Introduction

- Espionage techniques, such as laser microphones, are dangerous to society and can be utilized to compromise private and valuable information.
- Laser microphones are surveillance devices that use projected laser beams to detect sound (Fig. 1 and 2).

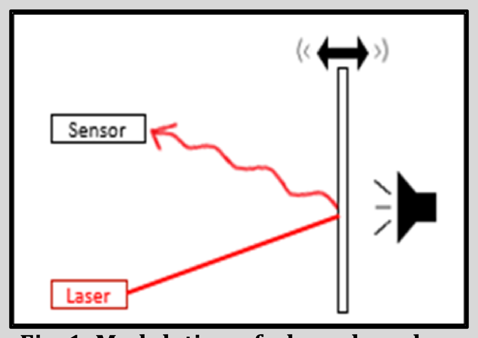

Fig. 1: Modulation of a laser based on vibrations of a window due to sound

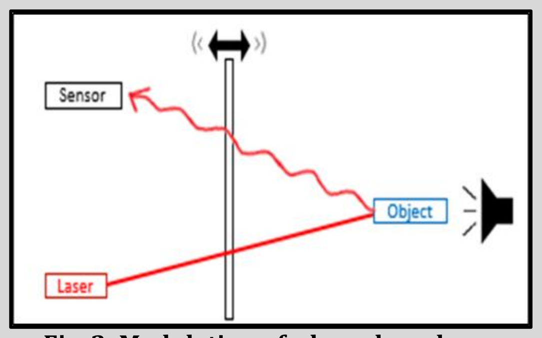

Fig. 2: Modulation of a laser based on vibrations of an inside object due to sound

- Windows and objects vibrate according to the sound waves in a room. The differences in amount of light, according to the displacement of the laser by sound waves, can be converted back to sound waves to eavesdrop (Wang et. al., 2009).
- The KGB, the main security agency for the Soviet Union used laser microphone to spy on British, French, and US embassies in Moscow (Graham 2008).
- A British intelligence agency feared that if Russian or Chinese agents were unsuccessful in penetrating computer systems, they might try to listen to discussions with a laser microphone (Bryant 2013).
- One countermeasure involves adding noise to the window vibrations, leaving the window vibrations as an inaccurate representation of the voices in a room, however the noise can be filtered out (http://www.spyville.com/laser-mic-surveillance-defeater.html). Additionally the instrumentation would be visible to the perpetrator and is also expensive.
- Previous research has achieved methods of reducing viability of a modulated laser signal through transparent irregular surfaces while maintaining light transmittance (Shah 2016) (Shah 2017). However, the signal used to modulate the laser was a simple sine wave signal. Whereas the research did show an ability to scatter the laser, no attempt was made to translate those results into speech intelligibility.
- **Goal: Quantifying the ability of irregular transparent treatments to mask reflected modulated laser signals carrying human speech while ensuring good image quality.**

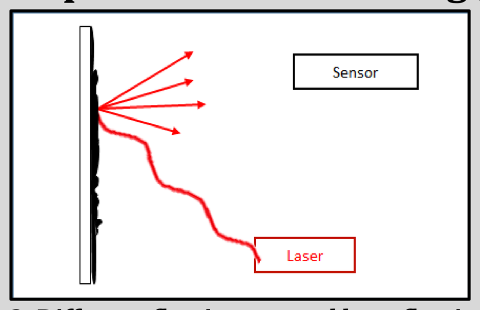

Fig. 3: Diffuse reflection created by reflecting a modulated laser off an irregular surface

Methods

Table 1: Composition of treatments on plastic microscope cover slips

Treatment	Method of Composition
Polydimethylsiloxane	A cover slip coated with a thin layer of polydimethylsiloxane.
Silica Nanoparticle-Epoxy Resin (Dense)	A cover slip coated with proportional amounts of silica nanoparticles and epoxy resin.
Silica Nanoparticle-Epoxy Resin (Sparse)	
Silica Nanoparticle-Dimethylsiloxane (Dense)	A cover slip coated with proportional amounts of silica nanoparticles and dimethylsiloxane.
Silica Nanoparticle-Dimethylsiloxane (Sparse)	
Dimethylsiloxane	A cover slip coated with dimethylsiloxane.

Phase I

A Class II red laser (635nm), modulated by a recording of human speech was reflected off glass slides treated with materials that facilitated diffuse reflection. A photovoltaic cell (PV) receiver and amplifier demodulated and replayed the voice signal allowing for speech recognition software to detect and recognize spoken words to test signal viability. The voice signal was also visualized by graphing the reflected modulated laser signal on a data logger.

