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Widely tunable Yb^{3+}-doped laser with all fiber structure

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Abstract

In this paper, an all fiber Yb^{3+}-doped fiber ring laser with large tuning range has been reported. A 976 nm laser diode (LD) pumped laser is used as the pump source and high concentration Yb^{3+}-doped fiber is adopted as gain medium. Adjusting the polarization controller (PC), a widely tunable range of 20 nm from 1030 to 1050 nm is obtained. The spectral linewidth of the pulse is less than 0.2 nm. Comparing with other fiber laser structures, the fiber laser with an all-fiber structure has higher efficiency and better stability. The laser also has very stable and flat output within the whole tuning range.

Keywords: Fiber ring laser; Widely tunable; Polarization controller (PC); High concentration Yb^{3+}-doped fiber

1. Introduction

Widely tunable light source is important for a wide range of applications including high-resolution spectroscopy, optical communication, and fiber sensors [1–3]. In recent years, many methods have been proposed to obtain tunable laser using tuning components such as Fabry–Perot filters or Lyot filters, *M–Z* interferometer, acoustic-optic filters, and fiber gratings. Unfortunately, these tuning components except for fiber gratings have complex structure and large insertion loss [4–7]. Furthermore, they are not suitable for integration and all fiber structure cannot be implemented. Most fiber gratings in the market are produced for communication, so the fiber gratings at 1040 nm cannot be bought and the price of making such component is very expensive. In this paper, we use polarization controller (PC) to obtain tunable fiber laser with simple structure and lower cost.

Great interest has been absorbed in Yb^{3+} as a laser ion recently because of its special characteristics. The Yb^{3+} energy level is simple, and there are no unwanted processes such as excited state absorption, multiphonon nonradiative decay and concentration quenching, and hence both broad-gain bandwidth and high optical conversion efficiency of operation can be achieved in the Yb^{3+} lasers. Yb^{3+}-doped silica fiber offers an almost ideal gain medium for the generation and amplification of widely tunable optical pulses around 1 μm [8–11]. High concentration Yb^{3+}-doped fiber is adopted to set up the fiber laser in our experiment. Comparing with linear cavity, the ring laser with all-fiber connection is

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more efficient and the structure is simple. To obtain all fiber widely tunable lasers, PC and polarization relative isolator are used in the Yb^{3+}-doped fiber ring laser and a tunable range of 20 nm has been achieved. Output power is 6.4 mW and linewidth is less than 0.2 nm as the pump power is 110 mW. The fiber laser has good stability and the output power is flat in the whole tunable range.

2. Experimental configuration and theory

The structure of the tunable fiber ring laser is shown in Fig. 1. It consists of a section of high concentration Yb^{3+}-doped fiber, a polarizing optical isolator (ISO/polarizer), two PC as PC1 and PC2, a 980/1053 nm wavelength divided multiplexer (WDM), and an output coupler. The pump source is a laser diode (LD) with center wavelength of 976 nm, which has a maximum output power of 230 mW. Through 980 nm/1053 nm WDM the pump light is coupled into the Yb^{3+}-doped fiber. The Yb^{3+}-doped fiber has high ion concentration as $1.93 \times 10^{26}/\mathrm{m}^3$, and the absorption efficiency of the fiber at 974 nm is 2100 dB/m. The mode field diameter and NA of the fiber are 4.8 μm and 0.18, respectively. The cut-off wavelength of the fiber is less than 826 nm. The Yb^{3+}-doped concentration is so high, hence, the absorption to the pump light and signal light is strong. A section of short fiber is perfect enough to obtain laser. The fiber length we used is 10 cm and the output coupling ratio of the coupler 1 is 90:10. Another coupler with the coupling ratio of 99:1 is connected to measure the output characteristics of the fiber laser. One port is connected with an optical spectrum analyzer and the other port is connected with an optical power meter.

In this paper, the component selecting wavelength consists of two PCs and an isolator with polarizer. The linear birefringence index of the fiber changes as the pressure is different by adjusting the PCs. Further more, the state of the polarization changes due to the birefringence of the fiber. Lasers under different polarization state experiences different polarization loss when they pass the detector. As a result, the output center wavelength of the laser changes according to the balance ship between the gain and the loss. For any optical system with polarization-independent loss, there exist two special pairs of orthogonal polarization states which are called the input and output principal states of polarization (PSP). Light which enters the system aligned with an input PSP will emerge in its corresponding output PSP, independent of the wavelength of first order. We show that the transmission can be found without knowing the polarization properties of the cavity in each optical frequency.

