Micron Scale Resolution of Structural Features in Mesoscale Material Systems using Laser Based Acoustic Microscopy

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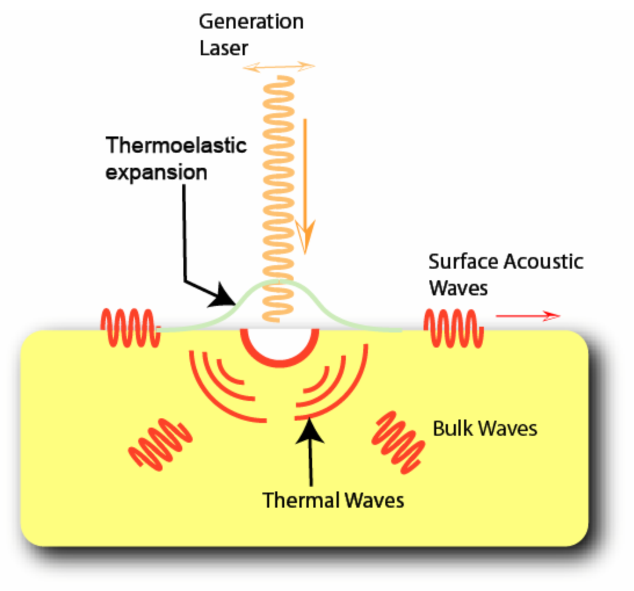
OUTLINE

- Laser Based Acoustic Microscopy: Background and Applications
- Motivation
- Experimental Setup and Preliminary Results
- Challenges – Measurement Constraints
- Conclusion

LASER BASED ACOUSTIC MICROSCOPY



- Pulsed or modulated CW laser illuminates the sample surface
- Absorption of incident light leads to local heating of the sample
- Thermoelastic expansion of the heat active region generates coherent acoustic waves
- Generated acoustic waves are detected by measuring the sample surface displacement or elastic strain using optical detection systems

Advantages of Laser Acoustic Microscopy over Conventional Acoustic Microscopy

- Non-contact, remote materials inspection
- Extremely high fidelity (generation and detection of acoustic waves over GHz bandwidth possible)
- High spatial resolution (important for the characterization of MEMS and nanoscale structures)
- Rapid scanning possible leading to reduced inspection time

Applications Include the Measurement of:

- Dimensional properties such as thickness or density of thin films and membranes
- Mechanical properties such as residual stress, elastic modulus, Poisson's ratio
- Micro- structural properties such as grain-size and texture
- Surface properties, surface defects, interface bond quality

Laser Sources used for Ultrasonic Wave Generation

GENERATION OF BROADBAND ULTRASONIC WAVES

- **Nanosecond sources: Q- switched lasers**

- **Femtosecond and picosecond sources: Microchip and Mode-locked lasers**

GENERATION OF NARROWBAND ULTRASONIC WAVES

- **Temporally modulated pulsed laser sources: Mode-locked or Q switched pulse trains, AO modulated Q switched lasers, Laser array sources**

OTHER:

- **Direct modulated CW laser: RF modulation, or Pseudo-random data sources**

Laser Based Acoustic Microscopy Systems

ULTRAHIGH FREQUENCY SYSTEMS –

- Applied routinely in the semiconductor industry
- Frequency range of ultrasound is in the hundreds of GHz range
- Spatial resolution is in the nanometer range

