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Flatness investigation of multiwavelength SOA fiber laser based on intensity-dependent transmission mechanism

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ABSTRACT

We investigate an influence of intensity to the flatness of multiwavelength fiber laser based on a mechanism of intensity dependent transmission. This mechanism is induced by nonlinear polarization rotation from a semiconductor optical amplifier and its combination with polarization devices. Due to the mechanism, a flatter multiwavelength spectrum can be achieved by reducing the bias current. The use of lower throughput port of an optical coupler can also increase the flatness of the multiwavelength spectrum. The flat multiwavelength spectrum has 153 lines within 3 dB bandwidth at current setting of 125 mA. This multiwavelength laser is stable within 60 min at power fluctuation of less than 0.2 dB.

1. Introduction

Multiwavelength fiber lasers have attracted considerable attention due to their simple configuration, low-cost and low optical loss. Various gain media have been used in producing multiwavelength fiber laser where mostly are configured in a ring cavity. Most of them used erbium doped fiber amplifier (EDFA) [1] and semiconductor optical amplifier (SOA) [2] as the gain medium in the cavity. As compared to EDFA-based lasers, SOA has been used in multiwavelength generation due to its simplicity, good short-term stability, naturally inhomogeneous and no optical pumping needed. Its inhomogeneous gain medium alleviates mode competition thus allows a stable and multiple lasing lines generation in a room temperature. On the other hand, EDFA provides the advantages of high saturation power, low threshold and less sensitive to polarization effect. However, a stable multiwavelength lasing based on EDFA is very hard to achieve due to its homogeneous nature, which leads to strong mode competitions. One of the solutions to reduce this problem is by inducing a mechanism of intensity dependent loss (IDL) [3–11] or intensity dependent transmission (IDT) [12–15]. Only one research has realized multiwavelength fiber laser based on the IDT mechanism using SOA [15]. In their work, they presented an ultra-narrow spacing of 0.08 nm and 20.2 nm of multiwavelength tunability.

Principally, the IDL and IDT mechanisms have different working states. For IDL, the transmission is inversely proportional to the input intensity. Meanwhile, for the latter mechanism, the transmission is proportional to the input intensity. The IDT and IDL mechanisms work as a saturable absorber and an intensity equalizer, respectively [16]. In the working state of either IDL or IDT, the transmission is inversely proportional to the cavity loss. The works on these mechanisms were applied to generate multiwavelength fiber laser [3–15], where they used different polarization states to adjust the number of lines [3,5,6,11–13] and multiwavelength tunability [4,7,8,15]. However, none of them investigated the intensity influence to the flatness of a multiwavelength spectrum. In this paper, we investigate and prove experimentally that the intensity in the ring cavity influences the multiwavelength flatness, due to the IDT working state. The multiwavelength generation is based on Lyot filter and SOA, containing 153 lines within 3 dB bandwidth without significant power fluctuations. The flat multiwavelength spectrum is achieved from low IDT strength due to the use of low intensity in the ring cavity which causing higher cavity loss. We demonstrate that as the intensity in the cavity is increased, the multiwavelength flatness is reduced.

2. Experimental setup

Fig. 1 depicts the configuration setup of multiwavelength fiber laser based on the IDT mechanism and Lyot filter. In the proposed ring cavity laser, the active device is only SOA, and the others are passive devices. The SOA from Qphotonics works as the gain medium. The SOA has maximum operating current and operating

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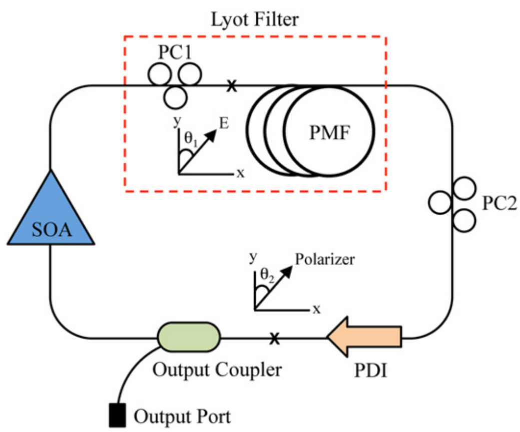

Fig. 1. Configuration setup of multiwavelength fiber laser based on IDT mechanism.

wavelength range of 400 mA and 1500–1560 nm, respectively. The Lyot filter serves as a comb generator and assembled from a section of polarization maintaining fiber (PMF) and a polarization controller (PC). Since the multiwavelength oscillation is in one direction (clockwise direction), only one PC is enough for the construction of Lyot filter [17]. A polarization dependent isolator (PDI) which works as a polarizer is used to provide an output of linearly polarized light and also utilized to create unidirectional propagation in clockwise direction. The multiwavelength laser is then extracted out through a tap port of an optical coupler. The output laser is analyzed by using an optical spectrum analyzer at resolution setting of 0.02 nm.

