

## Initial results from a simultaneous pyrometry and reflectivity diagnostic

Thomas A. Ota, David J. Chapman, James C. Richley, and Daniel E. Eakins

Citation: [AIP Conference Proceedings](#) **1979**, 130005 (2018); doi: 10.1063/1.5044950

View online: <https://doi.org/10.1063/1.5044950>

View Table of Contents: <http://aip.scitation.org/toc/apc/1979/1>

Published by the [American Institute of Physics](#)

---

### Articles you may be interested in

[Release path temperatures of shock-compressed tin from dynamic reflectance and radiance measurements](#)

[Journal of Applied Physics](#) **114**, 063506 (2013); 10.1063/1.4817764

[Broadband mid-infrared measurements for shock-induced chemistry](#)

[AIP Conference Proceedings](#) **1979**, 130004 (2018); 10.1063/1.5044949

[Line-RALF Doppler velocimetry](#)

[AIP Conference Proceedings](#) **1979**, 160007 (2018); 10.1063/1.5045006

[Reflectance changes during shock-induced phase transformations in metals](#)

[Review of Scientific Instruments](#) **81**, 065101 (2010); 10.1063/1.3430536

[In situ insights into shock-driven reactive flow](#)

[AIP Conference Proceedings](#) **1979**, 020001 (2018); 10.1063/1.5044769

[Path dependency of phase transformations](#)

[AIP Conference Proceedings](#) **1979**, 060001 (2018); 10.1063/1.5044798

---

**AIP** | Conference Proceedings

**Get 30% off all  
print proceedings!**

Enter Promotion Code **PDF30** at checkout



# Initial Results From a Simultaneous Pyrometry and Reflectivity Diagnostic

Thomas A. Ota<sup>1,2,a)</sup>, David J. Chapman<sup>2</sup>, James C. Richley<sup>1</sup> and Daniel E. Eakins<sup>2,3</sup>

<sup>1</sup>AWE, Aldermaston, Reading, Berkshire RG7 4PR, United Kingdom.

<sup>2</sup>Institute of Shock Physics, Blackett Laboratory, Imperial College London, London, UK.

<sup>3</sup>Solid Mechanics and Material Engineering, Department of Engineering Science, University of Oxford, Oxford, UK.

<sup>a)</sup>Corresponding author: thomas.ota10@imperial.ac.uk

**Abstract.** Pyrometry is an established technique used in high strain rate experiments (such as plate impact experiments) whereby the temperature of a sample is determined from the measurement of collected thermal radiation. By applying Planck's Law, radiometry data can be used to determine temperature. A significant source of uncertainty in applying pyrometry to high strain rate experiments is due to possible changes in emissivity after a sample has been shocked; thus it is desirable to determine emissivity during the experiment. Kirchhoff's Law, which states emissivity is the complement of reflectivity, can be applied to determine emissivity in high strain rate experiments. Ideally the sample's reflectivity would be measured at the same wavelength and on the same experiment as the pyrometry measurement. A diagnostic has been developed which produces a modulated reflectivity signal that is insensitive to tilt and surface finish. Following characterisation of the system in the laboratory, dynamic tests were conducted. During the dynamic tests, the reflectivity signal was multiplexed onto the radiance signal allowing simultaneous measurement of radiance and reflectivity. A description of the diagnostic, results from laboratory testing and results and analysis from dynamic experiments are presented. ©British Crown owned copyright 2017/AWE.