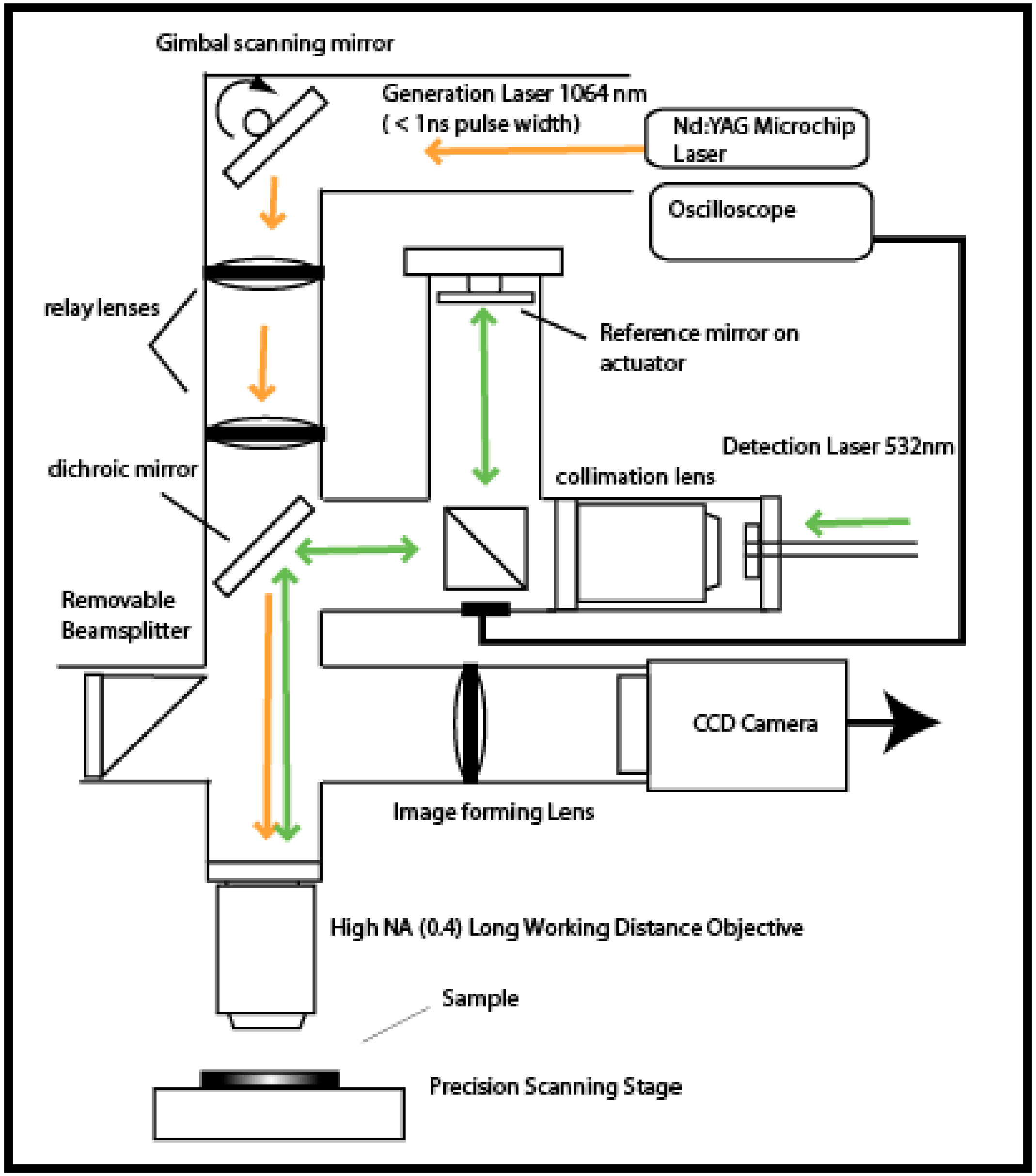
LOW FREQUENCY SYSTEMS -

- Applied in biological media, nondestructive evaluation, etc
- Frequency range of ultrasound is in the low MHz range
- Spatial resolution is in the millimeter range

