Remote LED lighting technology for producing and processing food

Francesco Battisti[1], Serena Pastore[2*], Luigi Scapin[1], Luigi Lessio[2]

1 IODA s.r.l, Rubano (Padova), ITALY
2 INAF-Astronomical Observatory of Padova, vicolo Osservatorio 5, Padova, ITALY
*[*serena.pastore@oapd.inaf.it](mailto:serena.pastore@oapd.inaf.it)*

Keywords: LED technology, food processing technologies, LED lighting, LED-UV, Deep LED UV

Abstract

Food producing and processing industries face with several challenges regarding food illumination (e.g., providing a high quality light experience and color rendering while facilitating inspections) and using Ultraviolet (UV) light for sanitizing, disinfection or germicidal treatments both in food production lines and for the food itself directly or through tools (i.e., used in packaging and processing). The paper describes the development of an innovative product, called RLTProFood (remote LED light technology for processing and producing food), that was designed for giving a customized LED-based lighting system able to deliver different source light from visible to UV according the benefits required by customers. Currently developed in two main configurations (e.g., LED visible light and UV LED light), the product has its main application in the context of processing and producing fresh and possibly organic food especially fruits and vegetables.

1. Introduction

Food producing and processing industries face with different challenges related to food lighting and the type of light source. An adequate visible light is needed to have better visibility both for direct lighting of the food (e.g., providing a high quality light experience and an excellent color rendering) and in food production line and working facilities for inspection activities. Ultraviolet (UV) light is instead used in the food industry as a sanitizing, disinfection and germicidal method [1] applied to productions lines, materials, surfaces and other tools as well as for air and water disinfection also in food production environment. Usually lighting in such environment is provided through traditional lamps. However, compared to LED lamps [2], traditional visible lamps (e.g., compact fluorescent lamps) have a short duration, higher operating and maintenance costs and energy consumption in addition to containing mercury. UV lamps manifest the same issues. Since, although with some exceptions, mercury is banned also in the European legislation [3], traditional lamps both in visible light than UV will be replaced with LEDs. The paper describes the development of an innovative product, called RLTProFood (remote LED light technology for producing and processing food), that was designed for giving a customized lighting system in a food working environment, and has received funding from the EU's Horizon 2020 research and innovation programme. Its specific features are related to the technologies and techniques used to provide the light in a remote way and to the design that allows customizing the type of source light from visible light to the UV light. The remote technique feature means that the product's components are not exposed to the food, since the product is installed outside the food-working environment and the light is guided through a road. In this way, the product could be also installed in environment with extremely high or low temperatures (e.g., backing ovens or fridges). Moreover, the possibility to deliver a light source in the whole spectral range and with different settings (e.g., light emitted and intensity of the light lumen) can meet the different requirements of final users (e.g., the customers) and help to propose different solutions for the different kind of benefit required (e.g., visible lighting, sanitizing, disinfecting, and germicidal method). RLTProFood is currently implemented in the visible LED configuration, while the UV LED-based configuration is available as a proof-of-concept (POC). Some open issues regarding the development of a prototype concern the availability and provision of the UV LEDs. The requirements related to the type of application and thus to the customers require the use of deep UV LED with higher output power (e.g., 50mW) and specific wavelengths (e.g., around 285nm), since the need of destroying bacteria, spoils and fungi that can contaminate the food (i.e., fresh and organic ones). Currently, deep UV LEDs with such features are not fully available at an affordable cost, while in general deep UV LED seems to manifest performance issues [4].

2. The remote LED technology

The RLT lighting system was designed, developed by IODA at the end of 2014. IODA has also applied for a patent (e.g., as utility model) in Italy (PD2014A0). The RLTProFood solution consists of a main system (Fig. 1) structured in four parts: the optical light driver (ODS) system, the hubs, the fixing system and the electronic components.

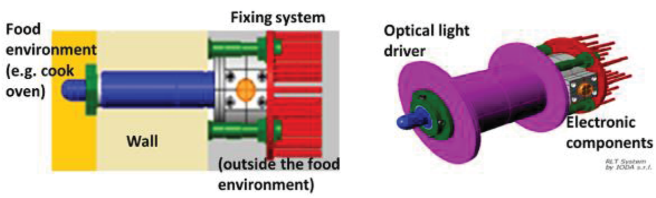

Fig. 1 Main components of the RLTProFood system and 3D representation.