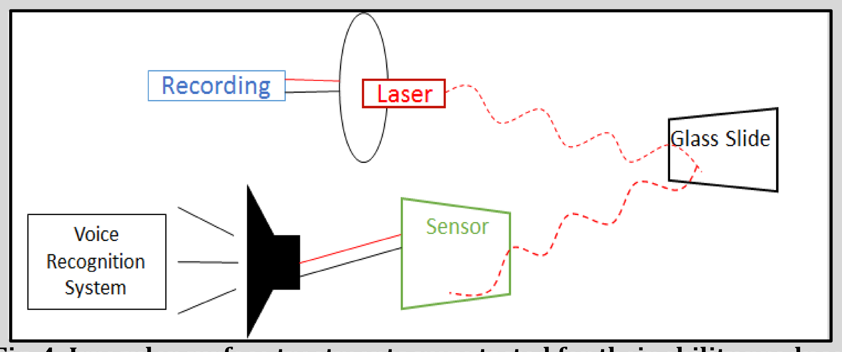

Fig. 4: Irregular surface treatments were tested for their ability produce poor intelligibility of a speech signal (a recording of 200 words).

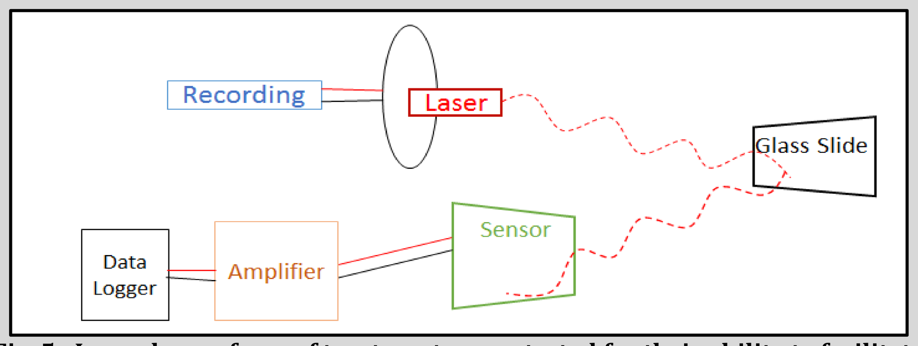

Fig. 5: Irregular surfaces of treatments were tested for their ability to facilitate disruption of a speech (recording of 3 words) modulated laser signal.

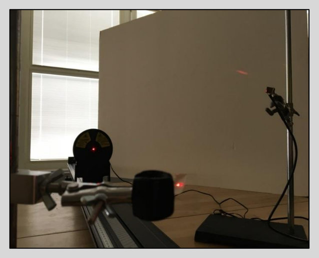
Fig. 6: Alignment of laser with treatment and PV.

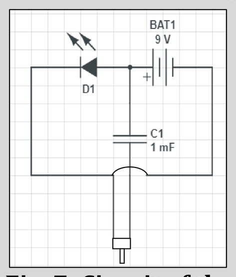
Fig. 7: Circuit of the modulated laser.

Methods

Phase II

A red laser was reflected off a window pane to more accurately simulate the laser microphone. The irregular surface treatments were tested for their ability to thwart a sine wave signal and speech signal. The red laser was reflected off a window pane vibrating according to the output of a speaker emitting a 100Hz frequency or voice signal. The reflection of the laser was directed through a spatial filter and PV into a data logger.

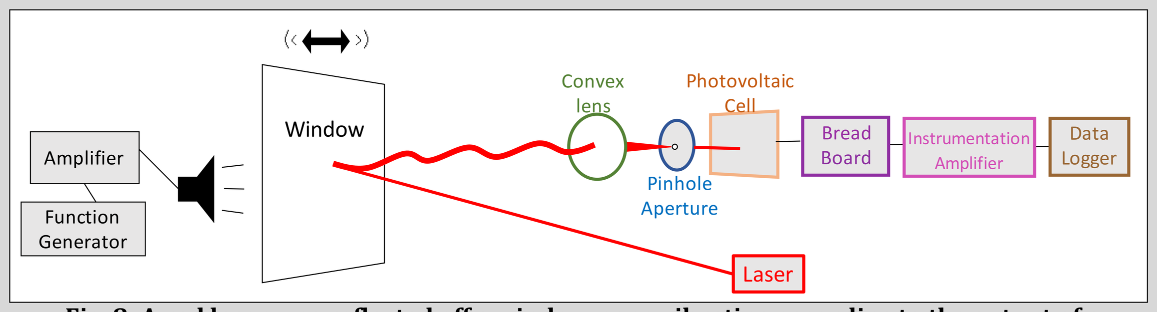

Fig. 8: A red laser was reflected off a window pane vibrating according to the output of a speaker emitting a 100Hz frequency from a function generator. The reflection of the laser was directed through a spatial filter (convex lens and pinhole), PV, and an amplifying mechanism (Fig. 11) into a data logger.

