# REALIZATION OF 650 NM FIBER-COUPLED DIODE LASERS MODULE WITH OUTPUT BEAM REDIRECTION FOR APPLICATION IN PHOTOTHERAPY AND PHOTODYNAMIC INACTIVATION OF BACTERIALS

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## ABSTRACT

Currently, diode lasers in the red wavelength region, especially at 650 nm, are extensively utilized in phototherapy and photodynamic inactivation of bacterials by numerous research groups in the field of lasers for biomedical application. These devices offer exceptional advantages, such as their compact size, ease of design and integration, user-friendliness, and high safety for both operators and patients. Among these, fiber-coupled diode lasers provide an efficient solution for delivering radiation from the laser chip to the desired location. However, further optimization is still required for the fabrication technological development of these devices to meet specific application needs. This includes aspects like reducing manufacturing costs, improving component usability during operation, and meeting specialized usage requirements. To develop the technology for device fabrication, addressing the aforementioned demands, we conducted research on the design, fabrication, and characterization of fiber-coupled semiconductor lasers operating at a wavelength of 650 nm. The characterization results demonstrate that the manufactured devices can operate at maximal pumping current of 100 mA and under varying temperatures from 25$^{o}$C to 40$^{o}$C. Additionally, a radiation output orientation module has been designed and integrated at the end of the optical fiber to meet various demands in phototherapy and photodynamic inactivation of bacterials.

**Keywords:** Radiation redirection module; 650 nm diode laser; phototherapy; photodynamic inactivation of bacterials.

## 1. Introduction

The red wavelength laser was first invented in 1960, opening up a new era for light and energy-related applications. To this day, laser technology has been widely applied in various fields such as material processing, optical communication, medicine, military, science, and data storage, etc. A type of laser with different wavelength and power as well as characteristics is required corresponding to each application field. Lasers with wavelength ranges from red to near infrared are commonly used in therapy [1] such as acupuncture, recovery of small wounds [2]; intravascular laser; diagnosis and treatment of ophthalmic and dental diseases in dentistry; combined treatments with photosensitizing biological active ingredients; restorative therapy in beauty salons and many other treatments [3-6]. In particular, the trend of promoting the application of less invasive treatment methods in treating diseases is becoming popular today. This creates opportunities for strong development of the application using laser radiation. Less pain, almost no side effects or sequelae after treatment, high selectivity in treatment, and high safety for both doctors and patients are the advantages of this method.

Diode lasers emitting in the red wavelength region are a special candidate in the field of phototherapy and photodynamic inactivation of bacterials because of their superior features such as: compactness, high reliability and life time, easy to adjust output power, much more efficient than other types of lasers. Currently, medical and health care equipments that uses lasers are mainly completely imported or just partially import the main components. Some domestic equipment use diode lasers that directly contact the patient, leading to increased possibility of component failure and low electrical safety due to lack of complete electrical isolation. This disadvantage can be resolved by fiber-coupled diode lasers or diode laser modules because the laser source is guided to the area to be treated through optical fibers.

In this article, 650 nm wavelength lasers have been investigated to ensure the ability to work at different optical power and temperatures. Laser modules are manufactured by coupling the radiation into optical fibers and improving perpendicular output beam redirection modules to meet the needs of phototherapy and photodynamic inactivation of bacterials.

## 2. Fabrication of red wavelength region laser modules

A diode laser with a wavelength of 650 nm has been used as the emitter source. The fiber patch cord multimode for pairing has an outer diameter of 3 mm, a coating of 125 μm and a core of 62.5 μm diameter. The heatsink submount, fixing disk and the module housing are fabricated to fit with the sizes of the diode laser (Figure 1). Initially, the photoelectric and spectral characteristics of the laser were investigated at different pumping currents as well as temperatures to ensure that the laser power and wavelength match the manufacturing requirements. The optical power and temperature of diode laser is controlled by a Thorlabs ITC 4005 power source. The pumping current comes from 0 mA to 100 mA in 1 mA steps. The measurement temperatures include 25$^{o}$C, 30$^{o}$C, 35$^{o}$C and 40$^{o}$C, which is the temperature range in which the device regularly operates. Optical power was collected by a photodiode detector and measured with a Melles Griot 13 PEM001 wide-band optical power meter. The laser spectrum was measured using Ocean Optics HR2000+ at different pumping currents and temperatures, respectively.

