Experimental Analysis of Luminescence in Printed Materials

A. D. McGrath, S. M. Vaezi-Nejad

Abstract - This paper is based on a printing industry research project nearing completion [1]. While luminescent pigments have been used for many years, provision of fast response quality control systems have been challenging, primarily due to large and expensive components that are integral to spectroscopy instrumentation. Characteristics of the light sources and detectors used together with application of three levels of detection systems are described.

Keywords: Colour detection, Luminescent pigmentation, Printed materials, Spectrometer.

1. Introduction

Fluorescence is the emission of light by a material that ceases as soon as the source is removed. In comparison, phosphorescence is mostly evident by an after-glow which can vary from micro-seconds to hours. Our investigation focused on the experimental analysis of fluorescent and phosphorescent materials using specialist equipment developed in house. Two forms of spectroscopy instrumentation have been assembled using different configurations which will be assessed using specific experiments.

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These materials were formulated into an ink system and printed on to a robust substrate for experimental work. In this paper, results of luminescent green emission as a function of print density variation is reported. In addition a Double Monochromator Spectrometer (DMS) incorporating a Photomultiplier Tube (PMT) [2], a Charge Coupled Device (CCD) spectrometer and PIN Photodiode measurements are discussed.

2. Excitation Sources

In order to improve experimentation and capability of luminescent work, it is highly desirable to understand the performance and limitation of the light sources suitable for this investigation. Our past experience in this area was found very useful in selecting the most suitable economical light source from Xenon (Xe) arc lamp, Light Emitting Diodes (LEDs) and semiconductor lasers [3-5].

3. Experimental results and discussions

3.1. Luminescent green emission as a function of print density variation

For the evaluation of print weight versus fluorescent green emission, the chosen excitation was 373nm as this was commercially available [6] as a low cost LED solution and was previously confirmed as being within the absorption band of the material under test. Four samples of different print weight form the measurement evaluation: *Control; Sample 1; Sample 2; Sample 3.* The resultant emission curves for the four materials are plotted graphically in figure 1. By observation it is clear that the detector performance distinguishes between changes in print weight. The spectral characteristics have remained consistent, both in terms of the peak emission and the Full Width Half Maximum (FWHM).

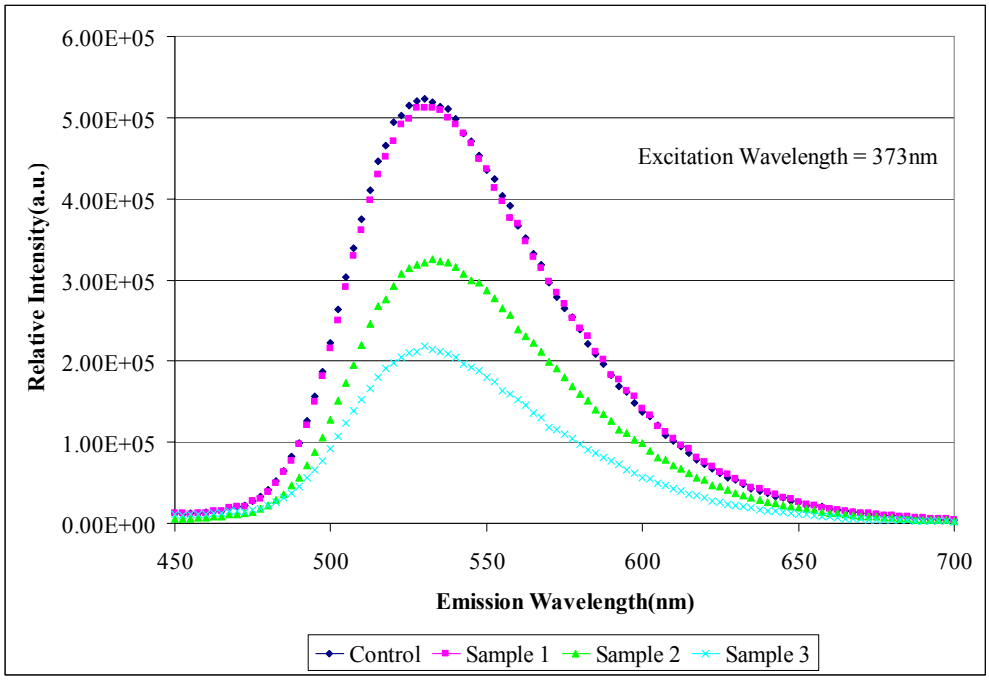

Figure 1: Fluorescent green emissions of four printed ink samples irradiated with a UV source and detected by a PMT sensor.

