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1.3mW 1550nm Er-DOPED SUPER FLUORESCENT FIBER SOURCE FOR MISSILE FIBER OPTICS GYROSCOPE

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ABSTRACT

Single - axis missile fiber optic gyroscope requires a light source with a band width> 10 nm and output power > 0.5 mW .The commercial FOGs weigh 200-250gms with a physical size of 100mmX100mmX50mm..The type of light source for missile fiber optic gyroscope is selected by operating wavelength, wavelength stability with temperature, volume and physical size. Incase of space fiber gyroscopes, the source should be insensitive to high energy radiation like proton and gamma radiations as well. Large bandwidth light source contributes to small bias drift by gyroscope. A small volume and light weight Single Pass Backward Signal Er^{3+} doped Super-fluorescent Fiber source was developed using only four commercially available components for use in missile single axis fiber optic gyroscope .The bandwidth and output power of the source are 30. 507nm and1.318mW respectively. We presented the experimental results along with non-flattened ASE spectrum. The packed super-fluorescent fiber source has a volume of 100mm X 100mm X 25mm and a weight of 150 grams which to our knowledge the smallest in volume and light in weight ever reported.

KEYWORDS:

Small volumeEr^{3+}Single Pass Backward Signal Super-fluorescent Source; erbium doped fiber; fiber optic gyro scope; missile.

1. INTRODUCTION

The low power about1.0 mW and broadband width ≥12nm, 1550nm erbium(Er)doped super fluorescent fiber Sources(SFSs) have been popular as light source for fiber optic gyro scopes (FOGs)for short range missile applications [1-3] as it operates in the third communication window of optical fiber Systems and insensitive to high energy radiation like proton and gamma radiations. Trommer et al constructed three- axis fiber optic gyro scope by coupling 20µW power from edge emitting light emitting (ELED) source at 1060nm and tested]. The 1550nm Er-doped super fluorescent fiber source pumped near 980nm is more stable than neodium (Nd)doped super-fluorescent fiber sources and superior to conventional laser diodes (LDs), edge emitting light emitting diodes (ELEDs) and super luminescent diodes (SLDs)[4-6]. The commercial Er-doped super fluorescent fiber sources at 1550nm supplied by M/S Thorlabs are only bench top sources and it is many times bigger than commercially available fiber optics gyro scopes.

The erbium doped fiber can be configured into four basic kinds and their derivatives[7]. These are single – pass forward signal(SPFS) SFS, single – pass backward signal(SPBS) SFS, double – pass forward signal (DPFS)SFS, double –pass backward signal (DPBS) SFS and fiber amplifier source (FAS).Some derivatives SFS include fiber amplifier sources (FASs) and single pass backward signal SFS , two erbium doped fiber amplifier(EDFA) combination, single pass backward signal SFS and fiber laser combinations(resonantly pumped) which are known as two- stage Er^{3+} SFS devices. Also there exits three-stage SFS devices that are combinations of seed SFS source –preamplifier – power amplifier for high output power and broad band widths >20nm . The FAS SFS configuration has an apparent disadvantage in that the source characteristics are susceptible to feed back from the fiber optic gyro scope since the source is not isolated. If the feed -back is time varying or time dependent on the rotation rate , it leads to a scale factor error or instability[8]. Various SFS configurations have been developed and tested, the single pass backward signal (SPBS) configuration proved most useful in missile fiber gyroscopes as it requires minimum number of components leading to light weight SFS compared with FOG [9-11] The characteristics of the erbium doped SFS strongly depends on which configuration that is employed. The Er^{3+} ion in erbium doped fiber can be excited at 514.5 nm, 650-680nm, 807 nm, 980nm and 1480 nm pump wave length [7]. 980 nm pump wavelength is preferred to pump Er-doped SFSs because this wavelength provides relatively high gain, low noise and very low excited state absorption (ESA). Laming et al brought out the superiority of 980nmpump wavelength than 1480nm [12]. The resonant Er-doped fiber sources] and non-resonant Er-doped fiber sources for FOG were reported [3]. The non-resonant Er3+ doped fiber sources have shown capable of large spectral width with long life (about 15years). The resonant Er^{3+} - fiber sources have the highest ratio of output power to pump power and non-resonant double pass SFSs offering intermediate value and single pass non-resonant SFSs giving the lowest value. Wang et al compared the efficiency and output powers of SBP, DPF and DPB SFSs configurations [8].