## INTRODUCTION

Pyrometry is an established technique for determining temperature in high strain rate experiments, such as plate impact experiments. The fundamental principle used in pyrometry is the measurement of thermal radiation emitted from a sample due to its temperature, the spectral density of this emission is given by Planck's Law,

$$L_{\lambda}(\lambda, T) = \epsilon(T, P, \lambda) \frac{2hc_0^2}{\lambda^5} \frac{1}{e^{\frac{hc_0}{\lambda k_B T}} - 1}, \quad (1)$$

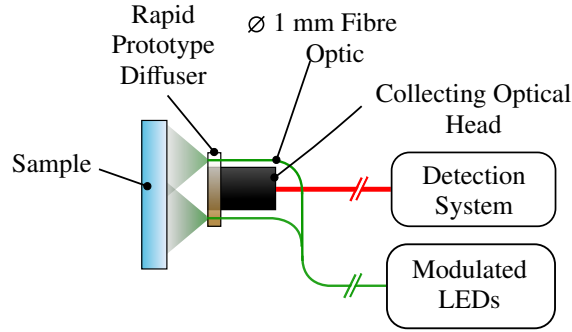
where  $L_{\lambda}$  is the spectral radiance in  $\text{W} \cdot \text{sr}^{-1} \cdot \text{m}^{-3}$ ,  $h$  is Planck's constant,  $c_0$  is the speed of light in a vacuum,  $\lambda$  is wavelength,  $k_B$  is Boltzmann's constant,  $T$  is temperature of the source, and  $\epsilon$  is emissivity which is a function of temperature,  $T$ , pressure,  $P$ , and wavelength,  $\lambda$ . From Equation 1 it can be seen that emissivity acts to scale the radiance. A significant source of uncertainty in applying pyrometry to high strain rate experiments is due to the unknown emissivity of the shocked sample. Thus in the application of pyrometry it is desirable to determine emissivity during the experiment.

In determining emissivity it is often convenient to apply Kirchhoff's law of thermal radiation which states that emissivity is the complement of reflectivity,

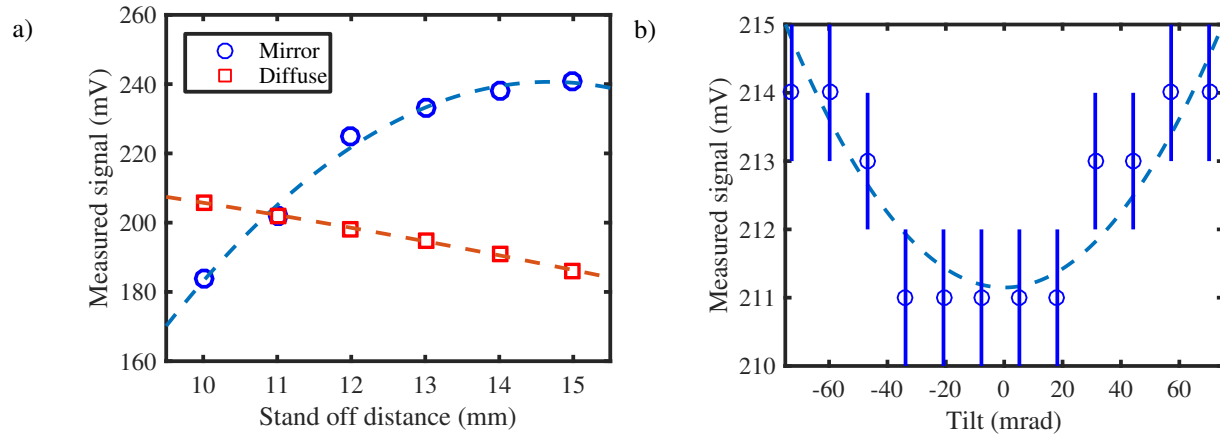
$$R = 1 - \epsilon, \quad (2)$$

where  $R$  is reflectivity.

The literature has numerous reports of reflectivity measurements conducted alongside pyrometry measurements. Partouche-Sebban *et al.* [1] performed a single wavelength reflectivity measurement on a single sample from a batch that were shock loaded in the same experiment; other samples were diagnosed with pyrometry. Turley *et al.* [2] and La Lone *et al.* [3] have performed multi-wavelength reflectivity measurements which are then used to interpret pyrometry data collected on separate, nominally identical experiments. However, ideally reflectivity would be measured



**FIGURE 1.** Schematic diagram of the diffuse illumination reflectivity diagnostic.



**FIGURE 2.** a) Plot of collected signal for two samples as stand off distance is varied. Dashed lines are values from a 2<sup>nd</sup> degree polynomial fit. b) Plot of collected signal from a diffusely illuminated mirror as the mirror was tilted.

on the same sample and at the same wavelength as the pyrometry measurement. The development of a diagnostic that simultaneously measures reflectivity during a pyrometry measurement is described here.

