Reduced Cladding Fibers:

The Benefits and Challenges For Small Form Factor Components

The adoption of reduced cladding thickness fibers by the telecom industry has greatly increased over the last year. In fact, almost every specialty fiber manufacturer has launched products aimed at the small form factor (SFF) market. Despite appearances the use of 80µm OD fiber, rather than 125 µm, has actually been commonplace for years in certain non-telecom applications, fiber optic gyros for example. The general move toward SFF components within the optoelectronics industry -- specifically telecom and datacom applications -- is also well underway.

This drive towards miniaturization of components is two-fold; primarily to save space and reduce costs for the current portfolio of products, and secondly to open up new applications in markets as yet untouched by fiber optics. One example is the recent appearance of SFF connectors onto the market (roughly half the size of the standard SC connector) allowing cabling densities for fiber optics to rival those of copper. New fiber connections may now fit in the existing equipment architecture and infrastructure, which in turn has driven down the installation costs of the new systems and raised the adoption rate of the new all-fiber architecture.

Not surprisingly, the trend in fiber optic product development is shifting towards progressively larger number of fibers in an increasingly smaller space, creating a demand for higher density and lower cost SFF solutions. Clearly these arguments are also relevant to the optical fiber itself, where the advantages of adopting a reduced cladding thickness fiber (80 µm vs. 125 µm) is attractive for applications in SFF components.

Fiber Produced Space Savings

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. Indeed the advantage of SFF is well known in fiber optic gyroscope (FOG) applications, where 80 µm OD fiber is the universal standard. In this case the space savings from winding (500 meters or even 5 kilometers depending on the particular application) are substantial. Also important is the increased number of windings per layer that are achieved with smaller OD fibers. This is true not only for FOG applications but also for piezoelectric and magneto-strictive windings, which are frequently used as low-cost phase modulators in sensor systems based on all-fiber scanning interferometers.

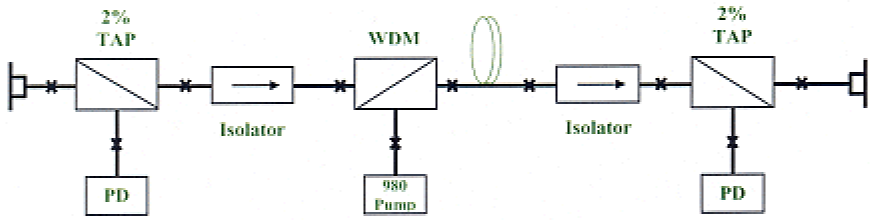

Figure 1. A tighter bend radius is the main advantage in using SFF fibers in a typical narrowband EDFA, shown.

The space savings achieved with SFF telecom components has now focused on the fiber itself. Erbium-doped amplifiers exemplify the details of such savings as well as the challenges (i.e. fiber bend loss) that may require careful design of fiber and coil properties to fully achieve the advantages of these fibers.

Figure 1 presents a schematic diagram of a typical narrowband erbium-doped fiber amplifier (EDFA). The fiber lengths on each of the indicated components may be made relatively short, varying from a meter or so for the fiber-tails on couplers and taps to ~10 or more meters for the erbium-fiber coil itself. Obviously, these are short compared with the gyroscope coils described above. Hence the main advantage in using SFF fibers in EDFA modules is not so much the reduction in total volume but rather the tighter bending radius of the 80 µm OD fibers compared with the industry standard 125 µm.

Figure 2 shows the calculated minimum long-term bend radius for a range of fiber diameters with the ~40% reduction in bend radius achievable in 80 µm fibers clearly highlighted. However, the actual minimum coil diameter that may be achieved in any particular application will depend on other variables. An example the effect of fiber strength is indicated in Figure 2. Proof-testing fiber to 200 kpsi may allow a factor of two reduction in the long-term bend radius. This amounts to a similar bend radius reduction as that achieved by adopting the 80 µm fiber over standard 125 µm.

