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Simulation of Ytterbium Doped Double Clad Fiber Laser Output Power by Using Liekki Application Designer Software

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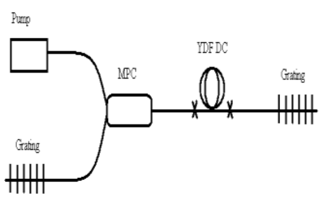
Graphical abstract



The setup of the simulation work for Ytterbium doped-double clad fiber laser.

Abstract

Erbium and Ytterbium doped fibers are usually used as optical amplifiers in fiber optic communications. For high power fiber laser application, Ytterbium doped Double Clad Fiber is among the best candidate. However, the appropriate power budget should be reviewed on the Ytterbium doped Double Clad Fiber that can be used for certain purpose of laser application. Due to high cost and limited budget to initiate the development of fiber lasers, it is necessary to simulate the power distribution that just enough to produce the laser. Every component in the software application acted as a real component in the fiber laser. Several parameters and configuration of fiber laser are investigated and discussed.

Keywords: Fiber laser; Ytterbium doped double clad

Abstrak

Gentian terdop Erbium dan Ytterbium biasa digunakan sebagai penguat dalam komunikasi gentian optik. Untuk kuasa yang tinggi bagi laser gentian, serat yang didopkan dengan dua dinding pelindung adalah antara pilihan yang terbaik. Walau bagaimanapun, bajet kuasa yang sesuai perlu dikaji semula pada serat terdop Ytterbium dua dinding pelindung yang boleh digunakan untuk tujuan tertentu penggunaan laser. Oleh kerana sangat mahal dan bajet yang terhad untuk memulakan pembangunan laser gentian, ia adalah perlu untuk mensimulasikan pengagihan kuasa yang cukup untuk menghasilkan laser. Setiap komponen dalam aplikasi perisian bertindak sebagai komponen sebenar dalam laser serat. Beberapa parameter dan konfigurasi laser serat dikaji dan dibincangkan.

Kata kunci: Serat laser; Ytterbium terdop dua dinding pelindung

■1.0 INTRODUCTION

Efficient and high power compact tunable or broadband laser source have attracted great interest in recent years due to their practical and potential applications in various domain including gas sensing, laser surgery, medicine or spectroscopy [1]. Jeong *et al*. demonstrated a CW output power of 1.36 kW at 1.1 µm in a near single-mode beam in 2004 [2]. Gaponstev [3] announced a 6 kW CW single-mode Yb^{3+} fiber laser in all fiber format. To relate this, Kelson and Hardy [4] and [5] have obtained the analytical expressions of output power, lasing threshold, slope efficiency, the optimal fiber length and reflectivity of output mirror for linear cavity DCFL without scattering loss based on the rate equations.

Ytterbium doped fiber lasers, YDFLs are well known for their excellent power conversion efficiency and broad gain bandwidth. Moreover, Ytterbium-doped fiber lasers are known for their simple energy level configuration [6]. Yb doped fiber laser operating in spectral range 1.0-1.1 µm has present a large absorption cross-section around 980 nm allowing for a pumping with low cost commercially available laser diodes [7].

For high power applications, single clad fibers are not suitable because of the very low injection efficiency of large stripe laser diodes. Therefore, double clad Yb-doped fiber laser was design with an attractive medium to gain high power, high brightness and broad wavelength tuning capability. Development of high power laser diode source with advance in design and fabrication of double clad fiber have successfully demonstrated kilowatt level fiber lasers and amplifiers pumped by 976 nm laser diode [8].

In this work, we attempt to design and develop a fiber laser system where the laser cavity consists of an array of fiber Bragg gratings which serve as wavelength selective feedback element and diffraction grating as output coupler. To study the output performance of Ytterbium-doped double-clad fiber laser (DCFL), parameters such as single and double clad fiber and pump power are studied. It shows that by varying these parameters, the output power of Yb-doped DCFL is changed as well.

2.0 THEORETICAL CONSIDERATION

The schematic diagram of a typical linear cavity Yb-doped double-clad fiber laser is shown in Figure 1. The pump power $P_P^+(0)$ at wavelength λ_p is inputted at the fiber at z = 0 from the left side, transmitted by Yb-doped double-clad fiber and is reflected at z = L.

