Stopping and storing light pulses within a fiber optic ring resonator

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A simple all optical system for stopping and storing light pulses is demonstrated. The system consists of an erbium-doped fiber amplifier (EDFA), a semiconductor optical amplifier (SOA), and a fiber ring resonator. The results show that the multisoliton generation with a free spectrum range of 2.4 nm and a pulse spectral width of 0.96 nm is achieved. The memory time of 15 min and the maximum soliton output power of 5.94 dBm are noted, respectively. This means that light pulses can be trapped, i.e., stopped optically within the fiber ring resonator.

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Multisolitons have been the interesting light source that can be used to drastically increase the communication channel capacity, while the high optical output is the second advantage for long-distance link. In principle, there are two techniques that can be used to generate the soliton pulses. The soliton pulses can be generated by using a pumped soliton pulse within a microring resonator system theoretically[1], moreover, the large signal amplification is also available. A Gaussian soliton can be generated, where the simple system arrangement can be set up to form the soliton pulse within the medium. Therefore, such a technique becomes a more attractive tool in the investigation for soliton generation. Generally, the basic requirement of the pumped soliton and Gaussian soliton is the intense input light into the system, and there are two ways to reach the requirement: using high power light source and reducing the media length, i.e., ring radius. However, there have been many research works reported both theoretically and experimentally to use a common Gaussian pulse for the study on soliton generation[2]. For further reading, many earlier works of soliton can be found in Ref. [3]. Many of the soliton related concepts in fiber optics have been discussed by Agrawal[4]. However, the problems of soliton-soliton interactions[5], collision[6], rectification[7], and dispersion management[8] require to be solved and addressed. Therefore, in this letter, a common laser source (Gaussian pulse) is employed, whereas the use of a Gaussian pulse to form a multisoliton band is recommended[9]. In practice, the intense pulse is obtained by using the erbium-doped fiber (EDF) and semiconductor amplifiers incorporating a fiber ring resonator in the experimental setup. The multisoliton band is formed by the modulated signals via the connecting fiber ring resonator. The other problems such as low output power and soliton collision can be solved by reducing the fiber ring radius and using the free spectrum range (FSR) design[10], respectively.

In principle, we consider the case when light from a pumping source is coupled into a fiber ring resonator with the light field amplitude E_0 and a random phase modulation ϕ_0, which is the combination of terms in attenuation α and phase constants ϕ_0, resulting in temporal coherence degradation. Hence, the time-dependent input light field E_{in} without pumping term can be expressed as[11]

$$E_{\text{in}}(t) = E_0 \exp^{-\alpha L + \mathrm{j}\phi_0(t)}, \tag{1}$$

where L is the propagation distance (waveguide length).

When the intense light pulse is input into the fiber ring, we assume that the nonlinearity of the optical fiber ring is introduced by the Kerr-type, i.e., the refractive index is given by[12]

$$n = n_0 + n_2 I = n_0 + (\frac{n_2}{A_{\text{eff}}})P, \tag{2}$$

where n_0 and n_2 are the linear and nonlinear refractive indices, respectively; I and P are the optical intensity and optical power, respectively; the effective mode core area of the device is given by A_{eff}.

When the intense Gaussian pulse from Eq. (1) is input and propagates within a fiber ring resonator, the nonlinear effect occurs, which is described by Eq. (2). The resonant output is formed, thus the normalized output of the light field is the ratio between the output and input fields ($E_{\text{out}}(t)$ and $E_{\text{in}}(t)$) in each roundtrip, which can be expressed as[10]

$$\left|\frac{E_{\text{out}}(t)}{E_{\text{in}}(t)}\right|^2 = (1-\gamma)\left[1-\frac{(1-(1-\gamma)\,x^2)\kappa}{(1-x\sqrt{1-\gamma}\sqrt{1-\kappa})^2+4\,x\sqrt{1-\gamma}\sqrt{1-\kappa}\,\sin^2(\frac{\phi}{2})}\right], \tag{3}$$

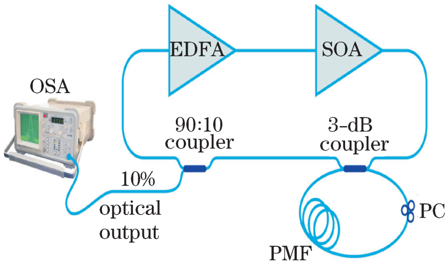

Fig. 1. Experimental setup.

