


IMPROVING EUV MASK SUBSTRATE AND BLANK CLEANING EFFICIENCY BY OPTIMIZING CLEANING CHEMICALS

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OUTLINE

- Introduction
- Experimental Results – Pit Formation
- Experimental Results – Particle Removal Efficiency (PRE)
- Summary
- Acknowledgement

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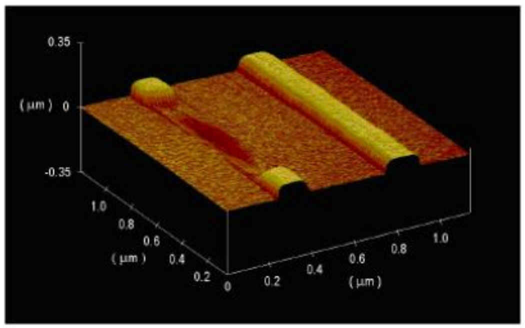
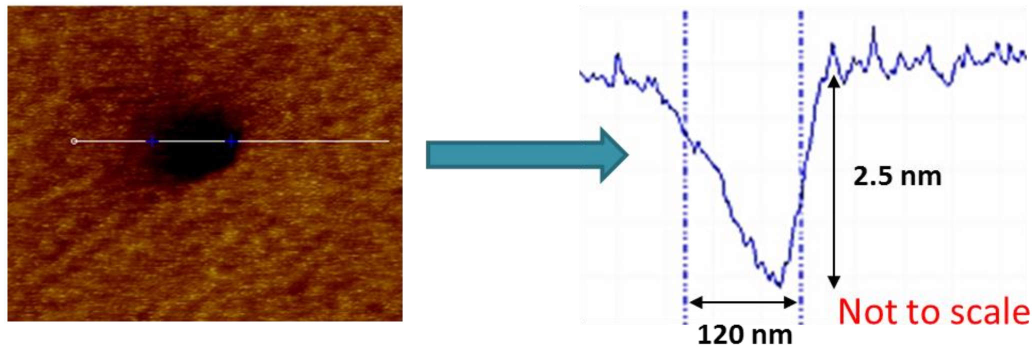
INTRODUCTION

Objective

- Acoustic cavitation is the major mechanism for particle removal in megasonic cleaning [1], [2]
  - However, damage of features and material removal from uncontrolled cavitation collapse (so called transient cavitation) is still a major concern in substrate, blank and also pattern mask cleaning



SRAF damage in patterned masks from megasonics



Material removal on EUV substrates (fused silica glass)

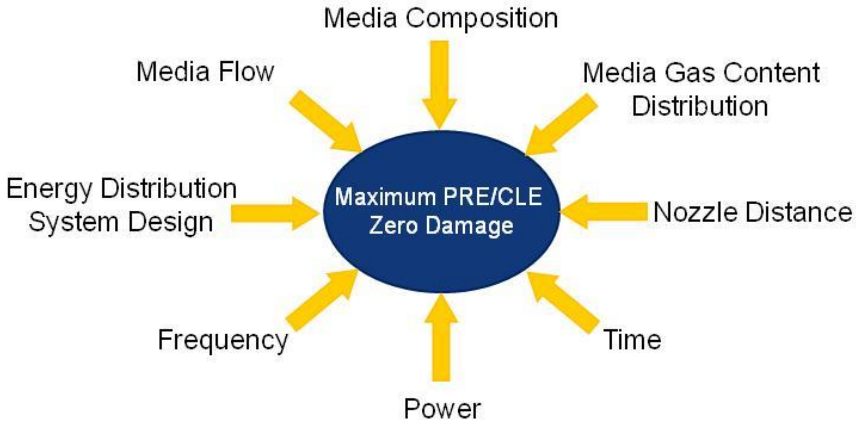
- Objective of this work is to optimize megasonic cleaning for high particle removal efficiency (PRE) without surface damage (pit formation) by optimization of various megasonic control parameters

Material and Methodology for this Study

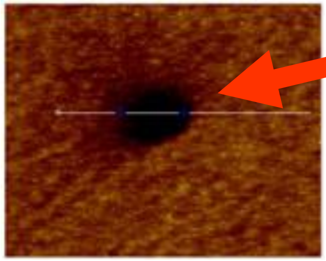
- Cleaning tool used
  - SUSS MicroTec MaskTrack
  - 1 MHz beam megasonic nozzle from SonoSys
- Material for damage analysis reported in this study
  - EUV substrates (fused silica glass) and mask blanks (Ruthenium Capped Mo/Si Multilayer)
- Damage inspection / metrology
  - Lasertec M7360 tool with inspection sensitivity > 40 nm, and AFM, SEM for defect type confirmation
- Particle inspection
  - Lasertec M1350 tool with inspection sensitivity > 65 nm

