Dispersion Flattened Highly Non-Linear Fiber

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Abstract *Using the MCVD process a conventional highly non-linear fiber with numerically small dispersion and low dispersion slope in the 1550 nm range has been developed. Dispersion characteristics and splicing results are presented .*

Introduction

Substantial effort has been put into development of highly non-linear fibers (HNLF) within the recent years. The applications are numerous, but in most cases rely on a combination of fiber non-linearity and numerically small dispersion. Different fiber manufacturing technologies provide different fiber properties. Highly non-linear fibers based on the MCVD process have been manufactured for several years. OFS' standard HNLF has a core with an almost flat and high refractive index. This fiber allows close control of the fiber dispersion as well as the fiber effective area, which is the main contributor to the fiber non-linearity. The VAD process also supports highly non-linear fibers [1]. The core index profiles usually obtained with the VAD process is graded. Such a core index profile can also be realized with the MCVD process. We have developed such a fiber, which shows a dispersion slope matching our standard HNLF, i.e., 0.02 ps/nm^2/km. We have investigated this design theoretically, and found, that it is very difficult to get a significantly smaller slope. A design has been presented [2] with a dispersion slope of 0.013 ps/nm^2/km, but this design requires a deeply depressed ring and a very high core index which increases the fiber loss. Micro-structured fibers (MSFs) can be realized with very small effective areas providing high non-linearity, but MSFs with zero dispersion wavelength (ZDW) around 1550 nm have non-linear properties similar to conventional fibers [3]. An MSF with a small dispersion slope of only 0.001 ps/nm^2/km was recently presented [3]. As demonstrated in the present paper, a low dispersion slope can also be realized using the MCVD process, giving a non-linear coefficient around 10.6 W^{-1} km^{-1}. Whilst this is comparable to that of the MSF, the loss of the fiber presented here is only 0.8 dB/km whereas the MSF loss in the order of 10 dB/km [3]. Also, while the coupling loss to the MSF was 0.25 dB per splice, the coupling loss for standard single-mode fiber (SSMF) to conventional HNLF fibers is smaller. We present a median loss for splicing of SSMF to HNLF of only 0.05 dB using production splicing equipment.

Fiber characteristics

The dispersion flattened HNLF (DFF-HNLF) is based on a flat core index profile with a deeply depressed ring around the core, similar to the standard HNLF. By carefully tuning the widths of the core and depressed ring, the dispersion slope can be controlled. Figure 1 shows the measured dispersion of 9 fibers with slightly different widths of core and ring. It is seen, that the dispersion slope increases as dispersion increases. This is inherent to this fiber design. Figure 2 shows the dispersion slope, obtained by numerically differentiating the curves in figure 1. As evident, very low dispersion slopes can be realized.

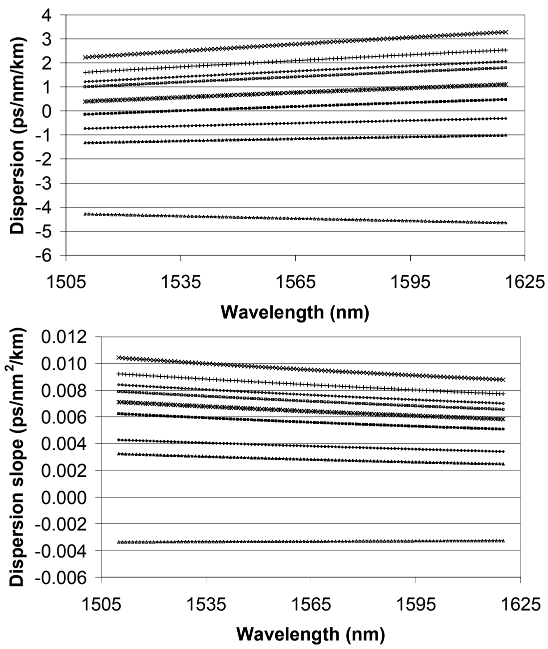

Figure 1 and 2. Measured dispersion of 9 DFF-HNLF fibers and calculated dispersion slope.

Table 1 summarizes fiber characteristics of about 2700 km standard HNLF and 126 km DFF-HNLF.

