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Original Research Article

Spooling effect of erbium doped fiber on the performance of superflourscent fiber source

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ABSTRACT
An inertial navigational system requires fiber optic gyroscope of class 0.01 deg/hr for aircraft and aerospace applications. This class of gyro requires source with high power, broad spectrum and stable mean wavelength. A Superfloursecent fiber (SFS) is advantageous for developing the high performance optical-fiber gyroscope. A SFS consist of a pump laser source operating at 980nm, Erbium doped fiber (EDF) of length 16m wound on a spool and a wavelength- division multiplexer (WDM) used to couple the pump power into EDF. Packaging of SFS source is critical on gyro application as EDF is to be wound on a spool of minimum diameter to ensure low loss and also minimize the size of the gyro. In this paper, the spooling effect of EDF, with different bend radius, on the performance of the SFS source are presented. The optimized parameters considered for designing the SFS source are described in this paper. Two fibers of different design parameters are chosen and their bending effect on the performance on the SFS source is studied. It is observed that the bending of EDF is critical and affect the performance of the fiber source. The effect of bending on SFS power and wavelength is measured. The simulation model for analyzing the bending effecton the output power of SFS source is given and the experimental results of various spool bending radius on the power output, average wavelength, spectrum width of SFS source are presented and discussed.

1. Introduction

The Erbium doped fiber (EDF) source have been preferred as an efficient source for developing the excellent performance optical-fiber gyroscope for inertial navigation because of their high conversion efficiency, broad bandwidth, and high spectral stability [1]. A large number of source designs, using the silica doped fibers, have been developed [2]; among these the configuration of superfluorescent fiber (SFS) is worth of note. This configuration consists of pump source operating at 980 nm spliced to wavelength division multiplexer (WDM) operating at 980 nm/ 1550 nm whose input end is coupled to the erbium doped fiber of length 16 m coiled on a spool. The other end of the fiber is terminated to prevent any back reflection as shown in the Figure 1.

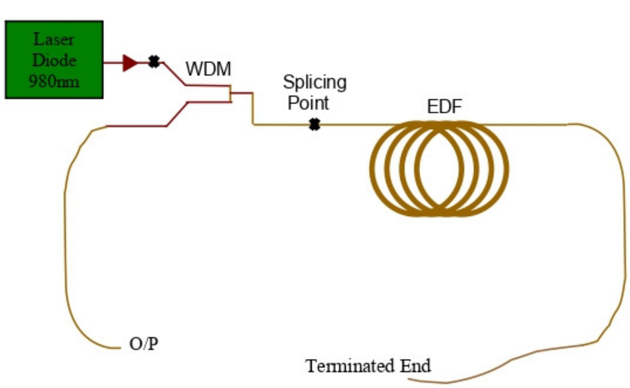

Figure 1. Configuration of SFS

The design of EDF has to be optimize for various applications. In spite of application, the highly efficient EDF exhibit some basic distinctiveness. These include high output power, high efficiency of conversion, broad bandwidth, high gain stability, high spectral stability, negotiable bending losses, and negotiable splice losses.

In this paper, the design of EDF for high power application is discussed. The optical spectrum characteristics of EDF, spooling effect or bending diameter to obtain the performance of SFS is also presented in this paper. The distribution of ASE filtering depends on the spooling diameter, thus the EDF has to be winded with an optimal diameter to obtain an optimum gain and noise figure.

2. Simulation model

In general, there are two different designing of EDF, viz. the doping composition designing, and the fiber waveguide designing. In the fiber waveguide designing, the parameters of interest which determine the interaction between the erbium ions and the optical field and consequently the overall performance of the optical fiber are the numerical aperture (NA), the cut-off frequency, and the confinement of erbium dopants. For applications requiring large values of optical field at 980 nm, the excited state absorption (ESA) from $^4I_{11/2}$ influences very strongly the performance of SFS source. Smaller values of NA of EDF cause the decrease of this nonlinear optical process. On the other hand, the dopant concentration, bending diameter of EDF also affects the performance of SFS.

For the deep understanding of highly efficient EDF, a simulation model is used to find the effect of spooling diameteron the performance of SFS.

