Probe Beam Deflection Technique as a Characterization Method for Nuclear Materials

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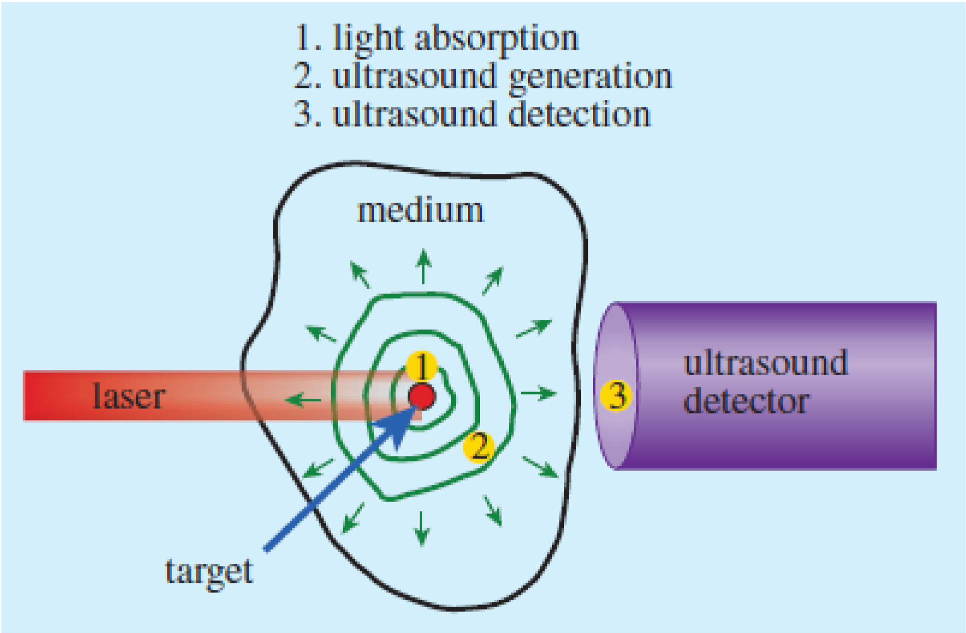
Abstract:

Probe beam deflection technique (PBDT) was evaluated as a potential method of characterization for both radioactive and non-radioactive materials. This method was chosen for its non-destructive nature. The analyte of interest was UB_2. Alternative fuel sources for nuclear reactors are being investigated as additives or replacements for UO_2 [4]; UB_2 was chosen for this purpose. CeO_2 was used because it is a surrogate for UO_2. No correlation was found between signal intensity and Eu-doping concentration was found.

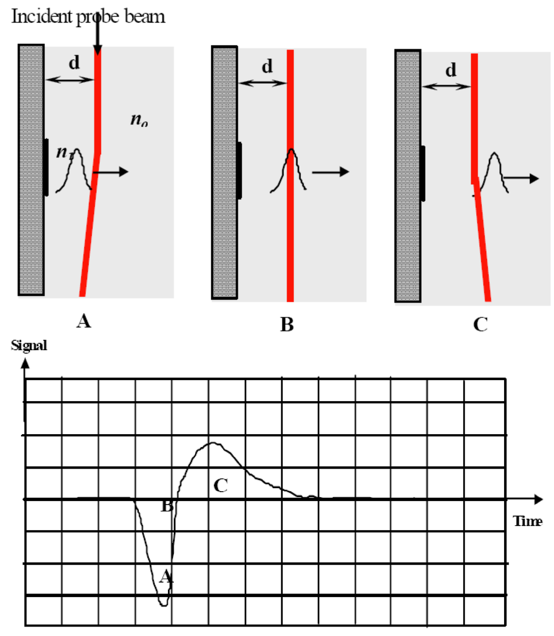
Background:

Probe Beam Deflection Technique (PBDT) utilizes a reference beam to measure the pressure gradient of an acoustic wave caused by an excitation beam. The excitation beam induces heat transfer to the sample – the rapid thermal expansion/contraction of the sample creates an acoustic wave in the medium.