The light driven by the optics and the LED source are emitted in the food target environment (e.g., a cook oven), while the other parts of the products potentially dangerous are left outside the area. The optical light driver is customized to capture the light emitted from the led source and guided it through a glass rod until the head of it. The fixing system, that allows installing the product in an easy way and no maintenance request, is able to compensate the thermal expansion of the wall structure/oven, and the differences in parallelism between the inner wall and the outer wall of the structure. For its design, it has an excellent compactness, it is IP 68 rating, and it has been designed with a specific attention to each component in order to be made with sustainable materials. For this attention, there is the intention for applying for the RLT system to be Ecolabelled [5] in order to certify towards customers that the company is increasing its environmental sustainability by manufacturing products of good quality with reduced environmental impact.

Considering the possibility of varying the source light changing the type of LED, currently the RLTProFood has been designed for two working configurations using visible LED and UV LED trying to address different issues in food industry. The product in the LED visible configuration is shown in Fig. 2 and was successfully applied in cooking ovens for bread. The target market is food industry considering in specific fresh and preferably organic food such as fruits and vegetables, fresh pasta and bakery, diary

Fig. 2 Overview of the final product (visible configuration), its installation in a wall (central figure), and application in a food cooking oven.

3.1. The visible LED RLT system

The RLT system configured for working with LED visible light, addresses the issue of the achievement of high visibility and well-distributed lighting in food working facilities. It has demonstrated its efficacy when installed into a cooking oven, since its compactness and robustness help to have a higher visibility, and reduce the waste of traditional lamps that in these extreme conditions are subjected to frequent breakages. In general, the product installed inside the processing/production facility, provides a set of benefits respect current solutions arising both from the use of an energy-saver technology (e.g., LED) as on the design and structure of the product itself. Actually traditional lighting are realized inside the environment where food is processed and packaged and makes use of traditional light sources (e.g., bulb light), even if in some contexts, such as the supermarkets, the use of LEDs for lighting food is spreading [6]. LEDs use less power (watts) per unit of light generated (lumens) assuring an higher life span (e.g., 6-8 watts and 50.000 hours against 60 watt and 1200 hours for the incandescent light bulbs and 13-15 watts and 8000 hours for the compact fluorescents (CFLs) lamps). An optimal lighting accentuates products (e.g., fresh food) and create an engaging shopping experience, since the unique properties of LED lighting brings bright colors and textures that enhance the appeal of merchandise on display. Moreover, LED light intensity does not decrease to the same extend as other form of lighting and has a low heat output so temperature levels can be easily maintained (i.e., useful for environment with low or high temperatures such as fridges or ovens) . In the US, the food and beverage industry is regulated by the Food and Drug administration (FDA), and all equipment and appliances used in food and beverage production and packaging, including lighting products, must meet stringent manufacturing standards set by NFS International (NSF). The same certification is however, request in some context in Europe [7].

3.2. The UV LED RLT system

The RLT system configured for working with LED UV light, will have, together the same benefits in energy and waste reduction, the value-added of an effective sterilization and/or germicidal technology as given by the UV light irradiation features. Optical radiation (Fig. 3) is any electromagnetic radiation in the wavelength between 100nm and 1mm, whose spectrum is divided into three main regions ultraviolet (UV), visible and infrared radiation. UV radiation, which is regulated in its use in a work environment by the European directive 2006/25/EC on the exposure to physical hazards, is further segmented into three areas: UV-A, UV-B and UV-C.