Let us consider that $P_s^+(x,\nu)$ and $P_s^-(x,\nu)$ represent the optical powers in EDF (with longitudinal coordinate *x*) corresponding to the forward and backward propagating optical fields in the frequency interval $\Delta\nu$, centered at mean frequency ν. If EDF is wounded around the radius *R*, the time-independent variations in $P_s^\pm(x,\nu)$ along the longitudinal coordinate of EDF may be described via relation [3, 4].

$$\frac{P_s^\pm(x,\nu)}{dz} = \pm\{\gamma_e(x,\nu)[P_s^\pm(x,\nu)+P_0]-[\gamma_a(x,\nu)+\alpha_b(\nu)]P_s^\pm(x,\nu)\}, \quad (1)$$

where $\gamma_a(x,\nu)$ and $\gamma_e(x,\nu)$ stand for the coefficients corresponding to the spectral absorption and emission, and these are functions of absorption and emission cross-sections, respectively. In Eq. (1), α_b represents the EDF bending loss coefficients. *R* is the bending radius. P_0 represents the power emitted in spontaneous process, i.e. the power of two photons per unit frequency in the bandwidth $\Delta\nu$ and it may be expressed as [7]:

$$P_0 = 2h\nu_s\Delta\nu\,. \quad (2)$$

The pump power is a function of longitudinal coordinate of EDF and it is given by [8]

$$\frac{dP_p(x)}{dx} = -[\gamma_p(x)+\alpha_b]P_p(x)\,, \quad (3)$$

where $\gamma_p(x)$ represents the coefficient of absorption.

Defining the signal gain as [3]: $10\log\frac{P_s(x)}{P_s(0)}$.

In order to determine the bending loss of step/graded indexed EDF, the stair-case approximation is generally employed [5]. The allowed values of bending radius $R(\nu;\alpha_b)$ are determined via ν and α_b. Under the rough estimation, the bending radius *R*, wavelength of optical wave λ, and relative index difference Δ are related as [6]:

$$\frac{\Delta^{3/2}R}{\lambda} = f(\nu;\alpha_b)\,. \quad (4)$$

Equation (4) shows the product $\Delta^{3/2}R/\lambda$ is expressed via the function $f(\nu;\alpha_b)$. For EDF having lower values of $f(\nu;\alpha_b)$ is tolerant in case of uniform bending with smaller radius of curvature. It is clearly understood that the EDF bending losses increase with decreasing either or both the bending radius and the cut-off wavelength.

3. Results and discussion

We have considered fibers of different designs whose parameters are listed in Table 1. The optimum parameters of the fibers such as length of the fiber, pump power that were considered in the experiment are also listed in Table 1. The variation in the power output, the spectral width, and the average wavelength of SFS source when EDF of two different types are being bend on a spool of different radius are shown in the following figures.

Table 1: Parameters of EDF for two different designs

Parameters	Fiber # 1	Fiber # 2
Peak absorption at 1531nm (dB/m)	7.15	5.99
NA	0.24	0.24
Cut-off wavelength (nm)	915	899
Attenuation @1200nm (dB/km)	3.6	8.5
Length of the fiber (m)	16	20
Pump power (mW)	100	100
Pump wavelength (nm)	980	980
Operating current (mA)	160	160

3.1 Variations in output power of SFS source w.r.t. to operating current for different spool radius for Fiber 1

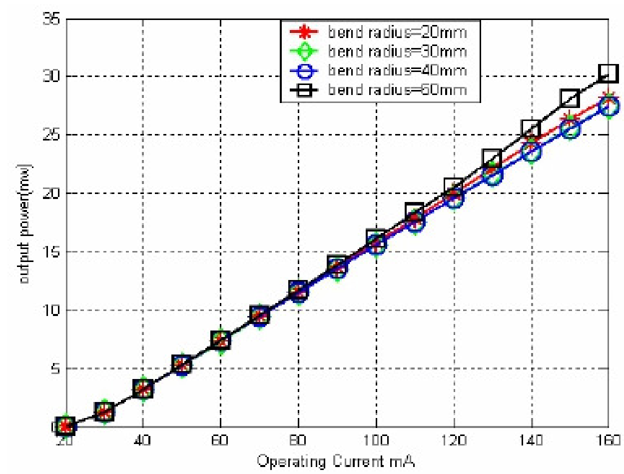

Figure 2. Output power versus operating current

Figure 2 represent the variation in the output power with operating current for different bend radius. It is seen that as the bend diameter of the spool is increased the out power of the SFS source increases; this is because the bend loss decreases as the bend radius increases which is also represented theoretically in the simulation equation (3).

3.2 Variations in mean wavelength and spectral width of SFS source w.r.t. operating current for different spool radius for Fiber 1.

The variation in the mean wavelength and spectral width of the SFS source with bending radius are shown in the Figure 4 and 5, respectively. As the bend radius decreases the mean wavelength shifts towards right and the spectral width decreases.

Figures 2, 3 and 4 show the variation in the output power, spectral width, and mean wavelength respectively for the Fiber 1; whose parameters are described in the Table 1. It is observed that for a fiber of length 16 meters, pump wavelength of 980 nm, pump power 100 mW, the output power and the spectral width of SFS source are more for a spool of radius 60 mm with the mean wavelength being highest for spool radius of 20 mm. The variation in the output power is in accordance to the equation (3). According to our source requirement, the variation in mean wavelength is permissible in the range 1550 ± 20, thus for the fiber 1 the appropriate bend radius is assumed to be 60 mm. We now consider the fiber 2 whose parameters are listed in Table 1 to determine its spooling effect on the performance of the SFS source.

