Phase Sensitive Amplification in a Highly Nonlinear Lead-Silicate Fibre

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Abstract: We experimentally demonstrate phase-sensitive amplification in a highly nonlinear lead-silicate W-type fibre. A phase-sensitive gain swing of 6dB was observed in a 1.56m sample of the fibre for a total launched power of 33dBm.

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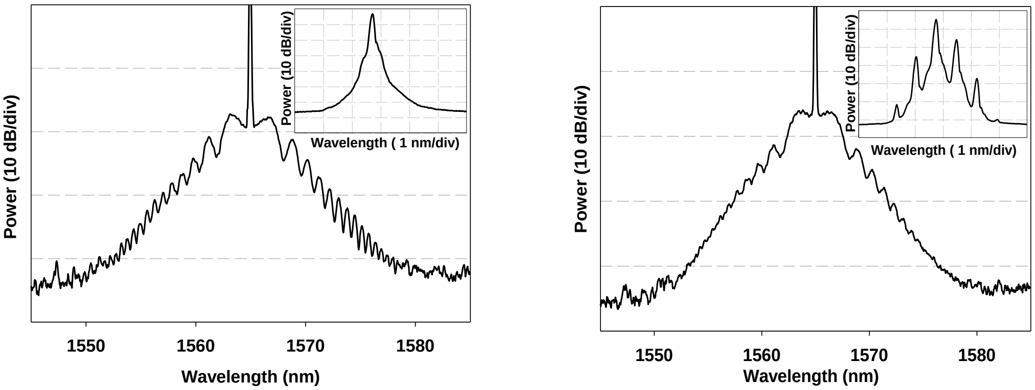
1. Introduction

The increasing demand in global communication traffic fuelled by the rapidly expanding high-speed high-bandwidth applications has led to a requirement for more efficient modulation formats than on-off keying, which for long has been used as the standard in optical communications. Consequently, the advent of modulation formats, such as differential- or quaternary-phase shift keying (D- or QPSK), have led to an increased research interest in phase-sensitive (PS) amplification. Phase-sensitive amplifiers (PSAs) can be used to efficiently amplify signal components of a certain phase, while they lead to de-amplification of any out-of-phase components [1]. PSAs can be implemented by making use of parametric effects in fibres, and have already been shown to allow amplification with a sub 3dB noise figure [2] and efficient regeneration of DPSK [3] and QPSK signals [4] by suppressing phase jitter.

Efficient parametric processes generally require fibre with a high nonlinearity, low loss, a broadband low dispersion profile and a high stimulated Brillouin scattering (SBS) threshold [5]. Germanium-doped highly nonlinear fibres (HNLFs) have proven to be an important tool for the observation of these effects, mainly due to their excellent dispersion characteristics. Their application however, requires the use of long lengths of fibre (typically a few hundreds of meters) which can be limiting in terms of the parametric gain bandwidth, device latency and stability. Moreover, SBS eventually limits the amount of narrow linewidth continuous wave pump power that can be coupled into the fibre unless active steps are taken to broaden either the linewidth of the pump or the SBS gain bandwidth – both of which add complexity and ultimately compromise the system performance. Nonlinear operation in far shorter fibre lengths can be accommodated through the adoption of soft glasses that exhibit both a far higher nonlinear refractive index and a better SBS figure of merit than silica [6,7]. Among the various soft glasses, lead silicates are commercially available and possess good chemical and thermal properties for fibre fabrication. We have recently shown that an all-solid lead silicate fibre based on a W-type refractive index profile can provide both a high nonlinear coefficient and a wideband low dispersion profile. We have also demonstrated a uniform four-wave mixing (FWM) conversion efficiency of 0 dB across a 40 nm bandwidth and a high SBS threshold in a 2m long sample of this fibre [7]. In this paper, we demonstrate PSA operation in this type of fibre. In addition, for the first time we report experiments performed in a fully-spliced set-up (our previous demonstrations relied on free-space coupling to the lead silicate fibre, greatly limiting the practicality of the applications).