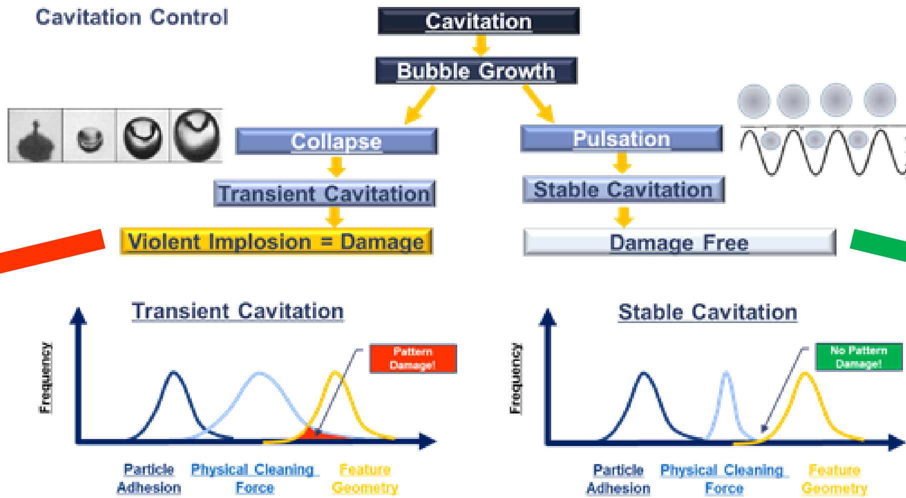
Megasonic Cleaning Overview

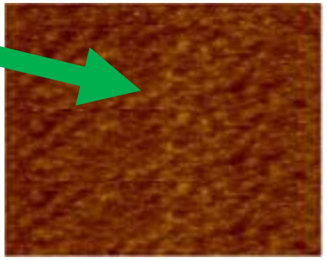
MegaSonic



The Bubble Equation	$R\ddot{R}+\frac{3\dot{R}^2}{2}=\frac{1}{\rho}\left\{\left(P_0+\frac{2\sigma}{R_0}-P_V\right)\left(\frac{R_0}{R}\right)^{\gamma}+P_V-\frac{2\sigma}{R}-\frac{4\mu\dot{R}}{R}-P_0-P_A\sin\omega t\right\}$
Pressure Inside the Bubble	$P_i=P_0+\frac{2\sigma}{R_0}$
Cavitation Threshold	$P_B=P_0+\frac{8\sigma}{9}\left[\frac{3\sigma}{2\left[P_0+\frac{2\sigma}{R_B}\right]R_B^3}\right]^{\frac{1}{2}}$
Boundary Layer Thickness	$\delta_H=0.16\left(\frac{\nu}{Ux}\right)^7\cdot x$
Drag Force	$F_D = 1.7009\ (3\pi\mu V d_p)$
Drag Moment	$M_D = 0.9439934\ (2\pi\mu V d_p^2)$







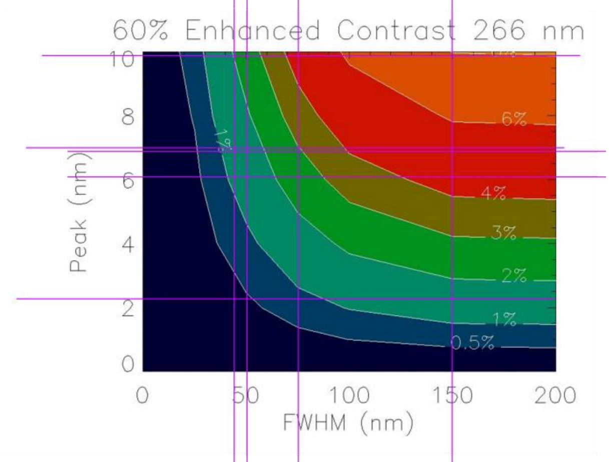
- Goal: Sharpen MegaSonic cleaning force distribution
- Stable Cavitation = Sharp cleaning force distribution = Damage Control

Reducing Damage by Optimizing Megasonic Parameters

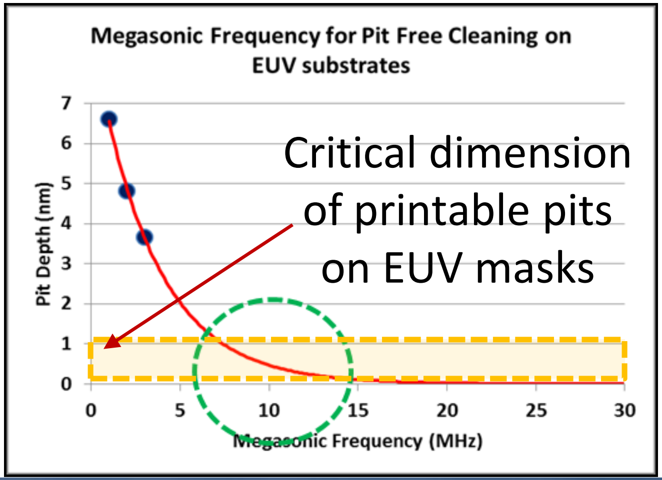
- Damage while cleaning using megasonics can be reduced by increasing frequency
  - **Cleaning optimized by 3 MHz for 40 nm and above for EUV substrates [3]**
- However, to further reduce damage for EUV substrates, other parameters need to be optimized along with frequency
  - Surface tension, σ
    - DI water, IPA-DI, TMAH, NH4OH
  - Density of medium, ρ
    - TMAH, NH4OH
  - Polytropic index of gas, γ
    - Ammonia, H2, CO2

Ultra-dilute TMAH is introduced as a potential chemical for damage free cleaning of EUV substrates

Printability data of small pits on EUV substrates

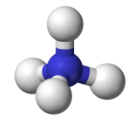


E. Gullikson, Dec 15, 2005

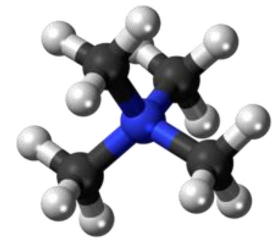


Motivation for Evaluating TMAH as a Cleaning Chemical

Chemical	pH	Zeta Potential (mV)	Cation Size (Å)
NH_4OH	10.55	-50.8	1.43
TMAH	13.45	-151.5	2.51

