Problem #7

Hearing Light

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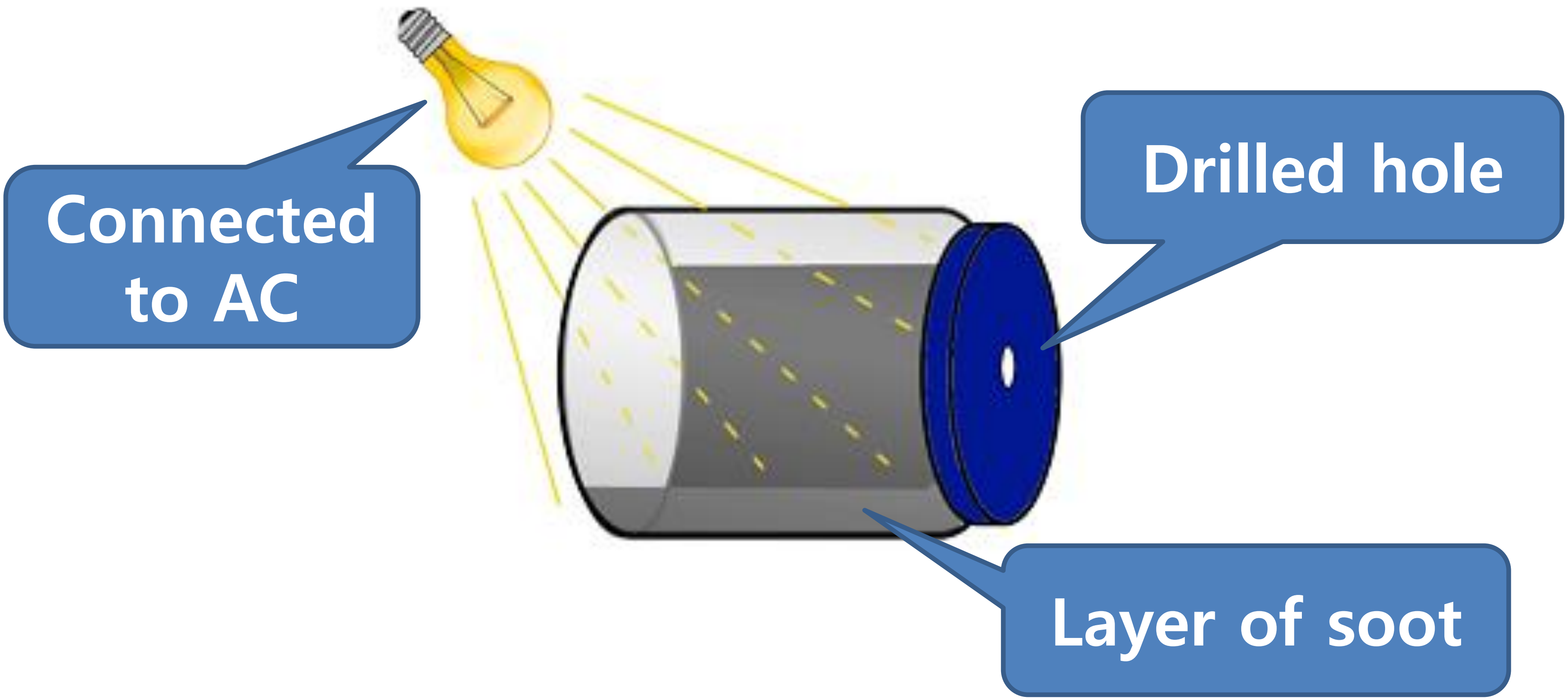
Team Korea

Problem Statement



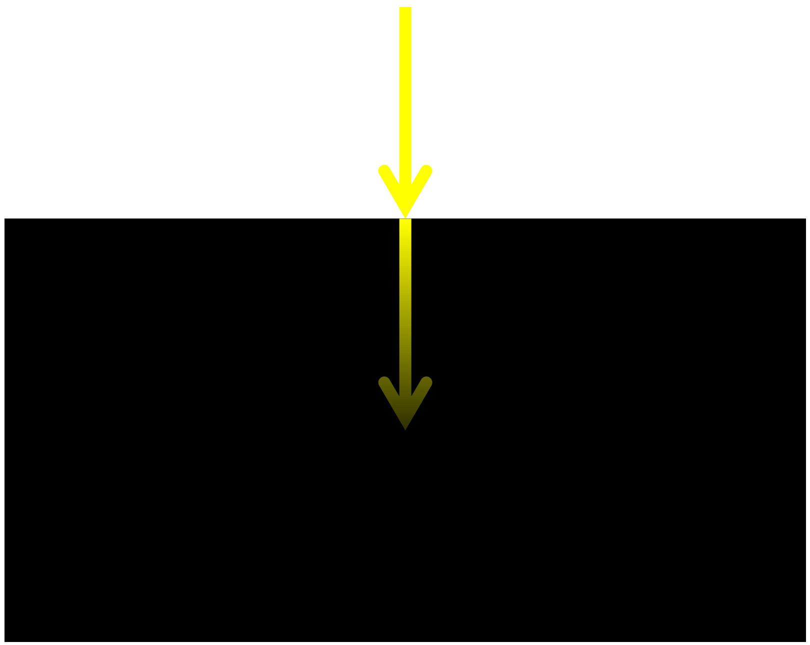
DISTINCT SOUND?

WHY does the sound occur?

Soot absorbs light

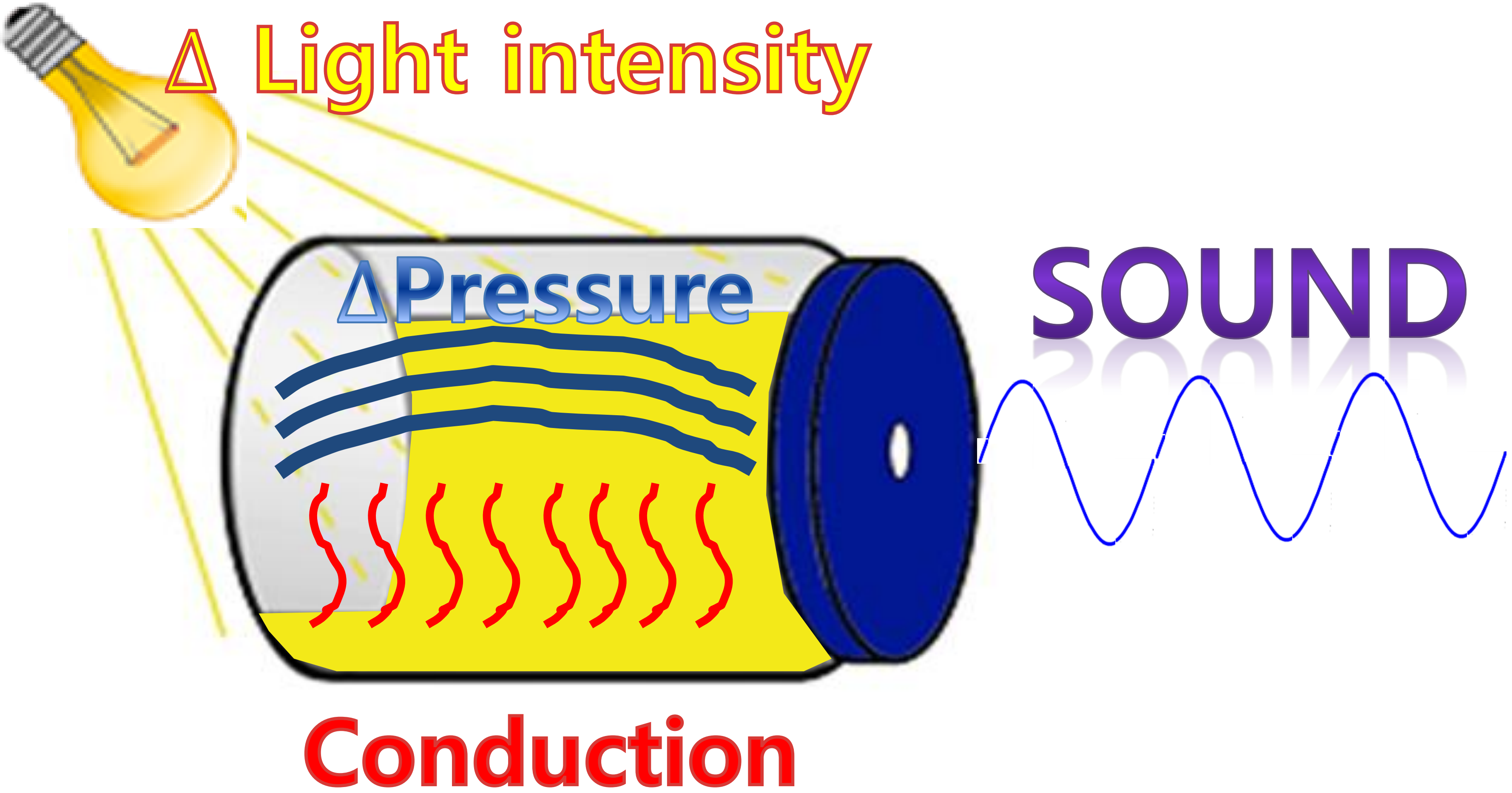
Absorption coefficient β

$I(x) = I_0 e^{-\beta x}$ (x : depth through sample)



Absolutely opaque: ALL light is absorbed

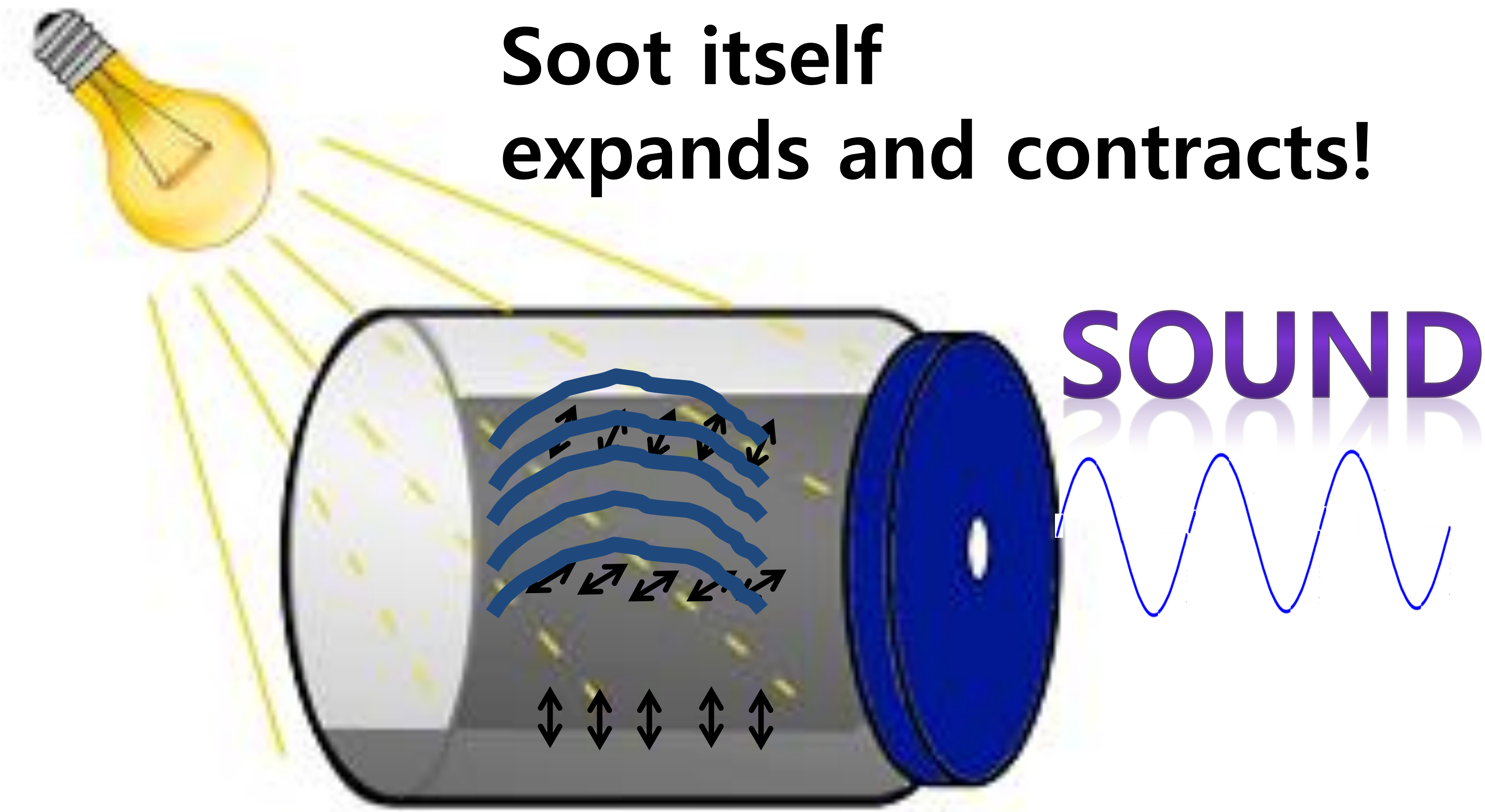
Explanation #1: Thermal Vibration



Allan Rosencwaig and Allen Gersho, Theory of the photoacoustic effect with solids, Journal of Applied Physics (Jan. 1976), vol. 47, No. 1

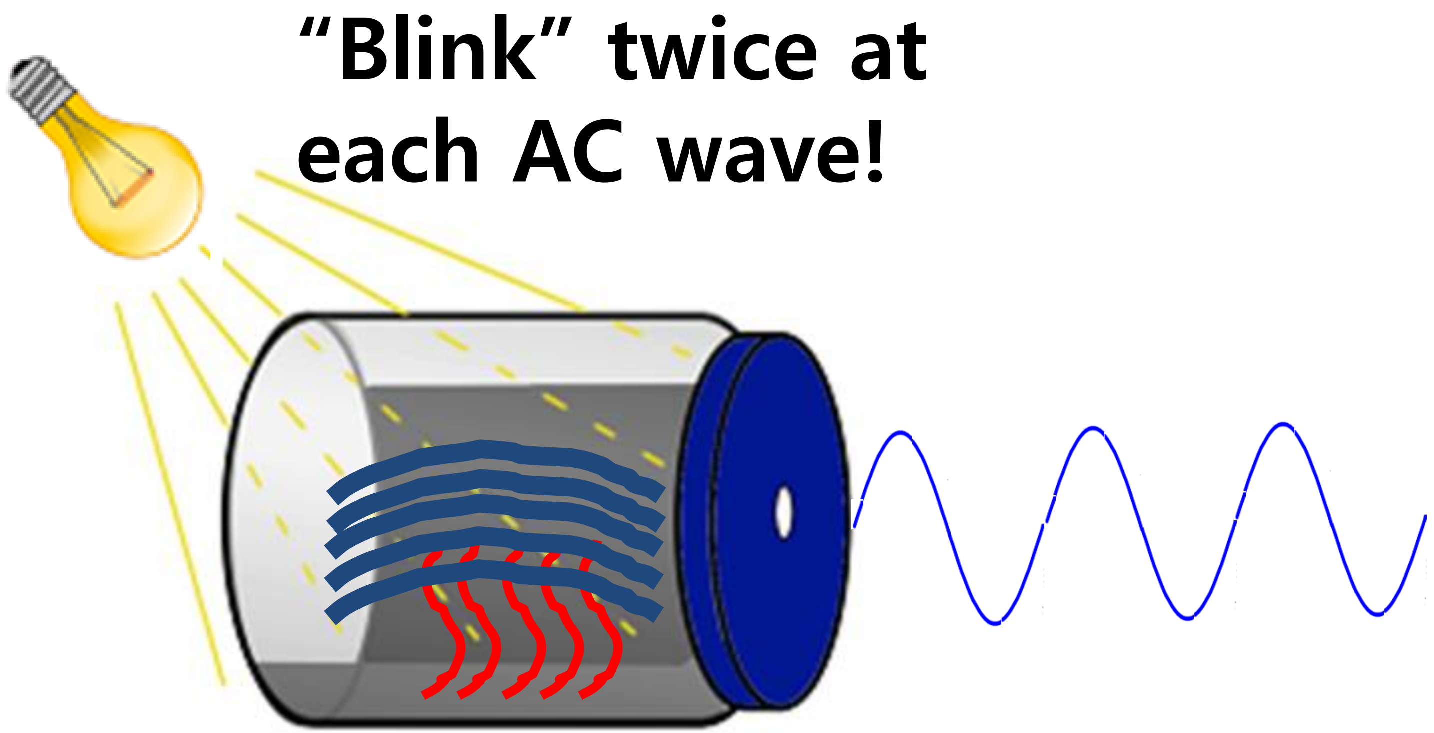
Explanation #2: Mechanical Vibration

Soot itself expands and contracts!



F. Alan McDonald, Photoacoustic effect and the physics of waves, American Journal of Physics (Jul. 1979), vol. 48

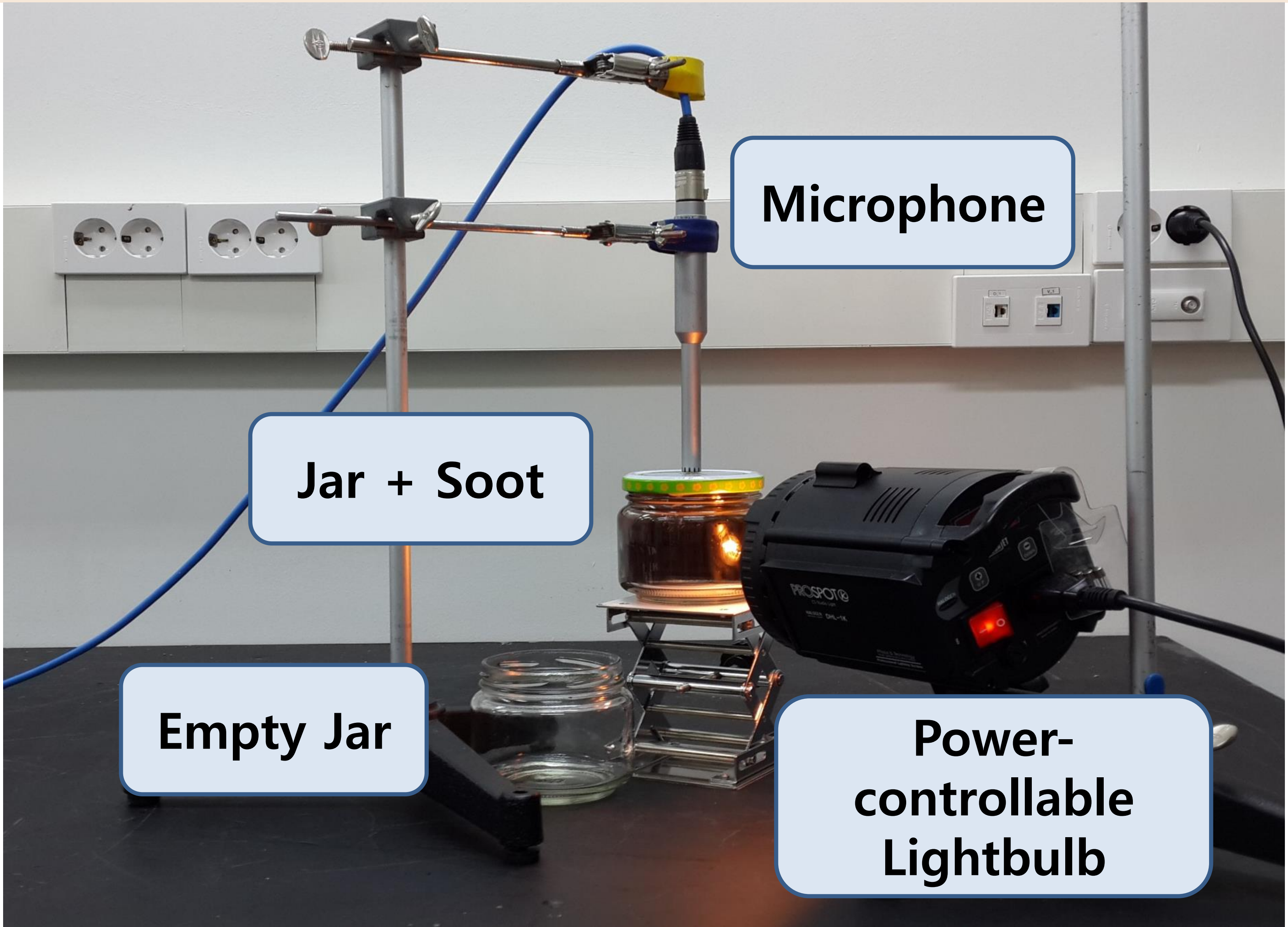
What is the frequency?



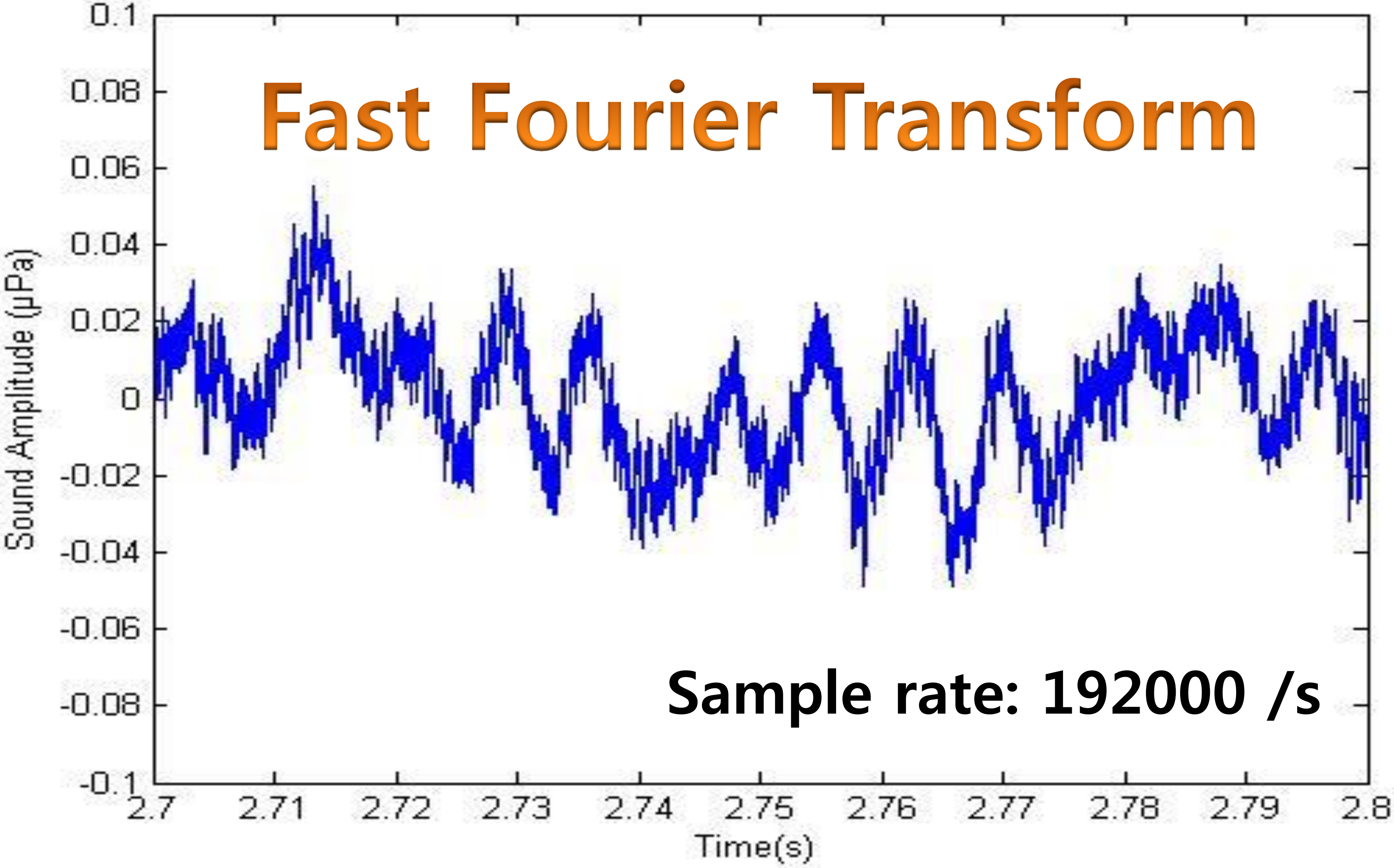
Sound frequency = 2×(AC frequency) = **120Hz**

Manfred Euler, Hands-On Resonance-Enhanced Photoacoustic Detection, Physics Teacher (Oct. 2011), vol. 39