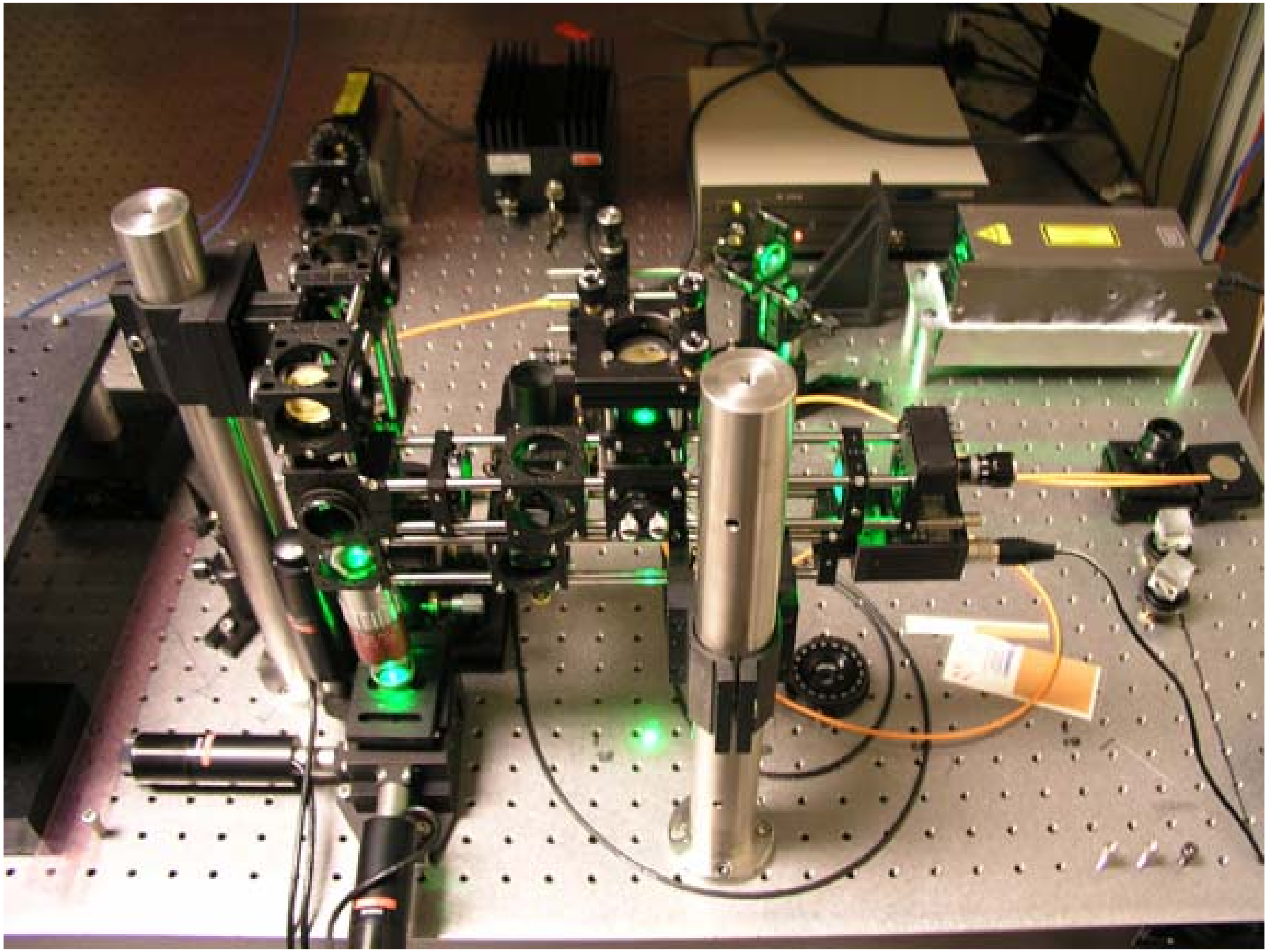
MID FREQUENCY SYSTEMS -

- To be applied in LLNL for the inspection of the NIF targets
- Frequency range of ultrasound is in the range of a few GHz
- Spatial resolution is in the micrometer range