In many situations, the outcome of bend-induced loss limits the practical coil diameter rather than the mechanical limits indicated in Figure 2. This is particularly true for the L-band (longer than 1580 nm) region of the spectrum. The full description of bend-induced loss, the wavelength dependence and fiber OD, is still under investigation but many SFF fibers may be optimized for reduced bend sensitivity. Most macrobend loss models assume an infinite cladding and predict an increasing loss as a function of wavelength. In reality, the measured loss differs from the predicted loss (using the 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.

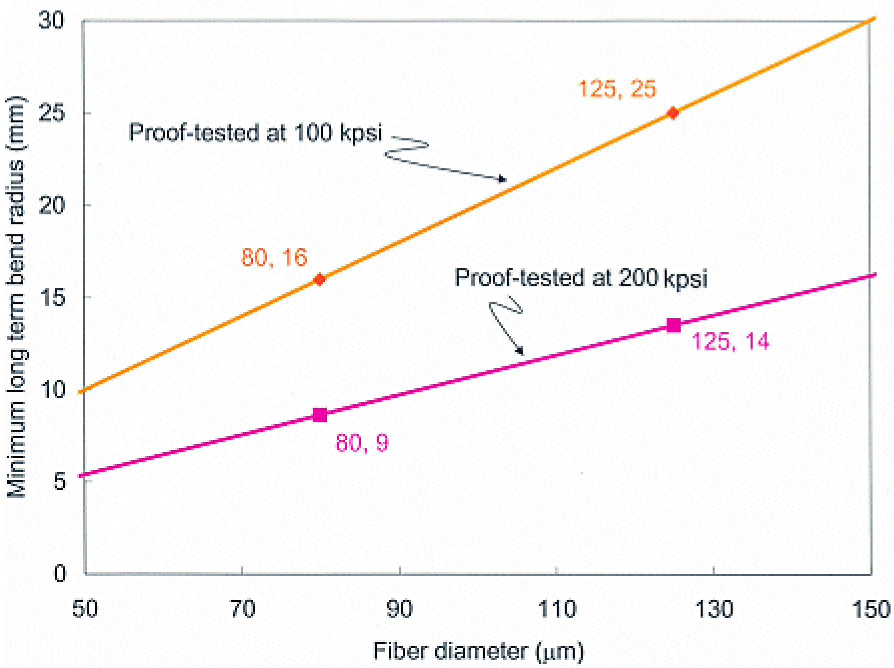

Figure 2. Among the calculated minimum long-term bend radius for a range of fiber diameters, 80 µm fibers stand out by enabling a ~40% reduction.

Cladding Diameter & Bend Loss

When discussing reduced cladding fibers it is necessary to understand the anomalous behavior of measured loss from theory, and the role of relative distance between the cladding edge and caustic location in this phenomenon. In order to demonstrate the impact of cladding diameter on the bend loss in a preform, we consider the example of an erbium-doped preform made with a simple step index profile and a targeted Dn of 0.0185. The preform is characterized to ensure axial uniformity along its length and then split into two halves. One half of the preform is sleeved to yield a single mode fiber when drawn to 125 µm (EDFC-980) while the other half is sleeved to yield a single mode fiber with similar cutoff and mode field diameters when drawn to an 80 µm (EDFC-980-80) fiber. This will provide a good comparison between fibers that are similar in all respects at the regular and reduced cladding.

These two fibers are drawn and wrapped on a mandrel with a 10 mm bend radius and the bend loss is measured using a standard cut back technique. Figure 3 compares the measured bend loss of 80 µm and 125 µm fibers. The measurements indicate 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. As shown in Figure 3 the simple model 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, where an excess loss is seen as a prominent hump in the wavelength range of 1600-1670 nm (this range overlaps into the L-band).

The 80 mm 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. The coiling radius can also be changed to shift the excess-loss band outside the wavelength of the operation region. Therefore, 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. A number of tools are available to carry out these changes without affecting the other operating characteristics of the system.

