Optik 121 (2010) 2053–2056

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Proposed solar energy conversion and storage system using a nano-ring in an array waveguide

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ARTICLE INFO

Article history:
Received 22 February 2009
Accepted 3 July 2009

Keywords:
Solar optics
Solar energy conversion
Solar energy storage
Nano-waveguide

ABSTRACT

We propose the new solar energy conversion and storage system using the array waveguide. It can be used to generate and store solar energy within the nano-array waveguide system. The system consists of micro- and nano-ring resonators incorporating a Mach Zhender Interferometer (MZI) that can be integrated into a single system. The large bandwidth signal, i.e. white light, is generated using a soliton pulse in a Kerr-type nonlinear medium propagating within a micro-ring resonator system. The control light concept is applied using a nano-waveguide incorporating an MZI, whereas the incoherent light is filtered being coherence, which is amplified and stored within the system. The white light can be re-generated using the stored coherent light pulse. Furthermore, the combination of signals is formed by the array waveguide, which is allowed to generate the huge amount of solar energy output.

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1. Introduction

Recently, Yupapin and Pornsuwancharoen [1] have shown the interesting result that light pulse can be stretched or compressed and stored within a tiny device known as "nano-waveguide". Several research works have also shown the interesting results that light can be stored within the micro-cavities [2], micro-sphere [3] and nano-waveguide [4]. The promising concept is that white light can be generated, amplified and stored within a nano-waveguide, which led to the concept of white light generation, i.e. solar energy conversion and storage. Many earlier works of soliton applications in either theory or experimental works are found in a soliton application book by Hasegawa [5]. Many of the soliton-related concepts in fiber optic are discussed by Agarwal [6]. The problems of soliton–soliton interactions [7], collision [8], rectification [9] and dispersion management [10] are required to solve and address. In practice, the soliton–soliton interaction would affect the dense wavelength division multiplexing (DWDM); however, this problem can be solved using the suitable free spectrum range arrangement, which can be designed [11]. To present this concept, the use of optical soliton in nano-ring resonator is performed the large bandwidth signal, i.e. white light, then it is compressed and filtered storing within a nano-waveguide. The downstream conversion of the trapping signal is formed using the de-coherence pulse. Finally, a large amount of output energy can be obtained using the array waveguide, whereas the combination can be performed.

To perform the proposed concept, a bright soliton pulse is introduced into the multi-stage nano-ring resonators as shown in Fig. 1; the input optical field (E_{in}) of the bright soliton pulse input is given by the following equation:

$$E_{in}(t) = A\,\mathrm{sech}\left[\frac{T}{T_0}\right]\exp\left[\left(\frac{z}{2L_D}\right) - i\omega_0 t\right], \qquad (1)$$

where A and z are the optical field amplitude and propagation distance, respectively. T is a soliton pulse propagation time in a frame moving at the group velocity, $T=t-\beta_1 z$, where β_1 and β_2, respectively, are the coefficients of the linear and second-order terms of Taylor expansion of the propagation constant. $L_D=T_0^2/|\beta_2|$ is the dispersion length of the soliton pulse. T_0 in equation is the initial soliton pulse width. t is the soliton phase shift time, and the frequency shift of the soliton is ω_0. This solution describes a pulse that keeps its temporal width invariance as it propagates, and thus is called a temporal soliton. When a soliton peak intensity ($|\beta_2/\Gamma T_0^2|$) is given, then T_0 is known. For the soliton pulse in the micro-ring device, a balance should be achieved between the dispersion length (L_D) and the nonlinear length ($L_{NL}=(1/\Gamma\phi_{NL})$, where $\Gamma=n_2 k_0$ is the length scale over which dispersive or nonlinear effects makes the beam wider or narrower. For a soliton pulse, there is a balance between dispersion and nonlinear lengths; hence $L_D=L_{NL}$.

When light propagates within the nonlinear material (medium), the refractive index (n) of light within the medium is given by

$$n = n_0 + n_2 I = n_0 + \left(\frac{n_2}{A_{eff}}\right)P, \qquad (2)$$

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doi:10.1016/j.ijleo.2009.07.007

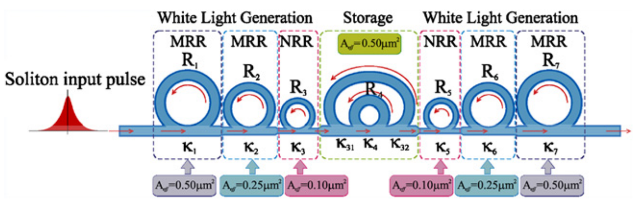

Fig. 1. A schematic of an upstream and downstream white light generation system with a storage unit, where R_s: ring radii, κ_s: coupling coefficients, MRR: micro-ring resonator, NRR: nano-ring resonator.

where n_0 and n_2 are the linear and nonlinear refractive indexes, 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}. For the micro-ring and nano-ring resonators, the effective mode core areas range from 0.50 to 0.1 μm^2 [12], where they found that fast light pulse can be slowed down experimentally after being input into the nano-ring.