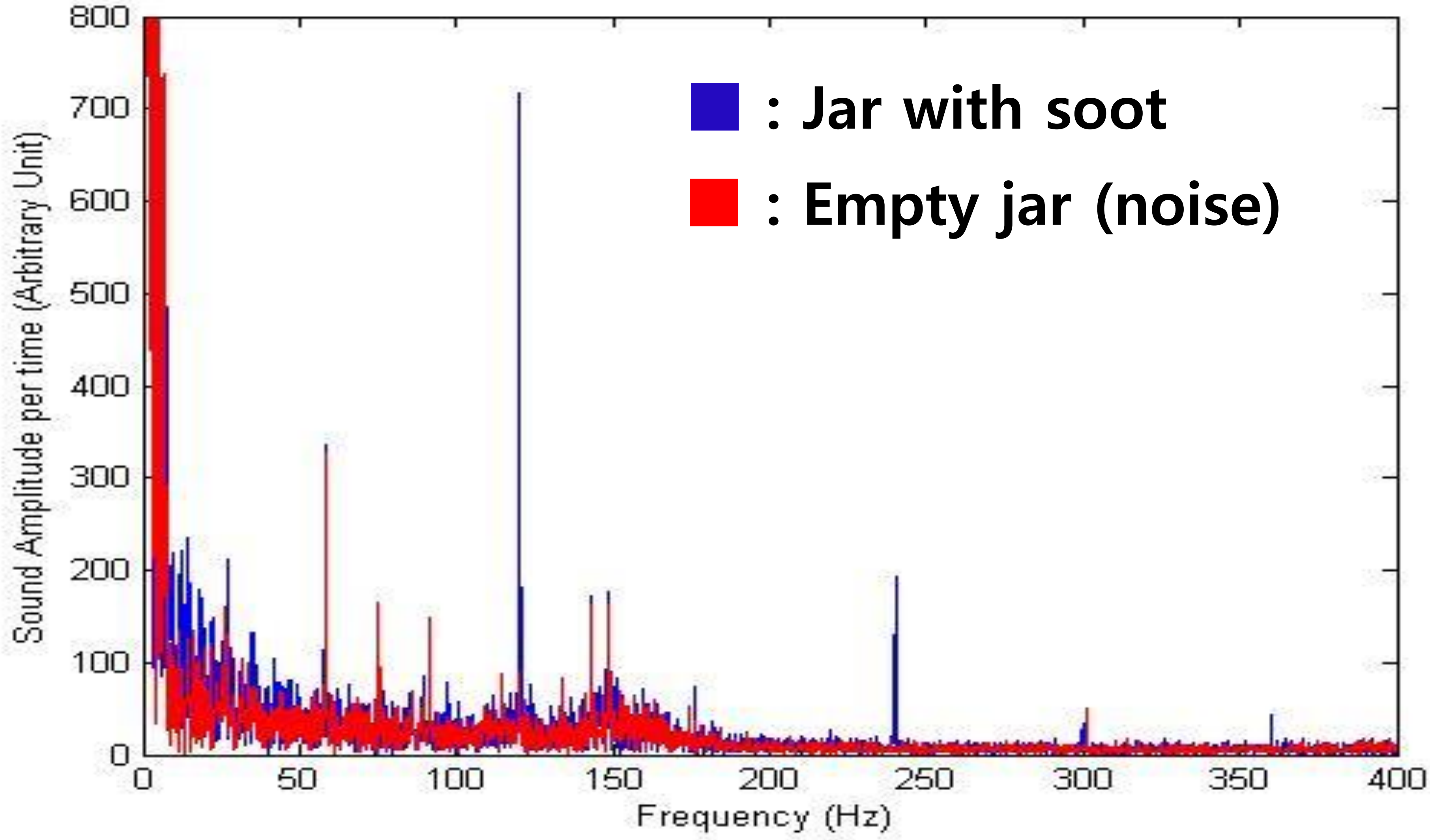
AC Bulb Experiment Setting



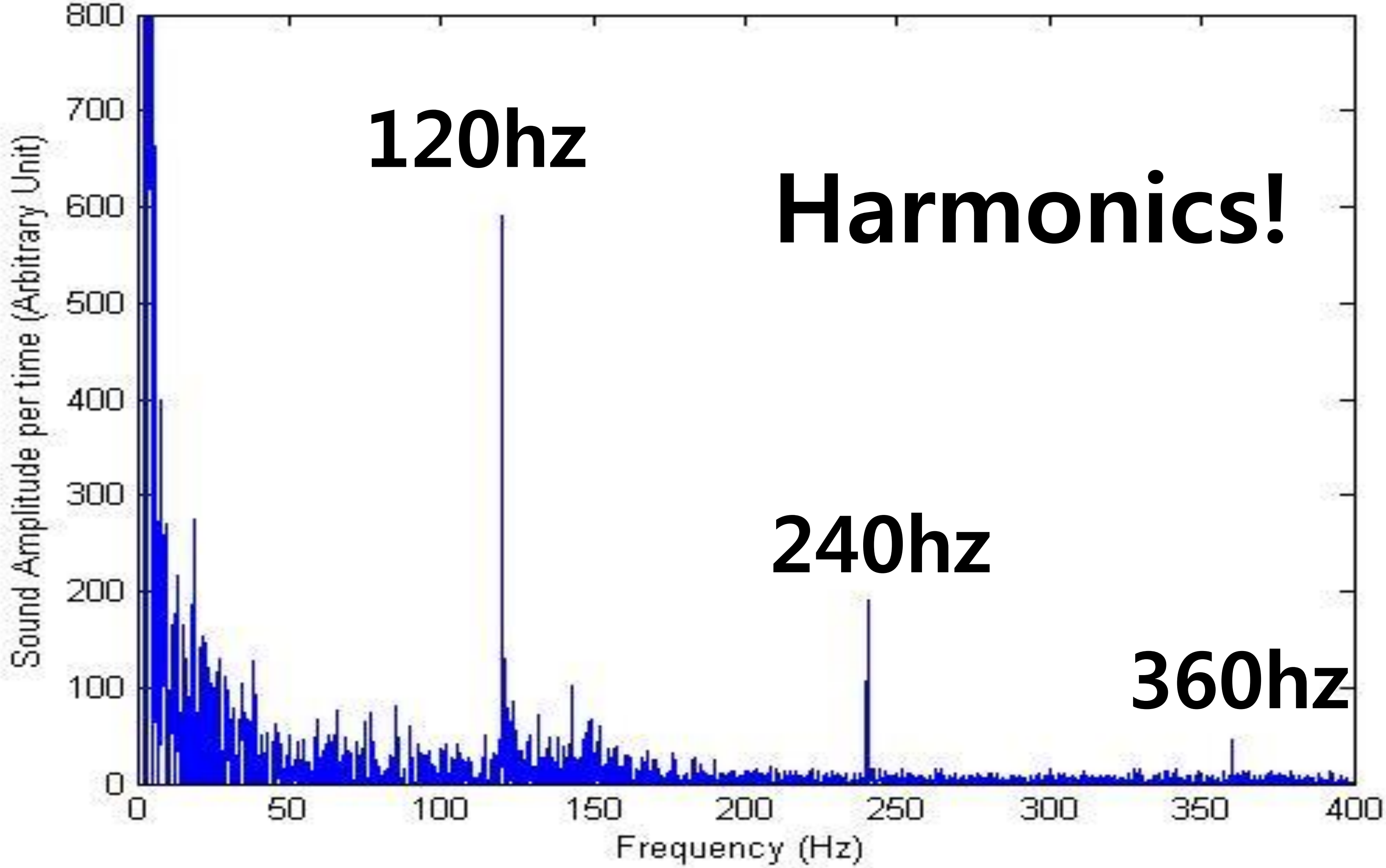
Recorded Sound



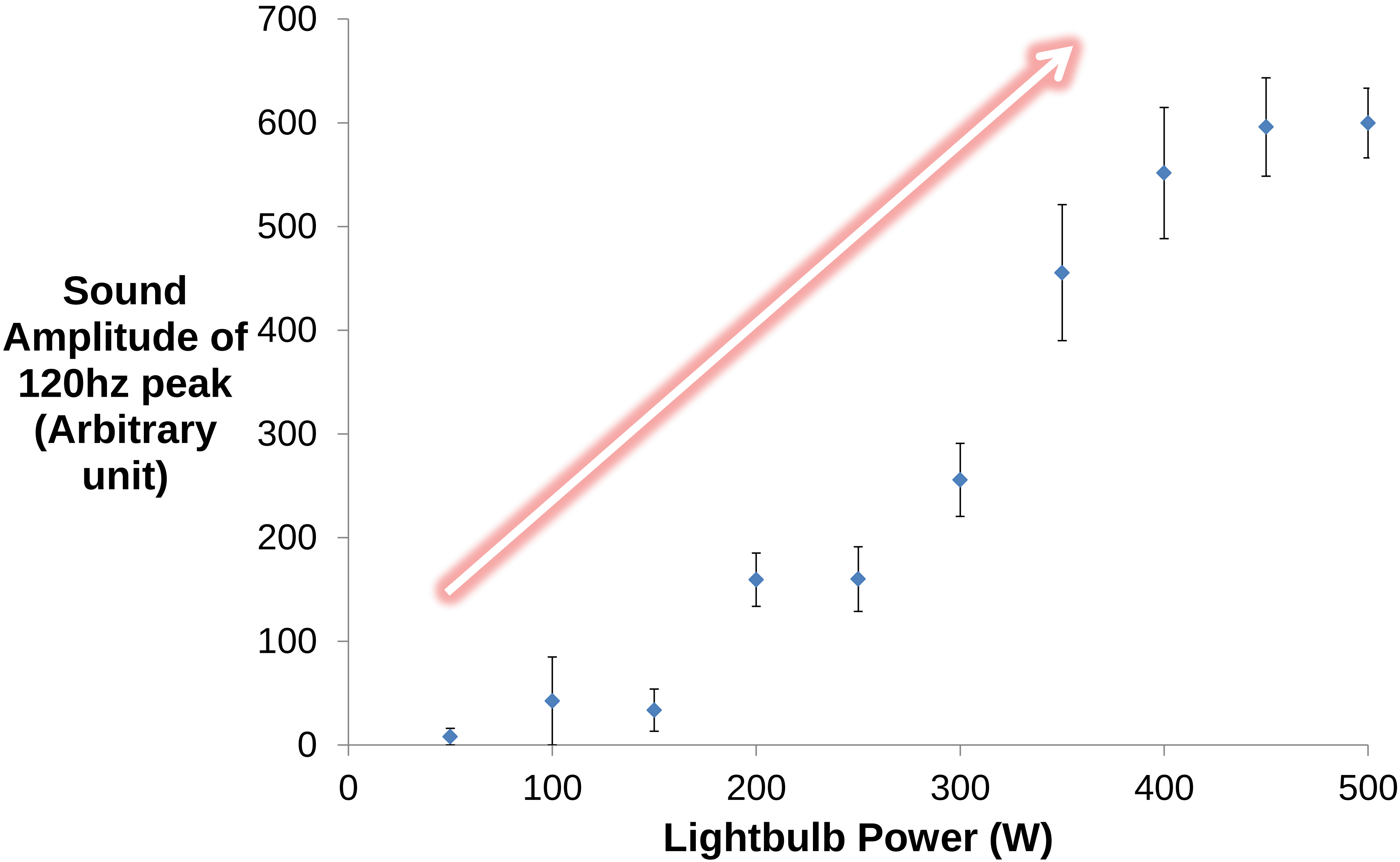
Frequency-Domain Graph



Frequency-Domain Graph



Light intensity
– 120hz peak intensity Graph

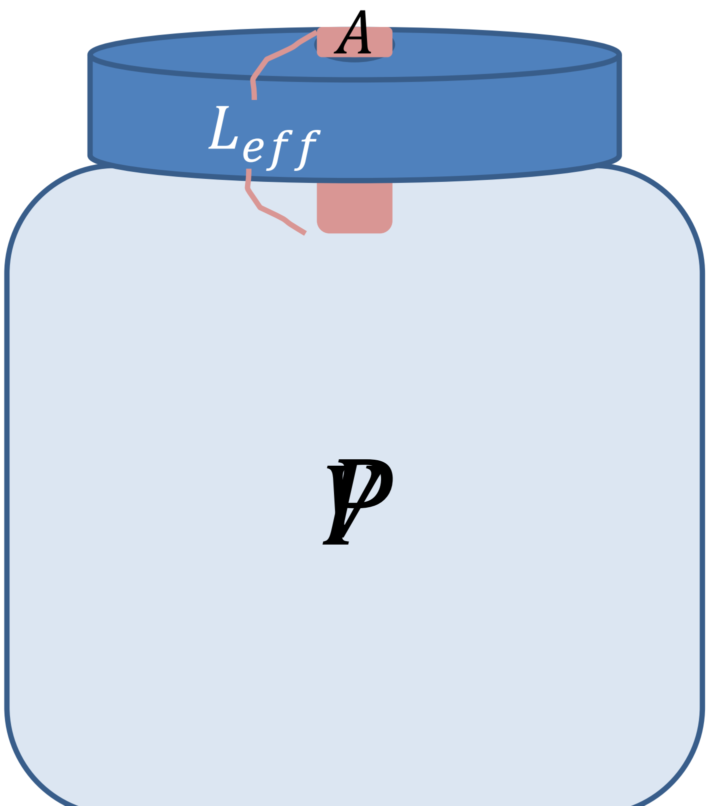


What is the role of the JAR?

Helmholtz Resonance

Resonance frequency of

AIR inside the jar



$$f_H = \frac{v}{2\pi}\sqrt{\frac{A}{V L_{eff}}}$$

v: speed of sound

$f_H \cong 120\text{Hz}$:

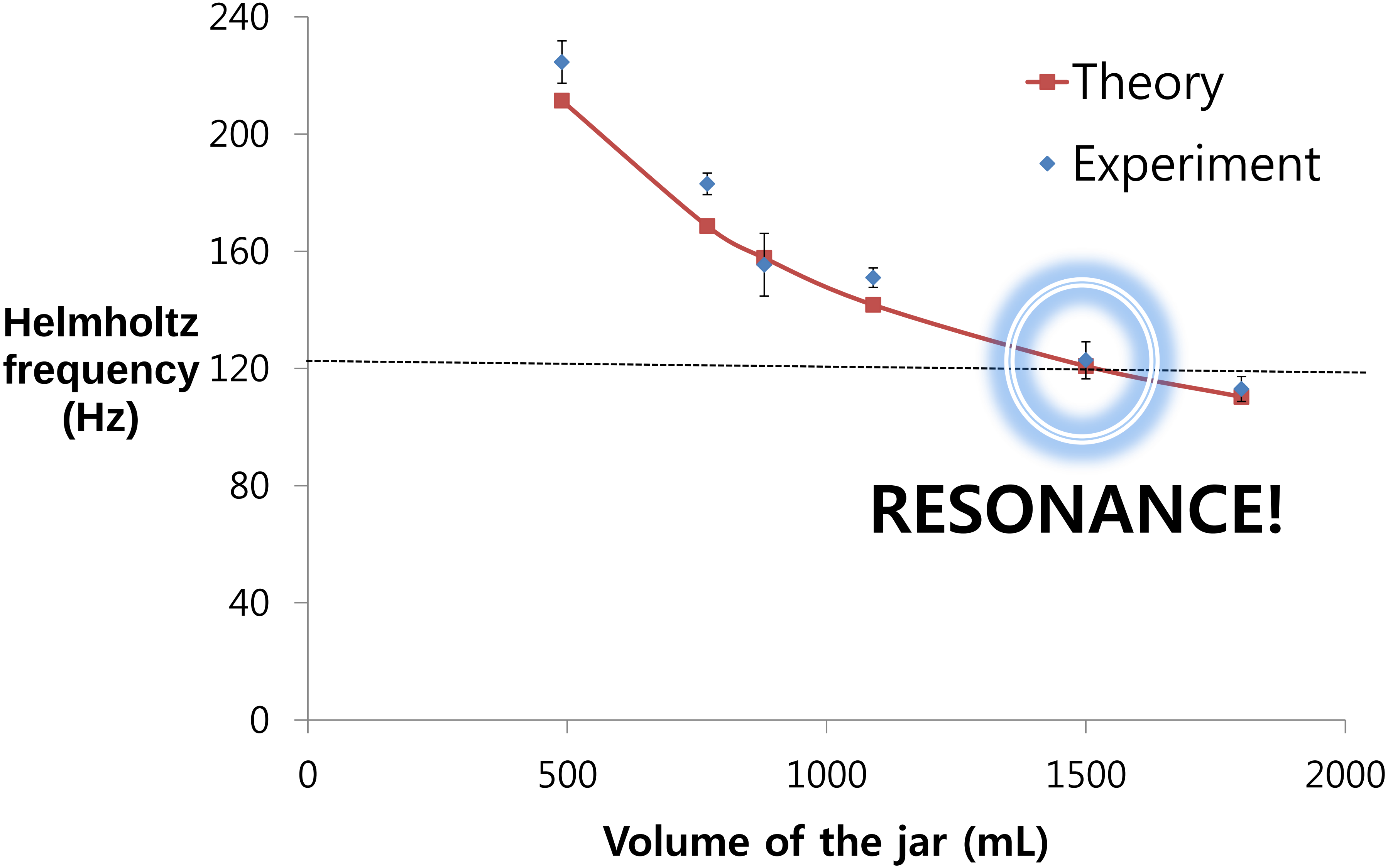
RESONANCE!

