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Research Article

# THERMAL LENSING: AN OVER VIEW

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## ABSTRACT

Thermal lensing is a photo thermal effect which is induced by temperature gradients and results when energy from a laser beam passing through a sample is absorbed, causing heating of the sample along the beam path. As a result of temperature difference, the temperature is varied causing a change in refractive index. A thermal lens in created as a result of change in refractive index. The effect, termed thermal lensing, arises when a high-intensity beam of light interacts with an absorbing medium and highly localized heating occurs.

## INTRODUCTION

Thermal lensing is a lensing effect induced by temperature gradients. It is a non-linear effect; a photo thermal phenomenon. In this technique the sample is illuminated using a Gaussian beam having intensity distribution across a beam. The thermal lens effect was discovered by Gordon, *et al.* [6]. Various applications are being used in the present. This paper presents an overview about what thermal lensing is and its applications.

### *Thermal Lensing*

### *Theory of Thermal Lensing*

The thermal lens effect has been theoretically derived under a variety of experimental conditions. Thermal lensing or thermal blooming occurs as energy absorbed from a Gaussian beam produces local heating of an absorbing medium about the beam axis [1]. It was discovered when Gordon, *et al.* [6] observed transient power and beam divergence changes in the output of a helium-neon laser after placing "transparent" samples in the laser cavity. The lens is created through the temperature dependence of the sample refractive index. The temperature distribution in the medium mimics the beam profile of the excitation beam and hence a refractive index gradient is created in the medium. Due to this modification in refractive index, the medium mimics a lens, called thermal lens (TL). The lens usually has a negative focal length since most materials expand upon heating and the refractive index is proportional to the density. This negative lens causes beam divergence and the signal is detected as a time dependent decrease in power at the center of the beam.[2]

The heating and subsequent lens formation is not instantaneous. It takes a finite time to develop, depending on the laser power and the thermal properties of the sample. In solution, the thermal properties of the solvent (heat capacity and thermal conductivity) determine the time for blooming to occur (typically milliseconds). To best observe the "grow-in" of the thermal lens effect, laser light is focused with a lens at a precise position in the sample. The pump laser is turned off and on with a rotating chopper. By correct choice of components, lens formation will occur during the "on" cycle of the pump laser through the chopper, and it will dissipate by cooling during the "off" cycle, so that the effect can be observed repetitively. During the formation of the lens, the probe beam is deflected and it comes back when the lens is destroyed.[2]

### *How to detect a thermal lens*

To detect the thermal lens, another laser beam (probe beam) can be used. There are two methods for that. In one case the probe beam is incident coaxially to the excitation one (pump beam), and in second method probe beam incident vertical to the pump beam. In both cases, the probe beam is deflected by the thermal lens. As a result, the intensity at the centre of the probe beam decreases and the variation depends on the size of the thermal lens [2].

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### *Historical developments of thermal lensing*

Gordon and his coworkers observed TL effect quite accidentally during their study of laser Raman scattering of pure liquids. The first use of the intra-cavity thermal lens to measure the absorptive of liquids was reported by Leite et at in 1964. Solimini [9] refined the apparatus and measured the absorption coefficients of 27 organic liquids. In 1967 Callen *et al* reported the observation of a pattern of concentric rings, which is now recognized as arising due to spherical aberration of the thermal lens. Akhmanov *et al* [7]. Carman and Kelly studied the time evolution of thermal lens and recorded the growth of thermal lens. Thereafter similar observations were made by scientists and several properties of samples were found out and several experiments carried out. Mild changes in theory can be observed on comparing the theories till present.

### *Application of Thermal Lens*

- The most important application is of the measurements of small absorbance, from experiment conducted by Gordon [6]
- Thermal lens spectrometry is used to study complex fluids. There are many important applications which are crucial in everyday life, such as the displays, electro-optical components, sensing, and so on.
- Used to asses oil – biodiesel blends to evaluate the behavior of the thermal and mass diffusivities that arose when oil was added to biodiesel and to verify the capability of the method to identify small concentrations of triacylglycerol in bio fuel.
- Binary liquid mixtures are studied using femtosecond pump–probe thermal-lens (TL) spectroscopy.
- Optical absorbance of dissolved organic matter in natural water is *studied using* the *thermal lens* effect.
- Differential TLS in the infrared region

Latest progress in TL technique is the construction of TL signal spectrometers, which operate in the IR region [76,77J. which enables better cancellation of the blank signal when two identical sample cells, containing the solvent in which the analyte is dissolved, are placed symmetrically with respect to the probe beam waist. With this setup they determined organophosphate and carbamate pesticides extracted into organic solvents and they determined pesticides at the ng ml'. However, this method did have limitations[3].

