Putting Confidence in Ultrasound

Characterization of Acoustic Cavitation from a Megasonic Nozzle Transducer for Photomask Cleaning

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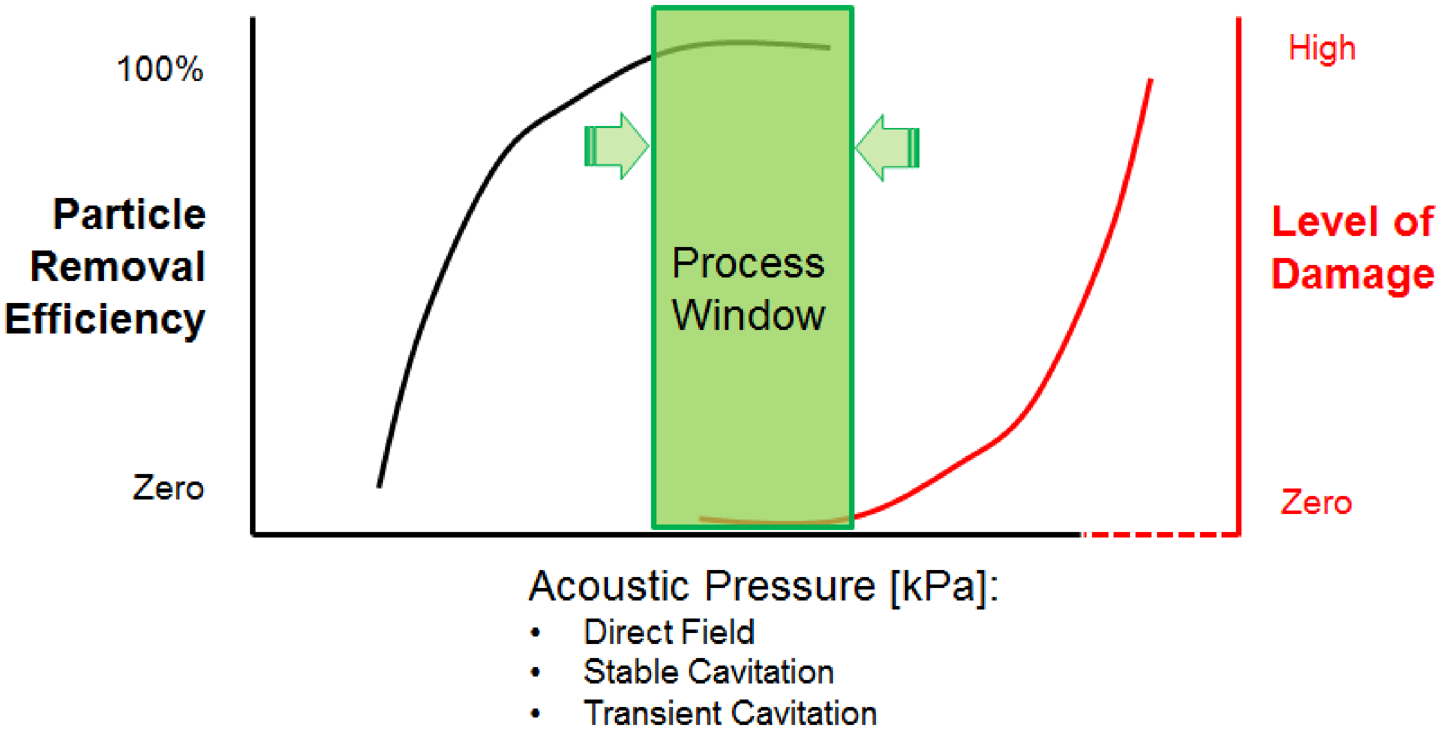
Mask Cleaning Trend: *Tighter Process Window*



- Continued use of megasonics in 193i and EUV
- Shrinking feature dimensions and more complex patterns
- **Tighter process window !**

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Photomask Cleaning Challenges

Skirt-Type
Transducer

Nozzle-Type
Transducer

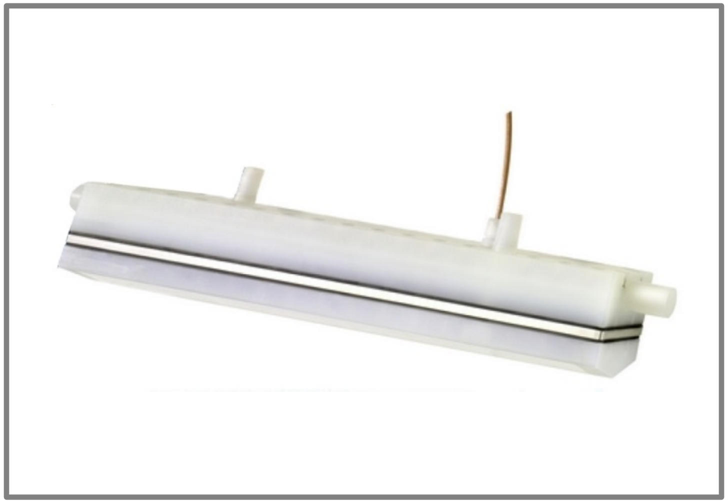
Plate-Type
Transducer

Dynamic Process:

- Transducer position
- *Acoustic uniformity*
- *Acoustic cavitation*
- Reflections
- *Flow rate*
- Water level
- Gas concentration
- Moving mask & transducer
- Temperature
- Chemistry
- *Frequency*
- *Generator power*
- Substrate material
- Process time
- And more…

