Making a Matching Layer for Acoustic Sensors

for a Dark Matter Detector

Justin P. Skycak

Marian High School

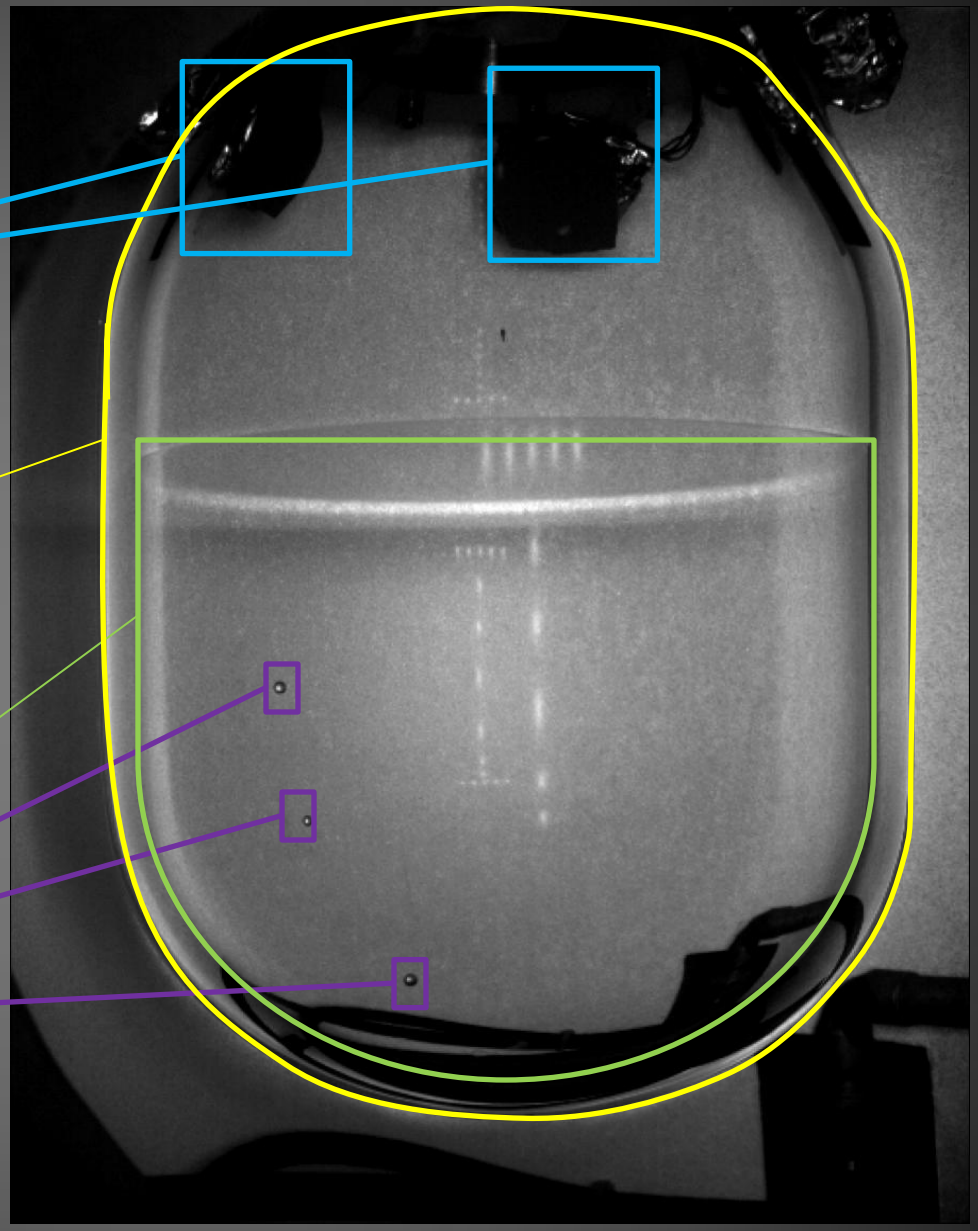
On behalf of the COUPP collaboration

Acknowledgements

- Professor Ilan Levine (http://mypage.iu.edu/~ilevine/) - mentor
- The COUPP collaboration (http://www.coupp.fnal.gov/)
- Mr. Edward Behnke, Mr. Adam Behnke, Mr. Cale Harnish, and Mr. Thomas Nania – advice, help in lab
- Indiana University South Bend – lab and equipment

COUPP Dark Matter Detector

- Acoustic transducers
- Glass bubble chamber
- Superheated CF_3I
- Bubbles



N.d. Fermilab Center for Particle Astrophysics. Web. 23 Feb 2013. <http://astro.fnal.gov/projects/DarkMatter/coupp.html>

Excess Noise

- Background radiation = unwanted bubbles
  - External neutron radiation
  - Cosmic rays
  - External alpha radiation
  - Neutron radiation from sensor's alpha emissions
    - not blocked