The diode laser with standard parameters will be removed the cap and then mounted on a heatsink submount. The optical fiber is stripped of its outer cover, retaining the glass core. We clean and cut the fiber tip flat so that the laser radiation can be coupled. The optical fiber is joined in the hole center of the fixing disk. The laser heatsink submount is placed on a Peltier temperature controller therefore the laser temperature is stable throughout the fabrication process. The optical fiber joined with fixing disk is hold on a 3-dimensional translation stages in front of laser facet (Figure 2). The pumping current of the laser is about 80 mA at the operating temperature of 25$^{o}$C. The emitted laser radiation is coupled into the tip of the optical fiber. At the output of the end of the fiber, we can observe the collected optical power by a power/energy meter. The 3-dimensional translation stages allow for spatial adjustment of relative positions between fiber tip and diode laser facet. When the maximum value indicated on power meter is obtained, which is the optimal position, the system is joined by epoxy glue and cured with heat. Finally, the system is housed of by outer cap to protect the module (Figure 3).

**Figure 1:** *Components for coupling the radiation from diode laser to optical fibers. From left to right: heatsink submount; fixing disk; outer cap*

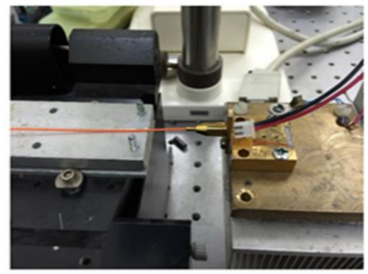

**Figure 2:** *Fiber-coupled semiconductor laser module manufacturing system*

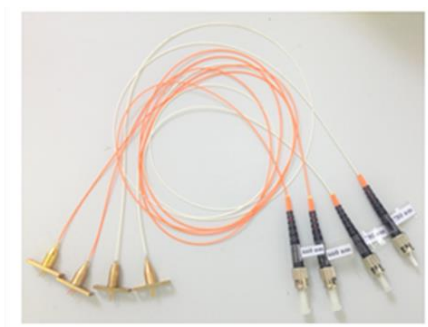

**Figure 3:** *Complete laser module*

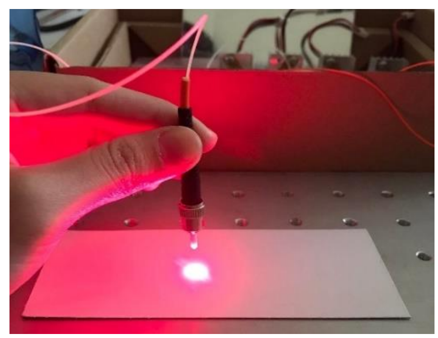

**Figure 4:** *Laser module with straight beam during operating.*

In the original design, output laser beam will irradiate straight from the laser head to the treatment area. When performing treatment, the laser head must be positioned perpendicular to the skin surface (Figure 4). The measurements are conducted to evaluate the module's parameters to see if the designed module meet treatment requirements. However, this original design has some disadvantages such as difficulty in positioning the treatment laser head, the laser beam can be deflected from the wound, the optical fiber can be broken by bending, so the longevity of device will be reduced. Therefore, a new design of the treatment laser tip to the skin is necessary. Redirecting the output laser beam from the treatment laser head perpendicular to the skin is feasible and possible, minimizing some inconveniences from the original design. The description of beam redirection method shown in Figure 5 will make it easier to fix the treatment laser head and protect the treatment fiber tip. The optic fiber output is reflected 90 degrees at the end, making it easy to place at the acupuncture point. In new design, a flat mirror with high reflectivity is used, the light guiding using a mica tube with a diameter of 3 mm. The flat mirror is installed at a 45° angle at the top of the mica tube (the tube's tip is also cut diagonally 45° so that when installing a small flat mirror, it fits 45°). Thus, according to the law of total internal reflection, the laser beam reaching the mirror will be changed the direction perpendicularly irradiating to the skin at an angle of 90° (Figure 5). We use a metal piece to fix the treatment head to prevent it's shifting during operation (Figure 6).

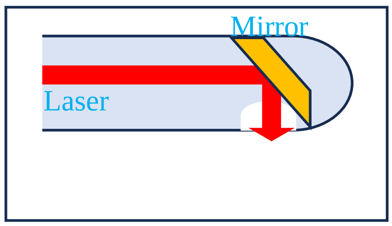


**Figure 5:** *Perpendicular laser head design*

**Figure 6:** *New design of the laser head*

### 3. Results and discussion

Figure 7 shows the optical power curve depending on the pump current of the laser at different operating temperatures. At a pump current of 100 mA and a temperature of 25$^o$C, the optical power reaches 46.47 mW. As the temperature increases, the optical power decreases: Corresponding to the temperatures 30$^o$C, 35$^o$C, 40$^o$C, the optical power is 37.60 mW; 33.68 mW; và 31.00 mW, respectively. This is consistent with the properties of diode lasers that the optical power decreases as the working temperature increases [7], however the power is still within the device's working range of more than 20 mW. After manufacturing the diode laser module, we investigate the power-current characteristics again as shown results in Figure 8. Optical powers of original design module (straight beam) at 100 mA pump current with operating temperatures of 25$^o$C and 40$^o$C are 44.33 mW and 30 mW, respectively. Thus, the pairing efficiency reaches 95%.

