Characterization of Stable and Transient Cavitation in a Dual-Frequency Acoustic Field using a Hydrophone

Mingrui Zhao[1], Anfal Alobeidli[2], Xi Chen[3], Petrie Yam[3], Claudio Zanelli[3] and Manish Keswani[2]

[1]Chemical and Environmental Engineering, University of Arizona, Tucson, AZ
[2]Materials Science and Engineering, University of Arizona, Tucson, AZ
[3]Onda Corporation, Sunnyvale, CA

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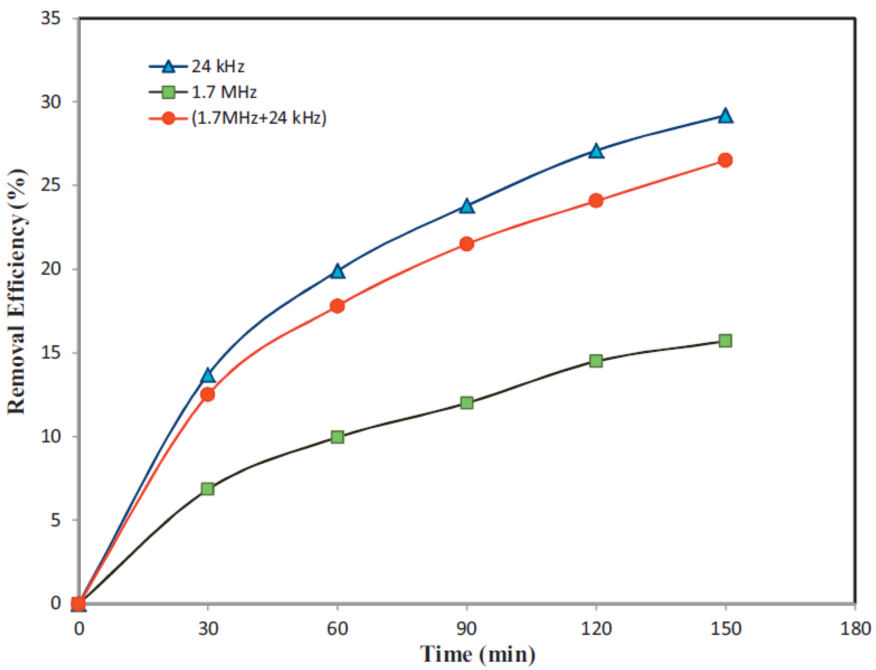
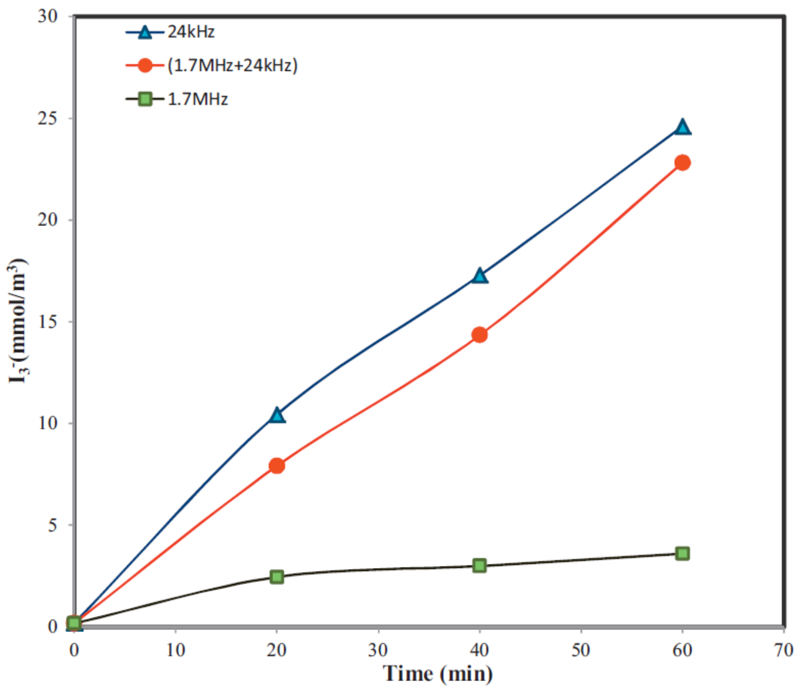
Introduction

- ***Ultrasonic irradiation – cleaning of optical parts, lenses and surgical instruments***
- ***Megasonic cleaning – particle removal in integrated circuit fabrication***
- ***Single frequency systems limit the extent, intensity and tunability of stable and transient cavitation***
- ***Combination of two or more frequencies is expected to achieve better cleaning efficiency as well as minimal feature damage***

Previous Work on the use of Dual-Frequency Sound Waves for Ammonia Removal



The removal ratio of ammonia versus time in the different modes of ultrasound irradiation. Input power density: 89.17 W/cm^2. Initial ammonia concentration: 100 ppm.

