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LED Bio-friendly Development of Fungal Skin Treatment Device

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Abstract

The purpose of this work was to examine which LED fungal treatment device can be applied to the face. Several methods were used for that purpose. More specifically, 240 50mA low-power LED chips were selected. As a result, a light distribution angle of 150 degrees was possible, and the temperature could be adjusted in the range of 27-32 degrees for fungal treatment (acne), making the device suitable for use. The results show that face use possible factor is more common than initially expected. Moreover, further investigation of the decreases in the angle for standardization of the temperature is required.

Keywords: *LED, Bio-friendly, skin treatment, photo-dynamic*

1. Introduction

LEDs, which have sufficient capacity and efficiency, have emerged as a new field owing to the technological development of medical treatment using light. Its application is especially important in epidemiology, but it has failed to achieve massive success due to difficulties in generating sufficient intensity of light and its control. Recently, however, rapid development in optical treatment is expected with recent technological developments.

Optical treatment is generally a field of optical epidemiology, and means the action of transforming a substance on the skin to another one. It includes all the areas of light application, from the epidermal system to the musculoskeletal system of an animal. The existing optical treatment methods include IR waves from a halogen lamp or UV fluorescent lamp, but methods using LEDs have been actively researched [1].

The LED may be applied to dermatological and surgical treatment using its various wavelengths and directly implemented in major operating and treatment devices in dermatology and ophthalmology. The skin treatment areas include skin reaction to in vivo changes like atopic dermatitis, leukoplakia, scleroderma, and scalp care (hair loss treatment), as well as fungal treatment like acne, dermatophytosis, and dandruff bacillus, along with anti-aging treatment to improve wrinkles on the skin. However, this study only focuses on developing devices for bio-friendly LED fungal skin treatment.

The features in the LED fungal treatment device is that compared to other light sources, the LED does not use harmful substances, is eco-friendly, has a narrow wavelength band, and may intensively achieve photons for certain lesions. In addition, the light does not emit harmful UV or unnecessary UV, and it has fewer side effects, long lifetime, and less power consumption. However, the heat dissipation would be an important issue for the LED fungal treatment device. To figure out the heat radiation from the device, the COMSOL program was used in this study to analyze the temperatures created from the device along with the service time. In the analysis, the spacing of modules, the housing material, and the shape of the PCB were considered to avoid potential problems from overall temperature increases of the device operated for a longer time. A simulation model was also prepared and pretested to verify the

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analysis. The volume is small and may be used in various places, and that is why this study is developing methods for LED fungal skin treatment.

Table 1. Review on the Applicability of the Light Treatment for each LED Wavelength

Wavelength range	Specification	Effect and application	Light source
UV-C	Far UV (100-280nm)	- Sterilization and purification - Bio medical sensor	LED(250nm) UV fluorescent lamp
UV-B	Mid UV (280-320nm)	- Form vitamin D - Leukoplakia, psoriasis treatment device	LED(315nm) UV fluorescent lamp
UV-A	Near UV (320-400nm)	- Atopic dermatitis treatment - Scleroderma, mycosis treatment	LED(365, 380nm) UV fluorescent lamp
Visible light	R.G.B (400-780nm)	- Jaundice treatment for new-born babies - Acne and freckle treatment - Skin improvement, optic nerve treatment - Depression, psychological treatment	LED (whole wave-lengths)
IR-A	Near IR (780nm -2.5μm)	- Pain treatment (relief) - Stimulate skin regeneration - Sutured treatment on the affected area after the operation	LED/LD(830nm) Halogen lamp
IR-B	Far IR (2.5μm-50μm)	- Pain treatment (heat treatment) - Musculoskeletal treatment	Halogen-tungsten lamp (4μm-18μm)

2. Design and Manufacturing the Device

2.1. Principle of Treatment

Photo-dynamic therapy (PDT) is a treatment technology for incurable diseases like cancer without the need for operation that uses a photo-sensitizer, which forcibly penetrates into the target cells, radiating with a certain wavelength to lead to the creation of extrication oxygen in the cells to selectively destroy the target cells [2]. After applying the photo-sensitizer prior to radiating the light, the light is absorbed along the pore into the sebum, as shown in Figure 1. Here, radiating the laser light causes the heat to focus on the photo-sensitizer, reducing the sebum lines and killing acne bacteria inside the line.

