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Application of High Brightness LEDs in the Human Tissue and Its Therapeutic Response

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1. Introduction

The peculiarities of the light emitting diode, such as low power consumption, extremely long life, low cost and absolutely secure irradiation power is a attracting many researchers and users. With the advancement and the emergence of new applications of LEDs on health manufacturers of these solid-state devices, they have improved in all parameters of interest to its applicability as the evolution of performance in the maintenance of lumen (photometric unit), several categories of power, availability and reliability of the color spectrum and wavelength.

The high intensity LEDs plays an important role in therapeutic application, aggregating the technology of solid-state devices and a variety of electronic converters that supplying these long-lifetime devices for controlling the output current, output power, duty cycle and other parameters that directly interfere in luminous efficiency in the wavelength and the response of treatments applied to human health.

In skin, the red light has restorative action, healing and analgesic, while blue has bactericidal action. The intensity of the beams of light emitted by LEDs on the skin is lower, since its cells maintain a good interaction with the light (Elder, D. et al., 2001). In addition to speeding up the cell multiplication, the light beam favorably act in the recovery of the skin affected by acne. A major advantage of LEDs is the emission of light in a broad spectrum, from ultraviolet to the near infrared.

Bearing in mind the important issues referred above, this work describes a wide study of the state of the art on this topic in concert with proposals of driver topologies and preliminary results based on ongoing experiments. The study has been motivated by the important benefits already mentioned and need of improvement of the driver topologies in this prominent field of study.

2. LED application in human tissue

The applications of LEDs in health are emerging as a wide interest filed in the scientific community due to its advantages, low cost and long lifetime of these devices.

2.1 Penetration of light generated by LEDs in human tissue

The process of refraction and reflection is intense in organic substrates. This process is responsible for the dispersion of light as shown in Figure 1. A detailed evaluation of this process is very peculiar, because the composition of substrates varies from person to person.

Despite the high spread, the degree of penetration is considerable, with approximately 50% of all incident radiation reaching the substrates immediately below of the skin (Yoo, B. H. Et al., 2002). By submitting the skin to the LED light in red (visible light) or near infrared (Arsenide of Gallium) radiation, a small portion is absorbed by the dermis and epidermis. This is due to the presence of these layers photoreceptors. As an example of photoreceptors present in these layers, we can mention the amino acids, the melanin, and other types of acids. Normally each type of photoreceptor is sensitive to a particular wavelength.

Thus, the light can be absorbed, depending on the color and the wavelength, so selective or not, depending on the need to which it applies. For example, the red light, near the infrared, easily penetrates the fabric because they are not blocked by blood and water as other wavelengths do.

Wavelengths of less than 630nm such as yellow, blue and green are considerably blocked by the hemoglobin in the blood, so they do not penetrate deeply (Marques C. et al., 2004). You can check this, for example, as a bright light through your fingers (the wavelength in red can cross).

Wavelength greater than 900nm are blocked by liquid from the skin and connective tissues. Many possible wavelengths in this range emit a large amount of energy away from the infrared that cannot be seen by the human eye, these type of radiation also starts to produces a certain amount of heat when interacting with the human skin (HTM, 2007).

2.2 Action of color and depth of penetration in human tissue

The blue is in the range of 430 to 485nm. The green is in the range of 510 to 565nm. The yellow is between 570 to 590nm. The red is in the range of 620nm to 700nm to the point that does not become more visible, in the range of 740nm.

Some companies that manufacture LEDs say that the yellow light helps remove wrinkles.

There is also some interesting research, which emphasize that the application of blue light helps in the elimination of bacteria that cause some forms of acne.

The phototherapy with the narrow band blue light seems to be a safe treatment and one additional effective therapy for treatment of mild and moderate acnes. Some researchers suggest that the green LED light can help against cancer, but this color cannot penetrate more than the skin.

3. Adequate wavelengths

There is some evidence that a wavelength provide better biological response than another.

Some research indicates that 620, 680, 760, and 820nm could be the most appropriate wavelength (Heelspurs, 2007) for health treatments. The LEDs commercially available emit light in some certain wavelengths, for example, at 630, 660, 850, and 880nm. These values are not exact, as may change during real operation and system unpredictable parameters (such as temperature and abnormal variation in the input current). There is a certain range of LEDs available with more biologically active action wavelengths. The wavelength of 630nm generated by certain LED can affect the peak of 620nm and the wavelength of 660nm generated by the LED is approaching the peak of 680nm, 850nm, and at the peak of 820nm. By operating the LEDs with currents in the range of mA, it is possible to improve the input waveform. It will be necessary to conduct a study before diagnosing which is the ideal wavelength for realizing the application and order which is intended. The best array of LEDs will be whatever the mixture a wavelength generated by LEDs and a non-pulsed,

although some wavelengths and with generation of pulses may reach deeper tissues (Heelspurs, 2007).
For the healing of cuts, wounds and ulcers to red light has a better performance in terms of its wavelength. The range of 800 to 850nm shows excellent healing characteristics acting to subcutaneous tissue.

3.1 Depth of penetration in human tissue depending on the wavelength

The penetration of light in human tissue is linked to the wavelength, that is, the greater the length greater will be their interaction in human tissues, since these wavelenghts respect the range of visible light (Heelspurs, 2007). Therefore, the application of a particular wavelength directly connected with the color to be used will depend on the application you want to achieve in the desired tissue segment, as shown in Figure 1.
The wavelength is controlled by tuning of the duty cycle of the converter. The value of the desired wavelength is measured by a spectrometer.

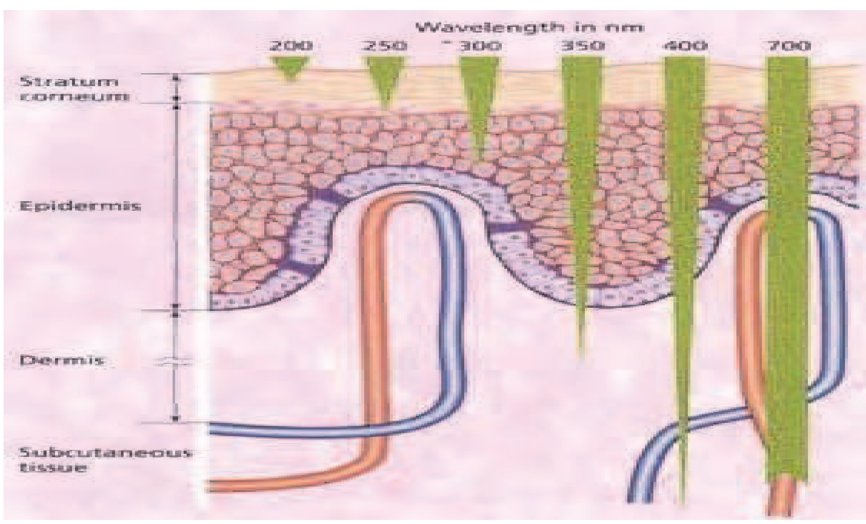

Fig. 1. Action of color and depth of penetration in human tissue.