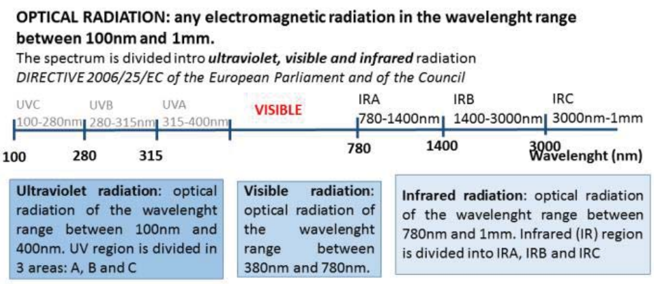

Fig. 3 Optical radiation

UVA or long-wave radiation is 400nm to 315nm and there are eye and skin safety concerns, but overall UVA is not nearly as dangerous as UVB or UVC, since the eye and skins damages increases as wavelength decreases, since energy increases. UVB ranges from 315nm down to 280nm. For over 40 years, UV light between 200 and 280nm has been used for disinfection of water, sterilizing air and surfaces [8]. When microorganisms are exposed to wavelengths between 200 and 280nm, the UV-C energy destroys DNS within bacteria. Germicidal disinfection peaks at between 260 and 280nm [9]. Currently UV light for germicidal treatment is mainly provided through mercury lamps, and most germicidal lamps use radiation near 254nm to break the molecular bonds within the bacterial and viral DNA, thus destroying them or prohibiting growth. Considering such effects, UV is used as a physical treatment for food to prolong the shelf life of products (e.g., especially important in the treatment of fresh fruits and vegetables to reduce the food-borne microbial load while maintaining nutritional properties even if frozen) and/or reduce health hazards associated with certain products due of pathogenic microorganism. These UVC lamps have a typical efficiency of approximately 30-40% (e.g., 30-40W of output), and are also used for disinfection of surfaces or packages where the food is in contact. UV is commonly used in the US with the FDA) approval [10] for some kind of organic food (e.g., cheeses, baked goods, and fresh produce). EU legislation approves (Directive 1999/3/EC) for foods and food ingredient irradiation on a specific list of products (e.g., fruit and vegetables, and casein). However, according to the EU experts [11], UV could be applied on all kinds of equipment used in plant or animal production or in food processing and handling, because this irradiation treatment leaves no residues in food, assuring food quality and authenticity. A list of the UV light irradiation's benefits in the several stages of food treatment (e.g., washing, packaging, freezing or backing) depending on the type of food (e.g., fruit and vegetables, pastries, bakery) can include:

- non-thermal, physical food preservation method which does not introduce any toxins or residues;
- increased shelf life of the food by retention of weight, freshness and colour for longer; reduced health risks such as Salmonella, E. Coli, Campylobacter and Listeria;
- improved quality, reduced spoilage waste and thus customer complaints, reduced use of chemicals, heat treatment, additives and preservatives.
- use of UV not only directly in the organic products but also to sanitize the production structure (trays, transport belts etc.)
- use of UV to reuse the washing water or purifying water provenience by spring sources.

In this context, the RLTProFood equipped with UV light, is an innovative product in the food industry for processing or producing food. It combines the several benefits of environment-conscious LED technology and UV irradiation, avoiding the harmful effects of traditional lamps (e.g., mercury), when applied in the organic food treatment market such as inside a bakery cooking oven (e.g., break down the bacterial load) or applied for product lines where fresh fruits, vegetables or fresh cheese are packaged. Currently in a POC version, there are some issues in the prototype development related to the availability in the market of the required UV LED and the specific regulations on food irradiation that are different in the several countries.

3.2. State of the art of UV LED and applications on food

UV LED light sources manifest more benefits compared to mercury lamps (Fig. 4). The LEDs instantly reach 100% intensity when turned on (i.e., stable optical output power with low voltage operation and instant on), the lifetime is not dependent on the number of on-off cycles (i.e., mechanically rugged) and they are mercury-free. Currently the issue is that there is a trade-off as the wavelength of an LED is decreased, so its efficiency. Moreover, efficacy drops off as the LED's temperature increases and reach thermal equilibrium (around 40°C and not 25°C that is the value provided for efficiency data by most LED manufactures). In addition, it is difficult to make a direct comparison with traditional mercury vapour UV lamps for the irradiance (watts per area) because the emitting area of an LED is different from a glass tube. From the market point of view, there is a distinction between near UV LED (NUV-LED) and deep UV LEDs (DUV-LEDs). The first ones (NUV-LED), that encompass the UVA spectral range and part of the UV-B (i.e. 300-400nm) currently represent the largest segment of the UV LED market.