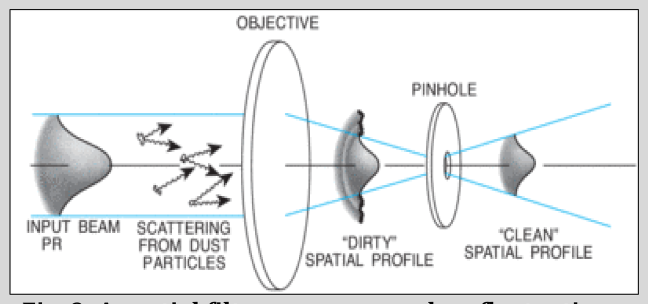

Fig. 9: A spatial filter removes random fluctuations (noise) from the intensity curve of a laser. The lens refocus the laser and pinhole blocks most noise.

Source: https://www.newport.com/medias/sys_master/images/images/hcc/hb4/8796836359198/SPATIALF-S-600w.gif


Fig. 10: Alignment of spatial filter with PV

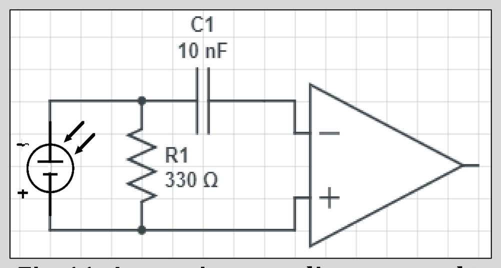

Fig. 11: A capacitor coupling was used to prevent the DC signal from affecting the original signal and an instrumentation amplifier to maximize the output.

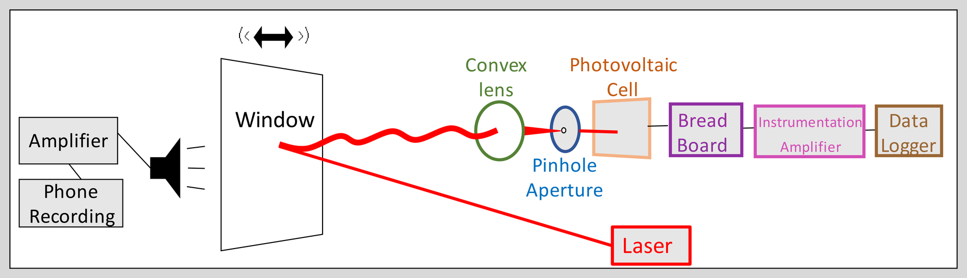

Fig. 12: A red laser was reflected off a window pane vibrating according to the output of a speaker emitting a voice signal from a phone recording. The reflection of the laser was directed through a spatial filter, PV, and an amplifying mechanism (Fig. 11) into a data logger.


Fig. 13: Speaker vibrating window pane


Fig. 14: Actual experimental set up of figure 8.

Phase III

- A word was printed out on paper and photographs were taken through each treatment at various distances.
- Light was transmitted at different wavelengths through untreated or treated cover slips and the transmission intensity and wavelength were analyzed spectrophotometrically.

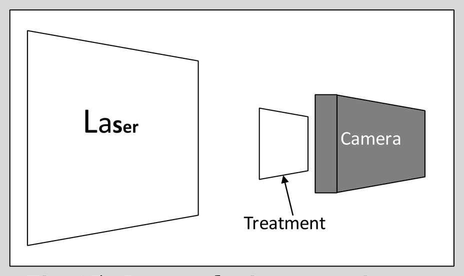

Fig. 15: Image clarity test using a camera to take pictures of the word "Laser" through each treatment at varying distances.

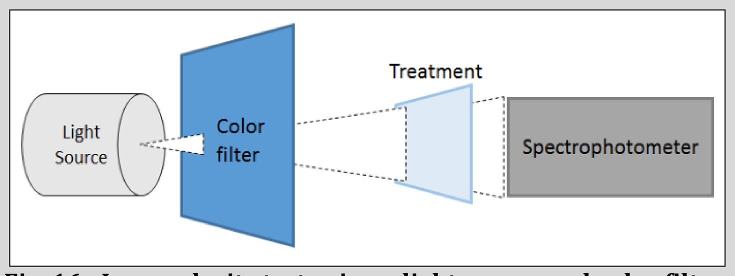

Fig. 16: Image clarity test using a light source and color filters to transmit different wavelengths (red, blue, green) through each treatment into a spectrophotometer and a data logger.

