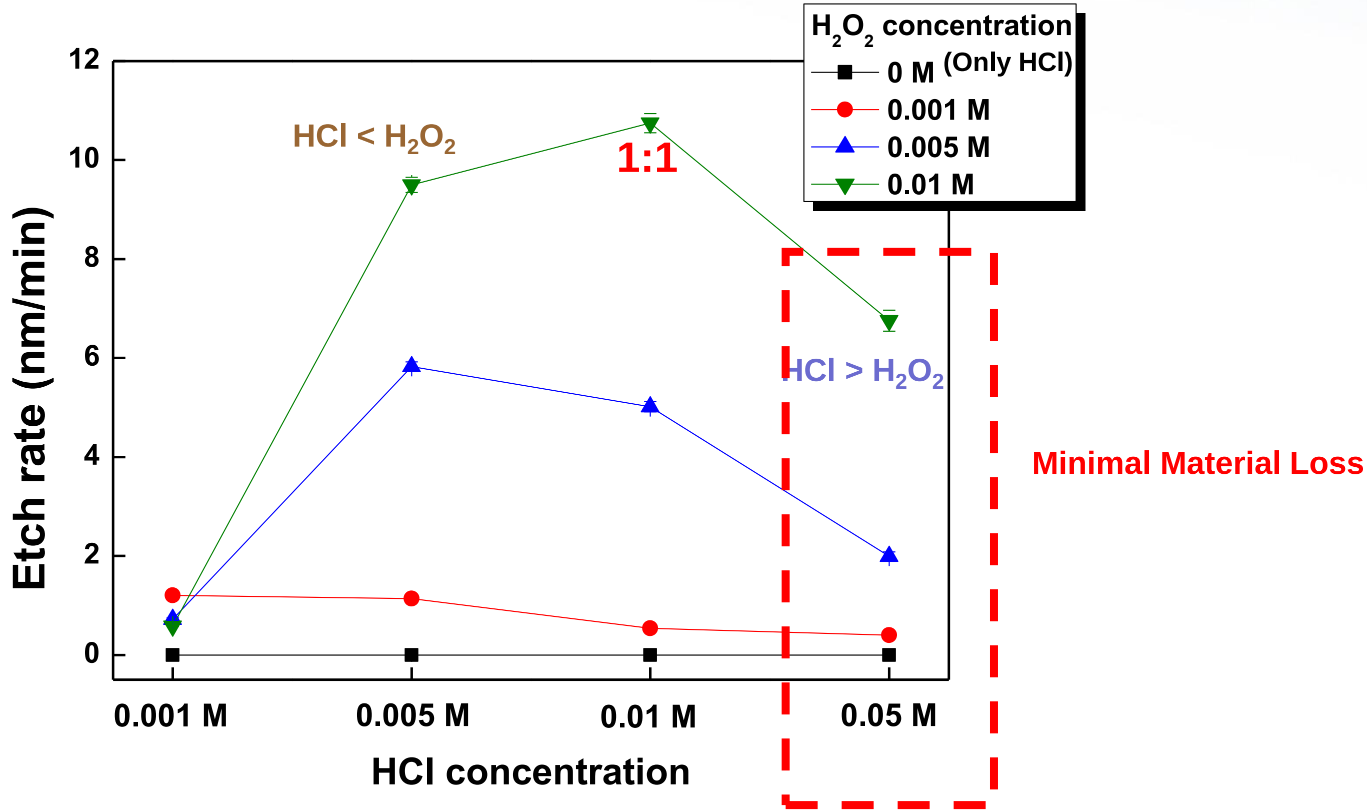




$$\text{Etch rate } \left(\frac{\text{Å}}{\text{min}}\right) = \frac{\text{Etched step height}}{\text{Etching time}}$$