The same procedure was performed for the phosphorescent green emission materials using an excitation of 980nm (laser source), although the emission spectrum was measured in 0.5nm step intervals.

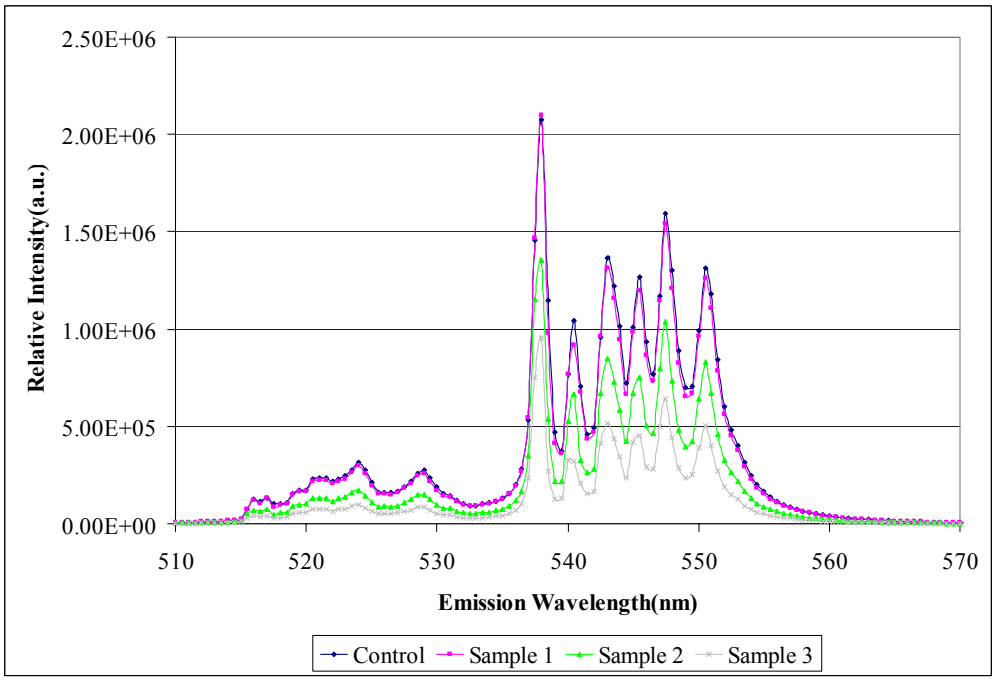

Figure 2: Phosphorescent green emissions of four printed ink samples irradiated with an IR Laser and detected by a PMT sensor.

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The resultant emission curves showed that the emission of the phosphorescent material has multiple narrow-band emissions that are present for each print weight variant. Improving measurement resolution from 1nm to 0.5nm enables the full structure of the phosphor based materials to be realised, especially when comparing these emissions with the fluorescent samples that are much broader and have a large FWHM.

3.2 CCD Measurements

The configuration for this experiment is much simpler, robust and cost effective for most applications of luminescent analysis. The system block diagram, as shown in figure 3, confirms the individual components required and the order in which they are configured. For the analysis of the fluorescent materials the light source in this case is LED [9] with an output peak of 373nm when driven from a constant current supply of 10mA. For the phosphorescent materials the light source was a 980nm TEC laser that was optically coupled to a fibre optic delivery cable using a SMA connector.