Need *in-situ* measurement solution to correlate with cleaning

Examples of Photomask Transducers



Quantification of Cavitation Pressure

Acquire data with Hydrophone

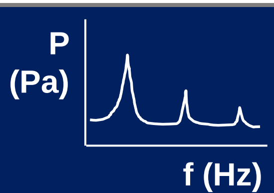
Voltage vs Time

Fourier Transform

Voltage vs Frequency

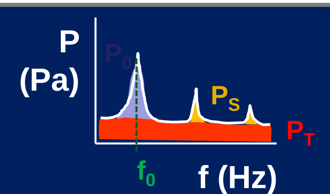
Apply Hydrophone Calibration

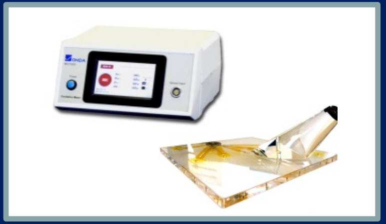
Pressure vs Frequency



Apply MCT-2000 Algorithms

Calculation of P_0, P_S, P_T, f_0

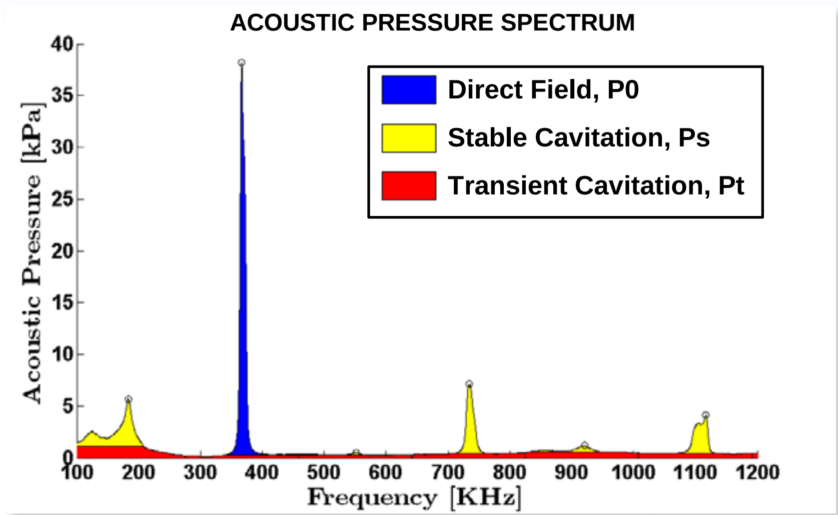


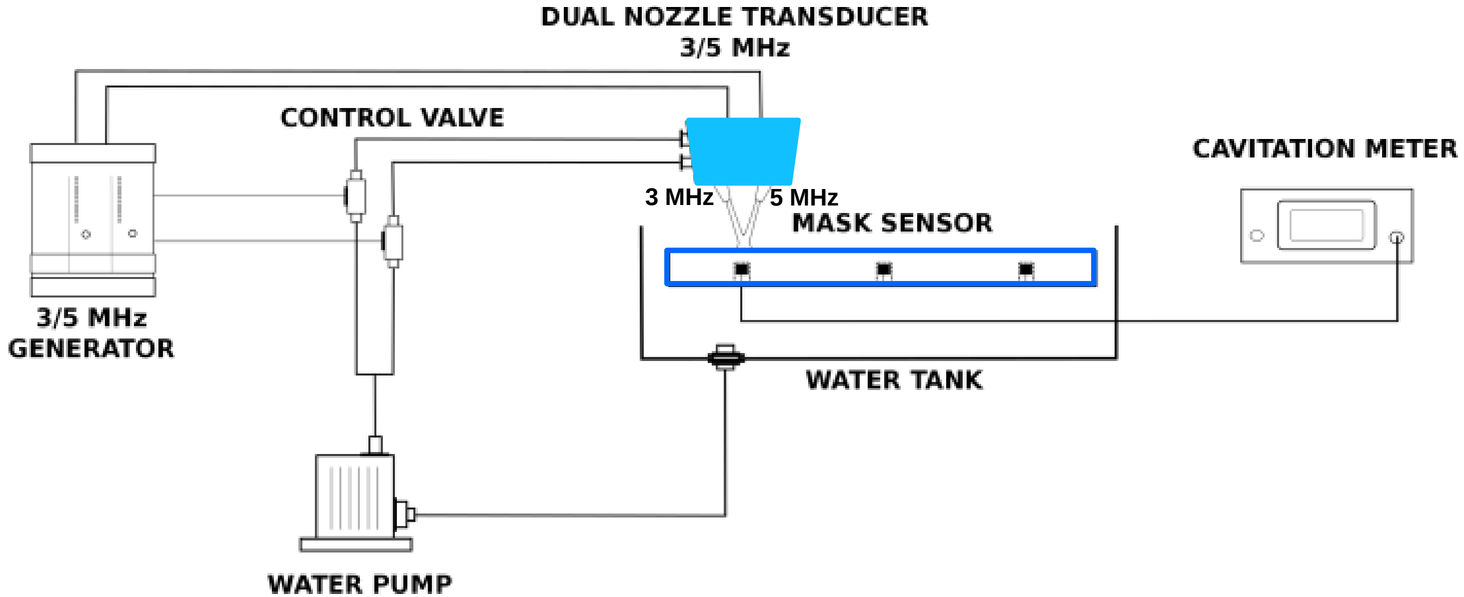


MCT-2000 Measures:

- V vs. t
- P vs. f
- P_0, P_S, P_T, f_0

Cavitation Meter with Mask Sensor





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Acoustic Test Plan

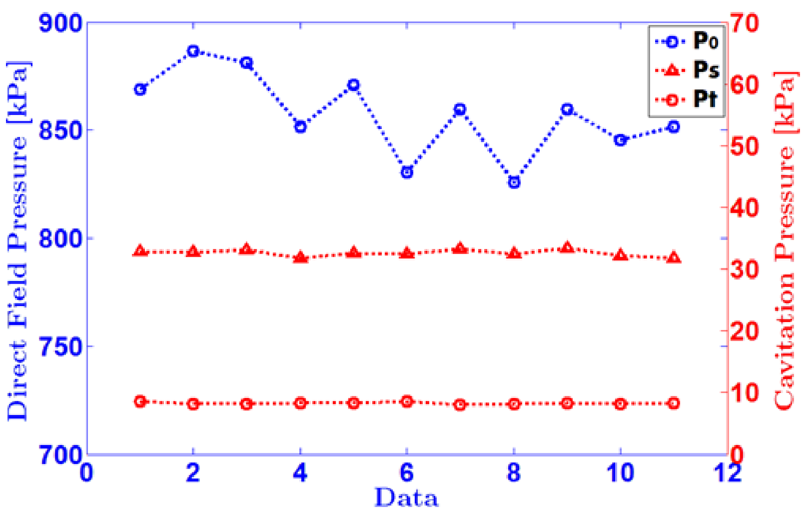
1. Gage Repeatability and Reproducibility (11 repeats)
2. Cavitation Pressure vs Frequency (3, 5, 3+5 MHz)
3. Cavitation Pressure vs Generator Power (10-100%, 35 W)
4. Cavitation Pressure vs Nozzle Distance (5-20 mm)
5. Cavitation Pressure vs Flow Rate (1-1.6 L/min)
6. Cavitation Pressure vs Sensor Position (A, B, C)

Gage R&R

Test Conditions:
- 3 MHz (50%), 5 MHz (50%)
- Nozzle Distance: 20 mm
- Medium: DIW
- Flow rate: 1.6 L/min