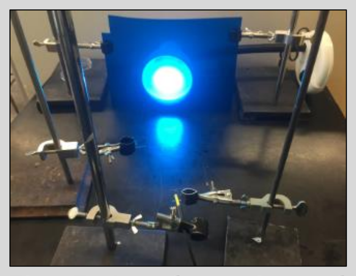
Fig. 17: Actual experimental setup of figure 16.

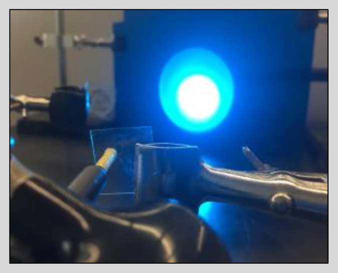
Fig. 18: Trial setup with light source, fiber optic cable, and treatments.

Discussion

Phase I

While epoxy resin surface treatments weakened the modulated laser signal, polydimethylsiloxane and all dimethylsiloxane treatments most effectively thwarted the modulated laser signal, allowing for poor speech intelligibility. Graphs of weakened signals demonstrated similar results: epoxy resin treatments shared attributes and recognizable patterns with the control graphs, whereas dimethylsiloxane and polydimethylsiloxane left the original signal indistinguishable and were constituted of random noise.

Phase II

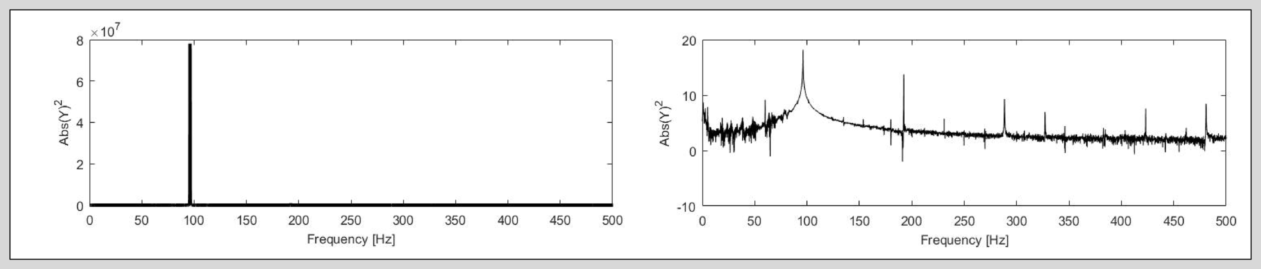
Fig. 34: FFT (left) and semilog of FFT (right) for control sine wave signal at 100Hz. The peak at 100 Hz in both graphs indicates that 100 Hz is the only prominent frequency in the signal. The semilog depicts that other noise was present but the 100Hz frequency overshadowed any noise.