Etch rate analysis

❖ Etch rate vs. various concentration of chemical

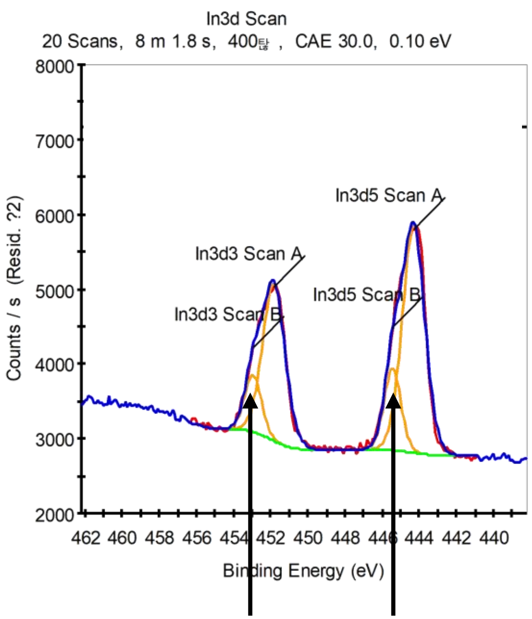


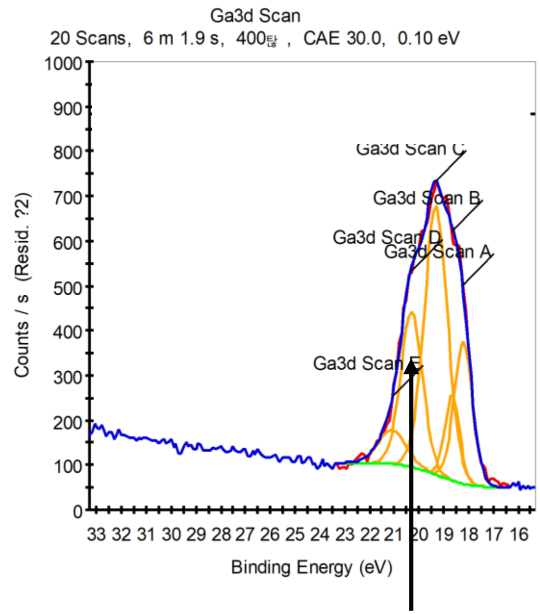
- Only HCl doesn't etch the InGaAs surface without H_2O_2
- **Highest etch rate** was achieved at **HCl : H_2O_2 = 1 : 1**
- **Lower concentration of HCl than H_2O_2** (ER ↑)
- **Higher concentration of HCl than H_2O_2** (ER ↓)

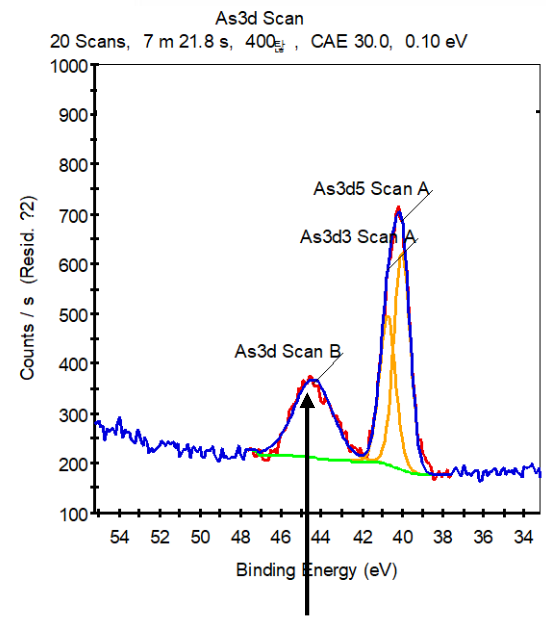
XPS analysis for oxide content

❖ **XPS analysis was carried out for analyzing the oxide percentage of InGaAs**

✓ Ref. (As-received wafer)





