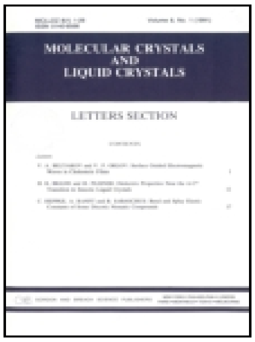

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Red/Infrared LED Unit with Moderate Light Intensity and Low Heat Generation for Personal Phototherapy Applications

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A new phototherapy unit for personal and home application is developed based on red and infrared LEDs. The wavelengths of the LEDs used are 660 nm for red light and 840 nm for infrared. The array of red and infrared LEDs were designed to generate mixture of red and infrared light and the current flowing through red and infrared LEDs were driven by using micro control unit (MCU) so that the light output and the heat generated from LEDs could be controlled in order not to exceed the certain limit. Light output from the personal phototherapy unit depends on the current flowing through red and infrared LEDs. The current can be controlled by MCU and constant current LED driver ICs by adjusting the duty ratio of the driving pulse generated by MCU and the operation time of the phototherapy unit is also controlled by MCU. The average red and infrared light output from the phototherapy unit developed for personal application was set to 50 mW/cm^2. The surface temperature of the phototherapy unit after 10 minutes operation did not exceed 41°C at the light output of 50 mW/cm^2 while LEDs were in contact with the skin.

Keywords LED; phototherapy; LLLT; irradiance. red/ infrared light

Introduction

Light therapy, or phototherapy has been used for healing various kinds of diseases for a long time. Lights with wavelength especially from 600 nm to 900 nm have been widely used for healing various kinds of diseases such as reduction of pains and wound healing[1,2].

Recently, many papers started to publish the phototherapy applications on treating Alzheimer's disease, Parkinson's disease, traumatic brain injuries, and age-related macular degeneration based on low level laser(light) therapy (LLLT)[3–8]. Red and infrared light from low level lasers have been the major light sources for phototherapy so far. But LEDs are now replacing lasers due to the lower cost, better safety, and wider application area so that LLLT can also stand for low level light therapy as well as low level laser therapy. Light output and dose are important parameters of phototherapy devices. Dose of the phototherapy devices is defined as the light energy received per unit area. Appropriate amount of dose needs to be absorbed by the cells to obtain some therapeutic effect from phototherapy. The

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examples of doses for various applications have been reported by many clinical trial data. Dose can be calculated easily if the light output of the phototherapy device is found. Light output, called as irradiance, of the phototherapy device, is defined as the light power per unit area. Therefore, dose can be found by multiplying the light power output by the amount of time used.

Very short period of time is required to get necessary amount of dose if the irradiance is high. Phototherapy device with high light output generates large amount of heat at the same time so that appropriate heat sinking method should be combined for operation with safety. The large amount of heat from the high light output phototherapy devices or equipments may generate skin burn if used improperly. Therefore, most of the high light output phototherapy devices or equipments are operated at the hospital under the guidance of the specialists. Patients need to visit hospitals frequently to receive the phototherapy treatments.

In this paper, a red and infrared LED phototherapy device with moderate irradiance is designed and developed for home and personal applications. The irradiance is variable and able to reach more than 50 mW/cm^2 depending on applications. The design, operation, and test results of the personal, home use, red and infrared LED phototherapy device were described. Temperature change of the LEDs of the red and infrared LED phototherapy device with its irradiance of 50 mW/cm^2 was described in more detail.

Therapeutic Effects of Phototherapy and Basic Mechanism of Phototherapy

At the beginning stage of LLLT, most of the applications of LLLT were concentrated on wound healing, skin rejuvenation, hair growth, reduction of pain from tennis elbow, carpal tunnel syndrome, shoulder, arthritis, neck, and etc[9–18]. Recently, there have been several hundreds of papers demonstrating the controlled clinical trial data on the mechanisms of phototherapy called as photobiomodulation and tens of thousands of research papers describing in-vitro and in-vivo therapeutic effects of LLLT including stroke, spinal cord injury, glaucoma, macular degeneration, heart disease, osteoarthritis, non-healing diabetic wounds, dentistry, and the neurodegenerative diseases such as Alzheimer's disease, Parkinson's disease, traumatic brain injury[19–24]. The most current publication of LLLT shows that LLLT even can help mediate dentin regeneration in vivo from the tooth pulp of rats, which indicates that phototherapy could be used in dental regeneration in people[25].