EXPERIMENTAL SETUP

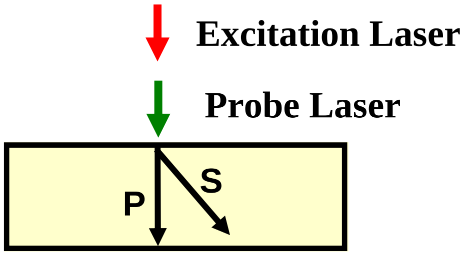


EXPERIMENTAL SETUP



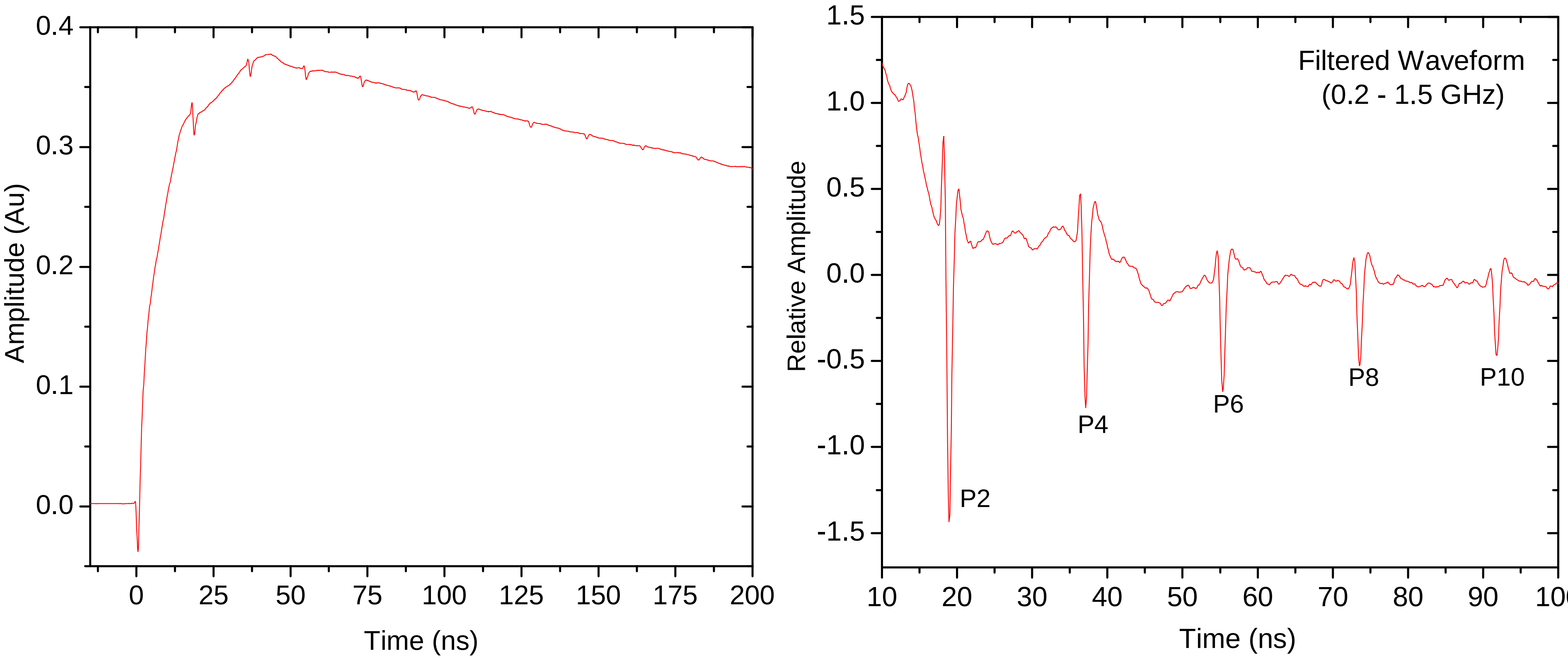
PRELIMINARY EXPERIMENTS

Generation and Detection of GHz Ultrasound



Gold foil – 25 μm thick

Measured Waveform



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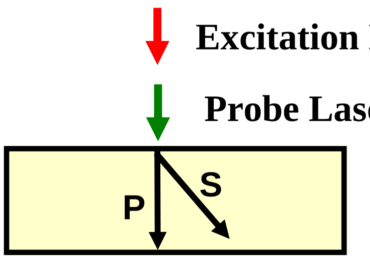

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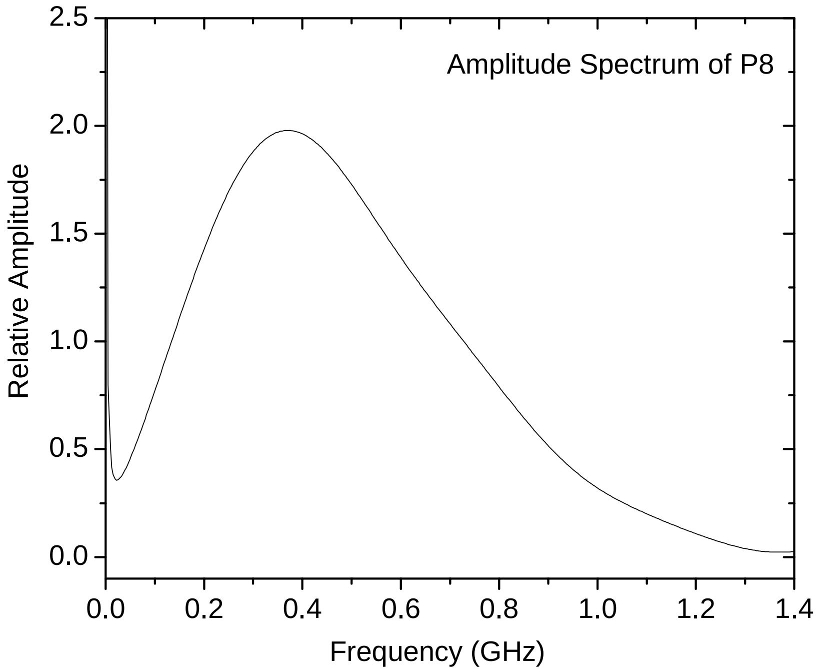
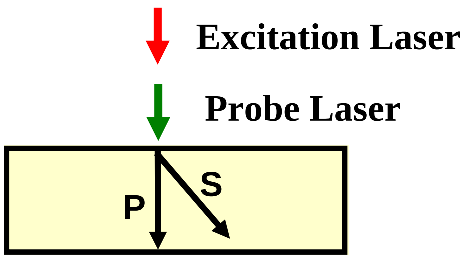


