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Soft Ceramic LED Phototherapy Mask and Its Application

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Abstract

Researchers have created optical masks using RGB LEDs to achieve the goal of facial skincare; among them, red light stimulates blood circulation, green light enhances endocrine functions, and blue light has antibacterial properties [1-3]. The current mask products are rigid in nature. Apart from being cumbersome, their design results in a distance of about 5 to 10 centimeters between the light source and the skin, causing uneven light distribution on the skin and posing a risk of eye damage due to direct exposure. Therefore, we propose the development of a flexible optical mask using a composite precision ceramic thermal-conductive material. This mask is soft and lightweight like silk, and it can snugly adhere to the facial skin through three-dimensional cutting, much like fabric. On each LED, a silicone lens with a refractive index of 1.4 is applied, increasing the LED's emission angle from 130° to 150°, thus achieving the most uniform distribution of light and eliminating the drawbacks of direct eye exposure. The high thermal-conductive ceramic material within the mask elevates its thermal conductivity coefficient to 2W/meK, ensuring the even distribution of accumulated heat and uniformly heating the facial skin. Finally, through microscopic imaging of fingertip nail capillaries, we discovered that the use of the optical mask results in a 4.2-fold increase in microvascular flow velocity within 2 to 3 seconds, confirming its highly effective metabolism-enhancing effect.

Keywords: Fingertip; Micro vessels; Photograph; LED source; Ceramic circuit; Optical mask; Three-dimensional cutting; Facial skincare; Blood circulation; Blood circulation; Micro LED; Medical treatment; Silicone gel; Microvascular flow velocity

Introduction

Traditional paper-based masks soaked in skincare solutions have become a routine skincare product for maintaining facial skin. However, due to factors such as low ambient temperatures or individual differences in skin absorption, these masks often fail to achieve the desired effects. As a result, researchers have developed small-scale light shields using LED arrays as auxiliary tools. These shields can be used to irradiate masks or directly treat skin coated with skincare solutions to provide warmth, enhance blood circulation, and improve the absorption of skincare products. However, due to the expensive and cumbersome nature of these masks, as well as their reliance on high-power LEDs positioned 10 to 15 centimeters away from the skin, achieving even light distribution has proven challenging. This leads to suboptimal skincare outcomes and the risk of eye damage from direct light exposure, making widespread adoption difficult.

Addressing these shortcomings, we have developed an optical mask using a flexible ceramic composite circuit board material and 640μm wavelength 0805 red LEDs. The primary objectives are as follows:

a) To create a soft, lightweight, portable, and easy-to-use optical mask that employs high thermal-conductive precision ceramic materials to uniformly distribute accumulated heat across the entire mask. This enhances the skin's effective utilization of heat.

b) To cover the LED surface with transparent silicone gel with a refractive index of 1.5, forming lenses and serving as a safety protective pad. This effectively widens the emission angle, ensuring uniform coverage of the entire face and achieving even lighting.

c) To use three-dimensional design and cutting techniques, similar to working with fabric, to enable the mask to snugly adhere to the facial skin. This allows for optimal light absorption while avoiding the risk of eye damage from direct light exposure.

d) To apply the mask to the hand and measure the microvascular flow velocity on the surface of fingertip nail beds, thereby confirming the effectiveness of promoting blood circulation.

Materials and Methods

Flexible Composite Precision Ceramic Circuit Board

We utilized silicone gel as the substrate mixed with precision ceramic powder of silicon carbide (SiC) with a thermal conductivity coefficient of 130W/m•K and particle size of 0.5μm to create the circuit board. Red LEDs with specifications of 0805 and a wavelength of 640μm were then soldered onto this board to form the flexible optical mask. Figure 1. Depicts a scanning electron microscope (SEM) image of the SiC precision ceramic powder, while Figure 2. Illustrates the structure of the flexible composite precision ceramic circuit board. Measured using the international standard ASTM D5470 thermal conductivity tester [4], the thermal conductivity of the mask was found to range between 2 and 3 W/m•K, as detailed in Table 1. Which presents the primary specifications of the flexible composite ceramic circuit board.