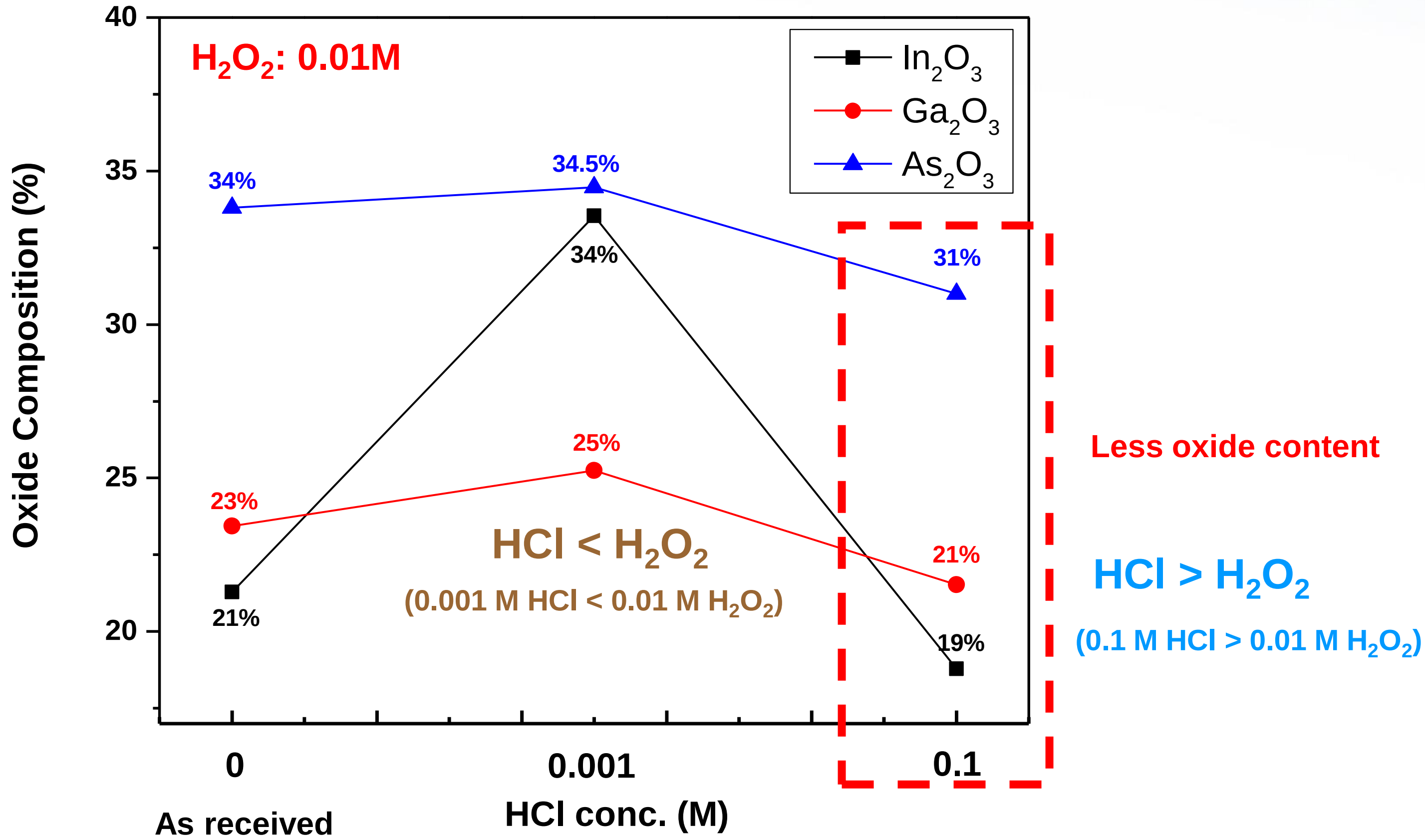


Chemical state	In_2O_3	Ga_2O_3	As_2O_3
O Atomic %	21.28 %	23.43 %	33.8 %

➢ **XPS was used to evaluate the cleaning chemical effect on InGaAs oxidation**

XPS analysis for oxide content

❖ Oxide content vs. HCl Conc.



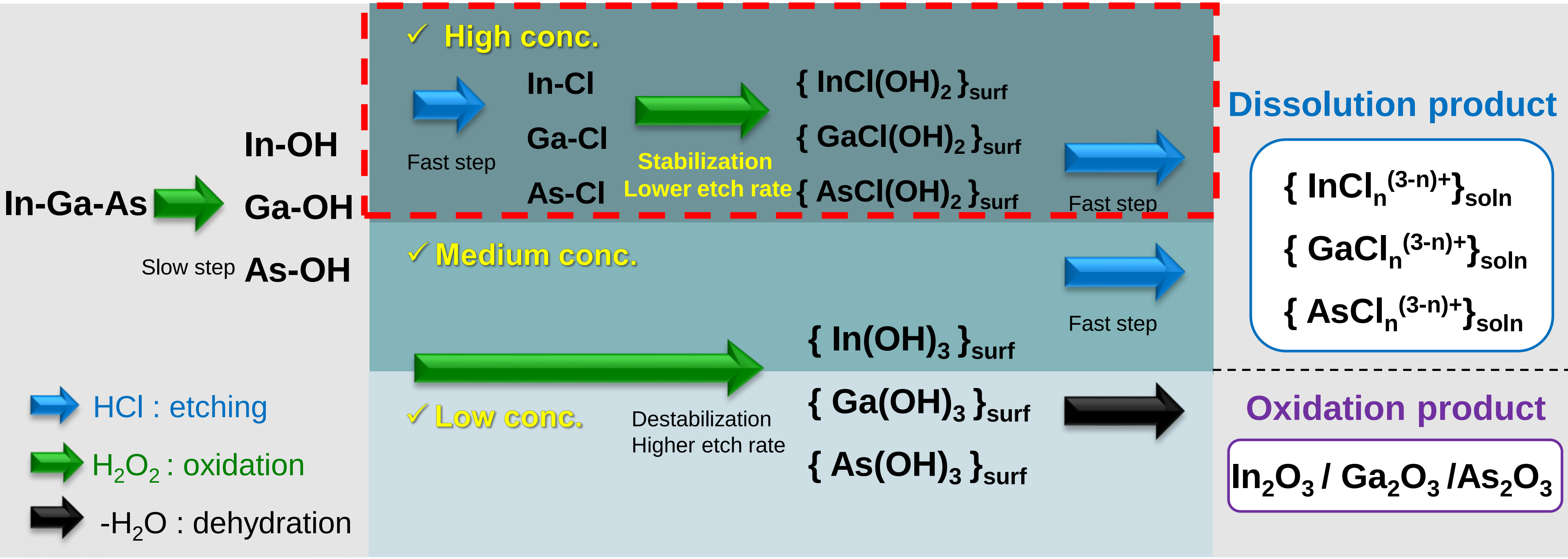
- Lower conc. of HCl increases the oxide composition
- Higher conc. of HCl decreases the oxide composition
- High conc. of HCl than H_2O_2 can minimize the oxide layer formation

Etching mechanism

❖ **Etching mechanism according to the HCl concentration**

✓ High HCl concentration: oxidation rate **<** dissolution rate (**ER ↓**) / (**Oxidation ↓**)

