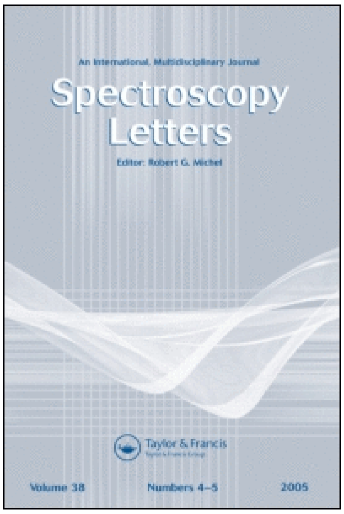

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INVESTIGATION OF TURBULENCE IN AN INCANDESCENT LAMP WITH PHOTOTHERMAL DEFLECTION SPECTROSCOPY

Erhan Demirbaş[a]; Robin Devonshire[b]
[a] Department of Chemistry, Gebze Institute of Technology, Gebze, Turkey [b] Department of Chemistry, University of Sheffield, Sheffield, UK

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INVESTIGATION OF TURBULENCE IN AN INCANDESCENT LAMP WITH PHOTOTHERMAL DEFLECTION SPECTROSCOPY

Erhan Demirbaş[1,*] and Robin Devonshire[2]

[1]Gebze Institute of Technology, Department of Chemistry, Gebze, 41400, Turkey
[2]University of Sheffield, Department of Chemistry, Sheffield, S3 7HF, UK

ABSTRACT

A pioneering study was made to investigate the presence of turbulence in the recirculating gas flows inside an incandescent lamp. The convective flows generated by the lamp filament were demonstrated conclusively to have turbulent character. The photothermal deflection spectroscopic technique was used to measure the total turbulent energy dissipation along a track through the lamp from wall to wall and maps produced. The results are the first to demonstrate and quantify the effects of turbulence.

Key Words: Turbulence; Photothermal deflection spectroscopy; Incandescent lamps; Laser

*Corresponding author. E-mail: erhan@penta.gyte.edu.tr

INTRODUCTION

A fluid system can be driven away from thermodynamic equilibrium by imposing a gradient in the velocity, the density or the temperature. If there is a velocity gradient, the distance away from equilibrium is conveniently characterized by a dimensionless quantity, the Reynolds number, Re which is defined by $\mathrm{Re} = UL/v$, where U and L are velocity and length scales respectively, and where v is the kinematic viscosity, the ratio of viscosity coefficient to the density. For simple pipe flow the onset of turbulent flow occurs for Re values above 2000.[1–4] It is not obvious how to estimate Re for the recirculating gas flows found in lamps to judge a priori whether or not turbulence exists. The temperature gradients are much higher than in conventional fluid flow laboratory experiments and the values of U and L are ill-defined. However, it is reasonable to imagine that as U increases the Reynolds number will pass out eventually of the range required by the solutions of the fluid flow equations to remain stable. The modelling of high temperature gases carried out in the High Temperature Science Laboratories (HTLS) in connection with a wide range of investigations has been based to date on the assumption that the flow behaviour of the gas is laminar in character, and not turbulent.[5] If a laser beam is passed through an incandescent lamp's envelope in such a way as to probe the regions near to the filament then the fluctuations in density along the path of the beam inside the envelope will result in both a time-dependent defocusing and deflection of the beam. Therefore, it was decided to address this issue experimentally to demonstrate the possible presence distribution and magnitude of turbulence.

THEORY

Photothermal spectroscopy is used to measure the optical absorption and thermal characteristics of a system. Light energy is absorbed and not lost by subsequent emission, which results in a localised sample heating. This heating gives rise to a temperature change as well as to changes in thermodynamic parameters of the sample which are related to temperature. The theory of PDS is presented in detail by a number of authors.[6–13] The propagation of the probe beam through the spatially varying index of refraction is given by Eq. (1)

$$\frac{d}{ds}\left(n_0 \frac{dr_0}{ds}\right) = \nabla_{\perp} n(r, t) \tag{1}$$

where r_0 is the perpendicular displacement of the beam from its original direction, n_0 is the uniform index of refraction, and $\nabla_\perp n(r,t)$ is the gradient of the index of refraction perpendicular to the ray path.