The UV disinfection is performed by radiating UV with the main wavelength of 253.7nm on microbes to destroy the DNA in the nucleus and mitochondria of the microbes, and to block the respiration activity and proliferation. This method is used to sterilize bacteria or microbes [3].

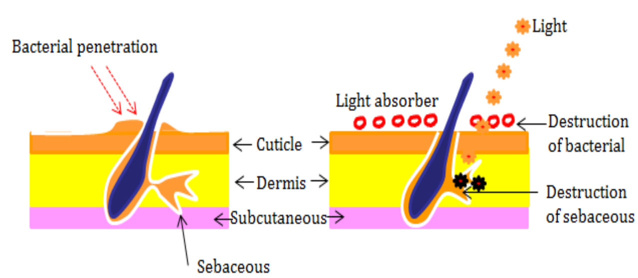


Figure 1. Principle of the Photo-dynamic Treatment

According to the roles for each wavelength, the 420nm region is used to treat the acne, and it removes and inhibits the bacteria by generating singlet oxygen through reaction with the porphyrin generated by the bacteria causing the acne. The 530nm region is used to treat freckles and blemishes, and it mainly removes the color pigment lesions. It may be applied to bright skin due to the high absorption of melanin. The wavelength region of 560 - 590nm is effective in treating flush, and 560nm and 590nm wavelengths are applied to bright and dark skins, respectively. The wavelength of 640nm is used to treat freckles, and is effective for incurable freckle treatment. This wavelength may achieve a large effect for periodical use.

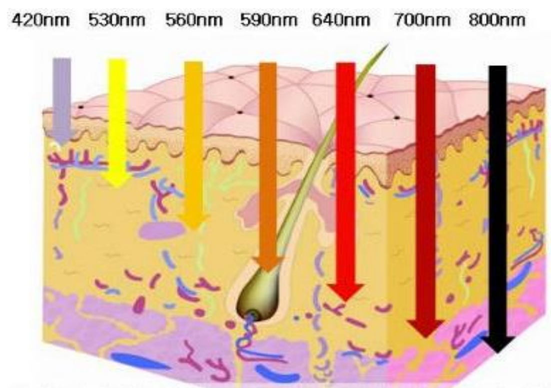


Figure 2. Treatment Ranges for Each Wavelength

2.2. Design Requirement for the Device

The design requires red 15W (60mW x 240) and blue 12W (50mW x 240) LEDs. The red LED uses 630nm and the blue LED uses 470nm as the light sources, and the light output for the red and blue LEDS are 60mW/㎠ and 50mW/㎠, respectively. Using the power LED provides stimulation on the face that is too intensive due to high spot intensity. Therefore, the system is configured with 50mW and 60mW chip LEDs, the light pulse frequency ranges from 100 to 99,000Hz, and the device temperature, the important part of the LED device, is designed not to exceed 55℃, considering that the light is radiated on the face.