Table 1: FCPCB Specification.

Characteristics	Unit	Typical Values	SPEC	Test Method
Number of Layer		Single side		
Base Film Thickness		0.050~0.50		
Copper Thickness		0.035(1oz)		
Volume resistivity	Ω-cm	10^{10}↑	10^{10}↑	IPC-TM-650
Surface resistivity	Ω	10^{10}↑	10^{10}↑	IPC-TM-650
Flammability	-	94V0	94V0	UL94
Peel strength 1 oz	Kgf/in	0.5		IPC-TM-650
Flexural strength	Mpa	100-		ISO-527
Coefficient of thermal expansion	cm/cm°C	1.5×10^{-4}		ISO-11359
Glass transition temp	°C	280		ISO-75
Dielectric Strength	V	5K	3K	IPC-TM-650
Solder Float	°C	280°C for >5min	-	IPC-4101C
Thermal Resistance	°C/W	<0.6	-	ASTM D5470
Working Temperature	°C	-40~250	<=150	ISO-75

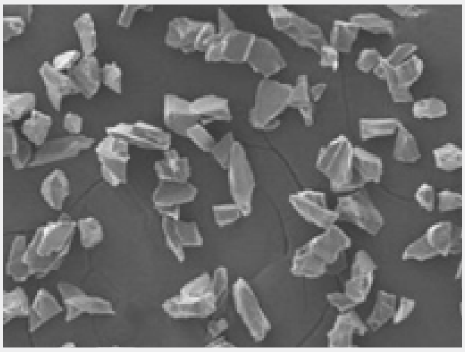

Figure 1: SEM image of the SiC powder.

Subsequently, we conducted material heating tests and employed a thermal imaging camera to observe the distribution of heat within the circuit board. Figure 3. Compares the heat distribution in the circuit boards under different operating conditions: (a) represents the flexible composite ceramic circuit board, and (b) represents a conventional circuit board. Results from the thermal imaging camera following the heating tests revealed that the high thermal-conductive material in the flexible composite ceramic played a crucial role in achieving remarkably uniform heat distribution.

Silicone Lens Covering LED Source

Figure 4 Illustrates the structure of LEDs soldered onto the mask and encapsulated with silicone gel. On the LED surface, we

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applied transparent silicone gel with a refractive index of 1.5 to create a lens with a curvature radius of 8mm. This silicone layer also serves as a safety protective pad. Figure 5. Showcases the optical simulation results, indicating a successful increase in the emission angle from 130° to 150°. Slight adjustments to the spacing between the LEDs are sufficient to ensure uniform light coverage across the entire face, achieving a greatly simplified uniform lighting effect Figure 6. Schematic representation of the relative positioning of LED light distribution and the skin.

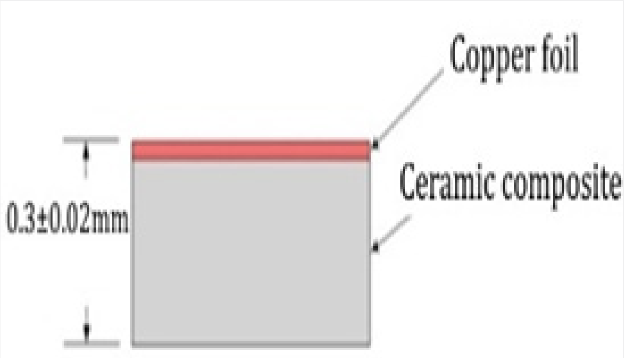

Figure 2: The structure of the flexible composite precision ceramic circuit board.