## REFLECTIVITY DIAGNOSTIC

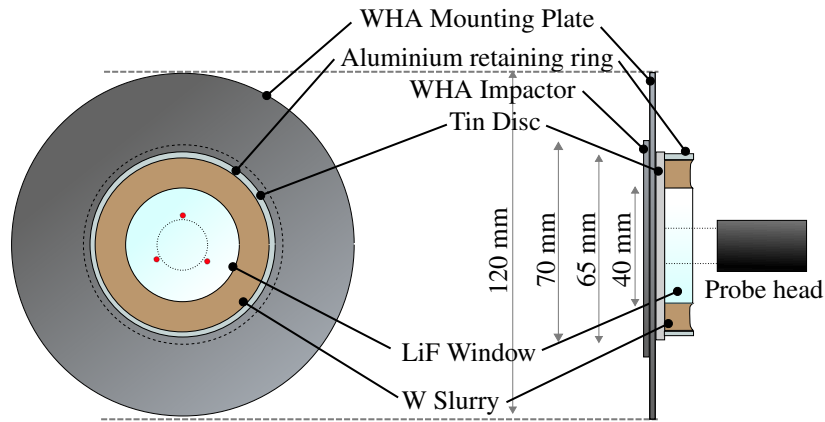
The reflectivity diagnostic is based on a similar principle to the inverse integrating sphere reported by Turley and La Lone where a sample is illuminated over a large solid angle and light collected from a limited solid angle. Rather than using an integrating sphere, optical fibres and a diffuser are used for illumination and the optical head used for pyrometry collects the reflected light, see Figure 1.

The diagnostic's sensitivity to surface finish was investigated by measuring the collected light level from both specular and diffuse samples as the sample-to-probe distance was varied, Figure 2a. The results indicated that, with a sample-to-probe distance of 11 mm, the probe collects the same light level with both surface finishes.

An 11 mm sample-probe distance was then used during investigations into the system's sensitivity to tilt; collected light level was measured while the sample was tilted to various angles. The collected light level varied less than a 1 % with sample tilt of up to 20 mrad, Figure 2b.

## DYNAMIC TESTING

The laboratory testing demonstrated that the reflectivity diagnostic can be made relatively insensitive to conditions of varying surface finish and tilt. However, as the measurements used continuous light sources, the system was not compatible with a simultaneous radiance measurement at the illumination wavelength. To enable a simultaneous measurement the LED sources were modulated at high speed. Modulation allows the reflectivity signal to be superimposed

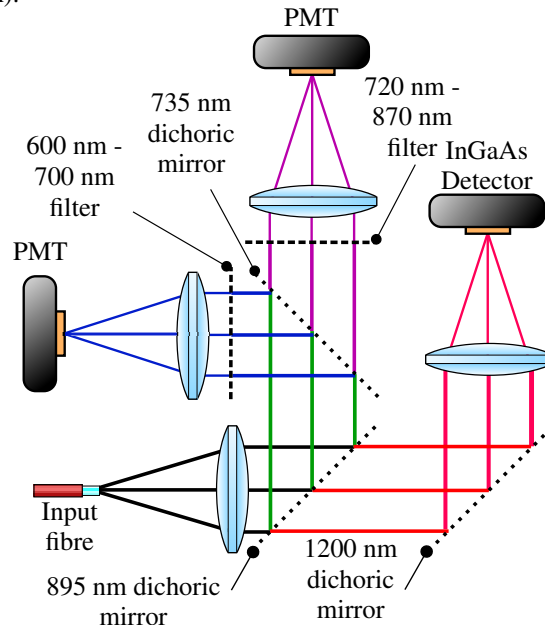


**FIGURE 3.** Schematic diagram of the target configuration for the plate impact experiment. The red dots indicate PDV probe positions, the dotted circle indicate the pyrometry probe collection area.