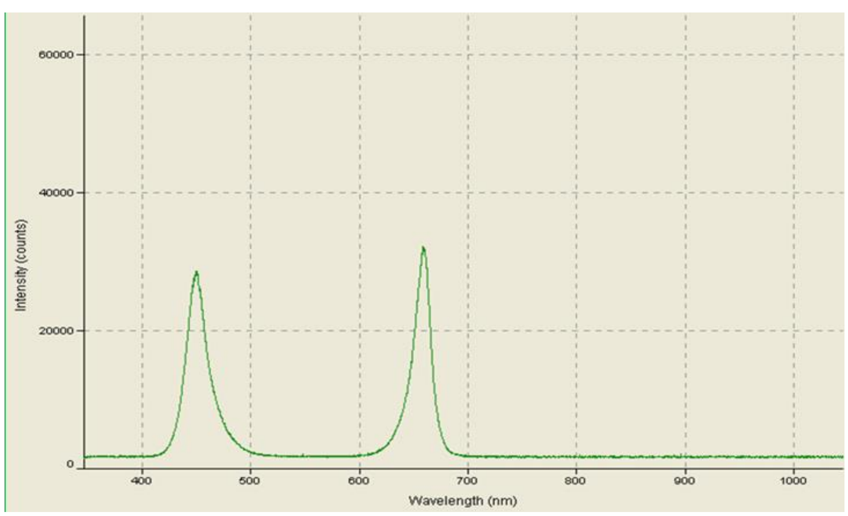


Figure. 3 Wave-lengths of Red (630nm) and Blue (470nm) LEDs

The power of the red (60mW) and blue (50mW) LEDs is different, but this study seeks to increase the efficiency of the light source with optical design by an array with a 90° single light distribution angle with the chip type. However, distributing the light on the face for treatment causes a narrow angle, forming locally strong rays. Therefore, this study forms a curved surface with every 5 and 10° to implement a light distribution of the module of 150°. Figure 4 shows the single light distribution of the LED used for manufacturing with a Lambertian distribution of about 120°. It is chosen considering the diffusion, because the small distribution requires a complicated process in the lens design.

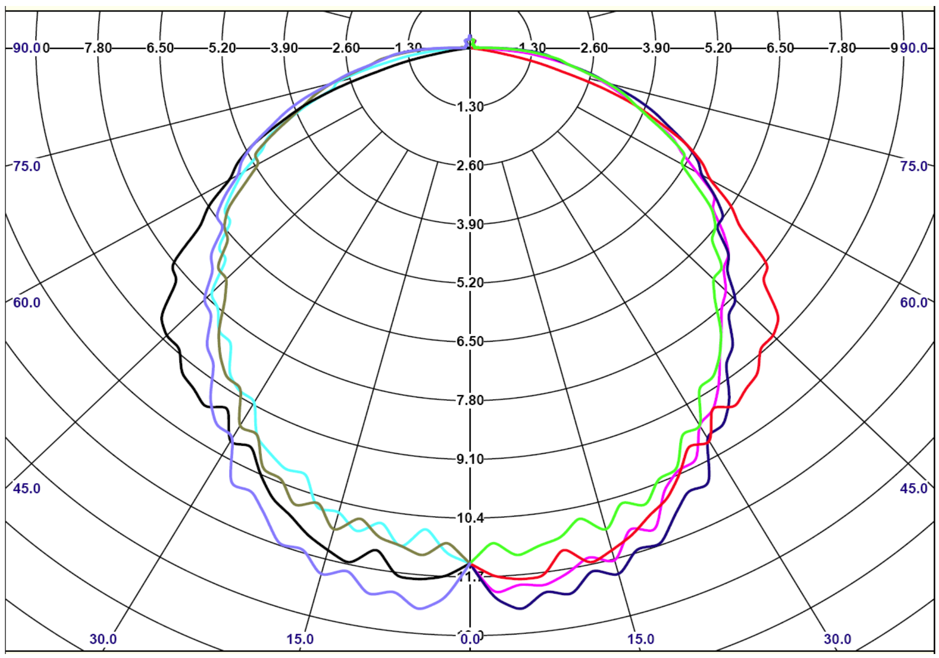
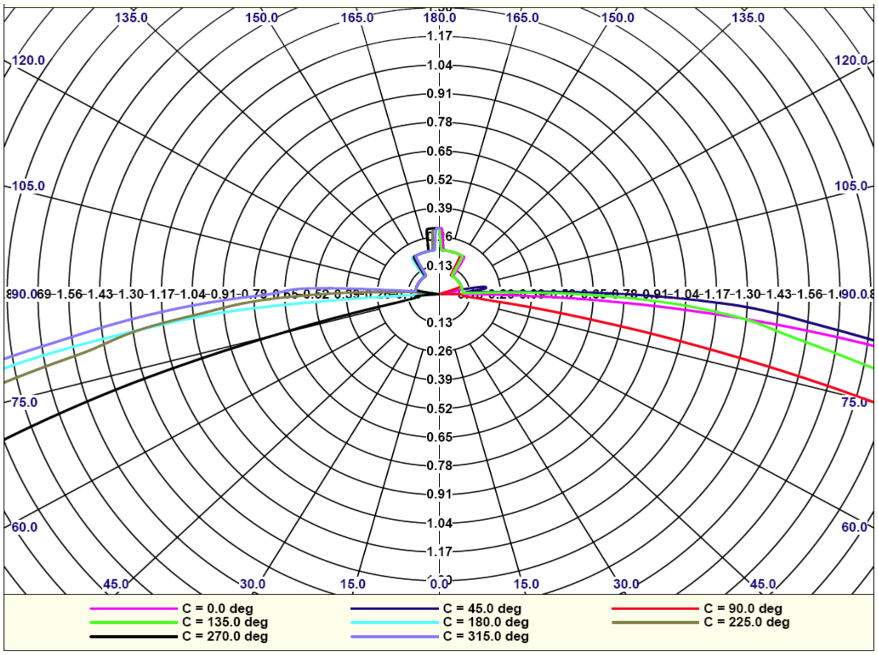