4. Changing the wavelength peak

Control brightness study (N. Narendran, et al., 2006) demonstrates that the light output of each LED junction temperature can be controlled by the output current reduction (RCC - Reduction of Direct Current) or reducing duty cycle (PWM). The Figure 2 illustrates the change of the peak of wavelength depending on the level of current and duty cycle for the four types of LEDs.
The LEDs of white light show peaks for the blue and may have portions converting to yellow. However, the change of the peak of wavelength to the peak of yellow can be reduced.
Therefore, only the peak of wavelength of the blue was considered. For the Red LED AlInGaP (Figure 2a), the peak of wavelength decreased, or changed to blue, with the reduction of current or duty cycle. These changes were very similar. For InGaN LEDs based on the green (Figure 2b), in blue (Figure 2c) and white (Figure 2d), the peak of wavelength increased with the reduction of the current or the reduction of duty cycle. The change of wavelength was reduced with the reduction of the current or the reduction of duty cycle in a

LED that emits red light, in the remaining tested cases the opposite was verified (N. Narendran, et al., 2006).

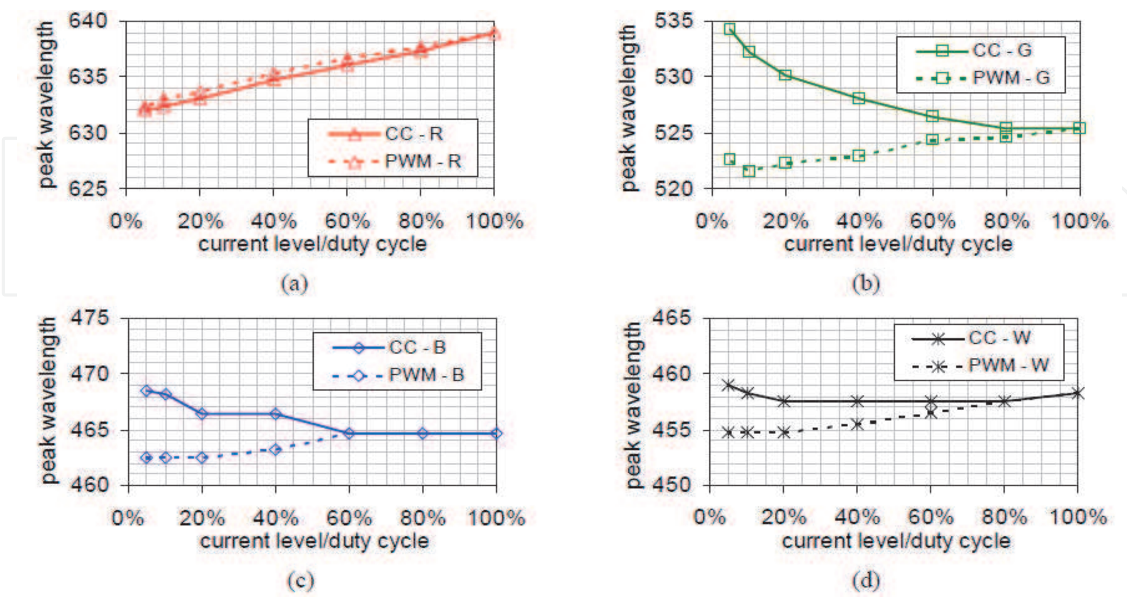

Fig. 2. Peak wavelength shift as a function of current level or duty cycle for (a) red, (b) green, (c) blue and (d) white LEDs.

5. Converters DC/DC applied in high-brightness LEDS

The application of switched converters in high-brightness LEDs is interesting, because these converters have higher efficiency than the linear converters. Thus, the main possibilities of implementing the isolated and non-isolated DC-DC converters. This analysis will facilitate the understanding of the effects of these converters and its influence on the high-brightness LEDs (Sá Jr., E. M., 2007). Resonating converters assist in the reduction of peak power; have low losses in switching and low electromagnetic interference. Therefore, these topologies are also of interest to applications with LEDs. The LEDs can also be fed by current chopper. Compared to a pure DC signal and this increases the peak value of the LED current. Moreover, the LED pulsing current contains high-frequency components. Some harmonics can cause problems of electromagnetic interference if the LEDs are separated from the converter. It is therefore of interest to quantify the generation of harmonics.

5.1 Converters not isolated commonly used for supply LEDs

The buck converter, shown in Figure 3, is widely used as power source for high-brightness LEDs.

The attribute of the source of current output makes such devices interesting electronic converters, mainly because its output current can be continuous.

Thus, the output capacitor C_{out} may have a small capacitance and it is unnecessary to use an electrolytic capacitor, which has the characteristic of a lifetime considerably smaller (Sá Jr., E. M., 2007).

The inductance output L_1, can be projected for the acquisition of a small ripple in the current wave, maintaining a stable optical characteristics and suitable temperature of the LED junction.

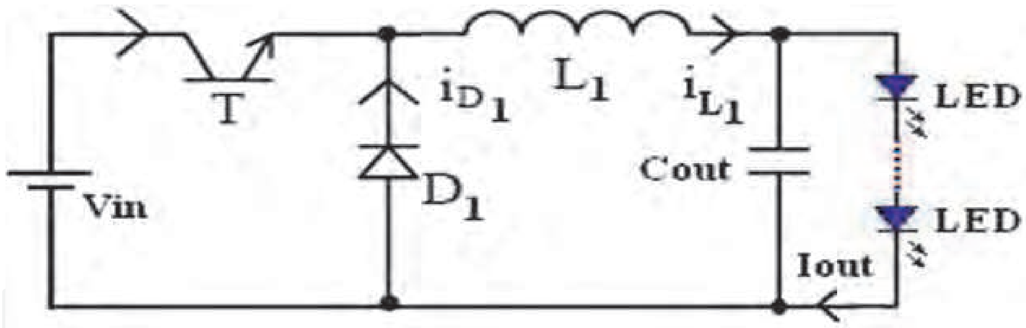

Fig. 3. Buck converter.

