Indirect Measurement of LP_{01} Effective Area Reduction in Bent Large-Core Step-Index Fibres Using Raman Scattering

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Abstract: We present an indirect measurement, using stimulated Raman scattering (SRS), of the fundamental mode effective area in several bent large-core step-index passive fibres used for industrial high-power high-brightness beam delivery. The increase of the SRS gain in bent fibres can lessen the benefit of such large-core fibres.

1. Introduction

High-power fibre lasers (FL) have transformed many industries and aim to offer 'smart', on-demand laser light to remote processing workstations around factories of the future [1]. Simple, low-cost and effective solutions to deliver high power beams with good beam quality over several tens to hundreds of meters of fibre are desired [2]. Typically, long length delivery fibres are limited in length and/or power by the onset of optical nonlinearities, particularly by SRS in CW industrial lasers. To allay SRS, the effective area (A_{eff}) of the core of the optical fibres is increased using so-called large-more area (LMA) fibres, thereby reducing the optical power density. However, this increase in effective area (and core size) leads to multimoded cores, which become susceptible to the bend-induced reduction of A_{eff} [3].

In this paper, we present an experimental investigation of the bend-induced reduction of A_{eff} in LMA fibres. We show a simple approach to estimate A_{eff}, based on relative SRS gain between two different bend radii. Using this approach, we investigate the impact of bending on long delivery fibres for high power FLs.

2. Method

We derive, from the well-known Raman gain expression: $G_{dB} = 4.34\, g_R P_p L/A_{eff}$ [4] for the case of un-depleted pump approximation, the following formula to estimate the relative effective area of the LP_{01} mode in the bent fibre with respect to the straight fibre:

$$A_{eff\_coiled} = 1/(1+ (S_{eff\_coiled} - S_{eff\_ref})A_{eff\_ref} / (4.34\, g_R L)) \qquad (1)$$

where S is the slope of the SRS power vs pump power such as $S = \Delta G/\Delta P = 4.34 g_R L/A_{eff}$, L is fibre length, A_{eff_ref} is the reference effective area of the straight fibre, and 4.34 g_R is the Raman gain in dB.µm^2/(kW.m) at 1µm for the first Stokes. The slope S is experimentally determined by the growth of the SRS power vs the pump power from the output optical spectra.

3. Experimental setup and measurements

The experimental setup to measure Raman scattering comprises an amplified narrow-linewidth pulsed passively Q-switched microchip laser that forms the SRS pump laser, a passive LMA fibre and some diagnostics instruments: a thermal power meter (OPHIR 12A) and optical spectrum analyser (ANDO AQ 6315A). The pulsed laser source emits at 1064nm pulses of 1.8ns duration at a repetition frequency of 108kHz. The average output power can be adjusted over ~1W, corresponding to a peak power of up to ~6kW. The spectral and temporal characteristics of the pump laser were chosen to have a clear Raman spectrum while avoiding Stimulated Brillouin Scattering. The optical pulses are launched into the LMA fibre through a single mode fibre spliced to a taper to achieve single-mode excitation. The LMA fibres used in those experiments have core diameters of 20µm NA=0.08 (fibre A), 26µm NA=0.08 (fibre B), and 35µm NA=0.1 (fibre C), and lengths of 9m, 24m, and 30m respectively. The fibres are coiled with different bending diameters.

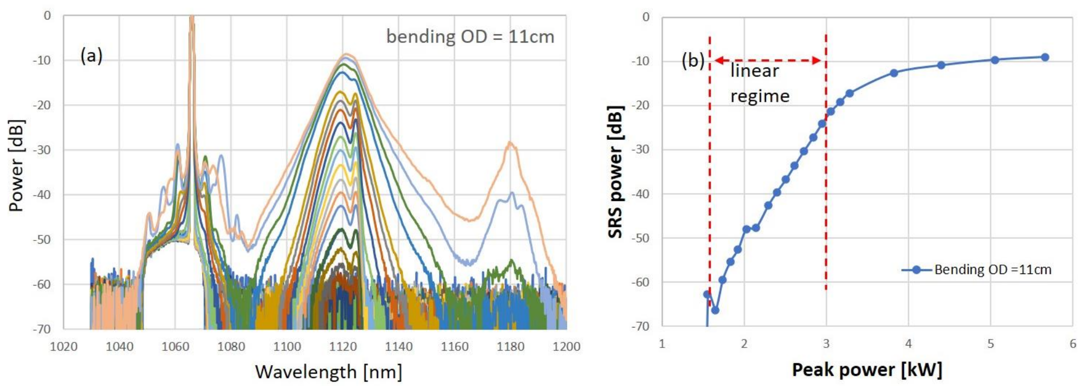

Fig. 1. Experimental results for fibre B (26μm core OD): (a) Output spectra for various input peak powers in range 0.8-5.7kW for 11cm bending diameter, (b) Corresponding relative first Stokes power vs. launch pump peak power.

For a given coil diameter, the output spectra are recorded with a resolution of 1nm for several values of launch pump power, as shown in Fig. 1.(a). The onset of SRS at the first Stokes can be observed with modest peak power of ~1.5kW. Figure 1.(b) shows the relative SRS power w.r.t. the launch peak power. The first Stokes SRS power grows linearly until the second Stokes appears. The slope *S* can be determined from the linear part of Fig. 1.(b) to calculate the effective area of a coiled fibre using the Eq.(1).

4. Results and discussion

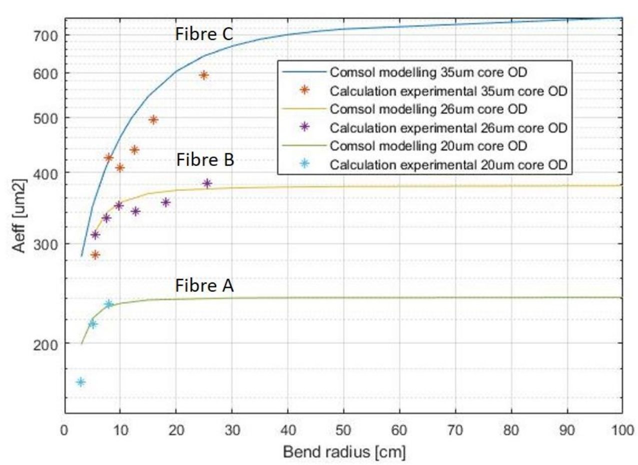

Fig. 2. Estimated (from experiments) and modelled effective area for LP_{01} mode as a function of bend radius for three different fibres.

Figure 2 shows the LP_{01} effective area obtained experimentally using Eq. (1) and the calculated modal effective area as a function of bend radius for the fibres A, B and C. COMSOL Multiphysics was used to numerically evaluate the effective area of the bent mode using conformal mapping and the measured refractive index of the respective fibres. The estimation of A_{eff} from the experimental data agrees with the modelling results. A small discrepancy exists due to the assumption that power loss is negligible in the bent fibre. Figure 2 shows that although Fibre B has an effective area half that of fibre C when straight, their effective areas become comparable when the fibre is coiled with around a 10cm bend radius. This is an important result indicating that the larger mode area high power delivery fibres might have limited benefits in real applications that require the fibre to be coiled. In this case, smaller core diameter delivery fibres could be preferable, also given their enhanced capability to launch and maintain the propagation of the fundamental mode and therefore achieve superior overall beam quality.

5. References

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