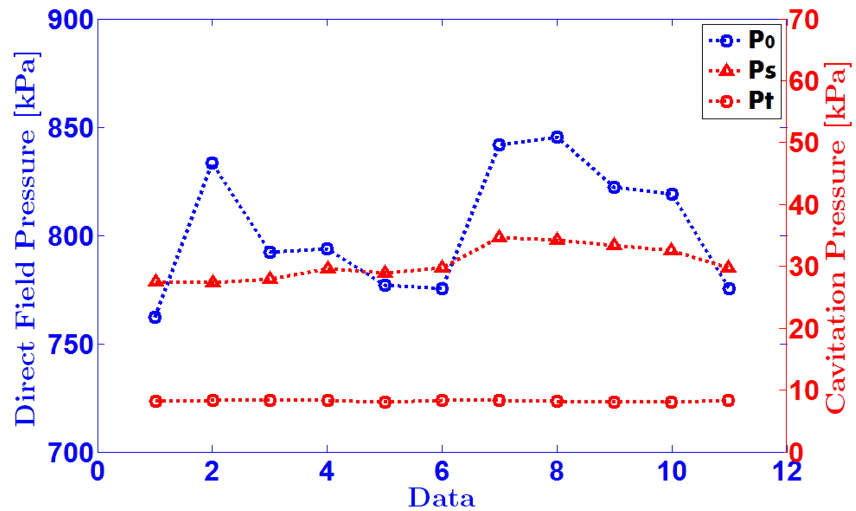
Static Repeatability (11X)

- Without Load/Unload of Mask Sensor



Reproducibility (11X)

– With Load/Unload of Mask Sensor

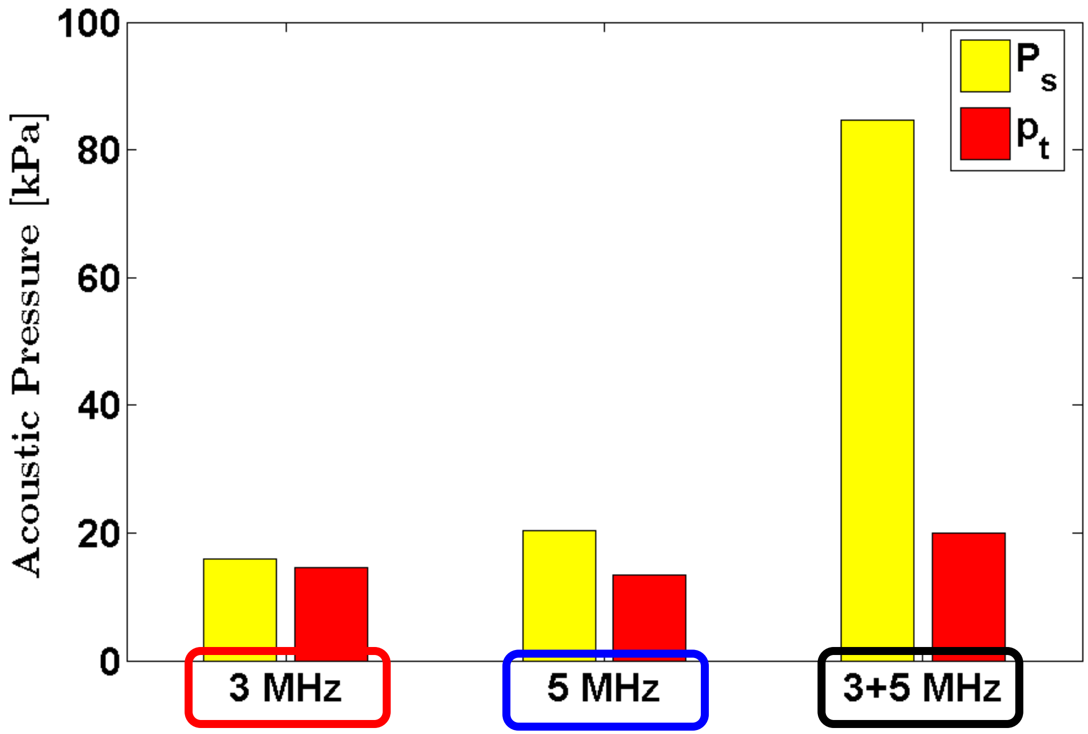


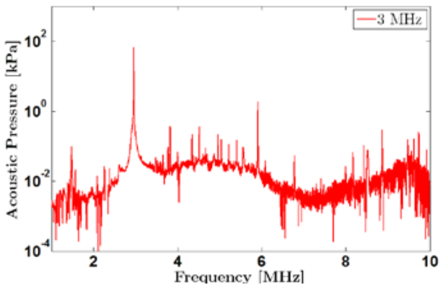
	Static Repeatability (% Std Dev)	Reproducibility (% Std Dev)
P0	2.2	3.7
Ps	1.6	9.4
Pt	1.9	1.4

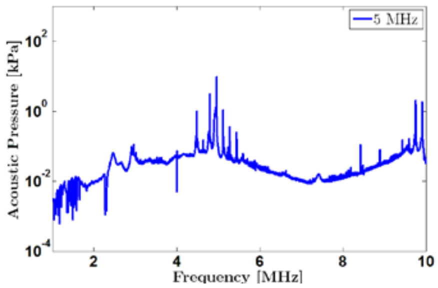
Cavitation vs. Frequency

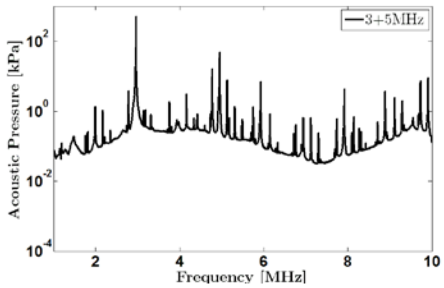
Test Conditions:

- 3 MHz (50%), 5 MHz (50%)
- Nozzle Distance: 20 mm
- Medium: DIW
- Flow rate: 1.6 L/min