Parameter	DFF-HNLF	Std. HNLF
1550 nm loss (dB/km)	0.798	0.767
1550 nm MFD (μm)	3.99	3.88
Cut-off wavelength (nm)	1234	1170
PMD (ps/√km)	0.048	0.060

Table 1. Median values for DFF-HNLF and standard HNLF fiber parameters.

The relationship between effective area and mode field diameter (MFD) has been evaluated using a far field scanner. The relationship is:

$$A_{eff} = 0.957 * \frac{\pi}{4} MFD^2$$

This gives a DFF-HNLF effective area median value of 12.0 μm^2, whereas for the standard HNLF, the effective area median value is 11.3 μm^2.

The median value of the Kerr coefficient (n_2) of standard HNLF is approximately 3.1×10^{-20} m^2/W giving a median value for the non-linear coefficient of approximately 10.8 W^{-1} km^{-1} at 1550 nm. The results for 10 fibers are shown in figure 3. As the core of the standard and DFF-HNLF is almost identical, the Kerr coefficient is approximately the same, hence, the non-linear coefficient will be slightly smaller due to the larger effective area. We measured 10 fibers giving a median non-linear coefficient of 10.6 W^{-1} km^{-1}. The results are also shown in figure 3.

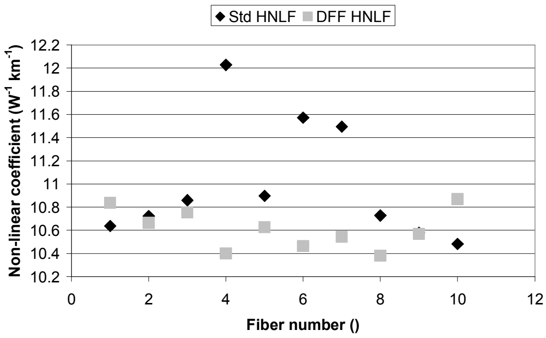

Figure 3. Non-linear coefficients of 10 standard (diamonds) and 10 DFF-HNLF fibers (squares) at 1550 nm.

The non-linear coefficient is measured using a beat signal of two CW sources [4], and were measured on fibers of approximately 220 m length. This allows high signal input power levels without suffering from SBS, and simultaneously makes the influence of fiber dispersion on the measurement negligible [4].

Splicing

The splicing properties of HNLF to SSMF are of special importance, as most amplifiers and signal sources use SSMF pigtails, and any coupling loss lowers the non-linear efficiency of the HNLF. As the MFD of the HNLF, whether standard or DFF, is much smaller than that of an SSMF, we use a special splicing technique that expands the MFD of the HNLF in the splice point to match that of the SSMF. There is no essential difference between the standard HNLF and DFF-HNLF splice properties, because the core design is identical. Hence, the mode shape is almost identical. We made 21 modules for different test purposes thereby making 42 splices. Of these, four modules were DFF-HNLF. The splicing loss data are summarized in figure 4. We obtained a median loss value at both 1550 and 1610 nm of only 0.05 dB in production.

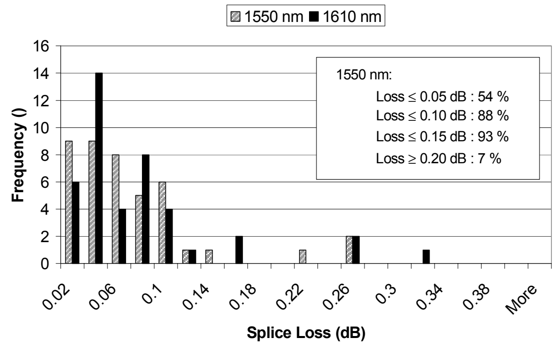

Figure 5. Splicing loss of DFF-HNLF and standard HNLF to SSMF.

The four DFF-HNLF modules had a median loss of 0.06 dB at 1550 nm and 0.05 dB at 1610 nm, showing the minimal difference in splicing properties between the two fiber types.

Conclusions

We have presented measurement results for a dispersion flattened HNLF that was implemented using the MCVD process. The numerically lowest observed dispersion slope at 1550 nm was 0.003 $ps/nm^2/km$. We measured a median value for the non-linear coefficient at 1550 nm of 10.6 W^{-1} km^{-1} which combined with a very low splicing loss of 0.06 dB (median value) makes the fiber a very effective non-linear medium. It was also demonstrated that a small dispersion slope and low splice losses were realized over a wide dispersion range.

References

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