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LEDs for energy efficient greenhouse lighting

Devesh Singh [1], Chandrajit Basu *, Merve Meinhardt-Wollweber, Bernhard Roth

Hannover Centre for Optical Technologies, Nienburger Str. 17, 30167 Hannover, Germany

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ABSTRACT

Light energy is an important factor for plant growth. In regions where the natural light source (solar radiation) is not sufficient for growth optimization, additional light sources are being used. Traditional light sources such as high pressure sodium lamps and other metal halide lamps are not very efficient and generate high radiant heat. Therefore, new sustainable solutions should be developed for energy efficient greenhouse lighting. Recent developments in the field of light source technologies have opened up new perspectives for sustainable and highly efficient light sources in the form of LEDs (light-emitting diodes) for greenhouse lighting. This review focuses on the potential of LEDs to replace traditional light sources in the greenhouse. In a comparative economic analysis of traditional vs. LED lighting, we show that the introduction of LEDs allows reduction of the production cost of vegetables in the long-run (several years), due to the LEDs' high energy efficiency, low maintenance cost and longevity. In order to evaluate LEDs as an alternative to current lighting sources, species specific plant response to different wavelengths is discussed in a comparative study. However, more detailed scientific studies are necessary to understand the effect of different spectra (using LEDs) on plants physiology. Technical innovations are required to design and realize an energy efficient light source with a spectrum tailored for optimal plant growth in specific plant species.

Contents

1. Introduction

Solid state lighting using light-emitting diode (LED) technology represents a fundamentally different and energy efficient approach for the greenhouse industry that has proficient advantages over gaseous discharge-type lamps (high pressure sodium lamps) currently used in

* Corresponding author. Tel.: +49 511 762 17904.
E-mail address: c.basu@hot.uni-hannover.de (C. Basu).
[1] Present address: Department of Environmental Sciences – Botany, University of Basel, Schönbeinstrasse 6, CH-4056, Switzerland.

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most greenhouses [1,2]. LED is a type of semiconductor diode which allows the control of spectral composition and the adaptation of light intensity to be matched to the plant photoreceptors in order to furnish better growth and to influence plant morphology as well as different physiological processes such as flowering and photosynthetic efficiency [3]. LEDs have the ability to produce high luminous flux with low radiant heat output and maintain their light output efficacy for years. The incandescent or fluorescent bulbs contain filaments that must be periodically replaced and consume a lot of electrical power while generating heat [4]. However note that the operational lifetime of fluorescent bulbs are in the order of 20,000 h while only 1000 h are expected for incandescent bulbs. LEDs, however, do not have filaments and, thus, do not burn like incandescent or fluorescent bulbs. Normally, LEDs are known to have lifetimes in the order of 30,000–50,000 h and even beyond. Due to low radiant heat production, LEDs can be placed close to plants and can be configured to emit high light fluxes even at high light intensities [4,5].

An LED is a solid state device and can easily be integrated into digital control systems facilitating complex lighting programs such as varying intensity or spectral composition over a course of plant developmental stages [3]. Light under which plants are grown affects their growth and physiology (flowering and photosynthetic efficiency) in a complicated manner [6]. Light quality and quantity affect the signaling cascade of specific photoreceptors (phytochromes, cryptochromes and phototropins) which change the expression of a large number of genes. Using LEDs as a lighting source, it is possible not only to optimize the spectral quality for various plants and different physiological processes, but also to create a digitally controlled and energy efficient lighting system [7,8].

The high capital cost of LED lighting systems is an important aspect delaying the establishment of LED technology in greenhouse lighting. However, technological development and mass production (based on high demand in general and in the greenhouse industry in future) is expected to reduce the capital and operating cost in the future significantly [2,9,10]. A properly designed LED light system can provide highly efficient performance and longevity well beyond any traditional lighting source [11]. Research on LED lighting for plant growth has been going on for almost two decades now. LED lighting on various vegetables has shown good results in terms of maximal productivity and optimal nutritional quality, paving the way for a wider acceptance of LED technology in greenhouse lighting in future. This review provides a summary of research done on plants (photosynthesis, growth, nutritional value and flowering) using LED lighting systems and addresses the important questions such as

- Why should LED lighting systems be preferred over traditional lighting sources?
- What spectral composition should be used and should it be adjustable?
- What are the major challenges for LED lighting systems?