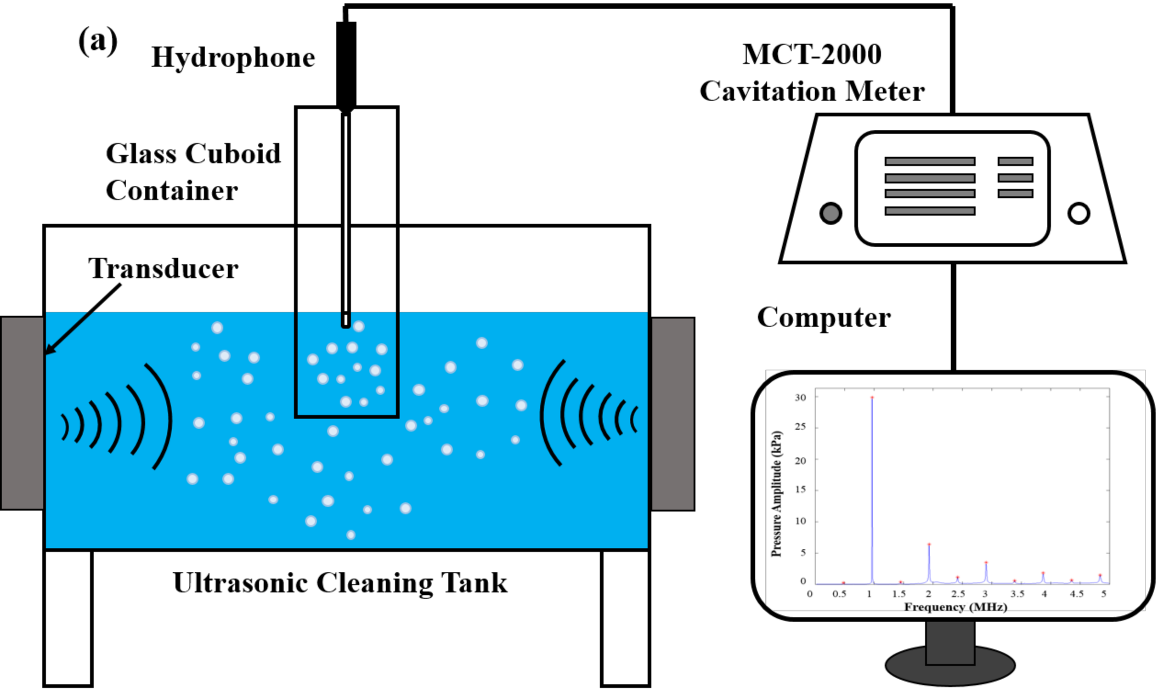


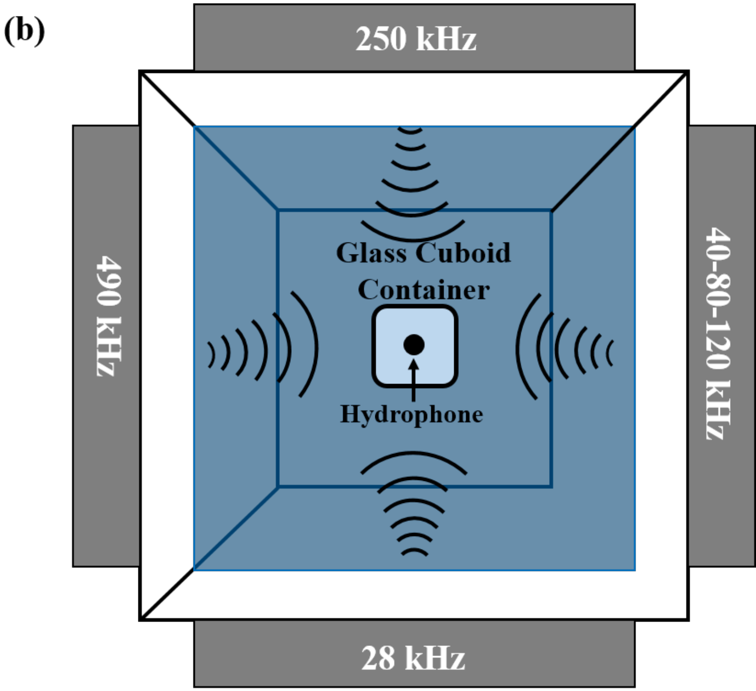
Iodide (KI) dosimetry. The effect of different modes of ultrasound irradiation on generation of OH radicals.