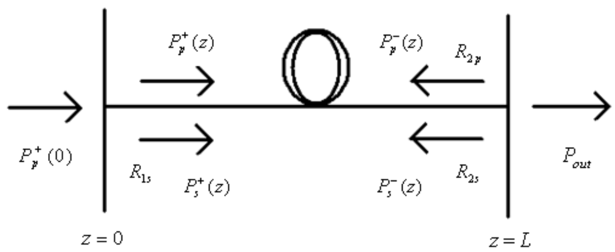


Figure 1 Schematic diagram of the linear cavity Yb-doped double-clad fiber lasers. [9]

Based on previous discussion [9,10,11], for continuous wave lasers, the time independent steady-state rate equations and propagation equations are described as

$$\frac{N_2(z)}{N}=\frac{\dfrac{(P_p^+(z)+P_p^-(z))\sigma_{ap}\Gamma_p}{h\upsilon_p A}+\dfrac{(P_s^+(z)+P_s^-(z))\sigma_{as}\Gamma_s}{h\upsilon_s A}}{\dfrac{(P_p^+(z)+P_p^-(z))(\sigma_{ap}+\sigma_{ep})\Gamma_p}{h\upsilon_p A}+\dfrac{1}{\tau}+\dfrac{(P_s^+(z)+P_s^-(z))(\sigma_{as}+\sigma_{es})\Gamma_s}{h\upsilon_s A}} \quad (1)$$

$$N_1(z)=N(z)-N_2(z) \quad (2)$$

$$\pm\frac{dP_p^{\pm}(z)}{dz}=-\Gamma_p(\sigma_{ap}N_1(z)-\sigma_{ep}N_2(z))P_p^{\pm}(z)-\alpha_p(z)P_p^{\pm}(z) \quad (3)$$

$$\pm\frac{dP_s^{\pm}(z)}{dz}=\Gamma_s(\sigma_{es}N_2(z)-\sigma_{as}N_1(z))P_s^{\pm}(z)-\alpha_s(z)P_s^{\pm}(z) \quad (4)$$

The Yb dopant concentration N is constant, which is independent of position along the fiber. τ is spontaneous lifetime. υ_p and υ_s are pump and laser frequencies, respectively. h is Planck's constant. A is effective core area. $\Gamma_p=S_d/S_{ic}$ is pump power filling factor, S_d and S_{ic} are the core and inner cladding cross-section. Γ_s is the signal power filling factor, α_p and α_s are assumed to be independent of the location, which represent the scattering losses for the pump and signal power, respectively. σ_{ap} and σ_{ep} are the pump absorption and the emission cross-section, respectively. In the same way, σ_{as} and σ_{es} is the laser absorption and the emission cross-section, respectively. The boundary values of the forward and backward laser power should meet the boundary conditions posed by the reflectors R_{1s} and R_{2s}. A straightforward integration of equation (4), it can be easily found

As explain in previous work [9], the approximate analytic expression of distributed laser and output power can be obtained

$$P_s^+(0)=R_{1s}P_s^-(0) \quad (5)$$

$$P_s^-(L)=R_{2s}P_s^+(L) \quad (6)$$

$$P_s^+(0)P_s^-(0)=P_s^+(L)P_s^-(L)=P_s^+(z)P_s^-(z) \quad (7)$$

$$P_{out}=(1-R_{2s})P_s^+(L) \quad (8)$$

The output power is not completely strengthened wih lengthening fiber length. Therefore, the output power is increased first and then is decreased with the variation of fiber length. So the fiber length is defined as the optimum laser length when the output power reaches its maximum value.

3.0 SIMULATIONS OF OUTPUT POWER YTTERBIUM DOPED DOUBLE CLAD FIBER LASER

The aim of this project is to simulate fiber laser system by simulation method where the rare-earth element Ytterbium doped and double-clad fiber was used in the simulation study. Liekki Application Designer (LAD) was used for the purpose of this simulation. LAD is a simulation environment for active fiber applications such as fiber lasers, fiber amplifiers, ASE sources and many other active fiber based applications. It provides all the tools for describing the set-up, for performing the calculations and displaying the results.

The parameters such as core diameter, and pumping configuration of the Ytterbium doped-double clad fiber laser were analyzed. Figure 2 below shows the setup of the simulation work for ytterbium doped-double clad fiber laser.

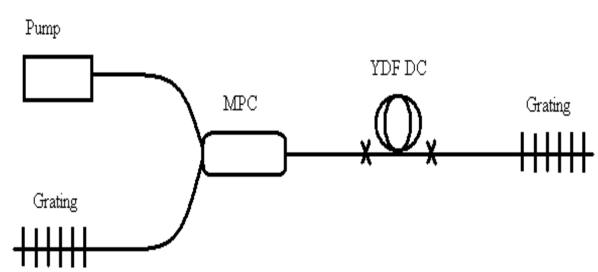


Figure 2 The setup of the simulation work for Ytterbium doped-double clad fiber laser

The fiber laser system contains Pump, Gratings, Multiplexing Combiner (MPC), Ytterbium doped fiber double clad (YDF DC) and splice connectors was designed. Pump provides the source to the fiber system and the value used in this simulation is 10 W. The output wavelength of the pump is 976 nm because it has higher cross section compared to 915 nm and 980 nm. The gratings were set to 1070 nm to provide controlled optical feedback from a narrow spectral band in order to lock the laser to a defined emission wavelength that matches the ytterbium absorption band. The splice connections were used because there will have signal loss in experimental work. MPC used to combine two inputs at different wavelengths into one output without exhibiting significant losses.