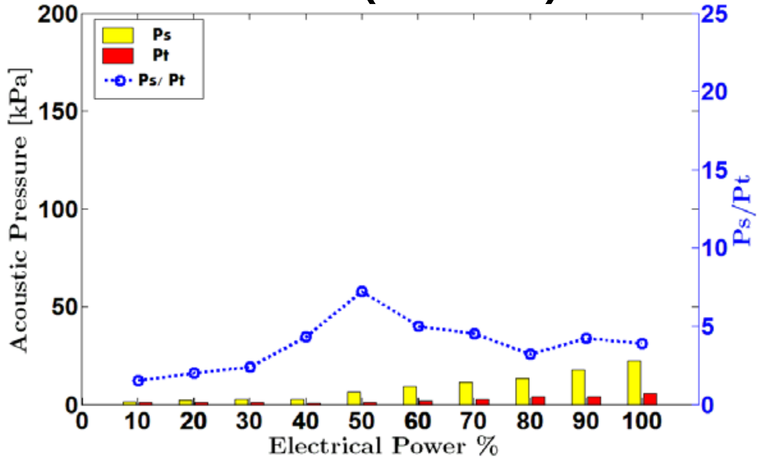




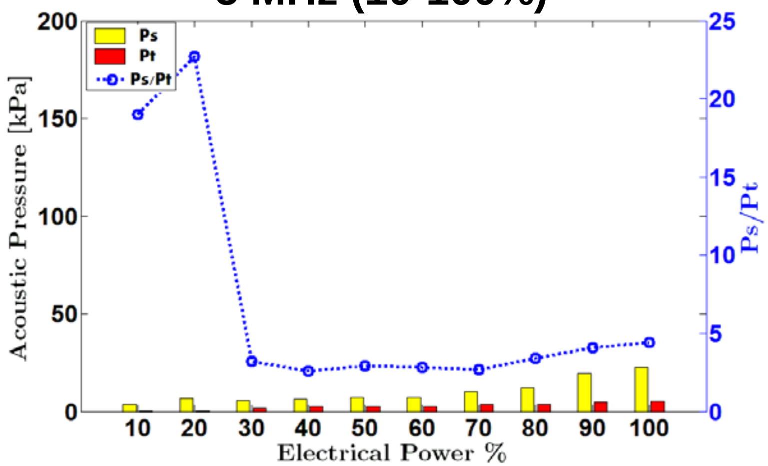
Cavitation vs. Generator Power

Test Conditions:
- Nozzle Distance: 20 mm
- Medium: DIW
- Flow rate: 1.6 L/min

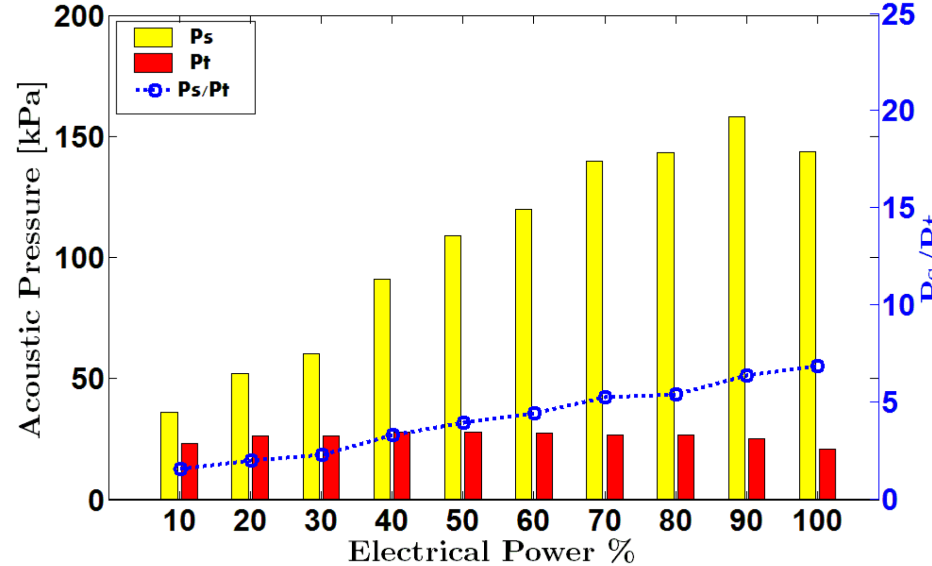
3 MHz (10-100%)