- ***NH_3 was removed due to collapse of bubbles***
- ***A lower NH_3 removal in dual frequency mode can be related to the negative interaction of the high and low frequency waves***
- ***KI dosimetry indicated less cavitation activity in dual-frequency mode compared to low frequency***

M. Rahimi, S. Safari, M. Faryadi and N. Moradi, Chem. Eng. Process. 78, 17-26 (2014).

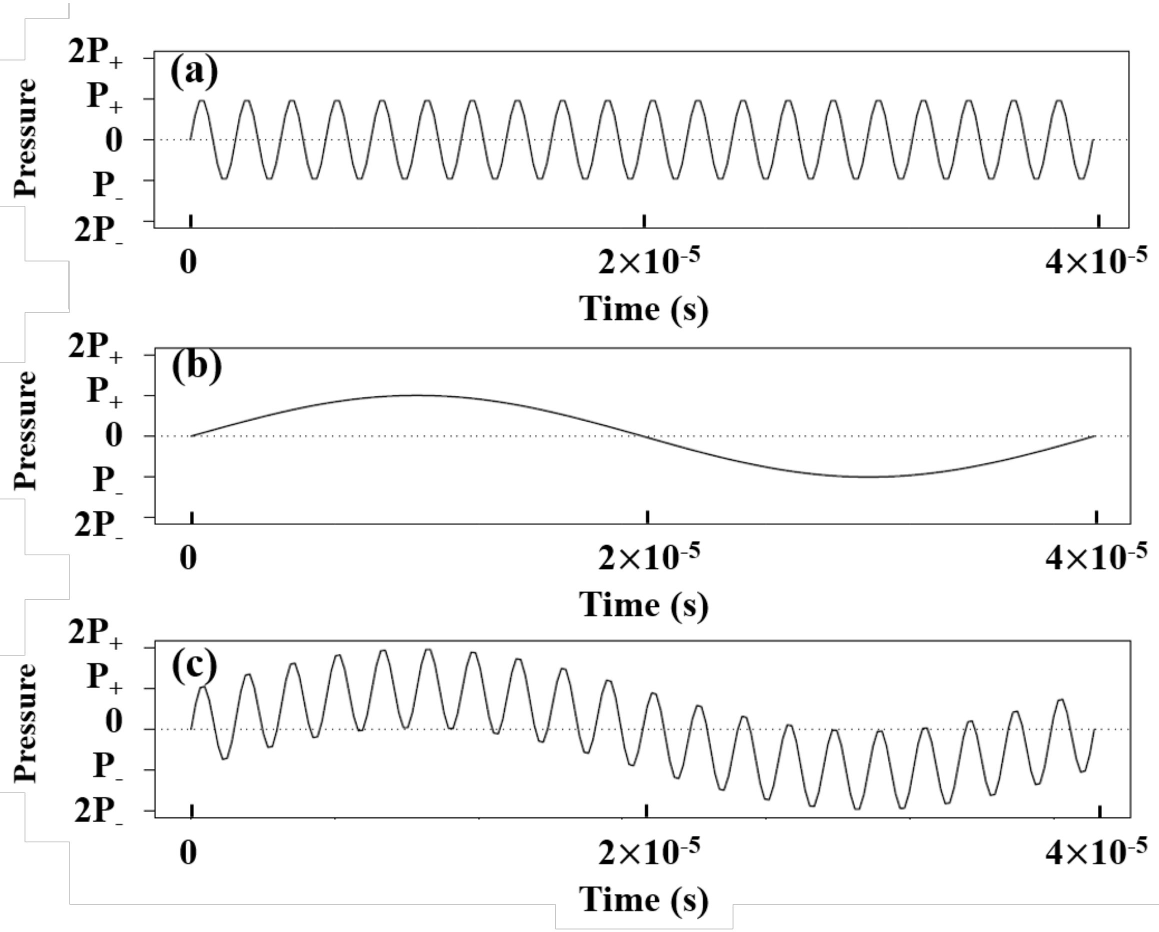
Experimental Set-up





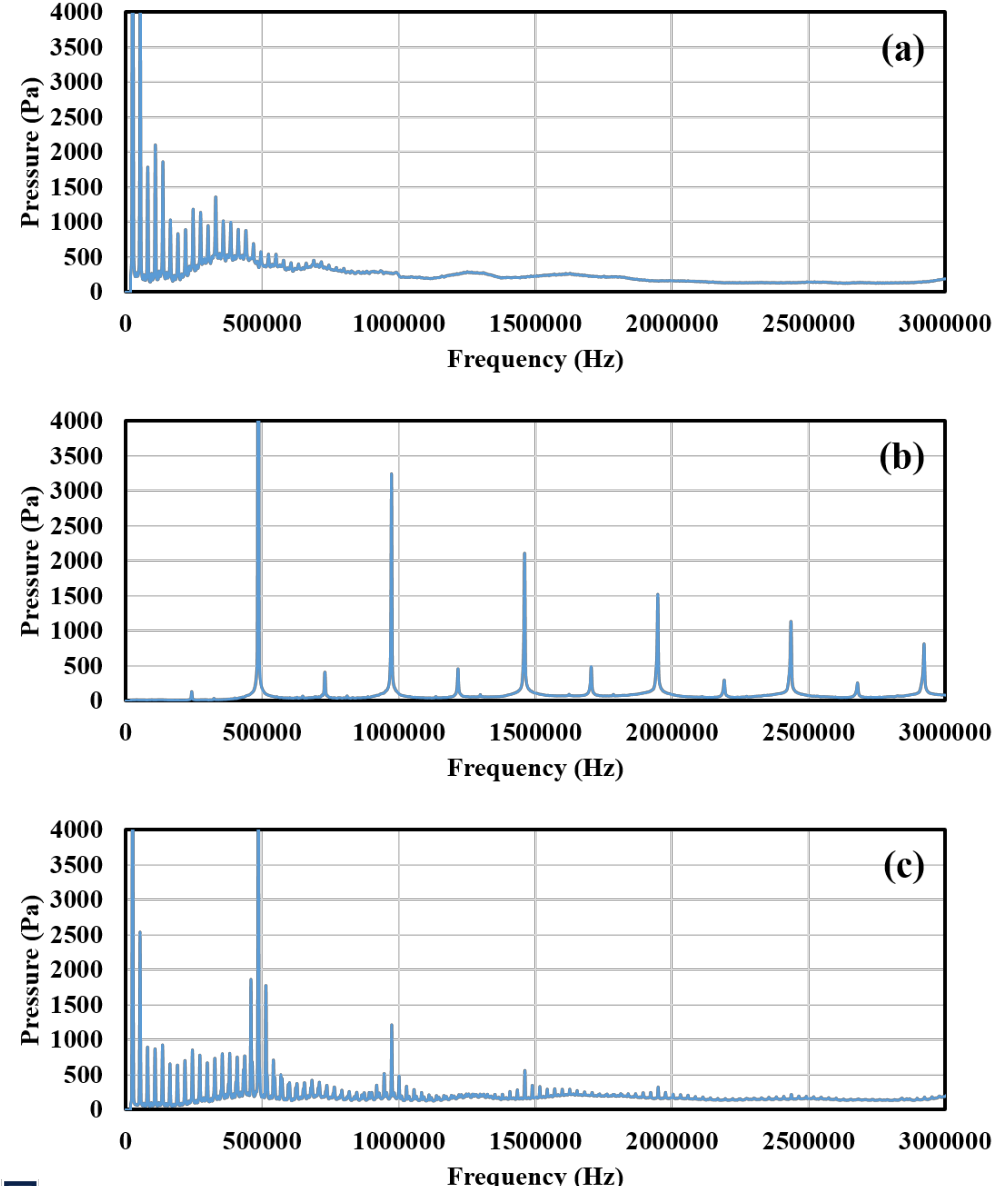
- ***Hydrophone based technique allows quantitative determinations of stable and transient cavitation pressures***
- ***A hydrophone (connected to a cavitation meter) was used for acquiring the data at high sampling rates (16.7M samples/sec)***