Figure 4. 90° of the Single Light Distribution

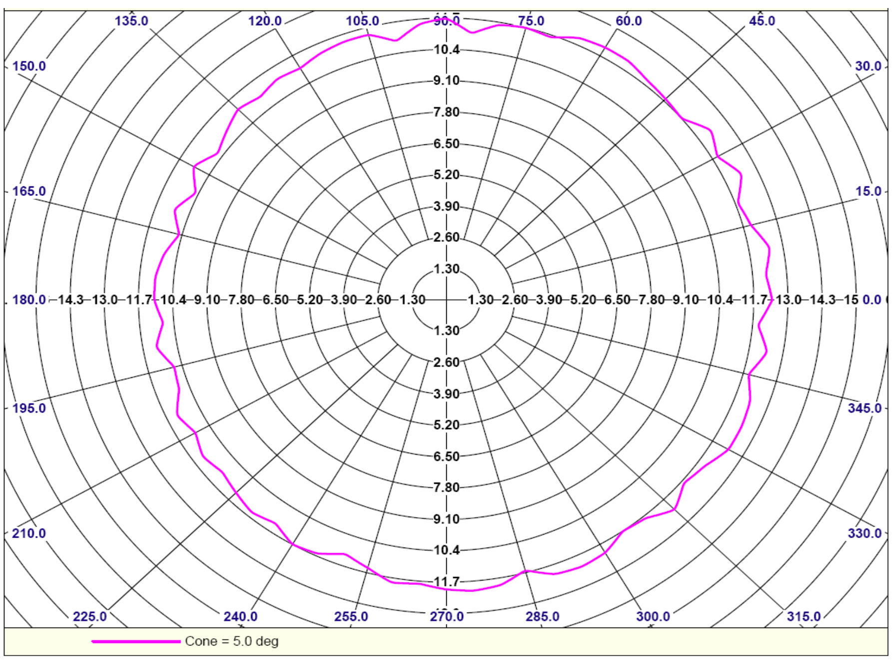
The temperature design is configured as low as possible due to the impact on the life and the efficiency of the LED. The temperature of the contact with the external air is configured below 30°C, because it is used on the face despite a small amount, and the material on the contact would be an important factor. The heat insulation material is aluminum, which has a thermal conductivity of 160W/m▪K, density of 2,700kg/㎥, and specific heat of 900J/Kg▪㎥ [5]. The total energies are red=0.033W/㎠(300㎜*150㎜) and blue=0.027W/㎠(300㎜*150㎜), and they are analyzed in steady state where a constant temperature of 50°C is maintained. The total temperature is designed not to exceed 85°C despite assuming a room temperature of 30°C.