If the output capacitor is removed from the basic DC/DC converters, the current in the LEDs is no longer purely DC, but contains a pulsating component. For Boost or Buck-Boost converters the load of the LED is powered by an almost squared wave with a sufficiently high reactance. The CUK electronic converter is composed by a boost converter entry in series with a Buck converter in the output and a merger of two converters in series using only one controlled key. The composition of these two converters in series allows the input and output to operate in continuous mode. The gain of such static converter is the same as the Buck-Boost converter. The buck converter used in the output stage, allows to obtain a low ripple current in the LED, even for a small amount of C_{out} (Sá Jr., E. M., 2007). The Zeta converter consisting of a Buck-Boost input converter in series with a Buck converter in the output. Similarly to the CUK converter, the buck converter allows the output to obtain a low current wave of the LED. The SEPIC converter is composed of a boost input converter in series with a Buck-Boost output converter. The discontinuity of current output in this configuration does not make it attractive to be used in conjunction with high-brightness LEDs (Sá Jr., E. M., 2007).

5.2 Converters not isolated commonly used for supply LEDs

Currently, there is a considerable range of converters that can be used to supply LEDs, such as that with galvanic isolation. This sort of application employ the Flyback, Push Pull, Forward and resonant converters (Moreira, M.C., et al. 2008). The Figure 4 shows a system for supplying power to LEDs using galvanic isolation.

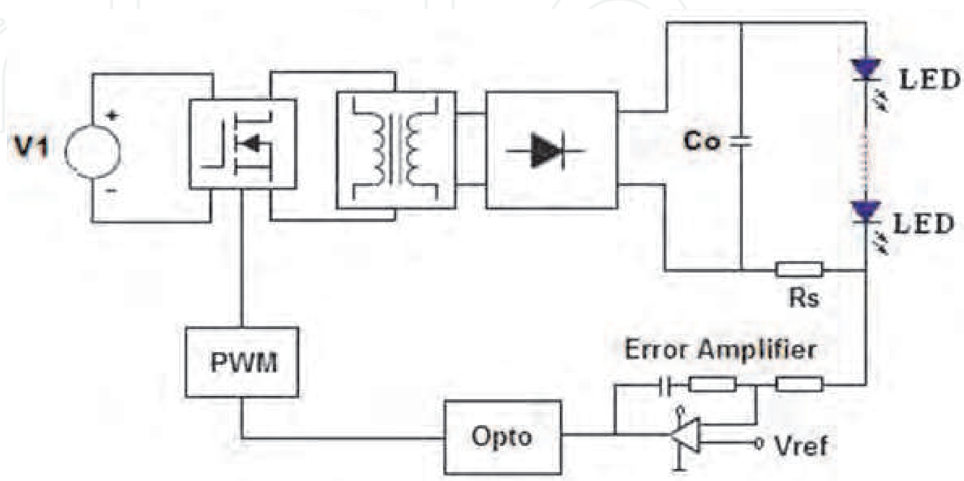

Fig. 4. Representation of a supply system for LEDs with galvanic isolation.

6. Topology proposals

After reviewing several possible topologies for LEDs power supply and control, four topologies are proposed for this study, considering their easy implementation and control of current making them attractive its use. Four converters have been developed. Flyback, Buck, Buck-boost and Sepic converters.
The Flyback converter was more robust and has the advantage of being isolated, but had some noise in the form of wave. The Buck converter controls the current and offers good response, but has the disadvantage of not being isolated.
The Buck-boost converter showed good response and a bit of noise. The Sepic converter showed a good response for current and stability.
In short, the Flyback converter was the most beneficial to the supply arrangements of LEDs. Will be presented the results of Buck and Flyback converters who had a good response (Moreira, M.C., et al. 2008).

6.1 Flyback converter

The Flyback converters of levels below 100W of power are widely used for the several applications and also for lighting with LED, normally, operating in discontinuous mode. This mode of operation is appropriate to control of current. The proposed topology is observed in Figure 5 and was developed to supply the array of LEDs, which produce red light (Moreira, M.C., et al. 2008).

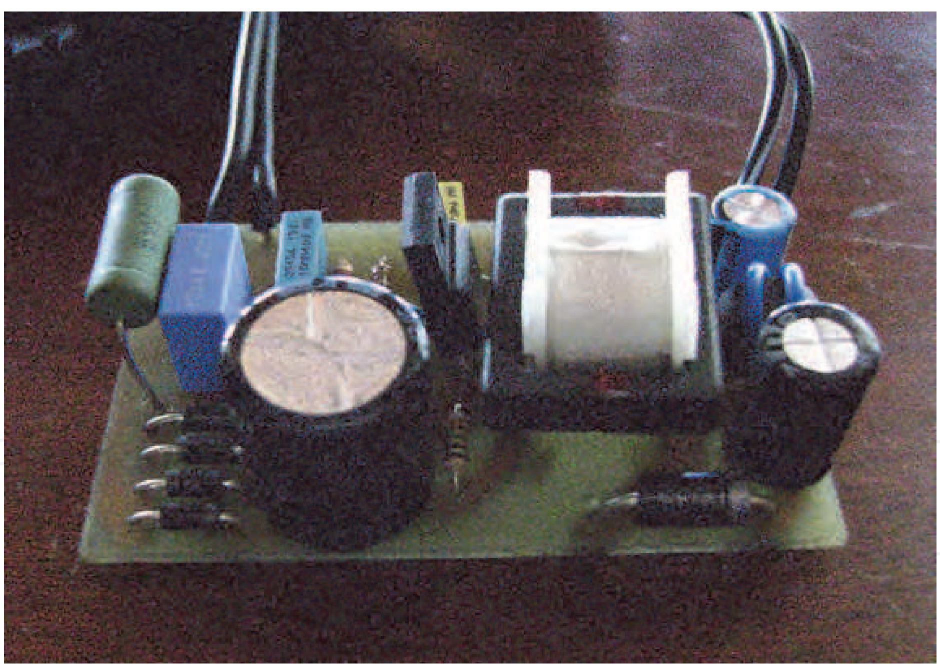

Fig. 5. LEDs powered by a Flyback converter.

The red color has a greater wavelength (in the range of 647 to 780nm) and penetrates more deeply into the tissue. Thus, it is indicated for healing and recovering deep tissues (Moreira, M.C., et al. 2008).
The Flyback converter employed in the experiments owns a universal voltage input and its maximum output voltage is 5V.
The maximum output current is 2A. His frequency of switching is 100kHz.