1.1Operation Of Super-Fluorescent Fiber Sources

Super -fluorescence is the process by which a fully population inverted atomic system emits coherently. The main issue in SFS is the phenomena of amplified spontaneous emission which occur in Er – doped fiber(EDF) oscillator . The Erbium in the doped fiber acts as three- level laser system. The three energy levels of interest for Er^{3+} pumped at 980 nm is high pump level $^4I_{11/2}$ and the two levels $^4I_{15/2}$, $^4I_{13/2}$ corresponding to the relevant laser transitions around λ=1530nm [11-14]. Erbium in glass host, the surrounding crystalline field causes a Stark splitting Er^{3+} orbital's and site-to –site variations of the field due to the amorphous nature of glass results in an inhomogeneous broadening of the transitions. The eight -fold and seven- fold Stark splitting of the ground $^4I_{15/2}$ and upper $^4I_{13/2}$ levels respectively combined with the effect inhomogeneous broadening makes Er^{3+} a complicated multilevel system. The Stark split components are generally separated by 10-100cm^{-1}[13]. When Er-doped fiber is pumped at 980nm wavelength, the electrons in ground state ($^4I_{15/2}$) absorb pump power and go to $^4I_{11/2}$ state which has a short life of about 7µsec. The exited electron from $^4I_{11/2}$ relaxes non-radiatively to upper –laser state $^4I_{13/2}$ which has a long life time of about 10msec. The amplified spontaneous emission occurs near 1550nm when electrons decay from $^4I_{13/2}$ which is upper laser state to the lower laser state $^4I_{15/2}$ which is a ground state. Both the upper laser state and ground state are Stark split manifolds with homogeneous and inhomogeneous broadening and both are occupied according to Boltzmann statistics. The entire emission spectrum spans from 1525 to 1565nm(C-band).

1.2SPB Er^{3+} -Doped SFS For FOG.

The single pass backward signal(SPBS) configuration has been widely used in an FOG because of its simple configuration and stable performance. In all other SFS configurations, accidental resonant lasing is a constant threat because optical components and FOG itself create feedback to the SFS.. Trommer et al constructed three-axis FOGs using single pass backward SFS [1].. Fesler et al developed 12nm band width , 1060nm Nd^{3+} single pass backward signal SFS pumped at 815nm and tested the fiber optic gyroscope(FOG) with coupled power of 1.5mW [15]]. K. Iwatsuki integrated 1550nm Er-doped SFS with coupled power of 0.3mW at a spectral width of 20nm with fiber optic gyro scope and achieved a short term resolution of 1.5deg /hour [16]. Single pass backward signal proved most useful [16]. This paper presents the development of 0.865 mW,1550 nm Er^{3+}-doped super-fluorescent fiber pumped at 980.300nm in single pass backward configuration with spectral width of 31.315 nm using commercially available optical components along with the experimental results. The figure 1 shows the configuration of SPBS super fluorescent fiber source.

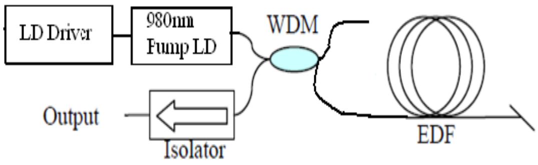

Fig.1: Single pass backward signal SFS configuration.

This configuration uses pigtailed pump laser diode, wavelength division multiplexing (WDM) coupler, erbium doped fiber (EDF) and fiber isolator.

2. MEASUREMENTS, EXPERIMENTAL SETUP AND RESULTS

The backward pump source is the one in which the amplified spontaneous emission (ASE) output is counter – propagating with respect to pump beam. The erbium doped fiber (EDF) procured from M/s OFS, USA has the Absorption and gain characteristics as shown in figure 2..