Blocked by location

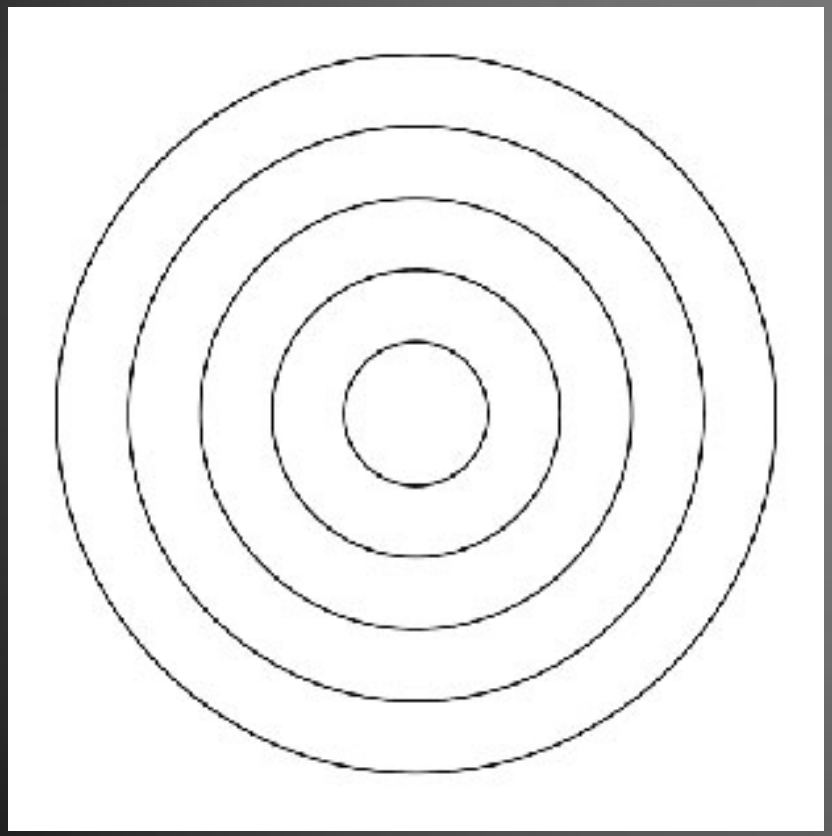
Problem

- Can’t remove acoustic sensors
  - Needed for discrimination

- Solution: Greater sensitivity = fewer sensors = decrease in background noise

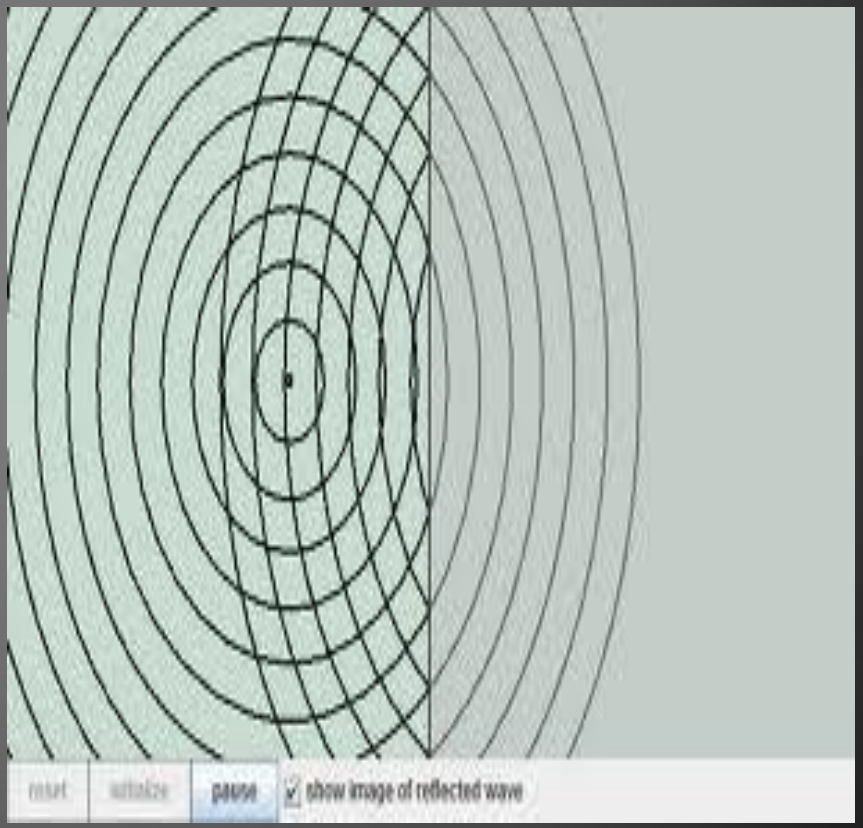
Sound Waves

Unimpeded Wave



Concentric Circles. 2013. bon appetit. Web. 23 Feb 2013. <http://www.bonappetit.com/tipstools/tips/2008/10/concentric_circles>.

Impeded Wave



Hwang, Fu-Kwun. *reflection of a point source wave from a wall*. N.d. NTNUJAVA Virtual Physics LaboratoryWeb. 23 Feb 2013.