Various jars

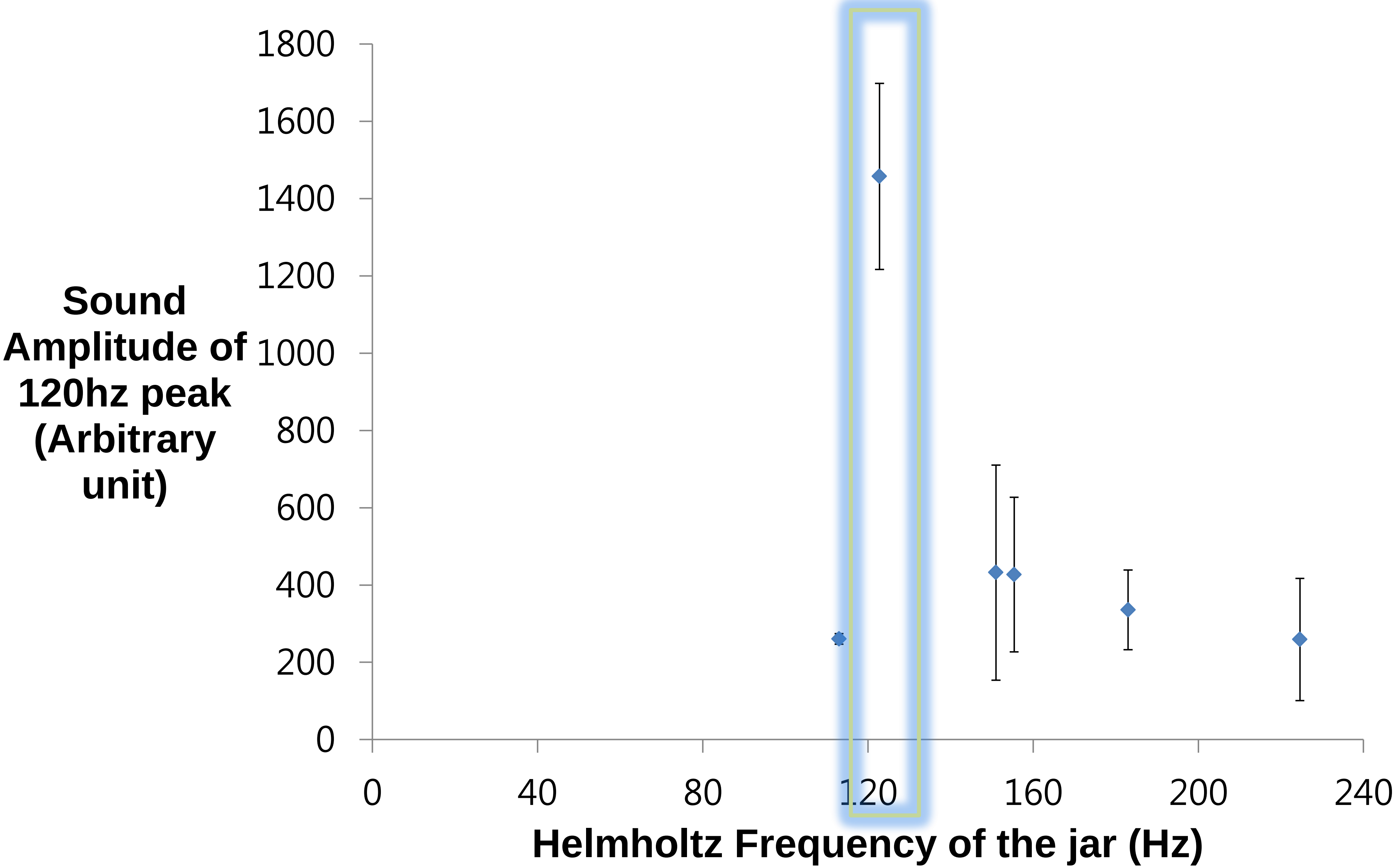
Parameter control for various jars

Slide-glass covered with soot

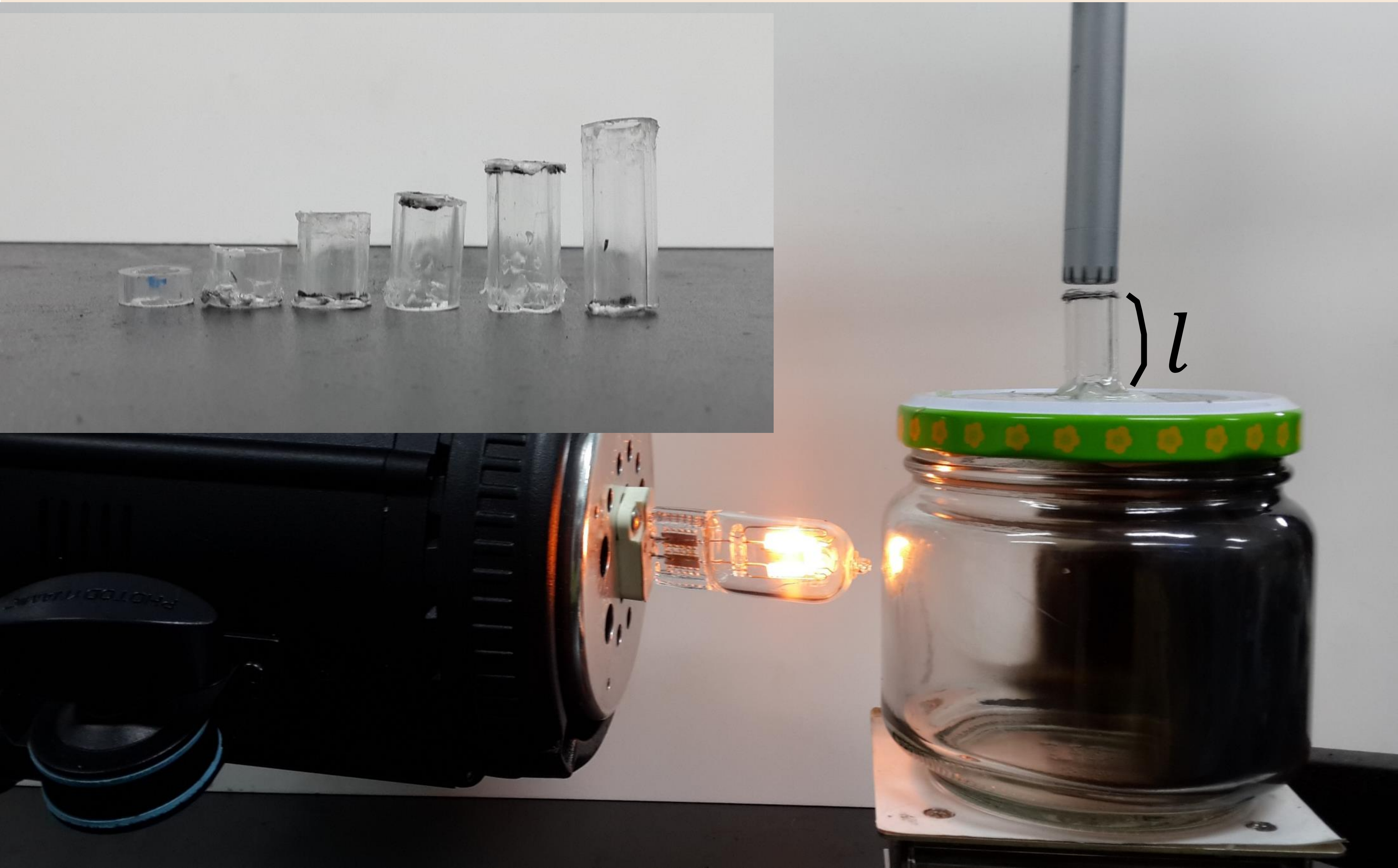
Helmholtz Frequencies of jars



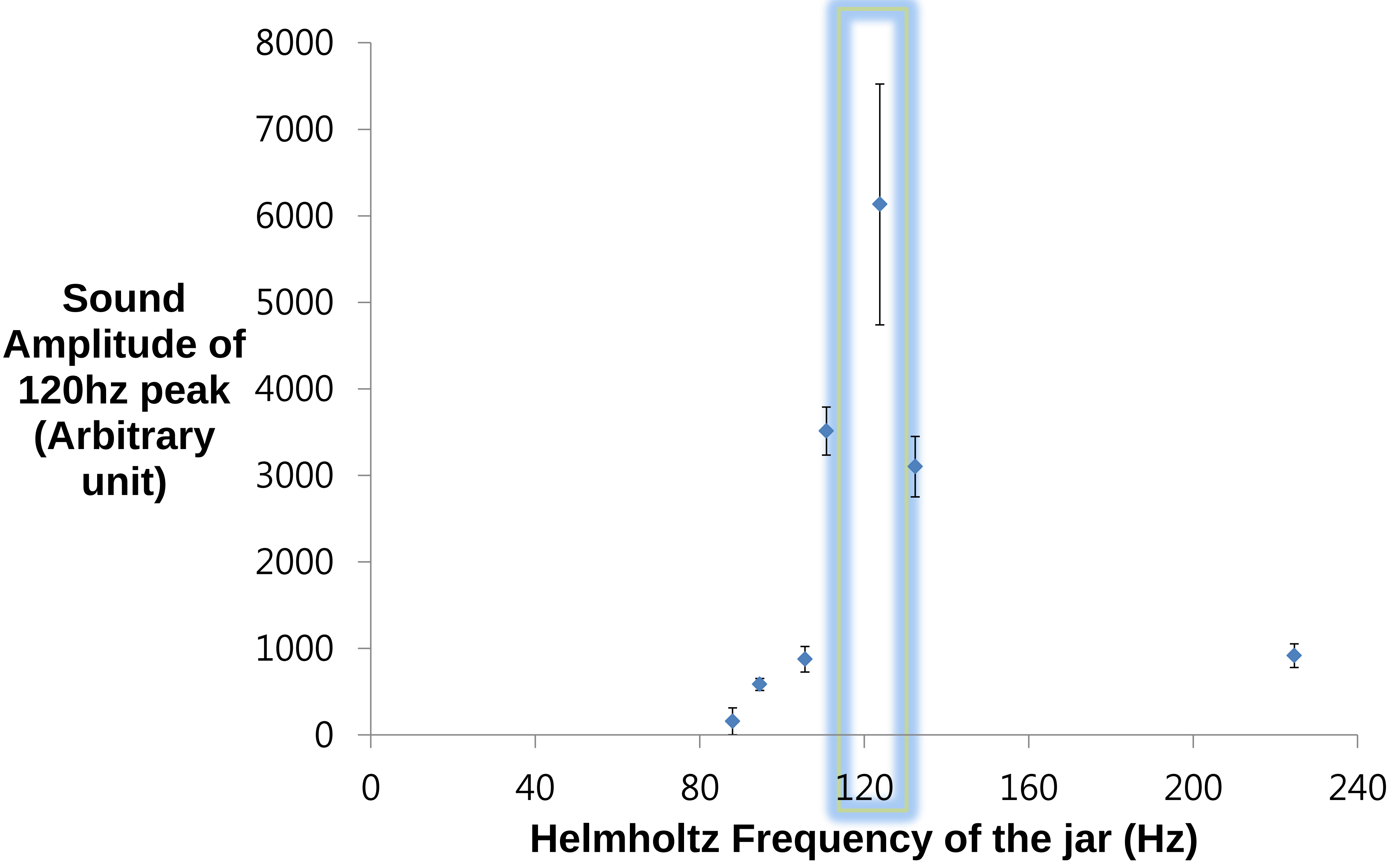
Sound produced in various jars



Another method to change Helmholtz Frequency: Neck Length



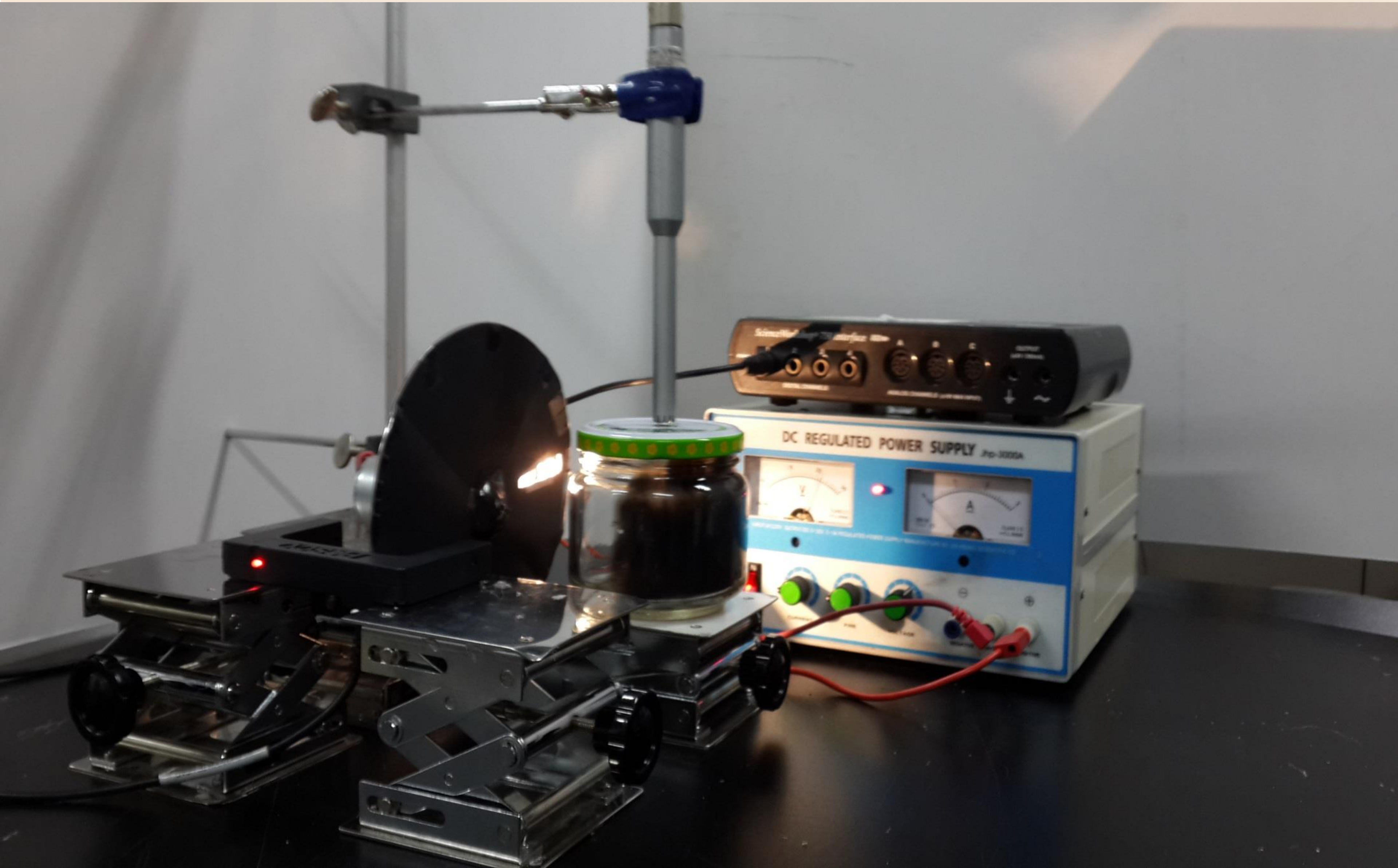
Sound produced by jars of different neck length



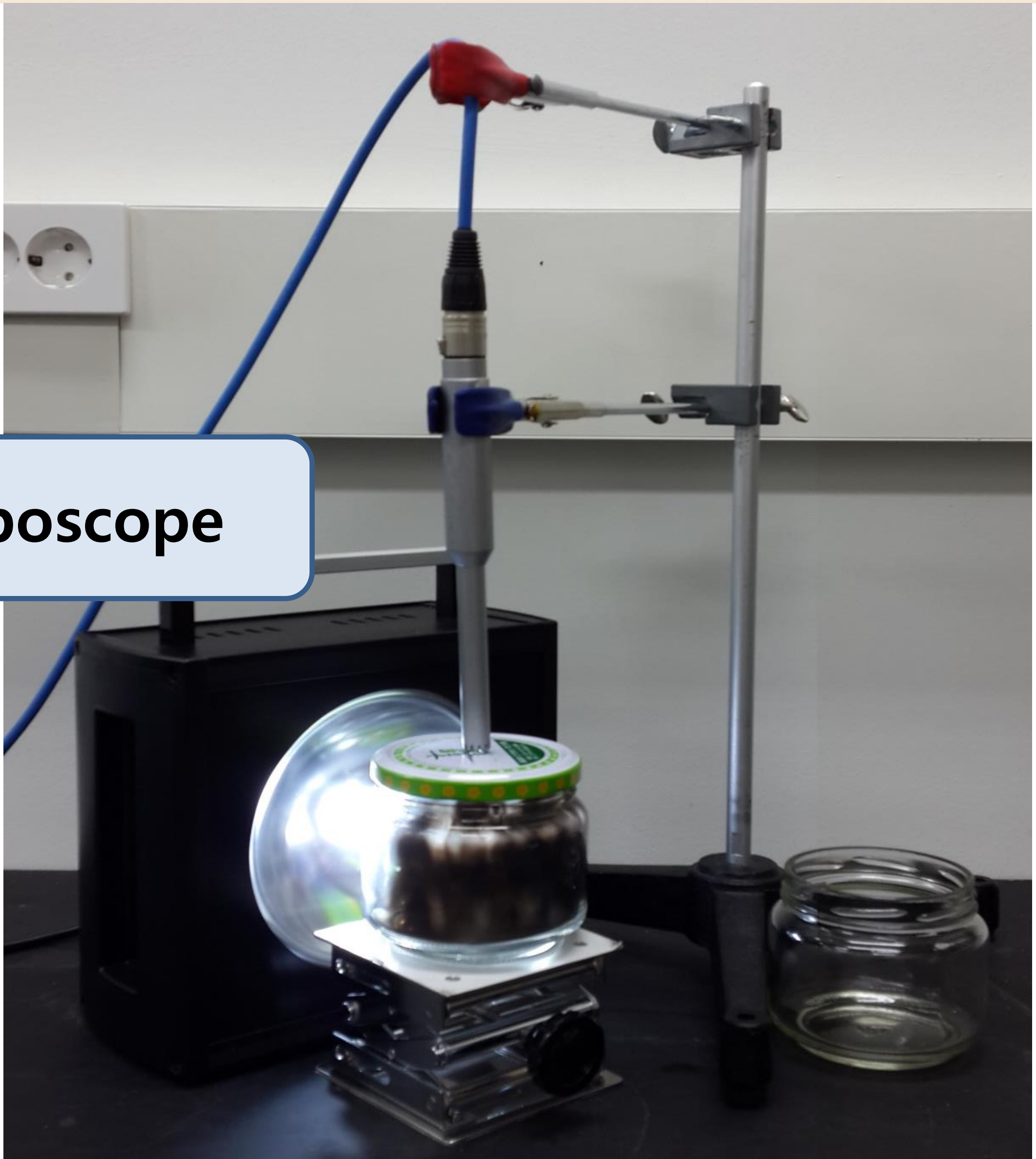
1. Frequency Control
2. Extract only the sound produced by light

- New Experiment Setting!

Preliminary Experiment Setting

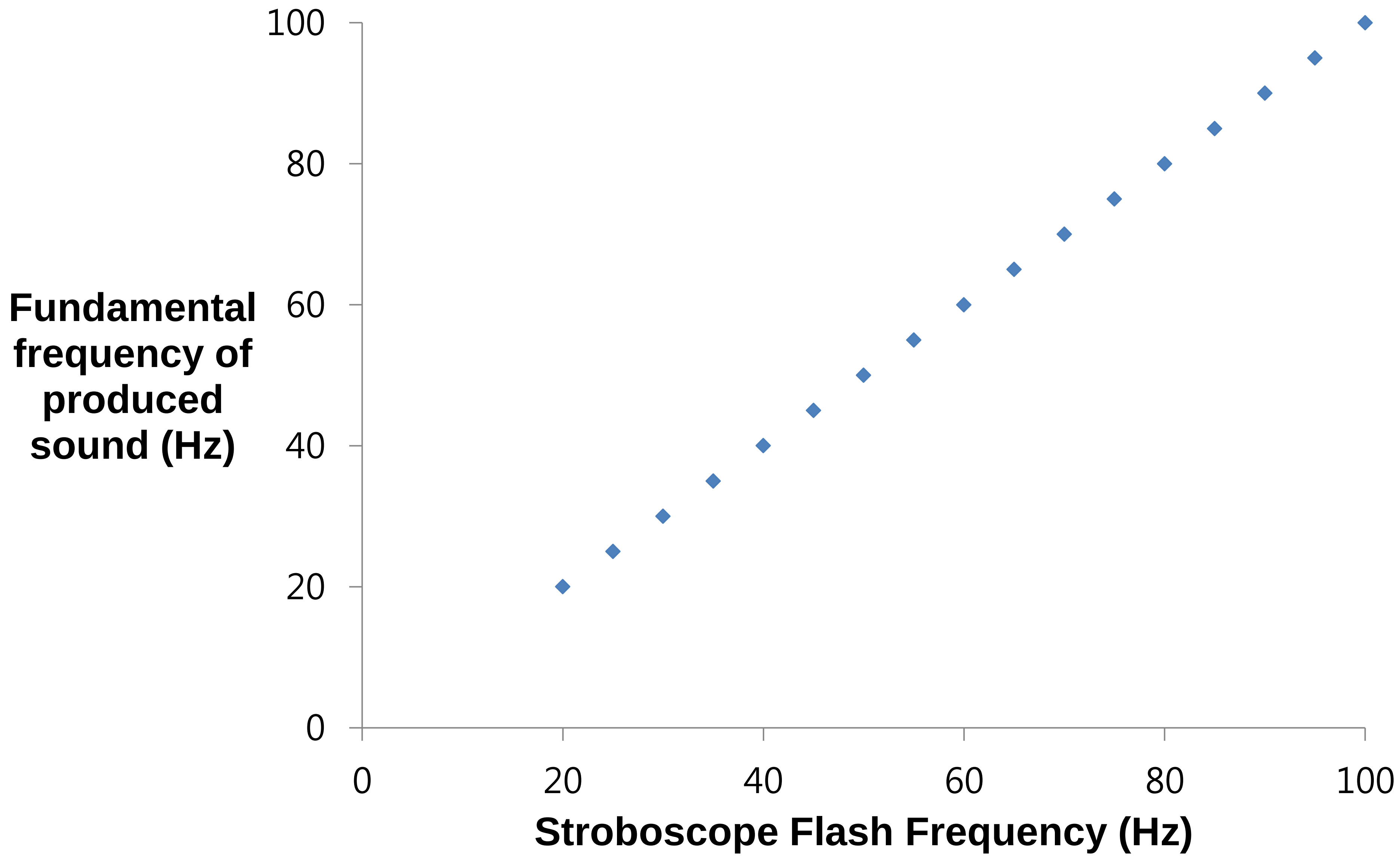


Stroboscope Experiment Setting



Stroboscope

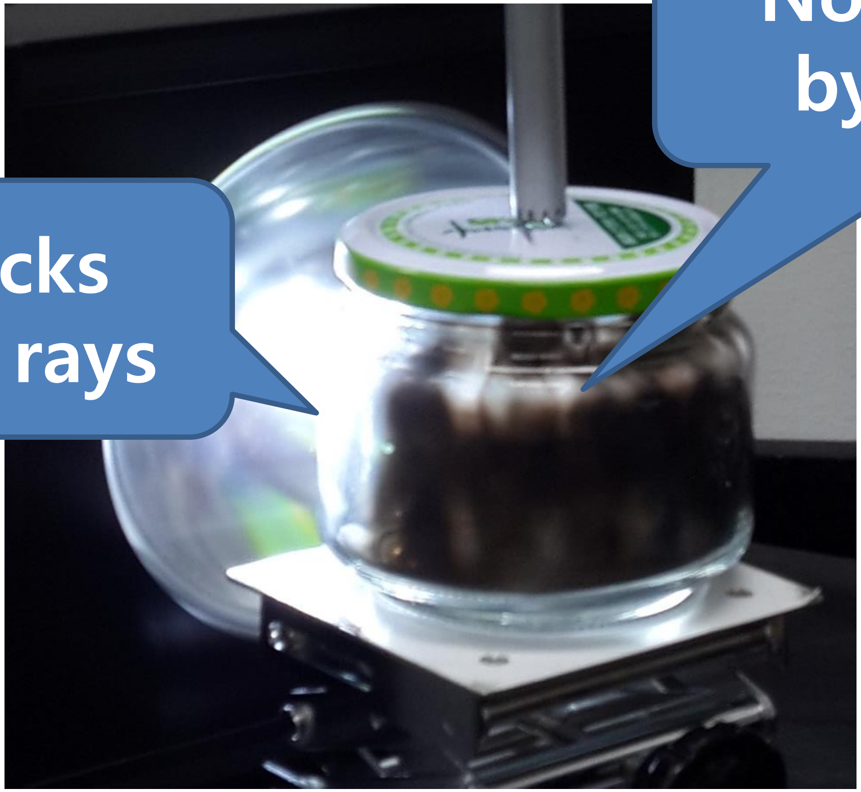
Flash frequency – Fundamental sound frequency graph



