

# Coupling Device with Output Power Continuously Tunable “Laser-infrared Optical Fiber” for Surgery

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## ABSTRACT

In the domain of the laser surgery, the most favorite laser beam is always CO<sub>2</sub> laser beam at 10.6μm because of its quite high energy intensity and a keen effect with biological tissues. In order to make an efficient surgery appliance for the clinical using, however, the most significant components should include an optical fiber which can transmit CO<sub>2</sub> laser efficiently and a “laser-infrared optical fiber” coupling device with a continuously and accurately tunable output power. A novel “laser-infrared optical fiber” coupling device therefore is proposed. Its outstanding feature is that based on the optical adjustment principles, the device is able to achieve the output power of a scalpel head tunable continuously and accurately in a board bandwidth on the premises of an optimal coupling state of the “laser-infrared optical fiber” and an optimal working state of the laser.

**Keywords:** laser surgery, infrared optical fiber, coupling device

## 1. INTRODUCTION

The laser surgery and laser medicine is one of most active research fields in the world presently. The medical laser technology has applied to surgery and diagnosis extensively, which proves that laser has transformed the conventional medical approaches and greatly accelerated the medical development. The experts in respect of ophthalmology, surgery, dermatology, urology and other medicine, therefore, have achieved the agreement that the application of laser is one of the most effective ways to improve the medical technology.

For the current medical laser application, CO<sub>2</sub> laser is the most favorable and widely applied example, especially the low-power CO<sub>2</sub> laser. In order to make it really used in the clinical occasions successfully, however, a technical barrier that should be solved is the laser transmission at wavelength 10.6μm. That is an attractive research hot spot currently and the perspective few years. For the conventional “optical joint arm” light-guidance system, it is always inconvenient for the operation. Hence, the study on the light-guidance system using “infrared optical fiber” to transmit 10.6μm laser and related technologies has fully shown its significance and brilliant future.

Recently, we study the operating equipment of the infrared optical fiber CO<sub>2</sub> waveguide laser and obtain the primary practical results. As the vital component of the infrared optical fiber light-guidance system: “laser-infrared optical fiber” coupling device, we mainly discuss its design, fabrication and testing in this letter.

## 2. THE DESIGN FOR A “LASER-INFRARED OPTICAL FIBER”

### COUPLING DEVICE

#### 2.1 Designing principle

Due to the intense effect of the 10.6μm CO<sub>2</sub> laser radiation to the human tissues, its major application is on the laser surgery operation, especially the microsurgery operations, e.g. the cutting and melding of the micrangium and nerve fibers, the exclusion of the thrombus in the blood vessel, etc.. For the most applications, a large laser power is unnecessary but there demands the continuously tunable laser power in the whole operation process, and the tuning rang should be as board as possible. The rang from a few milliwatts to a few watts is favorable. Generally, there are two methods to achieve the adjustment of the output power of the “laser-fiber” coupling.

One is to change the discharge conditions of the CO<sub>2</sub> laser, i.e. changing the working current of laser to change laser power. However, this method brings about two problems: **a.** the small tuning rang. For the gas lasers stimulated by the glow discharge like CO<sub>2</sub> laser, the corresponding relationship of its working current and output power is not sensitive virtually. The general tuning rang varies within a power magnitude. Therefore, it is impossible to satisfy the demand for tuning rang of “mW ~ W” through changing current. **b.** This method damages the optimal working conditions and states for laser operation. It influences not only the laser operation life, but also the output characteristics, and causes the change of the output modes and diffusion so as to deteriorate the performance of “laser-fiber” coupling device and the quality of output laser.

The other method to tune laser power is to change the coupling collimation of “laser-fiber” device, i.e. offsetting the optimal coupling state to change the output power. Obviously, this approach may reduce the quality of the output laser and make against the application of the fine laser surgery operation.

Based on the above situations, we propose a new type of “laser-infrared optical fiber” coupling device. Its favorable feature is to achieve the coupling of the power wide-rang continuously tunable “laser-infrared optical fiber” device on the premises of the optimal operation state of laser and the optimal coupling state of “laser-fiber” device.

2.2 Coupling device.

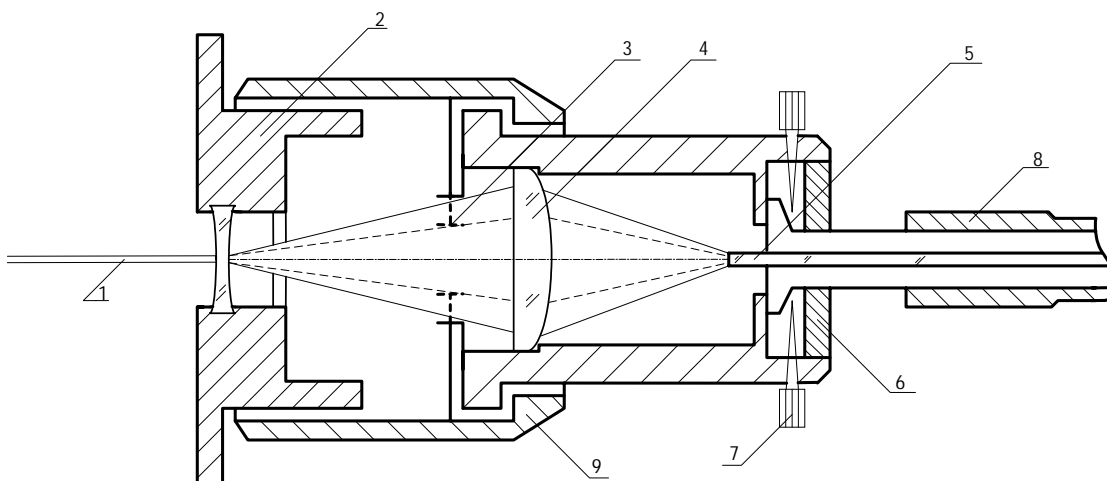


Fig.1 power tunable “CO<sub>2</sub> laser-infrared optical fiber” coupling device