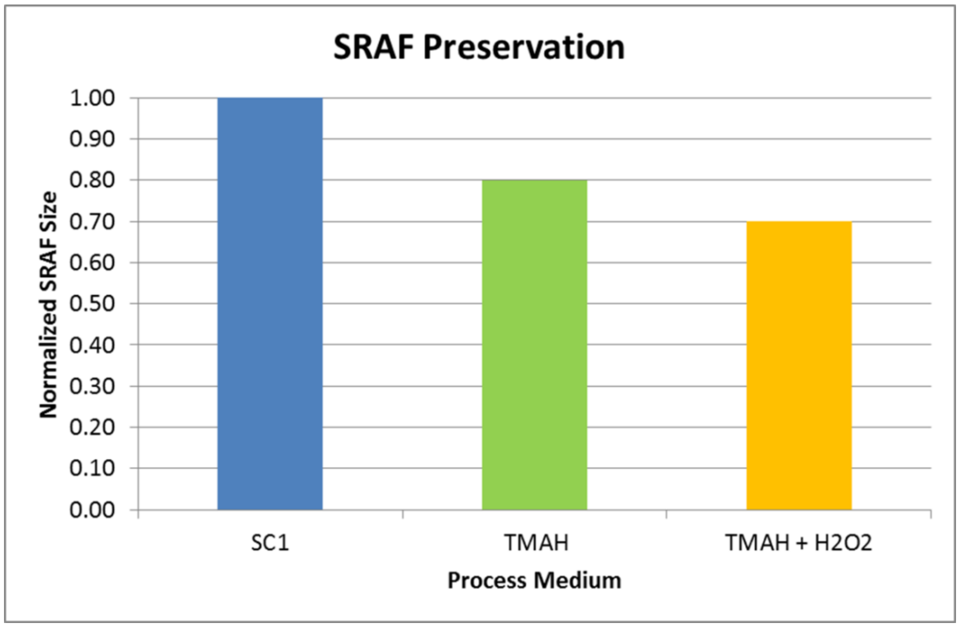


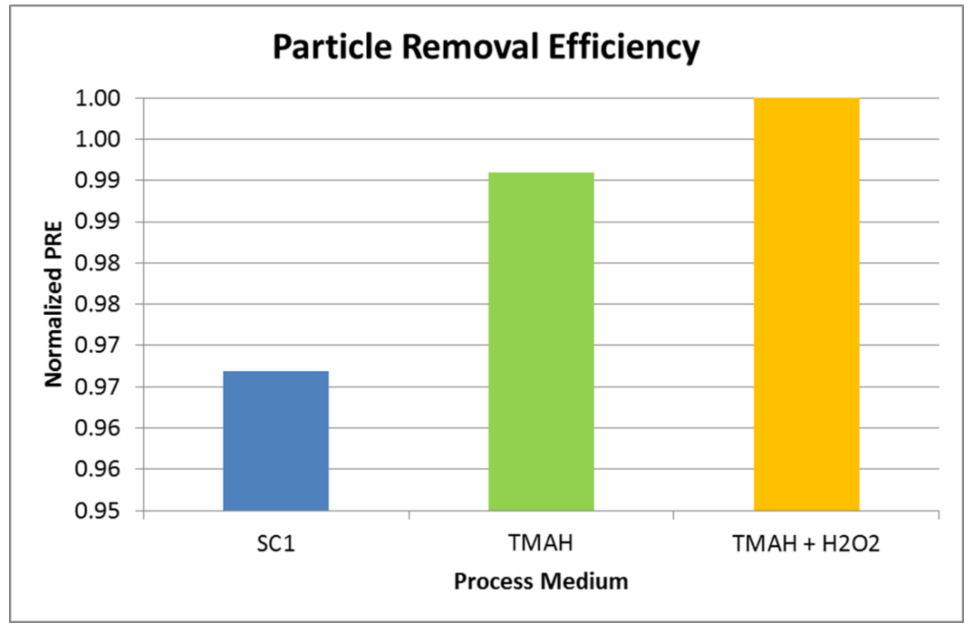
NH_4^+



$N(CH_3)_4^+$

Bigger ion sizes minimize etch rate into SiO2





Benefits of using TMAH and TMAH/H_2O_2 mix instead of NH_4OH or NH_4OH/H_2O_2 mix proven already for 193i pattern masks [5]