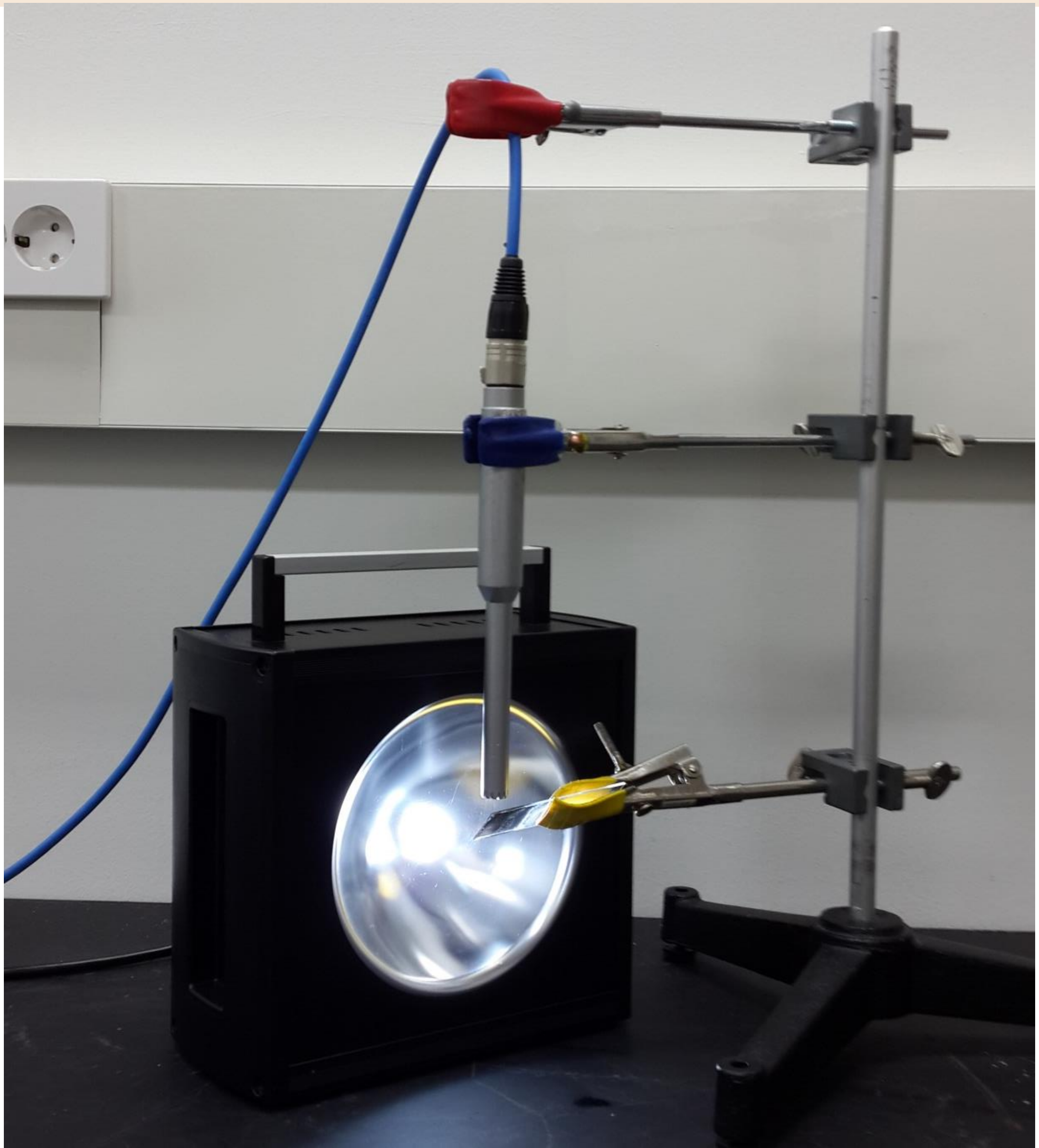
Limits of Stroboscope Setting

Noise caused by jar itself

Glass blocks ultraviolet rays



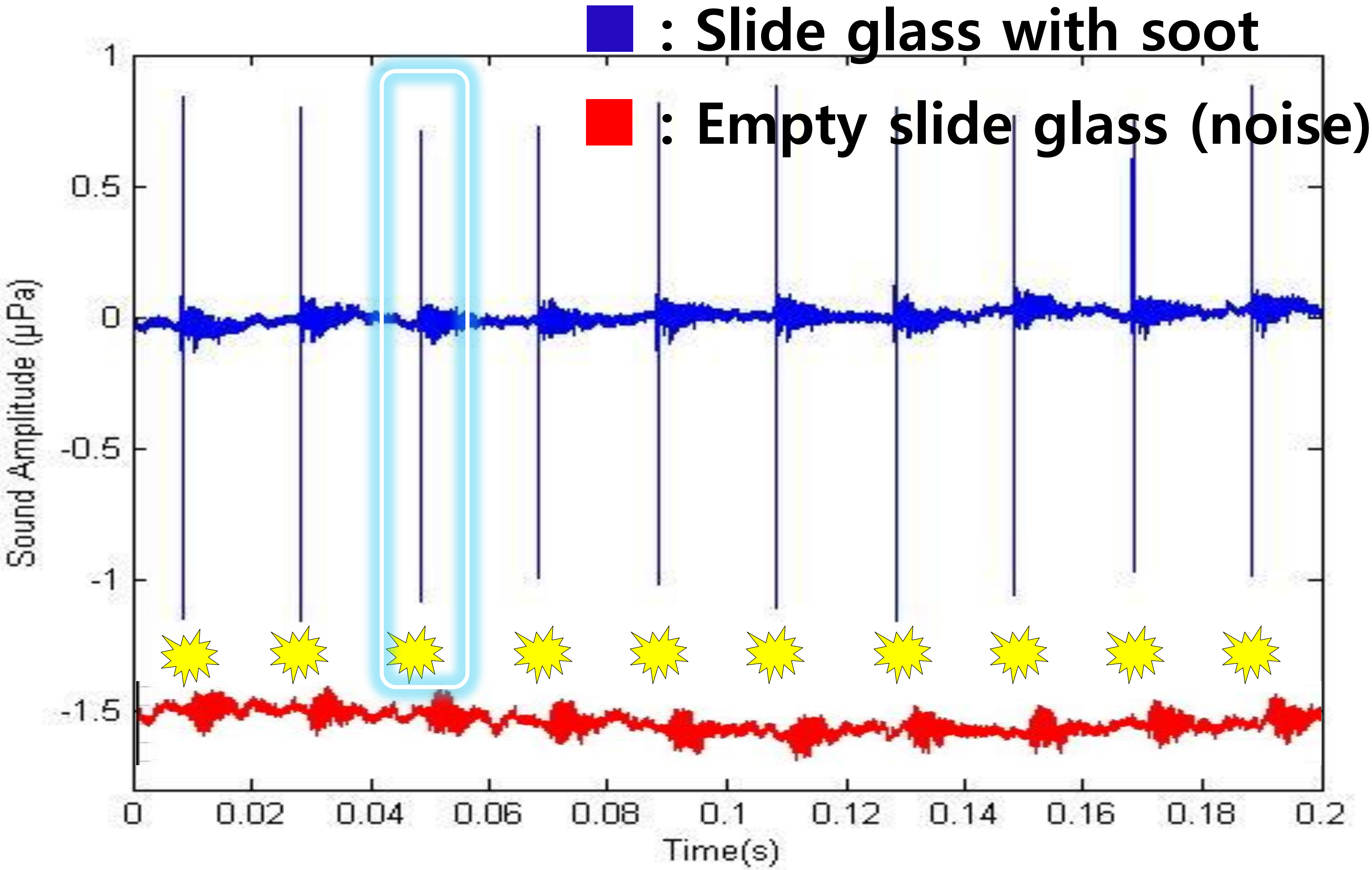
Revised Experiment Setting



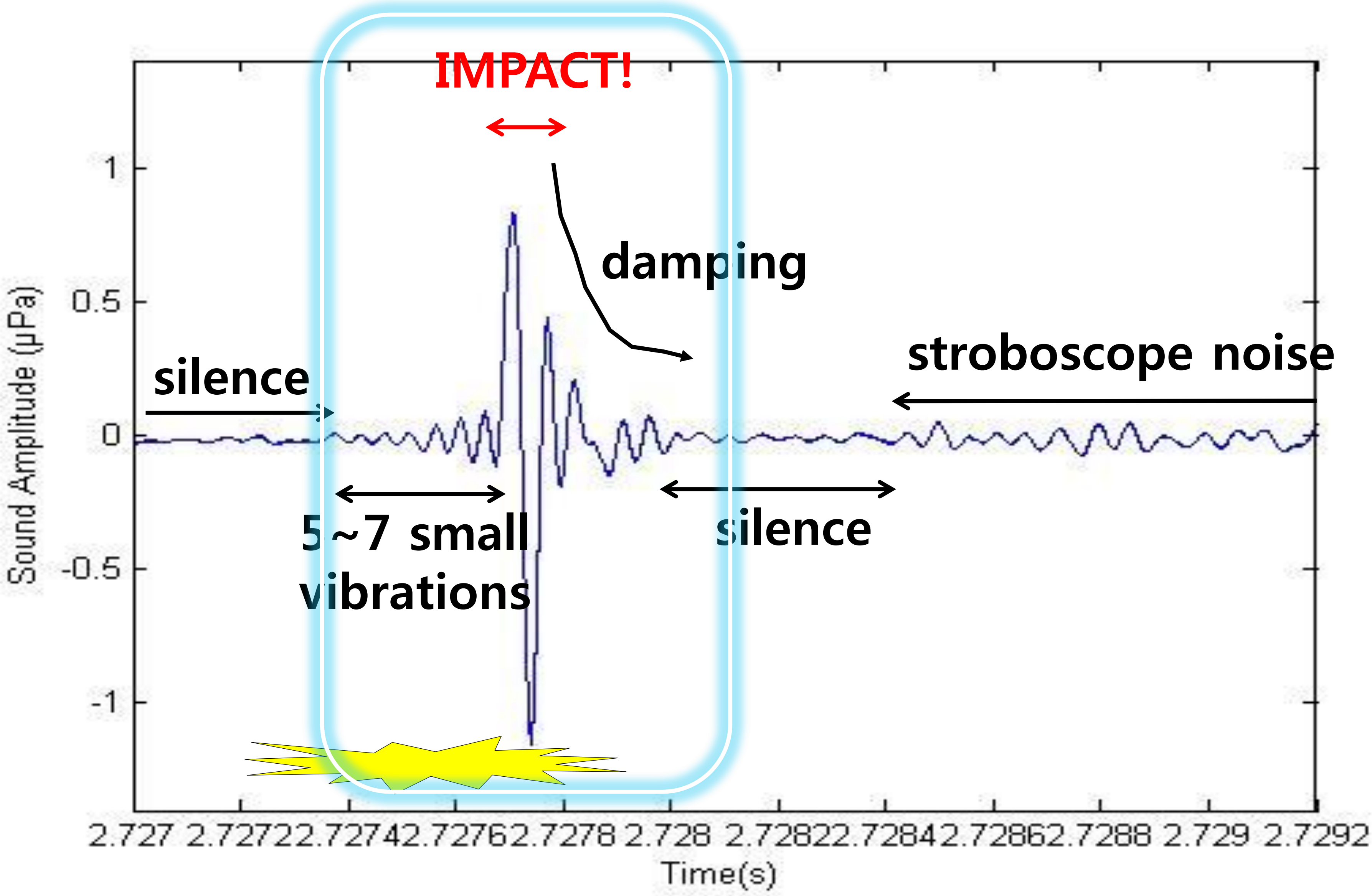
Fundamental Approach

1. Waveform
2. Material

Recorded Sound

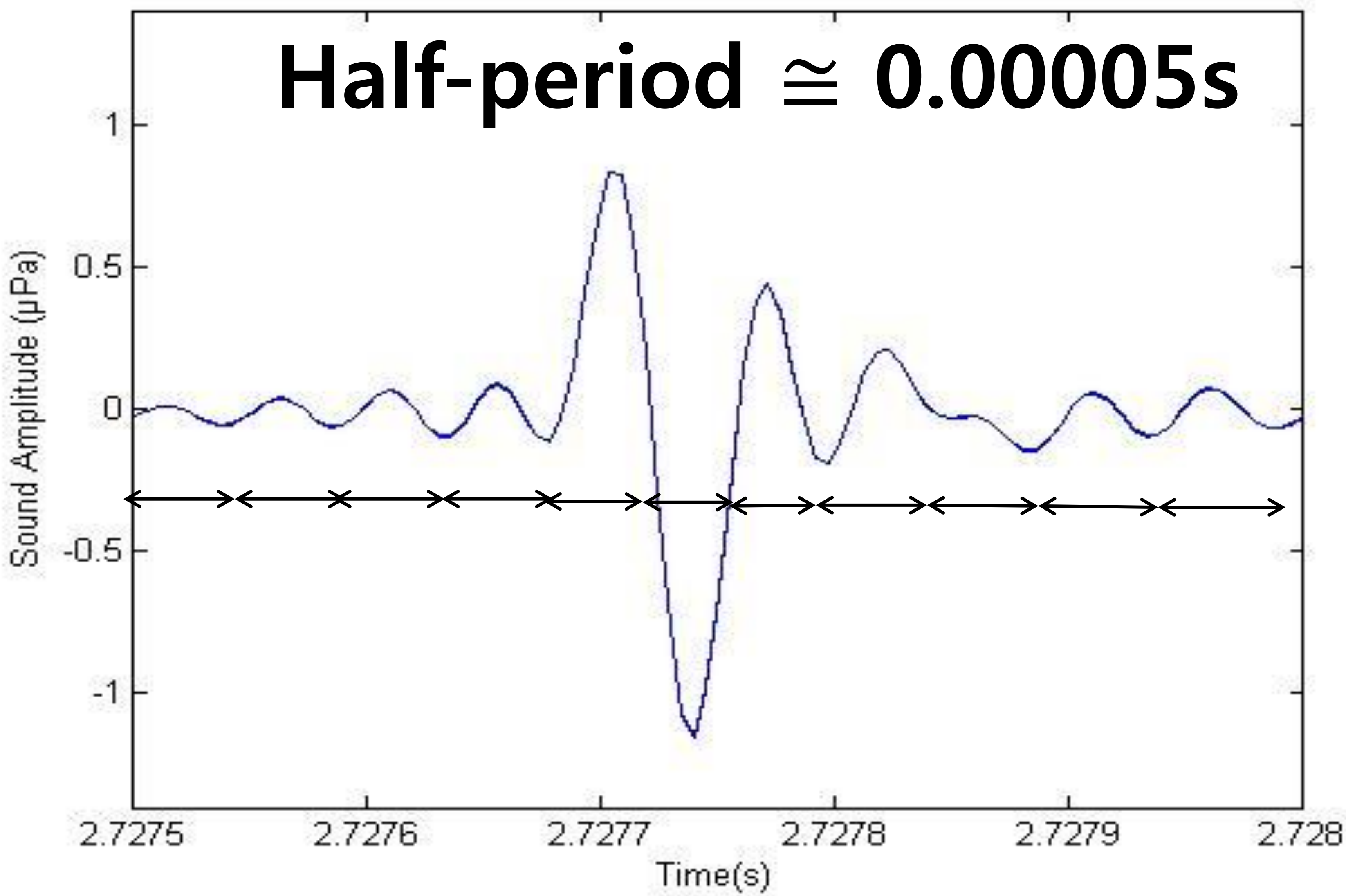


Zoom-in!



IMPACT!
damping
stroboscope noise
silence
5~7 small vibrations
silence
1
0.5
0
-0.5
-1
Sound Amplitude (μPa)
2.727 2.7272 2.7274 2.7276 2.7278 2.728 2.7282 2.7284 2.7286 2.7288 2.729 2.7292
Time(s)

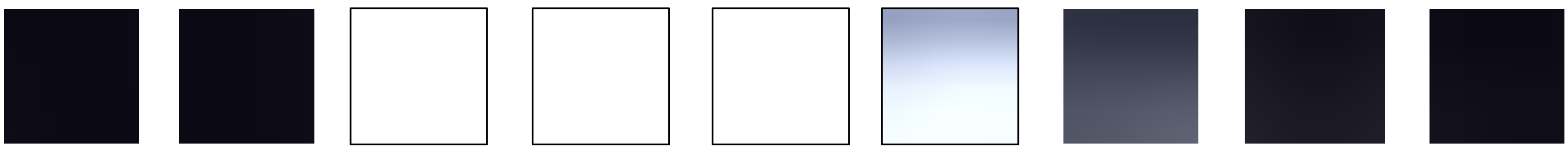
Sound caused by only light



Duration of Stroboscope Flash

Speed Camera

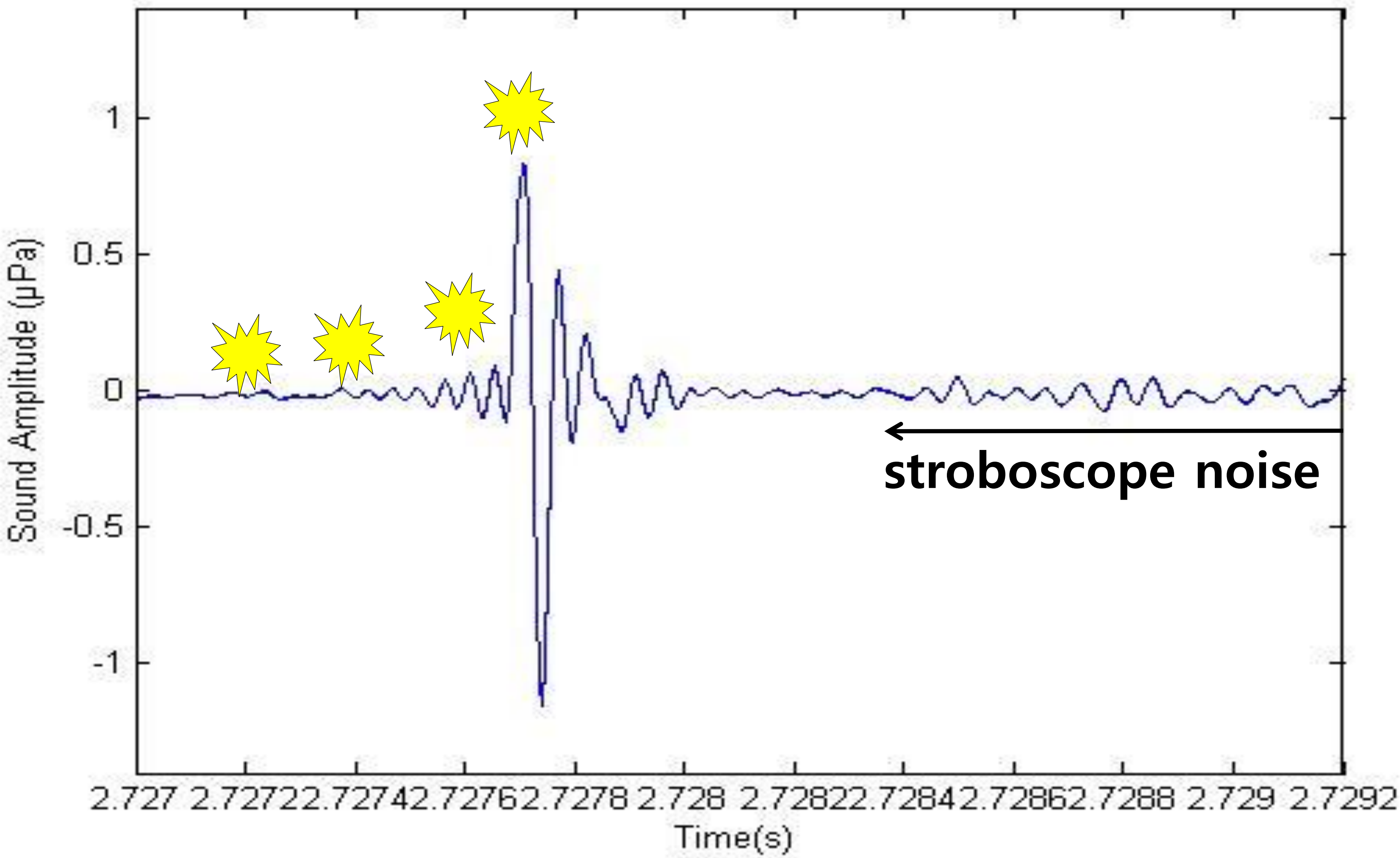
Resolution 32×32 Sample rate 83333 /s



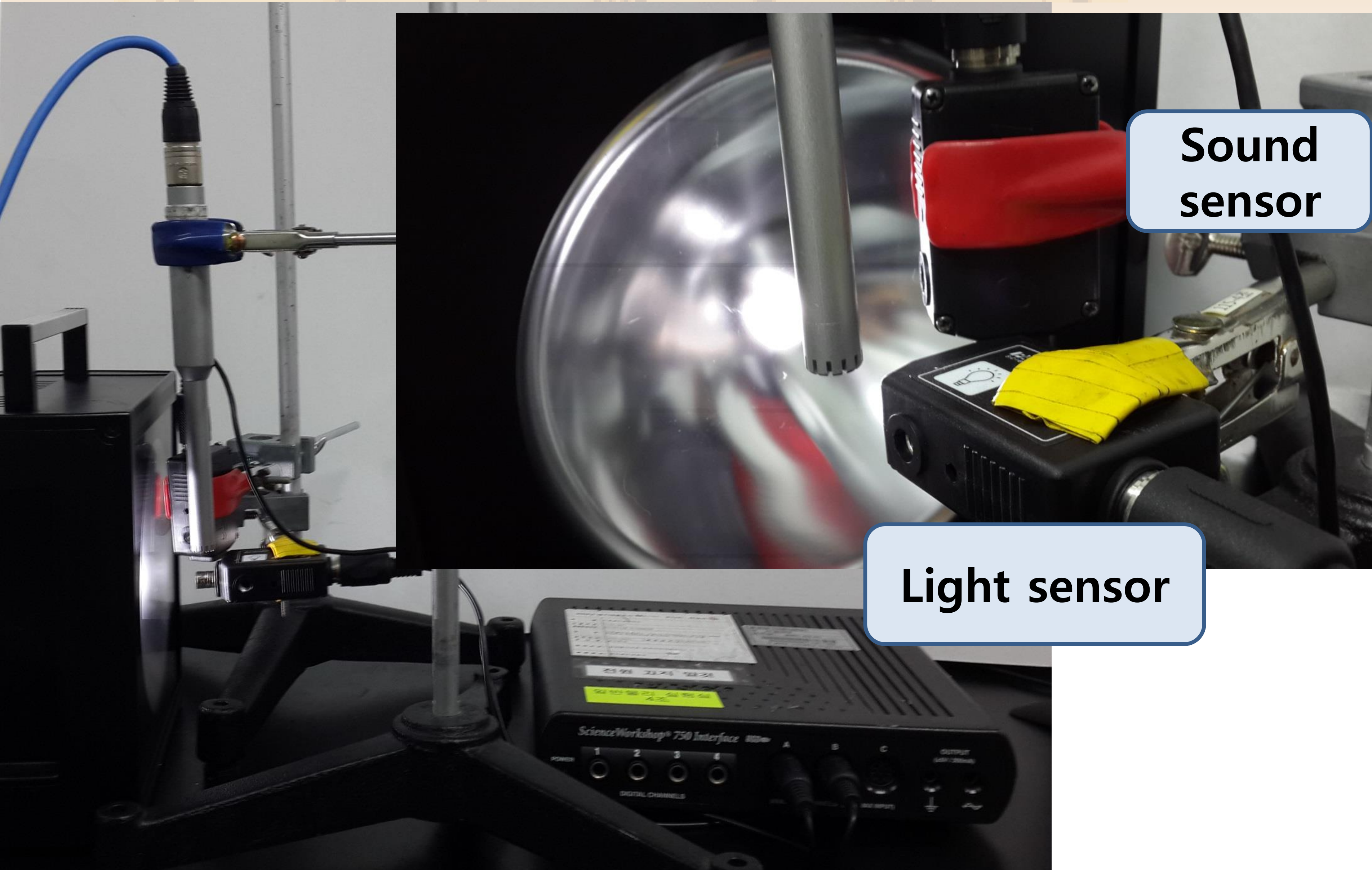
Duration of flash

$$\cong 4.5 \times \left(\frac{1}{83333s^{-1}}\right) = 0.00005s$$

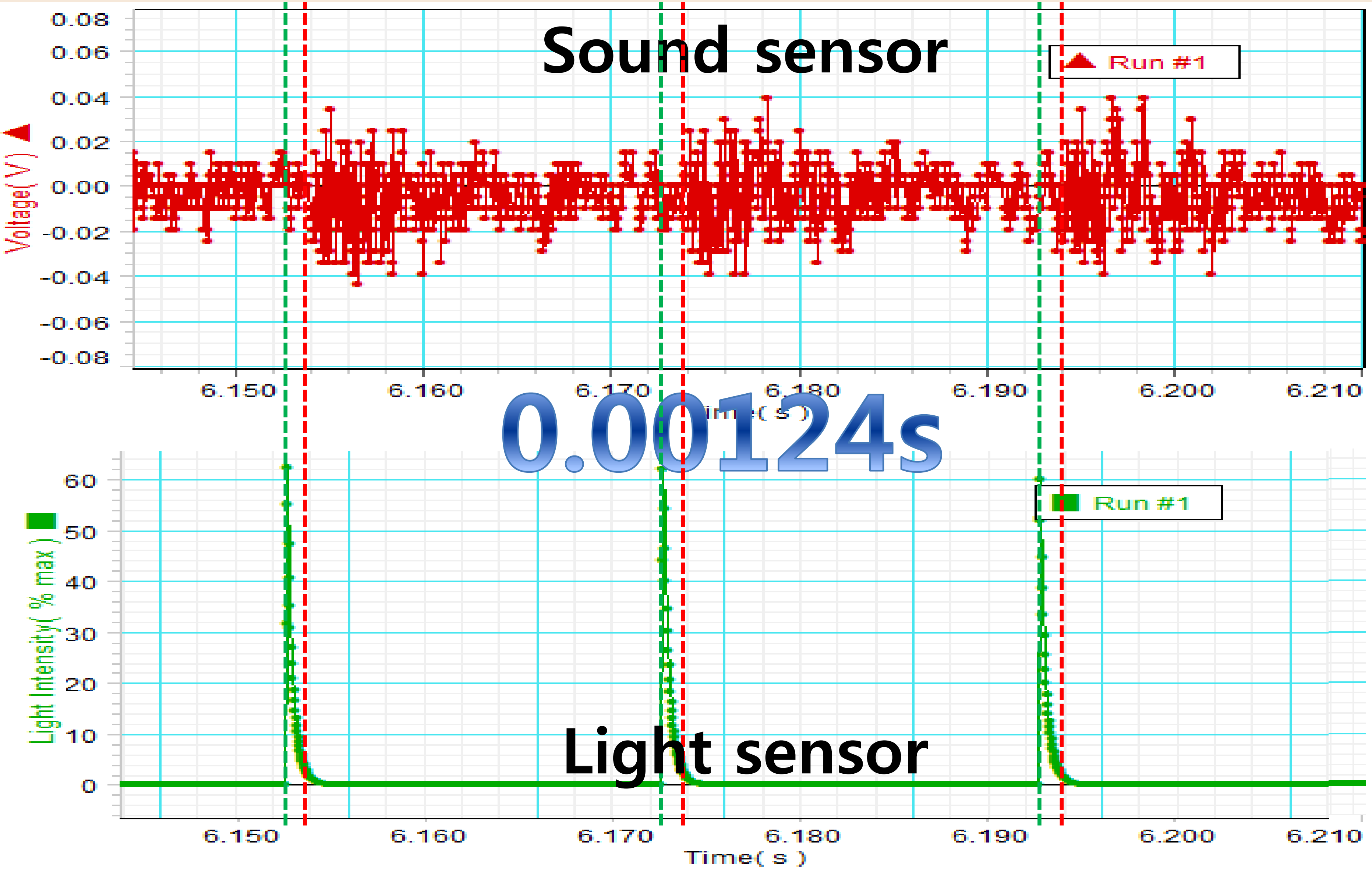
Flash at what point?



