The Effect of High Optical Power on Modern Fibre at 1.5 µm.

Naoise Mac Suibhne, Filipe M. Ferreira, Mary E. McCarthy, Arvind Mishra* and Andrew D. Ellis
Aston Institute of Photonics Technologies, Aston University, Birmingham, B4 7ET, UK
** Centre of Excellence, Sterlite Technologies Limited, E1-E3, MIDC, Waluj, Aurangabad, 431 136, India.*
e-mail: n.mac-suibhne@aston.ac.uk

ABSTRACT
Here we study the impact of high optical power, within the C-band, on the reliability of modern single mode fibre. Our experiments show that modern fibre demonstrates >10 dB higher power handling performance beyond what has previously been reported.
Keywords: optical fibre, fibre damage, fibre reliability, fibre loss, optical communications, high optical power, modern fibre.

1. INTRODUCTION

When optical fibres were first deployed there was considerable effort to establish the reliability of single mode fibre (SMF)[1,2]. Several of these studies examined the performance and reliability of optical fibre in the presence of high optical powers at 1.24µm [3] and 1.48µm [4]. Very little has been published on the verification of such models in recent history and results of fibre performance at 1.5 µm are sparse.

With the continued growth of fibre based communications, the demand to place higher optical power densities into optical fibres is ever growing. In current systems, optical amplifiers with over 20 dBm output power are not uncommon. Future applications that look at nonlinearity compensation and Raman amplification may involve even higher densities of optical power in the C-band [5]. These demands, coupled with advances in modern fibres, with reduced water peak and bend insensitive geometries suggest that a revisit to the topic of fibre reliability is now timely.

In this paper, we study the effect of high optical powers on SMF in the context of modern fibres and optical communication systems. Our studies go beyond previously published work by examining the reliability of fibres operating directly in the C-band. This consisted of a series of experiments, based on previously proposed models and experiments [1, 4, 6] to ensure a direct comparison can be made. Single mode fibres with both loss and bend insensitivity were subjected to a range of conditions involving bend induced loss and CW power handling. We note for severe bends the fibre shows large fluctuation in bend loss, in some cases >10 dB. Our experiments focused on class 1 fibre failure where the optical powers cause total destruction of the fibres wave-guiding ability in a number of seconds (<10s)[4]. This type of failure is of particular importance due to its rapid onset and is thus difficult to manage in a network scenario. These results show, for the first time to our knowledge, class 1 damage thresholds, caused directly by optical power in the C-band. The results indicate that modern low loss fibre has considerably greater power handling at 1560nm than previous work carried out at shorter wavelengths [4].

2. Experimental Setup

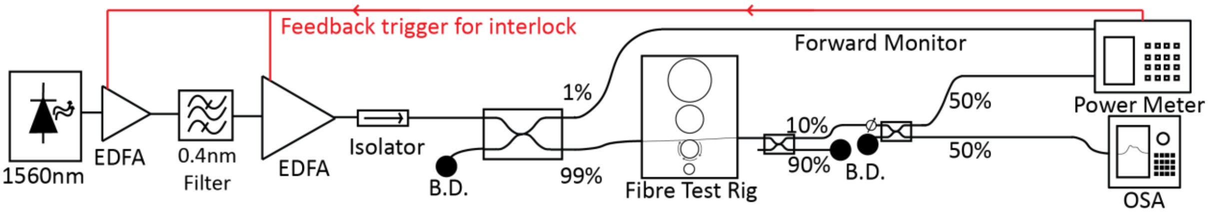

Figure 1: Experimental Setup. EDFA: Erbium Doped Fibre Amplifier, B.D.: Beam Dump, OSA: Optical Spectrum Analyser.

