2007-01-01

An Optimized Macrobending Fiber Based Edge Filter

Pengfei Wang
Dublin Institute of Technology, pengfei.wang@dit.ie

Gerald Farrell
Dublin Institute of Technology, gerald.farrell@dit.ie

Qian Wang
Dublin Institute of Technology, qian.wang@dit.ie

Ginu Rajan
Dublin Institute of Technology, ginu.rajan@dit.ie

Recommended Citation

Wang, P., Farrell, G., Wang, Q., Rajan., G. (2007) An optimized macrobending fiber based edge filter. *IEEE Photonics Technology Letters*, Vol. 19, No. 15, pp. 1136-1138, 2007. doi:10.1109/LPT.2007.901434

An optimized macrobending fiber based edge filter

Pengfei Wang, Gerald Farrell, Qian Wang, Ginu Rajan

***Abstract*—An optimized all-fiber edge filter is developed, based on a one-turn macrobending bare fiber structure. The discrimination range (DR) is 16.32 dB over a wavelength range from 1500 to 1600 nm, which can be employed for wavelength measurement applications. It offers a simpler structure compared to the previously developed macrobending fiber loss edge filters, without an increase in the polarization dependent loss (PDL).**

***Index Terms*—Macrobending loss, fiber edge filter, 1060XP fiber**

I. Introduction

Fiber bend loss (BL) has been investigated widely for optical sensing and optical communication applications [1-2], and recently, a macrobending standard singlemode fiber (SMF28) was investigated theoretically and experimentally and optimized as an edge filter for wavelength measurement applications using a bend radius circa 10 mm with multiple turns and a total fiber length about 1~2 meters [3-5]. Both theoretical and experimental results have shown that the polymer coating layer of SMF28 can not only affect the BL but also has a significant influence on the polarization dependence [6]. To remove this influence, a direct method is to strip the coating layers and utilise the bare fiber. However, bare SMF28 fiber after stripping is easily broken due to the mechanical stress. To reduce the bending induced internal stress, etching of the fiber cladding partially by chemicals is a possible solution [7], but it increases the fabrication difficulty and cost.

The formation of more compact structure for the fiber BL edge filter is one of our aims. A more compact structure is an advantage in many applications, for example in a handheld wavelength measurement instrument. To obtain the desired transmission spectrum with a shorter fiber bend length for fiber BL edge filter applications, a type of BL sensitive fiber could be employed, where the normalized frequency *V* should be lower. Therefore, in this letter an alternative BL sensitive fiber (1060XP) is considered compared to SMF28 fiber. The macrobending loss behavior of bare 1060XP fiber will be presented in this letter, along with consideration of the optimal design of a fiber BL edge filter. Finally the PDL behaviour of bare 1060XP fiber (using a single turn structure) with an optimal bend radius is also presented. Our investigation involves: 1) modeling BL; 2) the design of a BL edge filter and 3) experimental verification. The numerical theoretical modeling agrees with the measured results for the BL of 1060XP fiber with a correction factor of 1.298 at a wavelength of 1550nm. Through examination of the PDL behavior of bare 1060XP fiber with an absorbing layer, it is found that the BL of bare 1060XP fiber with absorbing layer can achieve a marginally better PDL behavior than an equivalent SMF28 based edge filter, with a more compact structure.

The authors are with the Applied Optoelectronics Center, School of Electronics and Communication Engineering, Dublin Institute of Technology, Kevin Street, Dublin 8, Ireland (e-mail: pengfei.wang@student.dit.ie).

II. Modeling and Optimal Design

Theoretical investigations about macrobending loss in optical fibers started in the 1970s. The models developed by D. Marcuse [8] treated the optical fiber as a core-infinite cladding structure. While an infinite cladding structure is not possible in practice, a bare fiber coated with an absorbing layer is approximately equivalent to a core-infinite cladding structure. In this investigation an absorbing layer is used over a conventional finite cladding and thus the analytical expression for calculating the fiber BL with an infinite cladding developed by D. Marcuse [8] can be used.