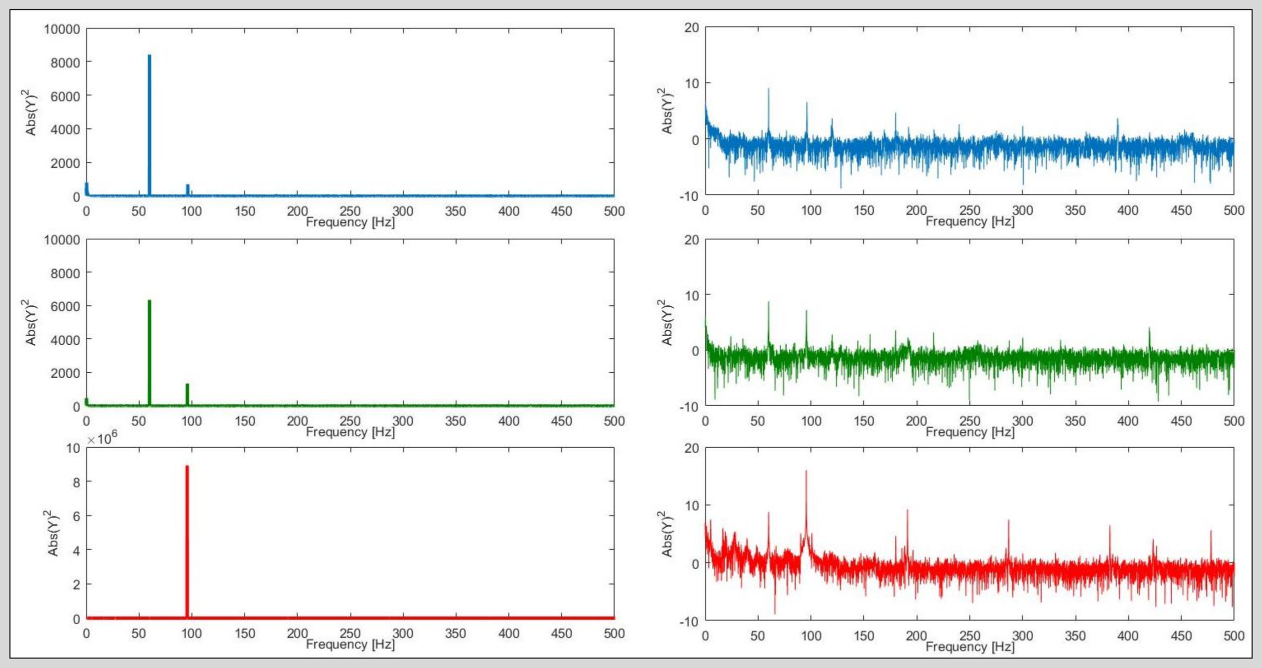
Fig. 35: FFT and semilogs in rows of polydimethylsiloxane (top), dimethylsiloxane sparse (middle), and epoxy resin dense (bottom) for sine wave signal of 100Hz. For polydimethylsiloxane and dimethylsiloxane the most prominent peak is 60 Hz located at a comparably drastically low power; the semilogs depict introduction of more noise. The epoxy resin dense has a high peak at 100 Hz and minimal introduction of noise, especially near 100Hz.

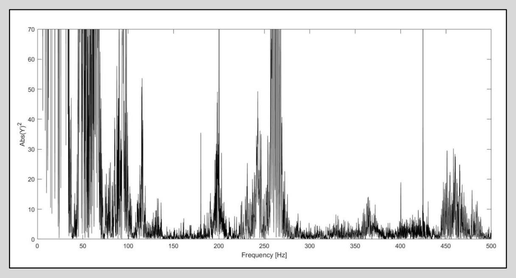
Fig. 36: FFT of control speech signal. There is a wide spectrum of frequencies in speech which is depicted in the graph. Noise is also present, especially at lower frequencies.

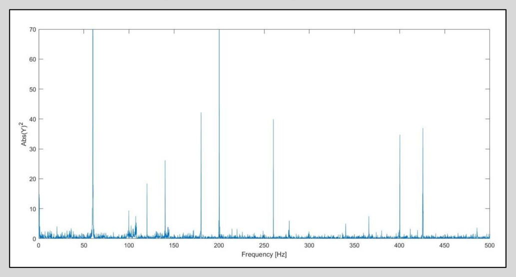
Fig. 37: FFT of speech signal thwarted by polydimethylsiloxane. Intensities were reduced considerably. The taller peaks are due to noise present in the room during experimentation.

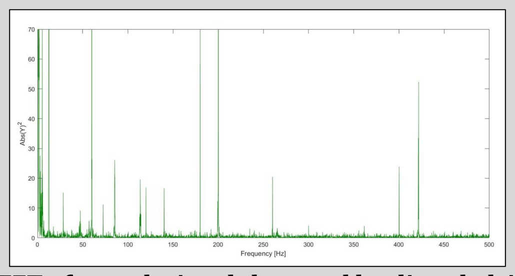
Fig. 38: FFT of speech signal thwarted by dimethylsiloxane sparse. Intensities were reduced considerably. The taller peaks are due to noise present in the room and are present at similar frequencies in all FFTs.

The polydimethylsiloxane and all dimethylsiloxane treatments reduced the signal to a bare minimum and masked the original signal with introduction of noise. The epoxy resin treatments were unable to thwart the signal, allowing for a small reduction in power but still maintaining most of the original the signal.

Phase III

- All treatments other than polydimethylsiloxane had optimal image quality. The word "laser" was legible at further distances for these treatments and their pixel luminosities were low, indicating lack of blurriness.
- There were minor percent differences between smooth and treated surfaces in terms of wavelengths. The greatest percent difference was less than 1% indicating that the treatments did not alter colors of the images viewed through them. Differences in intensities were also minor except for two outliers: polydimethylsiloxane and epoxy resin dense with major decreases in green and blue wavelength intensities respectively.
- Overall all treatments other than polydimethylsiloxane had acceptable image quality.