Red light and IR light are mostly used for phototherapy even though the other wavelengths of light are used as the sources of phototherapy for various applications. Out of all the wavelengths of light, not all of the light pass through the tissue in our body. In general, red and infrared lights only are able to pass through tissue up to 1∼2 inch deep. The ideal wavelengths for therapy are between 600 nm and 900 nm. Figure 1 shows the optical window for tissue in our body.

Red and infrared lights incident on the skin can penetrate 1∼2 inches deep into the tissue of body because of the low absorbance of red and infrared lights in the tissue. Red and infrared lights can be absorbed by the cell while penetrating into the body, which activates the creation of adenosine triphosphate (ATP), cellular energy, in the cell. Red and infrared lights penetrating through the tissue are absorbed by the photoacceptors called cytochrome c. oxidase (Cox) in mitochondria, which enhances the production of ATPs in the cell. Cox is believed to the primary photoacceptor for red and infrared lights in the mammalian cells. Nitric oxide (NO) is produced in the mitochondria and it can inhibit respiration by binding to Cox and competitively displacing oxygen delivered by the blood in the cell. Red and

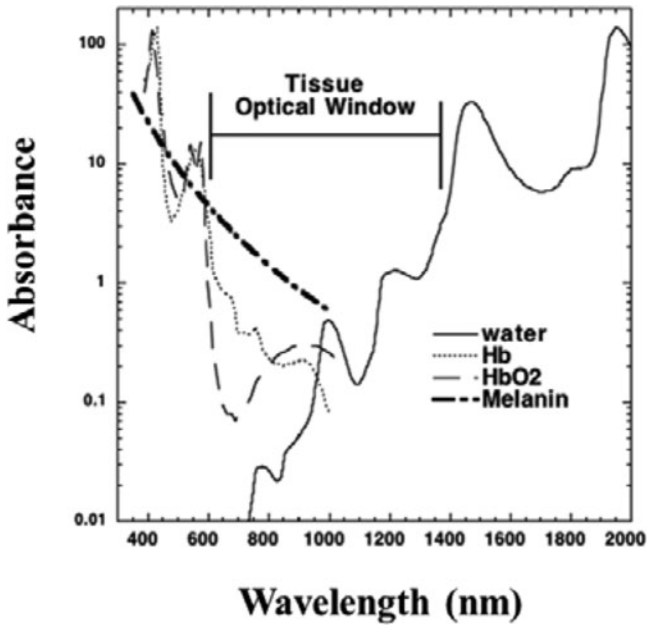

Figure 1. Absorption spectra of the main chromophores in living tissue on a log scale showing the optical window where visible and IR light can penetrate deepest into tissue[1].

IR lights absorbed by Cox dissociates NO from Cox, thereby reverses the mitochondrial inhibition of respiration due to excessive NO binding and allows an immediate influx of oxygen leading to resumption of respiration and resulting increased ATP synthesis, which leads to the increased metabolism of the cell, cell proliferation, and other beneficial effects to the cell. Generated NO gases help expand blood vessels, which leads to the increase of blood circulation in the tissue irradiated by red and infrared lights. NO also sends signals to the cell to increase RNA and DNA activities, which leads to the cell proliferation for wound healing and skin rejuvenation1. Figure 2 shows the absorption of red and IR light by specific cellular chromophores or photoacceptors localized in the mitochondrial respiratory chain.