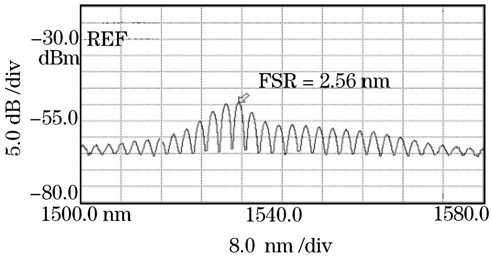

Fig. 2. Result of the ASE of EDFA.

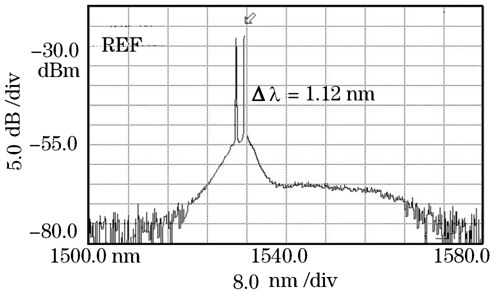

Fig. 3. Result of the spectrum of EDF lasing spectrum. Δλ is the spectral width.

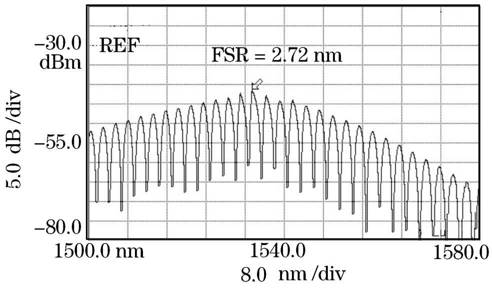

Fig. 4. Result of multi-wavelength generation.

where κ is the coupling coefficient, and $x = \exp(-\alpha L/2)$ represents a roundtrip loss coefficient. Equation (3) indicates that a ring resonator in the particular case is very similar to a Fabry-Perot cavity, which has an input/output mirror with a field reflectivity of $1-\kappa$ and a fully reflecting mirror. In this work, the iterative method is introduced to obtain the results as shown in Eq. (3) when the output field is connected and input into the other ring resonators.

The experimental setup of the multisoliton generation is shown in Fig. 1. The system consists of an erbium-doped fiber amplifier (EDFA), a semiconductor optical amplifier (SOA), a fiber ring resonator, and a 90:10 output coupler. The EDFA is constructed by using a 5-m-long EDF with erbium concentration of 950 ppm. The EDF is pumped by a 980-nm laser diode (LD) at a pump power of 66.0 mW. A wavelength division multiplexer (WDM) is used to combine the pump and laser wavelength. The SOA is incorporated in the ring cavity to amplify the signal from the EDFA. The ring resonator is constructed by using a 3-dB coupler. A polarization controller (PC) and 3-m-long polarization maintaining fiber (PMF) are included within the system. The principle of ring resonator is related to the interferometer configuration in which the four-port optical coupler with two inputs and two outputs has a 50:50 splitting ratio. The light beam is split into two beams, one propagates through the fiber ring, and the other propagates through the straight fiber. One of the beam polarization states is adjusted by using a PC within the fiber ring, and this produces a slicing effect, whereas the intensity is dependent on the interference of the two beams at the PMF. The change in fiber birefringence affects the change in fiber refractive index. The multisoliton band can be generated by adjusting the fiber ring radius and the birefringence, whereas the modulation signals, i.e., multisolitons can be observed over the base band signals. A 90:10 output coupler is used to tap the output of the ring cavity laser. The output signal is characterized using an ANRITSU optical spectrum analyzer (OSA) with a resolution of 50 pm.