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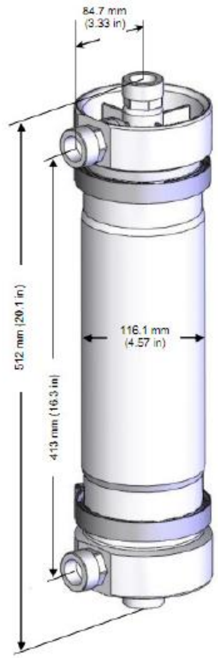
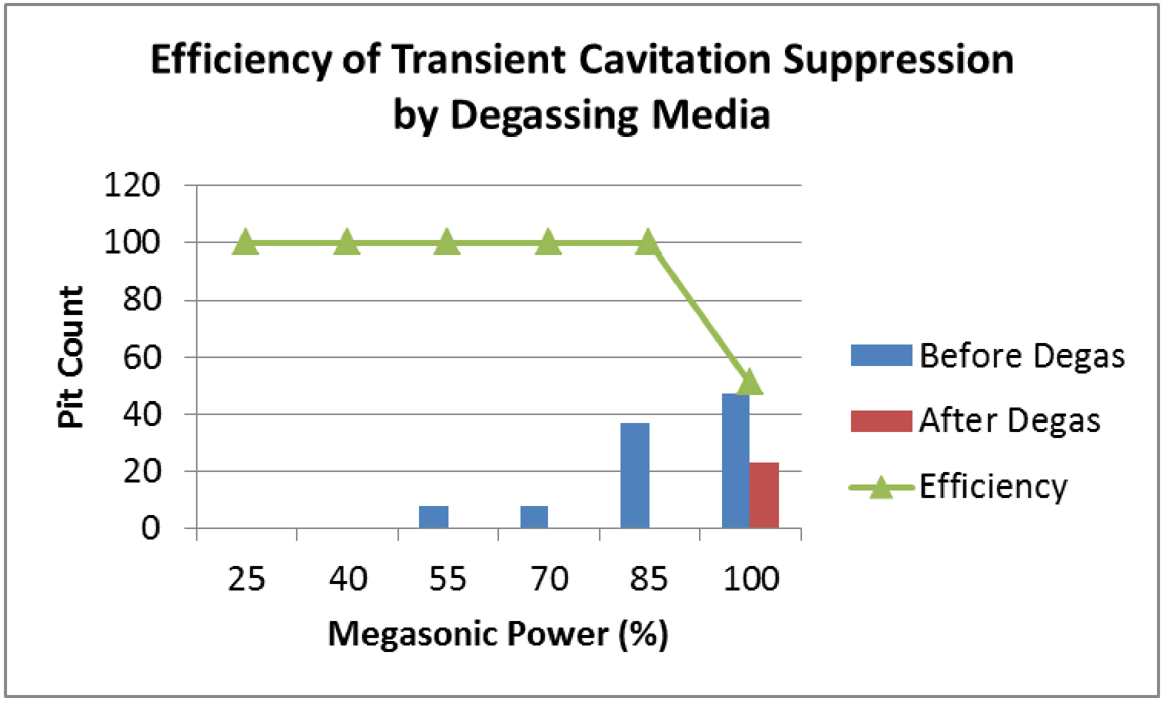
Isolating Role of Dissolved Gases in Cavitation Damage



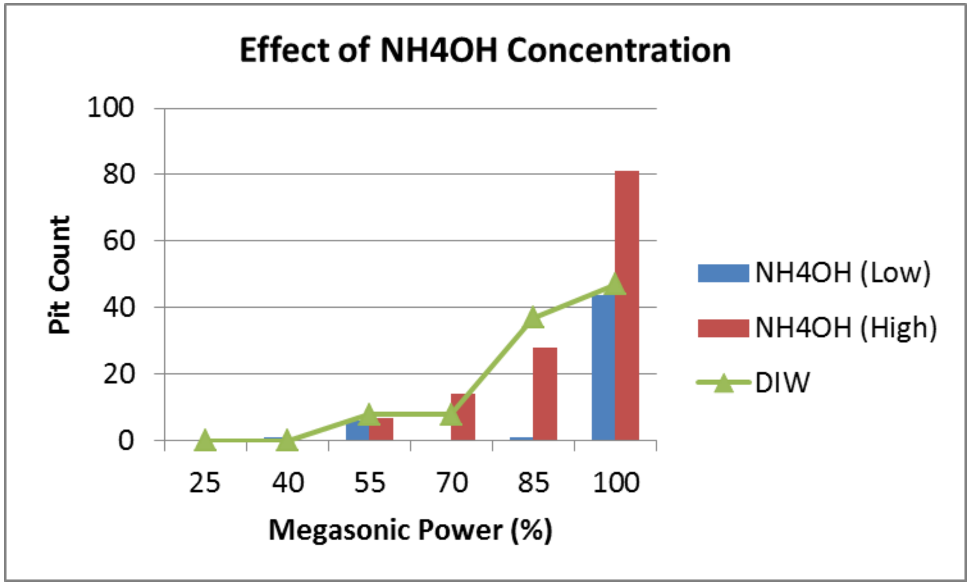
Degas Unit

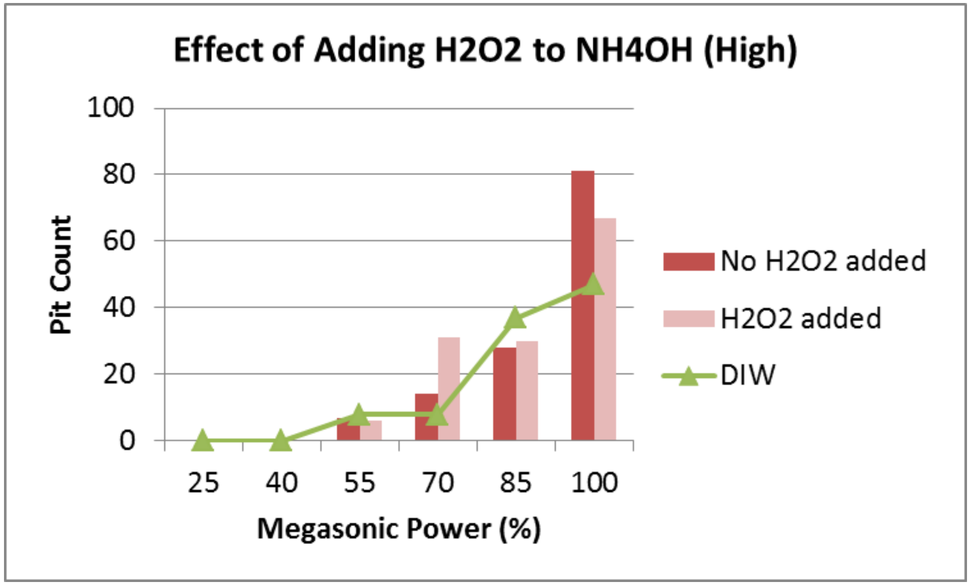


$$Degas\ Effieciency = \frac{Number\ of\ cavitation\ damage\ removed\ with\ degas\ cell}{Number\ of\ cavitation\ damage\ without\ degas\ cell}$$