The proposed arrangement of red LED contains 30 high-intensity LEDs of 5mm, with wavelength in the range of 725 to 730nm. The current in each LED is around 20mA.
The source was designed to support up to 100 LEDs.
The Figure 6 shows a picture of the implementation of red LEDs in a patient who suffered a suture of 6 points.

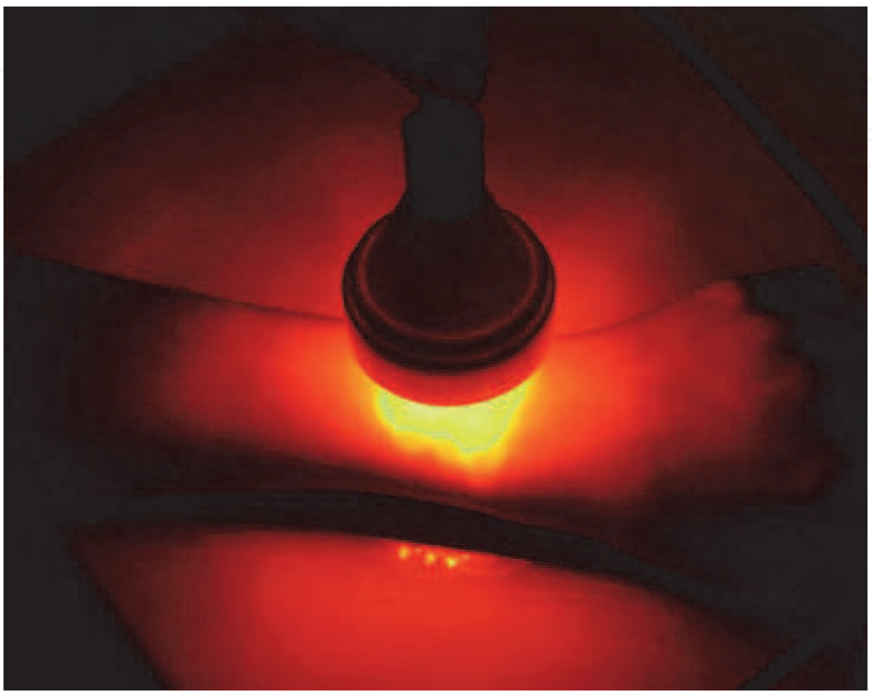

Fig. 6. Implementation of red LEDs in a patient who suffered a suture of 6 points.

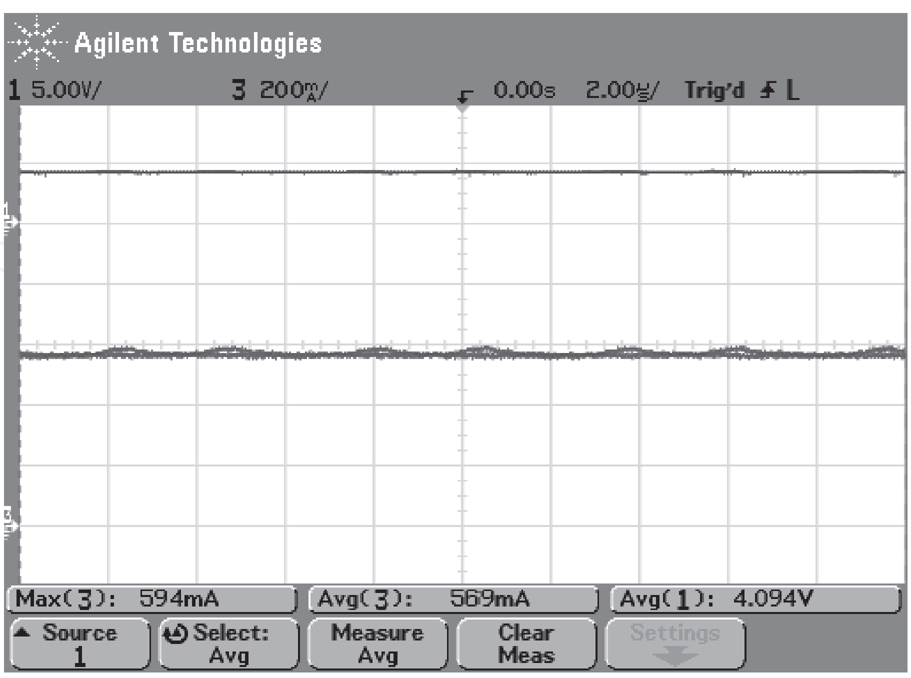

Fig. 7. Waveforms of voltage and current of the Flyback Converter - LEDs that emit the color red.

The estimate is that in 5 sessions (5 continuous days), 20 minutes each, the healing is complete, reducing the time for healing by 50% (Moreira, M.C., et al. 2008).
These tests are being conducted in patients with proper authorization and with the participation of two doctors, a surgeon and a dermatologist, in the West Regional Hospital in Chapecó, SC - Brazil.
Figure 7 shows the waveform of voltage and current of the Flyback Converter on the arrangement red. The voltage produced on the LED was 4.1V and current on the LEDs around 570mA.
The values obtained were close to the simulation and design (Moreira, M.C., et al. 2008).

6.2 Buck converter

The second converter developed has the Buck configuration as shown in Figure 8, with the following characteristics: Input Voltage DC-13V (after one stage rectified by with a Flyback converter) and the output voltage reaches 6V and maximum output current reaches 1A. The frequency of switching is 52kHz. The source has total isolation, even on short-circuit conditions in its terminals (Moreira, M.C., et al. 2008).