Design of Phototherapy Devices

As discussed in the previous section, red and near infrared light are able to pass through tissue up to 1∼2 inch deep. In general, low level lasers have been thought to be useful and effective for phototherapy. Phototherapy devices or equipments made of lasers have mostly been installed at the hospitals. Production cost of the laser phototherapy devices or equipments is very high in general. And the high intensity of laser light is very dangerous for eyes. Therefore, patients have been treated under the guidance of the doctors by visiting hospitals or clinics when necessary. Laser phototherapy devices or equipments are very expensive and not considered safe for home use. Since 1989, Tina Karu et al published papers in which the authors discovered the mechanisms of phototherapy[26–28]. Authors found that any light source that provide same or similar wavelengths and dose is as effective as laser lights.

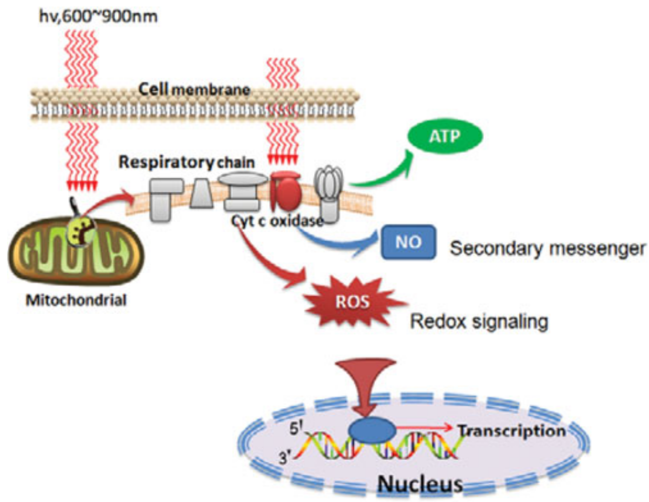

Figure 2. Schematic diagram showing the absorption of red and IR light by specific cellular chromophores or photoacceptors localized in the mitochondrial respiratory chain[1].

Recently, high luminous efficacy light emitting diodes with wavelengths of red and infrared lights are developed and produced. Phototherapy devices or equipments with lasers are now able to be replaced by the LEDs which produce the same or similar wavelengths of light. Low level lights from LEDs are safe and low cost so that the LED phototherapy devices are considered safe for home or personal applications. Diverse phototherapy equipments utilizing semiconductor laser or LED light sources are being produced and installed at many clinics or hospitals for pain relief, skin rejuvenation, and wound healing. Patients have to visit clinics or hospitals in order to receive phototherapy because the phototherapy equipments for clinics or hospitals have very high light intensity and heat generation so that they have to be used under the guidance of medical doctors. Most of the phototherapy devices developed for hospital applications are designed to generate high irradiance so that large amount of heat as well as light is generated. Our skin is vulnerable to heat so that burning may result during the phototherapy treatment if the high irradiance phototherapy device is in contact with our skin. Therefore, it is necessary to develop a phototherapy devices with moderate irradiance and small amount of heat for safety of each individual.

In this paper, red and infrared phototherapy device using red and infrared LED arrays for home and personal application was developed. The schematic diagram of the LED phototherapy device is shown in Fig. 3. In Fig. 3, the DC voltage from the adaptor is applied to regulator and LED driver ICs. Regulator output is applied to micro control unit (MCU) which provides pulse width modulation signals to LED driver ICs. Light output power of red and infrared LEDs can be controlled by programming of MCU. The operation frequency and duty ratio of the red and infrared LED phototherapy device can also be controlled by programming of MCU to increase the effectiveness of the red and infrared LED phototherapy device.

It is generally known that the necessary absorption dose for effective phototherapy is about 3 J/cm^2[29]. Considering the absorption efficiency of 10%, the phototherapy device should generate 30 J/cm^2 during therapeutic operation. Therefore, light output power of 10 mW/cm^2 requires the operation time of