For standard Corning SMF28 and 1060XP fiber, the corresponding parameters are shown in TABLE I:

TABLE I
PARAMETERS OF THE STANDARD CORNING SMF28 AND 1060XP FIBER; (THE REFRACTIVE INDEX VALUES ARE DEFINED AT A WAVELENGTH OF 1550 NM)

Parameter of fiber	1060XP	SMF28
Refractive index of fiber core	1.46313	1.4504
Refractive index of fiber cladding	1.45642	1.4447
Diameter of fiber core	5.3 ± 0.5 µm	8.3 ± 0.5 µm
Diameter of fiber cladding	125 ± 0.5 µm	125 ± 0.5 µm
NA (Numerical Aperture)	0.14	0.1285
V (Normalised frequency)	1.5035	2.1611

In previously published papers [9-11], to fit the calculated BLs with experimental results, a so-called effective bend R_{eff} has been used, which was different from the actual (experimental) bend radius R_{exp}. An effective bend radius is needed to allow for the change in refractive index of silica glass induced by bending axial stress. In practice it is represented as a wavelength dependent elastooptic correction factor relating R_{eff} and R_{exp}. For example in [11] for LB1000 fiber the correction factor is 1.325 at a wavelength of 1480 nm. It is also known that the exact correction factor value is wavelength dependent [9]. As shown in the Fig. 1, the BL of bare 1060XP fiber with an absorbing layer (to remove the reflection occurring at the interface between the cladding layer and air) was measured for a bending radii range from 8.5 to 14.5 mm when the operating wavelength is 1550 nm. For comparison, the calculated BLs (with/without a corresponding correction factor) are also presented in Fig. 1. It is evident that the results are incorrect if the correction factor is not used in modeling BL for bare 1060XP fiber with absorbing layer as compared to the measured results. The selection of 1.298 as the correction factor at 1550 nm was determined from an error analysis which compared the theoretical and experimental values over the range of bend radii employed. The correction factor varies with wavelength and while it is not practical to determine the value of the correction factor at all wavelengths, it was determined at 10 nm intervals over the wavelength range of interest between 1500 and 1600 nm. The correction factor as a function of wavelength is shown in Fig. 2.

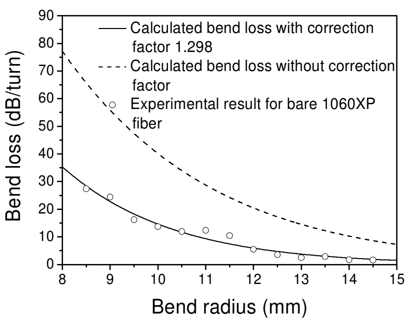

Fig.1: Modeling with (solid line) and without (dashed line) correction factor, and measured macrobending losses for bend radius ranging from 8.5 to 14.5 mm at a wavelength of 1550 nm.

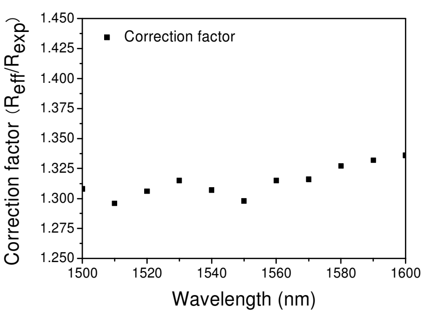

Fig.2: Correction factor as a function of wavelength.

An ideal edge filter provides a strong monotonically increasing wavelength dependent attenuation (DR) from a given start wavelength to an end wavelength, with a low inherent attenuation (baseline loss) at the start wavelength. In this case wavelength measurement over the range from 1500 nm to 1600 is envisaged. Thus there needs to be a low baseline loss (BL at the wavelength 1500 nm with the correction factor of 1.308) along with a desired DR (the difference in BL between 1500 and 1600 nm, with corresponding correction factors of 1.308 and 1.336, respectively) as shown in Ref. [5].

Based on the theoretical formulas presented in Ref. [8], Fig. 3 shows the calculated baseline transmission loss and DR as a function of bend radius for bare 1060XP fiber with an absorbing layer, with correction factors applied as appropriate. The curves in Fig. 3 simplify the design of a fiber BL based edge filter using a single turn of 1060XP fiber. In experiments, it is found that bare 1060XP fiber is easily broken when the bend radius is smaller than 10 mm. To reduce the bending stress and retain the mechanical reliability, bend radii less than 10 mm should be avoided. For a given fiber BL edge filter, the aim is to use Fig. 3 to select a working bend radius where the baseline loss is not excessive, while still retaining a reasonable DR. Using Fig. 3 it is possible to tradeoff higher baseline losses for an improved discrimination, but in a wavelength measurement application [5] while higher discrimination can improve measurement resolution, the consequent higher baseline loss will reduce the overall signal levels available for detection, decreasing measurement accuracy due to noise. Furthermore there is a limit on the discrimination which can be used. In [3] we showed that due to the limited Signal-to-Noise Ratio (SNR) of the input signal, the measured ratio at wavelengths where the edge filter attenuation is highest (toward the upper end of the measurable wavelength range) diverged from the value expected given the transmission response of the edge filter. Effectively this places an upper limit on the allowable maximum attenuation in the edge filter and thus the discrimination. For the experimental investigation in the next section, a bend radius of 10.5 mm was chosen which provides a reasonable baseline loss of 4.86 dB and a DR of 16.32 dB.