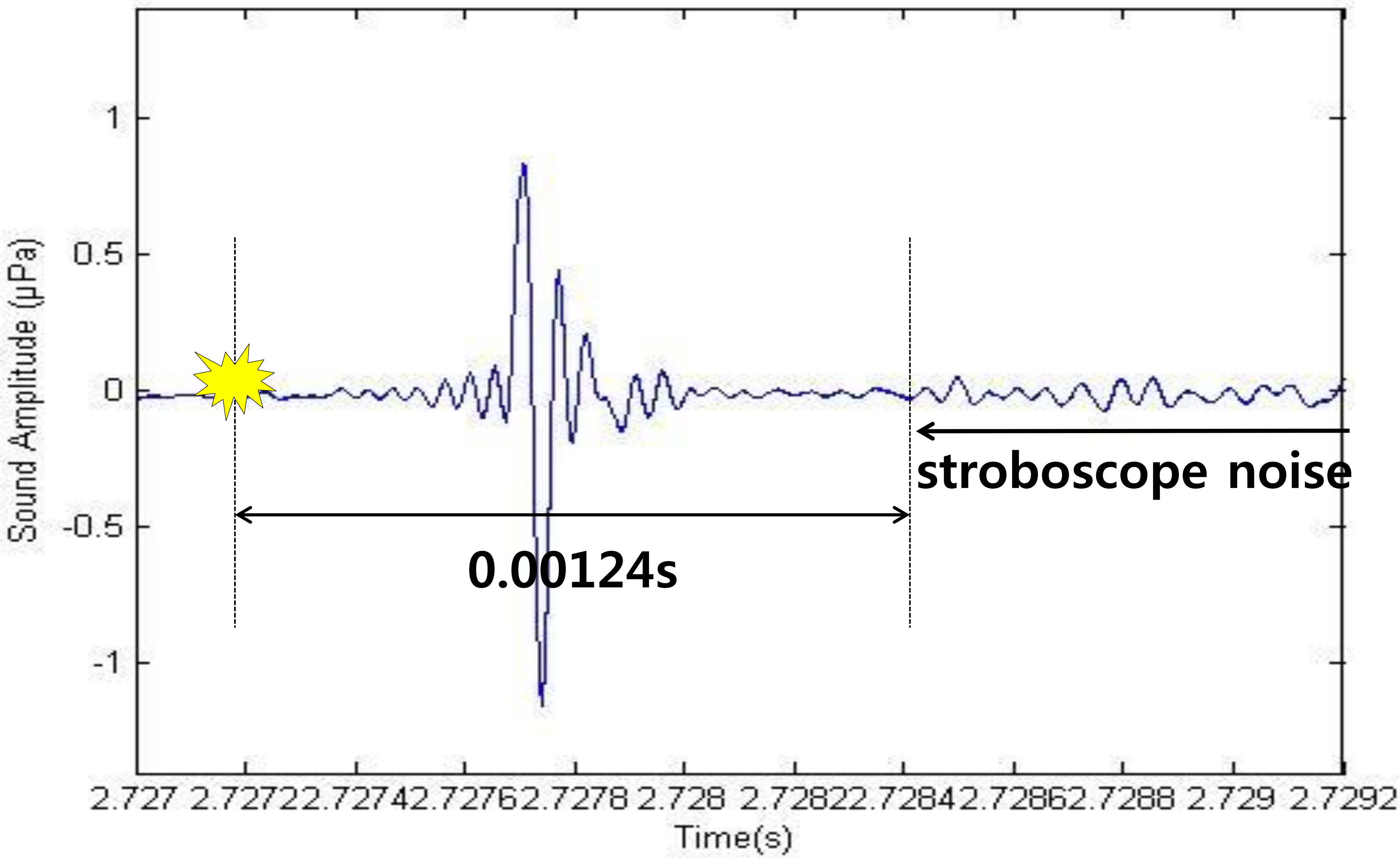
Experiment on Flash Time



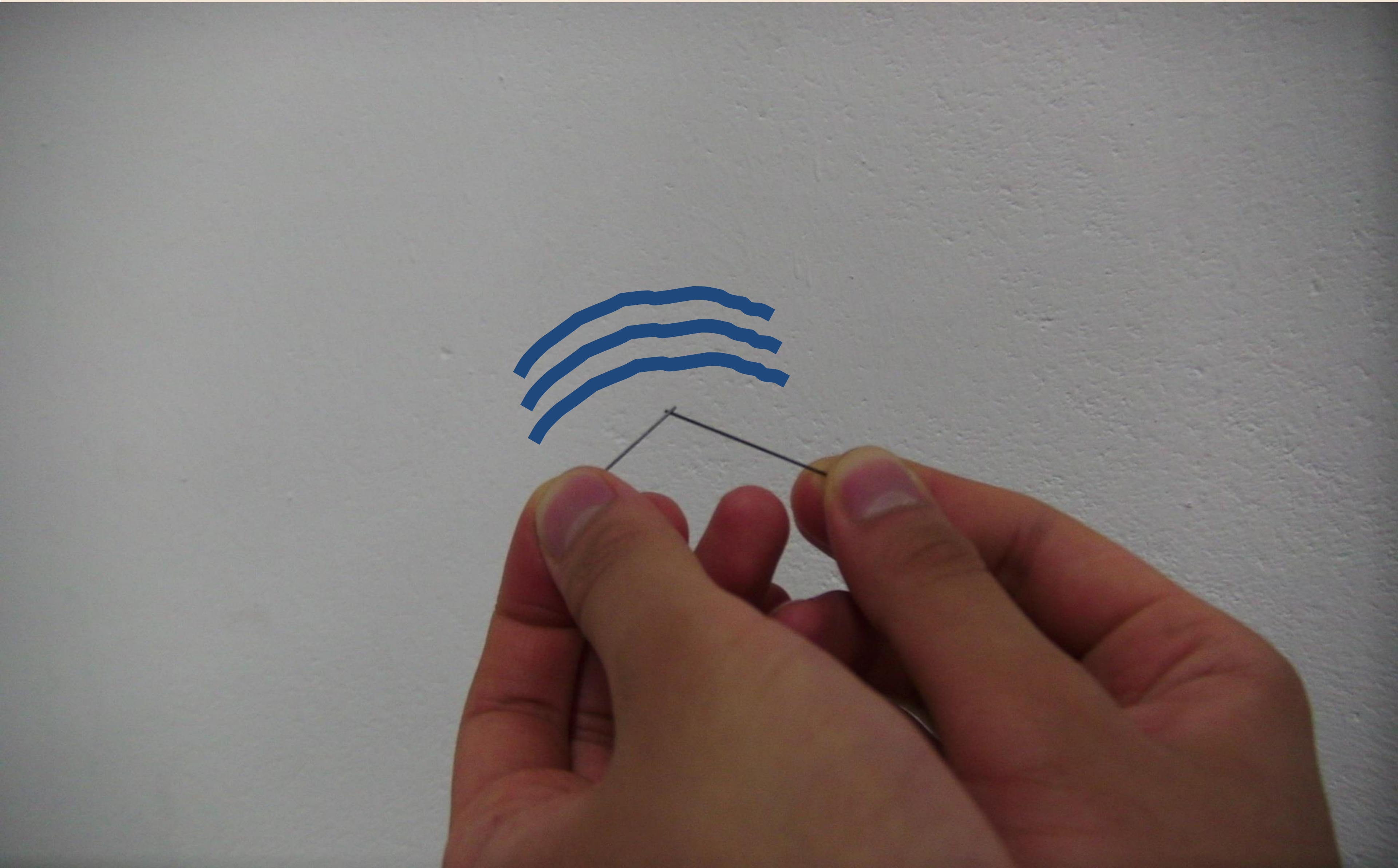
Time gap between sound and light



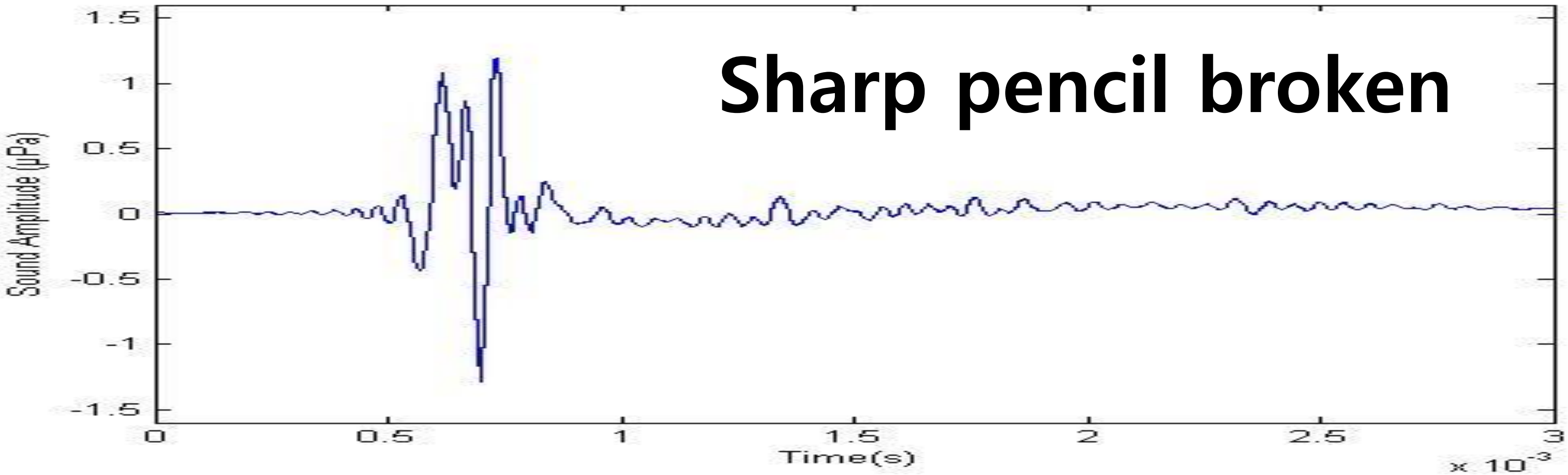
So the flash is at.....

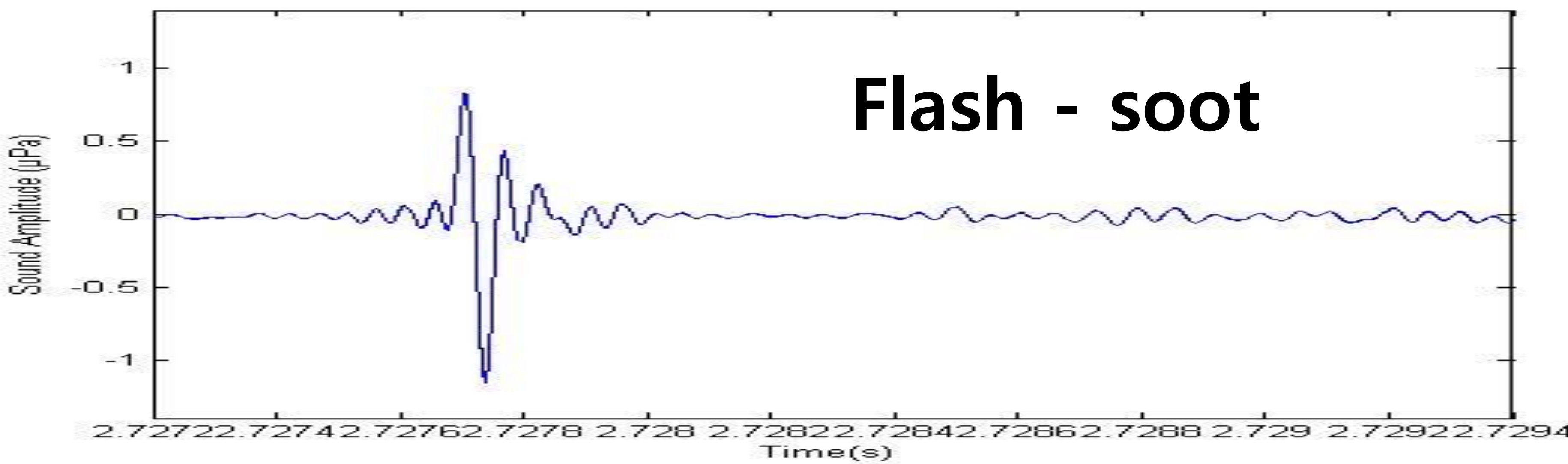


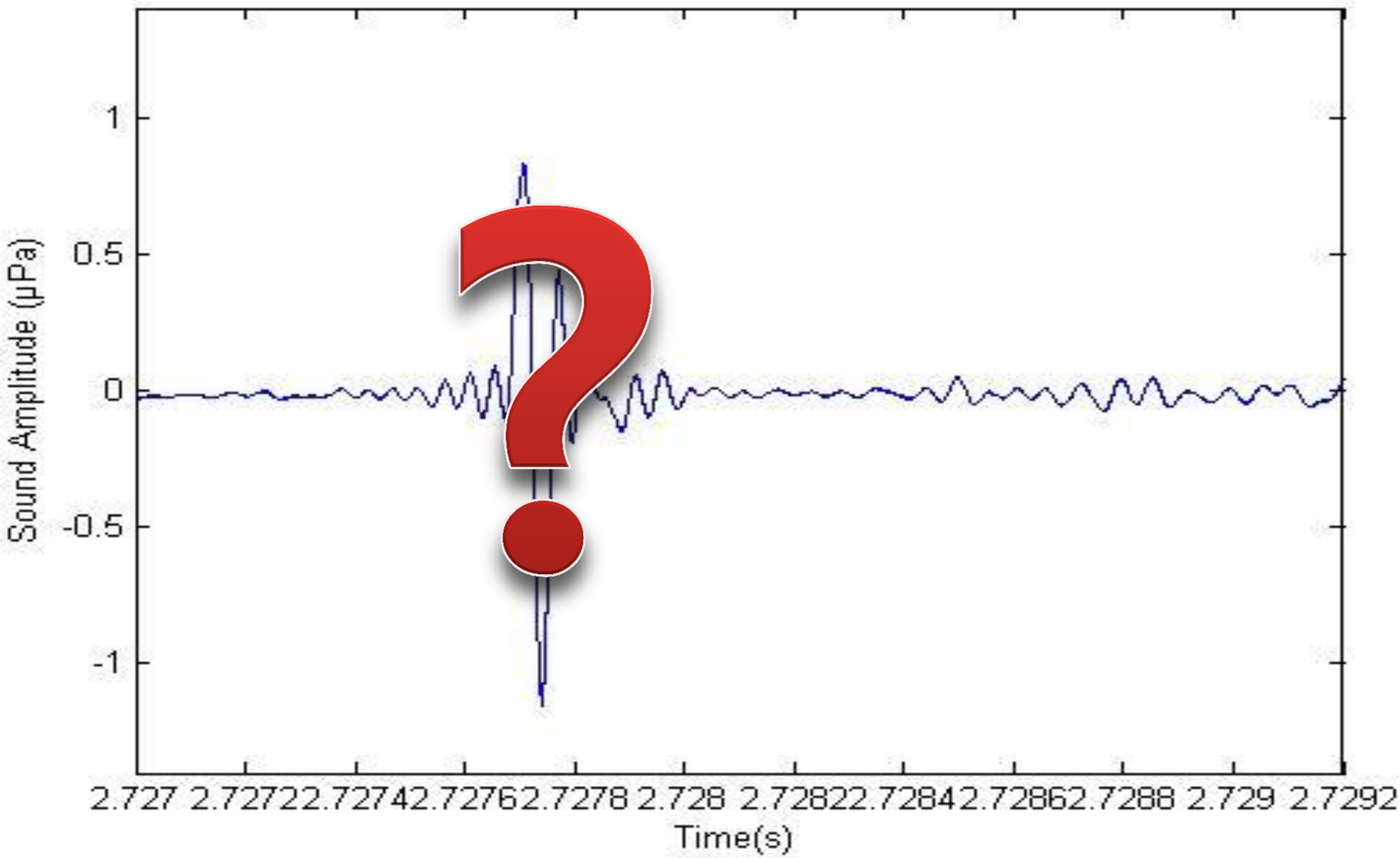
Shockwave?



Similar waveform!

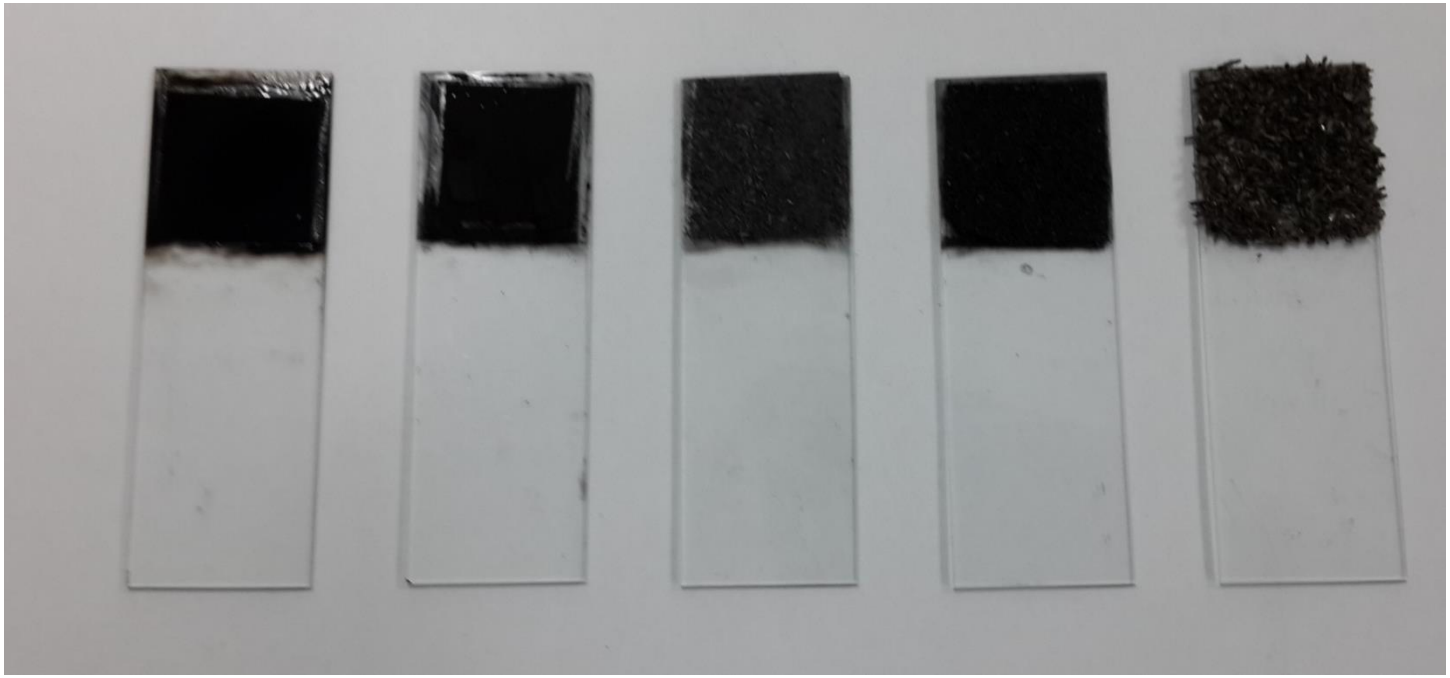






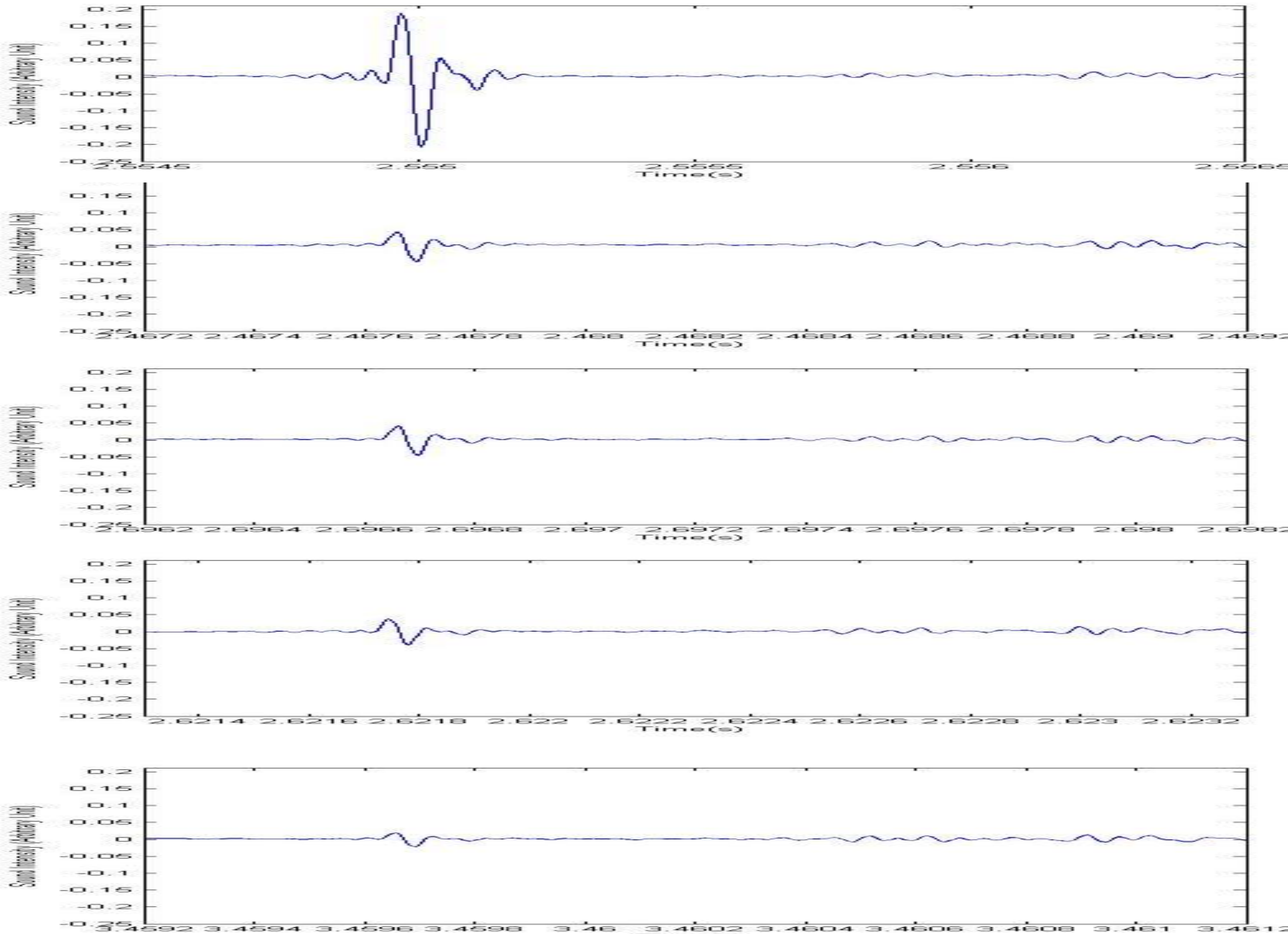
Sound Amplitude (μPa)
1
0.5
0
-0.5
-1
2.727 2.7272 2.7274 2.7276 2.7278 2.728 2.7282 2.7284 2.7286 2.7288 2.729 2.7292
Time(s)