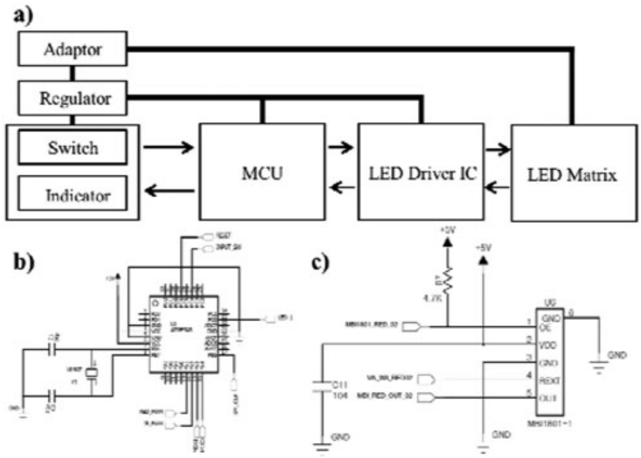

Figure 3. The schematic diagram of the LED phototherapy device: (a) block diagram of the system of LED phototherapy device, (b) configuration of MCU, and (c) LED driver IC for LED control.

50 minutes, while light output power of 50 mW/cm^2 needs the operation time of 10 minutes. The device with light output power of 50 mW/cm^2 can be more convenient for user than that with light output power of 10 mW/cm^2 owing to the advantage of shorter treatment provided that surface temperature of the device remains below 41°C for safety during operation. Thus, the phototherapy device with light output power of 50 mW/cm^2 and surface temperature of less than 41°C for 10 minutes after turn-on was developed in this study.

Figure 4. The assembly of the red and infrared LED phototherapy device.

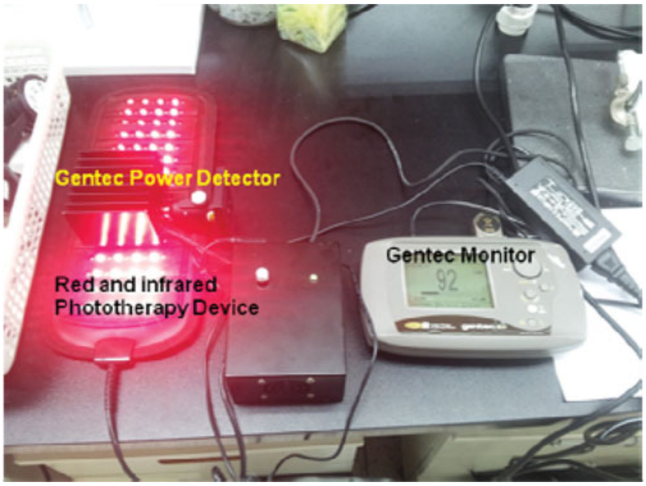

Figure 5. Light output power measurement set-up for red and infrared LED photo- therapy device.

Results and Discussion

Figure 4 shows the assembly of the red and infrared LED phototherapy device based on the design of Fig. 3. There are four red LEDs and five infrared LEDs in a row and the distance between LEDs is 10 mm. And the total number of rows are 16 and the distance between the row is 20mm. Therefore, the total number of 144 LEDs were used in the phototherapy device and the total light emitting area was 240 cm^2. The wavelengths of the red and infrared LEDs used were 660 nm and 840 nm, respectively.

Surface mounted LED chips were mounted on the PCB with via holes to help dissipate heat from LEDs to the backside of the PCB. Silicone pad with open holes were combined with PCB arrays on which LED chips were mounted. Light from LED chips through the holes in the silicone pad reachs the surface of the skin. LED chips do not directly touch the skin due to the thickeness of the silicone pad.

Gentec Power Meter and UP 19K-50L-H5 power detector module was used during the light output measurement. The measurement process was shown in Fig. 5. Ambient temperature during the measurement was 25°C. The duty ratio of the phototherapy device was set to 40% and the irradiance measured was 50 mW/cm^2.

