行政院國家科學委員會專題研究計畫成果報告
超螢光光纖光源的研發(I)
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一、中文摘要

我們成功地利用切平之摻鉺光纖當做複行後向架構之鏡面以產生波長穩定之寬頻超螢光光纖光源，該光源在適當的光纖長度泵源功率下，穩定性可達百萬分之五，且頻寬可超過10奈米。此新型之架構可簡化複行後向光纖光源，且其特性亦滿足高精準度光纖陀螺儀所需光源之標準，可適用於航太導航上。

關鍵詞：超螢光光纖光源，複行後向

Abstract

We demonstrate that by using a cleaved Er-doped fiber end as mirror a stable (<5ppm), broadband (>10nm), and high power (~23mW) superfluorescent fiber source in double-pass backward configuration would be obtained by properly choosing the EDF length and pump power. Such simplification light sources would benefit the development of navigation-grade SFS's.

Keywords: Superfluorescent fiber source, double-pass backward

II. Introduction

It is well known that the accuracy of rotation detection in a fiber optical gyroscope (FOG) is determined by the stability of scale factor, which in turn depends on the mean wavelength stability of the FOG's light source [1]. Recently diode pumped Er-doped superfluorescent fiber sources (SFS's) have been extensively studied because of their superior thermal stability over the semiconductor counterparts[2,3]. There are three thermally induced parameters that affect the mean wavelength stability of an SFS, namely the intrinsic, the pump wavelength dependent and the pump power dependent ones. The intrinsic parameter is typically less than 10 ppm/°C[2], while the pump wavelength dependent one can be minimized by operating the wavelength closer to the peak absorption, i.e. near 976 nm [4]. Therefore, it is the pump power dependent mean wavelength stability of major concern in this paper because of its configuration dependence. It is known that an SFS in single-pass backward (SPB) configuration would have a pump power independent mean wavelength operation [2,3], and such operation has also been experimentally shown in double-pass backward (DPB) configuration [5]. It should be noted that broadband and high output power are also desirable for the SFS's to be utilized for navigation grade applications in addition to wavelength stability.

Traditionally, a fiber mirror with reasonable reflectance and an additional WDM component are needed for a DPB SFS because the former is used to provide the double-pass function and the latter to filter out the residual pump. The mirror is generally realized by splicing an additional coated fiber end to the WDM. In this paper, we demonstrate a simplified DPB configuration which eliminates the need of these two components while still maintaining the characteristics required by a navigation-grade SFS.

III. Results and Discussion:

The simplified Er-doped DPB SFS is schematically shown in Fig. 1. It consists of a pump laser diode, a 980/1550 nm WDM coupler(WDM1), a section of EDF, and an isolator. The advantages of this simplified source over the previous versions is the saving of a WDM coupler(WDM2) and a coated fiber mirror. The EDF had a doping concentration of ~140 mole ppm, and its one end was cleaved to serve as mirror with an estimated 3.6 % reflectance around 1550 nm. The pump power reflected from this end was typically less than 1 μW for the shortest EDF length considered in the experiment, which might have little effect on the SFS performance. An isolator with an isolation loss of -57 dB was used to reduce the optical feedback.

The dependence of mean wavelength on pump power of the simplified SFS is simulated, and the result is shown in Fig. 2. For the EDF length smaller than 9.0 m, the mean wavelength tended to shift towards short-wavelength side as the pump power increased and thus no $\partial\bar{\lambda}_{source} / \partial P_{pump} = 0$ operation was obtained. For the EDF length greater than 10.0 m, the mean wavelength shifted towards short-wavelength, then long-wavelength, finally again towards short-wavelength sides as the pump power continued increasing, which generated two local extremes where the mean wavelength was independent of pump power. It is the second extreme (i.e. the local maximum) and, moreover, the range of this extreme that can extend is of particular interest since such range indicates the variation tolerance of pump power sustaining a pump power independent or nearly independent operation. Note that as the EDF length increases, not only the extreme moves with pump power but also the pump range significantly increases.