Degassing DI water results in reduction/elimination of transient cavitation by reducing dissolved gas content

Effect of NH_4OH and NH_4OH/H_2O_2 Mixture (APM) in DI Water without Degassing



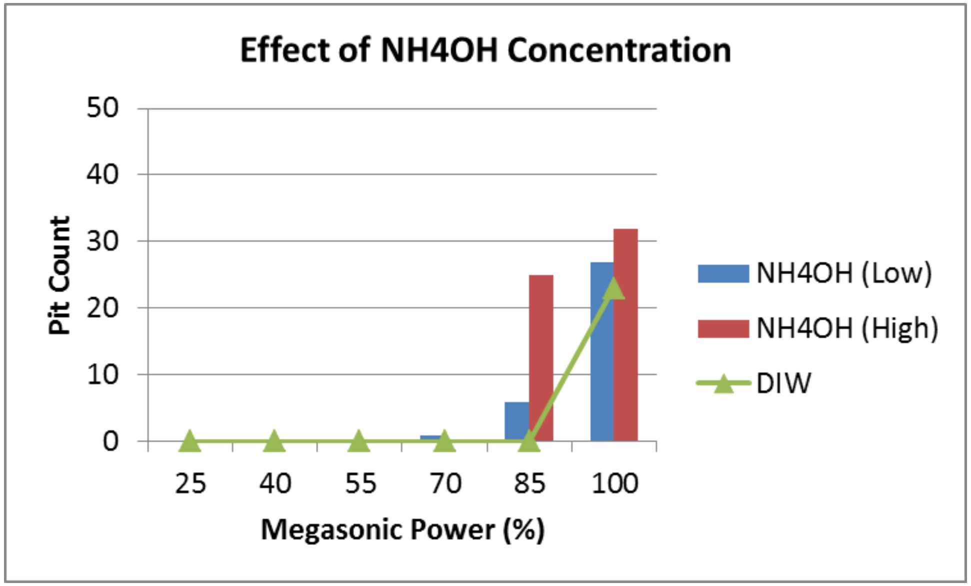


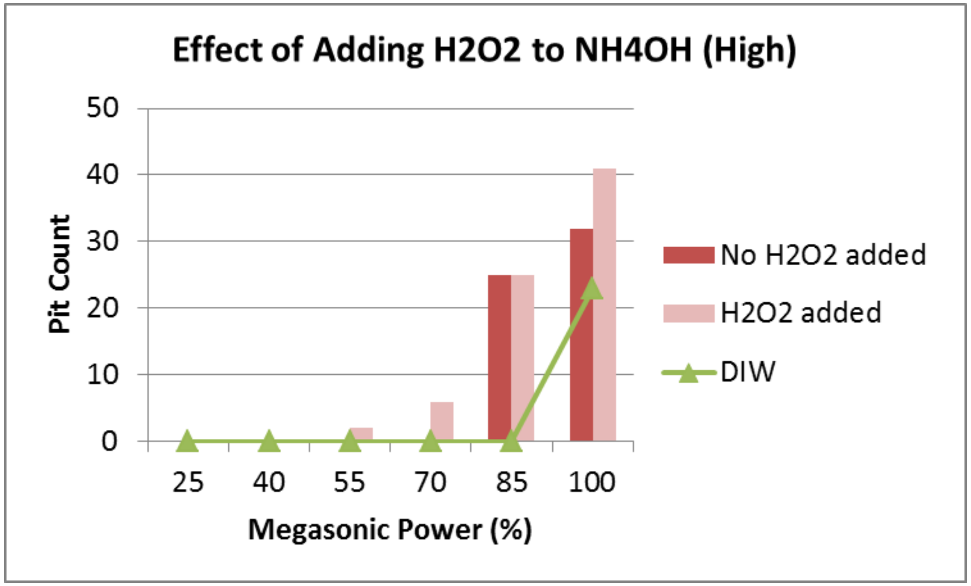
Adding NH_4OH at low concentration to none-degassed DI Water shows very little impact on pit formation.

Pit count increases when adding more NH_4OH. $NH_4OH \rightleftharpoons NH_3 + H_2O$ → **Transient Cavitation**

