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Optical bistability via an external control laser in an erbium-doped-fiber laser

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ABSTRACT

We demonstrate a new scheme for realizing the Optical Bistability (OB) in an erbium-doped-fiber laser with an external control laser. It is found that the OB can be significantly modified by changing the power and the wavelength of the control laser. We give an explanation of the bistability phenomenon based on numerical simulations, which are agreed very well with our experimental results. Our scheme provides a guideline for optimizing and controlling the OB in an erbium-doped-fiber laser, which might be useful for optical communications.

1. Introduction

In the last few decades, Optical bistability (OB) has attracted continued interest due to its potential application in such as optical transistor, memory element, and all-optical switching [1,2]. Many schemes [3–10] have been carried out to obtain OB in erbium-doped fiber laser (EDFL). For example, Jung Mi Oh and Donghan Lee demonstrated strong optical bistability in a widely tunable L-band erbium-doped fiber ring laser pumped by a 980-nm laser diode. They found that the bistable region is as much as 150-mW wide, and which can be controlled by the lasing wavelength or the length of erbium-doped fiber [8]. Later on, Shao et al. investigated OB in a single fiber ring laser employing erbium-doped fiber (EDF) as gain medium [9]. Quite recently, Juan C. Martín studied a sine-wave-modulated erbium-doped-fiber laser with an external signal coupled into its cavity and analyzed how the time-dependent laser emission changes as a function of the external signal power. Under appropriate working conditions, different bistable behaviors can be found [10].

In this work, we investigate the OB in an erbium-doped-fiber laser with an external control laser. Our study and the system are based on the Refs. [3–10], however, our work is drastically different from those works. First and foremost is that we are interested in showing the controllability of the OB behavior without need to resort the erbium-ion concentration or length of the EDF. Second, an important advantage of our scheme is that the power and wavelength of the external control field can affect the bistable region dramatically, which can be used to manipulate efficiently the threshold intensity and hysteresis loop of OB. Third, we give an explanation of the bistability phenomenon based on numerical simulations, which are agreed very well with our experimental results.

2. Experiment

The experiment setup is shown in Fig. 1. A optical ring cavity composes of six elements: a fiber filter with central wavelength of 1550 nm; 30 meters long EDF with $5.20 \times 10^{24}\,m^{-3}$ erbium-ion concentration; an isolator (ISO1), which is used to avoid backward amplified spontaneous emission (ASE); a 80/20 coupler(C1) employed to couple an external control laser into the ring while another 80/20 coupler(C2) is used to extract 20% of the laser power in the ring cavity linked to Power Meter or Optical Spectrum Analyzer (OSA) for detection; a 980/1550 Wavelength Division Multiplex (WDM) that couples pump power into the ring cavity. The control signal is injected into ring cavity via the Tunable Laser (TL, Agilent 81600B-160), and isolator2 ensures that the cavity light does not affect control laser.

3. Experimental results

In Fig. 2, we show the OB when the control laser is not considered. When the 980 nm LD is turned up to 72.0 mW (turn-up point), the 1550 nm laser appears in the ring cavity. The intensity of laser becomes increasingly strong as the pump power being gradually turned up. In contrary to the turning up process, the laser

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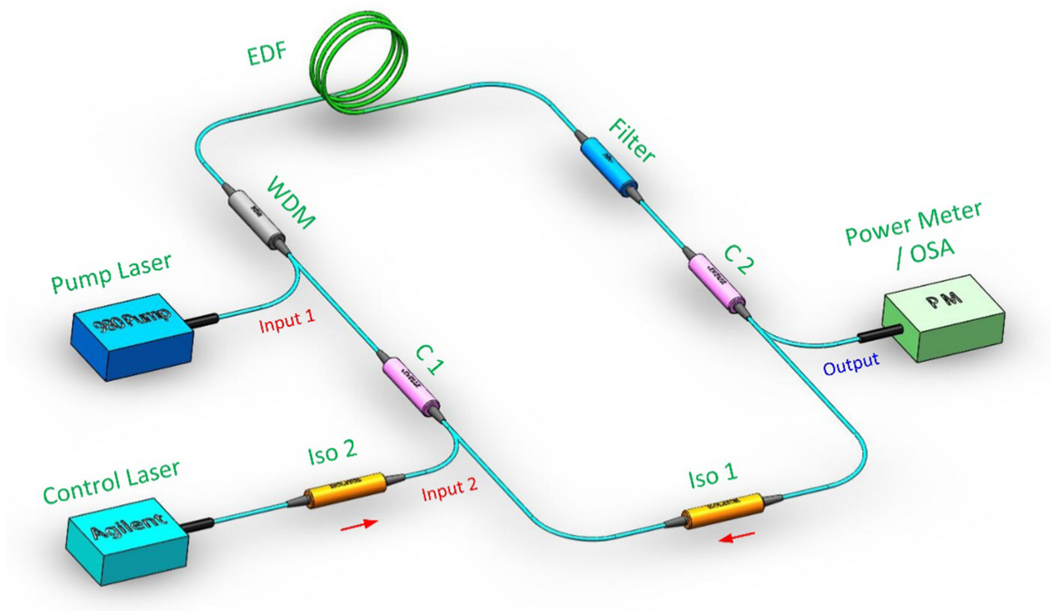

Fig. 1. Experimental setup.