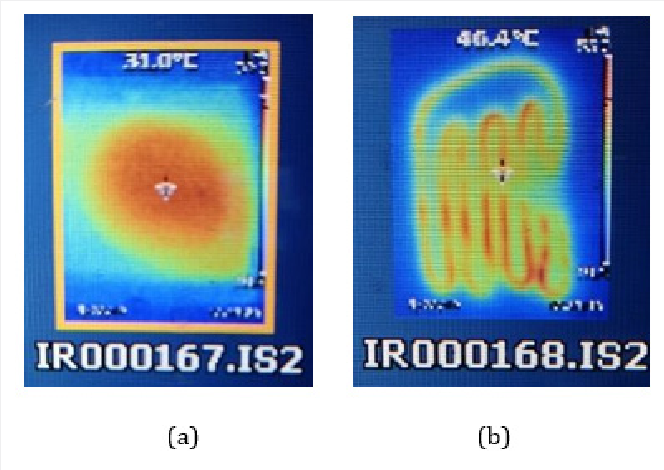

Figure 3: Compares the heat distribution in the circuit boards under different operating conditions:
(a) Flexible composite ceramic circuit board,
(b) Conventional circuit board.

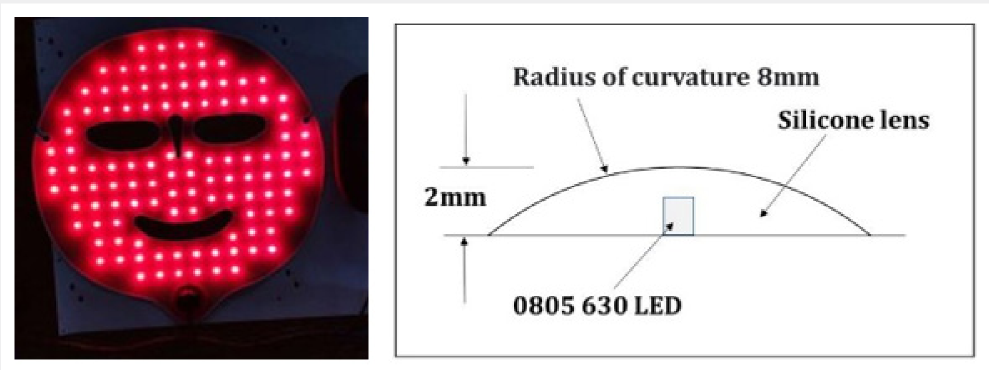

Figure 4: Silicone gel. On the LED surface.

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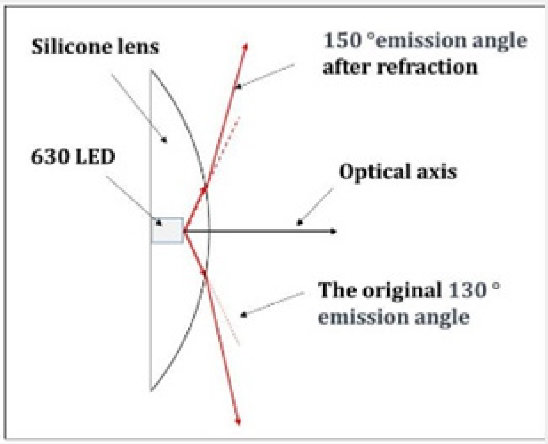

Figure 5: The emission angle from 130° to 150°.

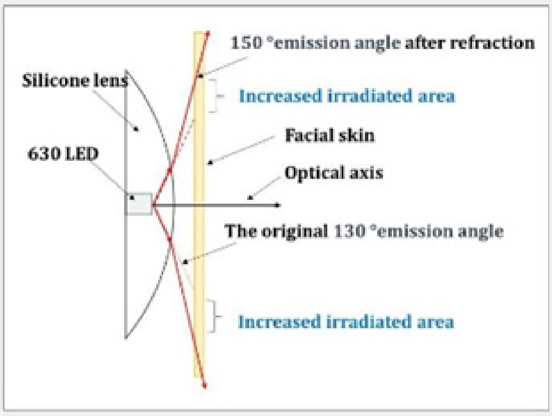

Figure 6: The relative positioning of LED light distribution and the skin.

Figure 7: The three-dimensional design of the mask.

