

Design and Construction of a Novel Thermal Interferometer

By

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DECLARATION

I here by declare that this thesis has been written by me and it contains no material which has been accepted for the award to the candidate of any other degree or diploma, except where due reference is made in the text of the thesis.

To the best of my knowledge it contains no material previously published or written by another person except where due reference is made in the text of the thesis and where the work is based on joint research or publications, discloses the relative contributions of the respective workers or authors.

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I hereby declare that the entire project and this thesis is my own work and has been completed in fulfillment of the degree of Master of Engineering with a view to contribute to academic research and its benefit to our society.

Thanking you all.

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ABSTRACT

The concept of 'Thermal Wave Interferometry' (TWI) is based on photothermal techniques, in which propagation of thermal waves is induced by an intensity modulated optical source. Interference of the thermal waves is observed in a target material and can be further analysed by recording the resultant acoustic waves. The practical application of TWI revolves around the measurement of the phase lag of these acoustic waves in order to infer the thermal diffusivity of the material.

The drawback of using the photo-acoustic technique is that the conversion of heat to sound at the surface of the sample has a complicated phase and amplitude relationship to the temperature fluctuations driving the photo-acoustic effect. In a photo acoustic technique there are three components of phase lag which need to be accounted for, which are: i) photothermal phase lag, which is constant and given by 45° , ii) thermal phase lag, which is created due to the interference of thermal waves inside the sample and, iii) thermo-acoustic phase lag, which includes the time of travel of acoustic waves from sample surface to the microphone. Usually the acoustic phase lag is ignored, assuming it to be very small due to the longer wavelengths of sound compared to the length of the acoustic cell. When a single beam excites a single-sided photo acoustic cell, all of the phase lag components are recorded and analysed. This leads to some uncertainty in the results and a calibration is required, which could not only be time consuming but could also degrade the accuracy of the measurement.

To overcome this disadvantage of a single-sided photo-acoustic cell and demonstrate thermal interference, the work undertaken here reports on the design, commissioning and performance of a double-sided photo-acoustic cell, referred to as a thermal wave interferometer. The double-sided cell uses modulated light impinging on both sides of the sample, where the frequency of the modulation of the two beams is synchronized, but the relative phase can be varied. The advantage of this novel technique is that the relative phase between the two modulated beams can be adjusted to generate the maximum or minimum amplitude of the acoustic response, corresponding to constructive or destructive interference between the thermal waves, respectively. By isolating the phase lag associated with the thermal wave interference, no further calibration is required to account for photothermal and thermo-acoustic phase lags.

By using this system several measurements of amplitude, phase and interference 'null

effect' have been performed in this project. Data has been recorded and used to test and explain different aspects of the thermal interferometry. The results confirm the basic model of TWI and also indicate the importance of the thermal diffusion length relative to the sample thickness. For thermally thin samples, where the thermal diffusion length is larger than the sample thickness, the interference effect can be significant due to multiple internal reflections of the thermal waves. In contrast, for thermally thick samples, the interference effect is less significant due to the rapid decay of the thermal waves. Also, the modulation frequency of the incident beam plays a vital role, as the accuracy of the measurement is reduced by the deterioration in signal to noise ratio at lower frequencies.

In this work, another significant factor responsible for errors in measurement of the thermal phase lag has been identified, that is the effect of the spot size of the incident beam. Generally in the hypothesis of TWI one-dimensional (1D) propagation of thermal energy has been assumed by researchers. But the 1D approximation holds good only when the thermal wavelength inside the sample is much smaller than the beam spot size. The thermal wavelength is related to the thermal diffusion length $\mu = (2\alpha / \omega)^{1/2}$, where α is the thermal diffusivity of the material and ω is the angular modulation frequency of the light beam. Hence the validity of the 1D approximation is usually not valid in the very low frequency range. Therefore a 3D analysis of heat propagation is required in such cases.