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Research Note

Stable and tunable self-seeded multiwavelength Brillouin-erbium fiber laser with higher OSNR

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ABSTRACT

A stable and tunable self-seeded multiwavelength Brillouin-erbium fiber laser (BEFL) is designed and demonstrated based on a Single-Mode-Multimode-Single-Mode (SMS) fiber filter. The SMS filter is fabricated by splicing a 15 cm long multimode fiber between two single mode fibers. The self-excited Brillouin pump is internally achieved by cascaded stimulated Brillouin scattering (SBS) in the single mode fiber. By applying axial strain (from 0 to 466.7 $\mu\epsilon$) to the SMS filter with the same step of 66.7 $\mu\epsilon$, the multiwavelength of the output laser is tuned from 1553.58 to 1559.79 nm correspondingly, and the tunable range is 6.21 nm. The generation of up to 16 Brillouin Stokes wavelengths with 30 dB optical signal to noise ratio (OSNR) are obtained.

1. Introduction

Multiwavelength fiber lasers have been aroused concern, for it is applied widely in dense wavelength-division multiplexing (DWDM) in optical communication systems, precise spectroscopy, optical sensing [1–6]. To date, several methods have proposed and constructed to generate a multiwavelength laser, such as the method of cooling erbium-doped fiber (EDF) [7], providing frequency shifter into cavity [8], and using an Er-doped twin-core fiber, [9] nonlinear polarization rotation (NPR) [10], nonlinear optical loop mirror (NOLM) [11], inserting semiconductor optical amplifier [12], and stimulated Brillion scattering or stimulated Raman scattering in the laser cavity [13]. Among them, the Brillouin-erbium fiber laser (BEFL) has advantage of simple configuration, lower pump power [14], rigid frequency spacing around 11 GHz in standard single mode fiber (SMF) [14,15] and extremely narrowlinewidth, this makes BEFL the most attractive for the next generating multiwavelength light source [15,16]. Meanwhile, stimulated Brillion scattering the main several kinds of methods have been proposed to achieve multiwavelength BEFL, namely external Brillouin pump, Self-seeded or self-excited BEFL. However, the use of external Brillouin pump is ineffective towards the cost for the laser system, especially the pumping power is high, and the wavelength of the external Brillouin pump should been adjusted accordingly in the process of wavelength tuning [15,17]. Self-seeded or self-excited BEFL is an internally self-generated Brillouin Stokes without external Brillouin pump. Hence, self-seeded or self-excited BEFL is more cost-effective, practical and simple.

Up to date, several self-seeded BEFL with different configurations have been reported. By incorporation of a polarization-maintaining/high birefringence fiber Sagnac-loop mirror, highly non-linear fiber, dispersion shifted fiber and in-line two-taper Mach–Zehnder interferometer filter in ring/linear cavity [16,18,19], a larger number of Brillouin Stokes and anti-Stokes are capable in producing, multiwavelength power distribution are fairly uniform among the Brillouin frequencies. But, the reported results indicates that multiwavelength BEFLs have average of less than 10 dB optical signal to noise ratio (OSNR) [16,20]. Moreover, the tuning process is discrete and unable to quantify [14,16].

In this paper, a tunable self-seed multiwavelength BEFL using a SMS fiber filter is proposed and demonstrated. The Brillouin pump is self-excited in the cavity rather than an external one. The SMS configuration is fabricated by splicing a 15 cm long multimode fiber (MMF) between two standard single mode fibers (SMF). By applying the same step axial strain to the SMS, the multiwavelength BEFLs are tuned, the tuning range is 6.2 nm. In addition, the OSNR is up to 30 dB, and the laser configuration is further simplified.

2. Theory of the SMS filter

The configuration of the SMS filter is shown in Fig. 1. In our experiment, the core and cladding diameter of the MMF is

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62.5 μm, 125 μm, separately. With the help of the fiber fusion splicer (FITEL fusion splicer, S178A), a 15 cm long MMF is spliced between two standard SMF (SMF-28), and the SMS filter is completely obtained.

In the left fusion junction, a beam of light in core mode of the SMF is coupled to the core mode of MMF, meanwhile, it excites a series of higher order core mode of MMF which can propagate along the MMF with low loss. Then, passing through the right fusion junction, a part of the excited core mode of MMF are coupled back to the core mode of the right SMF, and others may coupled to the cladding modes of the SMF, and these cladding modes would be a evanescent field [21].

Owing to the different propagation constants among the excited core modes of the MMF, they will form a phase difference among different modes when propagating through the same long MMF, they converge at another fusion junction. Then the interference would occurs, interference pattern among at different intervals is obtained [22]. The transmission spectrum of SMS filter is observed by an optical spectrum analyzer (OSA, ANDO AQ6319) with a resolution of 0.01 nm.

According to MMI theory, when the wavelength peak spacing can be given as [23]

$$\lambda_N - \lambda_{N-1} = \frac{16 n_{co} a^2}{(m-n)[2(m+n)-1]L} \tag{1}$$

Where, L and a are the length and core radius of MMF, n_{co} represents the core refractive index of the MMF, m and n are the modes number, and M is an integer, respectively.