The diagram in Fig. 1 shows the experimental setup that was used in order to test the fibres under several conditions. The experiment consisted of a 1560nm CW laser source that was first pre-amplified with an Erbium doped fibre amplifier (EDFA). The spectrum was then filtered using a 0.4nm optical filter to remove any unwanted amplified spontaneous emission (ASE) from the low power EDFA. The signal was then amplified using a high power narrow bandwidth EDFA capable of a maximum output power of 16 Watts and was then spliced to a high-power handling optical isolator. The signal then passed through a 2×2 coupler with a splitting ratio of 99:1. This allowed the launch power to be directly monitored on the 1% tap while the remainder of the power was launched into the fibre. The fibre under test was spliced into the system where the fibre was placed in the fibre test rig.

The fibre test rig consisted of several brass and stainless steel cylindrical mandrels of varying diameters, ranging from 31.74 mm to 1.97 mm. The fibre under test was wrapped around each mandrel where the fibre had a single 360° bend. Great care was taken to ensure the fibre remained on the same plane, where the input and output fibre holders were held in place with magnets and pulled taut until the magnets began to slide. Fibre overlapping was also avoided to prevent localised stress points at the fibre overlap.

After the test rig the signal passes through a series of couplers and attenuators to reduce the power before the test measurement equipment. The output signal was monitored using a power meter and optical spectrum analyser. Any unused coupler ports were terminated in beam dumps. An interlock system monitored output power and in the event of a fibre break triggered the interlock. This was for general lab safety and prevented potential self-propagating fibre fuses.

2.1 Fibres under Test

Table 1: Fibre Characteristics

	Loss (dB/km)	Type
Fibre 1	≤ 0.19	SMF Zero Water Peak
Fibre 2	≤ 0.20	SMF Bend Insensitive
Fibre 3	≤ 0.20	SMF Bend Insensitive

The three fibres tested in this paper are summarised in Table 1. The fibres in use were coated in a polymer coating and were not cabled. Fibre 1 was a standard SMF with zero water peak. Fibre 2 and fibre 3 were bend insensitive fibres where fibre 3 had enhanced macro-bend characteristics. All fibres are commercially available and adhere to ITU standards G.652 (Fibre 1) and G.657 (Fibre 2 and 3).

3. Results

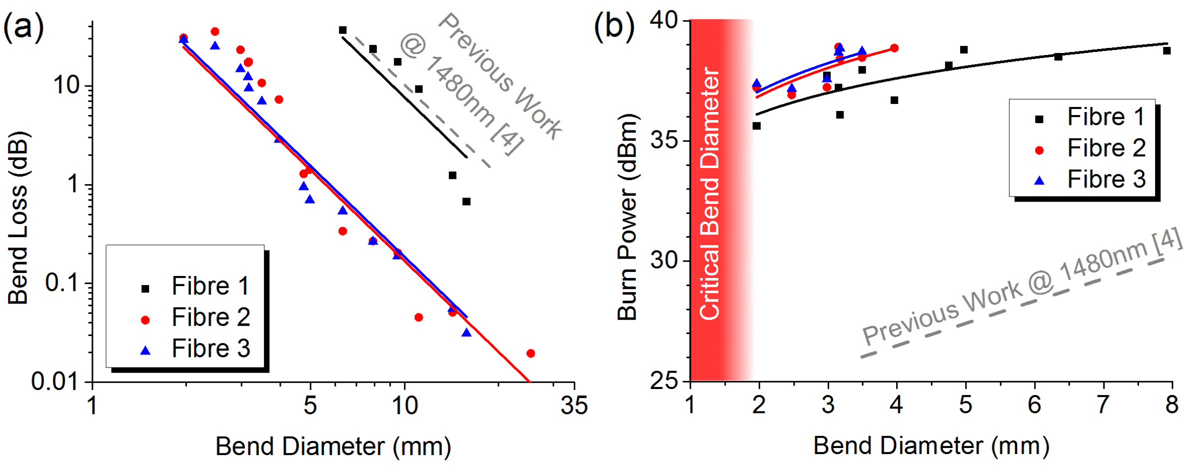

Figure 2: (a) Fibre Bend Loss versus Bend Diameter (b) Optical Power Damage Threshold versus Bend Diameter

All experiments were carried out at 1560 nm using the setup shown in Fig. 1. Initially the macro-bend sensitivity of each of the fibres was measured. This was done by measuring approximately 10 m of each fibre through the system with bends strictly >200 mm diameter and were considered to have a negligible bend loss for all fibre types. The launched and received power were recorded simultaneously over sixty seconds for decreasing fibre bend diameters at a constant launch power of 33.8 dBm. The power was measured with no bend, with a bend, and again after being bent without breaking any connection in order to avoid difficulties with connector reproducibility. The measurements taken before and during the bend allowed the bend loss to be calculated while the measurement taken after the bend was used to verify the consistency of calibration.