2. Experiments

In order to verify that PS operation could be achieved in our fibre, we started our experiments with a single-pump PS parametric fluorescence experiment. This comprised a phase-insensitive amplification (PIA) input to the PSA. The PIA consisted of a single CW laser pump operating at 1565 nm which was amplified before being launched to a 300-m long HNLF with a nonlinear coefficient of 11.6 /W/km, a zero dispersion wavelength (ZDW) of 1553 nm and a dispersion slope (DS) of 0.018ps/nm^2/km. A strain gradient had been applied to the HNLF to increase its SBS threshold. The amplified spontaneous emission (ASE) of the amplifier experienced approximately 3 dB of parametric gain at the output of the HNLF, thus forming a ~30nm wide relative phase stabilised signal. Both pump and ASE were amplified further to 32 dBm and were launched to the fibre under test. The fabrication of the lead-silicate glass W-type index profiled HNLF was described in detail in [7]. It had a core diameter of 1.66μm, a length of 1.56 m, a 2.7 dB/m loss, a nonlinear coefficient of 820 /W/km, and a dispersion of ~2 ps/nm/km and DS of -0.009 ps/nm^2/km at 1550 nm. Arc-fusion splicing with an asymmetric configuration [8] was used to splice the lead-silicate



(a) (b)

Fig. 1. Spectral traces of PS parametric fluorescence in (a) the 1.56 m lead silicate fibre and (b) a 2 m long bismuth oxide fibre (resolution bandwidth (RB) = 0.06nm). Insets show zoomed-in traces of the output pump spectrum (P = 32 dBm) for the two cases (RB = 0.01nm)

glass HNLF with a commercial Nufern silica fibre UHNA3 and then with a conventional silica SMF28 fibre. 4dB per splice was obtained between the lead silicate fibre and UHNA3, and 0.25dB between UHNA3 and SMF28.

Fig. 1(a) shows the spectrum measured at the output of the PSA. The wavelength dependant phase mismatch resulting from the dispersive elements prior to the PSA gives rise to the characteristic gain peaks and attenuation troughs in the form of ripples, a clear sign of PS behaviour. Owing to the low dispersion of the fibre across this whole wavelength range, the gain spectrum extends across the full 30-nm available bandwidth of the ASE.

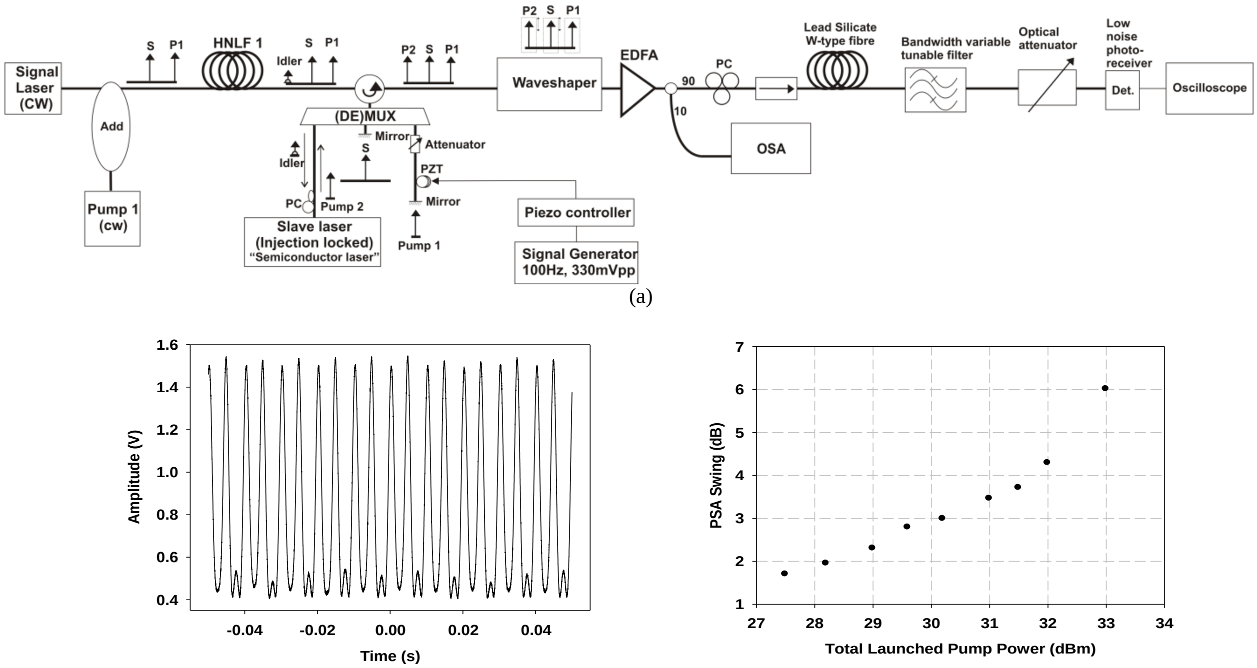
We have benchmarked this result against a second sample of soft glass fibre of a similar length. This was a bismuth oxide fibre of a similar type to that previously used for an earlier PSA demonstration in [9]. The sample was 2 m long and had a loss of 0.9 dB/m, a nonlinear coefficient of 1100 /W/km, and a dispersion of -260 ps/nm/km at 1550 nm. This sample was also spliced to silica pigtails at both ends and the splice losses were estimated to be approximately 3 dB per splice. Fig.1(b) shows the spectrum obtained at the output of this fibre. PS gain is also observed in this case, however its bandwidth is restricted to a much narrower spectral region, due to the higher dispersion of this fibre. In addition, the insets to the two graphs show spectral traces in the vicinity of the pump wavelengths for the same launched power (32 dBm). The onset of SBS can already be clearly seen in the case of the bismuth fibre whereas there is no evidence of SBS in the lead-silicate fibre. Indeed there was no SBS up to 33dBm the maximum available power in our current experiments.