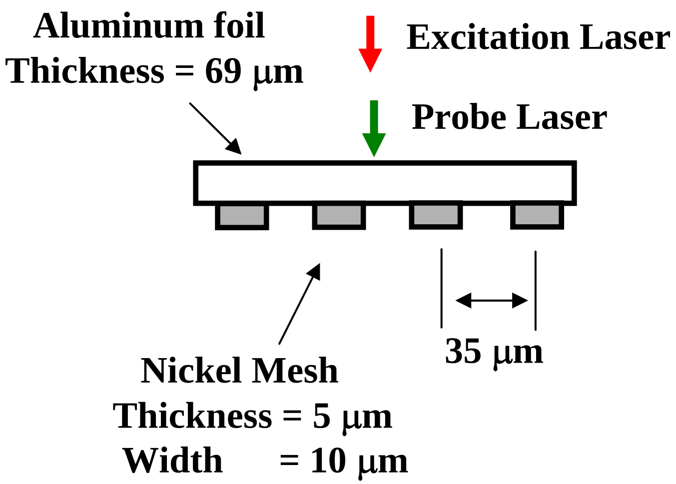


Metal foil
Thickness range: 25 – 127 μm

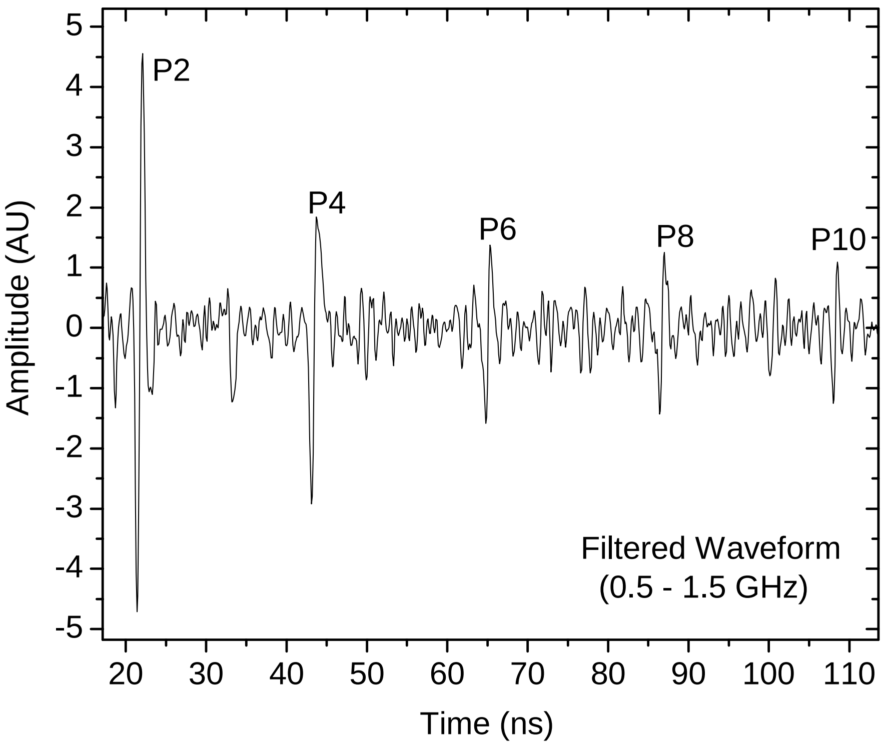
Metal Foils	Ultrasonic Attenuation
Gold	68 db/mm @ 1 GHz
Aluminum	25 db/mm @ 1 GHz
Vanadium	27 db/mm @ 1 GHz
Tantalum	50 db/mm @ 0.5 GHz