✓ Low HCl concentration : oxidation rate **>** dissolution rate (**ER ↑**) / (**Oxidation ↑**)



➢ **Based on the material loss and surface oxidation results, higher conc. of HCl (0.05 M) and lower conc. of H_2O_2 (0.001M) is considered as a optimized cleaning solution**

Experiments for the evaluation of PRE

❖ Materials & Experimental condition

- Substrate : InGaAs ($In_{0.47}Ga_{0.53}As$)
- Particle : Silica (130 nm, 289 nm)
- Optimized Conc. of cleaning solution: **HCl (0.05M) + H_2O_2 (0.001M)**
- **Surfactant : ADS** (Ammonium Dodecyl Sulfate) (0 – 0.5mM)
- **Megasonic: batch type, 1MHz, 600W**

Particle contamination

- **Particle contamination**
  - Wet deposition
  - 2 x 10^{-5} wt% Silica particle solution

Cleaning process

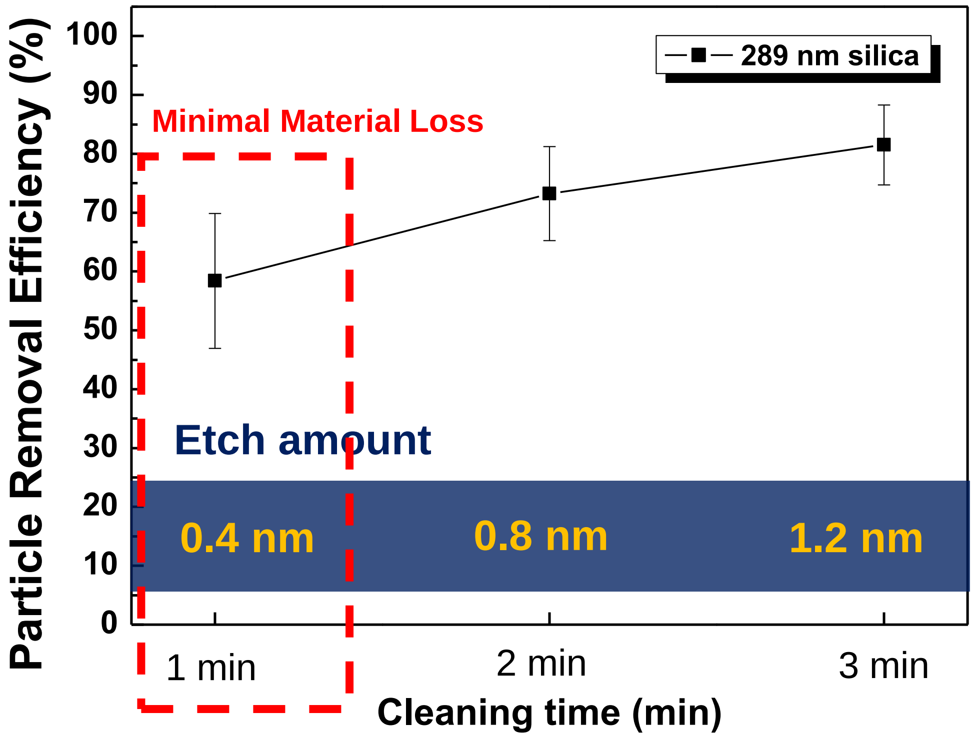
- **Chemical cleaning**
  - **Only Cleaning Chemical**
  - **Cleaning Chemical + ADS**
- **Physical cleaning**
  - Cleaning Chemical **+ MS**
  - Cleaning Chemical **+ ADS + MS**

PRE Analysis

- **Optical microscope (LV100D, Nikon, Japan)**
  - Particle counting (289 nm)
- **FE-SEM (MIRA3, TESCAN, Czech)**
  - Particle counting (130 nm)

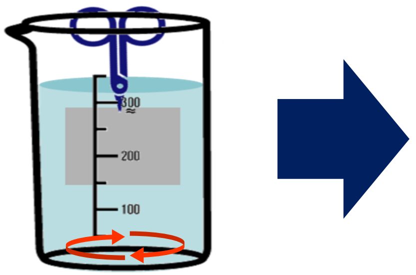
PRE vs. Etch amount

❖ PRE and Etch amount vs. Cleaning Time



❖ Cleaning condition

- Cleaning solution :
  HCl : 0.05M, H_2O_2 : 0.001M
  pH : 1.36
- Dipping process



- Dipping time
  - 1 min
  - 2 min
  - 3 min

- Cleaning time ∝ Etch amount
- **PRE is increased with increase in the etch amount**
- **Modification of zeta-potential is required to increase the PRE with minimal material loss.**
  - ✓ [Zeta-potential] particle : (-) , InGaAs : (+) ➡ particle : (-) , InGaAs : (-)