- All treatments other than silica nanoparticle-epoxy resin dense and sparse effectively masked the original modulated laser signal in Phase I and Phase II experimentation.
- All treatments other than polydimethylsiloxane had outstanding image clarity in Phase III for both image clarity and transmission tests.
- Overall, dimethylsiloxane can be identified as the optimal treatment for thwarting a laser microphone signal with both effective disruption of signals and great image quality.
- This material can be incorporated into windows and mass manufactured to be utilized everywhere from corporate offices to the average household to government offices or intel rooms to allow for privacy and security.

Future Studies

- Explore how varying methods of applying materials to glass slides disrupt the signal.
- Investigate the minimum amount of treatment needed to distort a signal.

Results

Phase I

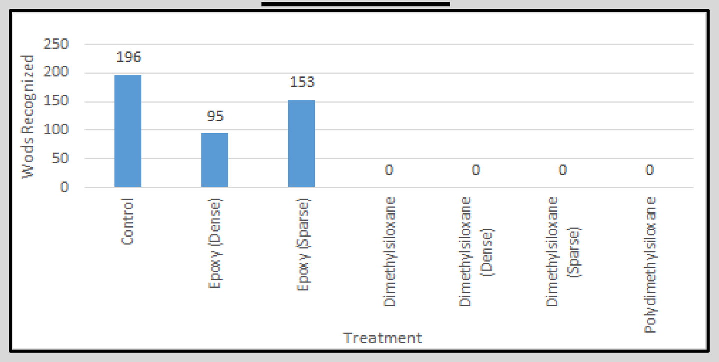

Fig. 19: Intelligibility of words for each treatment. 2 proportion Z test performed for each treatment (p<0.0001).

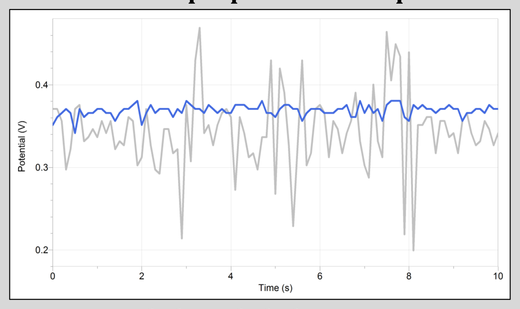
Fig. 20: Polydimethylsiloxane treatment signal (blue) vs control (gray).

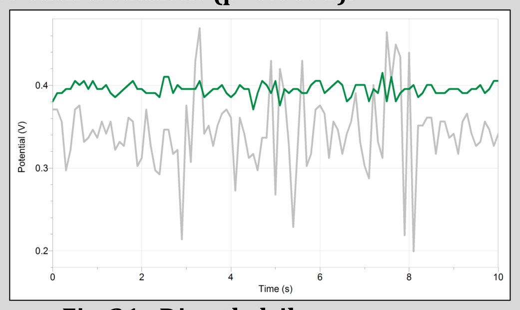
Fig. 21: Dimethylsiloxane sparse treatment signal (green) vs control (gray).

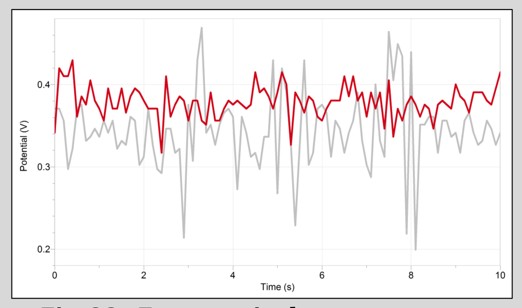
Fig. 22: Epoxy resin dense treatment signal (red) vs control (gray).

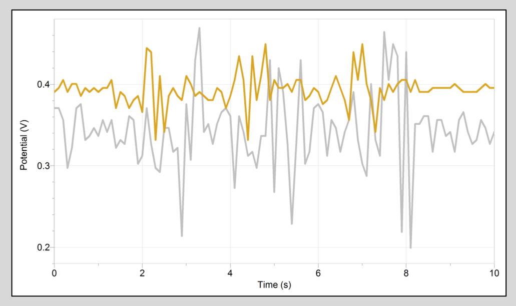
Fig. 23: Epoxy resin sparse treatment signal (yellow) vs control (gray).