PRELIMINARY EXPERIMENTS

Imaging of Sub-Surface Features



Measured Waveform



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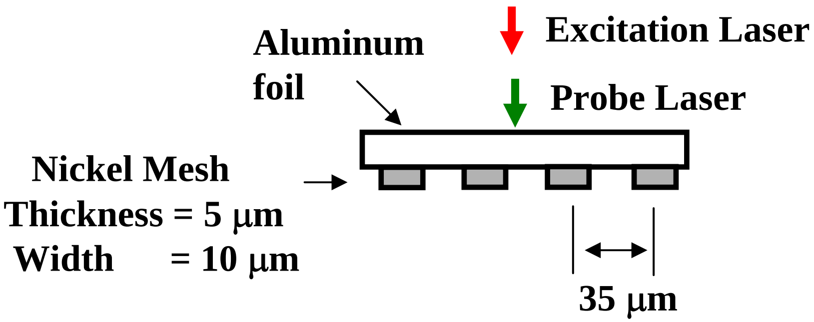
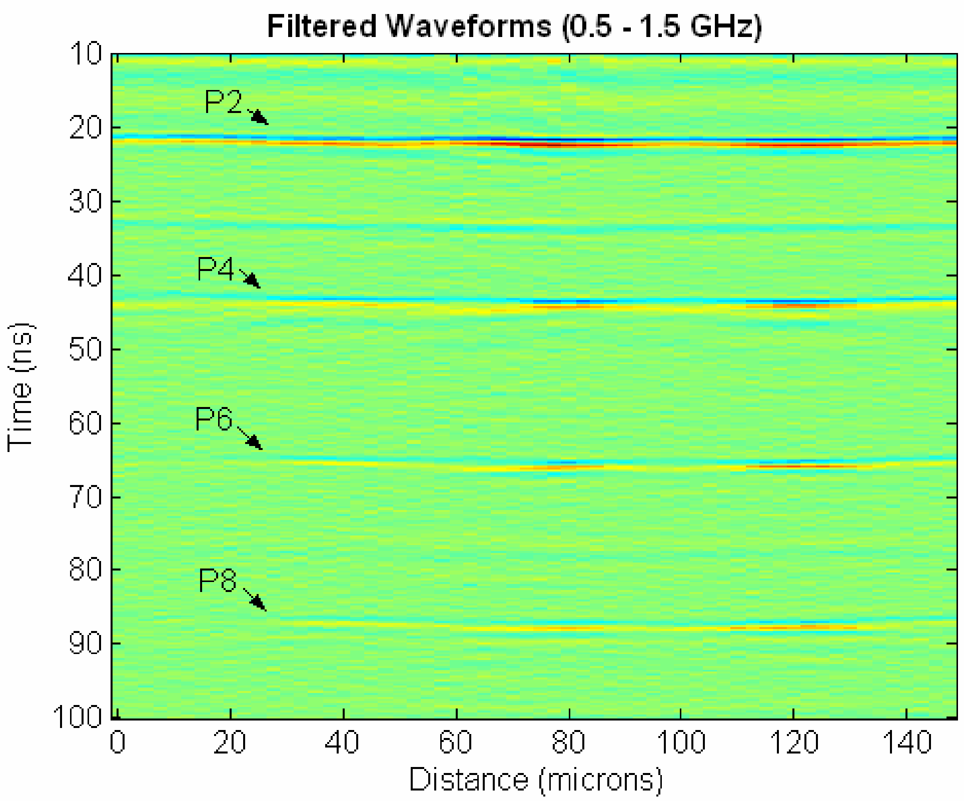
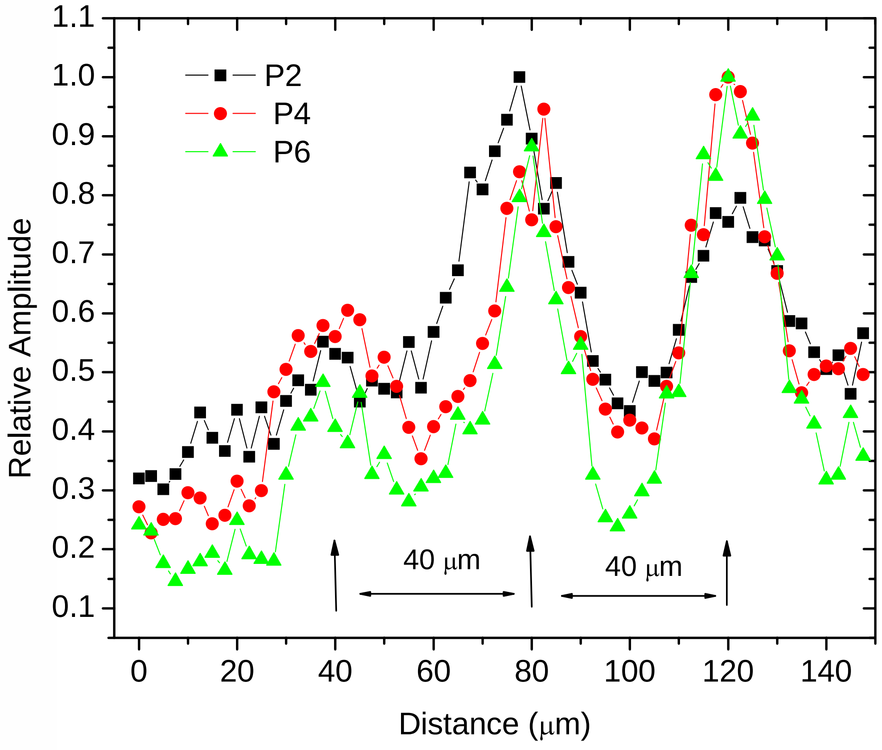


A- Scan Image



Amplitude Variation



CURRENT CHALLENGES

SIGNAL TO NOISE RATIO OF THE OPTICAL DETECTION SYSTEM

Noise Sources: Thermal noise, shot noise, etc (Wagner and Spicer, J. Opt. Sc. Am B 4(8), 1316, 1997, Wagner, *Physical Acoustics*)