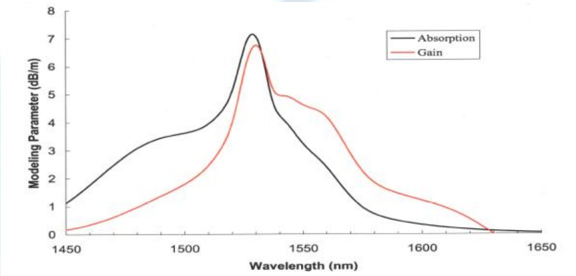

Fig. 2: Absorption and Gain characteristics of MP980 erbium doped fiber from M/s OFS, USA

The glass composition of erbium fiber core is Er- GeO_2 – SiO_2 –Al $_2O_3$. Er^{3+} ions and alumina are doped only in the central area in the radius less than one half the core radius. One end of the EDF polished at a 15degrees angle to reduce the reflectance to an estimated level of approximately -60dB. The EDF cut to 35meteres was longer than the optimal for generated backward ASE power for the pump power level considered. This extended EDF length served three main purposes. First, the length of EDF beyond optimal proved ASE absorption that reduced the round trip gain and prevented the resonant lasing. Second, this length guaranteed the absorption of almost all the pump power at a pump wave length of 980.300nm. finally , the forward ASE continues to pump EDF as it is absorbed and their by producing more backward ASE power. At this longer length of EDF, the backward ASE continues to grow at the expense of forward ASE power. Once the 980.5nm pump wavelength no longer provides gain along the EDF due to complete absorption of pump power, the forward ASE pump power begin to be absorbed by the EDF. The absorbed forward ASE power is converted to backward ASE power through stimulated and spontaneous emission in the backward direction thus the backward ASE power continues to increase along the 35meter length of EDF until the backward ASE power has grown to level at which it saturate the gain provided 980.300nm pump wave length or exits the erbium doped fiber. As long as pump power is absorbed by the EDF, the pump photons are available for amplification of spontaneous emission some where along the EDF. The specifications of 980 nm pump module, DC power supply, erbium doped fiber 315nmlaser diode driver and temperature controller procured for the development of SPB SFS are shown in tables 2,3,4,5 and 6.

Table 2. 980nm Pump Module

Series: 9000

Make: M/S Power Netix, USA

Parameter	Value
Pump power	10mW to 240mW continuous wave
Pump wave length	970 – 980nm
Pump stability	±0.5nm
Foot print	14-pin butterfly
Size	12.7mmX7.9mm
Thermo electric cooler	Inbuilt

Table3: DC Power supply

Make: wavelength electronics, USA
Part no: PWR PAK 5V

Parameter	Value
Voltage	0 – +5 VDC
Current	0 – 8A

Table4: Erbium Doped Fiber

Fiber type ED-MP980
Lot no. MP2A4201
Part no. 107770935

Parameter	Value
Loss at 1558.5nm	2.54dB/m
Peak absorption(near 1530)	7.15 dB/m
Peak absorption(980nm)	5.02 dB/m
Estimated erbium concentration	$10.62X10^{24}m^{-3}$
Background loss @ 1200nm	2.11
Estimated background loss @ 1550nm	0.71 dB/m
Cut of wave length	906nm
Numerical aperture	0.223
Refractive index difference (Δn)	0.017
Mode field diameter @ 1550 (Peterman II)	5.89µm
Core radius	1.55 µm
Fiber outer diameter	125 µm
Coating outer diameter	250 µm

Table5: Laser Diode Driver

Series PLD 5000
Make Wavelength Electronics, USA

Parameter	Value
Voltage	0 – 5.0V DC
Current	0 – 500 mA
Current stability	20ppm

Table 6: Temperature Controller

Make: Wavelength Electronics, USA
Model HTC 3000

Parameter	Value
Supply voltage	+5VDC to +1VDC
Maximum thermoelectric current output	±3A
Temperature stability	0.003degC(24hrs)
Integrator time constant range	0 to 10sec

The 980/1550 nm FWDM59 Series WDM coupler and 1550nm Single Stage Fiber Optical Isolator, 250 µm, Item # OISS511111).were procured from M/s Oplink Communications, Inc., USA.,

The mean wavelength of the pigtailed pump laser diode was measured using the Optical Spectrum Analyzer (OSA, ANDO model AQ6317C). The results of the measurements were shown in figure 3 and the output powers of the pigtailed pump laser diode upto 500mA input current is tabulated in Table 7..