The results for each of the three fibres tested can be seen in Fig. 2(a) where the macro-bend loss was calculated by taking the mean over sixty seconds of measurement both before and after bending the fibre. The results show bend loss (in dB) is inversely proportional to bend diameter where the trend lines show the average slope over all data points. This is in agreement with previous work [4] where results on standard SMF remain consistent. However, we also see modern bend insensitive fibres support much lower bend diameters, with over an order of magnitude reduction in bend loss for a fibre at the same bend diameter.

More interesting is that high bend loss does not correlate with higher damage thresholds. This can be seen in Fig. 2(b) where the amount of power required to cause class 1 fibre failure was measured. Here, class 1 refers to catastrophic damage where the fibres wave-guiding ability was suddenly destroyed and was typified by the fibre igniting and snapping away for the mandrel it was wrapped on, a similar definition for fibre failure has also been used by [4]. The resulting fibre end can be seen in the insert of Fig 4. As can be seen the fibres with high bend insensitivity (Fibre 2 and Fibre 3) showed a higher damage threshold, however this is not directly correlated with bend loss as the modern standard SMF (Fibre 1) has similar bend loss performance to older fibres [4](Fig. 2(a)). This work shows a ~10 dB higher damage threshold of modern fibres measured at 1.56 µm compared to previous work at shorter wavelengths. This ~10 dB difference can be attributed to being measured at different wavelengths where previous work may have had higher absorption due to operating closer to water peaks, depending on the fibre in use this may account for the difference in damage threshold with older fibres having higher water concentrations [7,8]. However, the waveguide geometry of modern bend insensitive fibres appears to increase the damage threshold even further.