Due to nonuniform radial temperature distribution, a time dependent refractive index gradient is formed inside the sample and can be described as

$$n(x,y,t) = n_0 + \left(\frac{\partial n}{\partial T}\right)_{T_A} T(x,y,t) \tag{2}$$

where n_0 is the unperturbed refractive index at ambient temperature T_A and $\frac{\partial n}{\partial T}$ is the change in refractive index with temperature. The deflection angle, ϕ, is given by the integral over the optical path of the gradient of the refractive index.

$$\frac{dr_0}{ds} \cong \phi = \frac{1}{n_0}\frac{\partial n}{\partial T}\int_{\text{path}} \nabla_\perp T(r,t)ds \tag{3}$$

The deflection angle is monitored using a position sensing detector placed at some known distance from the sample. A change in angle at the sample results in a displacement of the probe laser beam spot on the detector. For small angles, the linear displacement of the probe laser beam spot is directly proportional to the deflection angle.

EXPERIMENTAL

The position sensitive detectors (PSD) are single beam position sensors providing incident light position information in one dimension and two dimensions depending on the PSD construction. A Hamamatsu S1200 series 2D PSD was used in this study and driven by a high performance electronic circuit designed and built in the Electronic Department.[14–15] The output from the PSD device is a voltage that depends on the position of incident light on both the x and y axes.

The experimental set-up shown in Fig. 1 was involved using a green (543.5 nm) HeNe beam passing through a region of turbulence and the movement being detected on the PSD. The voltage output from the PSD was analysed using Tektronix 2642A Fast Fourier Transform (FFT) analyser. A FFT spectrum was averaged and then displayed for analysis.

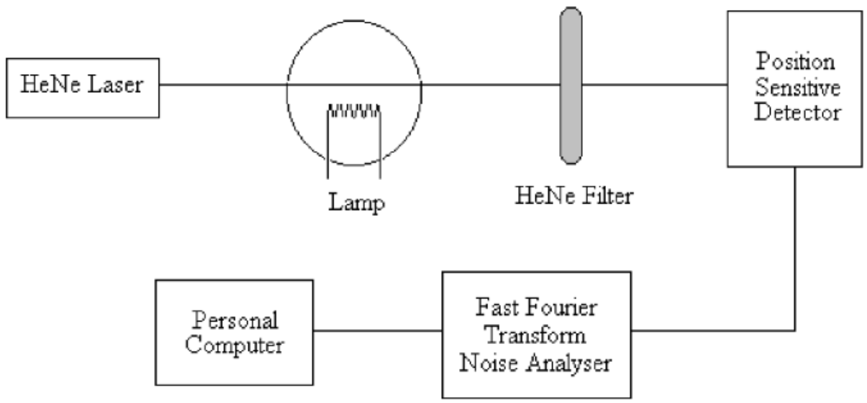

Figure 1. The turbulence experimental set-up for PSD measurements.

RESULTS AND DISCUSSION

The incandescent lamp was set at 240 V, 100 W and was connected to an x/y translator and FFT spectra were taken every 2 mm for both scanned across and scanned up the lamp. The power reading was taken from each spectra at 7 Hz and the results are shown in Figs. 2 to 4. The horizontal

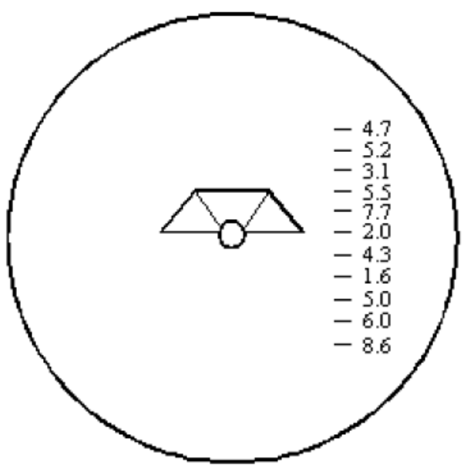

Figure 2. Power (1E-6 dB) measurements for x axis turbulence 3 mm above the filament.

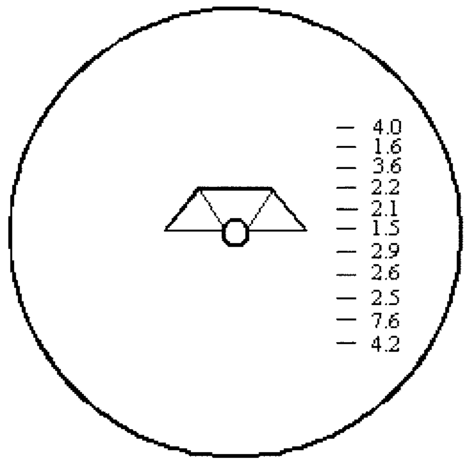

Figure 3. Power (1E-6 dB) measurements for y axis turbulence 3 mm above the filament.