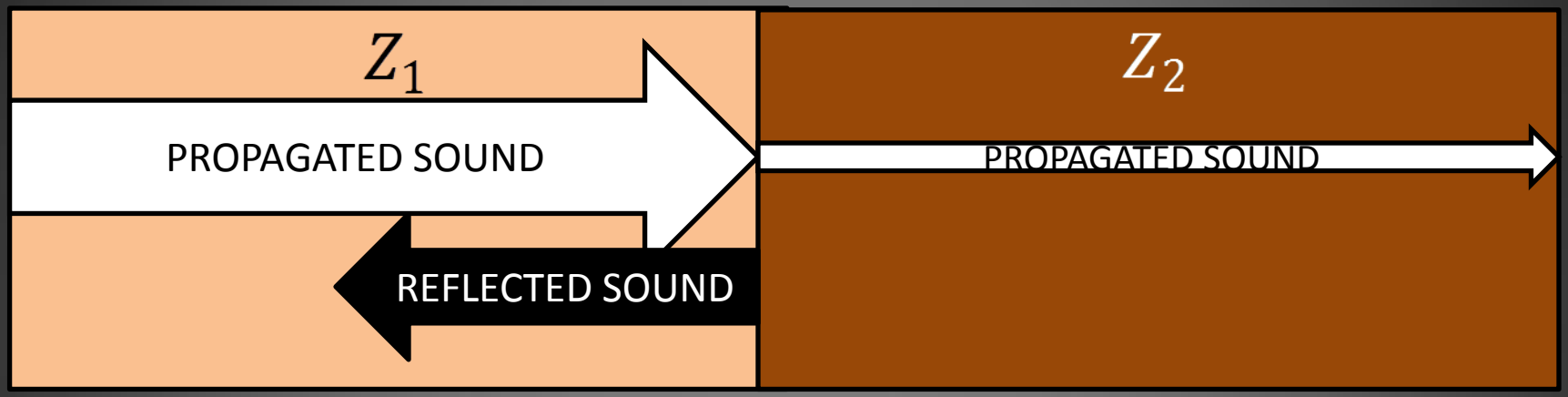
Reflection

- % Reflection: $R = \left(\frac{z_2 - z_1}{z_2 + z_1}\right)^2$

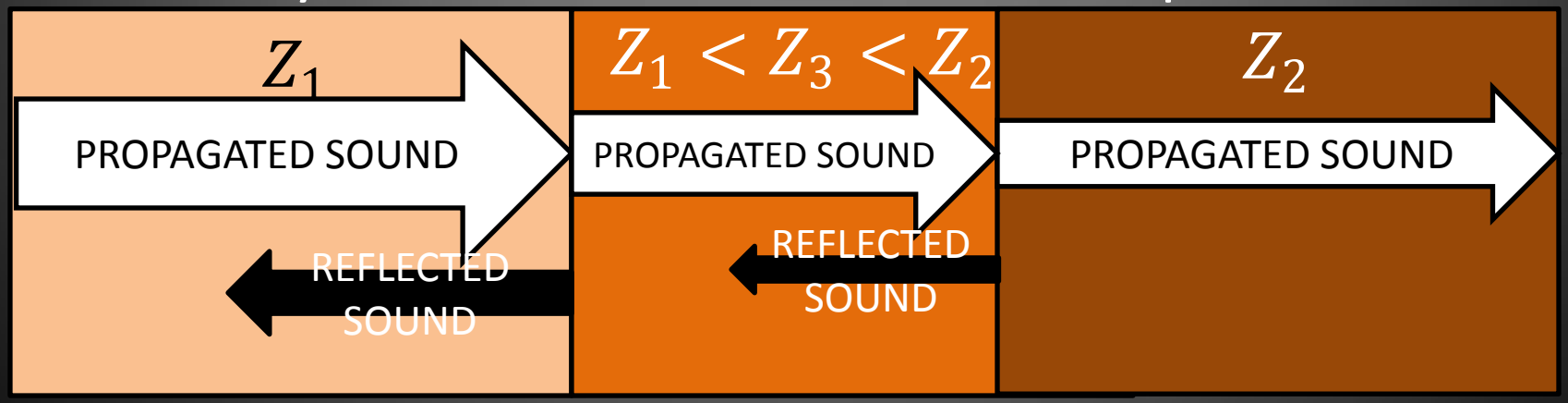
- Z = acoustic impedance = density * speed of sound
  - Rayl = $\frac{kg}{m^2 * s}$; Mrayl = $10^6 Rayl$
- Decrease acoustic impedance mismatch → decrease percent reflection

Matching Layer

- Without layer of intermediate acoustic impedance



- With layer of intermediate acoustic impedance



A Way to Improve COUPP Sensors

- Glass jar = fused silica quartz

$$Z = 13.156 \text{ MRayl}$$

- Acoustic sensor exterior = PZT made by Virginia Tech

$$Z = 18 \text{ MRayl}$$

Acoustic impedance mismatch → matching layer!