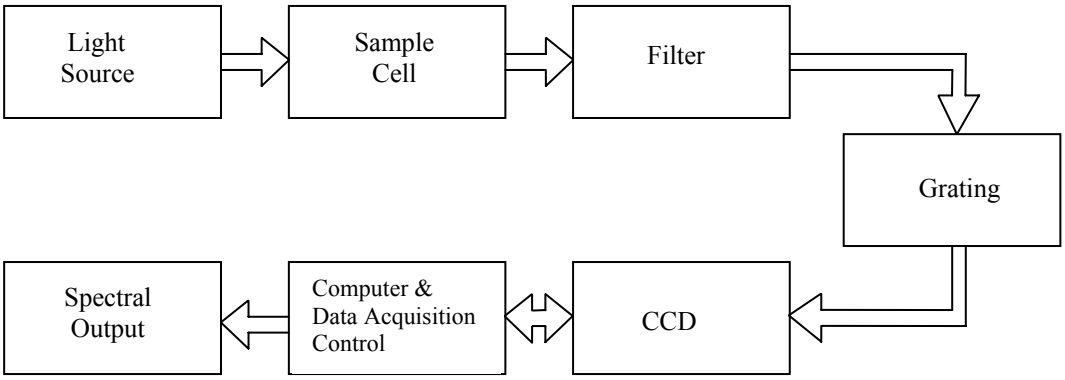

Figure 3: Block diagram of CCD spectrometer with fixed position grating

The material under investigation is located in the sample cell of which the fluorescent emission is scattered from the sample being irradiated, and optically guided through a filter to the fixed-position grating [7]. The grating is located on an optical bench that incorporates the CCD detector and mirrors to form the optical path. The particular arrangement is known as the Czerny-Turner layout [8].

The CCD detector consists of 2048 pixel configured in a linear array; the output of each pixel is converted to an electrical unit which is representative of the amount of energy that has fallen on each pixel. With the aid of dedicated electronics and software, these signals are converted and sent to a personal computer (PC) for post processing. This task computes the relative intensity against wavelength (nm) by utilising Universal Serial Bus (USB) connectivity.

The print density exercise was repeated to obtain the emissions for the UV to green materials, at four different print weights. Using a dedicated software protocol, the raw data was captured, processed and stored to a file for each of the four samples, which provided confirmation of system functionality and the first spectral measurements of the CCD detector for the UV to green emissions. It can be observed in Figure 4 below that a trend in the variations is similar to that witnessed by the DMS measurements recorded earlier, in Figure 1. The exercise was repeated to obtain the emissions for the IR to green materials, at four different print weights and once again the results confirmed that the variation in print density can be discriminated using the CCD detection method.

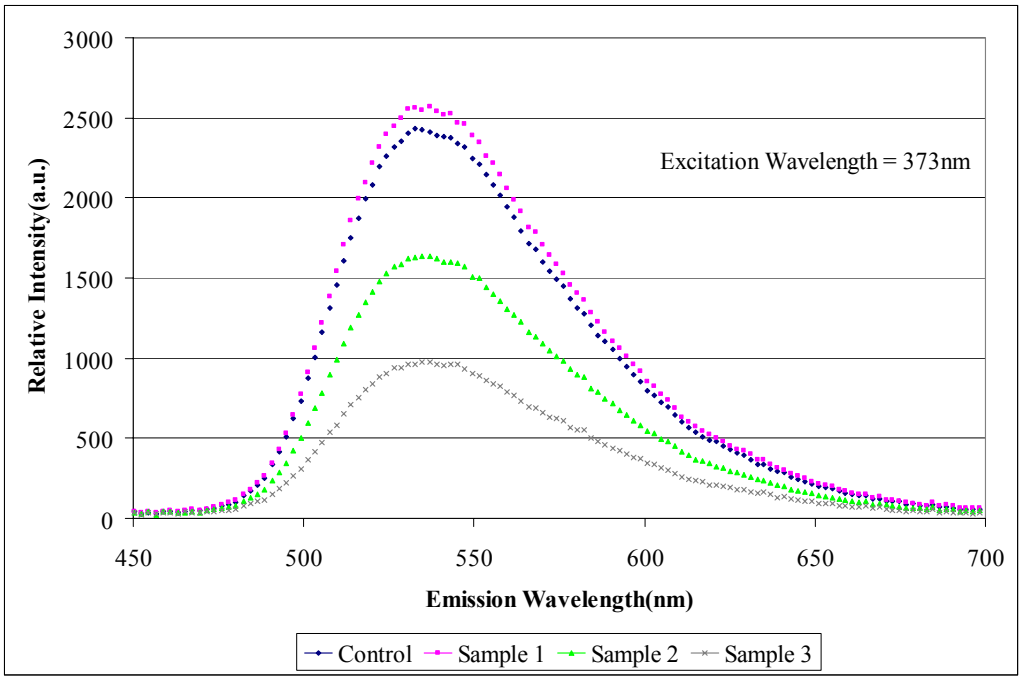

Figure 4: Fluorescent green emission of four printed ink samples irradiated with a UV LED and detected by a linear array CCD sensor.