4.0 RESULTS AND DISCUSSION

The output power for double clad fiber laser is in the range of Watt (W) but for single clad fiber laser the output power only in microwatt (µW) range. This is because in double clad fiber, the refractive index of inner cladding is higher compared to refractive index of outer cladding. This phenomenon allowed the inner cladding to guide light propagates in the core. Thus, less loss occurred and higher output power is produced. Figure 3 indicates the output power as a function of the ytterbium doped single and double clad fiber length. It shows that the output power is not completely strengthened with lengthening fiber length. The output power is increased first and then is decreased with the variation of fiber length. So the fiber length is defined as the optimum laser length when the output power obtained the maximum value. For this case where the input pump power is 10 W, the optimum length for double clad is 8.3 m at 3.70 W output power while single clad optimum length is 2.8 m at 5 µW output power. Therefore, double clad fiber laser can produce higher output power compared to single clad fiber laser.

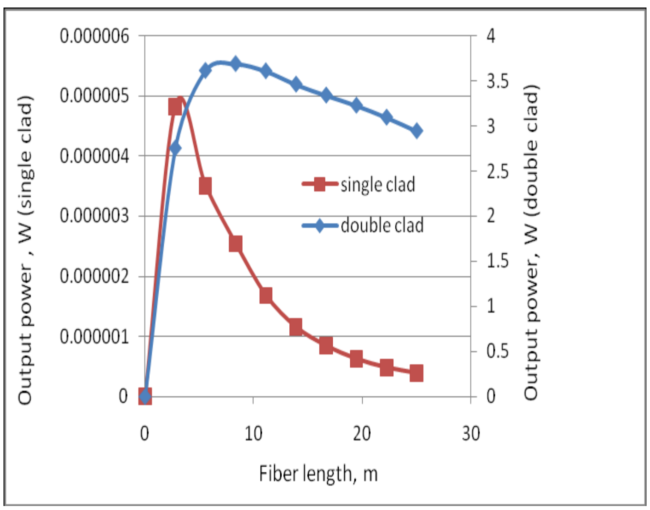


Figure 3 The output power versus fiber length for single and double clad ytterbium doped fiber laser

Figure 4 plots the output power as a function of the fiber length under the condition of different pump power entering from z = 0. This fiber had a 6 µm Ytterbium-doped core, and the inner cladding had a 125 µm diameter. It clearly shows that the laser output power can be improved by increasing the pump power. From Figure 4, the output power increases with fiber length due to the increase in the number of excited Yb ion. The output power drops slightly when the length is exceeded the optimum value. The optimum output power is found to be 1.8, 3.7, 7.5, 11.2, and 14.9 W for input pump power of 5, 10, 20, 30 and 40 W respectively.

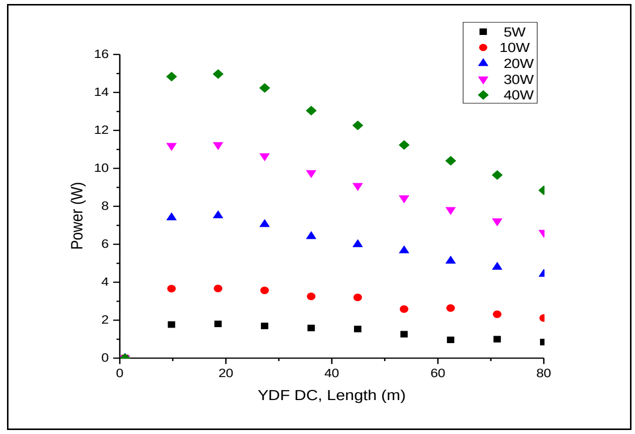


Figure 4 Output power as a function of laser length for the different pump power

5.0 CONCLUSION

In this paper, two parametric analyses which are the effect of fiber type and input pump power of Ytterbium-doped double-clad fiber laser on the output power are studied and analyzed in detail. It was successfully obtained by using Liekki Application Designer Software. The output power is higher by using double clad fiber which is 3.7 W compared to single clad fiber that achieved only 5 µW. This is due to the double cladding structure that allows the laser signal confining in the core fiber. Thus, less loss occurred and higher gain can be produced. For certain dopant concentrations, the optimum output power are found to depend on the fiber lengths. When the value of input power increases, the output power is increase as well. The optimum length does not have significant change with increase of input power. The input power of 5 W is appropriate high power Yb-doped double-clad fiber laser for certain purpose of laser application.

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