Three-dimensional tailoring of the mask

The human face has three-dimensional contours, and when producing optical masks from flat circuit boards, it is essential to Design circuitry that accommodates the contours of the nose and other facial features. The flexible composite precision ceramic circuit board material can be treated much like fabric, allowing

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for three-dimensional design and cutting. This approach enables the mask to be positioned 3 to 5 mm away from the facial skin, facilitating optimal light utilization. This design permits the use of energy-efficient low-power LEDs. Figure 7. Presents a photograph of the three-dimensional design of the mask, highlighting its positioning on the facial skin. Another advantage of directing light onto the facial skin is the avoidance of the risk of eye damage from direct light exposure. Illustrated in Figure 8. Are the benefits of the optical mask: (a) lightweight, soft, and flexible, (b) waterproof and washable, and (c) light sources directed onto the skin to prevent eye damage resulting from direct light exposure.

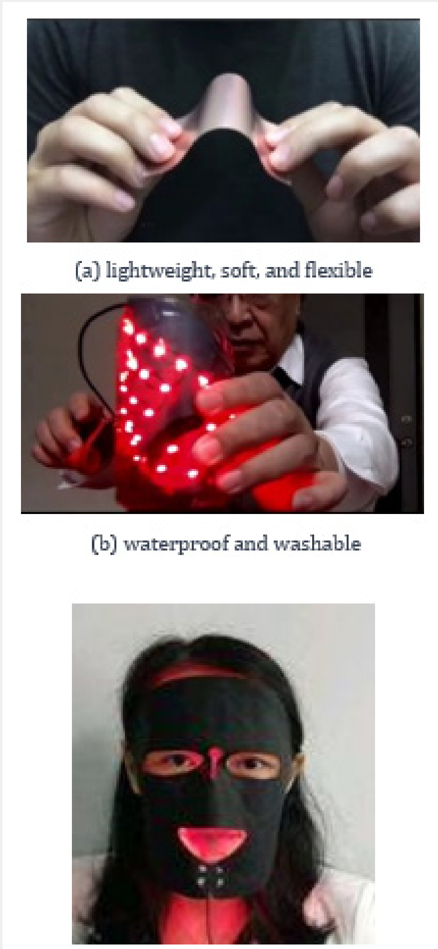

Figure 8: Are the benefits of the optical mask.

Pre-Processing

Measuring changes in microvascular flow velocity to verify the effectiveness of mask usage

As nail bed microvessels are easily accessible for measurement, we used the hand as a proxy for facial skin to assess variations in microvascular flow. Figure 9. Depicts a schematic of the microvascular flow velocity experiment. Initially, the microvascular flow velocity on the surface of the nail bed of the hand was measured without light exposure. Subsequently, the mask was applied to the hand, and the microvascular flow velocity on the nail bed's surface was measured again [5]. Figure 10(a) to (d) represents microscopic images of fingertip microvessels captured at 1200x magnification and a frame rate of 30 FPS. Through graphical analysis, equations (1) for no light exposure and (2) for red light exposure were obtained. Comparing Figure 10(a) and Figure 10(b), it can be deduced that the blood flow velocity is approximately 1.5 mm/sec when there is no light exposure.

$$\text{Flow rate} = \text{Moving distance} / \text{Spend time}$$

$$V_{\text{No-light}} = ((250-200) \times 10\text{-}6) / (1/30) = 1.5\text{mm/sec} \qquad (1)$$

Comparing Figure 10(c) & (d), it can be observed that the blood flow velocity during red light exposure is approximately 6.3mm/sec.

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V Red-light = ((250-40) ×10-6) / (1/30) = 6.3mm/ sec (2)

V Red-light / V No-light = 6.3 / 1.5 = 4.2 (3)

Figure 9: The microvascular flow velocity experiment.