We next set up a two-pump degenerate PSA in order to measure the phase sensitive gain swing achieved with the lead-silicate fibre (Fig.2(a)). The first stage of the setup consisted of a PIA stage which was configured to ensure phase-locking between the two pumps and the signal and allow control of their relative powers. This was done by coupling one pump (pump 1) and the signal from two independent CW lasers into a HNLF, resulting in the generation of a new idler field. The weak idler was then used to injection-lock a slave semiconductor laser (pump 2), boosting the power level at this wavelength to that of the pump and the signal. The three optical fields were then fed into a programmable optical filter (Finisar Waveshaper), allowing careful adjustment of their power levels, to ensure that the powers of the two pumps were equalized throughout the experiment and the signal power remained fixed at a certain level (6 dBm). The pumps and the signal were then amplified through a high power EDFA, and their power levels were monitored on an optical spectrum analyser (OSA) connected to the output of a tap coupler. The amplified beams were fed through a polarization controller and an isolator at the input of the lead silicate W-type fibre (PSA segment). The output of the PSA was subsequently filtered using a bandpass filter, rejecting the two pumps while keeping the signal. A piezo-electric transducer (PZT) driven by a 100 Hz signal generator was connected to pump 1 and periodically changed the phase of this field relative to pump 2 and the signal, thereby ultimately causing the PSA to swing between maximum gain and maximum attenuation. We used an oscilloscope at the output of the system to detect the effect of the PSA swing on the signal (Fig. 2(b)).

The PSA swing was measured as the total launched pump power into the fibre was varied from 27.5 dBm to 33 dBm. Fig. 2(c) shows the measured PS swing of the lead silicate fibre as a function of the total launched pump power. A maximum PS swing of 6 dB was measured for a launched pump power of 33 dBm (the maximum we could currently reliably launch from our available amplifiers).

3. Conclusion and Future Work

We have demonstrated PS amplification in a length of W-type lead silicate fibre. A PS parametric fluorescence



(a)

(b) (c)

Fig. 2. (a) The experimental setup of the PS swing characterization experiment. PC: Polarization controller. EDFA: Erbium-doped fibre amplifier. OSA: Optical spectrum Analyzer. (b) An example trace of the voltage swing detected by the photo-receiver shown by the oscilloscope from which we determine the PS swing. (c) Measured PS swing (dB) as a function of increasing launched pump power (dBm).

experiment demonstrated that PSA gain can be achieved over a broad bandwidth due to the relatively low dispersion of this fibre enabled by the W-index profile design. This was contrasted to the result achieved with a much higher dispersion bismuth oxide fibre of a similar length, which only showed strong PSA gain in a limited bandwidth around the pump wavelength. The PS swing was measured to be 6 dB for a pump power of 33 dBm in a two-pump degenerate PSA. There was no need to employ any SBS suppression schemes in any of the experiments. We believe that use of this fibre will prove beneficial in PSA-based processing applications of wideband signals.

4. Acknowledgements

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5. References

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