Investigations of Acoustic Cavitation in Aqueous Surfactant Solutions for Cleaning Applications

Mingrui Zhao¹, Anfal Alobeidli², Xi Chen³, Petrie Yam³, Claudio Zanelli³, Sharyl Maraviov⁴, Mona Nagel⁵ and Manish Keswani²

¹Chemical and Environmental Engineering, University of Arizona, Tucson, AZ  
²Materials Science and Engineering, University of Arizona, Tucson, AZ  
³Onda Corporation, Sunnyvale, CA  
⁴PCT Systems Inc., Fremont, CA  
⁵Carl Zeiss, Oberkochen, Germany

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Introduction

- Megasonic irradiation – Commonly used for particle removal in integrated circuit industry
- Use of surfactant assists in achieving higher cleaning efficiency and minimizing feature damage
- Limited literature available on characterization of acoustic cavitation in solutions containing surfactants
- Proper understanding of the effect of surfactant on the bubble behavior will enable development of damage-free and effective cleaning processes for the semiconductor industry
Effect of Surface Tension on Cavitation Behavior in Ultrasound Fields

Sound emission spectra of Triton X-100 solution and ultrapure water (UPW) for 100% O$_2$ saturation and 0.2 W/cm$^2$ applied power density. Frequency = 928 kHz.

- Sound emission spectra was obtained from hydrophone measurements
- Ultra-harmonics (1.5, 2.5, 3.5...) are present in the Triton solution while completely missing in UPW
- Bubble activity is highly enhanced at a lower acoustic power for a lower surface tension

Hydrophone Set-up

Ultrasonic Tank

Surfactant

HCT-0310 Hydrophone

MCT-2000 Cavitation Meter

\[ f_0: 490 \text{ kHz} \]
\[ P_{i_1}: 41 \text{ kPa} \]
\[ P_{i_2}: 28 \text{ kPa} \]
\[ P_i: 14 \text{ kPa} \]

Computer

Ethernet
Quantification of Stable and Transient Cavitation Pressure

Different pressure components contribute to cleaning and damage.

Fundamental \( f = 485 \text{ kHz} \)

Harmonic \( f = 970 \text{ kHz} \)

Sub-Harmonic \( f = 243 \text{ kHz} \)

Ultra-Harmonic \( f = 728 \text{ kHz} \)

Direct Field
Stable Cavitation
Transient Cavitation
Both stable and transient cavitation pressure generally decreased as frequency increased from 28 to 490 kHz.

Ratio of stable cavitation pressure to transient cavitation pressure increased from 0.7 to 2.1 in the frequency range observed.
Effect of Triton® X-100 on Transient and Stable Cavitation Pressure in Solutions Subjected to Single Frequency (4 W/cm²)

- **CMC**: 15E-3%; **Surface tension**: 35 mN/m
- **Stable cavitation pressure** decreased slightly or remained unchanged at all frequencies when Triton® X-100 was employed.
- **Transient cavitation pressure** decreased with addition of surfactant.
- **Ratio of stable cavitation pressure to transient cavitation pressure** increased in the presence of Triton® X-100.
Effect of Triton® X-100 on Stable and Transient Cavitation Pressure in Solutions Subjected Dual-Frequency

CMC: 15E-3%; Surface tension: 35 mN/m

Stable cavitation pressure was maintained and transient cavitation pressure was suppressed with the addition of Triton

Ratio of stable cavitation pressure to transient cavitation pressure increased in the presence of Triton
Damage Study

- Aluminum coated glass samples
- 200 and 500X magnifications
- Acoustic power: 4 W/cm²
- Duration: 1 hour

- Severe damage was observed on the surface when using UPW
- Surface damage greatly reduced by adding Triton® X-100
In a multi-bubble field, cavitation bubble growth can occur by either rectified diffusion or bubble coalescence.

Surfactants can adsorb at bubble-liquid interface and reduce the coalescence between bubbles and negatively affect rectified diffusion.

Transient cavitation is suppressed due to inhibition of bubble growth (preventing the bubbles from reaching pressure threshold for cavitation).

Retardation of diffusion also reduces the bubble growth and may affect the stable cavitation activity.
Summary

- Hydrophone measurements allowed quantitative characterization of stable and transient cavitation pressure in sound field.

- In single and dual-frequency systems, the ratio of stable cavitation pressure to transient cavitation pressure increased with addition of Triton® X-100.

- Surface damage significantly reduced in surfactant containing solutions compared to de-ionized water.