3. Results and Review

The result of the system with red 15W (60mW x 240) of 630nm and blue 12W (50mW x 240) LEDS of 470nm shows that the light distribution angle exceeds 150°. Figure 5 is the light distribution diagram of the red LED, and based on the light distribution diagram with the pole type in (a), the right distribution angle exceeds 75°, and the left angle is just below 75° at the light distribution line of 270°. Overall, the angle is just below 150°, but the distribution exceeds 150° at 225, 180, 135, 90 and 45°.



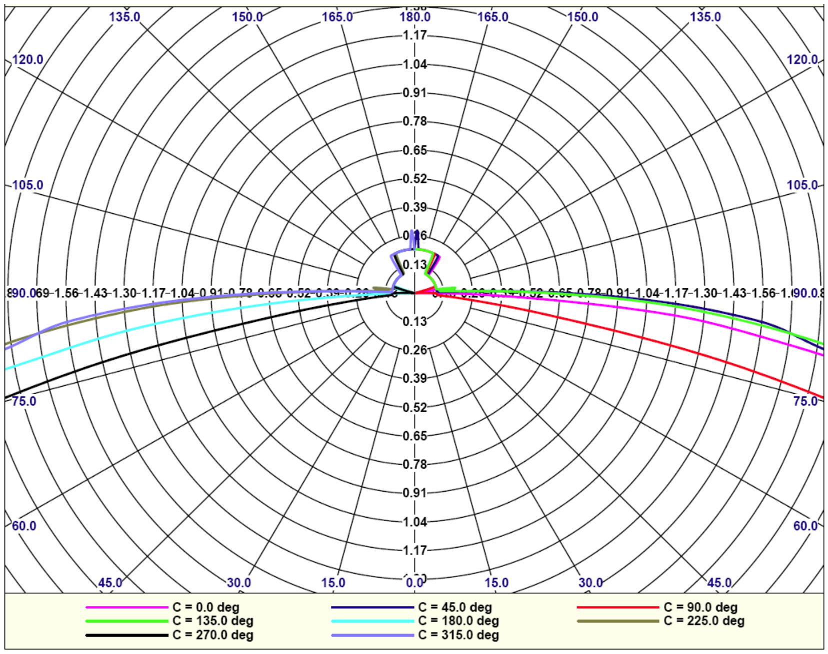
(a) Cone type



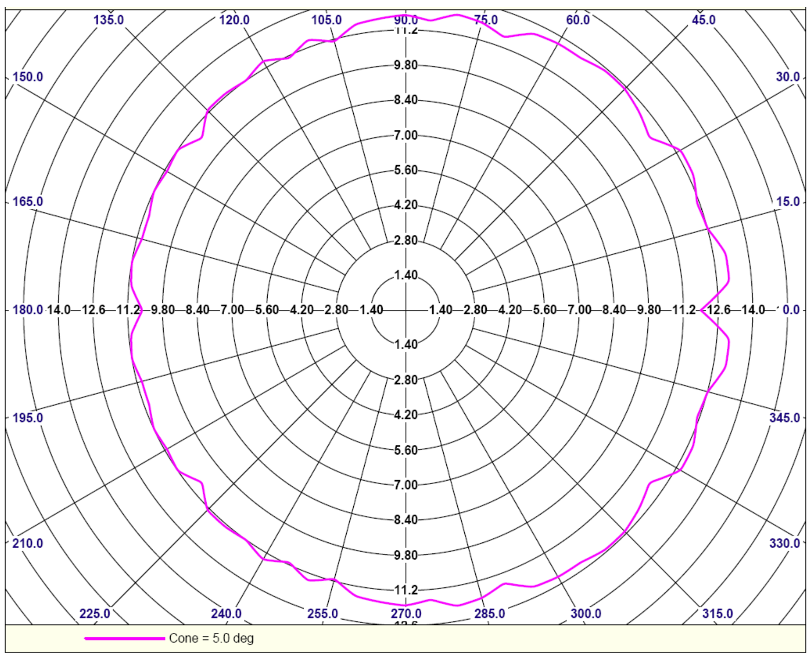
(b) Polar type

Figure 5. Light Distribution Diagram of Red LED

Figure 6 is the light distribution diagram of the blue LED, and all the light distribution angles on the right side exceed 75° and 150° at 270, 225, 180, 135, 90 and 45°.