5 MHz (10-100%)

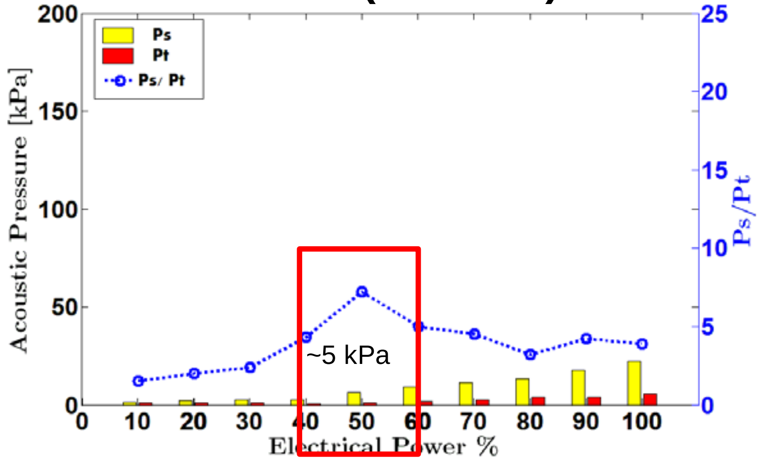


3 MHz (50%) + 5 MHz (10-100%)

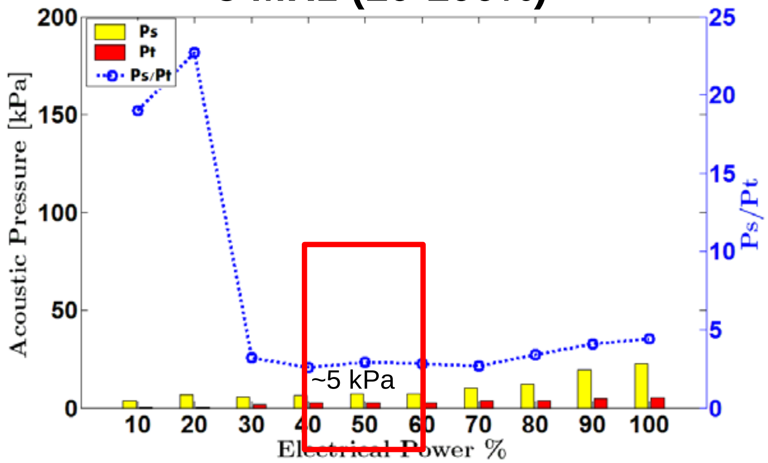


Cavitation vs. Generator Power

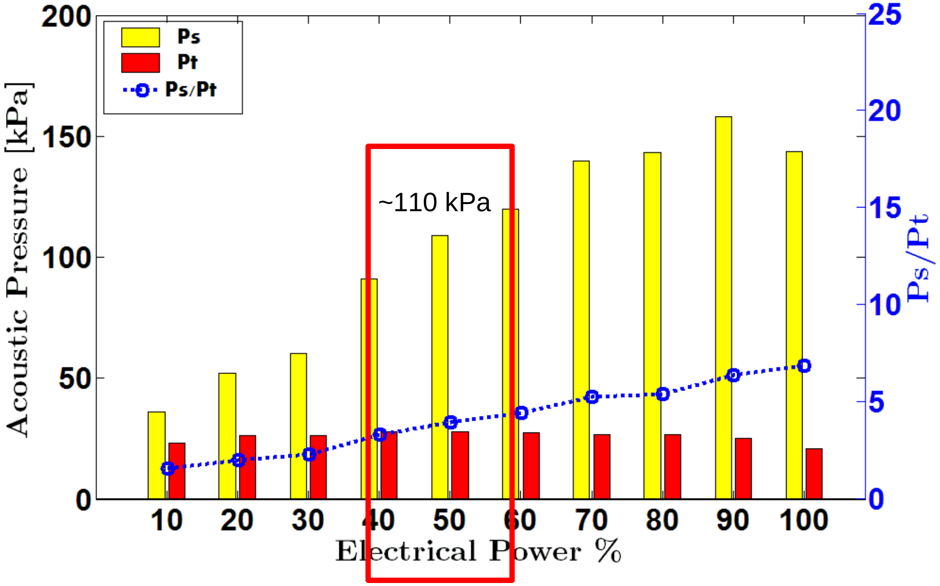
3 MHz (10-100%)



5 MHz (10-100%)



3 MHz (50%) + 5 MHz (10-100%)

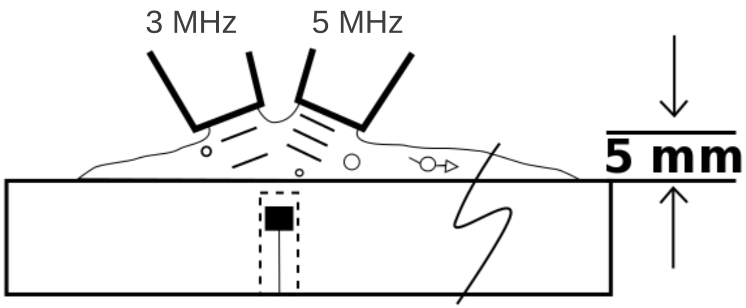


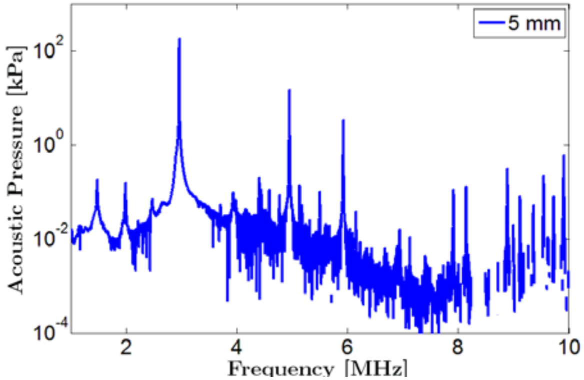
5 + 5 ≠ 110!

Cavitation vs. Nozzle Distance

At 5 mm:

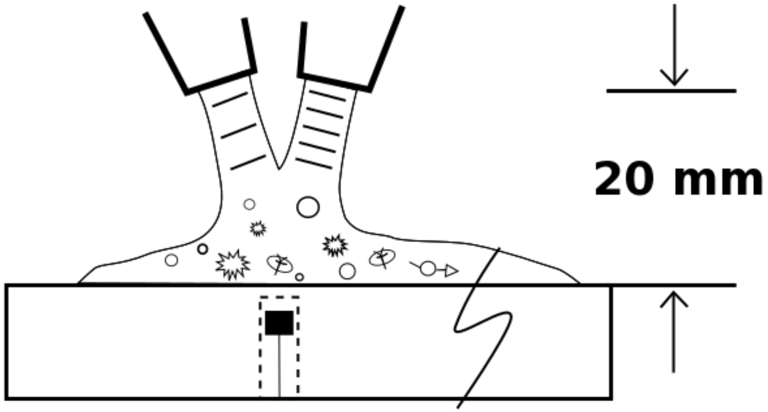
Lower presence of static bubbles which yields less stable cavitation

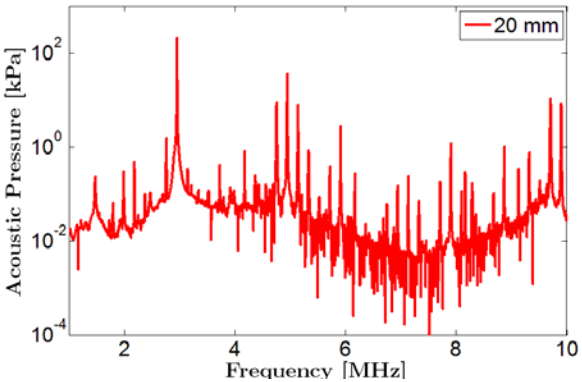




At 20 mm:

More static bubbles which promote generation of stable cavitation.

