Bend loss in reduced cladding optical fibers

Abstract

Reduced cladding fibers (80 μm vs. 125 μm) are attractive for small form factor components. Experimental and modeling data are presented to show that the fiber and/or the coil need to be redesigned for the impact of reducing cladding diameter on bend loss.

Introduction

Decreasing the cladding diameter of optical fibers permits component manufacturers to reduce the geometric form-factor of fiber-based components in two ways: (1) by lowering the volume occupied by the same length of fiber (volume reduction being proportional to the square of the fiber diameter), and (2) by improving the reliability of the bent fiber, through a reduction of fiber surface area per meter, thus allowing for smaller coiling dimensions. Both these factors work advantageously towards smaller component packaging. Since the composition, dimensions and index profile of the core remain the same, most waveguide-dependent optical characteristics of the fiber (such as cut-off, mode-field diameter and dispersion) remain unchanged. Therefore, the reduced-clad fiber could essentially be a drop-in replacement for larger diameter fibers. However, a change in bend-loss occurs with differing fiber diameter and needs to be taken into account. This is particularly significant with the current trend in erbium doped fiber amplifiers (EDFAs) and related components for metro applications, which are shifting to 80 μm fibers for both active erbium-doped fiber as well as the coupler and lead-in fibers.

Macrobend loss models assume an infinite cladding and predict an increasing loss as a function of wavelength[1,2]. In reality, the measured loss differs from predicted loss (using simplified models) due to coupling and stripping of light into radiative modes in the vicinity of the cladding-to-coating and the coating-to-air interfaces. This problem is similar to the hump produced in cut-off measurements of dispersion-shifted and unshifted fibers[3]. The authors proposed that this hump, which is equivalent to excess bend loss, resulted from coupling between whispering gallery modes and the LP_{11} mode. A similar theory was proposed to explain the periodicity in bend loss with wavelength for the higher order mode in few-moded fibers[4]. More recently, it has been observed that bend loss is more intense under specific bend radii rather than showing the intuitive inverse relationship.[5] In this case, the authors proposed a model based on a perturbed field of step-index like fibers due to the bend while assuming a plane cladding-coating interface. These results have shown that simplified models cannot be used as generalized predictors for all fibers. In this paper, we report the anomalous behavior of measured loss from theory, and discuss the role of relative distance between the cladding edge and caustic location in this phenomenon.

Experimental details

In order to demonstrate the impact of cladding diameter on the bend loss a preform was made with a simple step index profile and a targeted Δn of 0.0185. An erbium doped preform was chosen because of increasing demand for 80 μm erbium doped fibers for small form factor metro amplifiers. The preform was characterized to ensure axial uniformity along its length and then split into two halves. One half of the preform was sleeved to yield a single mode fiber when drawn to 125 um (EDFC-980) while the other half was sleeved to yield a single mode fiber with similar cutoff and mode field diameters when drawn to an 80 μm (EDFC-980-80) fiber. The drawn fibers were wrapped on a mandrel with a 10 mm bend radius and the bend loss was measured on a Nettest PK2500 optical bench using a standard cut back technique. Figure 1 compares the measured bend loss of 80 and 125 μm fibers. The data indicates that the optical bend loss of the 80 μm fiber deviates substantially from that for the equivalent 125 μm fiber in the 1600 nm to 1660 nm range. Several other 80 um fibers with different cutoff and mode field diameters (980-HP-80, 980M-HP-80, 1310-HP-80 and 1310M-HP-80) were also fabricated and their bend loss measured to study the impact of the fiber design on bend performance.

Bend loss of the various fibers were modeled using Fiber CAD. Figure 1 shows that the simple model used in this software is able to predict the bend performance of the 125 µm fiber . However, the model is unable to predict the experimentally observed bend loss for 80 µm fiber. In order to better understand the bend performance of the 80 µm fibers, the equivalent straight fiber index profile of the bent fibers were calculated. In addition, the location of the caustic (intersection of the equivalent straight fiber index profile with the LP01 modal index) was calculated for various fibers as a function of wavelength.

Bend loss results and discussion

We have observed that while the infinite cladding model can predict bend loss with reasonable accuracy at very short and very long wavelengths, there is a deviation in experimentally measured loss from the simplified prediction at intermediate wavelengths (Fig. 1). At 10 mm bend radius, the 125 µm diameter fiber showed a fairly good match with theory in the wavelength range of 1560 nm -1700 nm. However, in the case of the 80 µm fiber, an excess loss is seen which is prominent as a hump in the intermediate wavelength range of 1600-1670 nm.