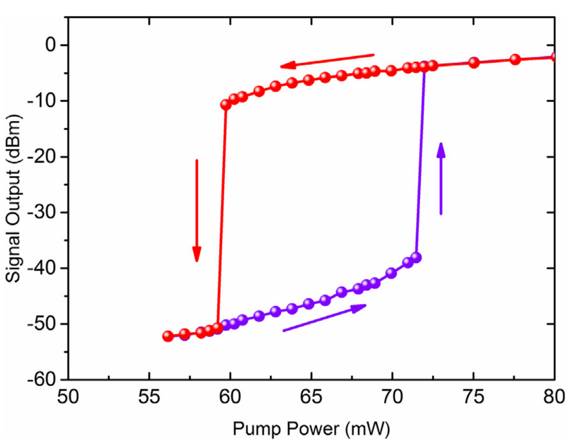

Fig. 2. Optical bistability curve without control laser field.

will not disappear unless the pump power is tuned down to 59.2 mW (turn-down point). The whole process indicates that OB exists even in a single fiber ring laser employing EDF. The power range of OB region is given by: 72.0–59.2 = 12.8 mW.

When the wavelength of control laser is fixed at 1510 nm, the Output Signal versus input Pump Power for different power of control laser is shown in Fig. 3. In the case of $P_c = 0$, as shown in Fig. 3(a), the range of OB region is 12.8 mW. When the control laser is tuned to $P_c = 0.1$ mW, one can see that the range of OB region decreases from 12.8 mW to 9.7 mW (see Fig. 3(b)). As we further increase control laser from 0.5 mW (see Fig. 3(c)) to 1.5 mW (see Fig. 3(d)) and then to 2.5 mW (see Fig. 3(e)), we found that both the threshold value and range of OB region decrease. Here, we also give the spectral of the ring cavity observed in the OSA, in the case that the wavelength of control laser $\lambda_c = 1510$ nm and $P_c = 0.5$ mW, as shown in Fig. 4.

In order to have a better idea about how the bistable threshold value changes with the wavelength of the control laser, in Fig. 5, we plot the output signal versus input pump power when $\lambda_c = 1520$ nm. By analyzing the results of Figs. 3 and 5, it can be easily seen that OB region is reduced with the increasing wavelength of the control laser field. That is to say, the wavelength of the external control field can also affect the bistable region, which might be useful to control the threshold value and the hysteresis cycle width of the OB simply by adjusting the wavelength of control laser field.

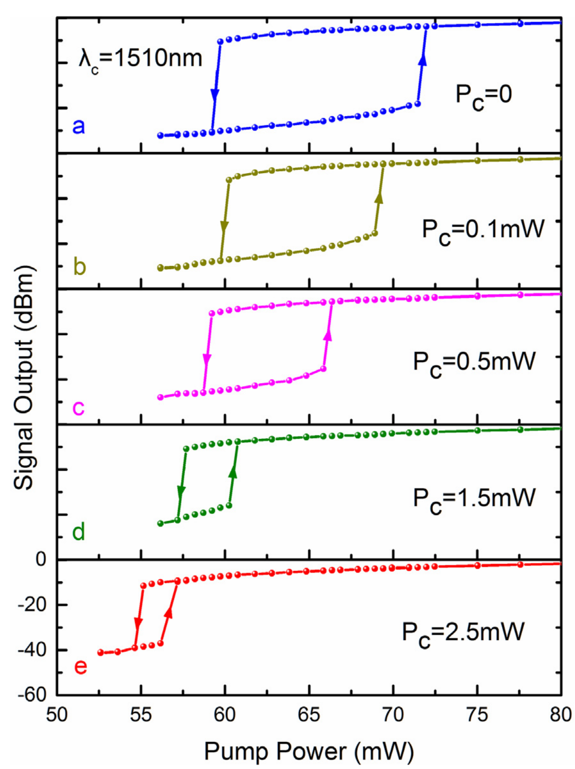

Fig. 3. Output Signal versus input Pump Power when the wavelength of control laser is fixed at 1510 nm.

Finally, we show the OB region as a function of input power of control laser in Fig. 6. From this figure, we can observe that the OB region decreases dramatically with the increasing power or