Fig. 3 shows the effect of EDF length on the mean wavelength stability at different concentrations of erbium ions. It is clearly shown that the pump power independent mean wavelength operation can be obtained for different concentrations. The required EDF length decreases with the concentration of erbium ions.

Fig. 4 shows the effect of pump wavelength on the mean wavelength. The minimum mean wavelength occurs at 976 nm. Therefore, if the pump wavelength is near 976 nm, the mean wavelength of the simplified DPB SFS's is nearly independent of the pump wavelength.

The effect of EDF length on intrinsic thermal coefficient is shown in Fig. 5. It is shown that the thermal coefficient is smaller than 2ppm/^{o}C for the EDF length between 11 and 12 m. If a simplified DPB SFS is operated with such a EDF length, it can be also operated at a pump-power independent mean wavelength operation as shown in Fig. 2.

Fig. 6 shows the measured mean wavelength versus the pump power at different EDF length. It is found that the pump power independent mean wavelength operation can be obtained for EDF length larger than 9.0 m. The results are consistent with the simulated ones.

Fig. 7 shows the pump efficiencies of SFS at various EDF lengths. Note the output power was measured after the isolator which had an insertion loss of 0.65 dB. The threshold pump power increased with EDF lengths, from 29.0 to 39.5 mW for 7.7 to 11.0 m long, owing to the length dependent loss. The pump efficiencies were similar over the lengths, and an average of ~ 42% was obtained. As depicted in Fig. 6, it is found that the SFS would have an output power of ~ 12 to 19 mW when an 11-m long EDF was pumped within the stable mean wavelength region as mentioned previously (70-85 mW). Such output power is apparently enough for the interferometric sensor applications.

The variation of linewidth with pump power at different EDF lengths is shown in Fig. 8. In general, the linewidths decreased with pump power in the small pump regions and then increased to reach saturated values as pump continued increasing. It was found that the saturated linewidth was larger for a longer EDF. When the EDF length was greater than 9.8 m, the linewidth was larger than the minimum bandwidth required for the FOG application, e.g. 10 nm. Note a bandwidth of 16.0 nm was obtained for the EDF length of 11.0 m when operating in the $\partial\lambda_{source}/\partial P_{pump} \cong 0$ region.

四、計畫成果自評

本計畫已完成部份既定目標，發表1篇會議論文[6]， 1篇期刊論文[7]，與1件專利[8]。

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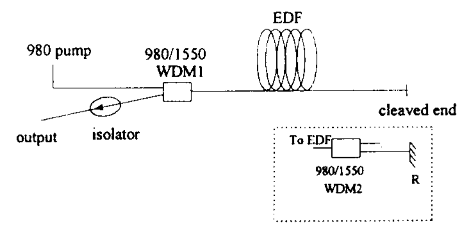


Fig. 1 A DPB SFS with and without (in dash box) simplified configuration.

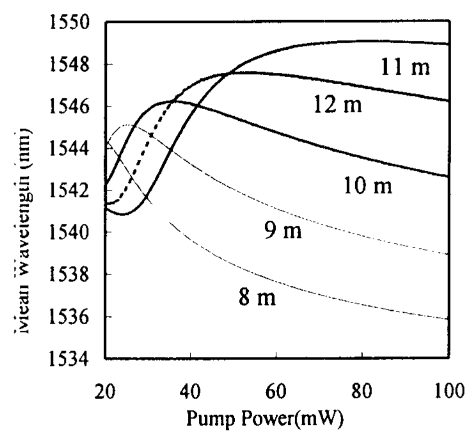


Fig. 2 Mean wavelength versus pump power.