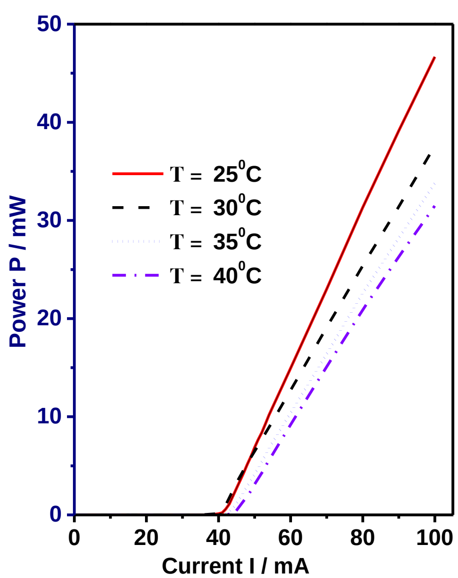


**Figure 7:** *The optical power depends on the laser pump current at different temperatures*

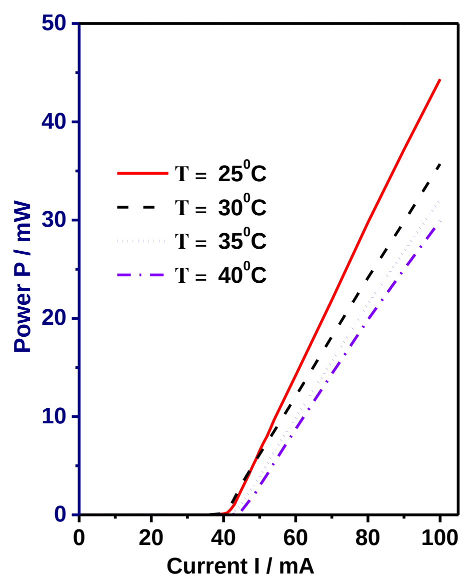


**Figure 8:** *The optical power depends on the pumping current of the straight beam laser module at different temperatures*

For the perpendicular beam module, the power-current characteristic shows that the optical power is reduced by 5% compared to the straight beam module (Figure 9). Thus, the efficiency of the perpendicular beam module is 90% and the optical power is still greater than 20 mW.

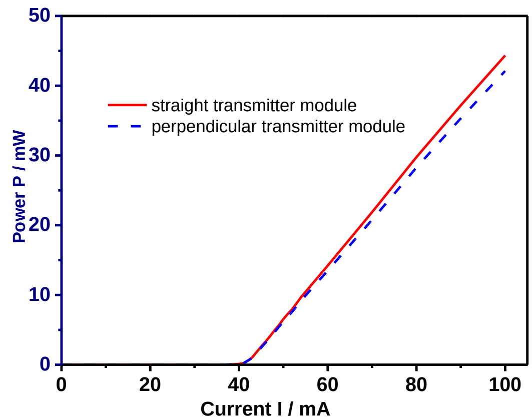


**Figure 9:** *The optical power depends on the pumping current of the laser module with 2 different types of treatment modules (straight and perpendicular beam) at the temperature of 25$^{o}$C*

Spectral characteristics of the laser before and after fabrication of laser modules were investigated dependings on pump current and temperature. Measurements show that lasers-fiber coupling does not affect the spectral characteristics of the diode laser. Figure 10 and Figure 11 show that as the pump current and temperature increases the wavelength peaks shifts towards longer wavelengths, specifically, the wavelength peak displacement coefficient according to pump current is $\Delta\lambda/\Delta I$ = 0,06 nm/mA and according to temperature is $\Delta\lambda/\Delta T$ = 0,33 nm/degree. For diode lasers, the spectral peak shift phenomenon according to the pump current is exactly as predicted theoretically due to the change in the energy gap [7]. The results show that no abnormalities occurred, and the laser radiation remained completely in the red wavelength region.