From Eq. (1), it can be derived that the length of MMF, the transmission spectrum of the SMS structure is related to core diameter, and the core effective refractive index. The variation of resonant wavelength caused by axial strain change can be calculated by the following equation [24]

$$\Delta\lambda = (\Delta n_{co}/n_{co} + 2\Delta a/a - \Delta L/L)\lambda \tag{2}$$

It is know that an applied strain (ε) induces a change in length (ΔL), core radius (Δa) of the step-index MMF and refractive index (Δn). For an applied strain, the change in MMF length, core radius, and refractive index can be expressed as [24]

$$\Delta L/L = \varepsilon \tag{3}$$

$$\Delta a = -\nu \times \mathrm{a} \times \varepsilon \tag{4}$$

$$\Delta n_{co} = -\frac{n_{co}^3[p_{12} - \nu(p_{11} + p_{12})]}{2}\varepsilon = -p_e \times \varepsilon \tag{5}$$

Where, υ is the Poisson ratio of the fiber, p_{11} and p_{12} are the Pockel's coefficients of the strain-optic tensor and p_e is the effective strain-optic coefficient.

According to the relationship among ΔL, ε, Δa and Δn, Eq. (2) can be rewritten as

$$\Delta\lambda = -(1 + 2\nu + p_e)\varepsilon \times \lambda \tag{6}$$

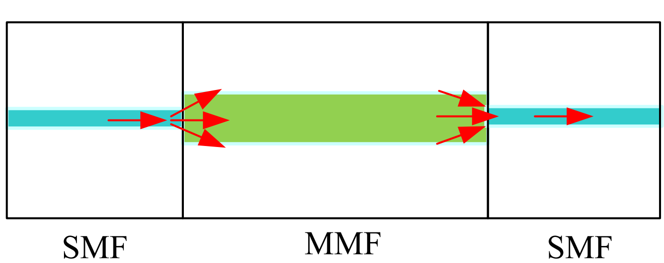

Fig. 1. Schematic diagram of SMS filter configuration.

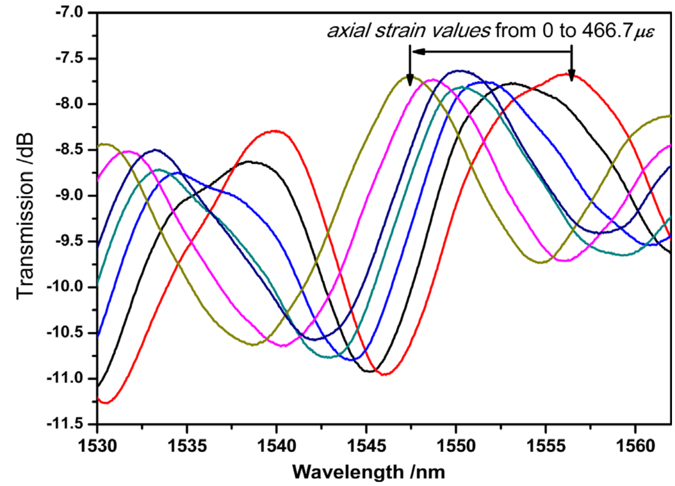

Fig. 2. Transmission spectra of the SMS filter at different axial strains applied to the MMF.

According to Eq. (3) and Eq. (6), the relationship between ΔL and $\Delta\lambda$ can be written as [25]

$$\Delta\lambda = -\frac{(1 + 2\nu + p_e)\lambda\Delta L}{L} \tag{7}$$

It can be found from Eq. (7) that the variable quantity of the output wavelength relates to the increased length of the SMS filter. This means that the peak wavelength would move towards the shorter wavelength. As shown in the Fig.2, when an axial strain is imposed on the SMS filter with the same step of ΔL(66.7 με), the transmission spectrum of the SMS filter will move toward the shorter wavelength accordingly. Meanwhile, the free spectral range (FSR) of the SMS around 1550 nm is varied. The FSRs are 18.8 nm and 16 nm, separatedly when the SMS filter are applied 0 με, 66.7 με, respectively. An axial strain applied to the SMS filter will cause the changing of parameters configuration of MMF. The interference effects among different mode will be changed [24]. As a result, the transmission will be also changed.

The tuning process as follows: Firstly, two ends of MMF are fixed in two stage with one stage can be moved, the length of MMF is 15 cm; then applying an axial strain to the filter by moving the biaxial platform to the left direction, the length of MMF increased correspondingly; finally, the output multiwavelength comb of the SMS filter with different axial strain are observed. The tuning configuration is depicted in Fig. 3. This strain characteristic of the MMF can be used for a comb filter to suppress the cavity modes' competition in the ring BEFLs. When the SMS filter is inserted into the ring cavity laser and applied axial strain, the central wavelength of output BEFLs will shift to short-wavelength with the increase of the axial strain correspondingly, and output BEFLs are realized to tune.

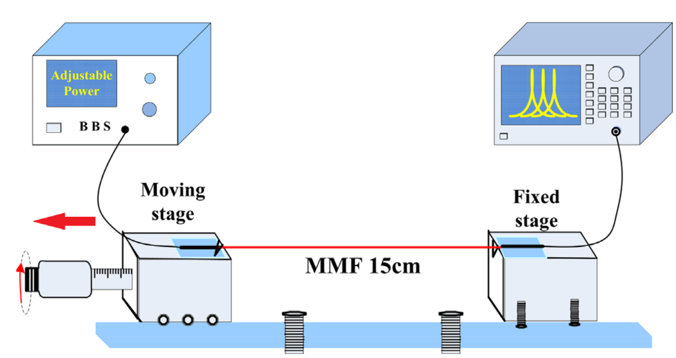

Fig. 3. Schematic diagram of the tuning configuration of the SMS filter.