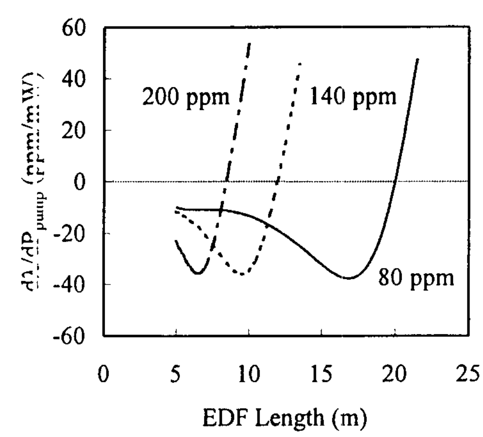
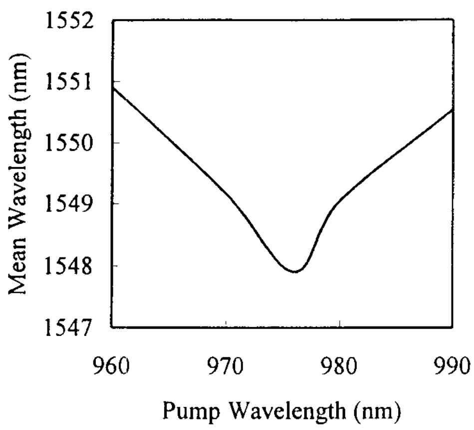


Fig. 3 Mean wavelength stability versus EDF length at different Er^{3+} concentration.



Fi.g 4 Pump wavelength dependence of mean wavelength variation for the SFS's.

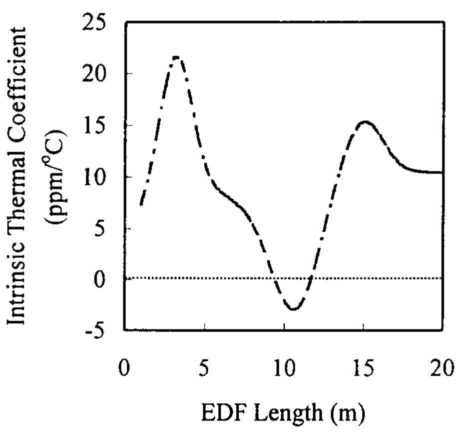


Fig. 5 Intrinsic thermal coefficient versus EDF length.

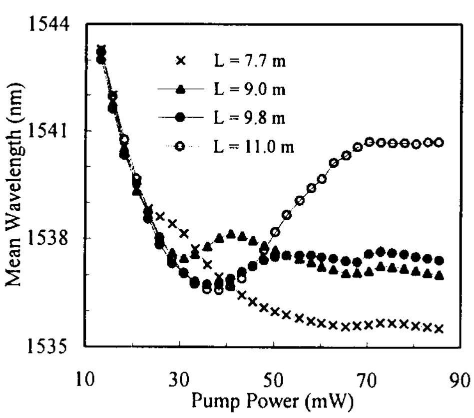


Fig.6 Measured mean wavelength versus pump power.

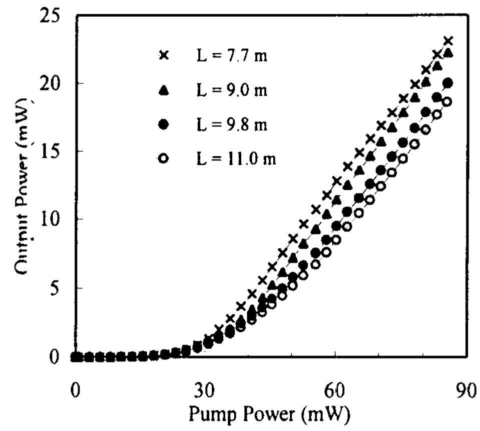


Fig. 7 Measured output power versus pump power.

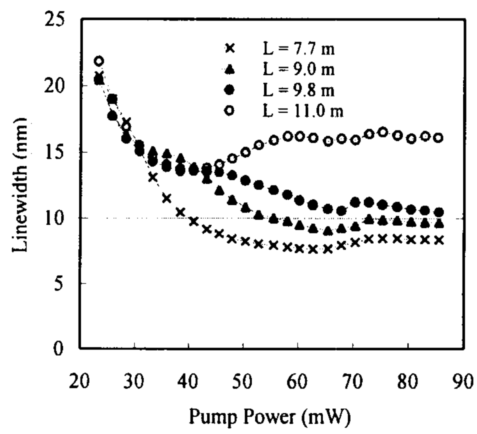


Fig.8 Measured linewidth versus pump power.