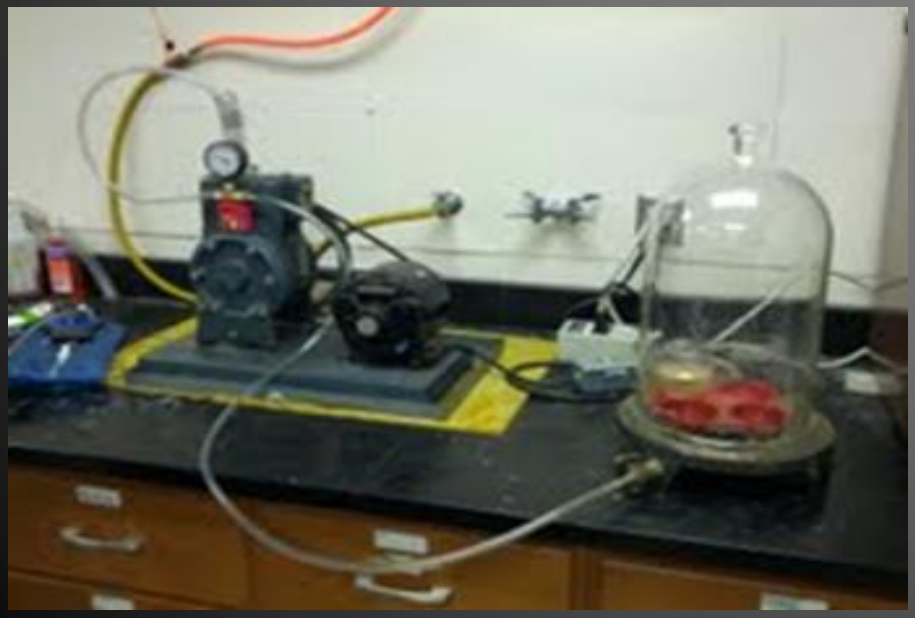
Simulate in Lab

- Glass: 8.26 MRayl
- pz-27 transducer: 23.5 MRayl

- Optimal matching layer: 13.9 MRayl

Making Samples

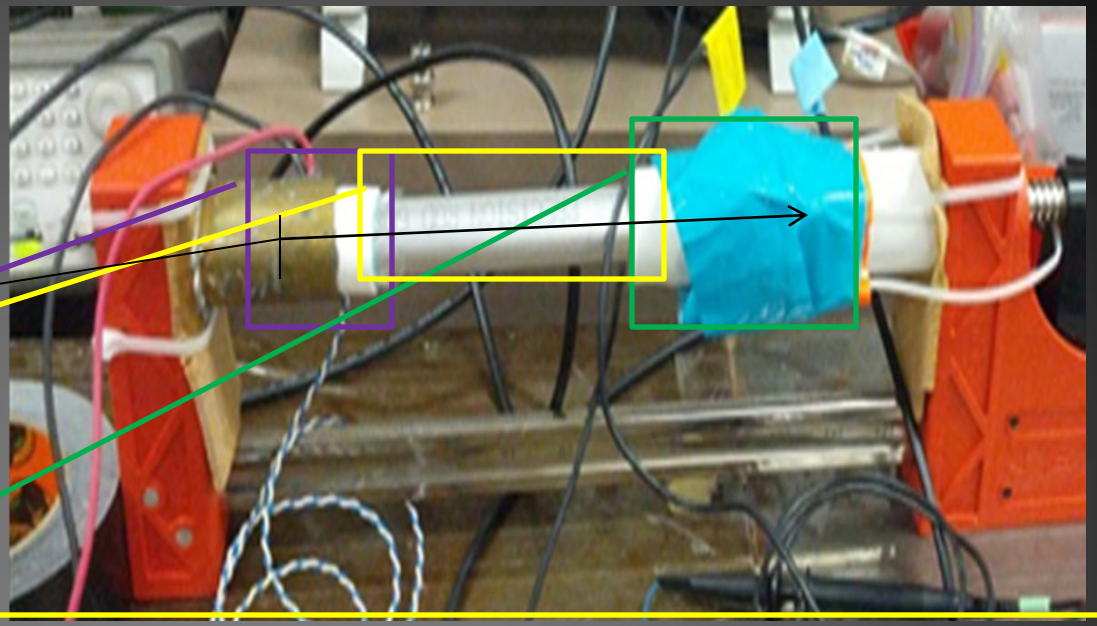
- Various proportions of tungsten carbide powder to epoxy
- Remove air with bell jar evacuation chamber
- Rotate to keep tungsten carbide powder from settling out



Measuring Acoustic Impedances

- Measure densities – scale and water displacement method
- Measure speed of sound – “Sono clamp”
  - First with aluminum sample (check)
- Acoustic impedance = density * speed of sound through sample

The “Sono Clamp”