Adding H_2O_2 to NH_4OH has very little impact on pit formation

Effect of NH_4OH and NH_4OH/H_2O_2 Mixture (APM) in DI Water after Degassing

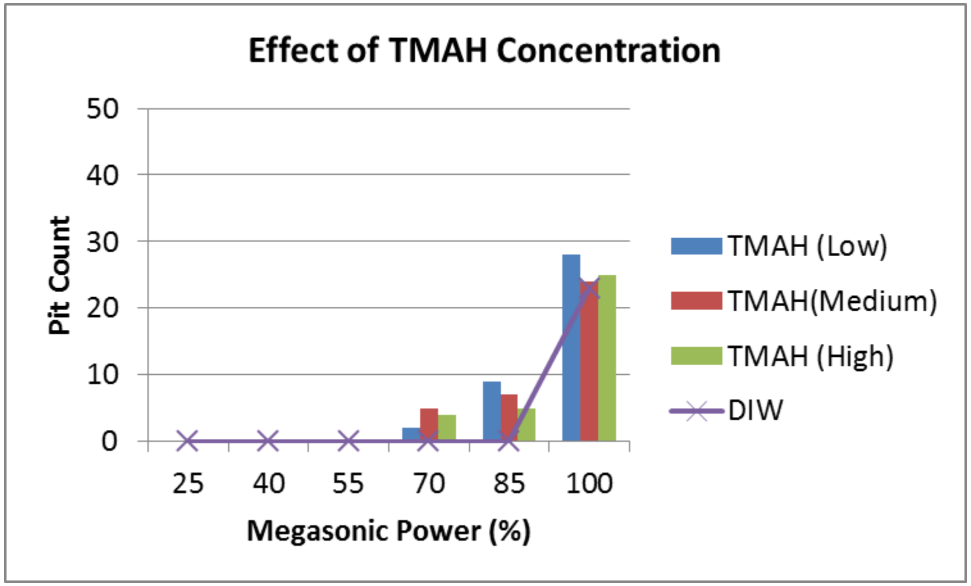


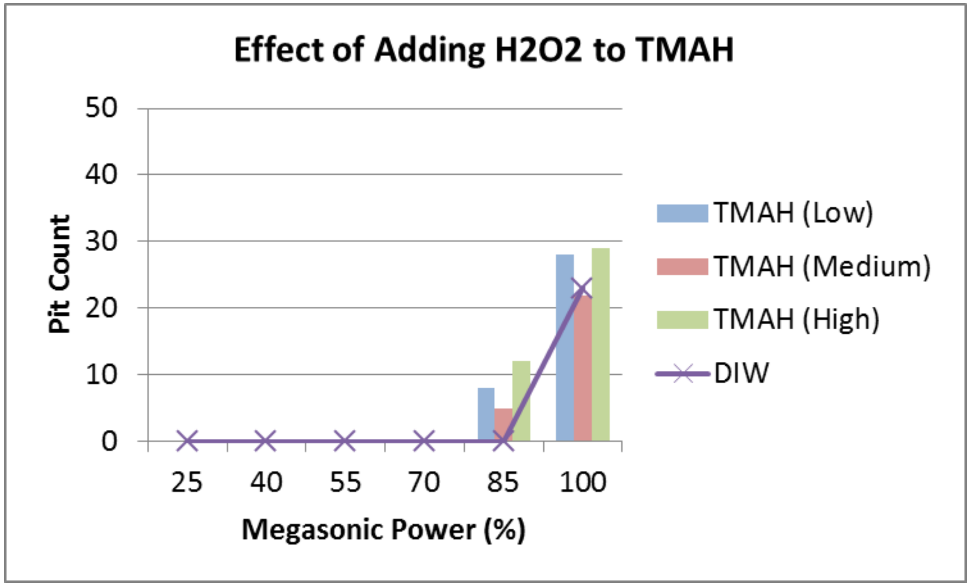


Adding NH_4OH to degassed DI Water results in increased pit count even at lower concentration.

Adding H_2O_2 to NH_4OH is further increasing the risk of surface damage. This is most likely due to O_2 gas released during H_2O_2 decomposition.