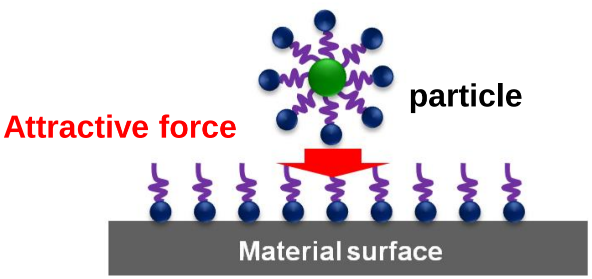
Mechanism of surfactant cleaning

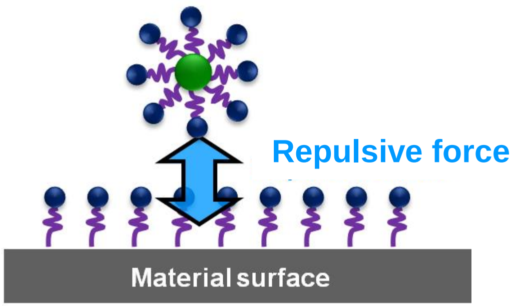
❖ Modification of electrostatic force using surfactant

➢ Introduction of strong electrostatic repulsion between particle and substrate can enhance the PRE during the post CMP cleaning process, which was achieved by using surfactant

Surfactant

✓ [Zeta-potential] particle : (-) ⇥⇤ InGaAs : (+) ➡ particle : (-) ⟷ InGaAs : (-)





❖ Ammonium Dodecyl Sulfate (ADS)

➢ ADS is one of an anionic surfactant widely used for cleaning process

< ADS Properties >

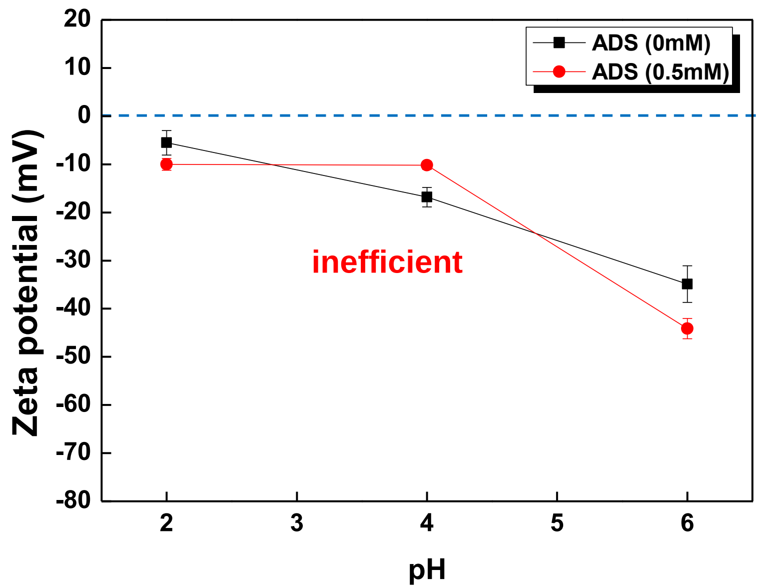
Chemical Formula : $C_{12}H_{29}NO_4$

CMC value: 6.6 mM

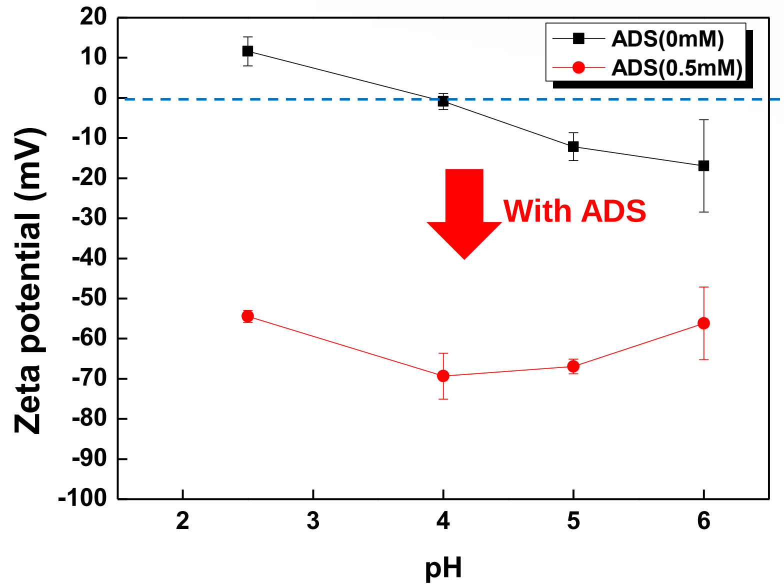
R. Vos, M. Lux et al., Journal of The Electrochemical Society, 148 (12) G683-G691 (2001)

Zeta potential Measurement

❖ Particle zeta-potential (silica)[1]



❖ Surface zeta-potential (InGaAs)[2]