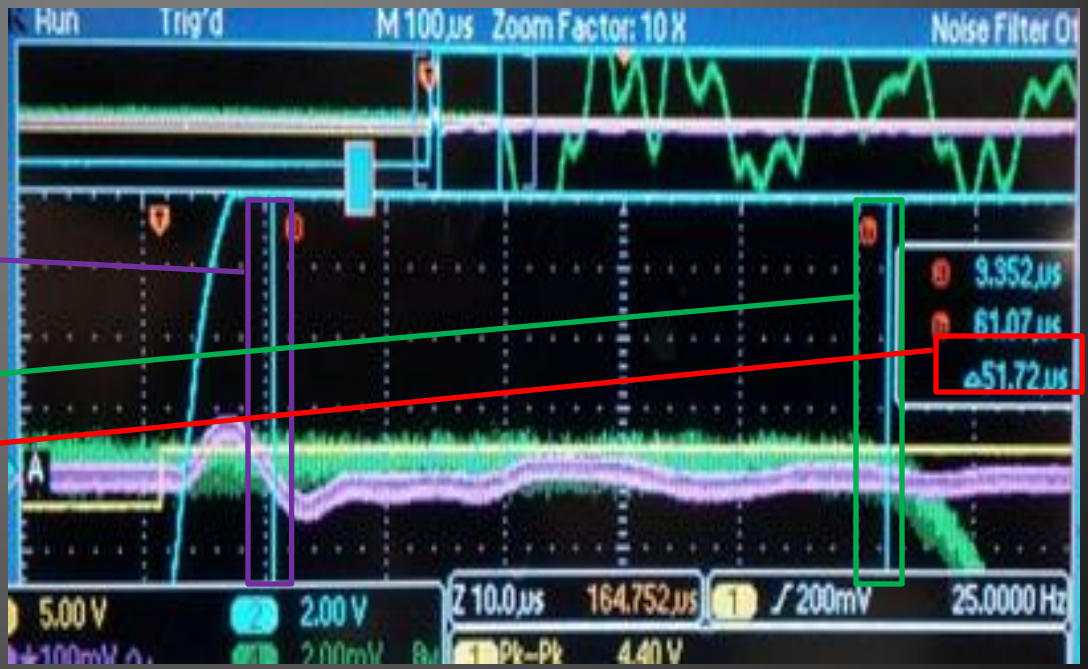


Pulse-emitting transducer

Pulse

Sample

Pulse-receiving transducer



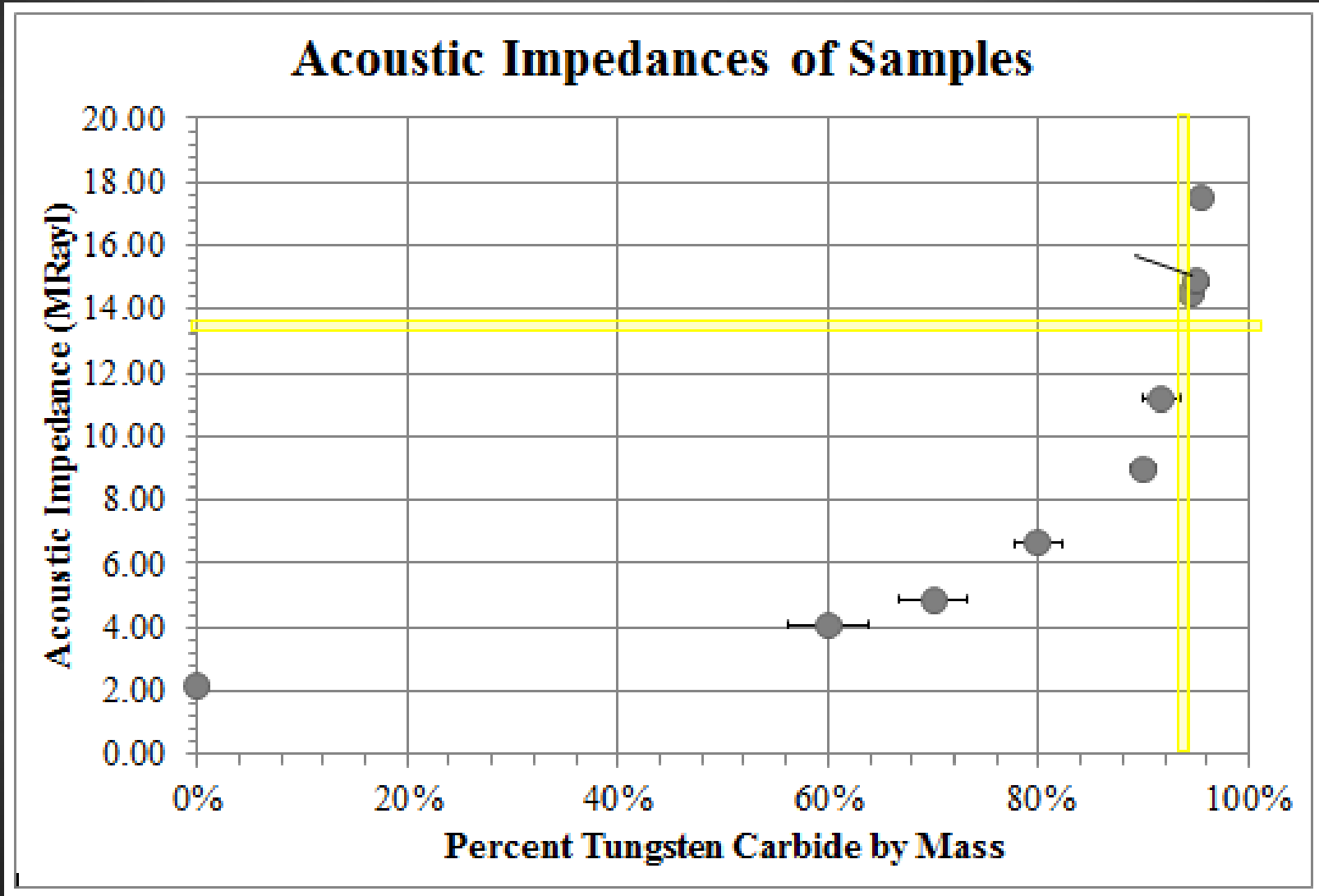
Oscilloscope display

Pulse leaves pulse-emitting transducer

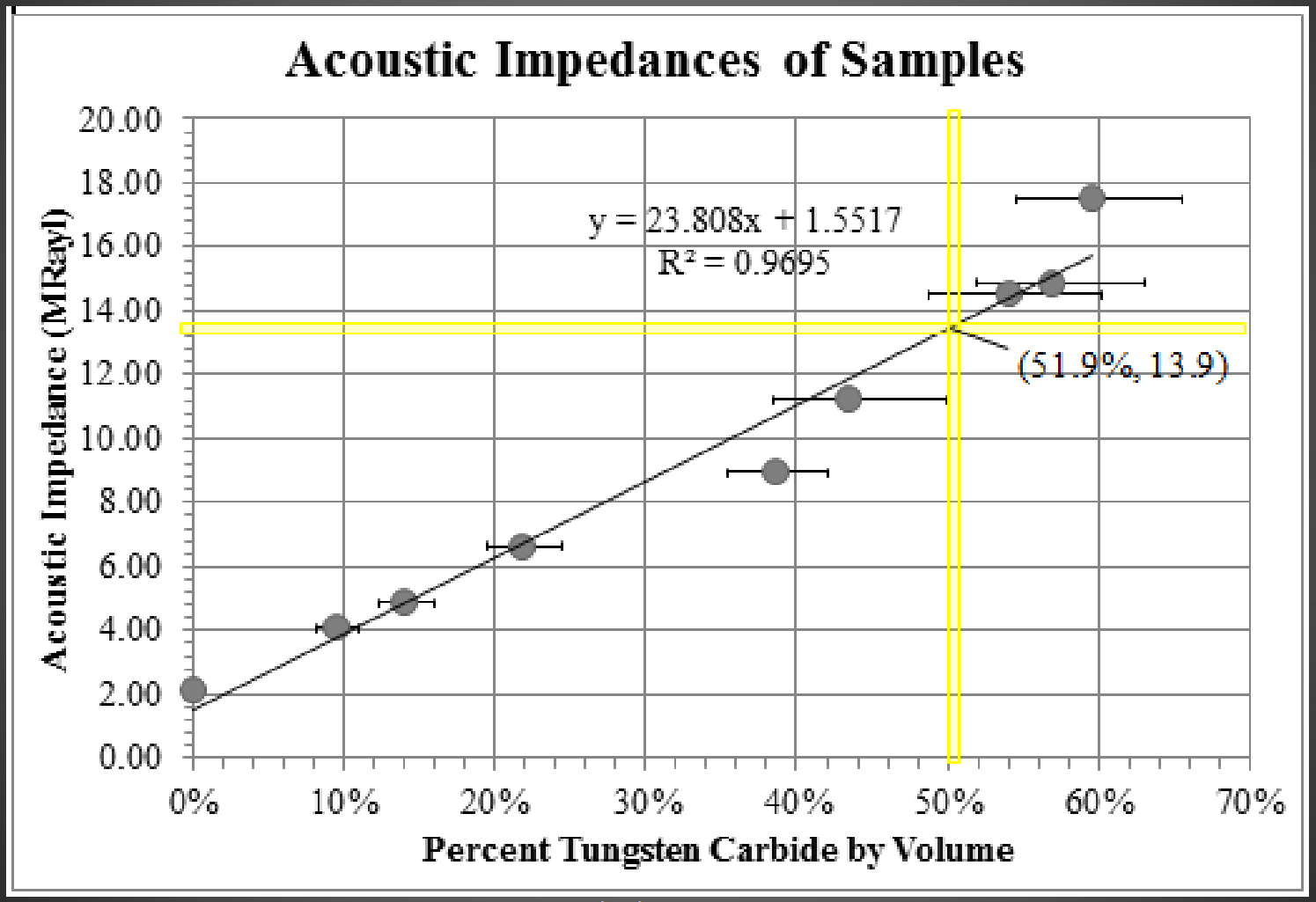
Pulse received by pulse-receiving transducer

Pulse transit time

Sample Data


Acoustic Impedances of Samples
Acoustic Impedance (MRayl)
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0%
20%
40%
60%
80%
100%
Percent Tungsten Carbide by Mass