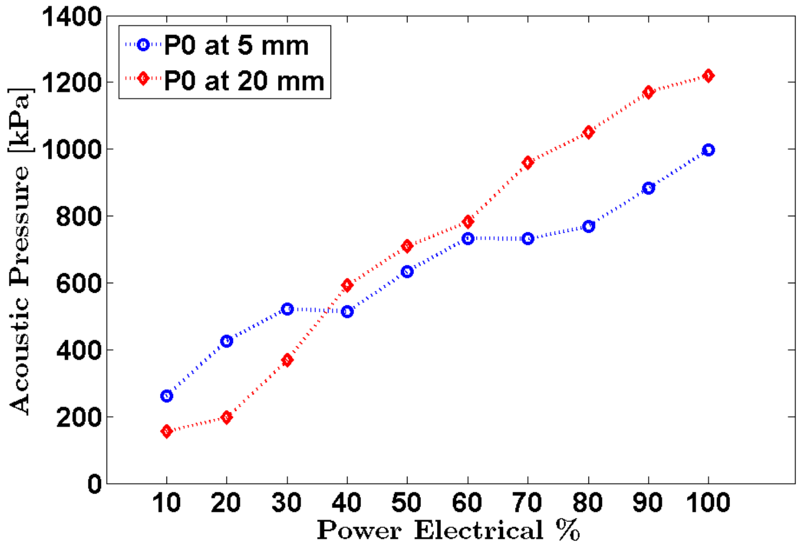




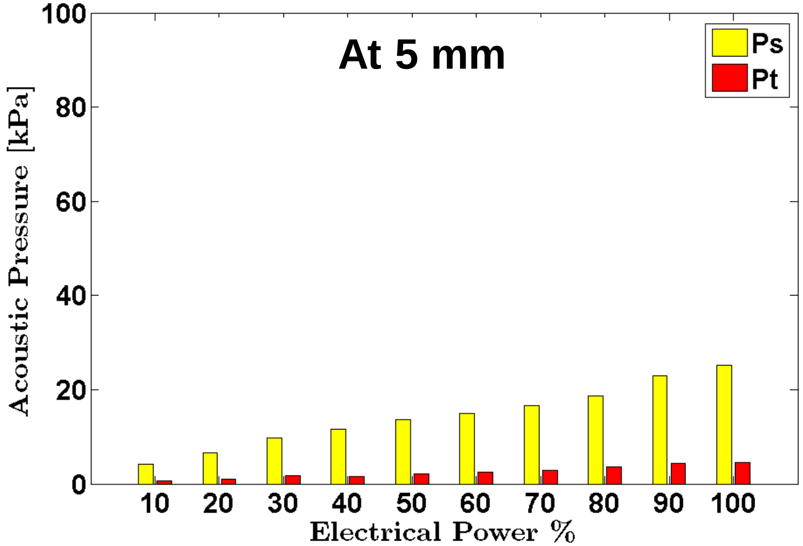
Cavitation vs. Nozzle Distance

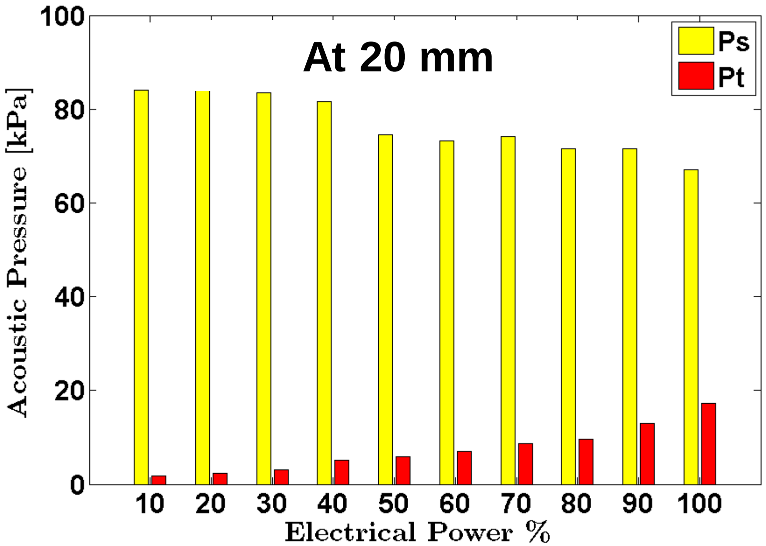
Test Conditions:

- 3 MHz (10-100%), 5 MHz (50%)
- Nozzle Distance: 5, 20 mm
- Medium: DIW
- Flow rate: 1.6 L/min



At 20 mm, Ps/Pt is maximized at low power.





Cavitation vs. Flow Rate

Low Flow (1.0 L/min):

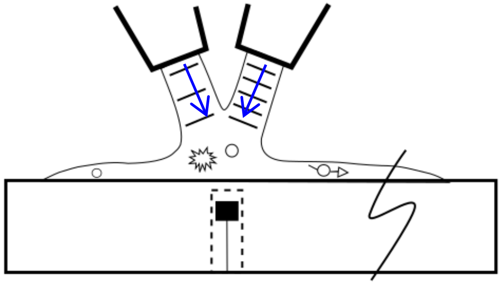
Generation of static bubbles from liquid flow

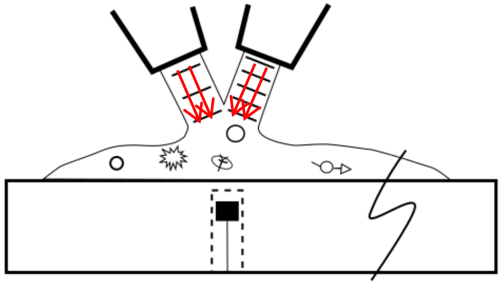
Medium Flow (1.3 L/min):

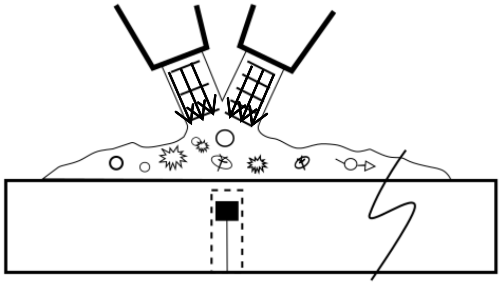
Generation of higher level of static bubbles with increasing flow rate

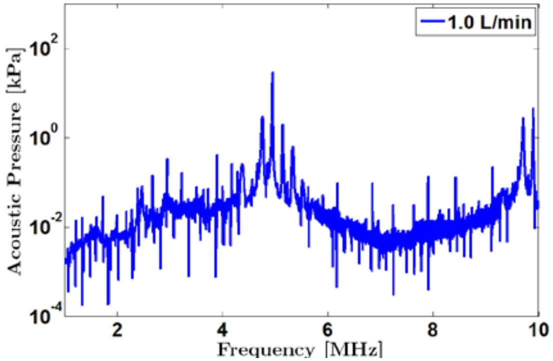
High Flow (1.6 L/min):

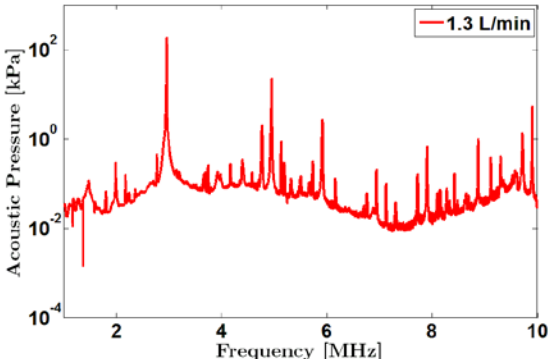
Static bubbles assist the generation of acoustic cavitation from direct field pressure

