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A comparison of the emission characteristics of UV-LEDs and fluorescent lamps for polymerisation applications

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Abstract

Ultraviolet (UV) fluorescent lamps are widely used in the manufacturing process of biomaterials. The possibility of replacing these lamps with ultraviolet light emitting diodes (UV-LEDs) was investigated and the results are presented here. A number of emission characteristics, including the spectral output and intensity of both light sources were measured and compared. The warm up time of the UV-LED was found to be faster than that of the fluorescent lamp while their stabilities were found to be comparable. The ability of each source to initiate photopolymerisation in a biomaterial sample was monitored using Fourier Transform Infrared spectroscopy and the percentage polymerisation calculated. The results presented here show that UV-LEDs are a viable alternative to UV fluorescent lamps in the manufacturing process of biomaterials.

Keywords: UV-LEDs; Fluorescent lamps; Photopolymerisation

1. Introduction

Lighting technology is constantly striving to develop ideal light sources with improved specifications such as ruggedness, longer lifetime and stability which would better tailor their suitability to applications in commercial and industrial lighting [1].

Light sources have evolved from early incandescent lamps to gas emission sources such as fluorescent lamps and then into recently developed solid-state sources such as light emitting diodes (LEDs) [2–4]. It is the application of the latter LED-based systems and how they can be used to replace the earlier sources, while eliminating many of the physical and commercial drawbacks that is of interest to the current research. The development of the first practical visible LEDs in 1962 heralded the beginning of a new era in the development of lighting technology [5]. Over time these LEDs have been replacing traditional lamps in a number of areas due to their lower energy consumption, stable optical properties and ruggedness [6]. The research presented here is concerned with replacing ultraviolet (UV) mercury (Hg) fluorescent lamps, currently being used by contact lens manufacturers in their photopolymerisation processes, with novel ultraviolet light emitting diodes (UV-LEDs). An example of this type of replacement technology has seen blue spectrum LEDs replacing traditional tungsten–halogen light sources in photopolymerisation processes in dentistry, where blue light sources have traditionally been used to photopolymerise the dental composites [7–9] For example, Fujibayashi et al. [10] showed that blue LEDs produce a degree and depth of photopolymerisation significantly greater than those obtained using halogen lamps.

When choosing ideal light source specifications for industrial processes, such as contact lens photopolymerisation, a number of factors need to be considered. These include output intensity and wavelength range and the related electrical output efficiency (i.e. conversion from electric energy to radiation energy), whether the light output is continuous or modulated (i.e. DC or AC), lifetime and start-up characteristics. For photopolymerisation processes it is important that the light source emits the majority of the output intensity at the key photopolymerisation wavelength

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Table 1
Comparison of LED properties to those of fluorescent lamp

LEDs	Fluorescent lamps (FL)
Long life (50,000–100,000 h) [24,25].	Short operational life (2000–10,000 h) [26].
Controlled wavelength range	Many wavelength peaks (need filters to get exact wavelength)
DC	AC
Cost efficient	Expensive (ballast & expensive electronic circuits required)
Energy savings (low heat, almost all energy converted to light)	Wasted energy (lot of heat generated)
Durable (shock & vibration resistant)	Fragile (minimal force, glass tube will break & lamp will cease working)
Environmental friendly disposal	Hazardous materials (Hg & glass)
Illumination is inbuilt	Unfocused, uneven illumination
Fit easier into modern electrical circuits & process lines	Repair/replacement of FL electronic components is not easy due to their size and is expensive

with high efficiency, rapid start-up and stabilisation and constant output. Table 1 outlines some of the advantages of LEDs over fluorescent lamps.

Many contact lens manufacturers currently use UV fluorescent lamps in their photopolymerisation process. An example of these sources is the Philips PL-S 9W/10 low-pressure Hg lamp (Eindhoven, The Netherlands), that according to the manufacturers specifications emits UVA [11] radiation in the 350–400 nm region and has a peak UV wavelength of 370 nm. These lamps consist of two singled-ended fluorescent tubes fused together and operate on the same universal ballast as other compact fluorescent PL-S lamps. The lamp voltage is 60 V with a corresponding current of 0.17 A, the UVA radiation output of these lamps is 1.9 W and they have a useful life of 2000 h [12] as quoted by the manufacturers, with a typical efficiency of 21%.

This research examines the possibility of replacing these UV fluorescent lamps with a UV-LED in photopolymerisation processes. To achieve this a range of specifications of these lamps and a new technology UV-LED, many of which are highlighted in Table 1, were examined and compared. The lamp and LED were then used to photopolymerise a test contact lens monomer and a comparison made of the extent of photopolymerisation achieved with both. This data was then used to investigate whether the LED can achieve a similar degree of photopolymerisation, or better, to that which is achieved using the Hg fluorescent light source. The purpose of this paper is to investigate and compare the emission characteristics of two different light sources with the potential of replacing one with the other in an industrial application. It is not the purpose of this paper to fully investigate the factors involved in the photopolymerisation process. Once proof of concept has been established the photopolymerisation achieved with the two different light sources will be fully characterised.

The LED used for comparison was the Roithner Lasertechnik model LED375-66-60-110 (Vienna, Austria). This UV illuminator consists of a total of 60 UV diode chips, which is quoted as having a typical total radiated power of 150 mW at a DC current of 200 mA and a peak wavelength of 375 nm [13]. LEDs have been quoted as having an efficiency of 30% [14].

For both the lamp and the LED, the key specifications outlined above were determined and compared, either from the available manufacturer's specifications or using a range of experimental techniques described below. This paper empirically examines the output characteristics of a number of UV sources for use in photopolymerisation, the essence of which is that the rate of cure is proportional to the square root of the absorbed light intensity [15]. While this theory is not rigorously proven in the methods and results below it essential governs the behaviour of the photopolymerisation examined. Once it has been shown that the novel LED sources provide a viable alternation to the existing Hg lamp technologies the theoretical behaviour of the LED output and its effect on the photopolymerisation process can be rigorously examined and correlated to known theory.

2. Method

To experimentally compare the specifications of the Hg fluorescent lamp and UV-LED a number of important factors relating to their respective configurations and operating principles have to be considered. The most important of these is how to relate the light output from a fluorescent tube to that of an LED so that a reasonably logical inter-comparison can be made. The output from the LED is relatively straightforward as it is simply a 12.3 mm diameter array of miniature diodes that is considered as a single output unit from which measurements can be directly made. As it has no front end lenses, the output light is measured by a detector system placed directly in front of it. Assuming the light collection optics of the detector is lesser than the output beam diameter of the LED a simple $1/r^2$ measurement can be carried out. The fluorescent lamp on the other hand consists of two 128 mm long, 13 mm diameter, fluorescent tubes that do not compare well with the LED in their output light field. To overcome this problem the lamp was completely masked off except for an area equal to the diameter of the LED. The output nature of the two sources was then reasonably similar so that certain specification comparisons could be made. While the output of the LED is planer the masking off of the fluorescent lamp leads to an approximation and does not take into account the curvature of the lamp behind it. This curving means that the emitting area of the lamp would be bigger but overall this error would be probably negligible.

As photopolymerisation is wavelength dependent, the first property investigated was the spectral output of each light source, i.e. the wavelength emitted. The spectrometer