[1] Three Components of Photoacoustic Spectroscopy

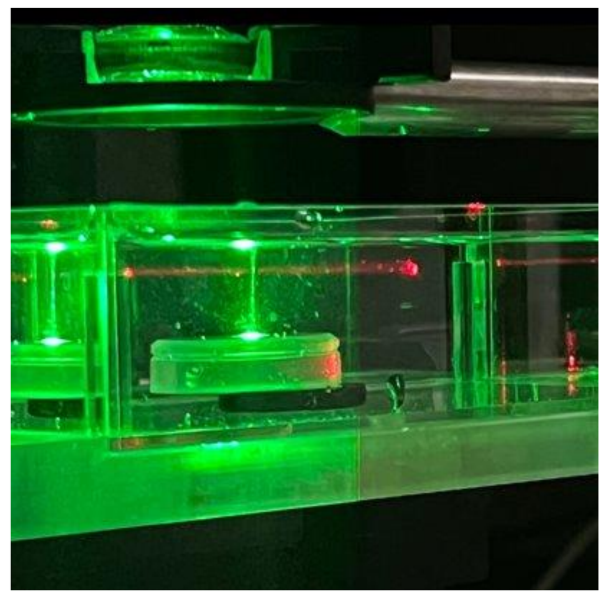
The propagation of the wave through mediums with different indices of refraction deflects the reference beam from its original path. This deflection is measured by a quadrant photodiode.



[3] Reference Beam Deflection Illustration

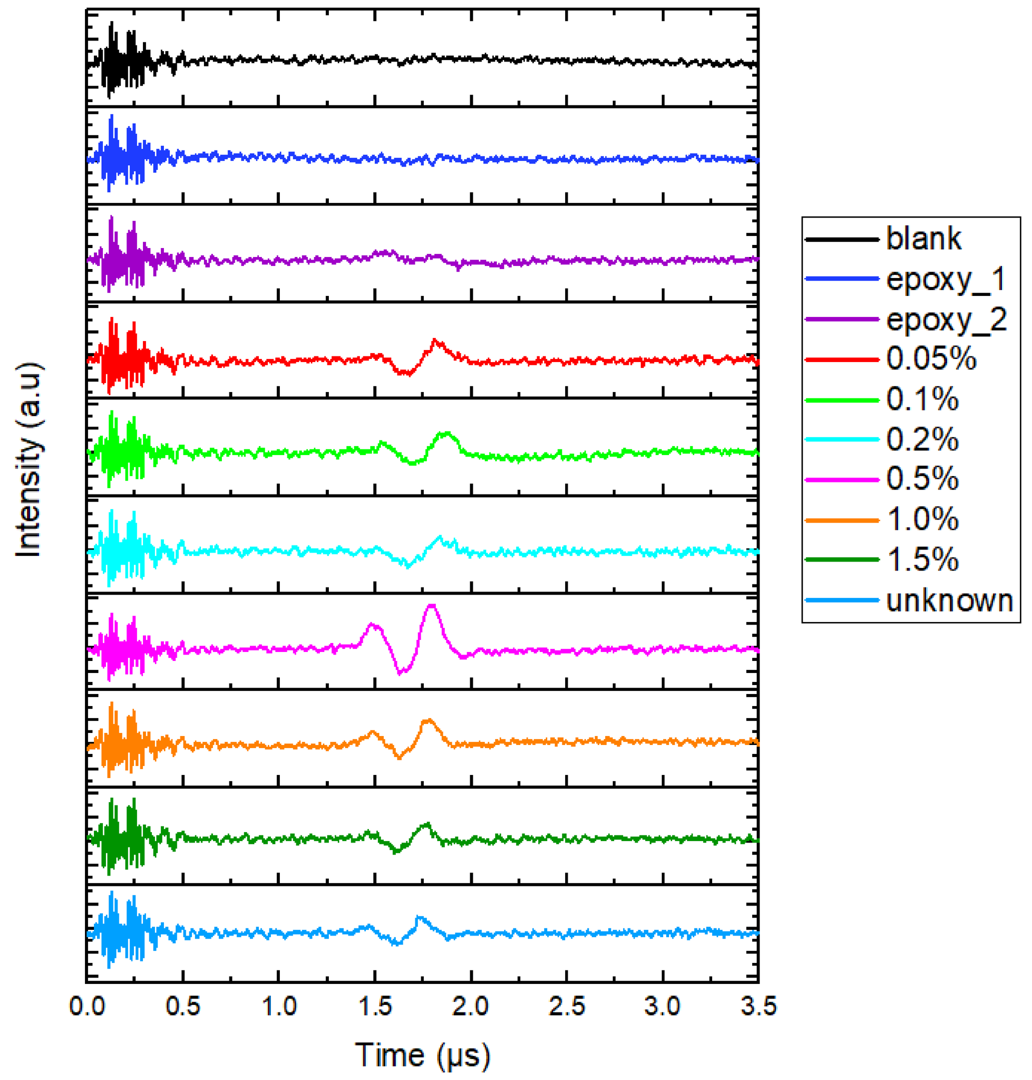
Experiment:

An optical parametric oscillator (OPO) was used as the excitation laser and a HeNe laser was used as the reference. The OPO was used at 532 nm. The reference and excitation beams were perpendicular to each other. Although this method was developed to be applied to UB_2 samples, Europium-doped CeO_2 surrogate pellets of varying doping percentages were used. The pellets were placed in a quartz cell with a DI water medium, which rested on a 3D programmable stage. A quadrant photodiode was used as a detector, connected to an oscilloscope to visualize measurements.



Results:

Eu-doped CeO_2 samples with concentrations ranging from 0.05-1.5 wt% were tested. The results indicated a clear photoacoustic response for all percentages, with 0.5% having the most intense signal. The blank measurement was taken when no sample (only water) was present in the cell and showed no response to excitation. However, the epoxy-only sample representing the baseline did have a response albeit less intense than the Eu-doped samples. The remaining samples were similar in peak intensity.



Results:

The distance d between the surface of the epoxy puck and the reference beam can be calculated using the time at the first peak.

$$d = vt$$

The velocity was the speed of sound in water (1480 m/s). The displayed displacement values were determined experimentally via laser alignment to give the optimal signal response.

Dopant %	t_min (μs)	Displacement (μm)
0.05	1.637	**2422.8**
0.1	1.693	**2505.6**
0.2	1.647	**2437.6**
0.5	1.620	**2397.6**
1.0	1.602	**2371.0**
1.5	1.605	**2375.4**
unknown	1.588	**2350.2**

Conclusion:

The probe beam deflection technique has many benefits, including being a non-destructive method of analysis. This helps manage the risk involved with the characterization of radioactive materials such as UB_2. The thermal properties of the sample could also potentially be calculated using this method. However, in the data collected from this experiment there was not a linear correlation between the signal intensity and the percentage of Europium-doping. More testing, especially with UB_2 samples rather than surrogates, will be necessary to fully understand the viability of using PBDT to characterize ATFs. The many advantages of this technique continue to make it an attractive area of exploration.

Future Work:

- Apply PBDT to UB_2
- Program software for PBDT scanning
- Image samples with SEM
- Perform Raman spectroscopy

References:

[1] "A Photoacoustic Demonstration Experiment." *PhysicsOpenLab*, 6 Apr. 2020, physicsopenlab.org/2020/04/06/a-photoacoustic-demonstration-experiment/.

[2] Barnes, Ronald A., et al. "Probe Beam Deflection Technique as Acoustic Emission Directionality Sensor with Photoacoustic Emission Source." *Applied Optics*, vol. 53, no. 3, Jan. 2014, p. 511, https://doi.org/10.1364/ao.53.000511.

[3] Khachatryan, E., et al. "Optoacoustic Microscopy Using Laser Beam Deflection Technique." *SPIE Proceedings*, edited by Alexander A. Oraevsky and Lihong V. Wang, vol. 8943, Mar. 2014, https://doi.org/10.1117/12.2040718.

[4] Watkins, Jennifer K., et al. "Challenges and Opportunities to Alloyed and Composite Fuel Architectures to Mitigate High Uranium Density Fuel Oxidation: Uranium Diboride and Uranium Carbide." *Journal of Nuclear Materials*, vol. 560, Mar. 2022, p. 153502, https://doi.org/10.1016/j.jnucmat.2021.153502.