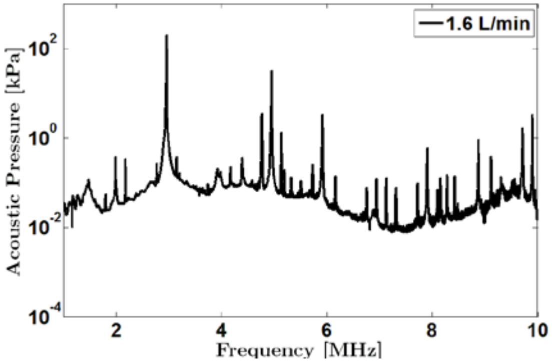












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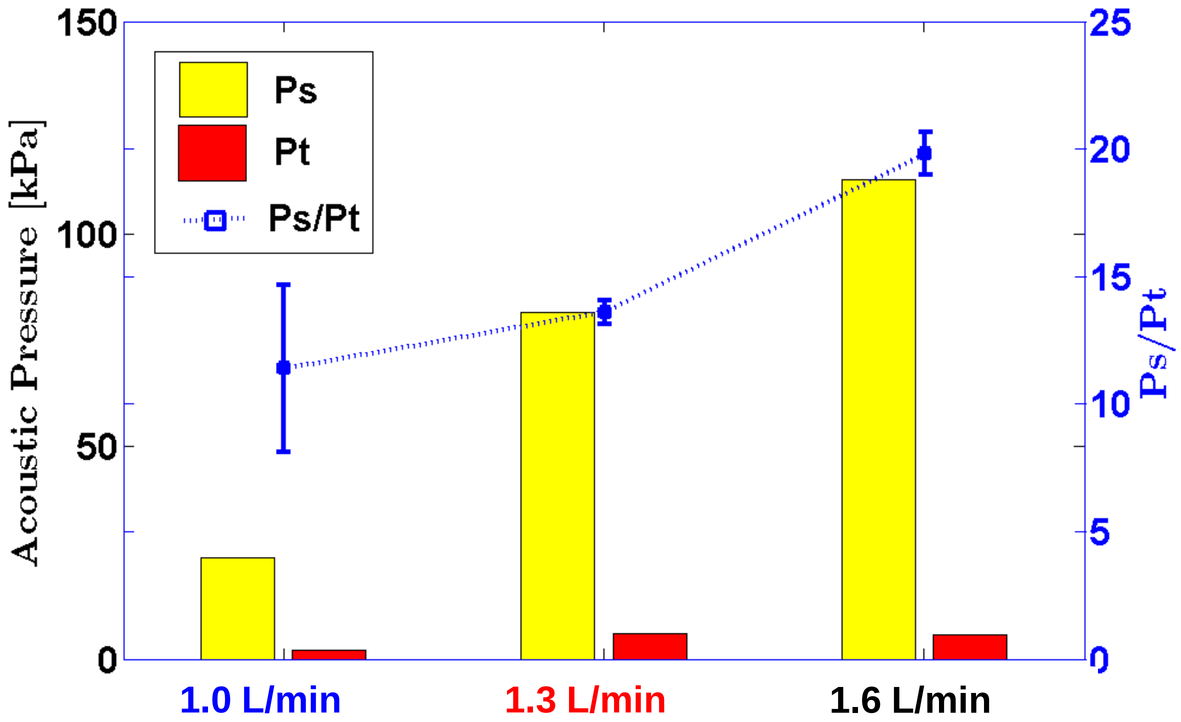
Cavitation vs. Flow Rate

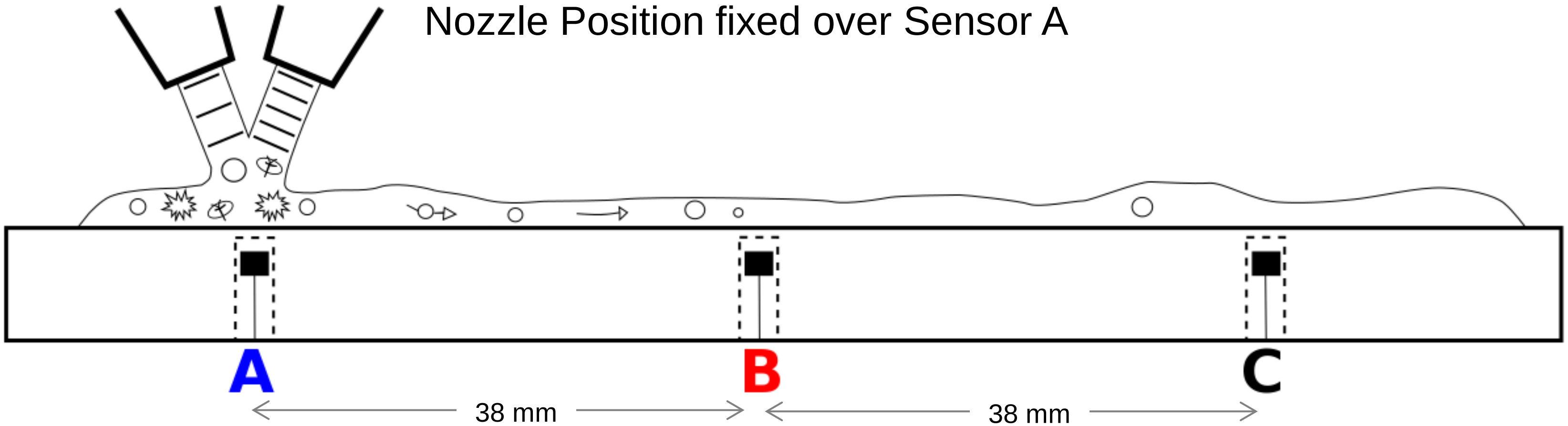
Test Conditions:
- 3 MHz (10-100%), 5 MHz (50%)
- Nozzle Distance: 5, 20 mm
- Medium: DIW
- Flow rate: 1.0, 1.3, 1.6 L/min