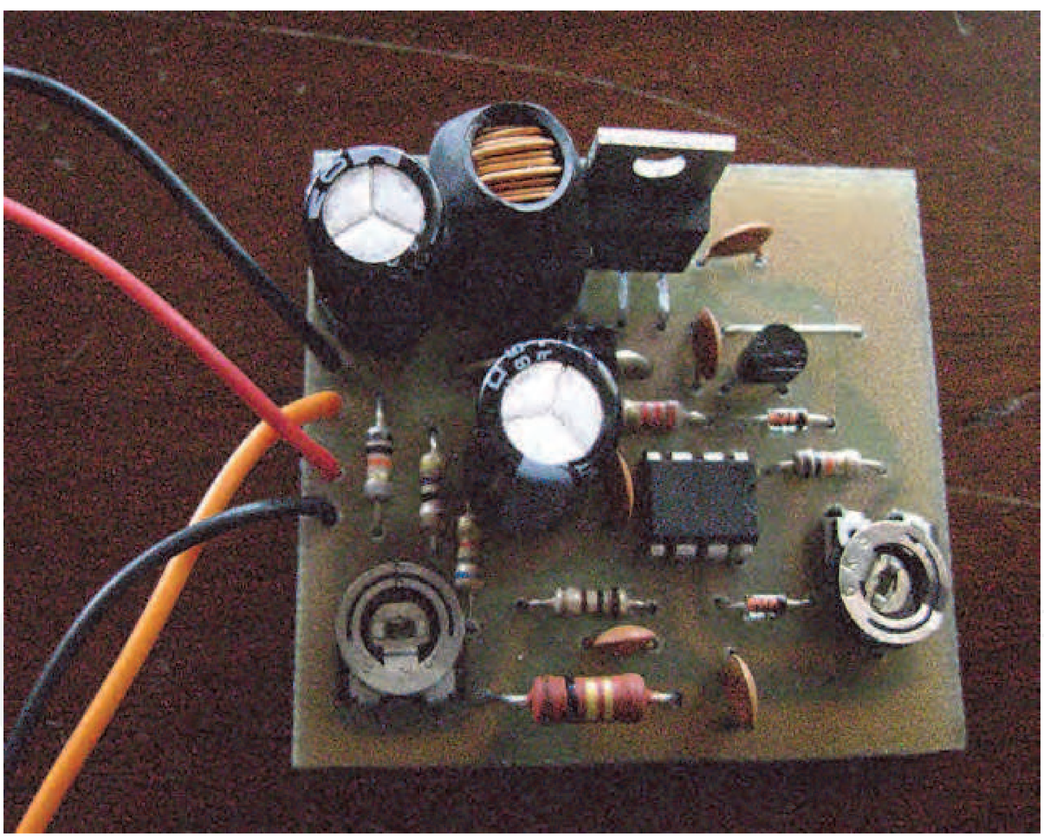

Fig. 8. Buck converter.

This topology has the same versatility of Flyback converter and supply the array of LEDs.
Figure 9 shows the waveform of voltage and current of the Buck Converter on the arrangement red.
The voltage produced on the LED was 3.8V and current on the LEDs around 580mA. The values obtained were close to the simulation and design.
Figure 10 shows the prototype in the laboratory.

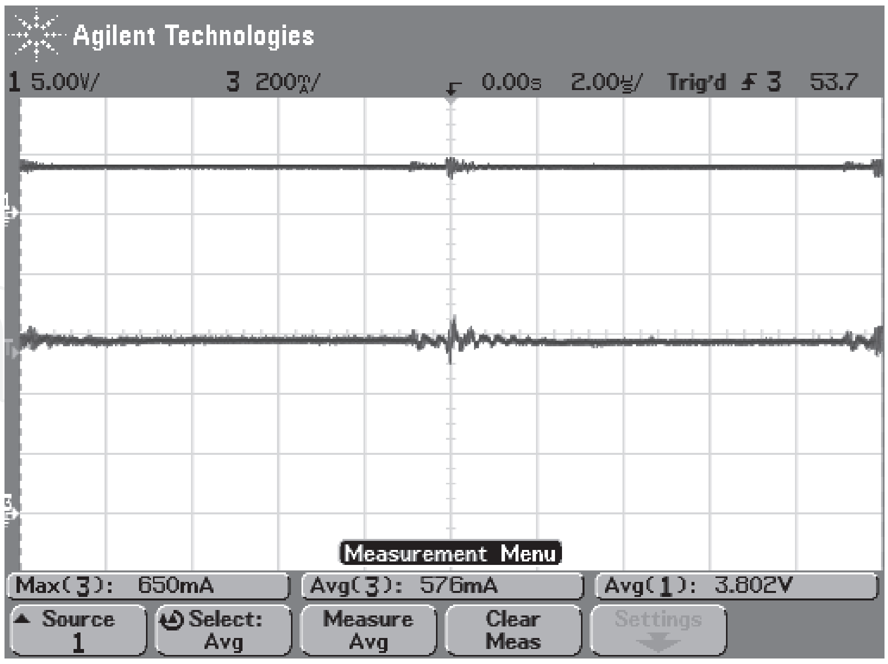

Fig. 9. The waveforms of voltage and current in the Buck converter - LEDs that emit red light.

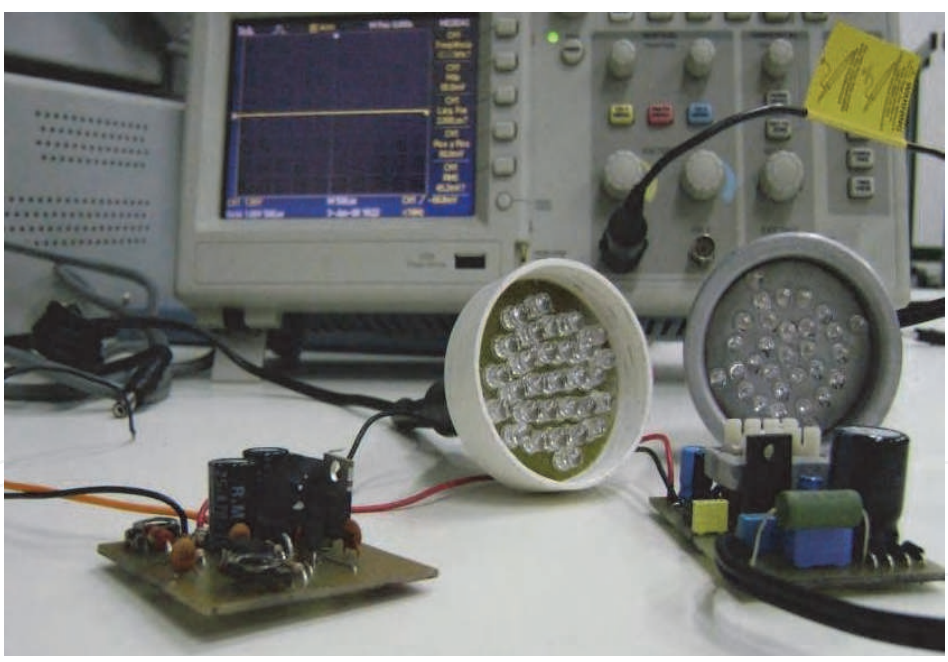

Fig. 10. Assembly of prototypes in the laboratory.

6.3 Dosage implementing the arrangement of LEDs

The concentration of light from the LED bulb can concentrate the same to a certain point that may have a high proportion in millicandelas, but passing through the skin undergoes a dispersion of its light concentration. The rate control devices is important because the total light energy emitted by the LED or energy in Watts per square centimeter, in units of mW/cm^2 is essential.