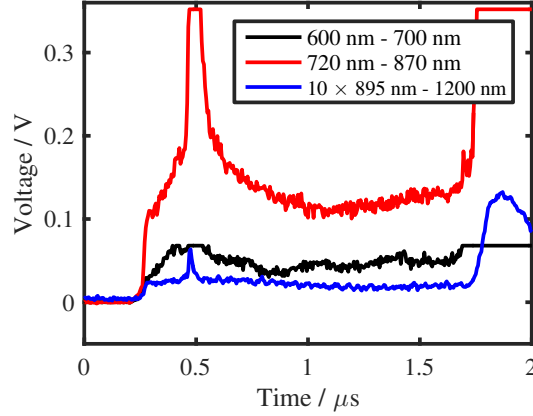
onto an associated radiance measurement channel, in this case a 650 nm centred LED was used for illumination. Plate impact experiments were used to test the dynamic performance of the reflectivity diagnostic.

The experiments consisted of a 50 mm diameter, 3 mm thick tin sample, mounted on a 120 mm diameter, 2 mm thick tungsten heavy alloy (WHA) plate. A 70 mm diameter, 2 mm thick WHA plate impacted the WHA mounting plate at approximately  $1550 \text{ m}\cdot\text{s}^{-1}$ . Complete release of the sample after shock was delayed by a 40 mm diameter, 10 mm thick lithium fluoride (LiF) window. To prevent luminescence of the edges of the LiF the window was surrounded with a tungsten loaded Sylgard potting. The target arrangement is shown in Figure 3.

In addition to the reflectivity measurement a three channel, spectral band pyrometer was used to measure the thermal radiance of the sample. The three channels covered wavelength ranges of 600 nm-700 nm, 720 nm-870 nm and 895 nm-1200 nm. The configuration of the pyrometer is shown in Figure 4. The reflectivity signal was multiplexed onto the 600 nm-700 nm channel. Three photonic Doppler velocimetry (PDV) probes measured the sample-window interface velocity and shock arrival times at multiple points (three, or more, arrival times allows tilt to be determined if impact plate velocity is known).



**FIGURE 4.** Schematic diagram of the pyrometer used in these experiments.



**FIGURE 5.** Radiance-time data from the first dynamic test.

## RESULTS

Two plate impact experiments were conducted. The interface velocities and interface pressures, calculated using the LiF Hugoniot [4] are shown in Table 1 while the unprocessed radiance data is shown in Figure 5.

**TABLE 1.** Interface velocities as measured by PDV and inferred interface pressures.

| Experiment | Interface Velocity<br>/ $\text{m}\cdot\text{s}^{-1}$ | Interface Pressure<br>/ GPa | Tilt<br>/ mrad |
|------------|--|-----------------------------|----------------|
| 1          | $1373 \pm 5$   | $25.37 \pm 0.3$             | 7              |
| 2          | $1373 \pm 3$   | $25.37 \pm 0.7$             | 5              |

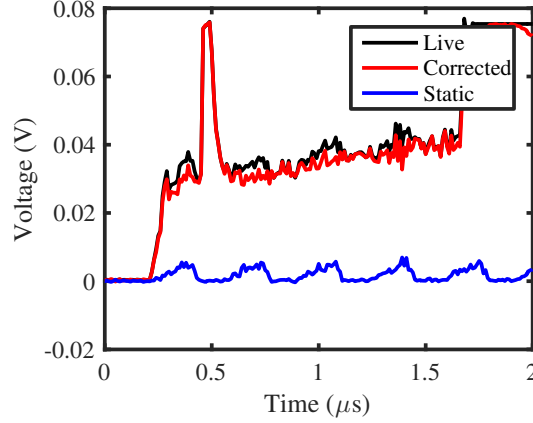
To determine the reflectivity it is necessary to analyse the multiplexed signal from the 600 nm-700 nm channel. The change in the reflectivity signal was determined using both the static reflectivity signal and the spectrally closest radiance channel as references. The first point to note is that from the 750 nm-850 nm pyrometry channel it can be inferred that, after a spike in intensity, the radiance varied smoothly. The following process was used to determine the reflectivity signal:

1. The dynamic signal was down-sampled to reduce noise.
2. The static signal was time-shifted and amplitude-scaled and the shifted signal down-sampled to the same time points as the dynamic signal.
3. The difference between the scaled static signal and the dynamic signal was calculated.
4. The difference was fitted with a 2<sup>nd</sup>-order polynomial and the mean residual between the difference and fitted curve calculated.
5. Steps 2 to 4 are repeated until the mean residual between the difference and fitted curve is minimised. The amplitude scaling factor indicates the change in reflectance.

An example of the results of this process are shown in Figure 6. Reflectance results from both experiments are shown in Table 2. The results from the two experiments are not consistent. The cause of the disagreement is unclear; potential explanations include lack of repeatability in the pulse intensity, incorrect alignment and shot-to-shot variation. Further testing is planned to investigate these issues.

## CONCLUSIONS

Initial testing of a reflectivity measurement system that operates on both the same experiment and the same spectral band as a radiance measurement has been developed and tested. While initial dynamic testing has successfully collected results, they appear inconsistent. Further testing will be conducted to try to determine the cause of the inconsistency.



**FIGURE 6.** Plots of the dynamic and static reflectivity signals from experiment 2. Also shown is the dynamic pyrometry signal with the reflectivity signal removed using the parameters determined by analysis.

**TABLE 2.** Relative reflectivity values as determined by the algorithm. The uncertainties quoted indicate to the repeatability of the algorithm.

| Experiment | Relative reflectivity |
|------------|-----------------------|
| 1          | $0.70 \pm 0.05$       |
| 2          | $0.55 \pm 0.05$       |

## ACKNOWLEDGMENTS

The authors wish to thank Susan Parker for extensive advice on the circuit design and implementation for high speed switching applications. The authors gratefully acknowledge Imperial College London for their continued support and AWE for providing the funding for this work.

©Crown copyright 2017. Reproduced with the permission of the Controller of Her Majesty's Stationery Office/Queen's Printer for Scotland and AWE.

## REFERENCES

- [1] D. Partouche-Sebban, J. Péliissier, W. W. A. F. G. Abeyta, M. E. Byers, D. Dennis-Koller, J. S. Esparza, R. S. Hixson, B. J. J. D. B. Holtkamp, J. C. King, P. A. Rigg, P. Rodriguez, D. L. Shampine, J. B. Stone, D. T. Westley, S. D. Borrer, and C. A. Kruschwitz, *Journal of Applied Physics* **97**, p. 043521 (2005).
- [2] W. D. Turley, D. B. Holtkamp, L. R. Veaser, G. D. Stevens, B. R. Marshall, A. Seifter, R. B. Corrow, J. B. Stone, J. A. Young, and M. Grover, *Journal of Applied Physics* **110**, p. 103510 (2011), <http://aip.scitation.org/doi/pdf/10.1063/1.3657465>.
- [3] B. M. L. Lone, G. D. Stevens, W. D. Turley, D. B. Holtkamp, A. J. Iverson, R. S. Hixson, and L. R. Veaser, *Journal of Applied Physics* **114**, p. 063506 (2013), <http://aip.scitation.org/doi/pdf/10.1063/1.4817764>.
- [4] S. P. Marsh, *LASL shock Hugoniot data / Stanley P. Marsh, editor* (University of California Press Berkeley, 1980).
- [5] W. D. Turley, G. D. Stevens, G. A. Capelle, M. Grover, D. B. Holtkamp, B. M. LaLone, and L. R. Veaser, *Journal of Applied Physics* **113** (2013).
- [6] A. Seifter, K. Boboridis, and A. W. Obst, *International Journal of Thermophysics* **25**, 547–560 (2004).