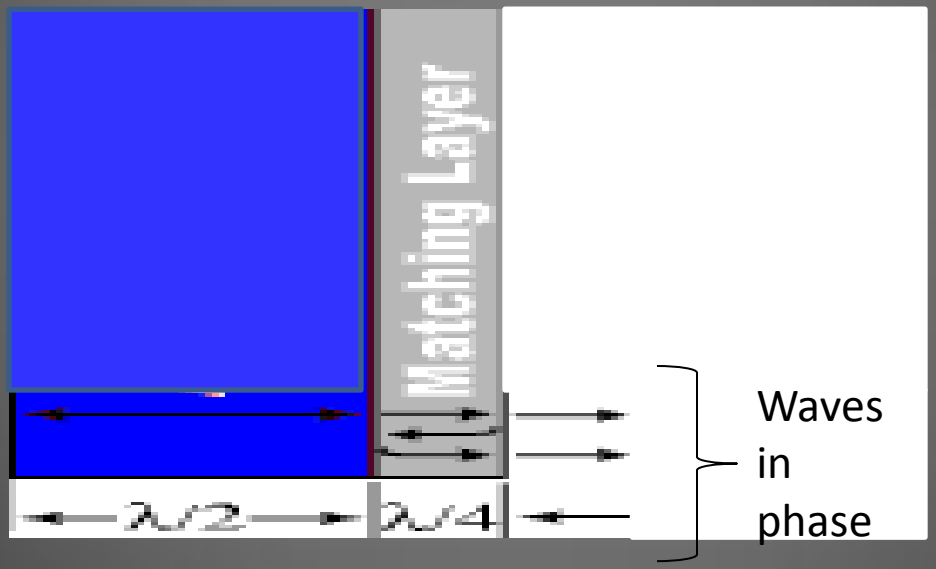
Sample Data



$$\chi_{TV} = \frac{1.1\chi_{TM}}{15.8 - 14.7\chi_{TM}}$$

Layer Thickness

Wafer must correctly couple to sensor (keep waves in phase)

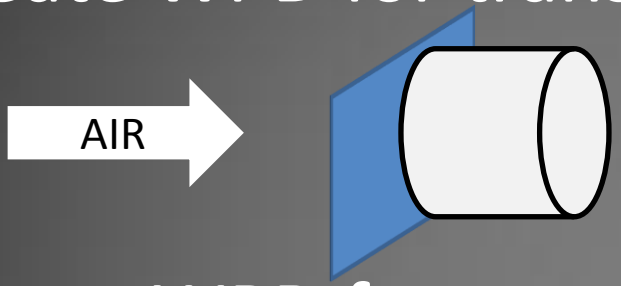


Thickness = 3.2mm

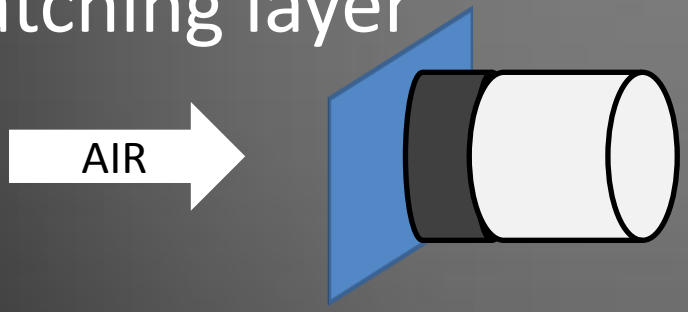
$$\frac{\lambda}{4} = \frac{1}{4} * \frac{speed\ of\ sound\ through\ sample}{resonant\ frequency\ of\ transducer}$$

Testing the Matching Layer

- Create WPD for transducer with glass only



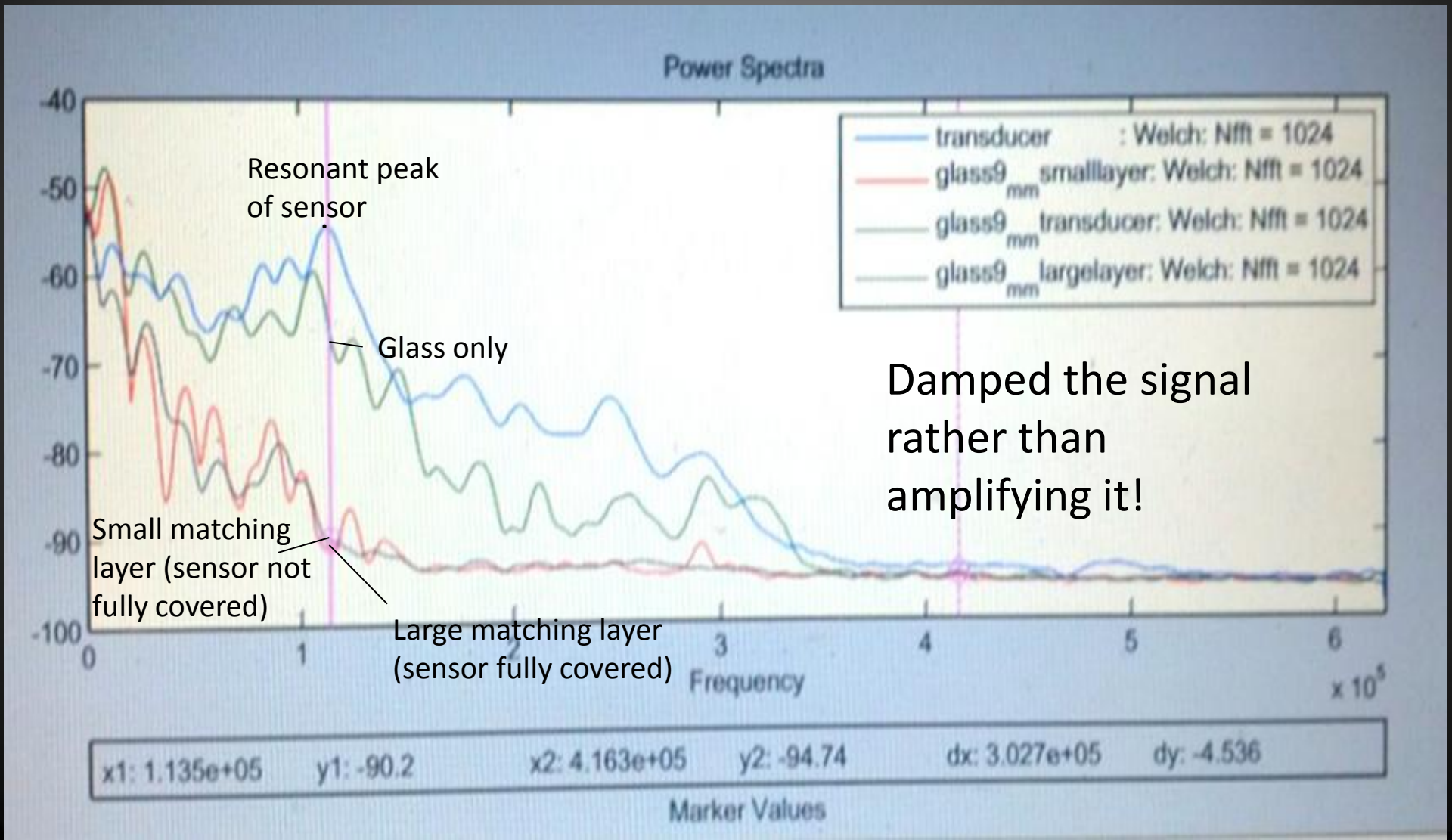
- Create WPD for transducer with glass and matching layer