More and more, the model of a stand-alone erbium-doped fiber amplifier is only applicable to a small range of system applications and a more complex functionality for the amplifier is increasingly required. Examples of this increased functionality include dynamic gain control for add/drop multiplexing, VOA incorporation, transient control, disable/eye safe mode, and tunable gain flattening filters. To compensate for added functionality, further reductions in the overall amplifier package are achieved by reducing the package size for the other components in the module. Miniature taps and couplers along with SFF isolators are now commonplace. In particular the adoption of coolerless pump modules in a SFF (miniDIL) package has reduced the total amplifier volume by as much 30-40%, coining the term ‘amplet’ to describe this functional sub-element.

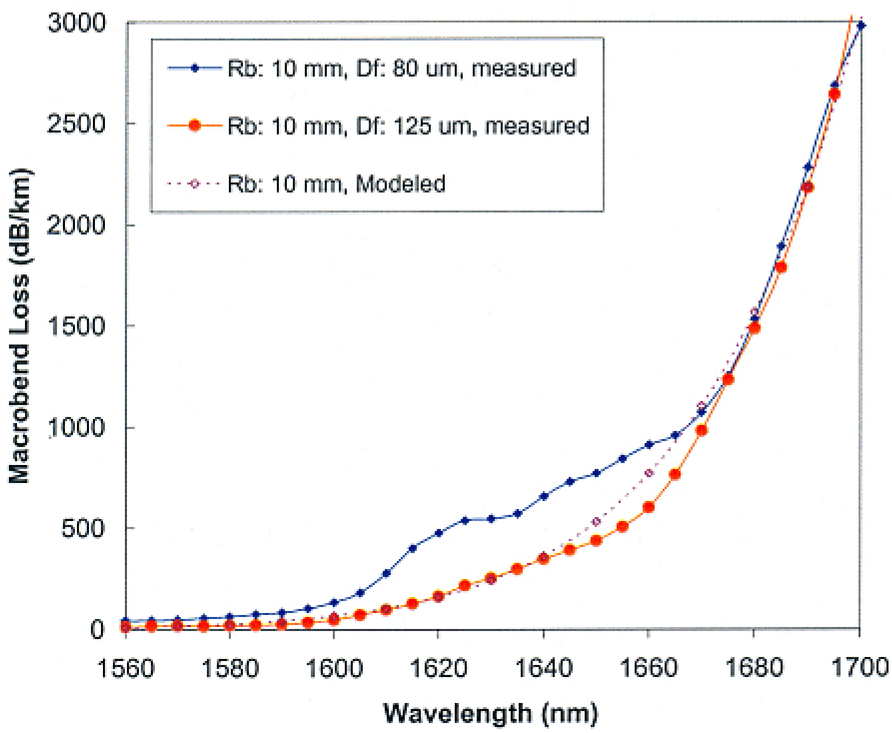

Figure 3. The optical bend loss of 80 µm fiber deviates substantially from that for the equivalent 125 mm fiber in the 1600 nm to 1660 nm range.

By enlarging the composition, dimensions and index profile of the core remain the same as the standard 125 µm fiber and consequently, most of the waveguide-dependent optical characteristics of the fiber (i.e. cut-off, mode-field diameter, and dispersion) remain unchanged. For that reason the reduced-clad fiber can be seen as essentially a drop-in replacement for larger diameter fibers, minimizing any redesign of the optical properties of the module. 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. For example, by reducing the cladding diameter of the fiber used in a small form erbium doped fiber amplifiers can enable a 30-40% reduction in the overall amplifier package size, critical for the development of next generation optical modules. In order to achieve this in certain cases the role of bend-loss must be carefully considered and may require optimization of fiber and coil designs to achieve the full potential of the SFF platform.

This article was contributed by Bryce Samson, director of business development, and Upendra Manyam, scientist, for Nufern (East Granby, CT). For more information, contact the author at bsamson@nufern.com or (860) 408-5015. Visit Nufern online at www.nufern.com.