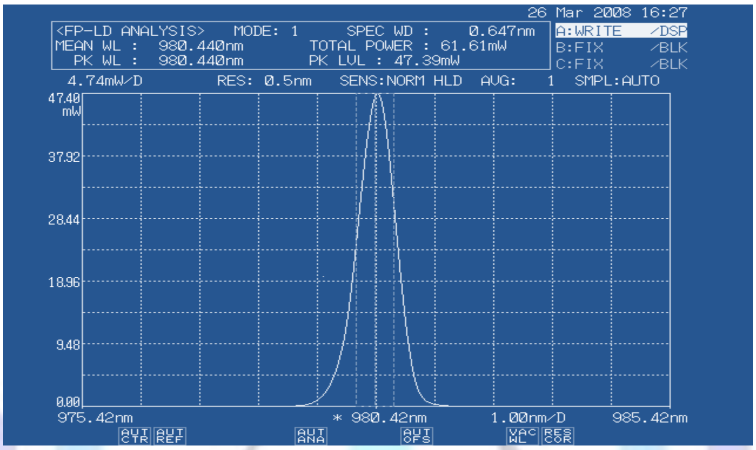

Fig.3: Mean wavelength of pump laser diode measured using Optical Spectrum Analyzer (OSA, ANDO model AQ6317C).

Table 7: Pump power as a function of LD input current.

LD Current(mA)	LD pigtailed power(mW)	LD Voltage(V)
0.1604	0.037563	1.0285
29.964701	0.004961	1.33143
49.961498	0.855444	1.36411
99.976402	7.44668	1.44048
149.983795	15.0585	1.51621
199.998703	22.5853	1.59173
249.998398	30.112	1.66703
300.013306	37.2136	1.74234
350.020691	44.017399	1.81753
400.028015	51.246498	1.89305
410.033997	52.649799	1.908
450.035309	58.092899	1.96835
500.050201	64.173897	2.04408

The pigtailed pump laser diode, WDM coupler, Erbium doped fiber and fiber isolator were carefully spliced to a splice loss of less than 0.02dBm. The fiber e isolator was introduced in the SPBS super-fluorescent fiber source to avoid the presence of pump wavelength in the backward amplified spontaneous emission (ASE)spectrum of fiber source.The pump power at 980.44nm was supplied to the EDF via WDM. The output power of laser diode was controlled via the drive current. The laser diode has been stabilized at the drive current, the thermo- electric cooler was adjusted to control the laser diode temperature. The pumped EDF produces ASE in both the forward and backward directions. The backward ASE is directed by a WDM coupler to a fiber pigtailed isolator. The spectrum of the source output We measured ASE power as a function of pump powers in terms of pump current levels for erbium doped fiber of length 35 meters. The experimental results of these measurements are shown in figure 4.

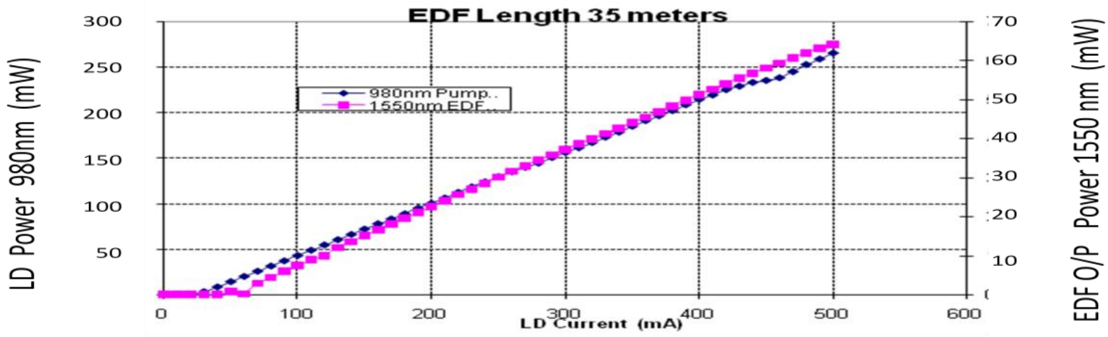

Fig. 4: EDF output power as a function of input pump power at 980nm. Pump wavelength for EDF length of 35 meters

2.1 The experimental setup of SPBS super fluorescent fiber source.

The figure 5 shows the experimental setup of SPBS super fluorescent fiber source. In the experimental configuration, fiber pigtail of pump laser diode, fiber pigtails at 4 ports of WDM coupler and input and output fiber pigtails were coiled to a diameter of 60mm. The MP980 erbium doped fiber was coiled to the diameter of 35mm. This results the actual placement of SFS components in SFS package leading to physical size of the devicewas measured using an Optical Spectrum Analyzer (OSA).