If the designer to use his knowledge to choose less expensive to manufacture power supply, then the power converter should be about 2 or 3 times more than the total of its light energy. The maximum light output of the output device is the source of half the power (W = Volt x Amps) of the transformer. The mW/cm^2 is the total light energy in mW divided by the length and breadth of the array of LEDs in cm.

7. Criteria, control and response to treatment of the patients who were treated by red light emitted by high-brightness LEDs

Patients who are subject to treatment will be properly classified with criteria established by the doctors who assist in the implementation of therapy. Among them, age, sex, physical condition and mental health. The therapy was performed with LEDs in the Western Regional Hospital in the city of Chapecó-SC, Brazil. An orthopedic surgeon and researcher will be responsible for the applications. The sessions were 40 minutes. Applications may be daily or not. Will depend on the type of cut or injury. Several may be twenty to forty sessions. Figures below are presented pictures of patients who are undergoing treatment. Figures 11 and 12, are of a patient who had leprosy and ostemeolite. Still has low immunity. After twenty sessions of 40 minutes the ulcer has reduced by 70% its size and depth, as shown in Figure 12 (Moreira, M. C., 2009). In this procedure was used the Buck converter who supply the LEDs that emit red light. The response of this converter was very good, because it presents a fine control of electrical current which is directly linked to the control of the wavelength.

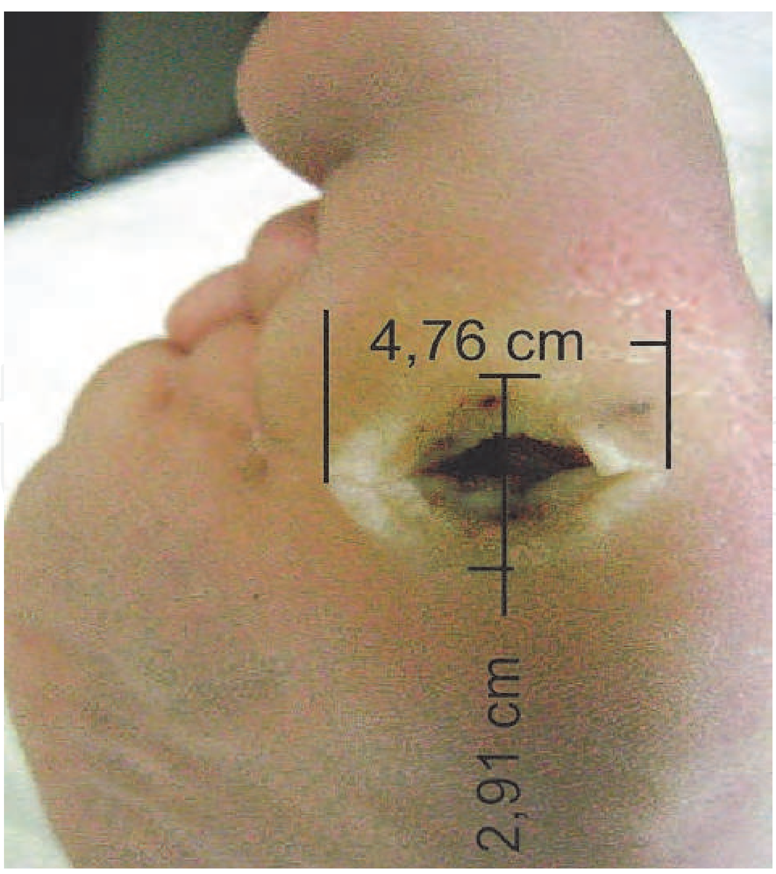

Fig. 11. Patient with ulcer in the sole of the foot before of therapy.

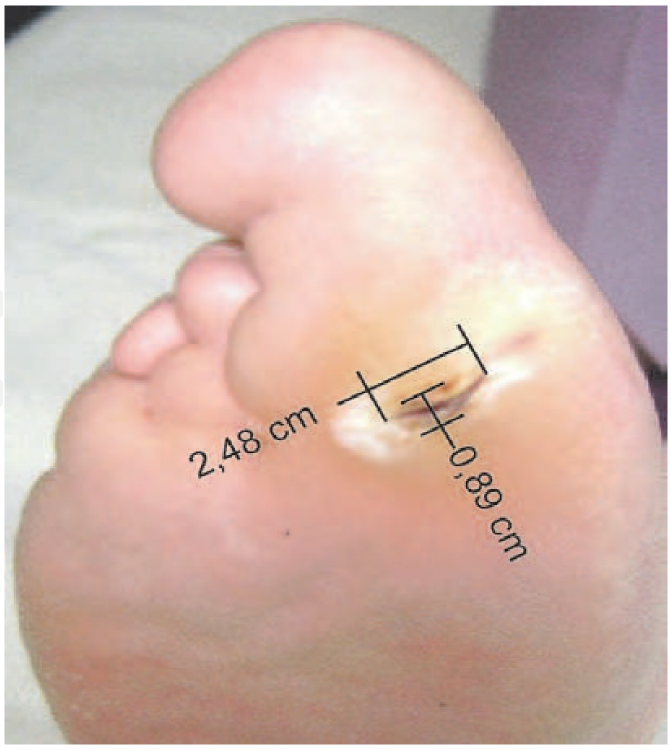

Fig. 12. Patient with ulcer in the sole of the foot after twenty sessions of LEDtherapy.

Photos 13, 14 and 15 show a patient who had an ulcer for more than two years.
The treatment lasted 50 days with applications of 40 minutes per day.
The patient had tried numerous types of treatment and was not successful.
During treatment with LEDs she did not use any kind of medication just LEDtherapy.
In this procedure was used the Flyback converter who supply the LEDs that emit red light (Moreira, M. C., 2009).