- **Analysis equipment**

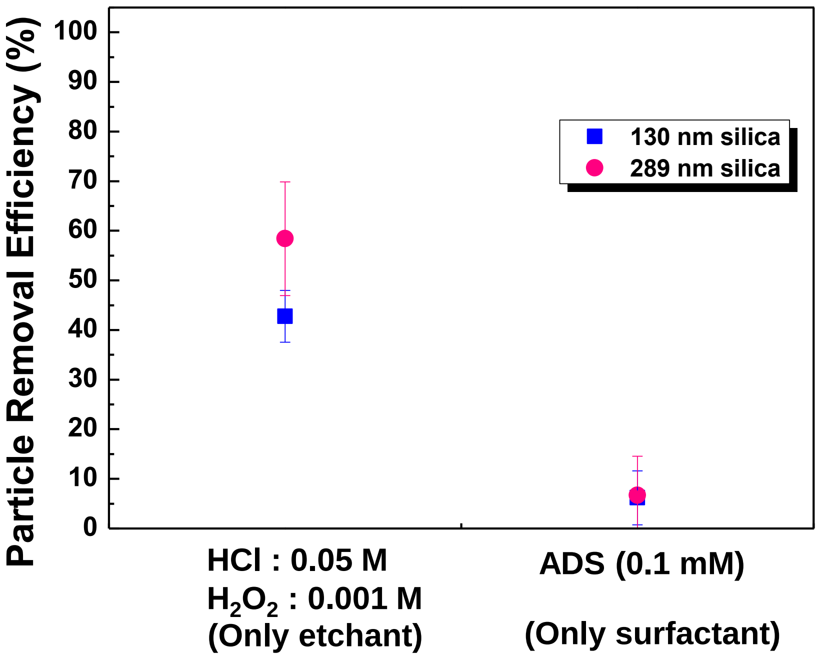
  ELS-Z (Electrophoretic Light Scattering Spectrophotometer) Otsuka, Japan [1]
  SurPASS Electrokinetic Analyzer Anton Paar, Austria [2]

- Zeta potential of InGaAs surface changed significantly after addition of ADS
  - ✓ (+) Z.P. **ADS** ➡ (-) Z.P. in acidic region

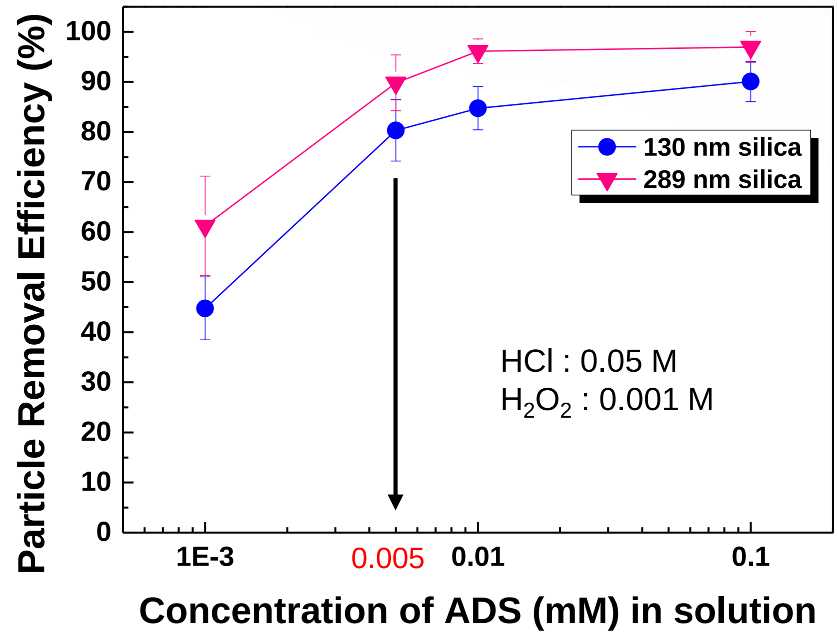
- **Addition of ADS introduces strong repulsive force between silica particle and InGaAs substrate**
  - ✓ **Silica particles can be easily removed from the InGaAs surface**

PRE vs. ADS conc.