Shot Noise Limited SNR: $SNR \; \alpha \; \frac{\delta}{\sqrt{B}}$

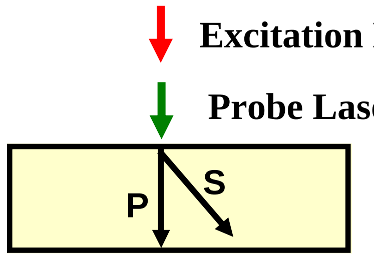
δ = Ultrasonic wave amplitude

B = Bandwidth of the detection system

CURRENT CHALLENGES

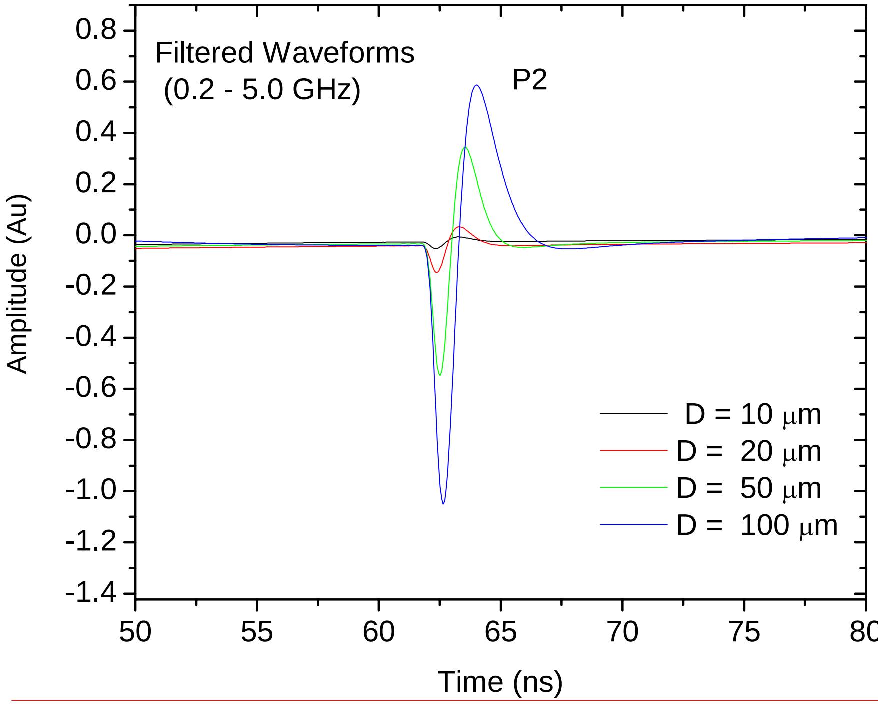
Ultrasonic Wave Amplitude - Limited by:

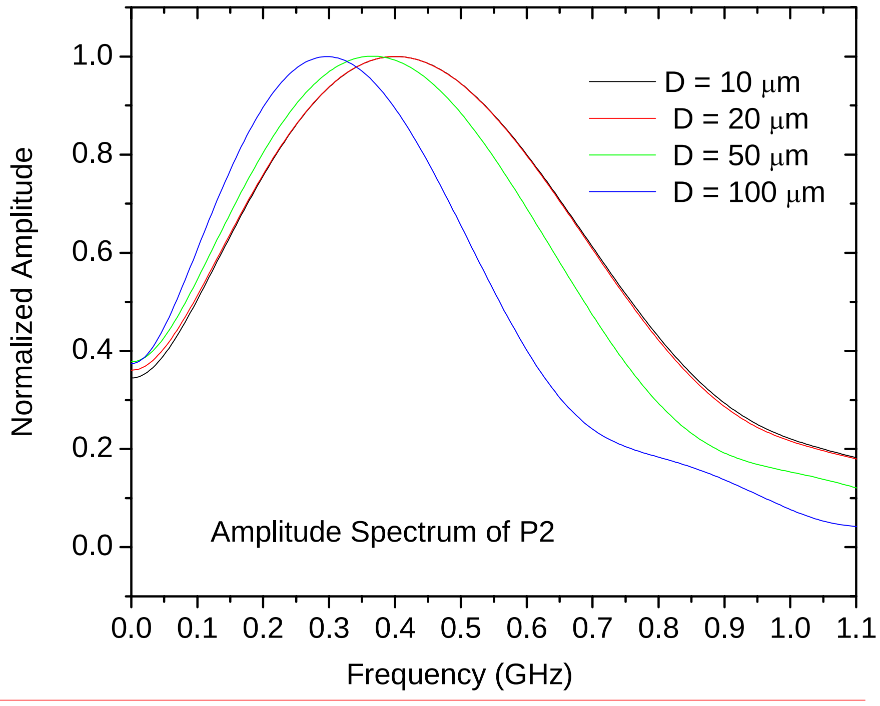
- Ablation threshold of the material,
- Ultrasonic attenuation (Geometric effects, grain scattering, grain anisotropy etc)