### *Microscopic TLS*

The possibility of focusing laser beam to points smaller than 1 urn in diameter opens an area of new applications of TLS. This includes the measurements of absorbance on the microscopic level and eventually inside a single living cell. Use of microscopic TLS demonstrated the measurements of pigments and colour distribution in a 5 urn- thick slice of human hair measuring 125 urn in diameter.[4]

### *Foodstuff analysis*

Applications of TLS to foodstuff analysis were governed by the need for new analytical tools to control the quality of foodstuffs and eventual adulteration. Adulteration of fruit juices and low quality of olive oils were detected using TL spectroscopy.

### *Analysis of environmental samples*

TLS is best suited for the analysis of liquid samples. Various organic pollutants, heavy metals and biologically active compounds can be detected with high sensitivity. Furthermore, the high sensitivity of TLS technique has been successfully combined with separation techniques such as HPLC and ion chromatography or bio-recognition methods such as biosensors.

### *Trace detection*

The high absorbance sensitivity of these methods has opened up new areas of trace chemical analysis based on optical absorption spectroscopy. A low power thermal lens spectrometer was developed to study the determination of $Cu^+$ having a molar absorption coefficient.

### *Measurements of absolute absorption coefficients*

The high sensitivity of thermo-optic spectroscopy methods has led to applications for analysis of low absorbance samples. Using this method, concentrations lower than 10'7 M of these strongly absorbing chromophores may be measured in standard cuvettes.

### *Measurement of Fluorescence Quantum yield*

Thermal lens spectrometer could be used to measure the fluorescence quantum yield of organic dyes using a reference standard.

### *Chemical kinetics of solution*

Dual beam thermal lens technique has been successfully employed for the study of the reaction kinetics in solutions. TL spectroscopy has been used to measure thermal diffusion coefficients, sample temperatures, bulk sample flow rates, specific heats, volume expansion coefficients, and heterogeneous thermal conductivities in solids[8].

Many more applications of Thermal lens spectrometry are being used worldwide for different purposes. Thermal lensing is even used in chemical analysis.

### *Theoretical Model – Sheldon Theory*

S.J Sheldon *et al.*[1] derived a theoretical model for the laser-induced thermal lens effect in weakly absorbing media. Taking the aberrant nature of the thermal lens into account, the intensity variation in the far field of the laser beam is predicted in the presence of a lensing medium, using this model. Various experiments were carried out which support the validity.

This model was set up in order to determine the intensity variation in the far field of the laser beam. This was conducted in the presence of a lensing medium. This is a theoretical model used to study the effect of laser induced thermal lens in a weakly absorbing media. The experiment was designed to test the thermal lens equations, when all parameters of both the sample and beam were known.

A He-Ne laser is used which is operated at 6328 A. This laser is operated in the $TEM_{00}$ mode which has an output power of 9.5 mW. The phenomenon observed is due to a lens produced inside the material because of the absorption of the laser beam.[1]

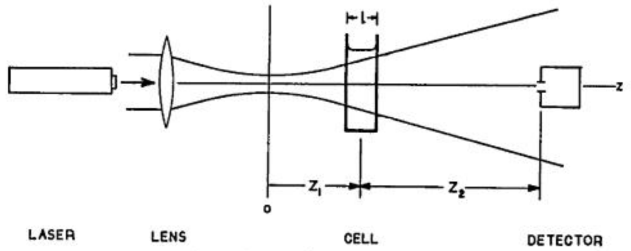

**Figure 1** Experiment was set up

This theory proposed by Sheldon had various limitations and drawbacks. In the coming years these limitations and drawbacks were covered up.