2. LEDs and their practical perspectives

Energy is an important factor which contributes about 20–30% of total production cost in greenhouse industry [12,13]. Appropriate crop lighting is a necessity of the greenhouse industry, particularly in regions where the seasonal photoperiod (natural day length) fluctuates and there is not sufficient light for optimal plant growth. Nowadays, high pressure sodium (HPS) lamps are the most commonly used light sources in the greenhouse industry. HPS lamps operate at high temperature ($\geq 200\,^{\circ}$C), resulting in significant radiant heat emission (infrared) in the direct environment [14]. Even though heat is required for plant growth in general, the radiant heat affects plants growth negatively if lamps are placed close to the plants. That is why these lamps are always placed at a certain (≥ 2 m for HPS) height. Of course, heating is a considerable cost factor in greenhouse industry, but heat generated by HPS lamps does not significantly contribute to keeping the greenhouse warm for optimal plant growth. The major reason for this is the fact that lighting and heating are usually necessary at different times of the day, i.e. heating at night when outside temperatures drop low and lighting during the day, when heating by solar radiation is maximal anyways. So, additional heating sources, especially in winter, are required to maintain the optimal growth temperature and it is generally more efficient to be able to control heating and lighting independently. Compared to radiant heat from HPS lamps, there are more economical and energy efficient ways to maintain the optimum temperature inside the greenhouse such as heating systems utilizing warm air or water flow, thermic screens, natural and forced ventilation. This characteristic (radiant heat production) restricts the possibilities for future use of HPS lamps in energy efficient greenhouse concepts [15]. Thus, a new technology which significantly reduces the electricity consumption and produces low radiant heat for crop lighting while maintaining or improving the crop value (growth and nutritional value) is of great interest to the greenhouse industry.

LEDs represent an energy efficient approach for greenhouse lighting that has technical advantages over traditional light sources with fragile filaments, electrodes, or gas-filled pressurized lamp enclosures [11]. LEDs have the potential to play a variety of roles in greenhouse lighting. They are also suited for research applications (e.g., in growth chambers for tissue culture applications). LEDs are solid state light emitting devices. The key structure of an LED consists of the chip (light-emitting semiconductor material), a lead frame where the die is placed and the encapsulation which protects the die (Fig. 1) [3]. Note that LEDs are available in different sizes and packages. An example of chip on board (COB) design is shown in Fig. 2. LEDs can be manufactured to emit broad-band (white) light or narrow-spectrum (colored) wavelengths specific to desired applications, for example plant responses [16]. In LEDs, waste heat is passed up separately from light-emitting surfaces through active heat sinks. This is particularly important for high intensity LEDs because the light source can be placed close to crop surfaces without risk of overheating and stressing the plants [11].

As the name suggests, an LED chip is basically a diode (pn-junction), designed to allow electrons and holes to recombine to generate photons. This is depicted in Fig. 3. The energy levels (and hence wavelengths) of the emitted photons depend on the semiconductor band-gap structures of the chips concerned. The detailed quantum mechanical description of the working principle of LEDs is beyond the scope of this review.

As far as efficiency is concerned, note that an incandescent lamp converts $<5\%$ of its input electrical energy into light [17] whereas commercial LEDs with $>50\%$ efficiency are well known. This indicates the potential of LEDs in energy efficient lighting.

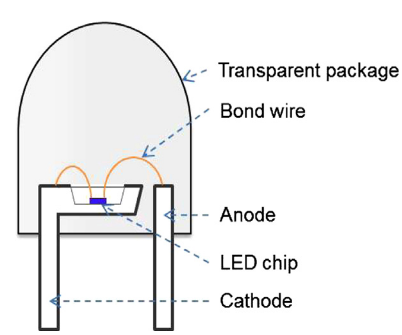

Fig. 1. The key structure of an LED.