Effect of TMAH and TMAH/H_2O_2 Mixture (TPM) in DI Water after Degassing



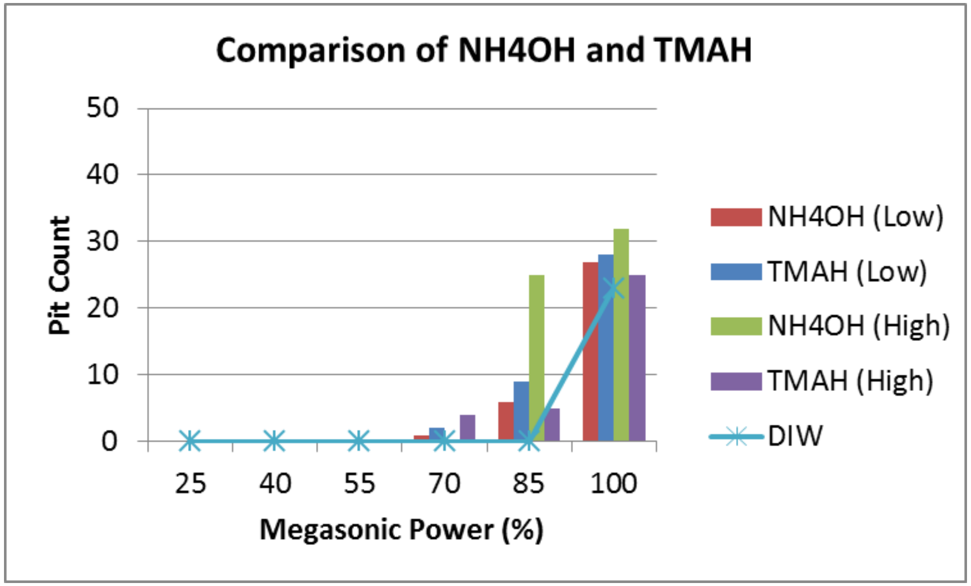


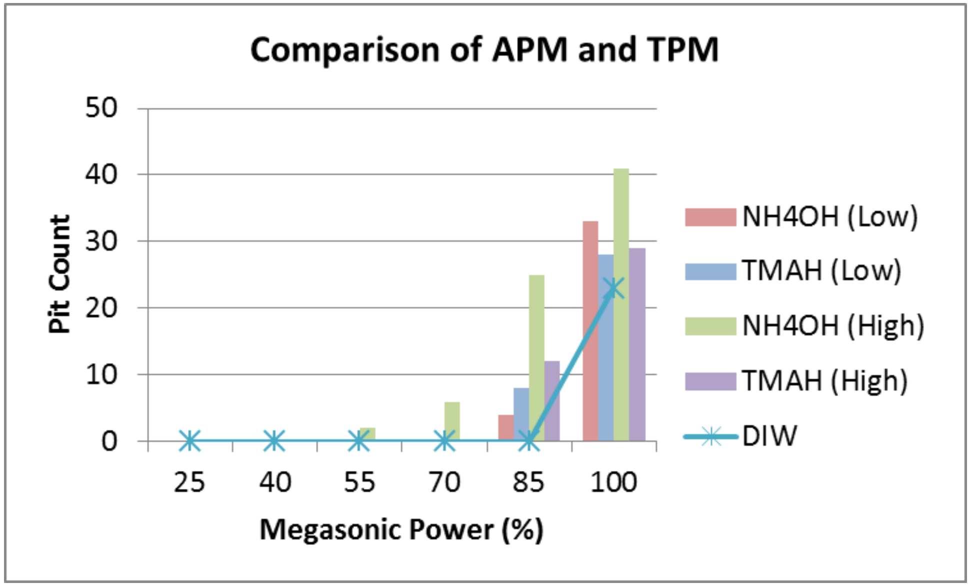
TMAH added to degassed DI Water is leading to slightly higher pit count, but independent of TMAH concentration.

Adding H_2O_2 to TMAH is reducing the risk of surface damage at Low and Medium TMAH concentration.

Pit count is slightly increased when H_2O_2 is added to high concentration TMAH

Comparison of NH_4OH and TMAH based chemistry in DI Water after Degassing





TMAH based chemistry is reducing the risk of surface damage

But what about Particle Removal Efficiency?

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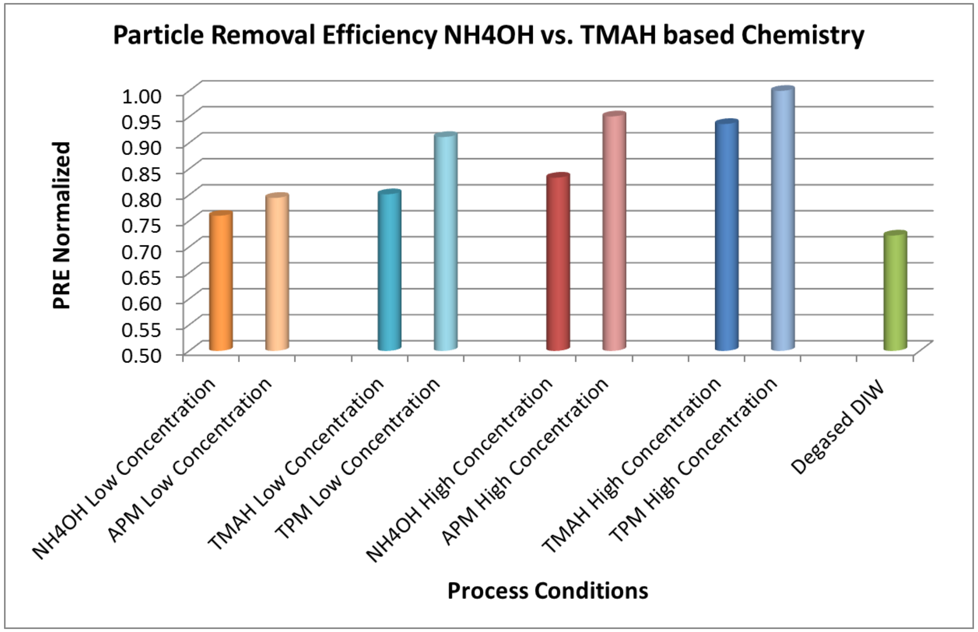
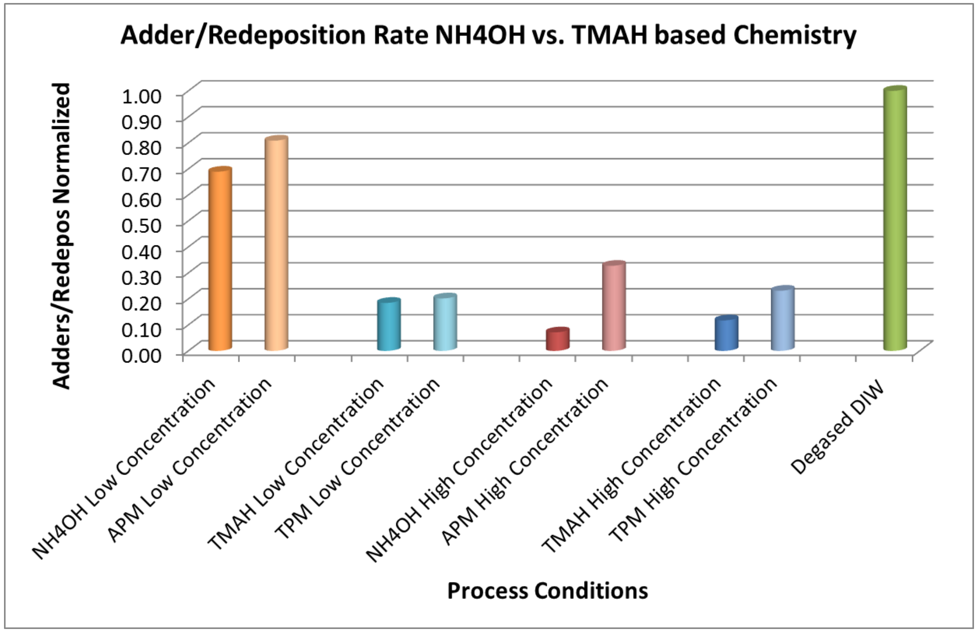
Effect of Media with megasonic power set below pit formation threshold