3.3 PIN Photodiode measurements

The photodiode selected for this experiment was the Thorlabs DET36A [10]. This photo-detector has a minimum response rise-time of about 14ns thus satisfying the desired time resolution for dynamic testing. All mechanical parts of the detector system (lens tubes, etc) are standard optical components so they are easily extendible, scaleable, and serviceable with a minimum of effort and expense.

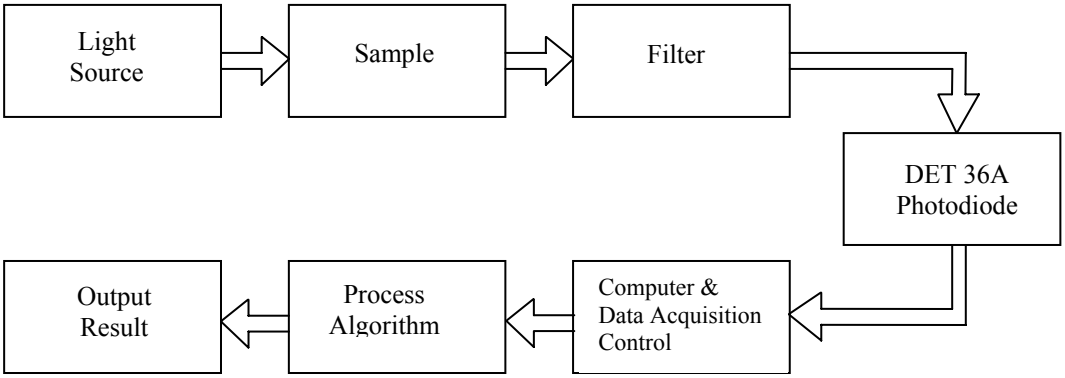

Figure 5: Block diagram of Photodiode and data reporting system.

The system block diagram is shown in figure 5, whereby the box representing Computer and Data Acquisition Control included proprietary software written by the authors for this experiment. In this case the hardware selected to interface the analogue signal from the photodiode to the PC was a PC-CARD DAS16/12-AO manufactured by Measurement Computing [11].