Interference of Sound Waves in a Dual-Frequency Acoustic Field



- *At ultrasonic frequencies, cavities have enough time to expand and collapse during rarefaction and compression cycles*
- *Interference of 490 kHz causes an increase in number of cycles per second*
- *Less bubble growth time and irregular cycles lead to less number of bubble collapses*
- *Lower feature damage is expected in dual-frequency mode*

Comparison of Pressure-Frequency Spectrums of 28, 490 and 28&490 kHz

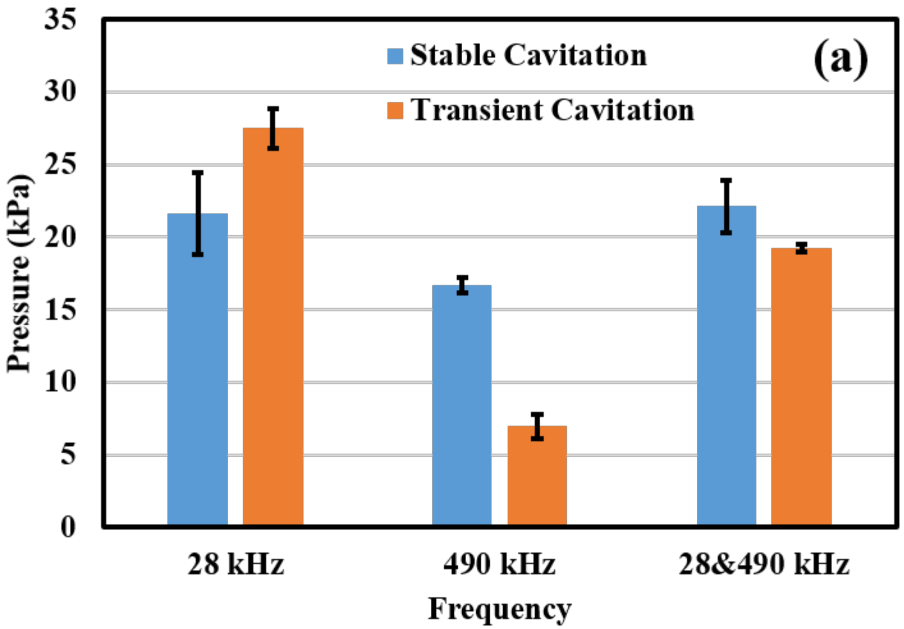


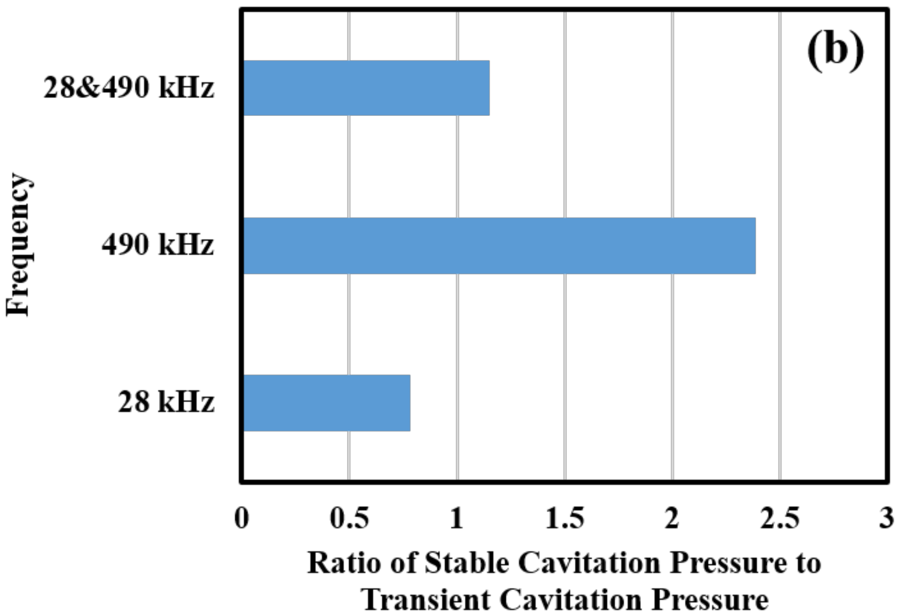
In dual-frequency mode:

- ***Combined frequencies (fundamental frequencies and harmonics) are generated***
- ***Wider size range of bubbles to undergo stable cavitation***
- ***Enhanced stable cavitation induces increased microstreaming and shear stress***

Comparison of Stable and Transient Cavitation Pressure in Single and Dual-Frequency Modes

Acoustic power for single frequency and each frequency in dual-frequency mode: 2 W/cm²





In dual-frequency mode of 28&490 kHz:

- *Stable cavitation pressure was the highest*
- *Transient cavitation pressure was 30% lower in comparison with 28 kHz*
- *Ratio of stable cavitation pressure to transient cavitation pressure increased by 46% comparing to 28 kHz*

Comparison of Stable and Transient Cavitation Pressure in Single and Dual-Frequency Modes

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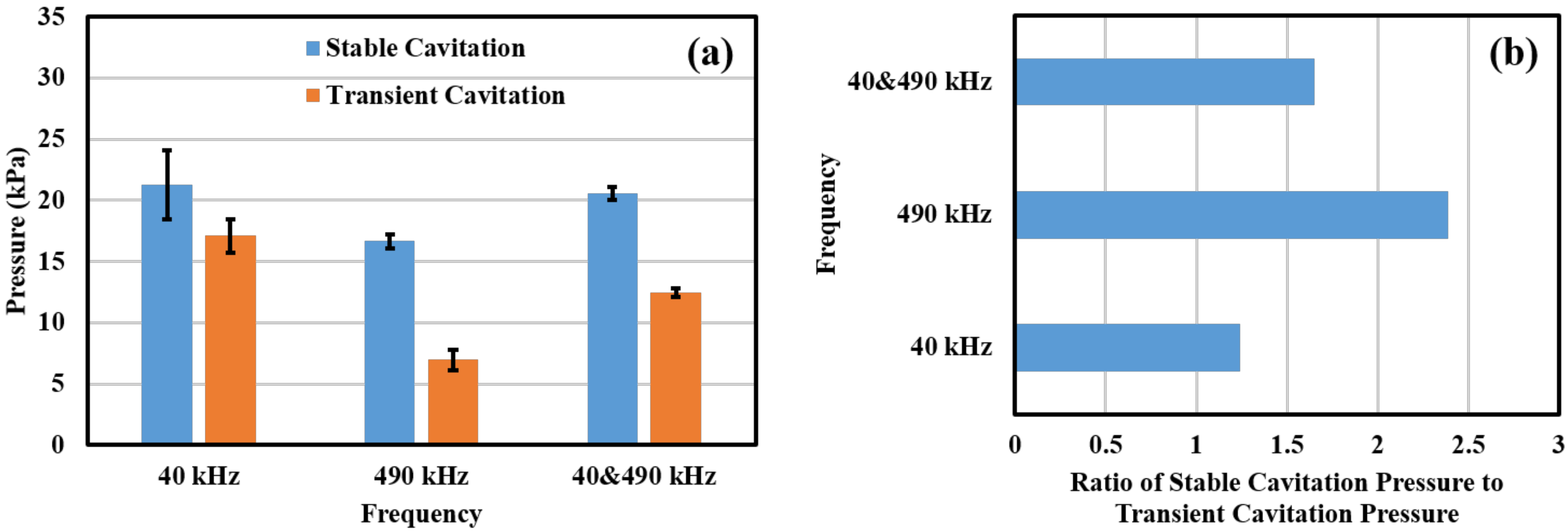

- ***Similar pressure value of stable cavitation observed at 40 and 40&490 kHz***
- ***Transient cavitation pressure at 40&490 kHz was 30% lower compared to 40 kHz***
- ***33% increase in ratio of stable cavitation pressure to transient cavitation pressure at 40&490 kHz compared with 40 kHz***