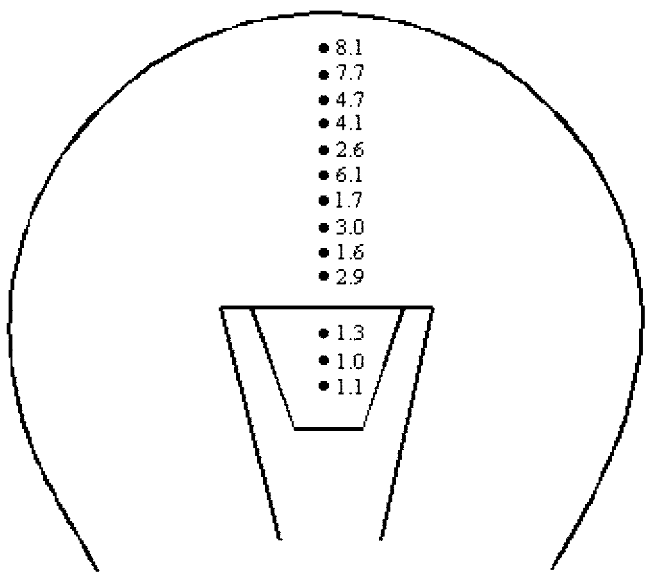

Figure 4. Power (1E-6 dB) measurements readings in the lamp for x axis turbulence.

Figure 5. FFT power versus voltage showing the onset of turbulence in an incandescent lamp.

scans shown in 2 and 3 show no trends of turbulence observed from the centre of the lamp. The vertical scan in Fig. 4 illustrates an easily discernible trend with a minimal amount of turbulence beneath the filament and an increasing amount of turbulence further up the lamp. This would agree with the results from Fluent modelling of the similar lamps.

It was also investigated the onset of turbulence could be seen in the lamp as the voltage increased. The lamp was connected to a variac (variable AC isolation transformer) and turbulence measurements were carried out at 7 Hz. The resulting spectrum in Fig. 5 shows an almost transitional change from laminar flow to turbulent flow at about 40 V and then a rapid increase for higher voltages.

CONCLUSION

Photothermal deflection spectroscopy is used as a diagnostic method for investigations of turbulence phenomena in the gas filling of an incandescent lamp for the first time. Turbulence is probed with a position sensitive detector provided a voltage output related to the position of the laser beam on its surface. The experiment was carried out to measure the total turbulent energy dissipation along a track through the lamp from wall to wall. This work has succeeded in showing that turbulence is present in the incandescent lamp and these original observations will have a significant impact on the modelling of lamp systems.

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REFERENCES

1. Swinney, H.L.; Golub, J.P. Physics Today **1978**, 41.
2. Mullin, T. New Scientist **1989**, *52* (11).
3. Gilliam, E.J.; Harmer, D.; Moore, J.R. Nature **1975**, *258*, 416.
4. Kay, J.M.; Nedderman, R.M. *Fluid Mechanics and Transfer Processes*; Cambridge University Press: Cambridge, 1985.
5. Demirbas, E. Ph.D Thesis, University of Sheffield, 1998.
6. Murphy, J.C.; Aamodt, L.C. J. Appl. Phys. **1980**, *51*, 4580.
7. Sell, J.A.; Cattolica, R.J. Appl. Opt. **1986**, *25*, 1420.
8. Weimer, W.A.; Dovichi, N.J. Appl. Opt. **1985**, *24*, 2981.
9. Whinnery, J.R. Acc. Chem. Res. **1974**, *7*, 225.
10. Jackson, W.B.; Amer, N.M.; Boccara, A.C.; Fournier, D. Appl. Opt. **1981**, *20*, 1333.
11. Sell, J.A. Appl. Opt. **1984**, *23*, 1586.
12. Franko, M. Rev. Sci. Instrum. 1996, *67*, 1.
13. Bialkowski, S.E. *Photothermal Spectroscopy Methods for Chemical Analysis*; John Wiley & Sons, Inc.: New York, 1996.
14. Hamamatsu Photonics UK Limited, Herts, England.
15. Li, K.F. Third Year Dissertation, University of Sheffield, 1995.

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