imposing a limitation on the sensor spectral separation. With a reasonable code sequence length of 127, the multiplexing of > 100 FBGSs in a single sensor array is possible.

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References

Gain-clamped fibre amplifier/source for gyroscope

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The authors propose and demonstrate feedback insensitive operation of a fibre amplifier/source (FAS) in a gyroscope by lasing the FAS with fibre gratings. Stable FAS characteristics that are almost independent of the rotation rate are obtained, eliminating most of the gyro output distortion due to the feedback effect.

Introduction: The erbium-doped fibre (EDF) source has been considered to be a promising source for the high-performance fibre-optic gyroscope. Among the various source configurations, the fibre amplifier/source (FAS) [1] is worthy of note. In this configuration, an active fibre is used both as a source and as an optical amplifier of the returning gyro signal. Hence, the detected optical signal power can be greatly increased, leading to the advantage of relaxed requirements for electronic circuitry. Despite this advantage, however, use of this configuration has been limited by the drawback of the feedback effect. As this scheme cannot use the isolator owing to its bidirectional nature, the feedback from the gyro coil to the FAS causes changes in the FAS characteristics and feedback level. Also, for accurate measurement, a filter with an isolator was used before the detector to ensure the complete blocking of the leaking laser light. However, these are not essential in this configuration. All the data that follow are for the phase difference modulation amplitude of 2.77 rad, where the average feedback level was ~14dB at zero rotation rate.

Experiment and results: A schematic diagram of the gain-clamped FAS with the testbed gyroscope is shown in Fig. 1. The FAS consisted of a 37m long EDF with 200µm concentration pumped by a 0.98µm wavelength laser diode. Backward amplified spontaneous emission (ASE) was used as the light source of the gyroscope. Two fibre gratings (FG1 and FG2) with the same centre wavelength of 1520nm were spliced at both ends of the FAS. It was found to be very important for stable operation that the reflectivity characteristics of the fibre gratings should be high enough to prevent the laser light from entering the gyro coil (and hence re-entering the laser cavity) and leaking onto the detector. Besides, the reflection bandwidth should be narrow so that the fluctuation of the lasing wavelength can be minimised. In the experiment, the reflectivity and bandwidth of FG1 were R = 98.9% and δλ = 0.13nm, respectively, and R = 99.5% and δλ = 0.08nm for FG2. The round-trip loss of the cavity formed with two fibre gratings was estimated to be ~4dB at the lasing wavelength, including splicing loss.

A depolarised gyroscope consisting of a 3.4km long singlemode fibre loop was used as a testbed gyroscope. The Sagnac loop included a PZT phase modulator and a depolariser composed of two pieces of highly birefringent fibres. The returning gyro signal (feedback signal) was amplified through the EDF and was detected with an InGaAs detector placed at the end of the gain-clamped FAS. The detected signal at the modulation frequency of 87.7kHz was measured with a lock-in amplifier. In the actual measurement, a 5% tap coupler was placed between the fibre polariser and the FG2 to monitor the variation of the source characteristics and feedback level. Also, for accurate measurement, a filter with an isolator was used before the detector to ensure the complete blocking of the leaking laser light. However, these are not essential in this configuration. All the data that follow are for the phase difference modulation amplitude of 2.77 rad, where the average feedback level was ~14dB at zero rotation rate.

Fig. 1 Schematic diagram of gain-clamped fibre amplifier/source with testbed gyroscope
FG: fibre grating

As the pump power increased, the source (backward ASE) and the detected power (falling on the gyro detector) increased until lasing started at 1520nm wavelength. With a further increase in pump power above the lasing threshold of
~18 mW, the source power and the average detected power dropped and were clamped at near 0.3 and 1 mW, respectively. The source power variation was measured by varying the rotation rate over the range between ± 19 deg/s, which corresponds to ± π Sagnac phase shift, and the result is shown in Fig. 2. At a pump power of 13 mW, below the lasing threshold, the source power varied by up to ± 6% for varying rotation rate, which is the case for a normal FAS without gain-clamping. In contrast, at the pump power of 49 mW, which is in the gain-clamping regime, the source power variation for varying rotation rate was within ± 0.3%. When an additional loss of 6 dB was induced in the gyro by bending the fibre, the source power variation decreased to within ± 0.1%. Source spectral output power was measured for the two rotation rates of 0 and 19 deg/s and is shown in Fig. 3. In the case of a normal FAS at 13 mW pump power, the spectral output changed with the mean wavelength variation of 0.3 nm (Fig. 3a). In the case with gain-clamping at a pump power of 49 mW, the source output spectrum remained nearly unchanged for the two rotation rates (Fig. 3b).

![Fig. 3 Source output spectra measured for two rotation rates of 0 and 19 deg/s](image)

The modulation frequency component of the detected output was measured as a function of the rotation rate with and without gain-clamping. In addition, the deviations of the normalised results from an ideal sine curve are plotted in Fig. 4. We can see gyro output distortion up to ± 5% showing nearly sin 2θ dependence in the normal FAS case at a pump power of 13 mW. In the case of the gain-clamped FAS, however, all the deviations from the sine curve fell within ± 0.1%, which we think is the resolution limit in our experiment.

**Conclusion:** We have proposed and demonstrated a scheme for feedback insensitive operation of an FAS gyroscope by lasing the FAS with fibre gratings. For stable operation, the laser cavity was designed so that the laser output entering the gyro and the detector is minimised. With this gain-clamping scheme, the source spectral output as well as the amplifier gain became nearly independent of the rotation rate, eliminating most of the gyro output distortion due to the feedback effect. Though the data presented are for a specific modulation amplitude, the proposed scheme can be applied regardless of the phase modulation amplitude.

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**Low-loss fattened fusion splices between different fibres**

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Using a fattening technique which requires a flame with a long hot zone, fibres with both different cladding diameters and NAs can be spliced with low loss. For instance, a standard 1250.9 μm telecommunications fibre (NA = 0.11), can be spliced to an 80/5.3 μm fibre (NA = 0.21) with 0.1 dB loss.

**Introduction:** In addition to the standard telecommunications fibre ($\lambda_c = 1250$ nm, cladding diameter 125 μm, core diameter 9.5 μm and NA = 0.11), there are, at the present time, many different fibres being deployed in modern telecommunications systems. For instance, the EDFA [1] WDM requires fibres which are singlemode at 980 nm and which should, for low loss, have mode compatibility at 1550 nm with the standard fibre and the high NA erbium doped fibre used. The Bragg grating fibre for DWDMs which has additional boron doping to enhance the photosensitivity [2] should also be mode compatible with the standard fibre.

Special fibres are also designed for specific sensor applications. For example, small cladding diameter, high NA fibres are used in the small diameter coils in gyroscope and hydrophone systems [3]. In some cases the lack of compatible fibre components limits the feasibility and escalates the cost of some of these special fibre systems. A previous report [4] of low-loss joints between dissimilar (yet equal cladding diameter) fibres, which used the powerfill tapering technique to equalise the modes across the splice joint, has not found widespread use due to the fact that in attempts at tapering a splice joint, the tapered section has always concentrated on one or other side of the actual joint. Other methods of improving the joins between dissimilar fibres involve splicing intermediate fibres [5] or core diffusion [6].

**References**