Phase II

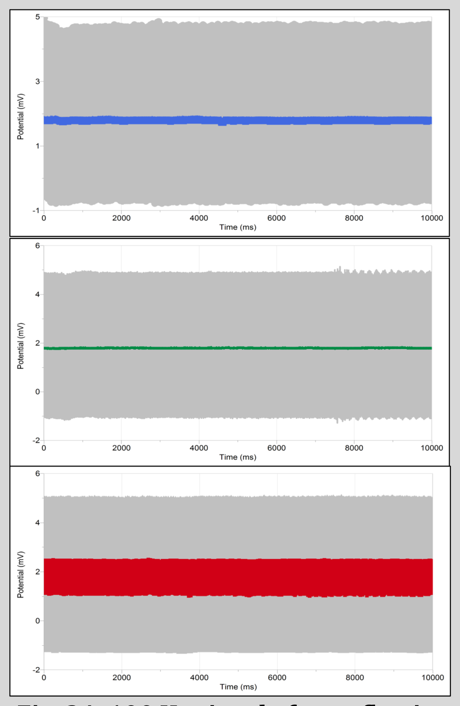
Fig. 24: 100 Hz signal after reflection off of polydimethylsiloxane (top), dimethylsiloxane sparse (middle), epoxy resin dense (bottom) treatments compared to control (gray).

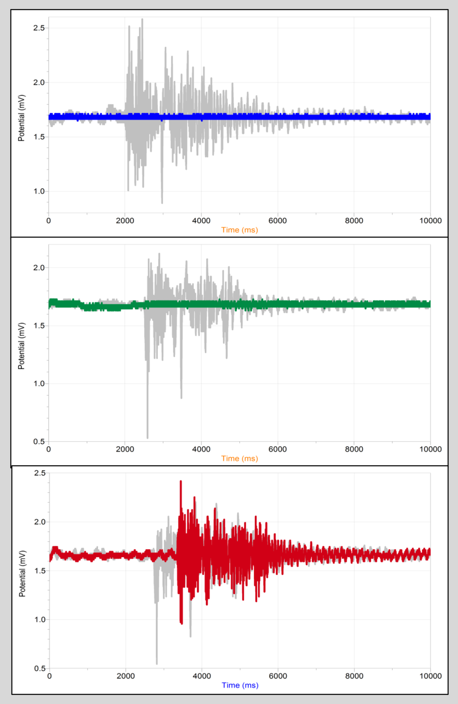
Fig. 25: Speech signal after reflection off polydimethylsiloxane (top), dimethylsiloxane sparse (middle), epoxy resin dense (bottom) treatments compared to control (gray).

Phase III


Fig. 26: Image quality through polydimethylsiloxane treatment at various distances.

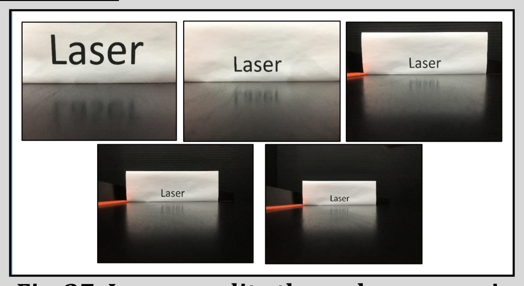
Fig. 27: Image quality through epoxy resin sparse treatment at various distances.

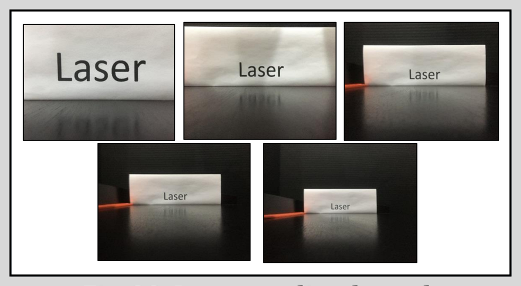
Fig. 28: Image quality through dimethylsiloxane sparse treatment at various distances.

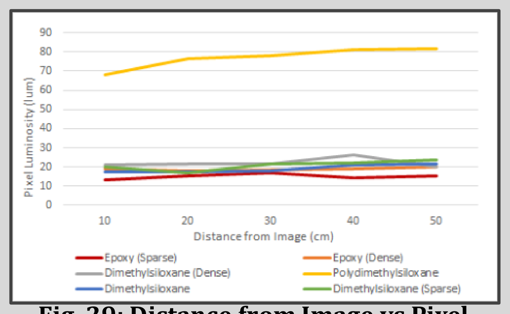
Fig. 29: Distance from Image vs Pixel Luminosities of Photographs; quantifying image quality through treatments.