Samples of various powders



Soot | Activated Carbon | Graphite (Grained pencil lead) | Charcoal | Iron

Sound from various powders



Soot
3.8

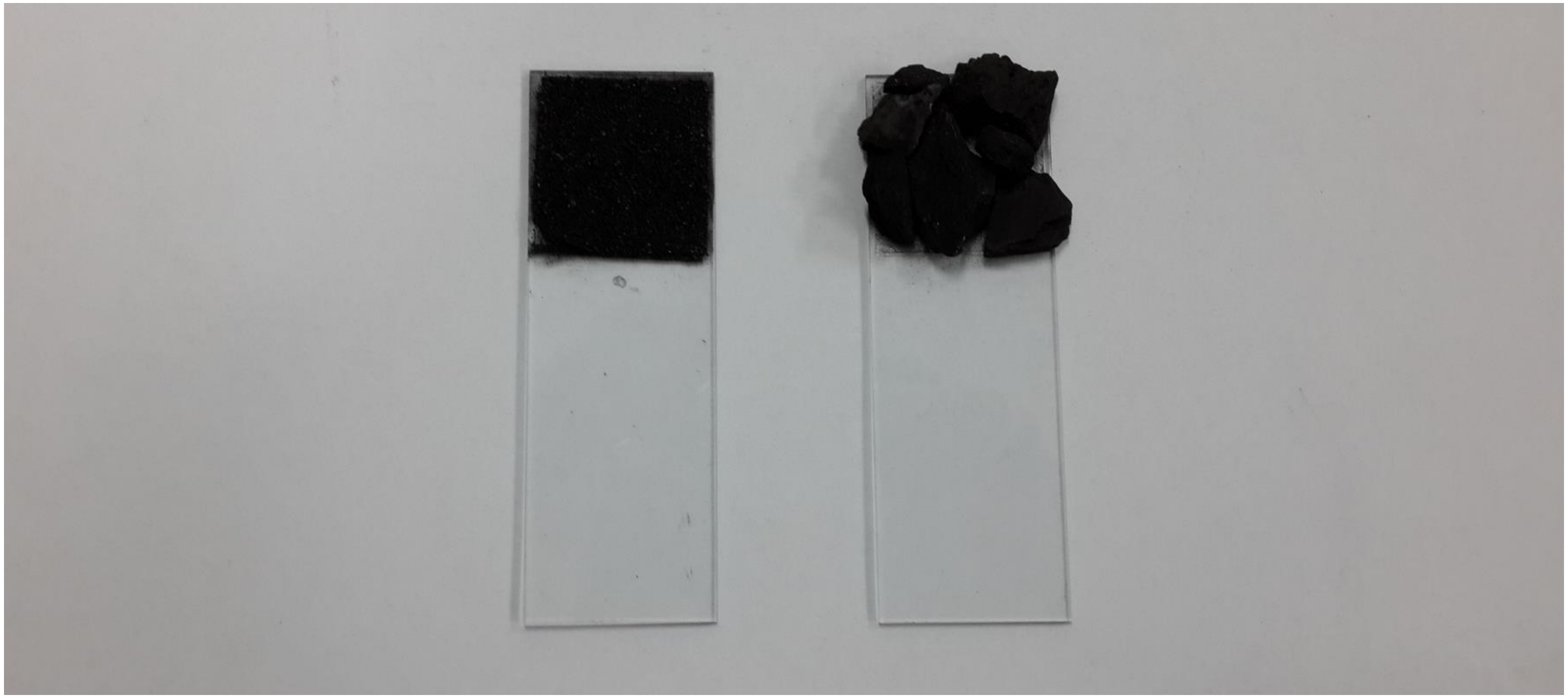
Activated Carbon
0.90

Graphite
0.86

Charcoal
0.76

Iron
0.40

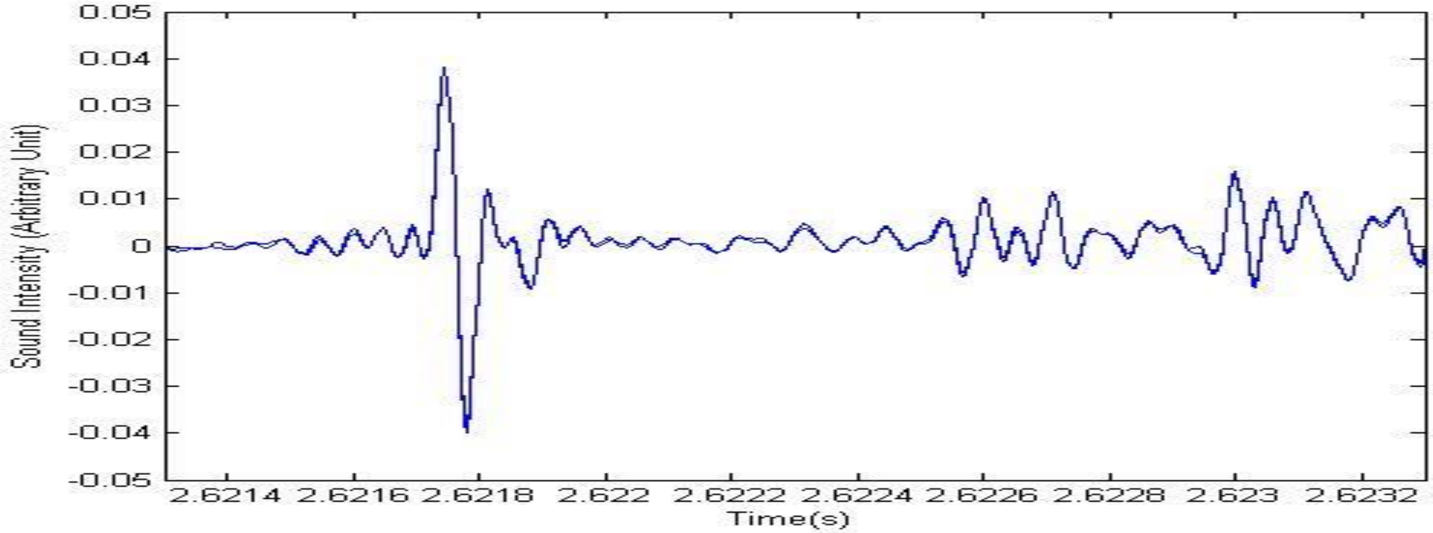
Sample of powder and chunk



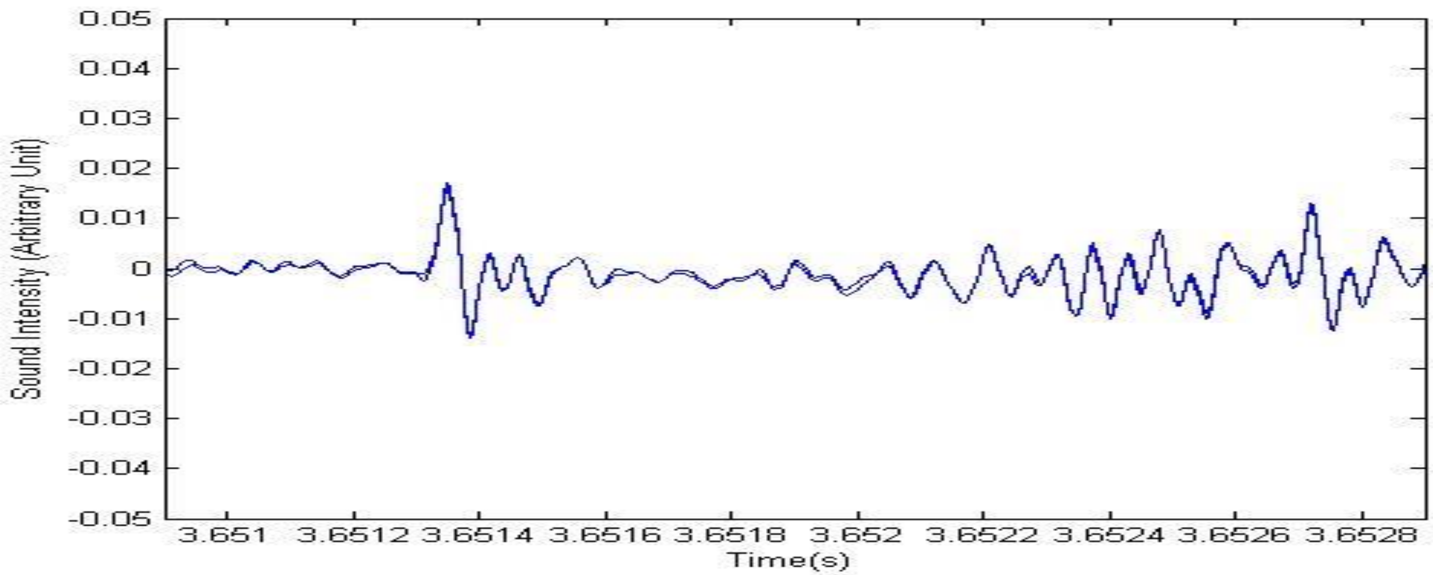
Charcoal powder

Charcoal chunk

Powder VS Chunk

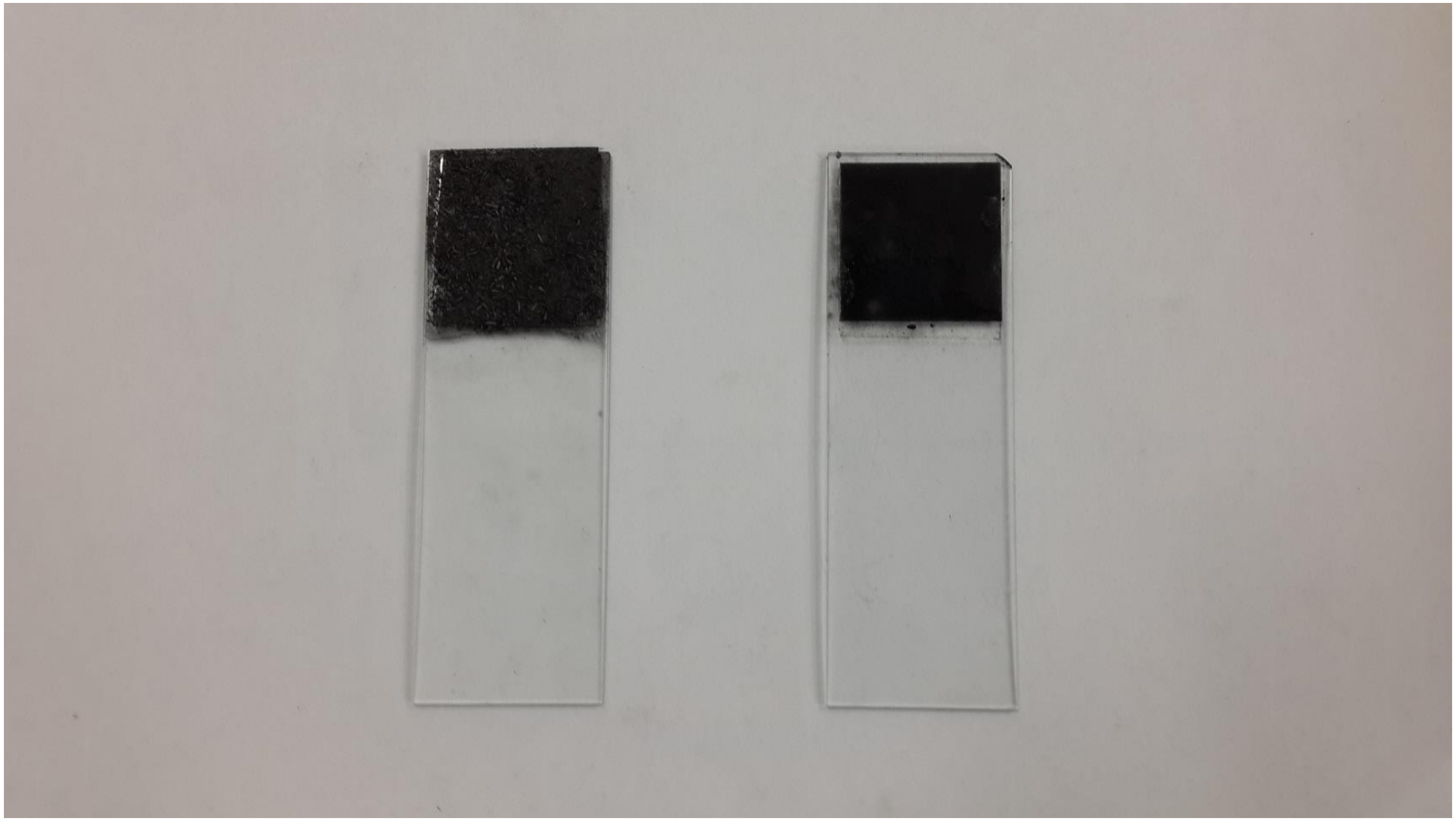


Powder
0.76



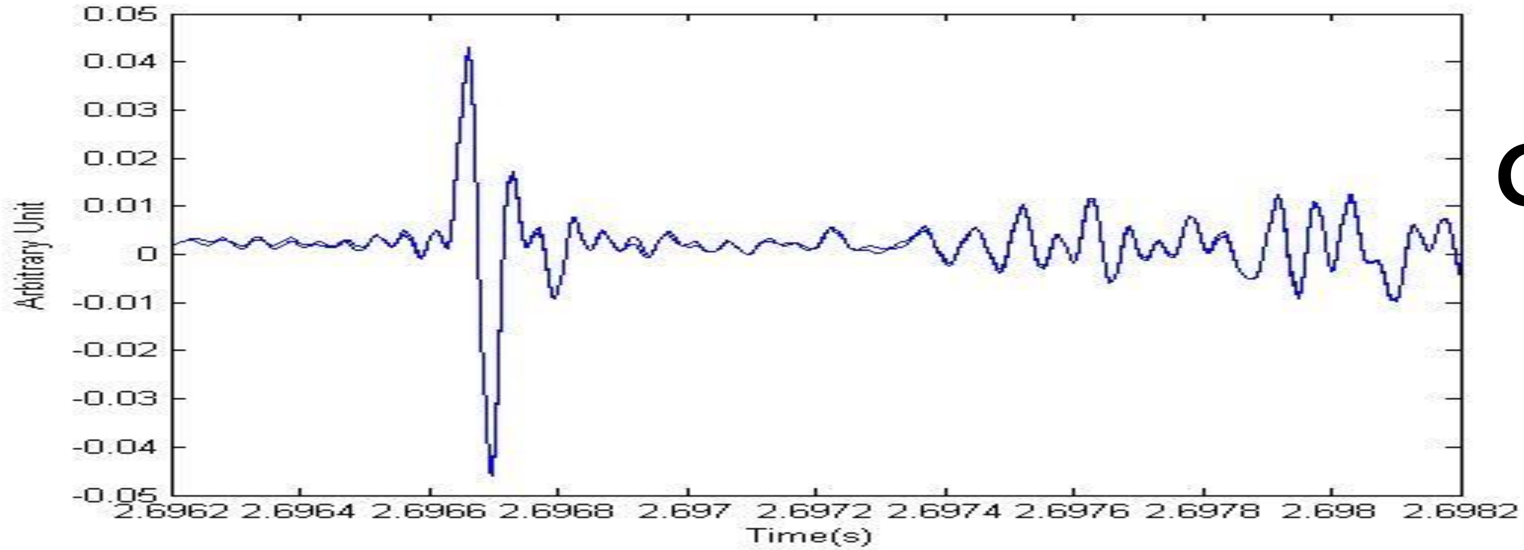
Chunk
0.34

Sample of powder and lubricant

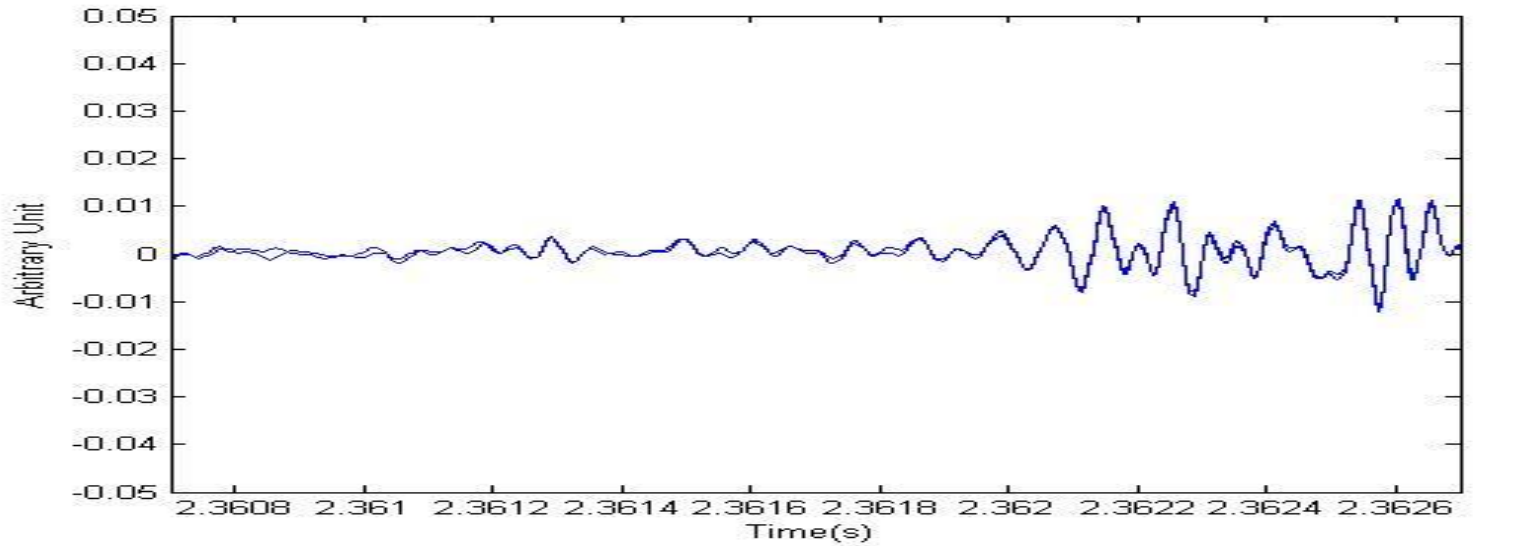


Graphite powder　　Graphite lubricant

Powder VS Lubricant

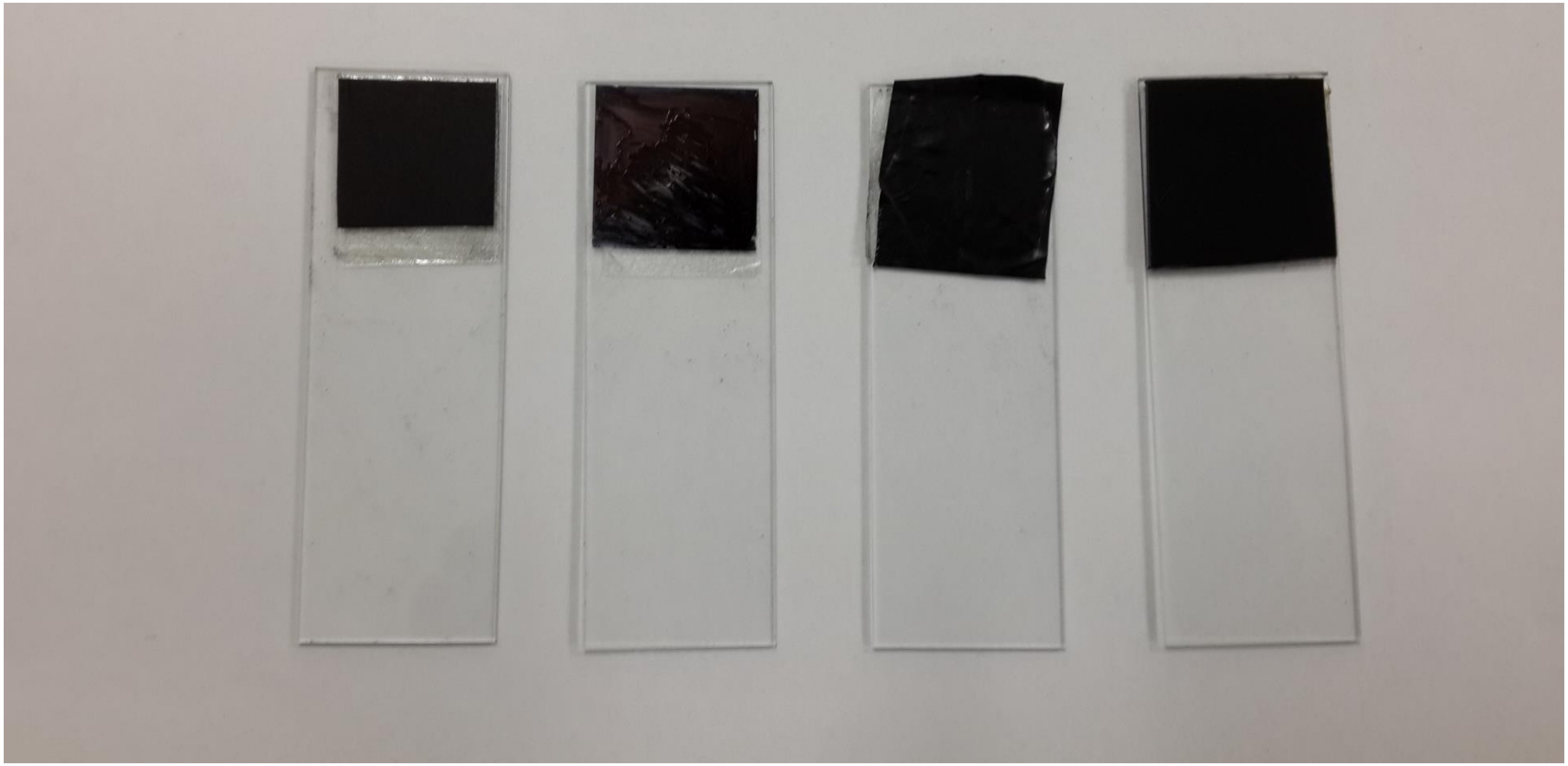


Graphite Powder 0.86



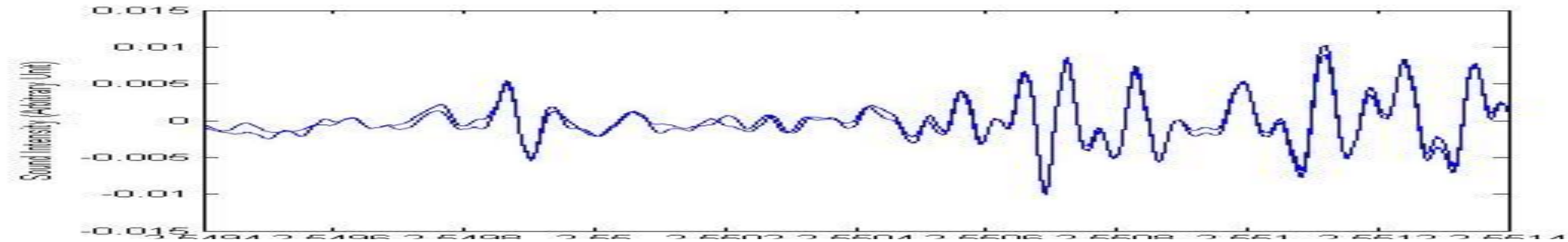
Graphite Lubricant ?

Samples of various surfaces

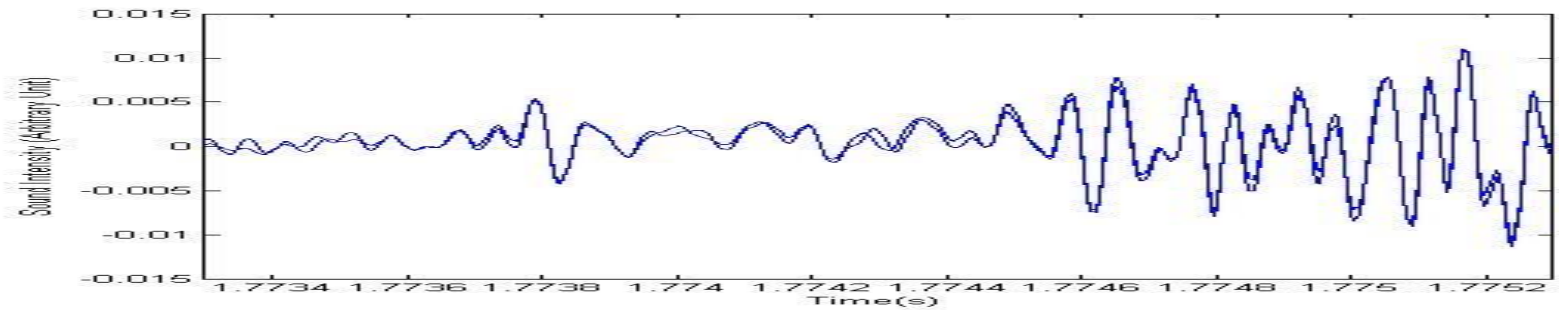


Paper Marker Vinyl Plastic

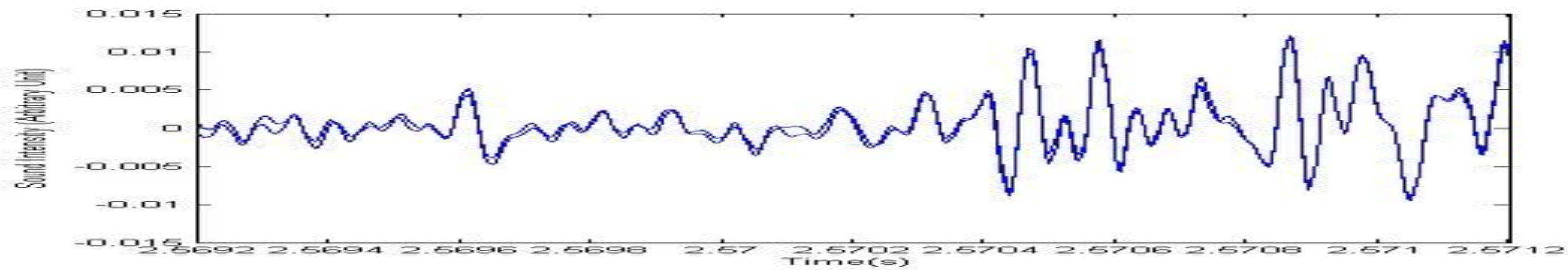
Sound from various surfaces



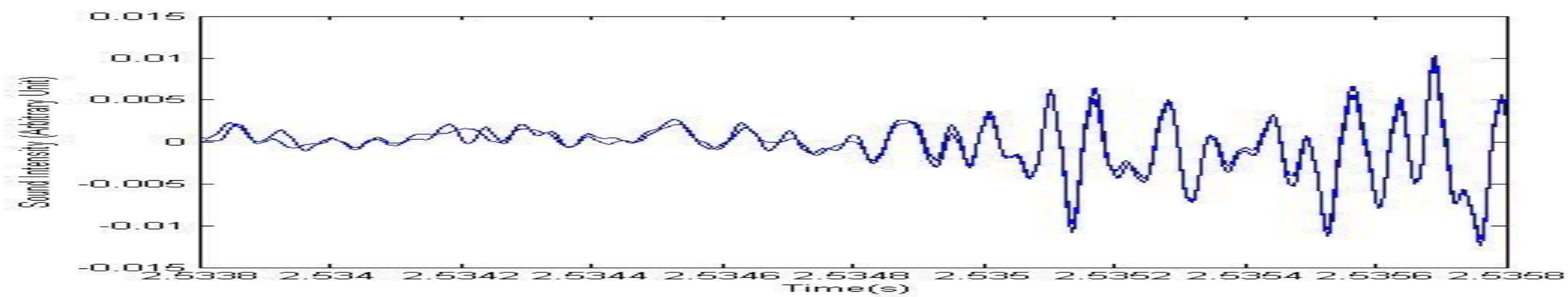
Paper
0.1



Marker
0.1



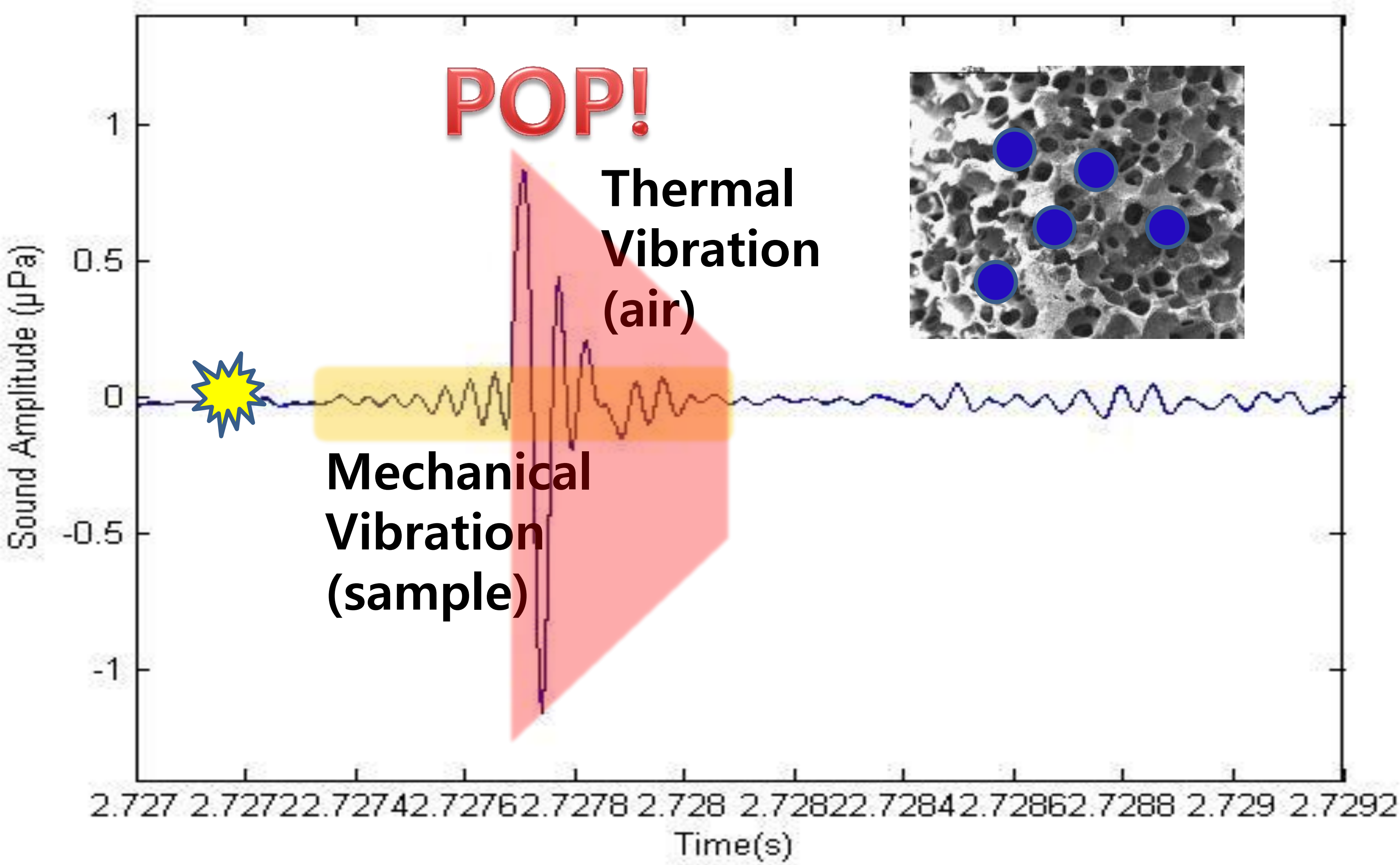
Vinyl
0.1



Plastic
?