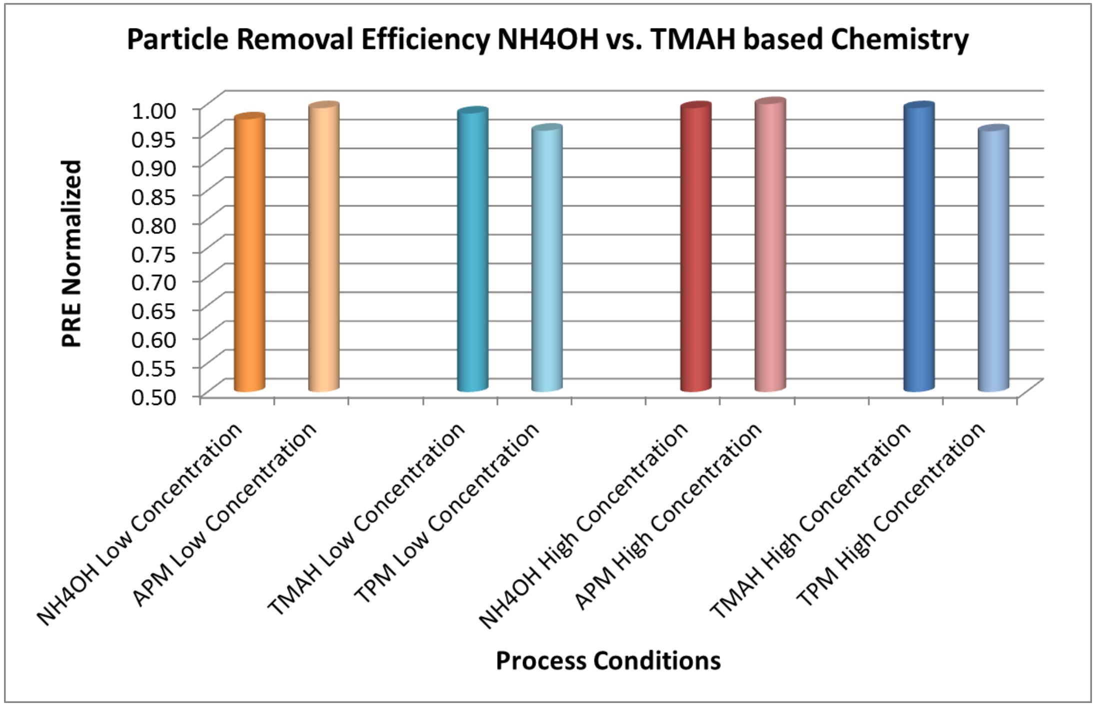




TMAH based chemistry provides higher PRE than NH_4OH based chemistry when operating megasonic power below surface damage threshold.

TMAH based chemistry also provides lower Adder/Deposition Rate than NH_4OH based chemistry.

Effect of Media with megasonic power exceeding pit formation threshold



PRE is slightly higher for NH_4OH based chemistry than for TMAH based chemistry when operating megasonic power above surface damage threshold.

However, this slightly higher PRE comes at a high cost of surface damage...

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SUMMARY

- Prior studies have shown that optimizing megasonic frequency and power alone does not achieve damage free cleaning for EUV substrates and blanks with high PRE [3]
  - Operating megasonic at high power above critical transient cavitation threshold carries high risk of surface damage with limited benefit for PRE
- Damage free cleaning is possible by combining frequency and power optimization with proper choice of process media
  - Operating megasonic at elevated power below critical transient cavitation threshold ensures high PRE without surface damage
- Dissolved gases in DI water contribute significantly to cavitation damage
  - Degassing DI water is critical in reducing cavitation damage
- This study shows that TMAH based chemistry is more suitable for damage free cleaning compared to traditional NH_4OH based chemistry
  - TMAH based chemistry provides higher PRE and lower surface damage as well as lower adder and redeposition rates compared to NH_4OH based chemistry

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ACKNOWLEDGEMENT

- Matt House and Martin Samayoa, SEMATECH, for their technical support
- Anil Karumuri, SEMATECH MBDC, for surface pitting and PRE data collection support
- SEMATECH MBDC, for providing substrates and blanks as well as cleaning and metrology tool access

LITERATURE REFERENCES

[1] D. Zhang, “Fundamental study of megasonic cleaning”, PhD thesis, University of Minnesota, (1993)

[2] F. R. Young, “Cavitation”, 1st edition, McGraw Hill Book Company, London, (1989)

[3] A. Rastegar “Cleaning technology challenges for sub 16 nm HP node” SEMATECH Mask Cleaning Workshop (2011)

[4] M. Keswani, S. Raghavan, R. Govindarajan, and I. Brown, “Measurement of Hydroxyl Radicals in Wafer Cleaning Solutions Irradiated with Megasonic Waves,” Journal of Microelectronic Engineering, 2014, to be published, Volume 118, 2014

[5] D. Dattilo, U. Dietze, “Efficient ozone, sulfate and ammonium free resist stripping process”, PMJ 2014

[6] S. Kumari, M. Keswani, S. Singh, M. Beck, E. Liebscher, P. Deymier, S. Raghavan, “Control of sonoluminescence signal in deionized water using carbon dioxide,” Journal of Microelectronic Engineering, doi:10.1016/j.mee.2010.10.03

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