Comparison of mercury and UV LED light sources		
Attribute	**Mercury Lamp**	**UV LED**
Bulb lifetime	10.000 hours	50.000 hrs
Warm-up time	2-15 min	Instantaneous
On/off cycles	Lifetime degradation	No degradation
Intermittent flow	10-60 min no-flow limit	Programmable
Drive circuits	Complex	Simplex, compact
Voltage	110-240	

Fig. 4 Comparison between mercury and UV LED

UV LEDs on the tail end of the blue spectrum, specifically those at 365 nm and 385mn are easier to manufacture and are currently the most efficient even if LED efficient at 365 nm is about 5-5% and thus limited for food context. Instead, deep UV LED (DUV-LED) [12] that are currently in the 250nm to 285nm spectral range could be more efficacy for food sterilization. UV LED solutions applied in food seem not available in the market. Probably, since the UV LED technology is already in development and thus its cost is very high considering the deep UV wavelength. There is, however, a great interest in the food market that has been showed for example by the US Sensor Electronic Technology (SeTi). Such UV LED manufacturer has conducted several studies [13] that have proven that UV LEDs with a wavelength of 285nm to 305nm are capable of raising the shelf life of fresh fruits and vegetables in refrigerators. Other studies [14] have also been made on lettuce and strawberries and results showed levels of polyphenol compounds can be maintained longer when exposed to UV LEDs. Strawberries in particular showed markedly visible effects of prolonged shelf life time, compared to other fresh produces. The three-year research conducted by USDA [15] showed UV light could raise anti-oxygen capacity in fruits and vegetables, and slow down the aging process by 20% to 50%.

Despite the interest, there are yet some issues related to DUV-LEDs components concerning their performance and provision considering the lower number of producers. Lately, these producers said they have done some progress in the deep UV technology. They are putting into production new UV LEDs for curing, disinfection and sterilization applications (e.g., an 50mW DUV-LEDs or a surface-mount device (SMD) LED at 275nm with 30mW of power at 350mA [16]). A summary of the different wavelengths used in UV lamps and UV LED is shown in Fig. 5, with its main applications.

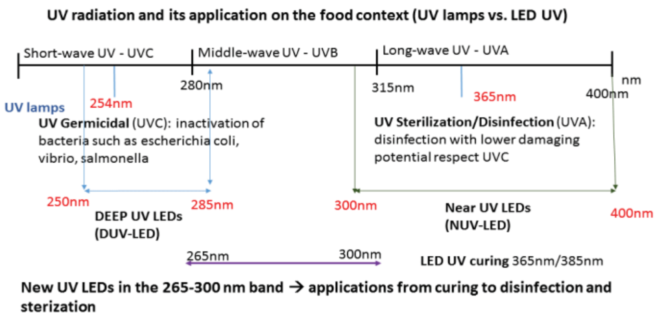

Fig. 5 Overview of the UV radiation and applications on food

For our specific food context, we have the need to customize the required UV LEDs (i.e., numbers, power and configurations) according the specific requirements of our customers. Some applications, for example in the packaging of fresh pasta, a requirement is the UV irradiation with a great intensity of light in a short time (e.g., around ms). This constraint requires UV LED of higher power (e.g., the 50mW DUV LED). Moreover, since the number of LEDs is related to specific type of bacteria or fungi different from each kind of food, also the specific configuration of LEDs is important.
We could use LED packaging or encapsulation by using Chip on Board (COB) or surface mounted as shown in Fig. 6.

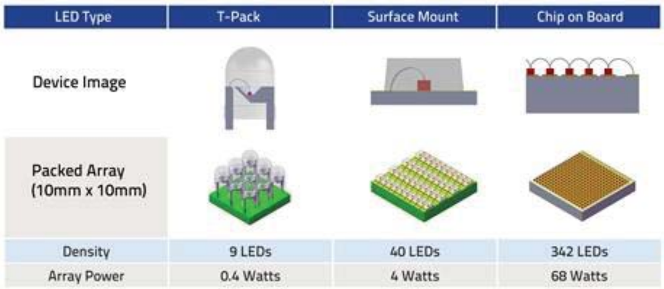

Fig. 6: Overview of LED array methods (source prophotonix.com)

However, the decision on the configuration is strictly dependent on the availability of the UV LEDs and their power.