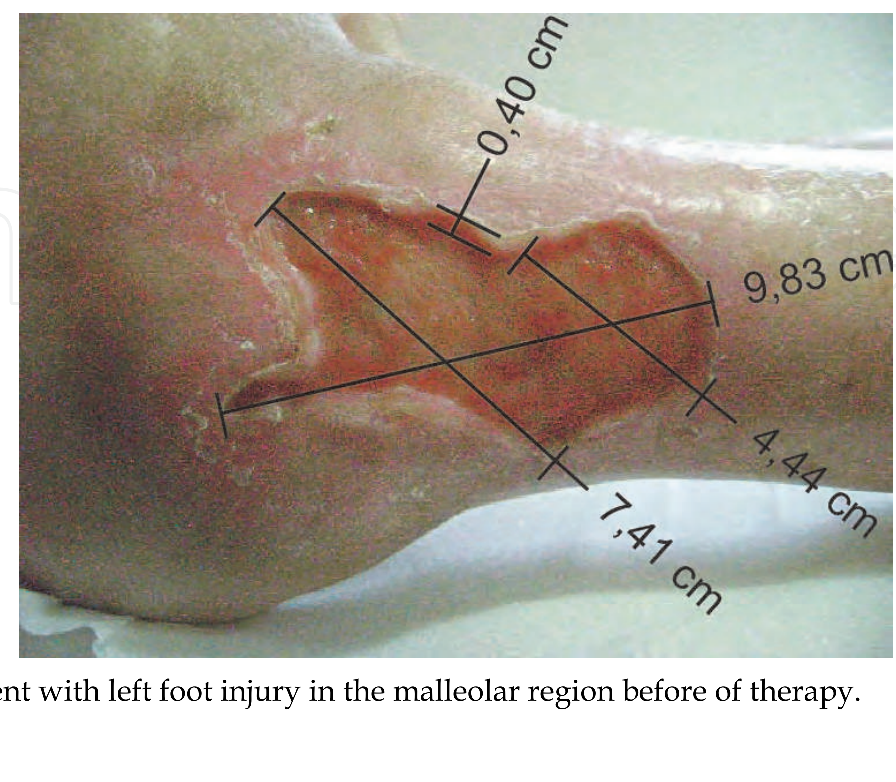

Fig. 13. Patient with left foot injury in the malleolar region before of therapy.

Fig. 14. Application of the array of LEDs during treatment.

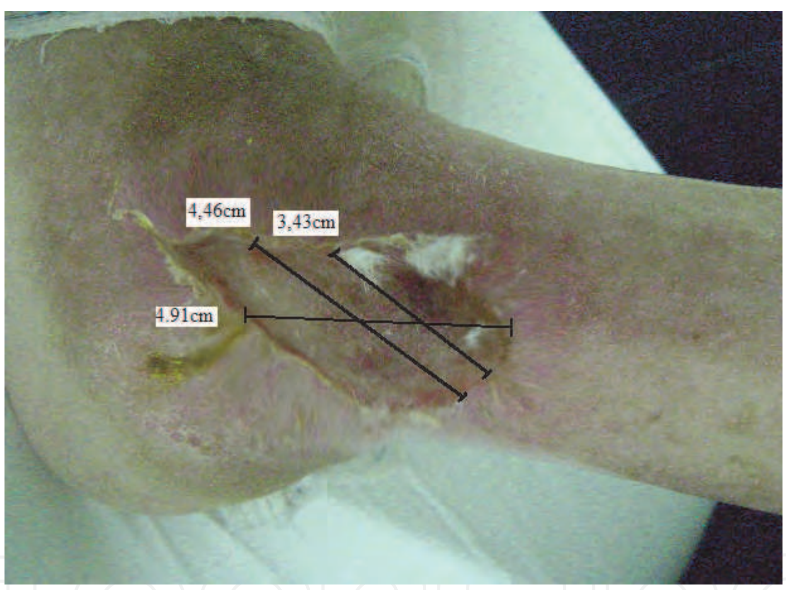

Fig. 15. Accentuated reduction of the ulcer injury.

The third case was a male patient, 27 years who had an accident with a tractor during their work activities where his left leg and right ankle suffered multiple fractures.
The ankle injury suffered a tendon rupture and left leg suffered several breakdowns and crushing bone and muscle. Performed three surgeries and the insertion of pins in order to restructure his leg.
He remained with sequelae such as disparity in length between your legs, swelling and deformity in her left leg and severe stasis ulcer that has formed around the medial malleolus and spread to leg edema presenting with dermatosclerosis. The ankle injury has healed.
The lesion of the left leg showed a great extent with the appearance of the ulcer, which reduced with time due to parallel treatments, but was not cured becoming chronic for a year and two months.

The patient in a routine consultation was invited by the doctor who attended to participate in therapy with LEDs. Occurring contact and accepted, the researcher and medical treatment was started with the issuance LEDterapia red light in the affected region.
In reviewing the case, the group proposed to the patient 20 applications of red light emitted by the array of LEDs, one on each day lasting 40 minutes per session.
Figure 16 shows the lesion in patient. Figure 17 shows the implementation of the arrangement of LEDs. Figure 18 shows the reduction of lesion during treatment. Figure 19 shows the healing of the lesion.
In this procedure was used the Buck converter who supply the LEDs that emit red light.
As the photos show the patient had complete healing of his injury using and enjoying only the application of red light generated by LEDs. The patient did not use any medication during treatment (Moreira, M. C., 2009).

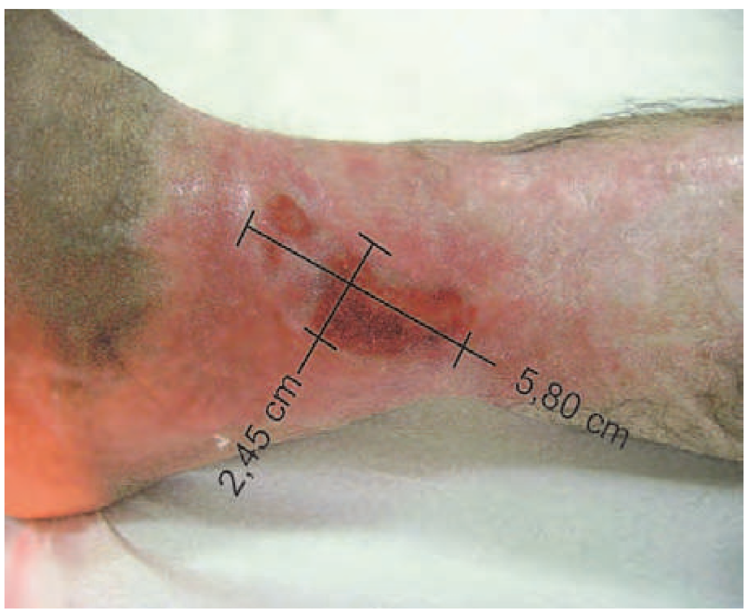

Fig. 16. Initial injury.

Fig. 17. Application of LEDs.

Fig. 18. Reduction of lesion during treatment.

Fig. 19. Healing of the lesion.