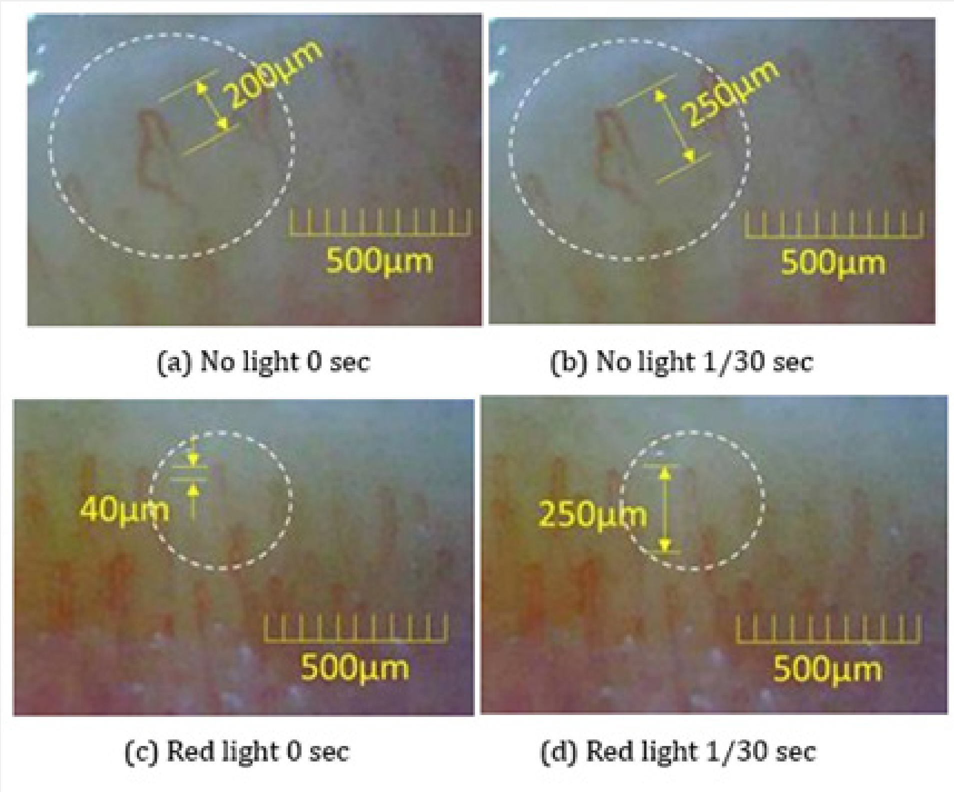

Figure 10: (a) to (d) represents microscopic images of fingertip microvessels captured.

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Taking the average of 30 measurements with an error within 2%, the results demonstrate that the blood flow velocity during red light exposure increases by over 4 times compared to when there is no light exposure. Therefore, the optical mask provides significant assistance in improving blood circulation.

Conclusion

The optical mask made from flexible composite precision ceramic circuit board material possesses advantages such as flexibility, lightweight, foldability for easy portability, and user-friendly operation. Experimental findings confirm the following characteristics:

a) The utilization of high thermal-conductive precision ceramic materials enables the mask's thermal conductivity coefficient to reach 3W/m•K. This facilitates the even distribution of accumulated heat across every part of the mask, enhancing the skin's effective utilization of heat.

b) By covering the LED surface with transparent silicone gel with a refractive index of 1.4, lenses with a curvature radius of 8mm are formed, also serving as safety protective pads. This effectively widens the emission angle from 130° to 150°, ensuring uniform coverage over the entire face and achieving a uniform lighting effect.

c) The flexible composite precision ceramic circuit board can be treated like fabric, enabling three-dimensional design and cutting. This design allows the mask to snugly adhere to the facial skin, ensuring optimal light absorption. This approach enables the use of energy-efficient low-power LEDs and also avoids the risk of eye damage from direct front-facing light exposure.

d) We applied the mask to the hand and measured the microvascular flow velocity on the surface of fingertip nail beds. Comparing the flow velocities before and after using the mask, it can be observed that within 2 to 3 seconds, the flow velocity increases from around 1.5mm/sec to approximately 6.3mm/sec, an enhancement of over 4 times.

In terms of future prospects, while optical techniques currently serve as auxiliary tools in medicine, with the advancement of RGB LEDs, micro LED components, manufacturing techniques, and the accumulation of more medical cases, we anticipate that multi-color light therapy techniques might eventually play a primary role in medical treatment.

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