❖ (HCl + H_2O_2) vs. ADS

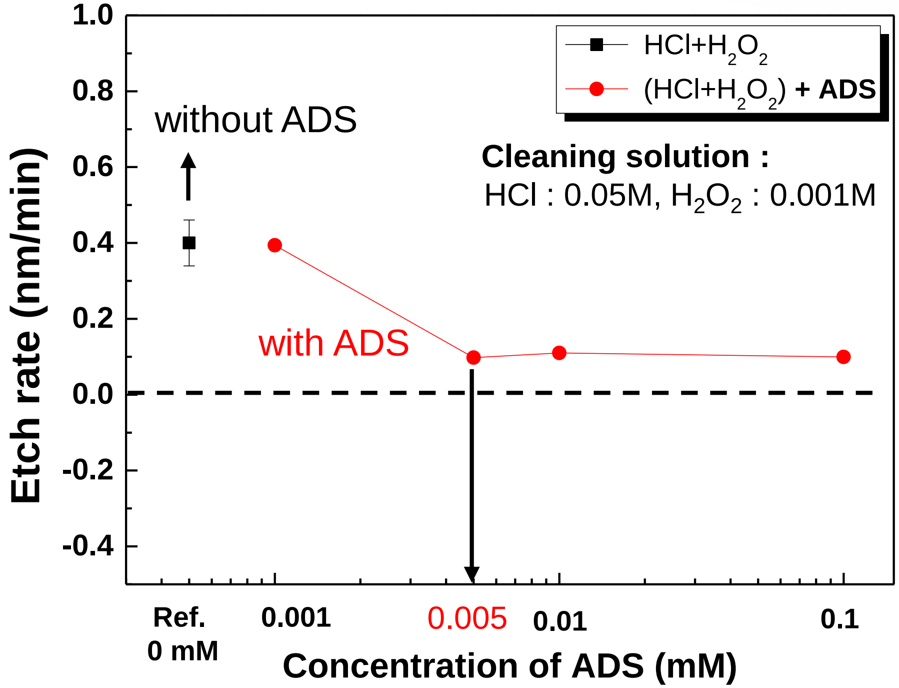


❖ (HCl + H_2O_2) + ADS



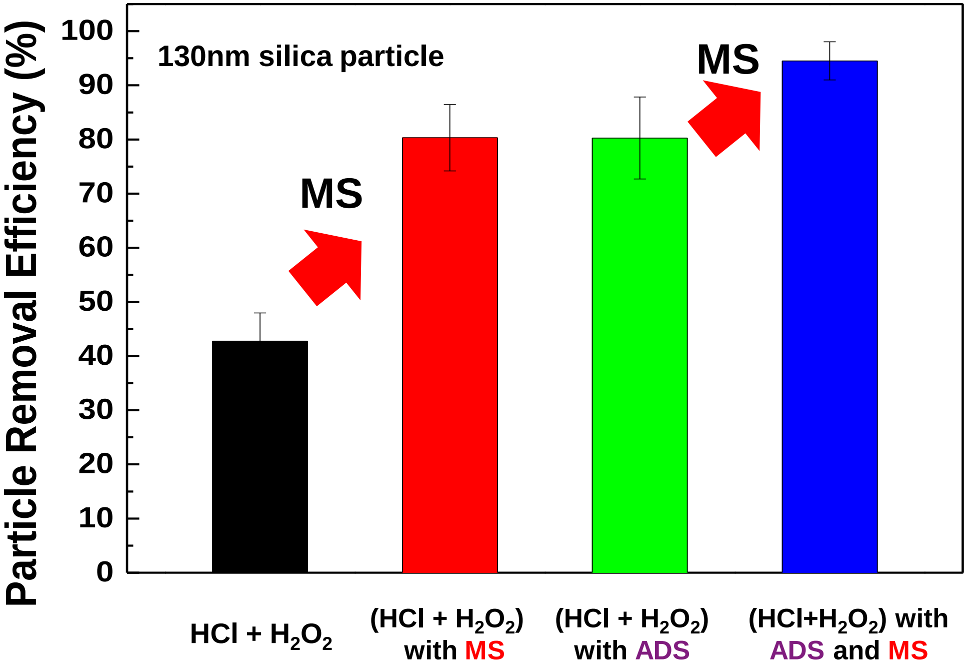
- Using ADS alone is ineffective to remove particles without etchant
  - ✓ Etching process is necessary to remove the particles
- **PRE increases dramatically with the addition of ADS**
  - ✓ Combined effect of surface etching and electrostatic repulsive force increases the PRE
  - ✓ PRE was increased drastically at the addition of 0.005 mM conc. of ADS

Etch rate vs. ADS conc.



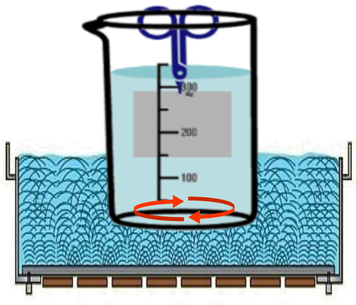
- **Addition of ADS decreases the etch rate of InGaAs**
  - ✓ Etch rate was decreased drastically at 0.005 mM and above conc. of ADS
  - ✓ Introduction of ADS not only increasing the PRE but also decreasing the material loss