- Compare WPDs

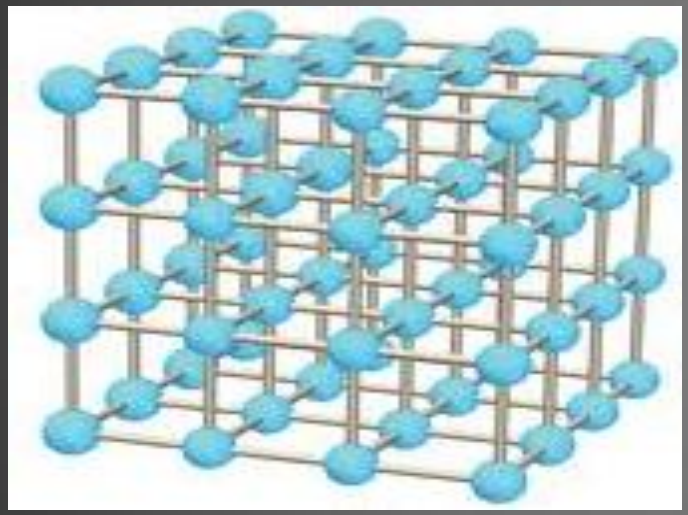
Results from 15 MRayl Layer

(13.9 Mrayl layer still needs to be tested)



Possible Explanation

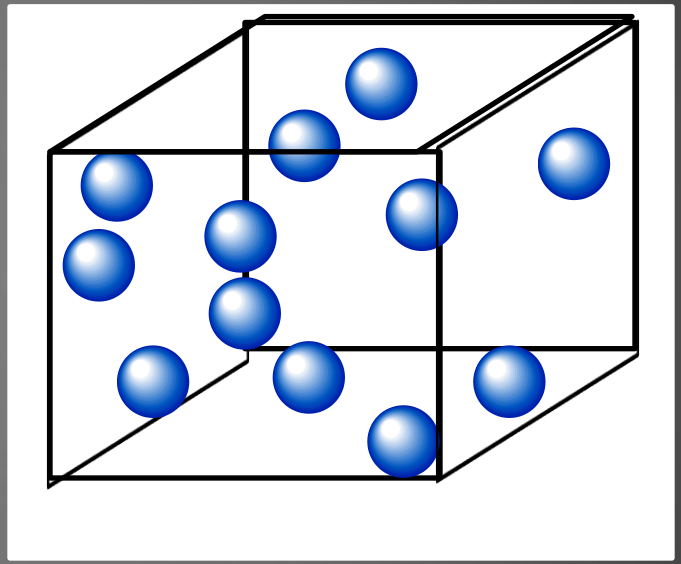
Lattice (Structured)



N.d. University of Maine. Web. 24 Feb 2013. <http://chemistry.umeche.maine.edu/~amar/spring2012/bur25542_1213.jpg>.

- No density fluctuations
- Speed of sound constant throughout
- Same wave speed

Mixture (Unstructured)



- Density fluctuations
- Speed of sound varies throughout
- Different speeds for different parts of wave

Conclusions/Future Action

- Tungsten powder/epoxy mixture may not be ideal for matching layer
- Need to test 13.9 MRayl layer
- Application as backing layer
  - Absorb sound energy → control vibration of sensor

Are there any questions?