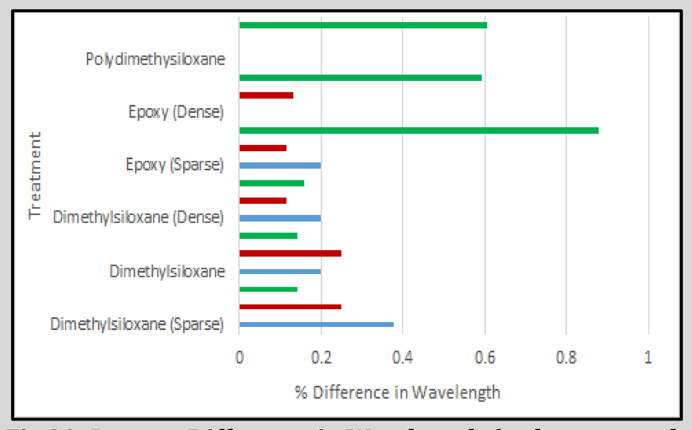

Fig 30: Percent Difference in Wavelength (red, green, and blue) vs Treatments

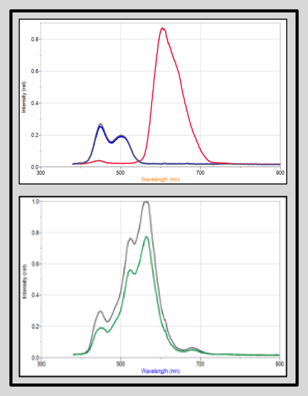
Fig 31: Wavelengths and intensity of colored light through polydimethylsiloxane

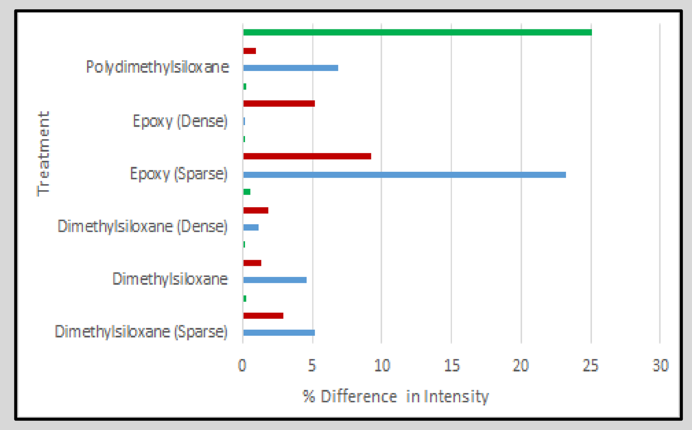

Fig 32: Percent Difference in Wavelength (red, green, and blue) Intensity vs Treatments

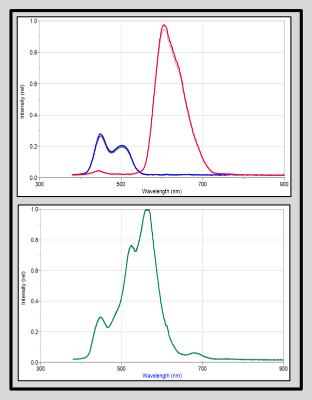
Fig 33: Wavelengths and intensity of colored light through dimethylsiloxane sparse

Literature Citations

Bryant, Chris. "Q&A: Laser Microphone Surveillance." *The World*. N.p., n.d. Web. 01 Mar. 2018. <http://blogs.ft.com/the-world/2013/08/qa-laser-microphone-surveillance/>.

Graham, Brad. "Build the LASER SPY DEVICE," 2008. *LucidScience*.

"Laser Mic Surveillance Defeater Laser Countermeasure Surveillance Protection Device." *Laser Mic Surveillance Defeater Laser Countermeasure Surveillance Protection Device*, 2017, www.spyville.com/laser-mic-surveillance-defeater.html.

Shah, Sharmi. "Transparent Irregular Surfaces as sound-Modulated Laser Transmittance Countermeasures." NJRSF Rutgers University, March 2016

Shah, Sharmi. "Analysis of Reflected Laser Signal Disruption via Transparent Irregular Surfaces." NJRSF Rutgers University, March 2017

"Technical Note: Spatial Filters." *Modular Integrating Spheres*, www.newport.com/n/spatial-filters.

Wang, Chen-Chia, Sudhir Trivedi, Feng Jin, V. Swaminathan, Ponciano Rodriguez, and Narasimha S. Prasad. "High Sensitivity Pulsed Laser Vibrometer and Its Application as a Laser Microphone." AIP Scitation. American Institute of Physics, n.d. Web. 6 Feb. 2018.<http://scitation.aip.org/content/aip/journal/apl/94/5/10.1063/1.3078520>.