Gold foil – 100 μm thick

THEORETICAL CALCULATION

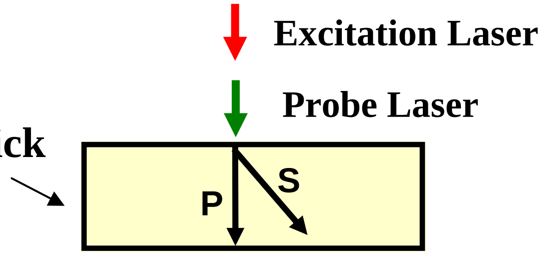




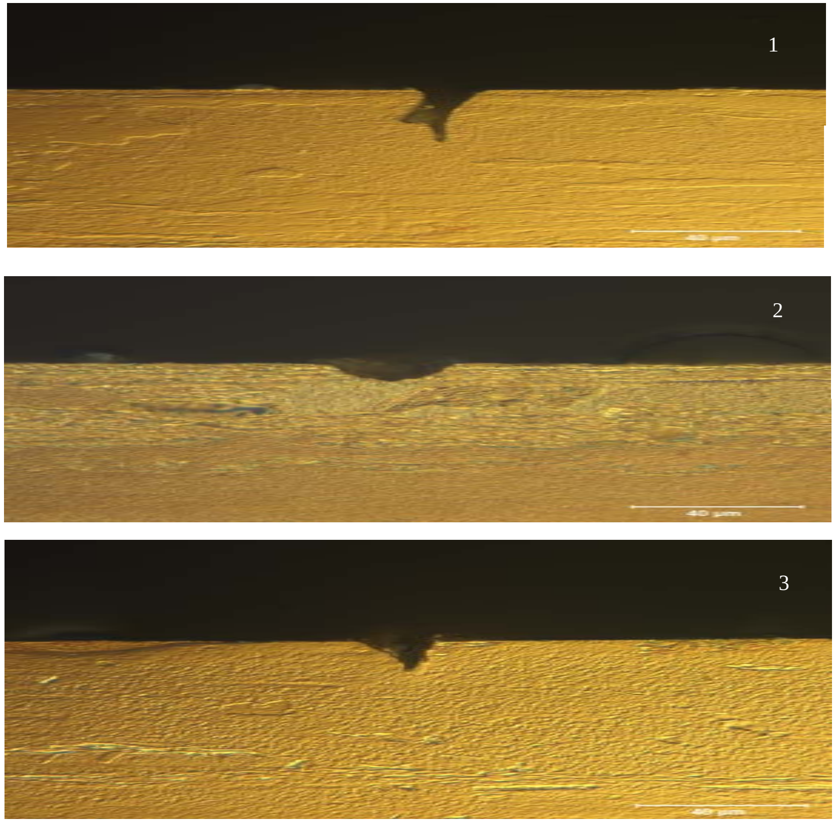
CURRENT CHALLENGES

Material Grain Anisotropy

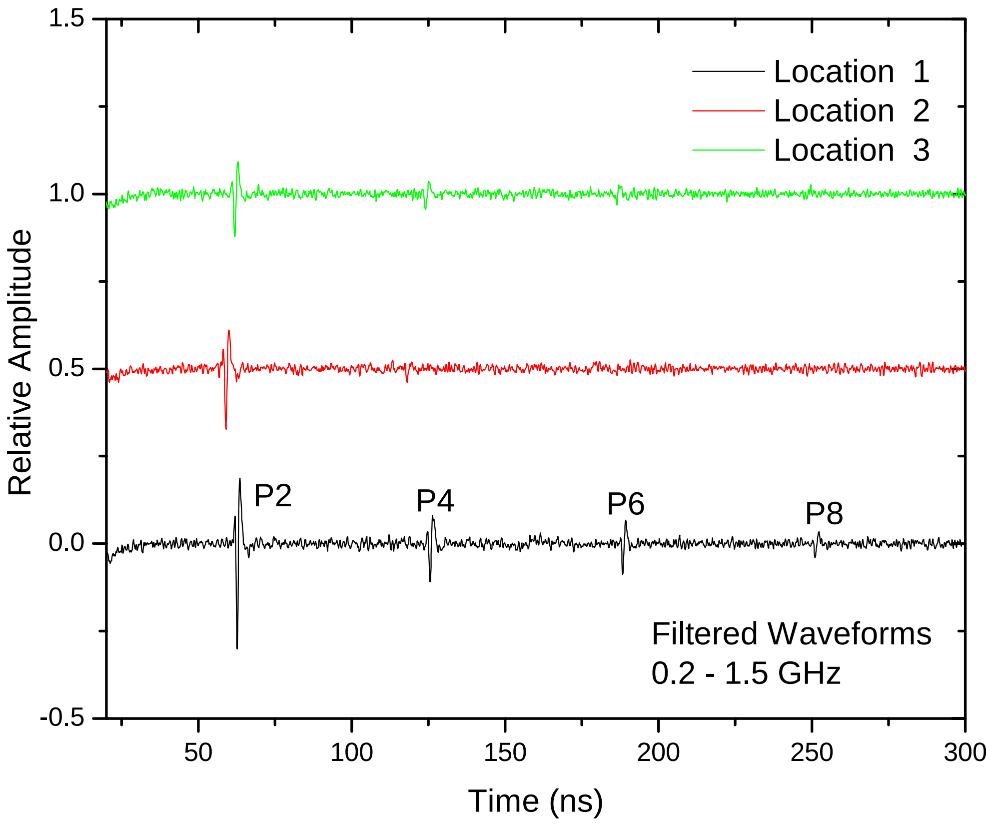
Gold foil – 100 µm thick



Optical Micrographs



Measured Waveforms



FUTURE WORK

- Monitor the presence of disbonds or sub-surface defects in the NIF targets using the laser based acoustic microscopy system developed
- Conduct pilot experiments to determine the limiting spatial resolution of the microscopy system for two dimensional imaging of sub-surface structures
- Study the dependence of the intrinsic ultrasonic attenuation at GHz frequencies on the grain structure in mesoscale material systems