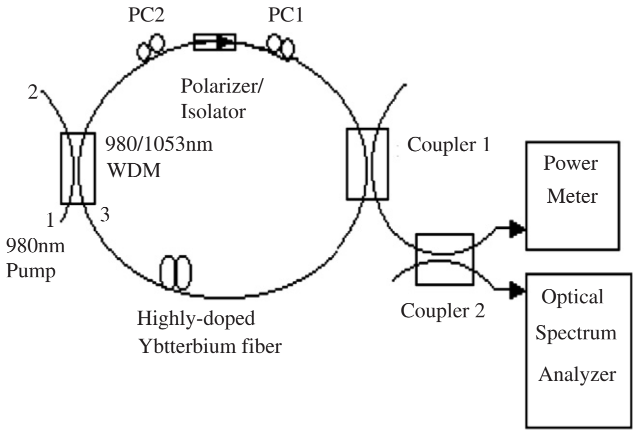

Fig. 1. Schematic diagram of tunable Yb^{3+}-doped fiber ring laser.

$e^{\pm}_{\mathrm{in}}(\omega_0)$ and $e^{\pm}_{\mathrm{out}}(\omega_0)$ are the unit vectors of the input and output principal polarizations, and the output can be described as [12,13]

$$e^{\pm}_{\mathrm{out}}(\omega_0) = M(\omega_0)e^{\pm}_{\mathrm{in}}(\omega_0), \tag{1}$$

$$e^{\pm}_{\mathrm{out}}(\omega) = \exp[\mathrm{i}\Delta\phi^{\pm}(\omega,\omega_0)]e^{\pm}_{\mathrm{out}}(\omega_0) = M(\omega)e^{\pm}_{\mathrm{in}}(\omega_0), \tag{2}$$

where $M(\omega)$ is the polarization transform matrix of the system, $\Delta\phi^{\pm}(\omega,\omega_0)$ is the phase change between the output polarization vector $\mathbf{e}^{\pm}_{\mathrm{out}}(\omega)$ and the output principal polarization vector $\mathbf{e}^{\pm}_{\mathrm{out}}(\omega_0)$ caused by the frequency change. The output signal $E_{\mathrm{out}}(\omega)$ is as following:

$$E_{\mathrm{out}}(\omega) = a_1 M(\omega)\mathbf{e}^{+}_{\mathrm{in}}(\omega_0) + a_2 M(\omega)\mathbf{e}^{-}_{\mathrm{in}}(\omega_0), \tag{3}$$

where a_1 and a_2 are the projections of the output vector to the input principal polarization:

$$a_1 = a_x \exp(\mathrm{i}\varphi_x), \quad a_2 = a_y \exp(\mathrm{i}\varphi_y), \tag{4}$$

where a_x and a_y are input signal amplitude in the horizontal direction and vertical direction. The transmission function is calculated as following:

$$T(\omega,\theta) = |P(\theta)E_{\mathrm{out}}(\omega,\theta)|^2, \tag{5}$$

where $P(\theta)$ is the unit polarization vector of PC2, and θ the angle between polarization axle and the vertical axle of the reference frame. Then the following formula can be obtained:

$$T(\omega,\theta) = \frac{|a_x|^2\cos^2\theta + |a_y|^2\sin^2\theta + |a_x||a_y|\sin(2\theta)\cos(\Delta\delta)}{|a_x|^2 + |a_y|^2}, \tag{6}$$

where $\Delta\delta = -\Delta\varphi + \Delta\beta(\omega_0)L + (\omega-\omega_0)\Delta n_{\mathrm{g}}L/c$,

$$\begin{aligned}\Delta\varphi &= \varphi_x - \varphi_y \\ &= -\frac{\mathrm{d}\beta_x(\omega)}{\mathrm{d}\omega}(\omega-\omega_0)L + \frac{\mathrm{d}\beta_y(\omega)}{\mathrm{d}\omega}(\omega-\omega_0)L,\end{aligned}$$

$$\Delta\beta(\omega_0) = \beta_x(\omega_0) - \beta_y(\omega_0),$$