Mechanism of heat conduction
Something special about

Hypothesis for Photoacoustic Mechanism



Thermal conductivity

$$Q = \frac{kA(T_1 - T_2)}{L}\Delta t$$

Graphite: 119~165 W/m·K

Air: 0.0257 W/m·K

Mechanical vibration starts EARLIER!

Thermal expansion coefficient

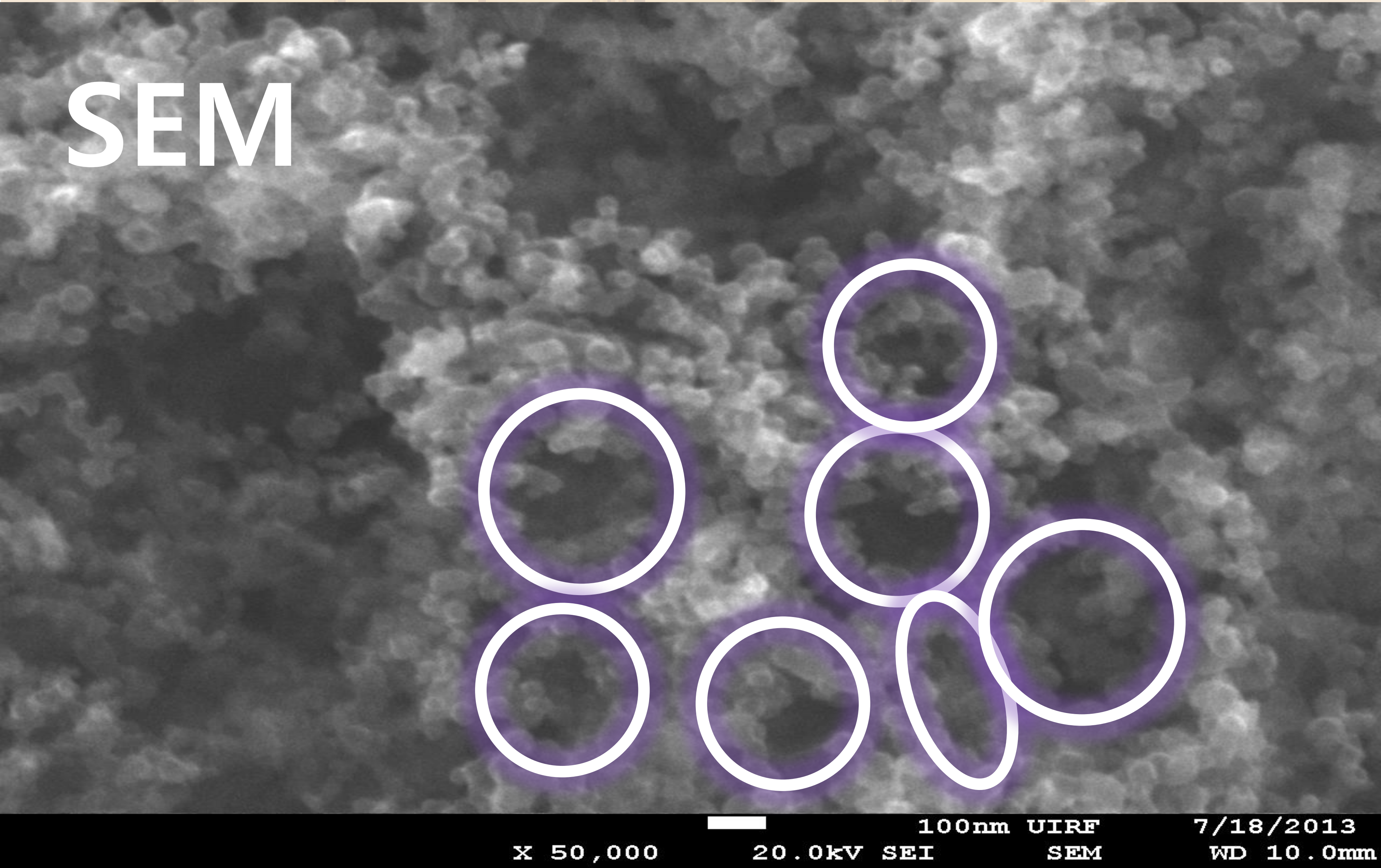
$$\Delta V = \beta V \Delta T$$

Graphite: $2.4 \times 10^{-5}\ \mathrm{K}^{-1}$

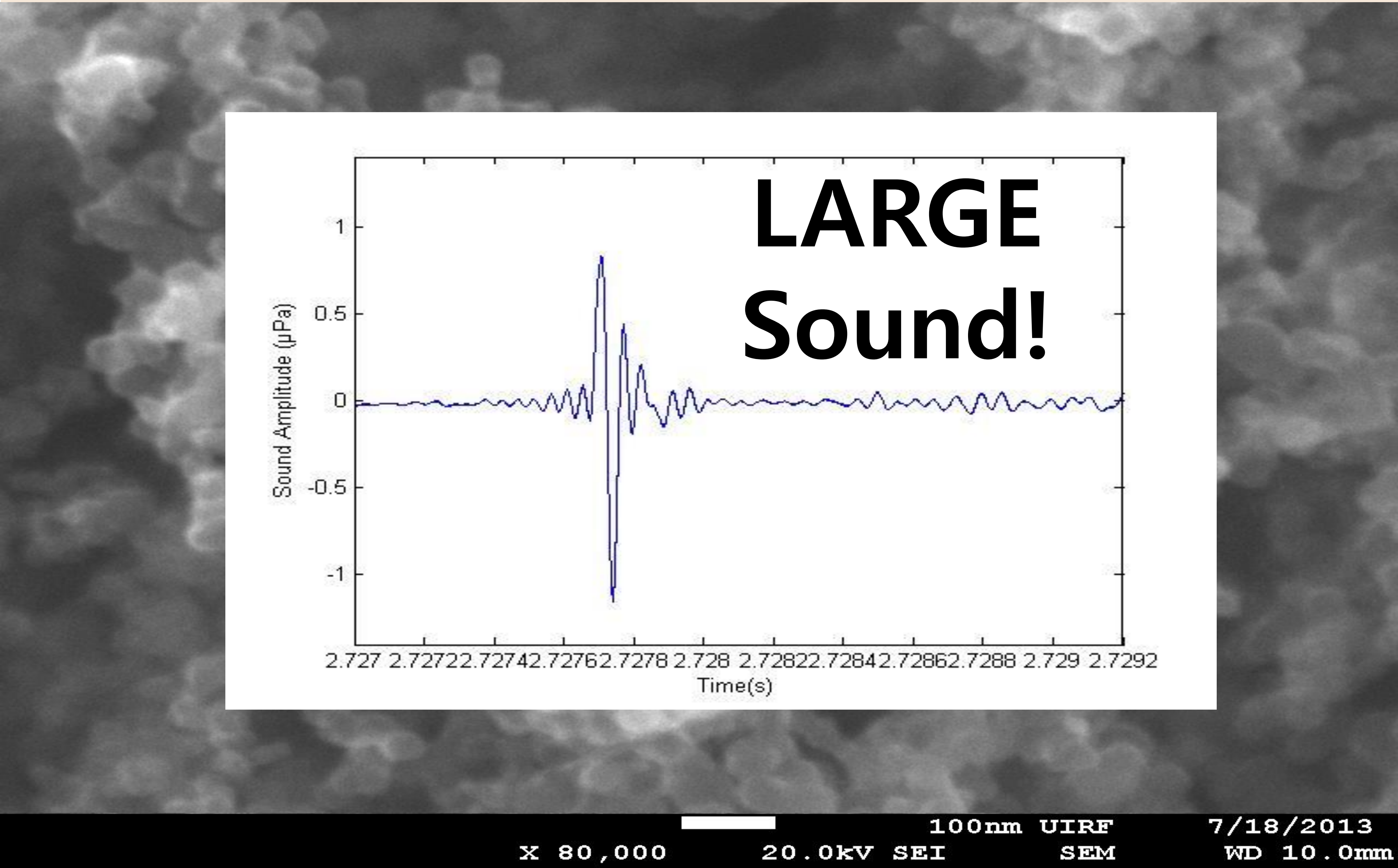
Air: $3.4 \times 10^{-3}\ \mathrm{K}^{-1}$

Thermal vibration has bigger AMPLITUDE!

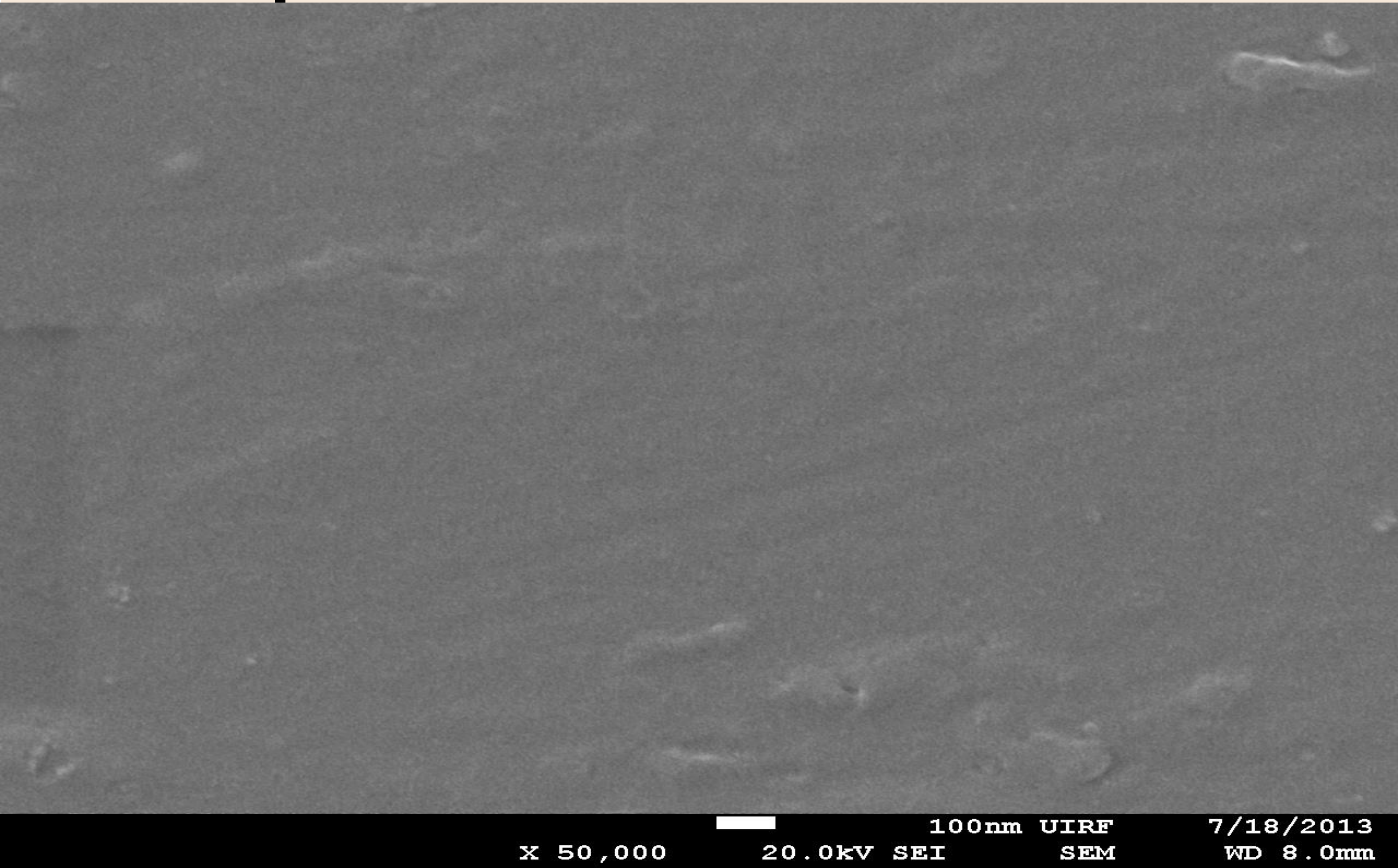
Porous Structure of Soot



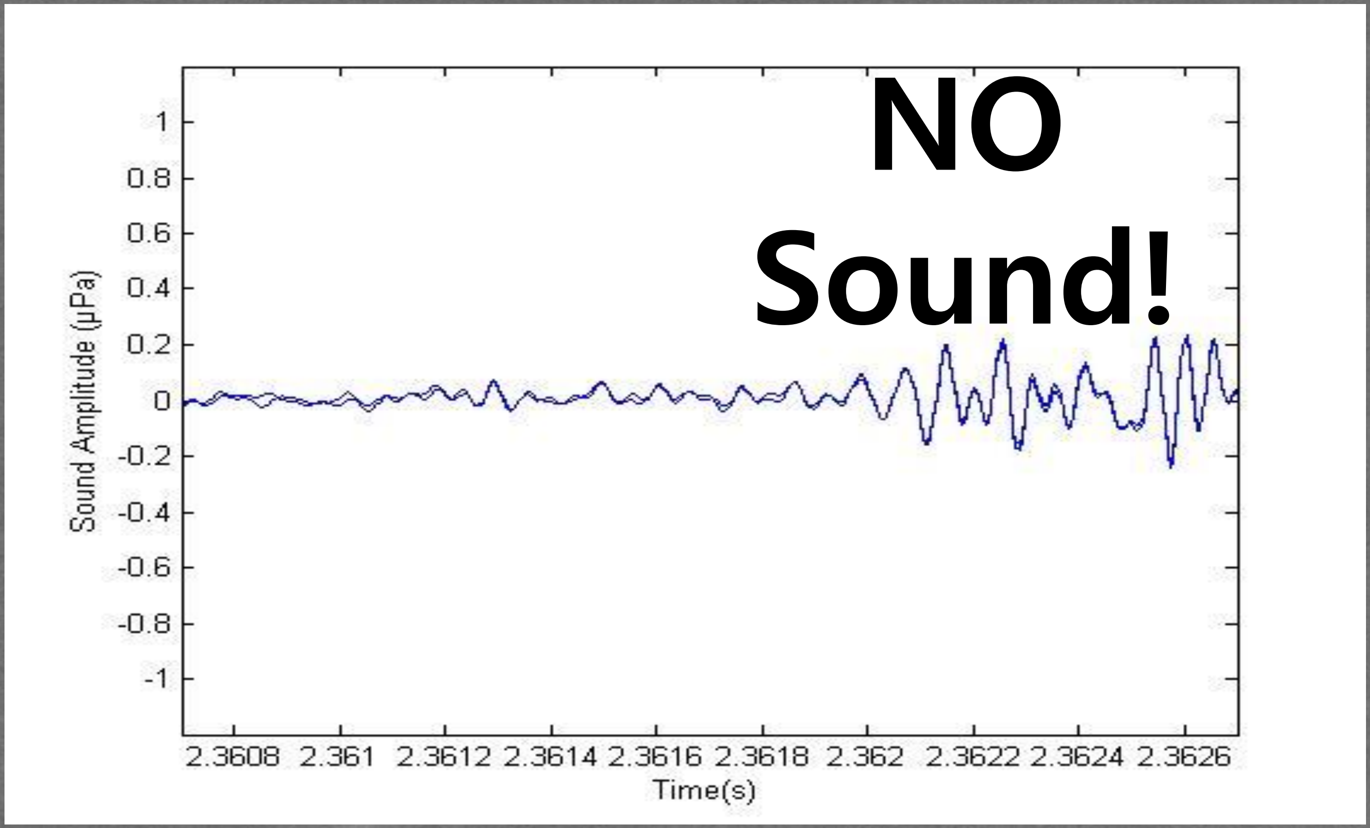
Porous Structure of Soot



Plane Structure of Graphite Lubricant

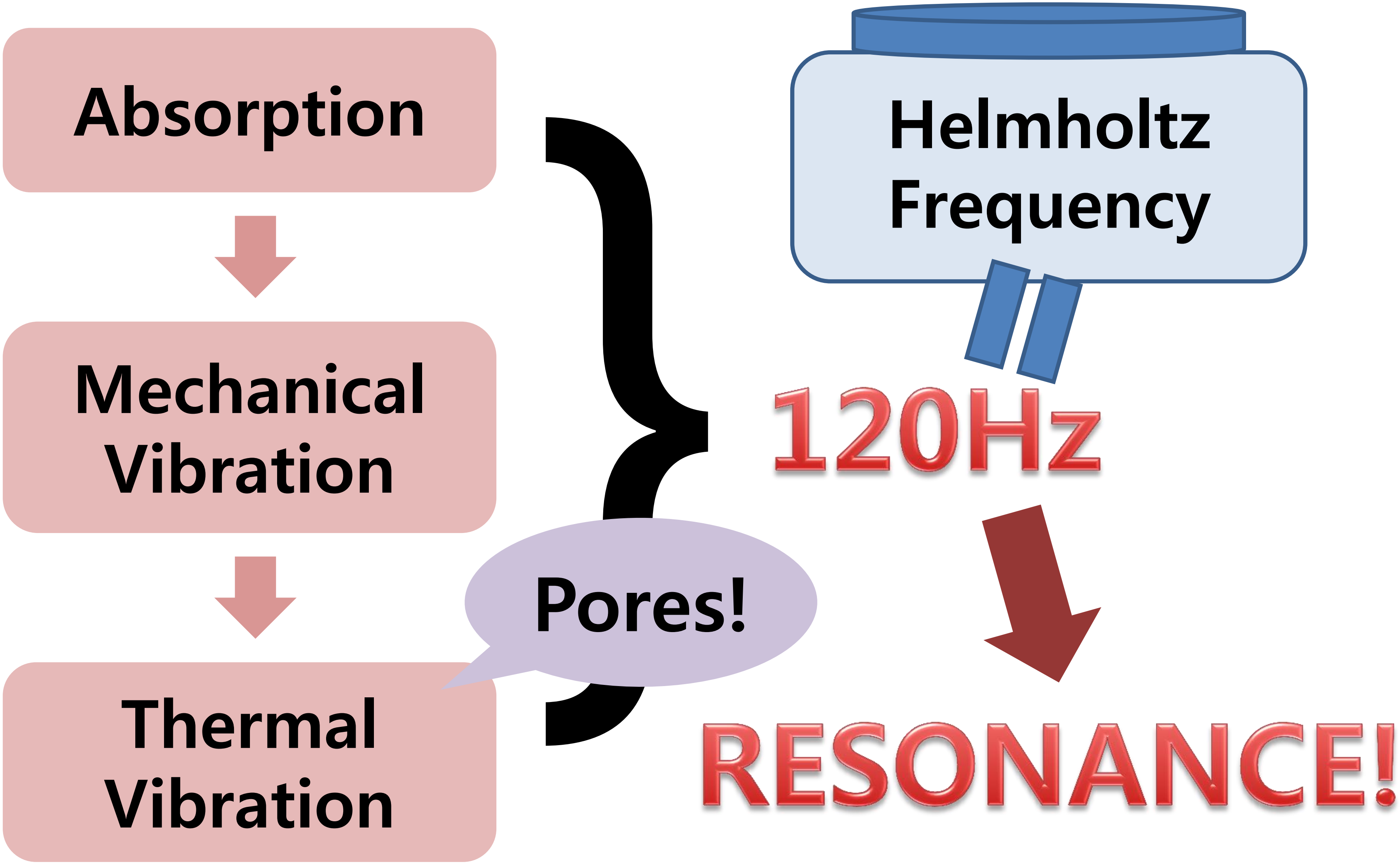


Plane Structure of Graphite Lubricant



100nm UIRF 7/18/2013
X 80,000 20.0kV SEI SEM WD 8.0mm

Conclusion


Absorption
Mechanical Vibration
Thermal Vibration
Pores!
Helmholtz Frequency
120Hz
RESONANCE!

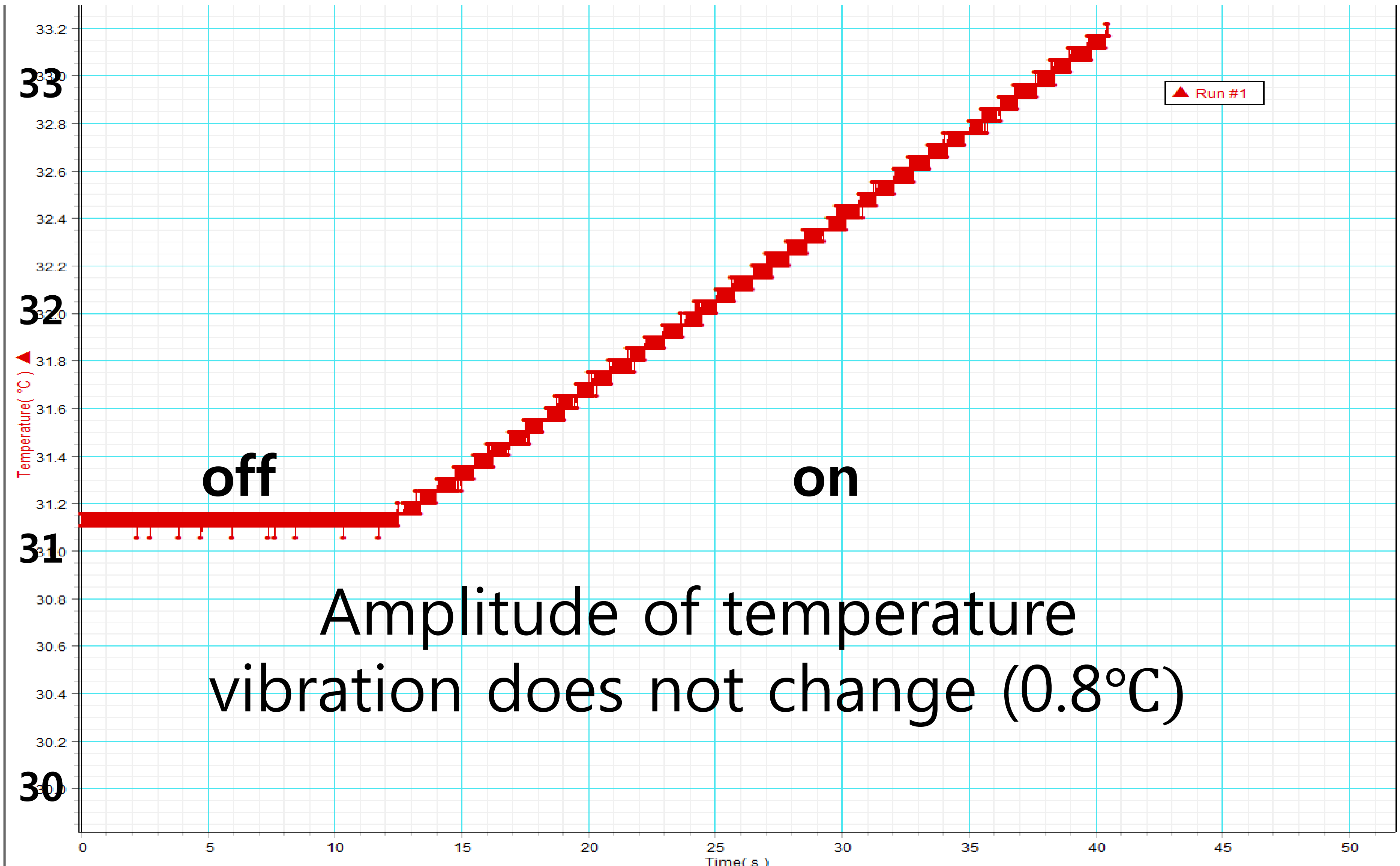
Thank You

MATLAB FFT Code

```
[nSamples, nChannels]=size(data);
data=data*20;
waveFileLength=nSamples/fs;
N=2^(nextpow2(nSamples));
Y=fft(data(:,1),N);
NumbUniquePts=ceil((N+1)/2);
Y=Y(1:NumbUniquePts);
P=abs(Y)/waveFileLength;
f=(0:NumbUniquePts-1)*fs/N;
plot (f,P)
xlabel('Frequency (Hz)')
ylabel('Sound Intensity (Arbitrary Unit)')
axis([0, 400, 0, 10000])
```