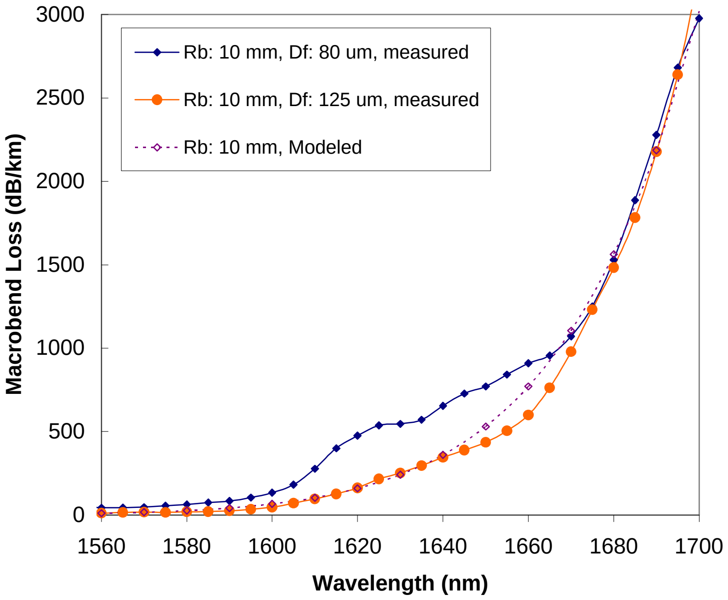

Figure 1. Bend loss for erbium-doped amplifier fibers with diameters D_f = 80 µm and 125 µm at bend radius R_b = 10 mm

In order to understand this excess loss, we begin with the simple waveguide model wherein the bent fiber refractive index profile is represented by the equivalent straight fiber profile shown in fig. 2[1]. The intersection of the cladding index with the LP_{01} modal index determines the location of the caustic beyond which power is lost through radiation. Since the modal index decreases as a function of wavelength relative to the core and cladding index differences, the caustic moves towards the core with increasing wavelength. Fig. 3 shows the caustic radius as a function of wavelength at a bend radius R_b = 10 mm. This inward movement of the caustic results in the exponential-like bend-loss function with wavelength. At the same time, the separation between the caustic and the cladding-coating interface is increasing, thus reducing the extent of coupling to the radiative mode. Thus, at short wavelengths, even though the caustic is closer to the