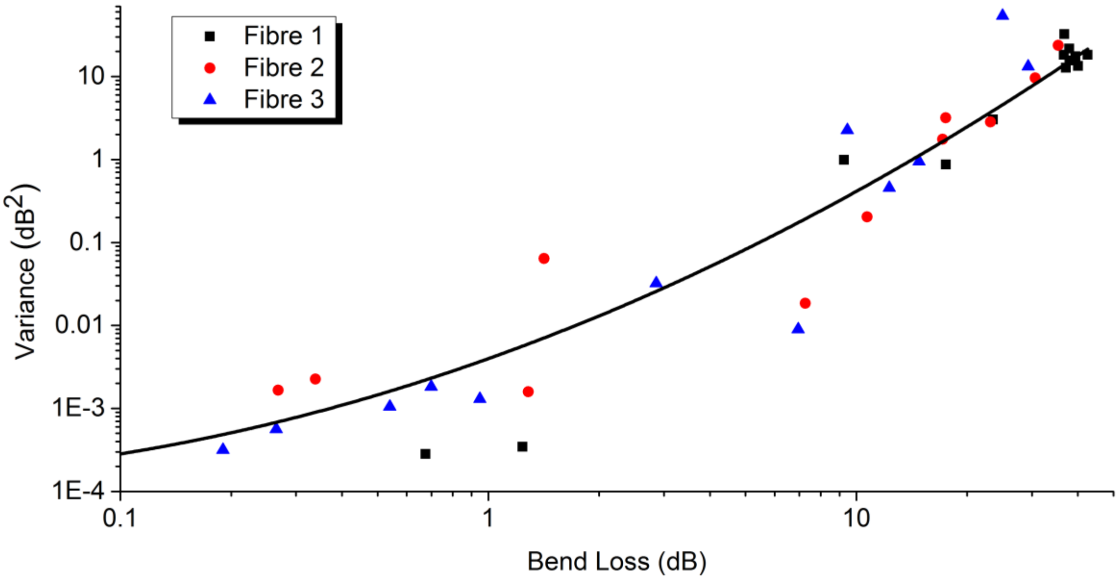

Figure 3: Bend Loss versus Bend Loss Variance

When the fibre had very severe bend diameters (<5mm), it was observed that the bend loss was not static and varied considerably over time. It was noted that as the bend diameter decreased the variance increased. On closer investigation it was found that the variance of the received power in dB has a quadratic relation with mean bend loss (measured in dB) and is plotted in Fig. 3. No direct relation between fibre burn and instantaneous bend loss was observed (see Fig. 4), with the burn process being dominated by the average bend diameter.

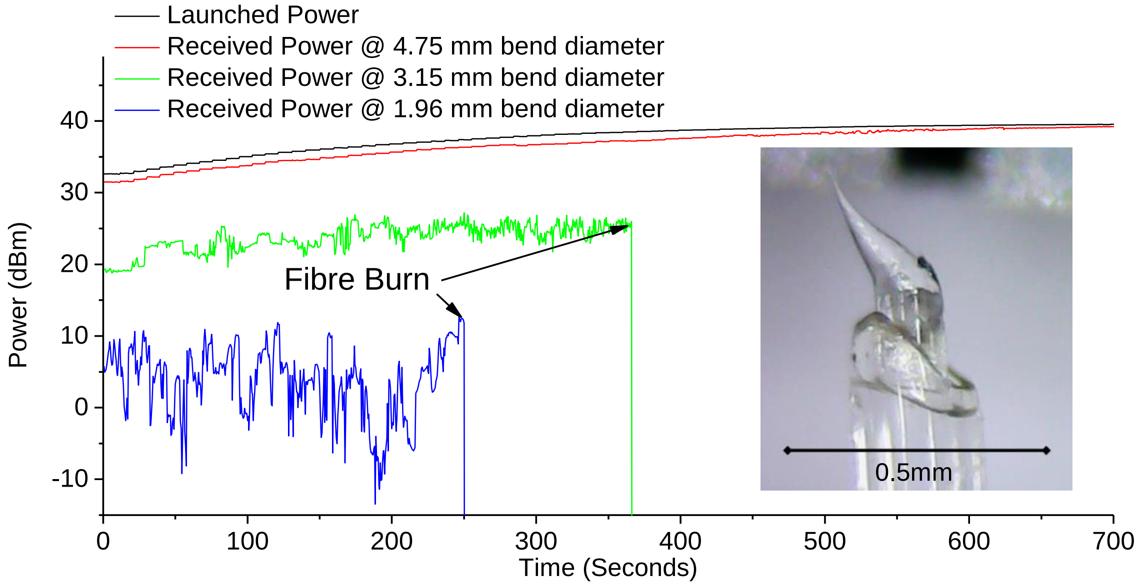

Figure 4: Real-time power measurements for three bend diameters, showing high bend loss variation and fibre burn for small bend diameters with insert illustrating the resulting fibre after fusing.

Fig. 4 shows an example of measured optical power for three bend diameters on Fibre 3. As can be seen the bend loss around the 1.96 mm mandrel (difference between black and blue lines) is considerably higher than the 4.75 mm mandrel (difference between black and red). The large variation of received power for smaller bend diameters (1.96 mm in blue and 3.15 mm in green Fig. 4) mandrel is clearly evident and its effect on the failure mechanising will be the subject of future work. Finally it can be seen that as input power increased there comes a point where there is a rapid drop in received power, this is due to a catastrophic fibre failure where the resulting microscope image of the fibre fuse is shown in the insert of Fig. 4.

4. CONCLUSIONS

Here we study the impact of high optical signal powers on modern SMF. Several fibre types are studied where a series of reliability experiments, measured directly in the C-band for the first time. We show that >10 dB improvement in optical power damage threshold with modern fibres were obtained when class 1 failure dominates maximum power handling.

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