In the first experiment with a standard EDFA configuration, the amplified spontaneous emission (ASE) occurs concurrently with signal amplification. This consequently causes the increase of noise configuration. As a forward pumping scheme is adopted, a better noise figure can be obtained. Figure 2 shows the obtained ASE spectrum after being sliced by a ring resonator. As depicted in this figure, the ASE power is obtained around 1530 nm, where more spontaneous emission occurs. The maximum amplified power is −49.19 dBm, whereas the ASE spectrum is then looped back to the EDFA. The measurement is performed by using 10% of the output spectrum coupled by the 90:10 coupler and observed at the OSA. Figure 3 shows the EDF lasing spectrum, where the bandwidth of the lasing spectrum is 14.3 nm with the maximum lasing power of 5.94 dBm.

In the second experiment, the multi-wavelength, i.e., multisoliton investigation for SOA with the saturated power (maximum bias current) of about 10 dBm (400 mA) is investigated. The operating temperature of the SOA is set at 30 °C with the bias current of 200 mA. The ASE of SOA taken after the ring resonator is shown in Fig. 4. The extension ratio and the spacing between two peaks are dependent on the length of the PMF and

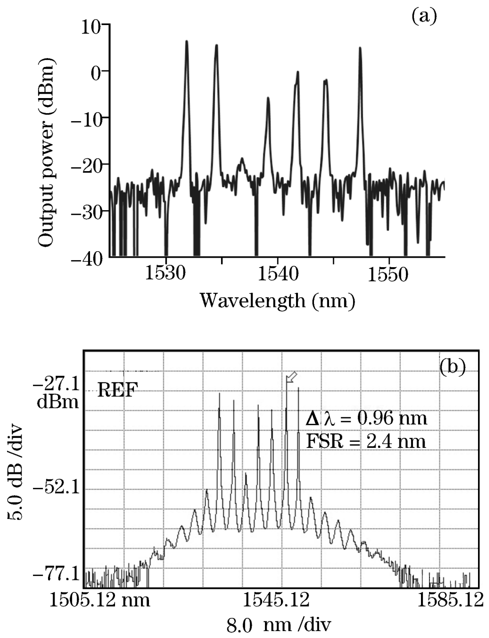

Fig. 5. Result of multisoliton band with the center wavelength at 1.54 μm. (a) Optical signals after 15 min, (b) OSA output signals.

the birefringence, where the higher output power than the case in Fig. 2 is seen. In Fig. 5(a), the optical signal with the memory time of 15 min is noted, which confirms the behavior of stopping and storing light. Several works have also been reported for this behavior[12−14]. In Fig. 5(b), the multisolitons are generated with the center wavelength at 1.54 μm, the multisoliton band with a FSR of 2.4 nm and a spectral width of 0.96 nm is observed, and the maximum output of −6.0 dBm is noted.

In conclusion, we have generated the mutisolitons using a Gaussian pulse in a fiber optic ring resonator, an EDFA, and a SOA. The multisoliton band is observed by adjusting the coupling power and the coupling ring radius. Initially, the Gaussian input pulse is pumped and amplified via the EDF and the SOA, respectively. The suitable experimental values such as driving current, coupling power, and fiber ring radius are arranged to meet the multisoliton generation conditions. The generation of multi-wavelength laser, i.e., multisoliton band, has been demonstrated, whereas the multisoliton pulses are also generated when the flat amplified output is seen. The number of wavelength generated can be controlled by adjusting the SOA bias current, while the channel spacing and output spectral width can be controlled by adjusting the birefringence in the ring cavity length, i.e., ring radius, using the 3-dB couplers and PC.

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