3. Current development and open issues

The novelty of such project is a product, the RTL lighting system that is able to deliver in a remote way different range of lights in food production and processing facilities with the several benefits depending on the use of LEDs and the type of light delivered. In its main configuration, it offers energy and waste reduction, and efficient lightning without dispersion when working with visible light, while disinfection or germicidal solution when working with UV. While the product has demonstrated its efficacy in the visible light, the work in the UV LED is under development. The issues are currently related to the provision of suitable Deep UV LED (e.g., 285nm, 50mW) to provide the necessary power in a limited period as a constraint of the specific food application. Moreover, since the faster development in such technology towards the manufacturing, probably this problem will be resolved in the coming months, and a prototype version of the UV LED RLTProFood could be developed as ready to the market.

Acknowledgements

The project has received funded from the European Union's Horizon 2020 research and innovation programme under the grant agreement n.694588.

References

[1] Koutchma, T.: 'UV light for processing Food', IUVA News, 2008, 10, (5), pp. 24-29
[2] Narendran, N., Deng, L.: 'Color rendering properties of LED light sources', Proceeding of SPIE 4776 Solid State Lighting II, 2002.
[3] 'Regulation (EC), N. 1102/2008 of the European parliament and of the council of the banning of exports of metallic mercury and certain mercury compounds and mixtures and the safe storage of metallic mercury', http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32008R1102, accessed 1 August 2016
[4] Shatalov, M., Lunev, A., Hu, X., et al.: 'Performance and applications of deep UV LED, Int. Journal of High Speed electronics and systems, 2012, 21, (01).
[5] 'EU ecolabel for business, European commission, Environment', http://ec.europa.eu/environment/ecolabel/eu-ecolabel-for-businesses.html, accessed 30 July 2016
[6] Ames, K.: 'Go green and clean with LEDs for food and beverage lighting', 2016, LEDs magazines, 13, (2).
[7] 'NSF International, NFS-FoodEurope, Food equipment certification', http://www.nsf-foodeurope.com/service.asp?service_id=FEC, accessed 29 July 2016
[8] Mori, M., Hamamoto, A., et. al., 'Development of a new water sterilization device with a 365 nm UV-LED', Med. Bio. Computing, 2007, 45, (3), pp. 1237-1241.
[9] Allendre, A., Artes, F.: 'Combined ultraviolet–C and modified atmosphere packaging treatments for reducing microbial growth of fresh processed lettuce', Food Sci. Technol. /LWT, 2003, 36, pp. 779-786
[10] 'U. S. Food and Drug Administration, Irradiation in the production, processing and handling of food, http://www.fda.gov/OHRMS/DOCKETS/98fr/cf00135.pdf accessed 28 July 2016
[11] 'EU expert group, Agriculture and rural development', http://ec.europa.eu/agriculture/organic/eu-policy/expert-advice/documents/final-reports/index_en.htm accessed 29 July 2016
[12] Koutchma, T., Forney L.J., Harrison, E.A., Morau, C. I.: 'Ultraviolet Light in Food technology: principles and applications', in CRC Press, Taylor & Francis Group, 2009.
[13] Britz, S., Gaska, I., Shturm, I., Bilenko, Y. et al.: 'Deep Ultraviolet (DUV) Light-emitting diodes (LEDs) to maintain freshness and phytochemical composition during postharvest storage', Proc. of CLEO: applications and technology conference, OSA technical digest, 2013.
[14] 'SETI, Extended shelf life with UV LEDs', http://www.s-et.com/food-preservation.pdf, accessed 1 August 2016
[15] 'US FDA, Kinects of microbial inactivation for alternative processing technologies, Ultraviolet light, http://www.fda.gov/Food/FoodScienceResearch/SafePracticesforFoodProcesses/ucm103137.htm accessed 29 July 2016
[16] Wright, M., 'Nikkiso delivers 50-mW deep UV LEDs with 10,000-hour lifetime', LED Magazine, Feb. 2016, http://www.ledsmagazine.com/articles/2016/02/nikkiso-delivers-50-mw-deep-uv-leds-with-10-000-hour-lifetime.html, accessed 1 August 2016