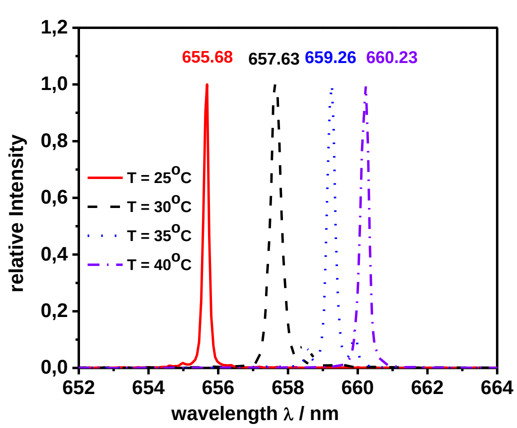


**Figure 10:** *Laser module spectra vs temperatures at 80 mA operating current*

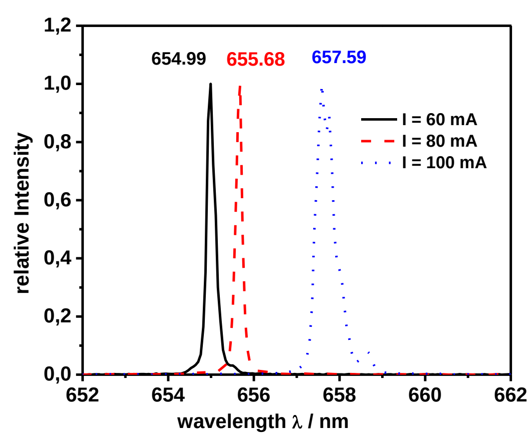


**Figure 11:** *Laser module spectra vs pump currents at 25$^{o}$C*

Thus, the designed and manufactured fiber-coupled diode laser can fully meet the operating conditions in phototherapy or photodynamic bacterial inactivation equipment. Laser transmission through optical fiber is very safe for users. If these modules operate at a pump current greater than the critical level or under high temperature, it may lead to rapid aging and failure of the devices. Therefore, it needs to be warning or measuring of supply current limit the and to stabilize the operating temperature of the laser to ensure the longevity of the devices.

## 4. Conclusions

Fiber coupled diode laser modules in the 650 nm wavelength region with two configurations straight and perpendicular beam were successfully manufactured. The radiation coupling efficiency into the optical fiber of the modules achieves over 90%. The devices can operate in the temperature range from 25$^{o}$C to 40$^{o}$C with a maximum pumping current of up to 100 mA, ensuring optical power to fulfil the requirements for therapeutic and bio-phototherapy devices. Laser radiation with a pump current displacement coefficient of 0.06 nm/mA and a temperature of 0.33 nm/degree, guaranteed to operate completely in the red wavelength region. These above components are suitable for manufacturing laser equipment for medical, health care and cosmetic applications.

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## TÓM TẮT

## NGHIÊN CỨU CHẾ TẠO MÔ ĐUN CHUYỂN HƯỚNG BỨC XẠ LASER BÁN DẪN GHÉP SỢI QUANG 650 NM ỨNG DỤNG TRONG QUANG TRỊ LIỆU VÀ QUANG SINH DIỆT KHUẨN

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Hiện nay, laser bán dẫn vùng bước sóng đỏ (đặc biệt là vùng 650 nm) đang được ứng dụng rộng rãi trong quang trị liệu và quang sinh diệt khuẩn tại nhiều nhóm nghiên cứu laser cho y sinh trên thế giới nhờ các ưu điểm vượt trội như kích thước nhỏ, gọn dễ thiết kế, tích hợp, tiện lợi trong việc sử dụng, độ an toàn của linh kiện, thiết bị cho cả y bác sĩ và bệnh nhân cao. Các laser bán dẫn ghép nối sợi quang là giải pháp hiệu quả cho phép đưa bức xạ từ chip laser tới vị trí cần sử dụng. Tuy nhiên, các nghiên cứu công nghệ chế tạo linh kiện này để phù hợp với các mục đích ứng dụng cụ thể vẫn còn nhiều khía cạnh cần phải tiếp tục tối ưu, đặc biệt là các vấn đề như giảm chi phí chế tạo, tăng sự tiện dụng trong quá sử dụng của linh kiện, thỏa mãn các nhu cầu sử dụng chuyên biệt. Để làm chủ công nghệ chế tạo thiết bị, chúng tôi đã tiến hành nghiên cứu thiết kế, chế tạo và khảo sát các đặc trưng của laser bán dẫn ghép nối sợi quang phát tại vùng bước sóng 650 nm. Kết quả đo đạc cho thấy các linh kiện đã chế tạo có thể làm việc tại dòng cấp đến 100 mA và nhiệt độ thay đổi từ 25$^o$C tới 40$^o$C. Đồng thời, mô đun chuyển hướng bức xạ đầu ra cũng đã thiết kế và tích hợp vào cuối sợi quang để đáp ứng các nhu cầu cụ thể trong quang trị liệu và quang sinh diệt khuẩn.

**Từ khóa:** Mô đun chuyển hướng bức xạ; laser bán dẫn 650 nm; quang trị liệu; quang sinh diệt khuẩn.