The general standard IEC 60601-1 is a widely accepted benchmark for medical electrical equipment, and compliance with IEC60601-1 has become a requirement for the commercialisation of an electrical medical equipment in many countries. It is provided in the IEC 60601-1 that surface temperature of an object in contact with human body should not exceed 41°C. Accordingly, the temperature of the LEDs needs to be designed not to exceed 41°C during the use of phototherapy device in contact with the skin. Cold burn may result during phototherapy treatment in contact with the skin if the skin temperature exceeds 41°C for some amount of time. Therefore, it is strongly advised to control the temperature of the phototherapy device not higher than 41°C to prevent skin burn. The temperature of phototherapy of the skin may exceed 41°C if the phototherapy devices is used longer than the suggested amount of time. Therefore, it is important to set up the condition of operation so that the skin temperature does not exceed 41°C while using the red and infrared LED

(unit : °C)

Operation time (min)	P1	P2	P3	P4	P5	AVG
+0	25.4	25.4	25.4	25.4	25.4	25.4
+5	33.5	33.6	33.9	34.8	34.7	34.1
+10	37.8	37.3	39.1	37.2	37.2	37.7
+15	38.4	39.5	41.3	40.2	40.7	40.0
+20	41.9	41.7	43.4	41.2	41.6	42.0

Figure 6. Temperature change at 5 points according to the elapsed time at the light output of 50 mW/cm^2.

phototherapy device in direct contact with the skin. The most appropriate amount of irradiance of the red and infrared LED phototherapy device is calculated to be 50 mW/cm^2 and 10 minutes of operation. Average temperature of the red and infrared LED phototherapy in the manufactured device was measured to be 37.7°C after 10 minutes operation, and 40.0°C after 15 minutes operation. Figure 6 shows the results of the temperature measurement at 5 points on the phototherapy device. It shows that the temperature of the phototherapy device stays below 41°C during 15 minutes after operation. Therefore, it is safe to use the phototherapy device in contact with the skin for 10 minutes

Sometimes it is necessary to increase the light output power of the phototherapy device on such an occasion as thermo-photottherapy. It is possible to control the electrical currents of the red and infrared LEDs by changing the program of the MCU. The red and infrared LED phototherapy device with light output power of more than 50 mW/cm^2 can be used in the thermo-phototherapy operated at a higher temperatire with short treatment time. However, in the phototherapeutic treatment, proper methods of heat dissipation are necessary to prevent the temperature of LEDs in contact with the skin from exceeding 41°C during high light output power LED therapy device operation.

Therefore, the shorter operation time is required from the higher light output phototherapy device. The temperature of LEDs may exceed 41°C due to the higher light output power, which may generate skin burn. In the phototherapy device developed in this paper, use of silicone pad which covers LEDs, adoption of via holes in the PCB, adjustment of electrical current flowing through LEDs by controlling MCU, and adjustment of operation duration were all combined together to control the safe operation of the high light output LED phototherapy device. The temperature of the phototherapy device did not exceed 41°C after 15minutes operation and it is safe to use the 50mW/cm^2 phototherapy device in contact with the skin for 10 minutes.

Conclusions

A new phototherapy unit for personal and home application was developed based on red and infrared LEDs. The wavelengths of the LEDs used were 660 nm for red light and 840 nm for infrared. The array of red and infrared LEDs were designed to generate mixture of red and infrared light and the current flowing through red and infrared LEDs were driven by using MCU so that the light output and the heat generated from LEDs could be controlled in order not to exceed the certain limit. Irradiance from the personal phototherapy unit depends on the current flowing through red and infrared LEDs. The current can be controlled by MCU and constant current LED driver ICs by adjusting the duty ratio of the driving pulse generated by MCU. The operation time of the phototherapy unit is also controlled by MCU.

The standard red and infrared light output from the phototherapy unit developed for personal application was set to 50 mW/cm^2. Irradiance of the phototherapy unit developed can be controlled to 50 mW/cm^2 by adjusting the duty ratio of the driving pulse. The LED temperature of the phototherapy unit with 50 mW/cm^2 did not exceed 41°C after 10 minutes operation. The room temperature was 25°C during the temperature test. Therefore, there is no side effect such as skin burn during operation even if the phototherapy unit is contacting the skin for 10 minutes. LED current control, absorption and dissipation of heat by the LED pad and PCB via help the LED phototherapy unit maintain low temperature during operation. The light output of the phototherapy unit developed can be adjusted above 50 mW/cm^2 for some special high light output applications. Stable and safe operation was confirmed by adjusting the irradiance and treatment time in the newly designed phototherapy device with high light output power.

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