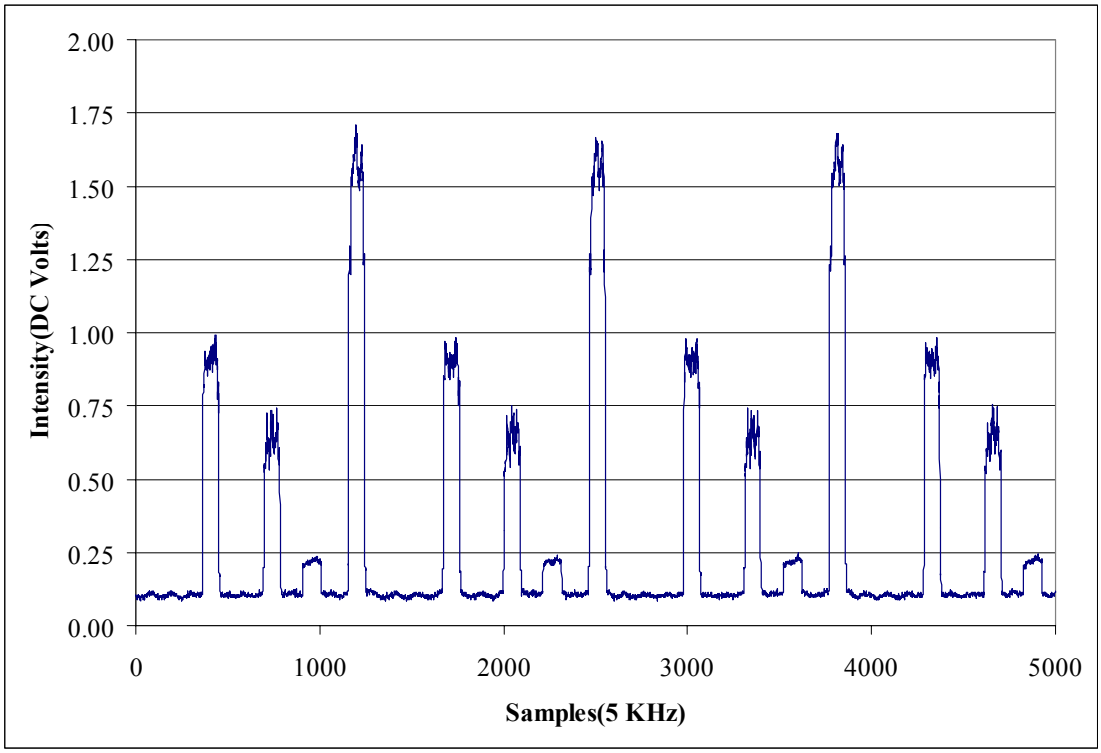

Figure 6: Detection of Fluorescent samples using a PIN Photodiode.

For this part of the experiment, samples were attached to a rotating drum-rig that was driven by a variable speed motor and controller. In the case of measuring the presence of the fluorescent samples, three samples of different print weight (descending order) and one sample with no print was attached to the drum-rig at approximately 90 degree displacement. Figure 6 shows the output response of the photodiode for each of the four samples, in descending order of heaviest print weight to lowest print weight, and the fourth sample with no print. The sampling rate of 5KHz is confirmed, effectively collecting the emissions from the samples for 1 second, of which during this period the drum-rig has rotated nearly four times, hence the reason for seeing the same samples repeated.

The experiment was successfully repeated for phosphorescent materials in that discrimination between different print densities were observed. In this case the light source was a 980nm laser which is very close to the peak response of the photodiode (970nm), so a balance of optical attenuation with filtering versus analogue output is paramount in succeeding with a low cost high speed photodiode detection system.

4. Conclusion

Three measurement systems have been evaluated for the detection of luminescence from printed samples irradiated by UV and IR radiation were reported in this paper. Experimental data show that the DMS offer superiority in analysis of materials in terms of resolution, PMT sensitivity and excellent signal to noise ratio. In comparison, the low cost CCD spectrometer can achieve merits in resolution, sensitivity and signal to noise, albeit not to the level of the DMS, but good enough to be considered for batch to batch measurement of ink formations and quality control measurements. In addition a high speed luminescence detector has been proven to demonstrate the ability to assess the presence of luminescence and that discrimination between print weights is achievable up to 15 samples per second.

The final outcome of the above investigation resulted in the prototype development of a fully integrated CCD spectrometer, tested, and evaluated for the use of UV and IR luminescent materials. The high speed

photodiode option has been commissioned into an online quality control inspection system.

References

[1] A D McGrath and S M Vaezi-Nejad" Measurement of Luminescence in Coloured Printed Materials" Journal of Metrology and Measurement Systems, 2006, Vol.XIII, No3, Sep 06 pp221-230

[2] M Vicic, L G Sobotka, J F Williamson, R J Charity and J M Elson, " Fast Pulsed UV light source and calibration of non-linear photomultiplier response", Nuclear Instruments and Methods in Physics Research A, 507 (2003), p.636-642.

[3] R P Jenner and S M Vaezi-Nejad "Development of novel light source for investigation of amorphous semiconductors as sensors for process tomography", Measurement + Control Journal of Institute of Measurement and Control, Vol. 32, No: 3, pp.75, April 1999.

[4] S M Vaezi-Nejad, Editor "Selected Topics in Advanced Solid State and Fibre-Optics Sensors" published by the IEE in 2000.

[5] S M Vaezi-Nejad, "A Random Walk in Sensors: Recent Advances and Market Opportunities", Measurement and Control Journal of Institute of Measurement Control, Vol. 31, pp.80, April 1998.

[6] Nichia Corporation, specification for Nichia UV LED, 2002.

[7] C Fitzpatrick, C O'Donoghue and E Lewis, "A novel multi-point ultraviolet optical fibre sensor based on cladding luminescence" Measurement Science and technology, 14 (2003), p.1477-1483.

[8] C Palmer, Diffraction Grating Handbook, 4th Ed, Richardson Grating Laboratory, New York, 2000, See Chapter 6 on Plane gratings and their mounts.

[9] E F Schubet, "Light Emitting Diodes", Cambridge University press, 2003, p59.

[10] Thorlabs, specification for DET 36A Photodiode.

[11] Measurement Computing, specification for the DAS 16/12-AO.