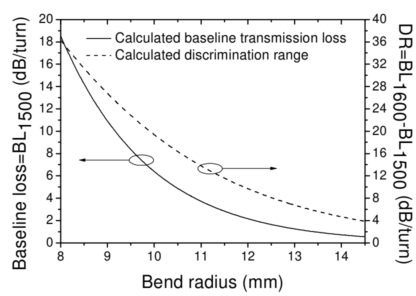

Fig. 3 Calculated baseline loss (BL at the wavelength of 1500 nm with the correction factor of 1.308) and discrimination versus different bend radius.

III. Experimental Results and Discussion

Experimentally, the bare section coated with an absorbing layer, was bent to form a small 360^{o} bend in free space, with a bend radius of 10.5 mm, with the bare fiber crossover point protected by a short polymer jacket to improve mechanical stability (see Fig. 4). The ends of fiber were connected to a tunable laser and an optical spectrum analyzer, respectively, to determine the value of the macrobending loss.

The theoretical and experimental macrobending loss curves over the wavelength range from 1500 to 1600 nm for a bend radius of 10.5 mm are presented in Fig.5. There is very good match between the calculated modeling and experimental data. The experimental transmission spectrum shows a suitable macrobending loss characteristic which matches the design predictions well, in that the measured baseline transmission loss is about 5.23 dB at the wavelength of 1500 nm and the measured DR is circa 16.33 dB from 1500 to 1600 nm. These values compare well with those achieved for SMF28 fiber [5], but with the advantage that only one fiber turn is required in this case, instead of 22 turns for the SMF28 case. The divergence between the experimental and theoretical results may be caused by: 1) the experimental accuracy of the bend radius (both baseline loss and DR are sensitive to the bend radius as shown in Fig. 3) and 2) the application of a correction factor at a limited number of wavelength intervals (10 nm) in the calculation of BL.

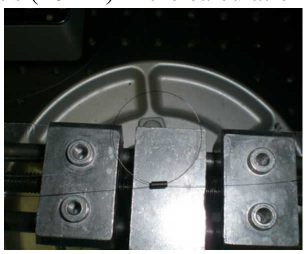

Fig. 4 Photograph of bend bare 1060XP fiber coated absorbing layer.

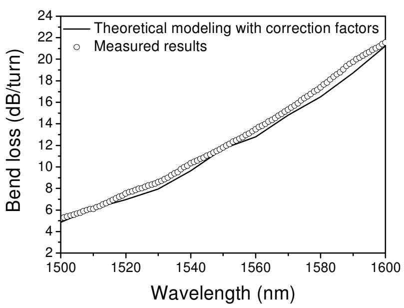

Fig. 5 Calculated and measured macrobending results for bare bend 1060XP fiber with absorbing layer when the bend radius is 10.5 mm, the fiber length is single turn.

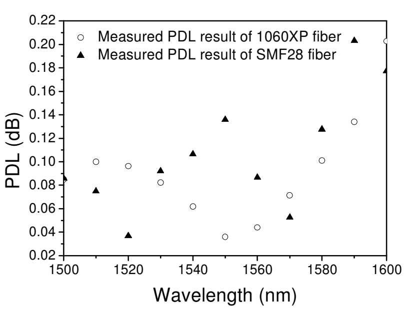

Fig. 6 Measured PDL in wavelength ranging from 1500nm to 1600 nm for bare 1060XP fiber coated absorbing layer(circles) and SMF28 fiber with coating and absorbing layers(solid triangle).