PMF is chosen due to its highly birefringence as well as its mechanism to preserve the polarization state (PS) of light. The multiwavelength generation based on Lyot filter is based on constructive interference, and the operation principle is discussed as follows. At first, PC1 is adjusted to ensure the light entering PMF has 45° angle with respects to the polarization axis of the PMF. The condition agrees well with a standard Lyot filter definition in a ring cavity configuration. With the 45° angle, the light splits orthogonally into two polarization components along those polarization axes at different speeds. Both of the traveling lights now have the same amplitude and PS, and combine in-phase at the end of the PMF resulting twofold of amplitude at the same wavelength. The process is known as the constructive interference and has a phase shift of

$$\Delta\phi = \frac{2\pi BL}{\lambda} \tag{1}$$

which varies at different PMF length (L), the operating wavelength (λ) and the PMF birefringence (B). The channel spacing is determined using

$$\Delta\lambda = \frac{\lambda^2}{BL} \tag{2}$$

where λ, B and L are the operating wavelength, PMF birefringence (4.5×10^{-4}) and PMF length, respectively. The multiwavelength spectrum can be plotted based on the calculated channel spacing, $\Delta\lambda$ using the following equation:

$$T(\lambda) = \cos^2\left(\frac{\lambda\pi}{\Delta\lambda}\right) \tag{3}$$

The transmission equation is expressed as follows [4,10,18]:

$$|T|^2 = \cos^2\theta_1\cos^2\theta_2 + \sin^2\theta_1\sin^2\theta_2 + \tfrac{1}{2}\sin2\theta_1\sin2\theta_2\cos(\Delta\phi_L + \Delta\phi_{NL}) \tag{4}$$

where θ_1 is the angle between the output polarization of PC1 (E) and the vertical axis of the PMF (y), and θ_2 is the angle between the axes of polarizer and the axis of y [4]. Both θ_1 and θ_2 are displayed in the configuration setup as shown in Fig. 1. Meanwhile, ϕ_{NL} is a nonlinear phase shift between the two orthogonal polarization components. The nonlinear phase shift is proportional to the SOA current as demonstrated in [19] and derived as follows:

$$\phi_{NL} = k_0 \frac{dn_r}{dn_c} n_c{}^0 \Gamma L_a \tag{5}$$

where

$$k_0 = \frac{2\pi}{\lambda} \tag{6}$$

k_0 is the wave number in vacuum, dn_r/dn_c is the nonlinear change in refractive index, n_c^0 is the equilibrium of excess carrier density, Γ is the optical confinement factor and L_a is the length of the SOA's active region [19]. Using typical values of $dn_r/dn_c = -1.2\times10^{-25}$ m^3, $n_c^0 = 4.8\times10^{22}$ m^{-3}, $\Gamma = 0.3$ m and $L_a = 250\times10^{-6}$ m, the value of nonlinear phase shift at -0.557π is obtained. According to the Eq. (4), we can obtain a working state of either IDT or IDL at different value of θ_1 and θ_2 by adjusting PCs.

3. Results and discussion

In this experiment, we used a PMF length of 26.6 m to determine 0.2 nm of channel spacing. The two PCs are always adjusted to obtain the highest extinction ratio (ER) of spectrum for all experimental results. The proposed laser structure has a lasing threshold around 110 mA and its performance is recorded beyond this threshold value. Fig. 2 shows the flattest multiwavelength spectrum at 125 mA of SOA current and 10% of throughput port (TP). The lasing lines count is relative to the

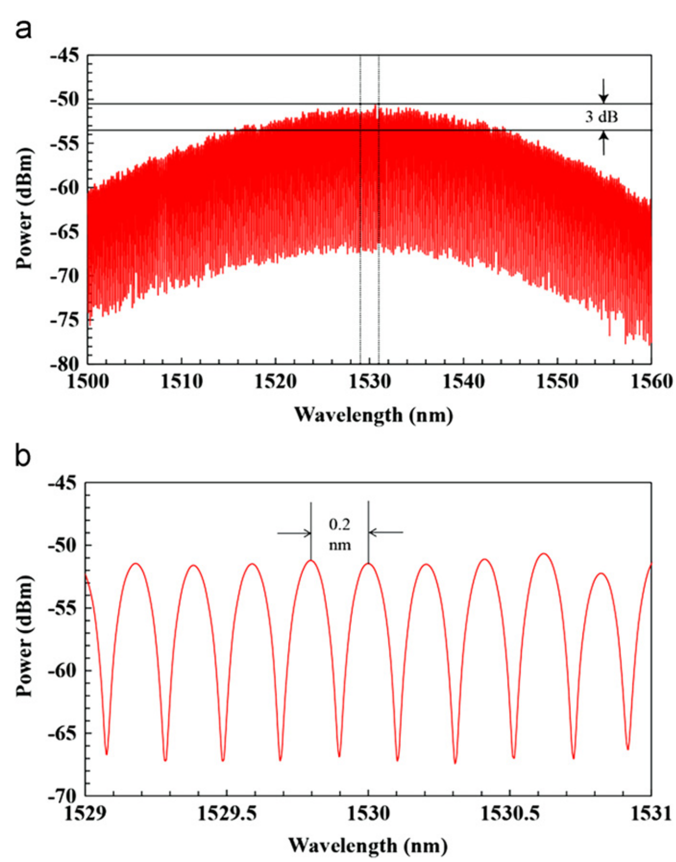

Fig. 2. (a) The multiwavelength spectrum based on IDT at SOA current of 125 mA. (b) Magnified view within dashed lines of (a).