PRE vs. Megasonic



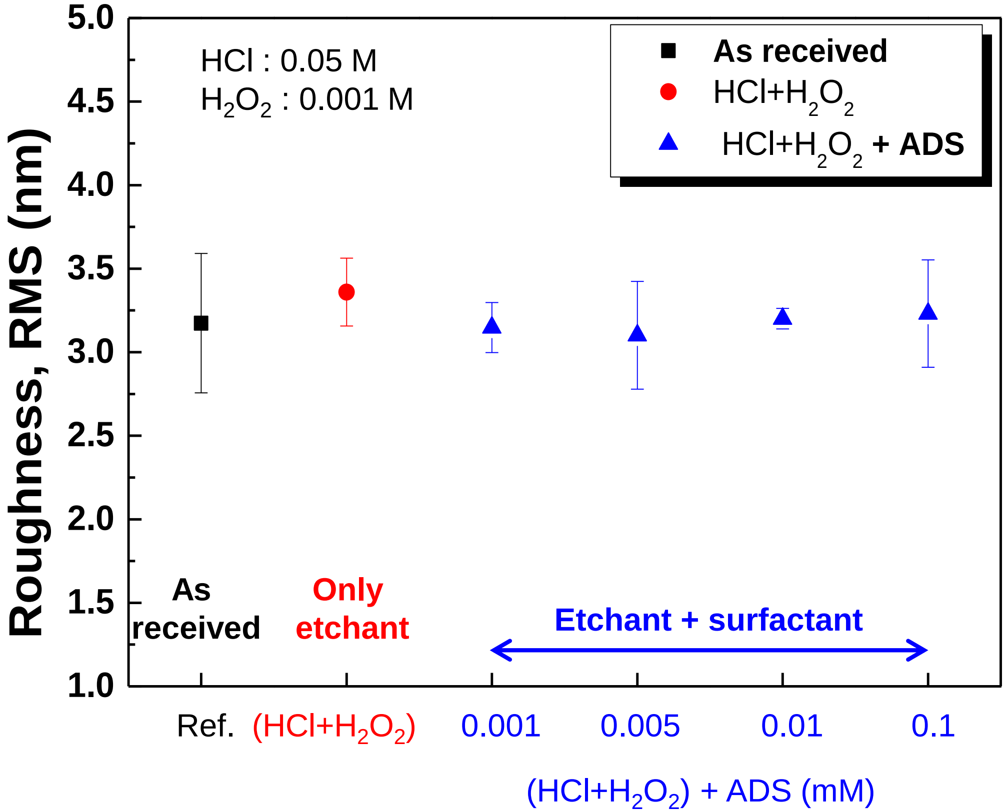
❖ Cleaning condition

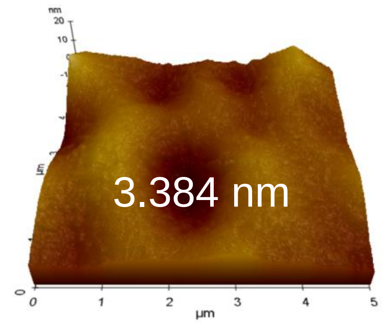
- ✓ Cleaning solution :
  HCl : 0.05M, H_2O_2 : 0.001M
  ADS (0.005 mM)
- ✓ Megasonic (1 MHz, 600 W)



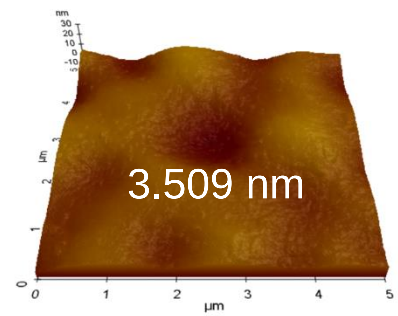
- Megasonic increases the PRE of various cleaning solutions
- **HCl and H_2O_2 cleaning solution with ADS and MS achieved above 95% PRE**
  - ✓ Mechanism of megasonic cleaning : acoustic streaming, bubble collapse
  - ✓ Combined effects of physical force, surface etching and electrostatic repulsive force

Surface roughness

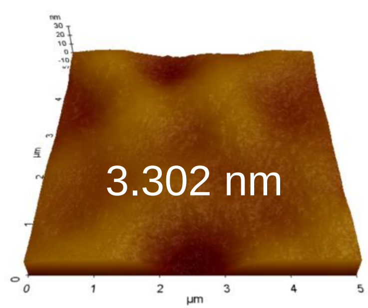




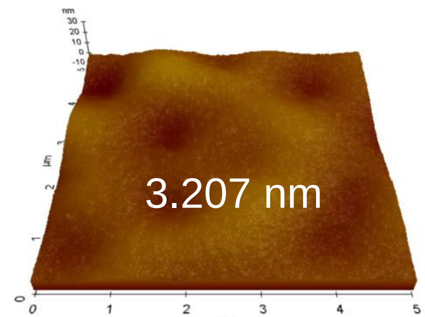
As received



($HCl+H_2O_2$)



($HCl+H_2O_2$) + ADS (0.001 mM)



($HCl+H_2O_2$) + ADS (0.005 mM)

- After cleaning process, there is no significant change in roughness compared to the initial state
  - ✓ Etch amount was negligible to affect the roughness (minimized surface damage)

Summary

- ❖ **Acid cleaning solution** was used for **post InGaAs CMP cleaning** process.
- ❖ **Higher HCl conc. than H_2O_2** is considered as a **optimized cleaning solution** based on the results of material loss and surface oxidation.
- ❖ **ADS** was introduced for **increasing repulsive force** between silica particle and InGaAs substrate to **enhance the PRE**.
- ❖ Introduction of **ADS** not only **increasing the PRE** but also **decreasing the material loss**.
- ❖ There was **no noticeable roughness change** was observed after cleaning process compared to the initial state.
- ❖ **Acid cleaning with surfactant and megasonic achieved above 95% PRE.**

Thank You for Your Attention !!