When a soliton pulse is input and propagated within a micro-ring resonator as shown in Fig. 1, which consists of a series of micro-ring resonators, the resonant output is formed; thus, the normalized output of the light field is the ratio between the output and the input fields ($E_{out}(t)$ and $E_{in}(t)$) in each roundtrip, which can be expressed as [1,11]

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

The closed form of Eq. (3) indicates that a ring resonator in the particular case is very similar to a Fabry–Perot cavity, which has an input and output mirror with a field reflectivity $(1-\kappa)$ and a fully reflecting mirror. κ is the coupling coefficient, and x=ex-p$(-\alpha L/2)$ represents a roundtrip loss coefficient, $\phi_0 = kLn_0$ and $\phi_{NL} = kLn_2|E_{in}|^2$ are the linear and nonlinear phase shifts, respectively, and $k = 2\pi/\lambda$ is the wave propagation number in a vacuum, where L and α are the waveguide length and linear absorption coefficient, respectively. In this work, the iterative method is introduced to obtain the results as shown in Eq. (2), similar to when the output field is connected and input into the other ring resonators.

2. Proposed solar energy conversion and storage system

In principle, to perform the concept of white light generation, the large bandwidth signal within the micro-ring device can be generated using a soliton pulse input into the nonlinear micro-ring resonator. This means that the white light spectra can be generated after the soliton pulse is input into the ring resonator. The schematic diagram of the proposed system is as shown in Fig. 1. A soliton pulse with 50 ns pulse width, peak power at 0.65 W, is input into the system. Suitable ring parameters are used, for instance, ring radii R_1 = 10.0 μm, R_2 = 7.0 μm and R_3 = 5.0 μm. In order to associate the system with the practical device [12,13], the selected parameters of the system are fixed to λ_0 = 1.55 μm, n_0 = 3.34 (InGaAsP/InP), A_{eff} = 0.50, 0.25 and 0.10 μm^2 for a micro-ring and nano-ring resonator, respectively, α = 0.5 dBmm^{-1} and γ = 0.1. The coupling coefficient (kappa, κ) of the micro-ring resonator ranged from 0.03 to 0.2. The nonlinear refractive index is $n_2 = 2.2 \times 10^{-13}$ m^2/W. In this case, the wave-guided loss used is 0.5 dBmm^{-1}.

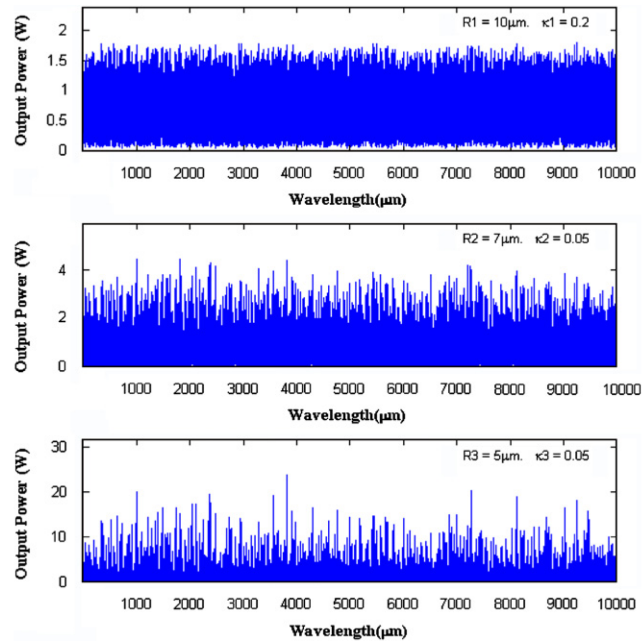

Fig. 2. The upstream white light output spectrum using a soliton pulse within a ring resonator.

The input soliton pulse is chopped (sliced) into a smaller signal spreading over the spectrum (i.e. white light) as shown in Fig. 2, which shows that the large bandwidth signal is generated within the first ring device. The coupling coefficients are given as shown in the figures. We also found that the light pulse energy recovery (amplification) can be obtained by connecting the nano-ring device into the system. The coupling loss is included due to the different core effective areas between micro- and nano-ring devices, which is given by 0.1 dB. The key point of this proposal is that the solar radiation can be amplified up to 20 W, which is available for solar energy collection and amplification. This is the target for the improvement of solar energy collection efficiency. The amplification occurred due to the same amount of energy (i.e. energy conservation) bounded within a smaller device. In order to coherently stop a light pulse within a given bandwidth, the following criteria must be satisfied: (i) the system must process an initial state with a sufficiently large bandwidth and (ii) the modulation accomplishes coherent frequency conversion for all spectral components and reversibly compresses the pulse bandwidth. The spectral width of light pulse is decreased within the trapping ring resonator, for instance, the spectral width is decreased from μm to fm.

The input soliton pulse is chopped (sliced) into a smaller signal spreading over the spectrum as shown in Fig. 3(b), which shows that the large bandwidth signal is generated within the first ring device. We find that the large bandwidth signal does not occur when the Gaussian pulse is input into the same system. Fig. 3(c) and (d) shows the compression in spectral width of the output signals, with the parameters being R_2 = 7 μm and $R_3 = R_4 = R_5$ = 5 μm. In operation, the upstream and downstream conversion of white light generation can be performed using the system as shown in Fig. 1. Furthermore, the generated white light signal can be stored within a nano-waveguide (ring R_4), which is confirmed by Yupapin and Pornsuwancharoen [1]. The trapping pulse is circulated within the nano-waveguide (stopping/storing pulse), which is available to detect, i.e. it is slowed down such that it can be detected by any available detector. They have also found that the light pulse energy recovery can be obtained by connecting into the nano-ring device. Using Eq. (2), the output light pulse within a

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