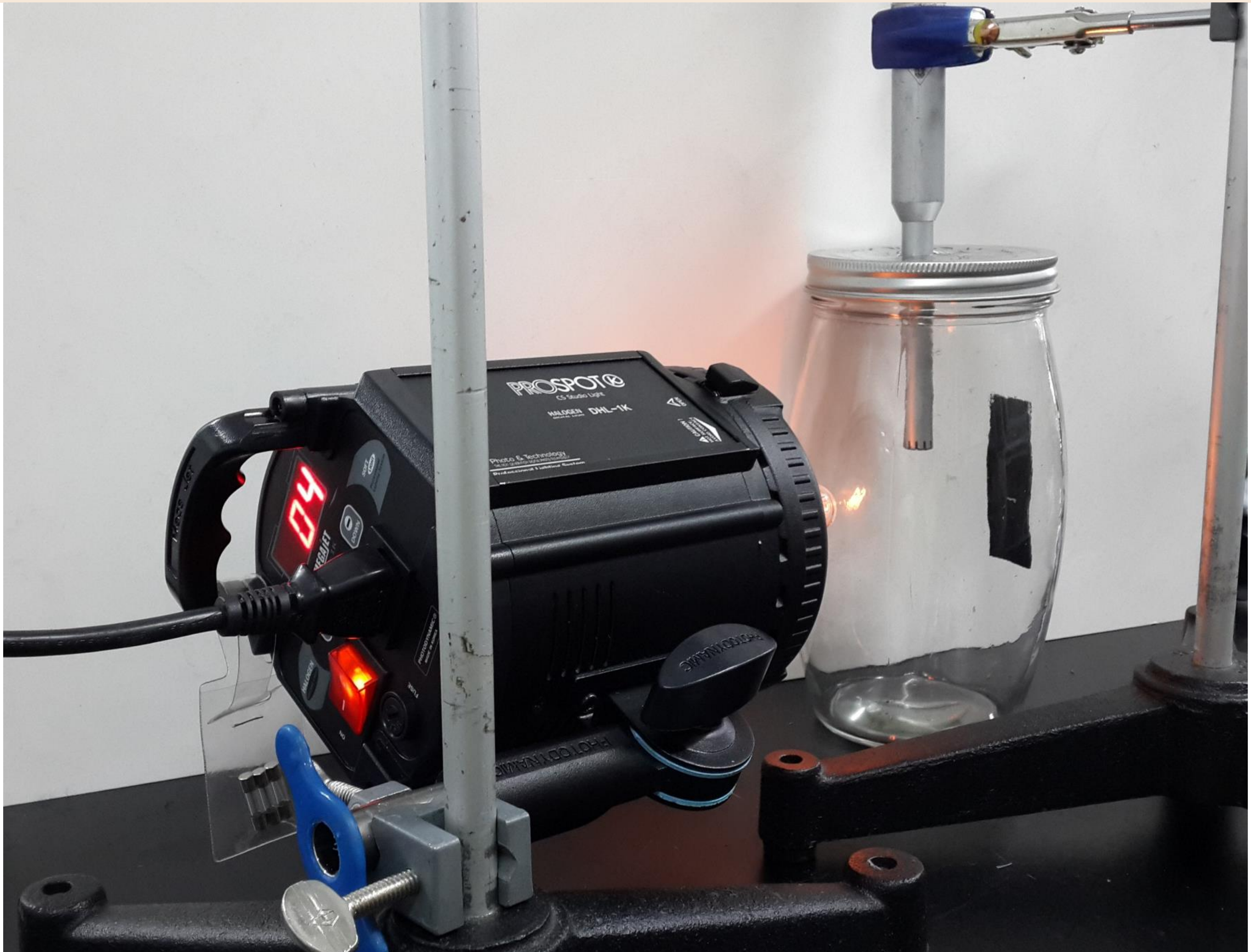
FFT Number determined!

Heat vibration caused by lightbulb

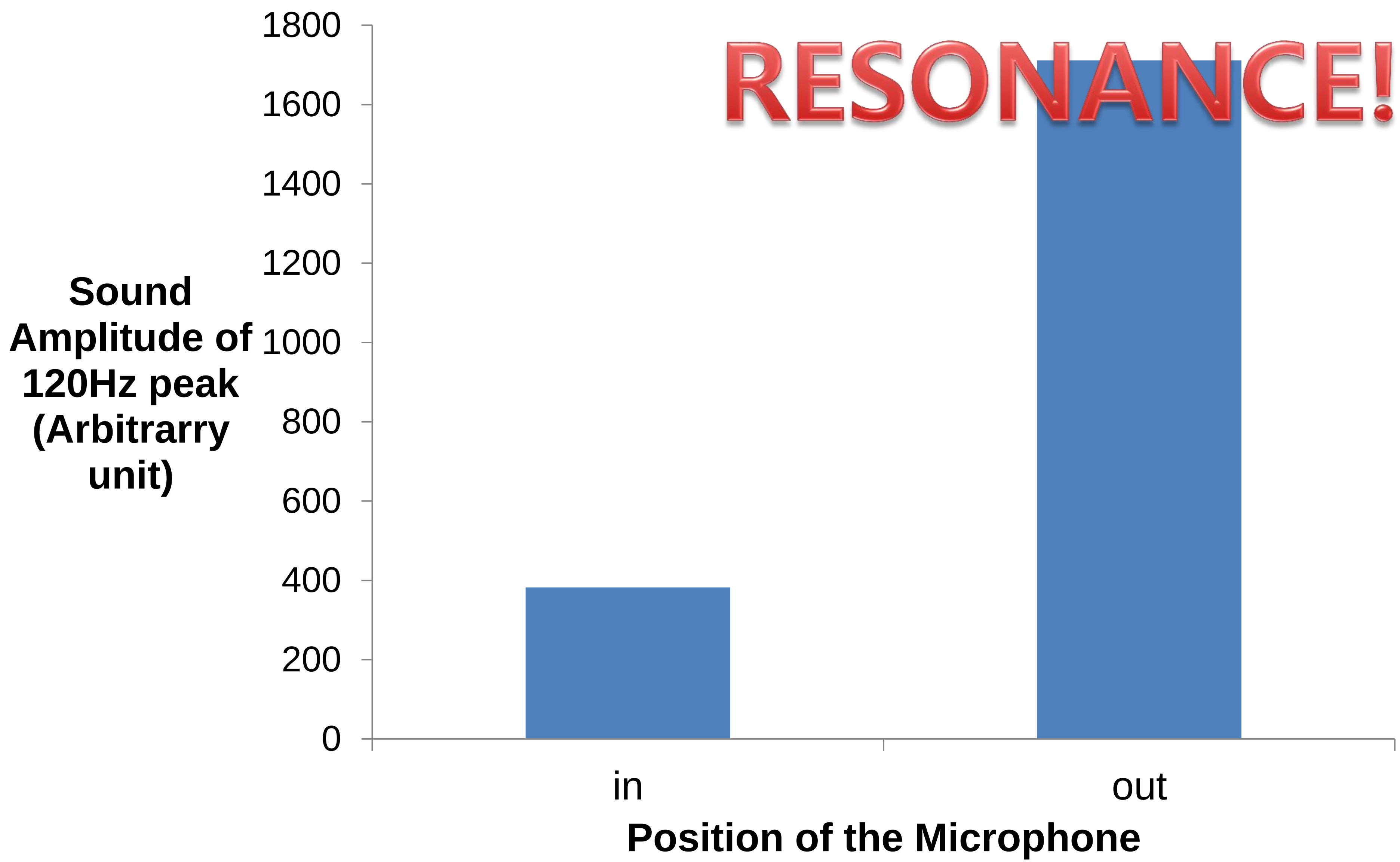


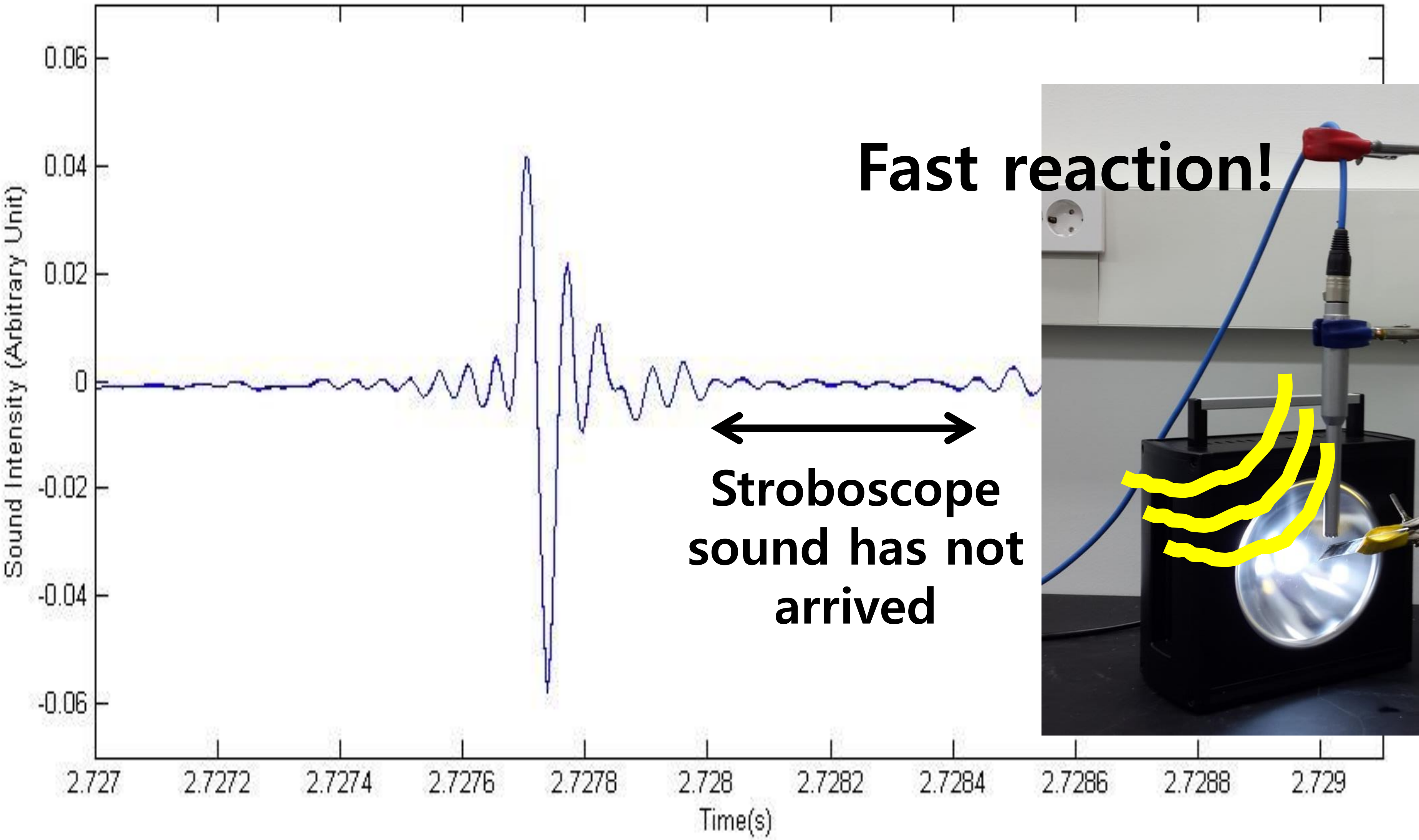
Amplitude of temperature vibration does not change (0.8℃)

Microphone inside the jar

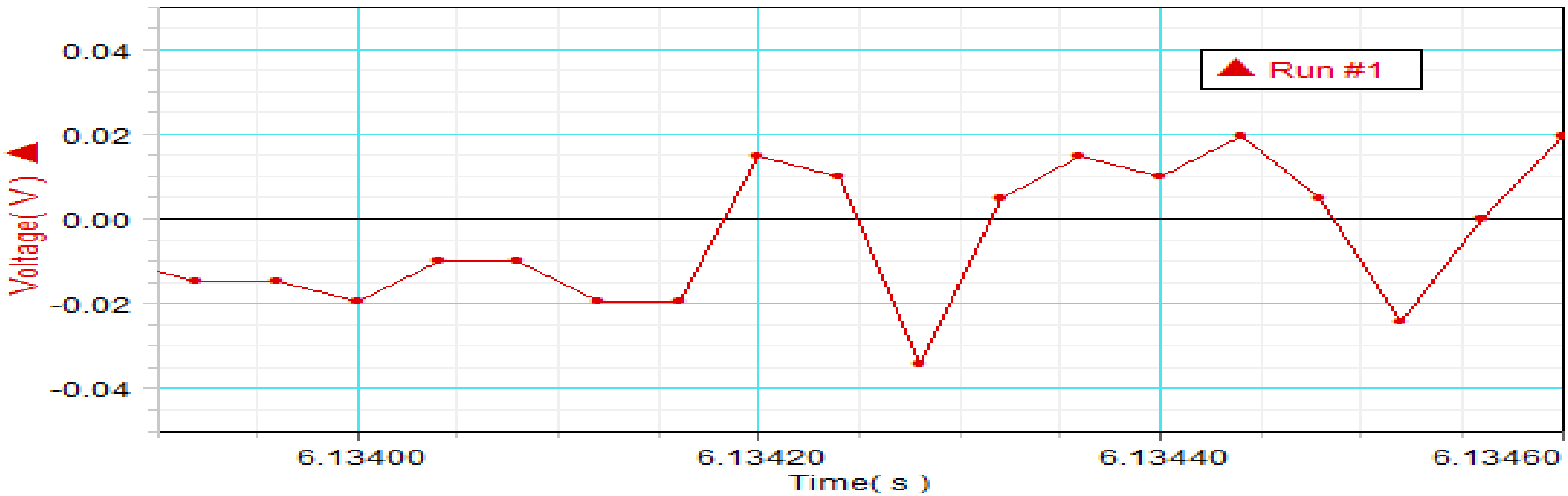


Microphone position and Resonance effect

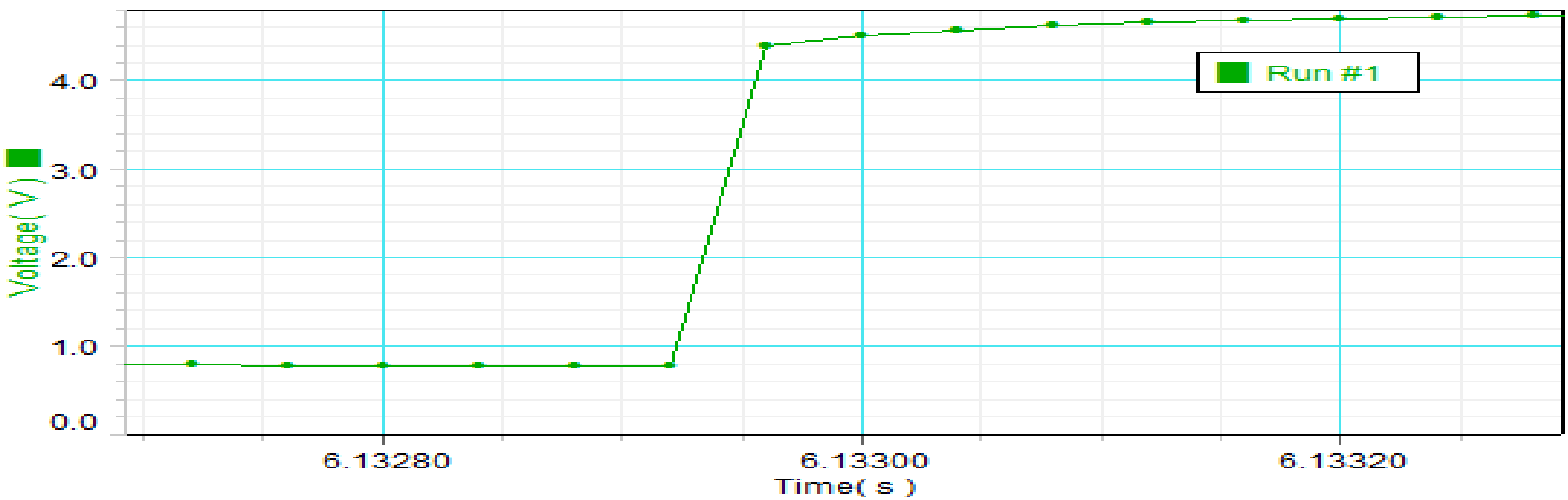




Fast reaction!
Stroboscope sound has not arrived
Sound Intensity (Arbitrary Unit)
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
2.727
2.7272
2.7274
2.7276
2.7278
2.728
2.7282
2.7284
2.7286
2.7288
2.729
Time(s)

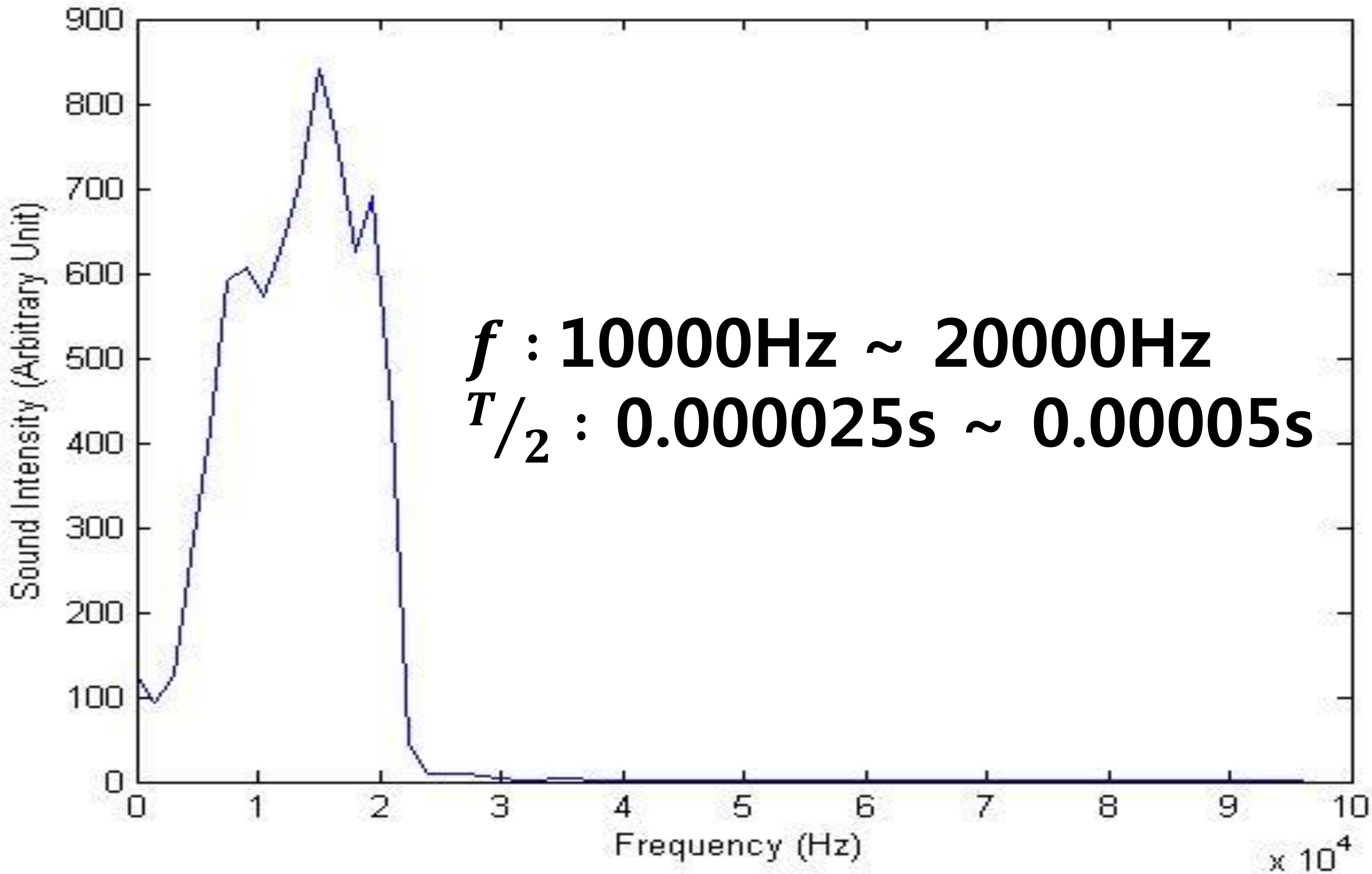


Run #1
Voltage(V)
0.04
0.02
0.00
-0.02
-0.04
6.13400
6.13420
6.13440
6.13460
Time(s)



Run #1
Voltage(V)
4.0
3.0
2.0
1.0
0.0
6.13280
6.13300
6.13320
Time(s)

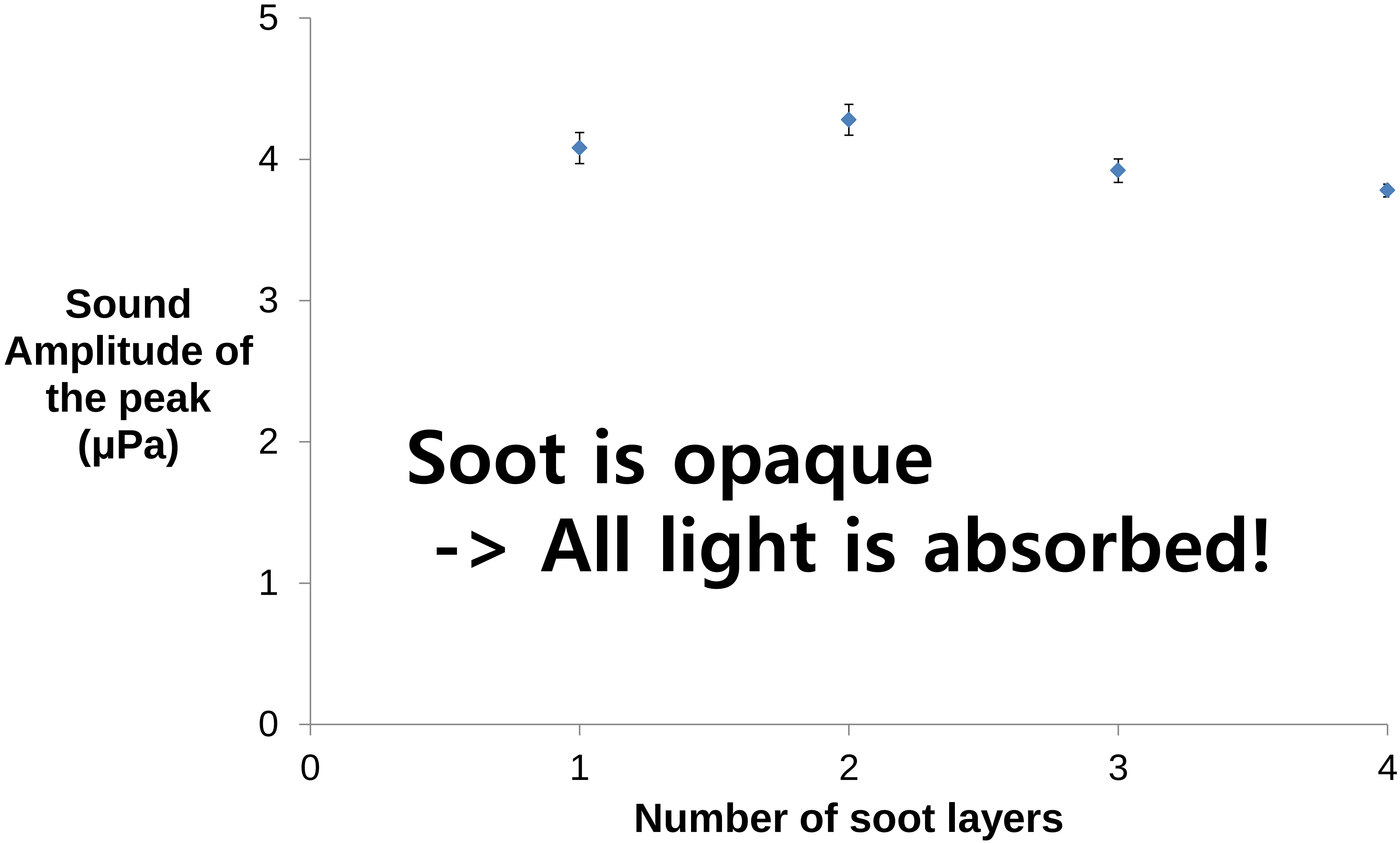
FFT: Sound caused by only light



f : 10000Hz ~ 20000Hz

$T/2$: 0.000025s ~ 0.00005s

Depth of soot is not important



Soot is opaque

-> All light is absorbed!

- Effect of heat from lightbulb (justification)
- Sound absorption due to thermal conduction (fundamentals of acoustics)