- ① waveguide CO<sub>2</sub> laser; ② ZnSe infrared diffusive lens; ③ variable diaphragm (Φ2-10mm); ④ ZnSe infrared convergent lens; ⑤ AgCl crystalline infrared fiber; ⑥ fiber chuck; ⑦ adjusting screw of the fiber head; ⑧ fiber jacket; ⑨ adjusting drum of the variable diaphragm;

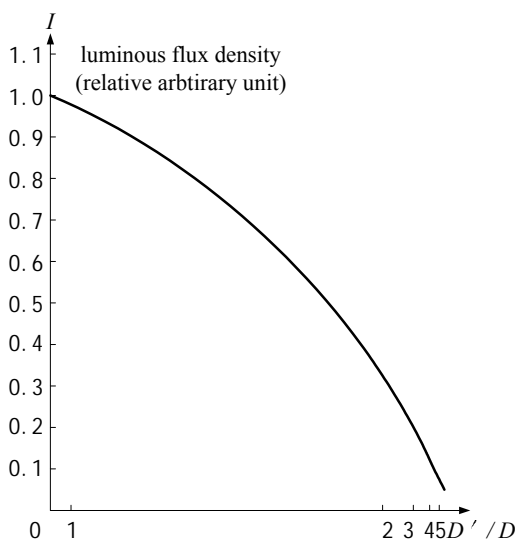


Fig.2 relationship curve of the relative aperture of the variable diaphragm and laser luminous flux density

Figure 1 is the configuration of the power tunable “CO<sub>2</sub> laser-infrared optical fiber” coupling device that we made and designed alone. The device contains a pair of diffusive and convergent lens whose focal lengths are -5mm and 25mm respectively, and made of ZnSe infrared material. The surfaces of lens are plated with the infrared reflection reducing coating and the transmission ratio for the 10.6μm radiation is over 98%. A variable diaphragm is placed between the two lenses and close to the convergent lens.

The laser source is a CO<sub>2</sub> waveguide laser and its cavity is 30cm long. Under the optimal operation state, the output power is 6W; the lowest order waveguide mode is EH<sub>11</sub>; the diameter of the output

laser beam is 2mm with a small diffusion. The light of path from laser to the center of the first lens is equivalent to the quasi-parallel light. The output laser beam ① is extended to diaphragm ③ by the first lens-diffusive lens ②. Then the beam diameter is extended to 10mm around. Correspondingly, the laser average optical power reduces to the  $1/c^2$  ( $c$  is the ratio of two beam sizes before and after extension.). The diameter of the variable diaphragm can vary continuously in a rang of  $\Phi 2\sim 10$ mm. Hence, laser reaches the convergent lens ④ after the adjustment of the diaphragm and then is coupled to the infrared fiber ⑤. We thus realize the laser power continuous adjustment of “ $1\sim 1/25$ ” finally.

Figure 2 shows the relationship curve of the relative aperture  $D'/D$  of the variable diaphragm and the density computing of the coupled optical flux.  $D'$  represents the largest aperture of the variable diaphragm and  $D$  represents the smallest one. Demonstrated as the Figure 2, the optical flux density that is coupled to the fiber through the lens ④ increases from  $1/25$  to 1 when the diaphragm diameter  $\Phi 2\text{mm}\rightarrow 10\text{mm}$ .

The whole coupling equipment has a fine configuration design. A pair of lenses and diaphragm are coaxial to the optical axis. Their respective positions are determined by design requirements and equipped with the fine tuning mechanism. First, we adjust the  $\text{CO}_2$  waveguide laser and make the output laser beam coaxial with the optical axis of the lens group. Then the convergent spot after the coupling lens group should be settled at the center of head face of the AgCl infrared fiber, and the optical axis should be perpendicular to the head face. We design the fiber adjusting head and achieve the this demand through accommodating the ⑥,⑦,⑧.

### 3. CONCLUSION

We have tested the performance of the “laser-infrared optical fiber” coupling device and the results agreed with the designing demands quite well. This type of the device has the following favorable characteristics:

- (1) Since the laser and fiber coupling head keep the optimal state in operation all the time, the output laser quality is always good and stable. The output power in each level is also very stable, which is benefit to the scaling of the power density.
- (2) The variable diaphragm is camera diaphragm made of sheet steel. Experiment shows that it can bear the optical radiation energy on its surface completely. The absorbed optical power is been transferred to thermo and the thermo then radiates out of the surface naturally so as to keep the thermal balance. We surly think that this variable diaphragm is applicable to the “laser-fiber” coupling device with a higher power (tens or hundreds of watts) only if the design of the diaphragm is optimized further.

Through designing the relative variation of the diaphragm diameter, the relative adjustment of the optical power in arbitrary rang is obtained. Furthermore, based on the relation of the aperture and the optical power, we can make a relative scaling for the output optical power on the adjusting drum ⑨ of the variable. This kind of working state with the arbitrary adjustment and continuously variable power is definitely welcome by the operators who utilize laser in the process of surgery operations.

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