We have achieved continuous wave (CW) ASE output power of 1.318mW with a bandwidth of 30.507nm for 1550nm Er-doped super florescent fiber source pumped at 980.440nm pump wavelength in single pass backward configurations.

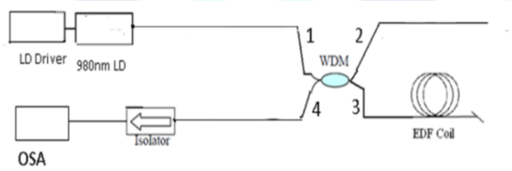

Fig.5: The experimental setup of SPBS super fluorescent fiber source

Presently, the commercial FOGs weigh 200-250gms with a physical size of 100mmX100mmX50mm. The experimental configuration was realized with minimum optical components for SFS so that the weight is restricted to below 100 grams and the size to 100mmX100mmX15mm. We understand this weight and size of SFS attract considerations as an optical source for applications like FOG and other fibre optic sensors.In this work the super fluorescent output signal was measured in backward direction using Optical Spectrum Analyzer (OSA, ANDO model AQ6317C).The output power in the forward direction was about one nano watt.The output amplified spontaneous emission from the SPBS super fluorescent fiber source was measured using Optical Spectrum Analyzer (OSA, ANDO model AQ6317C) and the results are shown in figure 6.The ASE power in the forward direction at port 2 of WDM coupler was about one nano watt. Since the source is SPBF SFS, the forward ASE output power and spectrum have hardly any relevance. This one nano watt power indicates that most of the forward ASE power in the EDF was converted to backward ASE which appeared at output port of fiber isolator.

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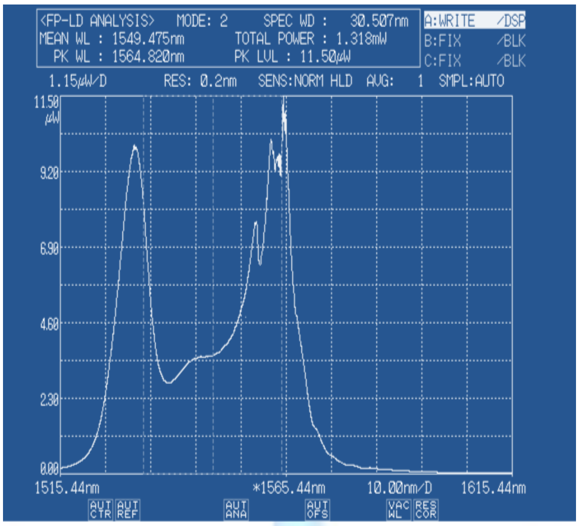

Fig.6The ASE spectrum of SPBS super fluorescent fibre source at61.61mWinput pump power. were measured using opticalspectral analyses (OSpoA,ANDO model AQ6317C). The ASE output power is 1.3 18mWand the spectral width is 30.507nm.

The novelty of this device is that we have achieved 1.318mW output power and 30.507nm band width for Er^{3+} doped SFS in single pass backward configuration pumped at 980.440nm fabricated with all commercially available optical components. the SFS package occupies volume of 100mmX100mmX25mm which is the smallest ever reported.

3. CONCLUSIONS

This publication presents the results of single pass backward signal Super-fluorescent fiber source having an output power of 1.318mW and a spectral width of 30.507nm at a pump wavelength of 980.300nm.. This represent SFS has a broad band width over the previously developed 1550 nm SFSs of 12-20nm band width [1,12.25.33]. For the first time to our knowledge the publication reports the SFS with 31.315 nm broad spectral width using SPBS configuration .The SFS was developed and packaged into a volume space of 100mm X 100mm X15mm using MP 980 erbium doped fiber coiled to the diameter of 35mm and pigtails of other SFS fiber components coiled to the diameter of 60mm for the fiber optics gyroscope. This SFS meets the basics requirements of single axis fiber optics gyroscope which requires a power of 0.5mW to 1.0mW at 1550nm operational wavelength and a minimum spectral width of 10nm.for short range missiles.

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