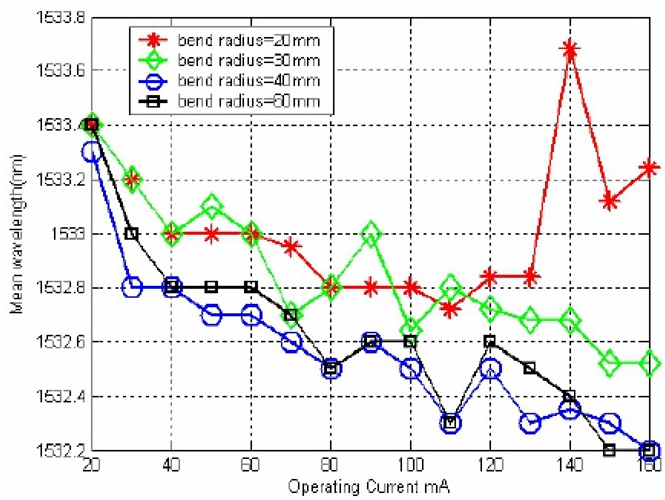

Figure 3. Mean wavelength versus operating current

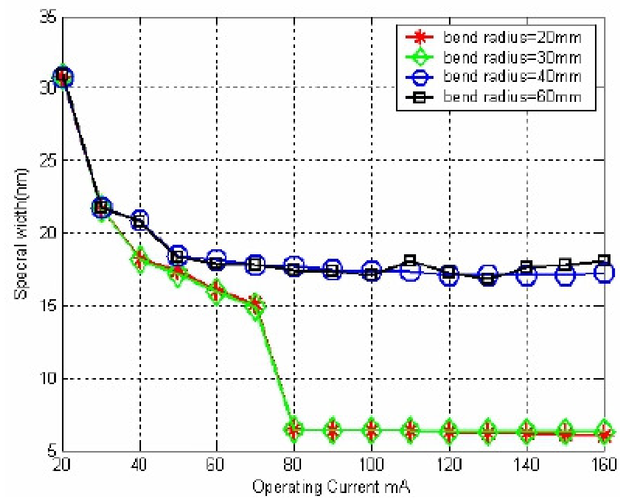

Figure 4. Spectral versus operating current

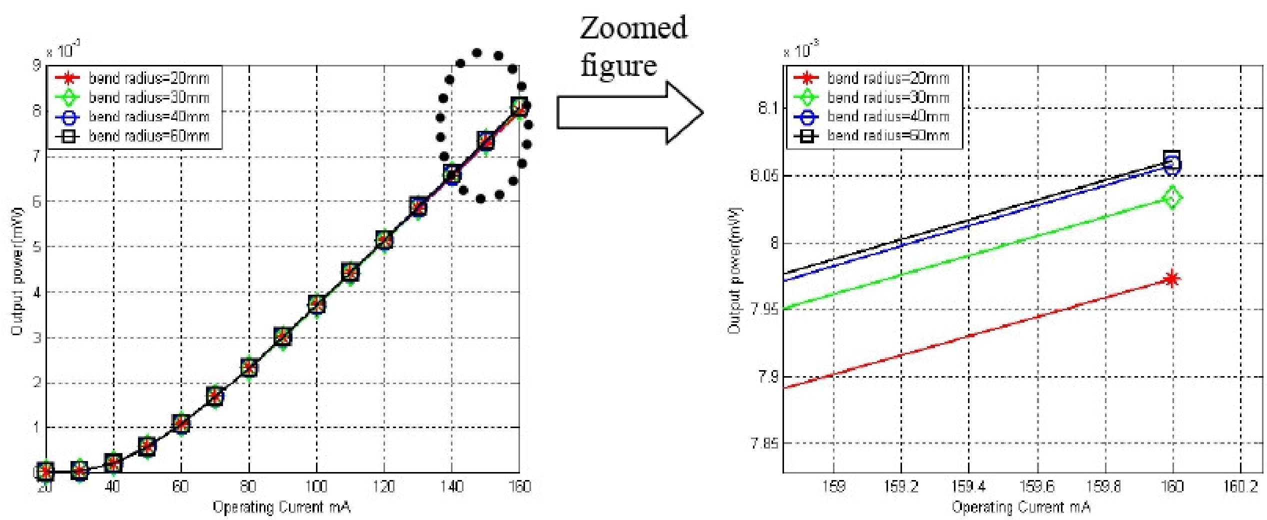

Figure 5. Output power versus operating current

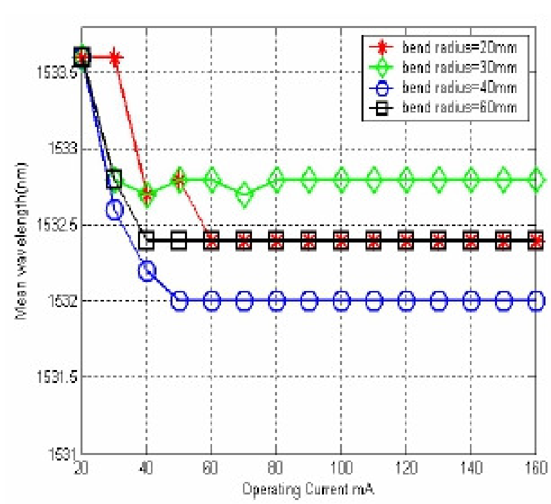

Figure 6. Spectral width versus operating current

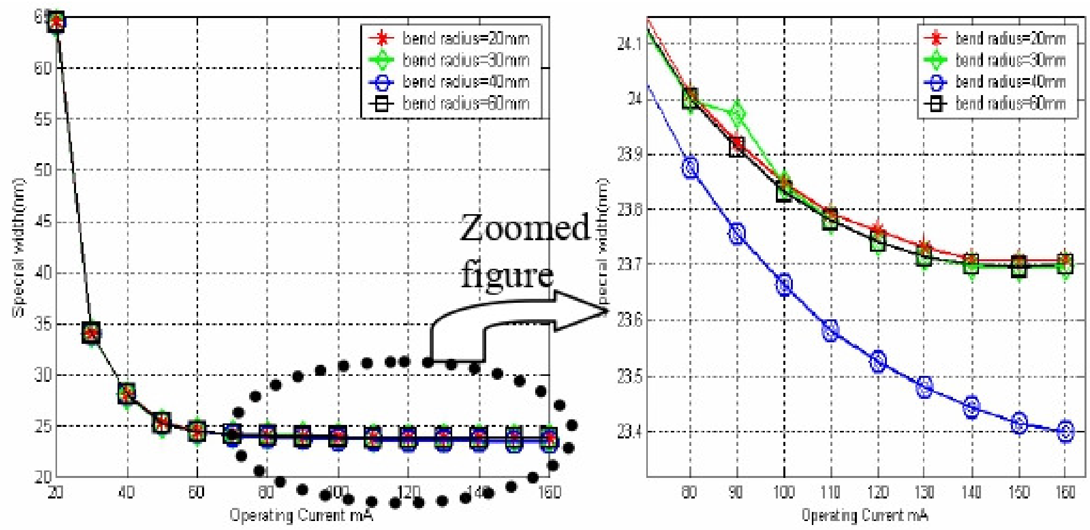

Figure 7. Mean wavelengths versus operating current

3.3 Variations in output power of SFS source w.r.t. operating current for different spool radius for Fiber 1

We see from Figure 5 that, though the power output varies linearly with bending radius, the effect is very negligible, the bending loss in this fiber is very loss compared to the loss in the Fiber 1; this shows that the bending loss also depends on the materialistic properties of the fiber.

3.4 Variations in mean wavelength and spectral width of SFS source w.r.t. operating current for different spool radius for Fiber 2

The above figures show the variation in the spectral width, and the mean wavelength of SFS source due to different bending spool radius. It is observed that the bending of fiber on different spool radius has negligible effect on the mean wavelength and the spectral width; consequently if the EDF laser source is developed, the optimum parameters may be selected for reducing the spooling effect of EDF fiber on the performance of the SFS source.

4. Conclusions

In this paper, I considered the optimum parameters of EDF for designing SFS source. I listed the parameters of two different fibers and have compared their effects of bending on different spool radius on the performance of the SFS source used in the development of fiber optic gyro. The fundamental observation that has been made in this experiment is the emission of the green light, its luminance is more as the EDF is coiledwith a lesser spool radius, this is due to radiation of light in the cladding portion whose intensity decreases exponentially and hence, as the bend radius is decreased the output power of SFS source decreases; this is in accordance to the simulation model presented in the paper. The dependence of spectral width and mean wavelength of SFS source on the bending radius are also analyzed in this paper, the observed variation in the mean wavelength is negligible, though it shifts towards right as the bend diameter decreases and spectral width of source is more for the higher spool radius for the fiber 1. The performance of fiber 2 compared to the fiber 1 is good and the effect of bending on the fiber 2 is negligible compared to the fiber 1, thus we conclude that by optimizing the parameters of EDF in designing the SFS source, we can disregard theeffect of spooling and by minimum allowed bend radius of the spool we can reduce the size of the source thereby resulting in the miniaturization of gyro.

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