(a) Cone type



(b) Polar type

Figure 6. Light Distribution Diagram of Blue LED

The heat flow in the LED module can be identified through the heat transfer mechanism. The heat conduction in the solid medium would show the temperature gradient identifying the heat transfer from the high temperature to the low one. The practical heat flow rate depends upon the specific thermal conductivity K of corresponding solid medium which follows the Fourier's law of heat flow.

The heat capacity Q can be obtained from the following expression.

$$Q = -K \cdot A_c \cdot \frac{\Delta T}{L} \tag{1}$$

Where, $$\Delta T = \frac{Q \cdot L}{K \cdot A_C} \tag{2}$$

In the formula, Q is the heat flow rate (W), k is the thermal conductivity of the material (W/m.K), Ac is the cross sectional area for heat transfer(㎡), ΔT is the temperature differential (°C), and L is the length of heat transfer (m).

The convection, a form of thermal energy exchanging process, occurs by the density differences of fluids in contact with solid media surfaces with different temperatures, and can be classified into natural or free convection and forced convection. The natural or free convection occurs by the buoyancy generated by the fluid density differences, while the forced convection can transfer a large amount of heat by using an air blower or air fan.

$$Q_c = h_c \cdot A_s \cdot (T_s - T_{ref}) \tag{3}$$

$$\Delta T = \frac{Q_c}{h_c \cdot A_s} \tag{4}$$

In the formula, Q_C is the convective heat flow rate from the surface (W), A_S is the surface area for heat transfer (㎡), T_S is the surface temperature (°C), Tref is the coolant media temperature (°C), and h_C is the coefficient of convective heat transfer (W/㎡.K)

The heat transfer coefficient of convection h can be expressed as the following:

$$h = \frac{Q / A}{(T_S \cdot T_{ref})} \tag{5}$$

Where, A denotes the surface area in contact with the fluids, T_S denotes the heat transferring surface temperature, and T_{ref} denotes the remote, unperturbed temperature away from the surface.

Table 2. Approximation of Convective Heat Transfer Coefficient

Convection and fluid	h(w/㎡·k)
Natural Convection, air	5-25
Natural Convection, water	20-100
Forced Convection, air	10-200
Forced Convection, water	50-10,000
Boiling water	3,000-100,000
Condensation of water vapor	5,000-100,000

Away from convection or conduction, the heat can be transferred from the surface in the perfect vacuum, and the amount of heat radiation at the light speed in the form of electromagnetic wave depends upon the absolute temperature of the surface and the surface configuration. The heat radiation from the perfect radiator or from the "blackbody" can be expressed as the following equation:

$$Q_r = \varepsilon \cdot \sigma \cdot F_{1,2} \cdot A(T_1^4 - T_2^4) \quad (6)$$

In the formula, Qr is the amount of heat transferred by radiation(W), ε is the emissivity of the radiating surface (highly reflective=0 , highly absorptive=1.0), σ is the Stefan-Boltzmann constant (5.67×10^{-8} W/㎡.^{K4}), F1, 2 are the shape factors between surface area of bodies 1 and 2 (≤1.0), A is the surface area of radiation (㎡), T_1 is the surface temperature of body 1(K)
T_2 is the surface temperature of body 2(K)

By applying the above equation, the temperature of the internal surface of the channel on backside of the PCB can be predicted approximately by assuming the uniform heat flux radiated evenly from the overall surface of the PCB with ignoring the local hot spot phenomena. For example, the Tb (PCB surface temperature) can be predicted approximately by assuming the 80%-90% of the heat radiation from the backside of the PCB at Q=0.85.