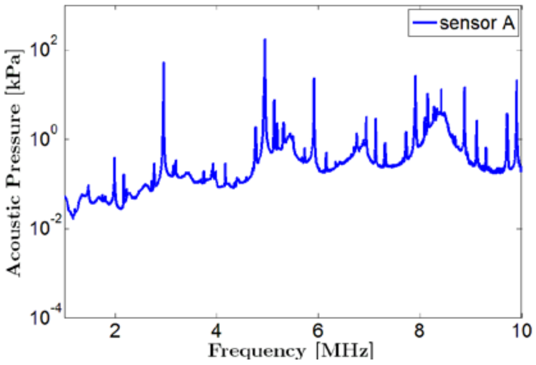


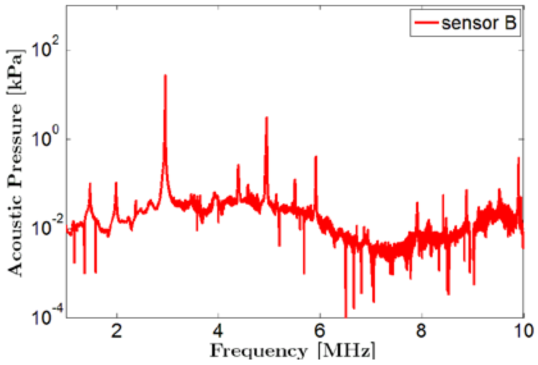
Higher flow rates yield higher levels of static cavitation relative to transient cavitation

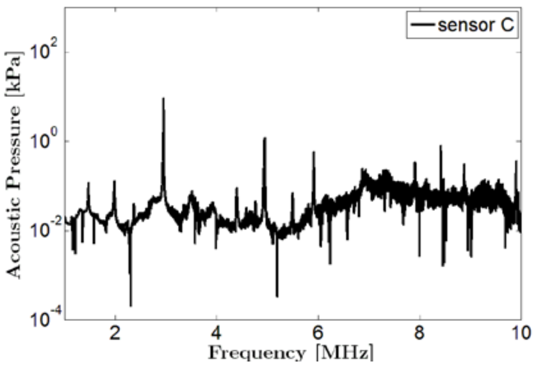
Cavitation vs. Sensor Location

Nozzle Position fixed over Sensor A

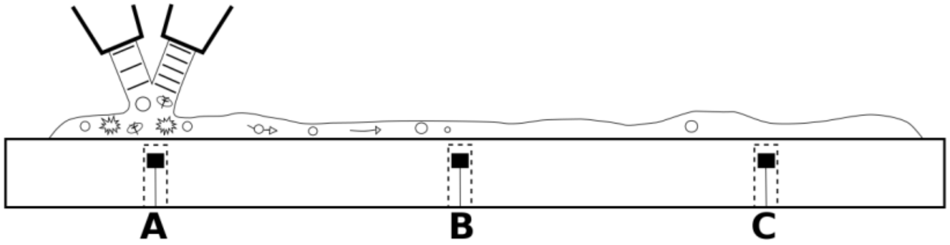


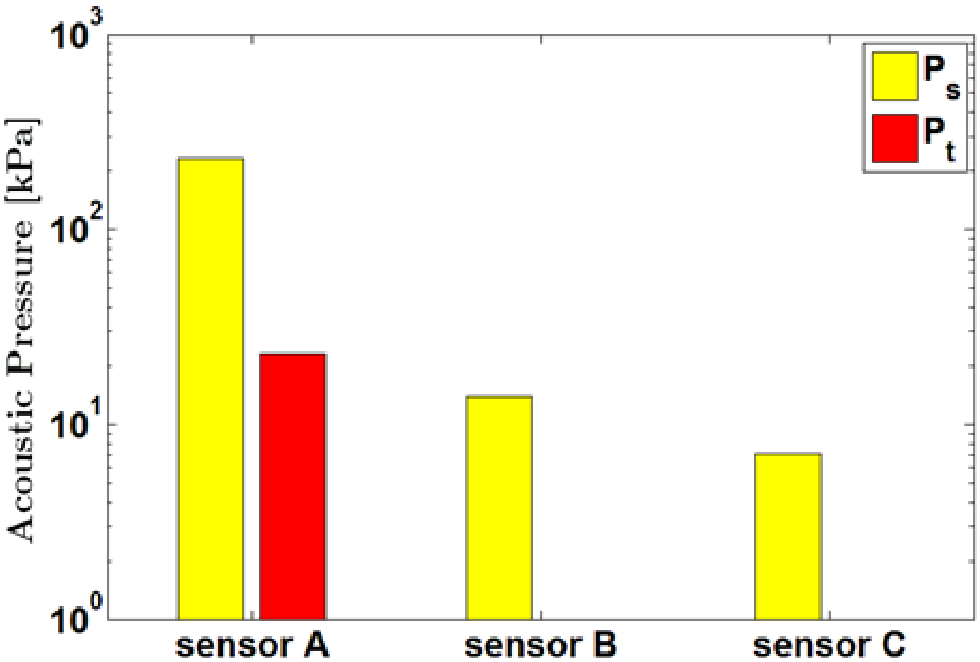






Cavitation vs. Sensor Location





At sensor B:
•Ps reduced more than 10X
•Pt is negligible

At sensor C:
•Modest level of Ps detected
•Pt is negligible

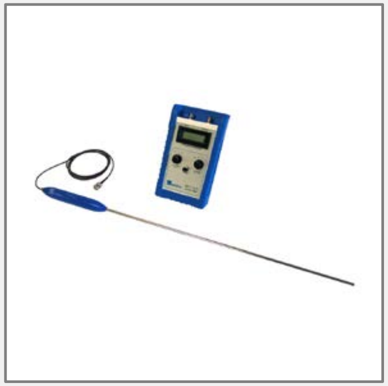
Conclusions

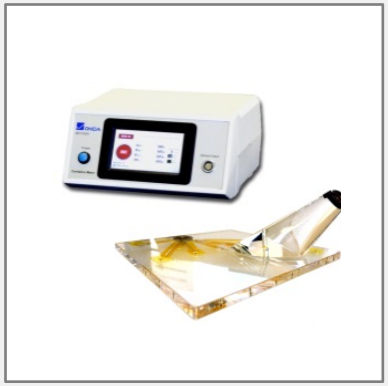
- The *in-situ* mask sensor enables one to define cavitation limits that correlate to PRE and pattern damage
- Differentiating between stable and transient cavitation is integral to control this process window.
- This solution allows measurement of cavitation as a function of:
  - Drive frequencies
  - Electrical power
  - Nozzle distance
  - Flow rate
  - Acoustic pressure distribution
- Future work: acoustically characterize variables such as gas concentration, chemistries, temperature and complex patterns, and understand their **correlation to cleaning and damage**.

Thank you

Ultrasound Measurement Solutions

Hydrophones
Meters
Arrays
Scanners





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