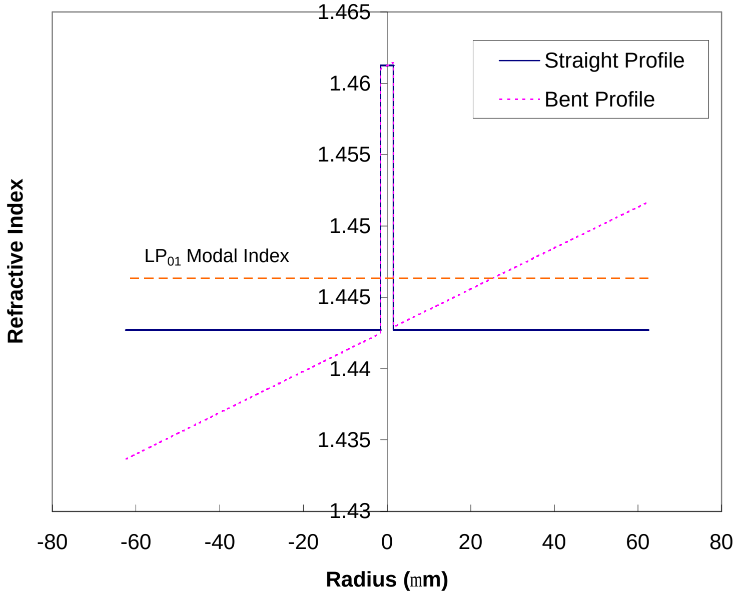

Figure 2. Straight and bent fiber refractive index profiles at 10 mm bend radius

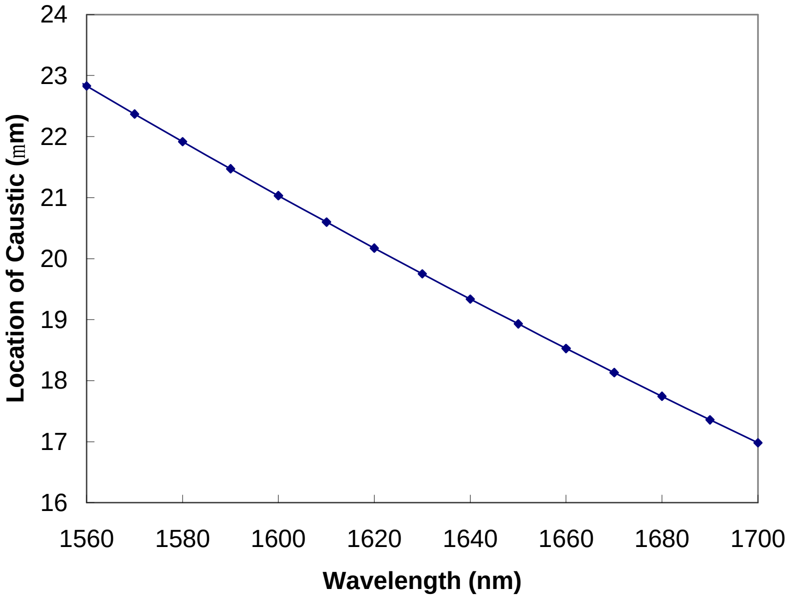

Figure 3. Movement of caustic with wavelength at bend radius R_b = 10 mm

edge of the cladding or even outside it, the overall bend-loss is small, and there is a good agreement between the predicted and measured bend loss. At very long wavelengths, the caustic is sufficiently far from the cladding that the coupling effect is again minimal. Hence, there is again no deviation from the predicted loss even for the 80 µm diameter fiber. At intermediate wavelengths, however, this effect is strong and is responsible for differences in loss between theory and measurement. For the conditions under which the present measurements were made on the EDF fibers, the excess-loss region overlaps with the L-band.

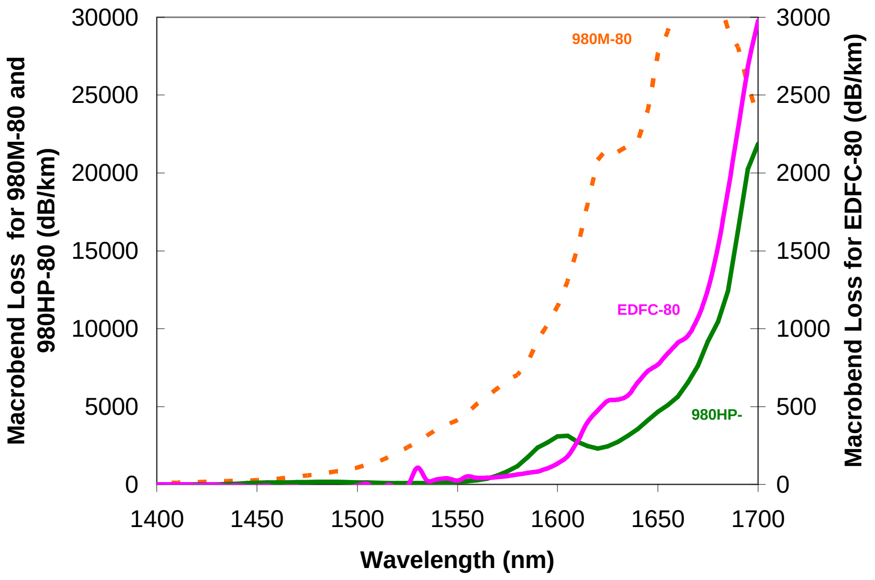

Figure 4. Bend loss for 980HP-80 and 980M-80 fibers compared to EDFC-80 for R_b = 10 mm

Bend loss measurements under similar conditions for other fibers with 80 µm cladding diameter are shown in figure 4. These fibers have a lower core refractive index compared to the EDF, but similar LP01 cut-off. Hence the bend loss is an order of magnitude higher. At the same time, we can see that there are similar deviations from a monotonous function in these fibers. As per the model developed by Faustini and Martini, these take on the shape of an oscillatory function of varying periodicity[5]. The wavelength bands at which the excess loss occurs depend on the core profile, bend radius, cladding diameter and index of the coating. The 80 µm fiber can be made more bend-insensitive by redesigning to increase the cut-off, using a lower index coating, or changing the cladding index structure. In addition, the coiling radius can be changed to shift the excess-loss band outside the wavelength of the operation region. Thus, in order to ensure that the bend performance of the fiber is acceptable, it is necessary for the fiber and component design to be carried out in conjunction with each other.

Conclusion

Excess measured bend-loss, over the theoretical predictions, is observed in reduced cladding-diameter fibers over a certain wavelength band. This deviation is caused by the position of the radiation caustic relative to the edge of the cladding. Since bend loss is a critical issue with the current trend towards smaller form-factor components, the fiber design and deployment conditions have to be adjusted to eliminate or shift the band to wavelengths outside the operating window. Further work is being performed to evaluate the influence of the core structure of the fiber and deployment conditions in order to predict the position of the excess-loss band for different fibers.

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