According to Newton`s cooling law,

$$Q = h \cdot A \cdot (T_b - T_m) \quad (7)$$

$$Q = m \cdot C_P \cdot (T_o - T_i) \quad (8)$$

$$T_o = \frac{Q}{m \cdot C_P} + T_i \quad (9)$$

$$T_m = 0.5(2T_i + \frac{Q}{m \cdot C_P}) = T_i + \frac{Q}{(2m \cdot C_P)} \quad (10)$$

By replacing the term in equation 7 with equation 10,

$$Q = h \cdot A(T_b - T_i - \frac{Q}{2m \cdot C_P}) \quad (11)$$

$$T_b = [\frac{1}{h \cdot A} + \frac{1}{2m \cdot C_P}] \cdot Q + T_i \quad (12)$$

In the formula, Q is the power dissipation(w), m is the mass flow rate(kg/s), h is the heat transfer coefficient(w/㎡.k), Tb is the PCB surface temperature, Ti is the inlet temperature, To is the outlet temperature, Cp is the specific heat (kj/kg.k), and Tm is the average of T1 and To.

The simulation is performed by the Multi-physics of COMSOL after designating the features of the aluminum heat insulation plate and the indoor air at the temperature of 20°C for the heat analysis with the features of density=1.127kg/㎥, thermal conductivity= 0.027W/m▪K, and specific heat=1,005J/Kg▪㎥.

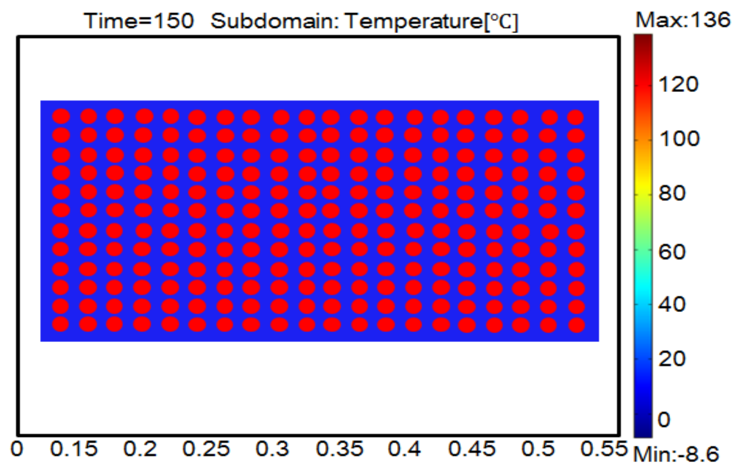


Figure 7. Temperature Distribution Diagram for the Whole Surface

One of the analysis methods is to perform the analysis until there is almost no change in the temperature and velocity pressure at the peak to obtain the value from the stable state. This is a temporary analysis to check the changes in the temperature, velocity and pressure. Generally, the stable state analysis is performed to check the convergence of each item (temperature, pressure, velocity, density) mainly for the heat transfer analysis of the LED. The analysis selects a value from 0 to 150 in the iteration to run in the analysis for the configured value. A small save interval exceeds the storage capacity of the PC, requiring maintenance of the proper value. As shown in Figure 8, the temperature distribution of the whole surface ranges 27-32°, which is a very appropriate temperature feature.