The last case presented it is an old lady of 94 years who had a right foot injury. Underwent 20 daily applications of 30 minutes.
The result was the healing of the lesion.
In this procedure was used the Flyback converter who supply the LEDs that emit red light (Moreira, M. C., 2010).
This patient stated that the lesion had existed for over six months and was due to a fall. She complained of pain at the site and had visited a doctor and used several medications.
Figures 20, 21 and 22 show the process of treatment in the patient

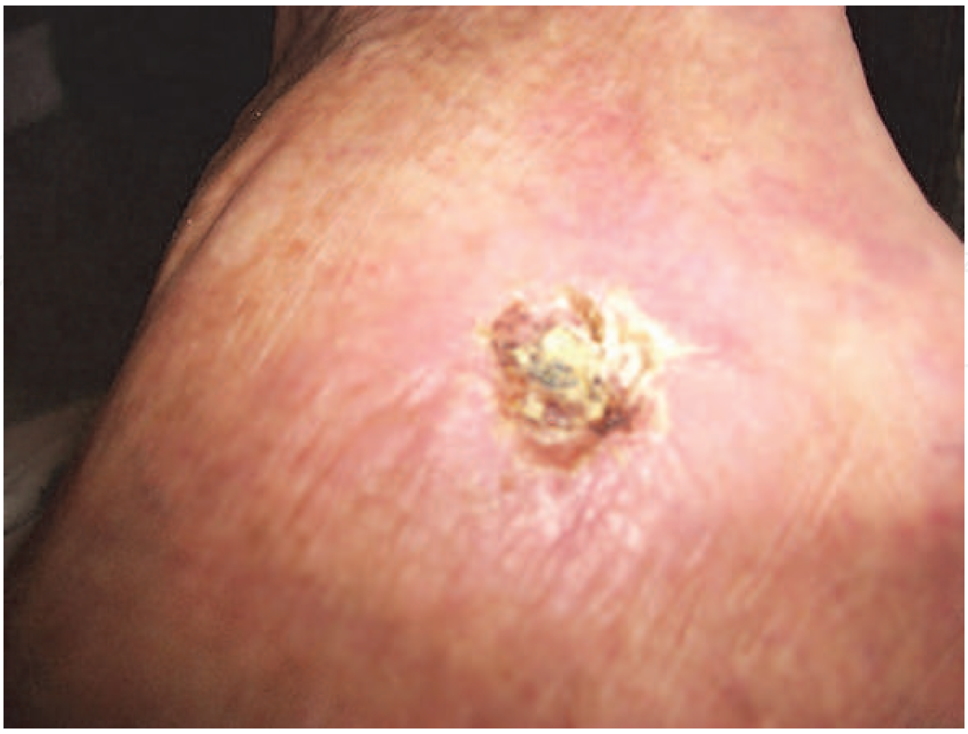

Fig. 20. Initial injury.

Fig. 21 Application of LEDs.

Fig. 22. Final result of treatment.

The arrangement of LED that emits red light contains 30 high intensity LEDs 5mm, with a wavelength in the range of 725 to 730nm. The current in each LED is around 20mA.
The current in each LED is around 20mA.
A total of 30 high-brightness LEDs that emit light in red. The power LEDs, high brightness can be used in LEDtherapy, yet high-gloss generate little heat on human tissue when compared with power LEDs, making high-brightness LEDs longer recommended for use in tissue recovery.
The high-brightness LEDs were used in this research. Well, it requires low power for this purpose and they serve this need in its characteristics, in addition to their low cost.
Buck and Flyback converters had very positive responses. Both presented an optimal control of electrical current that is fundamental to get the desired wavelength (Moreira, M. C., 2009).

8. The future of LED therapy

The application of high-brightness LEDs in human tissue to increases every day. Several scientific institutions have explored this theme.
Much research is underway on the use of therapy with the LED to determine if there are other applications for light therapy. The survey is being conducted on the effects of different spectra of light different in living tissues. The visible red spectrum, which is roughly in the range of 600-700 nanometers, is effective between the cornea to the subcutaneous tissue, such as care of wounds and sores, the wavelengths higher, including infrared, are more penetrating, can reach the bone. Studies also suggest that the spectrum down to 400 or 500 nanometers, which is light blue, can be effective in treating skin diseases, including acne, stretch marks, cellulite and scars.
Probably in the coming years, LEDtherapy is the main treatment for wounds, such as post-surgical wounds and not cured as diabetic ulcers.
Researchers seek to test the technology LEDtherapy in other clinical situations such as spinal cord injuries and for the treatment of Parkinson's disease, strokes, brain tumors and tissue and organ regeneration.

With the advancement and development of new applications for LEDs in health, the manufacturers of these devices have a solid improvement in all parameters of interest for their applicability to the evolution of performance in maintaining lumen (photometric unit), several categories of electric power, availability and reliability of the color spectrum and wavelength.

9. Conclusion

The application of LEDs in interaction with the human tissues shows a great interest of manufacturers and researchers. The correct use of LEDs in this context directly depends on the tissue nature where he wants the light to interact (Moreira, M. C., 2009).
Several parameters are important for satisfactory results, such as wavelength, the kind of color, temperature control of the LED, the characteristics of the used converter, control the brightness, output current, duty cycle and all the observations made in the previous sections of this work.
This is because a small spectral change can lead to a major shift in the lighting characteristics. The LEDs are increasingly becoming a great option to help cure various diseases and to prevent others.
Thus, this work contributed to the development of LED application in human tissues showing that the effect of the emission of light through the high-brightness LEDs offer a new treatment option for opening new ways of therapeutic technique LEDterapia applied to human tissues.

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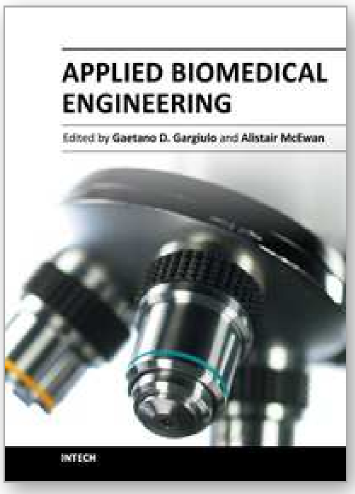

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This book presents a collection of recent and extended academic works in selected topics of biomedical technology, biomedical instrumentations, biomedical signal processing and bio-imaging. This wide range of topics provide a valuable update to researchers in the multidisciplinary area of biomedical engineering and an interesting introduction for engineers new to the area. The techniques covered include modelling, experimentation and discussion with the application areas ranging from bio-sensors development to neurophysiology, telemedicine and biomedical signal classification.

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