### *Application of Thermal Lensing In Chemical Analysis*

In 1992, Jun Shen *et al*. Presented a paper which deals with thermal lens spectrometry in chemical analysis. A theoretical model for cw laser induced thermal lens spectrometry is derived. An optically active liquid is used as a sample here. To determine the temperature coefficient of optical path length at different wavelength of optically active liquid which is used as the sample, time resolved and steady state mode mismatched thermal lens technique is used. Various properties of the sample are found out and calculated using mathematical expressions.

The drawbacks and limitations of Sheldon's theory were covered up by Shen. In this technique both mode matched and mode mismatched lens technique could be used. Both the probe beam and excitation beam was allowed to pass through the sample i.e. This model is suitable also for mode-matched dual-beam or the single-beam situations, as shown in the figure.

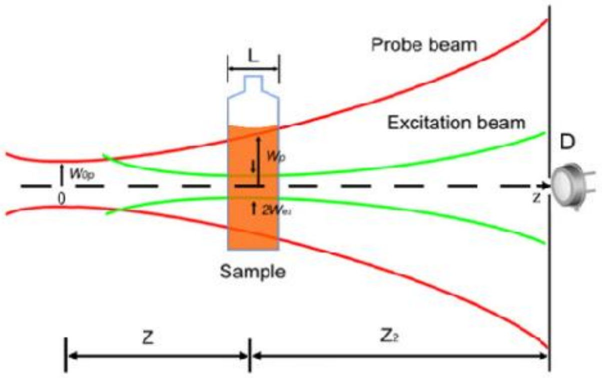

**Figure 2** Mode matched dual beam or single beam

Various assumptions were made by Shen during his experiment in order to overcome the limitations of Sheldon. Different properties of the sample were derived using mathematical expressions.

## CONCLUSION

Thermal lensing occurs as a result of change in refractive index caused due to a temperature gradient. It is a nonlinear photo thermal phenomenon with various applications. In this report the Sheldon's theory and the new theoretical model which was proposed by Shen in order to overcome the limitations of Sheldon is discussed. It was observed that Sheldon[1] proposed a theoretical model for thermal lens effect in which a laser was induced. This theory had various limitations and drawbacks which was overcome by Jun Shen in his theoretical model,'[5]. It was observed that the model proposed by Shen was suitable also for mode – matched dual beam or the single beam situations. This report gives an over view of the Thermal lensing effect its historical developments and its various applications.

## References

1. S. J. Sheldon, L. V. Knight, and J. M. Thorne, (1982) "Laser-induced thermal lens effect: a new theoretical model," APPLIED OPTICS , Vol. 21, No. 9.
2. Koechner W (1970), "Thermal Lensing in a Nd:YAG Laser Rod.". APPL OPT, Vol 9 Issue 11.
3. Achamma Kurian,(2002) "Characterization ion of Photonic Materials Using Thermal Lens Technique", PhD Thesis, Cochin University of Science and Technology, Kerala
4. M. Motamedi; A.J. Welch; W.-F. Cheong; S.A. Ghaffari; O.T. Tan, (1988) "Thermal lensing in biologic medium," IEEE Journal of Quantum Electronics, Vol (24), Issue(4).
5. Jun Shen, Roger D. Lowe and Richard D. Snook, (1992) "A model for cw laser induced mode-mismatched dual-beam thermal lens spectrometry", Chemical Physics1 Vol 165, Issue 2, p. 385-396.
6. J. P. Gordon, R. C. C. Leite, R. S. Moore, S. P. S. Porto, and J. R. Whinnery(1965)"Long-Transient Effects in Lasers with Inserted Liquid Samples"
(Published online 2004)Journal of Applied Physics 36,3,doi.org/10.1063/1.1713919
7. S. Akhmanov, D. Krindach, A. Migulin, A. Sukhorukov and R. Khokhlov, "Thermal self-actions of laser beams," in IEEE Journal of Quantum Electronics, vol. 4, no. 10, pp. 568-575, October 1968, doi: 10.1109/JQE.1968.1074930.
8. J. R. Whinnery, Laser measurement of optical absorption in liquids,(1974),Acc. Chem. Res. 1974, Vol 7, Issue 7, 225–231 (Published online 2002 , doi.org/10.1021/ar50079a003.
9. Domenico Solimini, (1966),"Loss Measurement of Organic Materials at 6328 Å", Journal of Applied Physics 37, 3314, (Published online 2004), doi.org/10.1063/1.1703200.

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