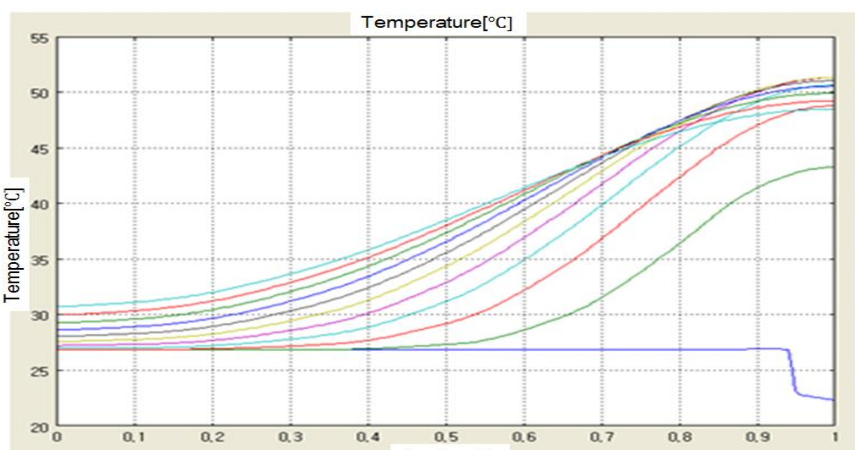
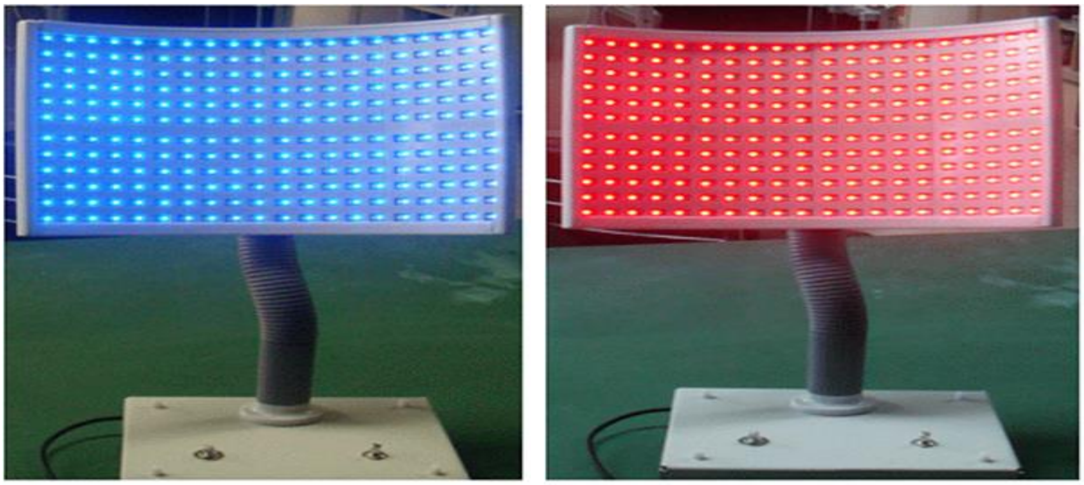


Figure 8. Temperature Distribution Curve for the Whole Surface



(a) blue (470nm) (b) red (630nm)

Figure 9. Final Product

4. Conclusion

The optical design for the LED fungal treatment device was simulated by COMSOL for the heat insulation design with Photopia, and the result was used to manufacture a device. A conclusion was achieved after receiving an assessment.

1. First, a sufficient result is achieved at the target light distribution (150°) against the single light distribution (90°). Smaller light distribution narrows the area, increases the light intensity, and causes scars on the face, but a distribution that is too small may provide less treatment due to scattering of the light intensity. The result of this study meets the requirement in both aspects. The application to dermatology based on the light source uses the advantage of existing treatment devices, and at the same time, it minimizes the side effects due to destroying skin tissues in the treatment process, while quickly stimulating skin metabolism and recovering and managing the skin. The purpose of developing the device is to meet the requirements above, as well as to develop an affordable light treatment device.

2. The device temperature decreases to below 55° using the heat insulation design due to the features in changing the lifetime and the efficiency of the LED depending on the temperature. The whole temperature is designed not to exceed 85°C by estimating an indoor temperature of 30°C. Therefore, this study would be used to provide an optimal system for those who require integrated treatment with multiple light sources and accompanied treatment by controlling various output variables in the light source modules.

3. The development of the device is complete, but it is necessary to perform a clinical test for it to be approved as medical equipment, and the complement shall be reflected if any. In addition, the structure may be modified with various forms depending on the face types.

4. The trend is to develop light source lamps that meet international standards and to perform mechanism research and experiments with the new concept of directly radiating light onto a patient through medical activities based on the stability assessment standard for medical / treatment equipment using the existing optical device with the new type of medical equipment by developing an engine to implement the system for the optimal treatment and

controlling parts and modules in the medical equipment with related fundamental technologies.

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