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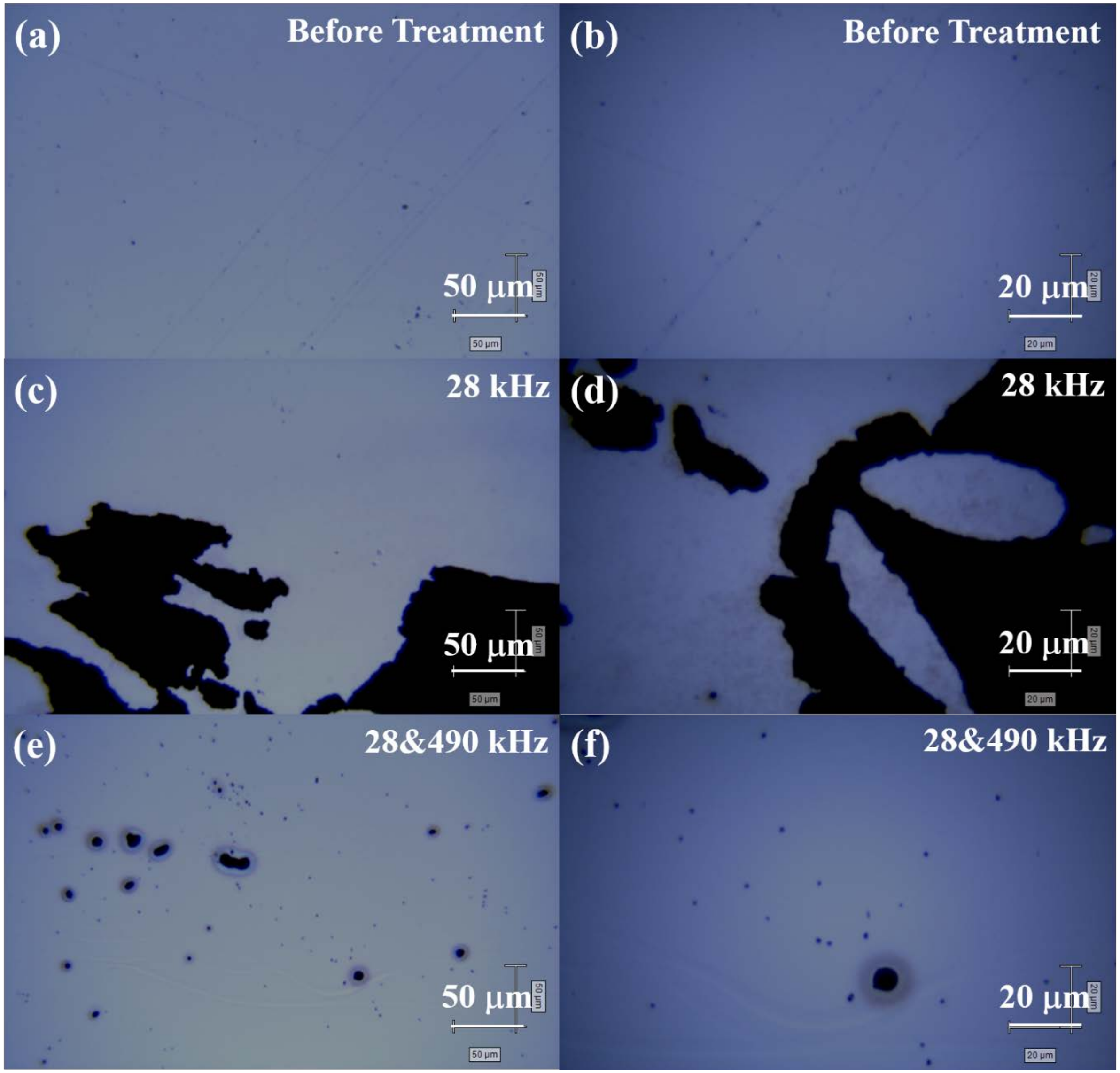
Damage Study



- Aluminum coated glass
- 200 and 500X magnification
- Acoustic power for 28 kHz and each frequency in dual-frequency mode: 2 W/cm^2
- Duration: 1 hour

- ***Severe damage was observed on the surface when irradiated with 28 kHz***
- ***Sample treated with dual-frequency mode showed much lower cavitation erosion***

Summary

- ***Cavitation performance quantified by measuring acoustic emissions with hydrophone***
- ***Applying multiple drive frequencies presents possible variable to "tune" the level of stable and transient cavitation***
- ***Critical to optimizing cleaning performance, namely maximizing particle removal while minimizing damage***