PDL is also an important parameter for a fiber BL edge filter [6]. For bent bare 1060XP fiber coated with an absorbing layer, the calculated PDL is very small in the fiber core-infinite cladding structure (about the 10^{-12}dB with the bend radius of 10.5 mm). In Fig. 6, the experimental PDL versus wavelength over the range from 1500 to 1600 nm with bend radius of 10.5 mm for bare 1060XP fiber coated with an absorbing layer. As a comparison, the measured PDL results of SMF28 fiber with coating and absorbing layer is also presented in Fig. 6. As shown in Fig. 6, the minimum PDL is 0.0359 dB at the wavelength of 1550nm, and the average value of PDL experimental results of bare 1060XP fiber is 0.0922 dB, lower than 0.1072 dB of PDL average value of SMF28 fiber which was presented in Ref. [6].

The divergence between the experimental and theoretical PDL results for 1060XP fiber is most likely caused by the imperfect absorbing layer material coated on the bare fiber cladding surface. If this layer is not absorbing all the radiation from the core at the bend then partial radiation will reflect from the fiber cladding-air boundary and recouples with the fundamental propagation mode, resulting in changes the polarization states of fundamental mode. It should be noted that there is about 0.02dB variation exists in the wavelength measurements due to the SNR of tunable laser source, and it effects the PDL measurement result as well. Overall we can conclude that the use of 1060XP fiber, to allow for the implementation of compact single turn fiber BL edge filter does not compromise PDL performance by comparison with SMF28 fiber.

IV. Conclusion

In conclusion, an optimal design of fiber macrobending loss based edge filter for BL sensitive fiber (1060XP) is presented, and the experimental macrobending loss data has a good agreement with the proposed theoretical modeling. Compared with the performance of standard SMF28 fiber presented previously, both theoretical and experimental results have shown that the bend bare 1060XP fiber with an absorbing layer is more compact and is suitable for the fiber BL edge filter applications.

References

[1]. S. H. Nam, and S. Yin, “High-Temperature Sensing Using Whispering Gallery Mode Resonance in Bent Optical Fibers,” IEEE Photon. Technol. Lett., Vol. 17, No. 11, pp. 2391-2393, 2005.

[2]. M. D. Nielsen, N. A. Mortensen, M. Albertsen, J. R. Folkenberg, A. Bjarklev, and D. Bonacinni, “Predicting macrobending loss for large-mode area photonic crystal fibers,” Opt. Express, Vol. 12, No. 8, pp. 1775-1779, 2004.

[3]. Q. Wang, G. Farrell and T. Freir, "Study of transmission response of edge filters employed in wavelength measurements," Appl. Opt., Vol. 44, No.36, pp. 7789-7792, 2005.

[4]. Q. Wang, G. Farrell and T. Freir, "Theoretical and experimental investigations of macro-bend Losses for standard single mode fibers," Opt. Express, Vol.13, No.12, pp. 4476-4484, 2005.

[5]. Q. Wang, G. Farrell, T. Freir, G. Rajan and P. Wang, "Low-cost Wavelength Measurement based on a Macrobending Singlemode Fiber," Opt. Lett., Vol. 31, No. 12, pp. 1785-1787, 2006.

[6]. Q. Wang, G. Rajan, P. Wang, and G. Farrell, “Polarization Dependence of Bend Loss for a Standard Singlemode Fiber,” Opt. Express, Vol. 15, No. 8, pp. 4909-4920, 2007.

[7]. P. Wang, Q. Wang, G. Farrell, G. Rajan, T. Freir and J. Cassidy, “Investigation of Macrobending Losses of Standard Single Mode Fiber with Small Bend Radii,” Microw. Opt. Techn. Lett. , to be published.

[8]. D. Marcuse, “Curvature loss formula for optical fibers,” J. Opt. Soc. Am. Vol. 66, No. 3, pp. 216-220, 1976.

[9]. A. B. Sharma, A. -H. Al-Ani and S. J. Halme, “Constant-curvature loss in monomode fibers: an experimental investigation,” Appl. Opt. Vol. 23, No. 19, pp. 3297-3301, 1984.

[10]. H. Renner, “Bending losses of coated single-mode fibers: a simple approach,” J. Lightw. Technol., Vol. 10, No. 5, pp. 544-551, 1992.

[11]. L. Faustini and G. Martini, “Bend loss in single-mode fibers,” J. Lightw. Technol., Vol. 15, No. 4, pp. 671-679, 1997.