FEATURE

LIGHTWAVE

By JOHN A. JAY

Optical fiber design to improve microbending resistance

Choosing the right combination of the several options available is the key to overcoming microbending-induced attenuation.

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OPTICAL FIBERS are recognized as the superior medium for delivering high-bandwidth communications signals over long distances. The key attribute that enables this performance is very low attenuation.

It is critical that the fibers' inherent low attenuation be preserved in service. Microbending is a common source of attenuation when the fiber is bent from a straight axis. Some bending in service is unavoidable, e.g., shipping and storage, optical cable manufacturing and installation, and fiber termination and deployment. Understanding the fundamental nature of microbending enables development of products to maintain the initial superior attenuation of optical fiber. Several optical fiber design options are available to improve microbending resistance.

Microbending background

Microbending is an attenuation increase caused by high-frequency longitudinal perturbations to the fiber[1] (Figure 1). The perturbations cause small-radius bends of the fiber core that for singlemode fiber couple power from the guided fundamental mode (LP01) to lossy higher-order modes.[2] The perturbations are caused by lateral contact with surfaces like the optical cable.

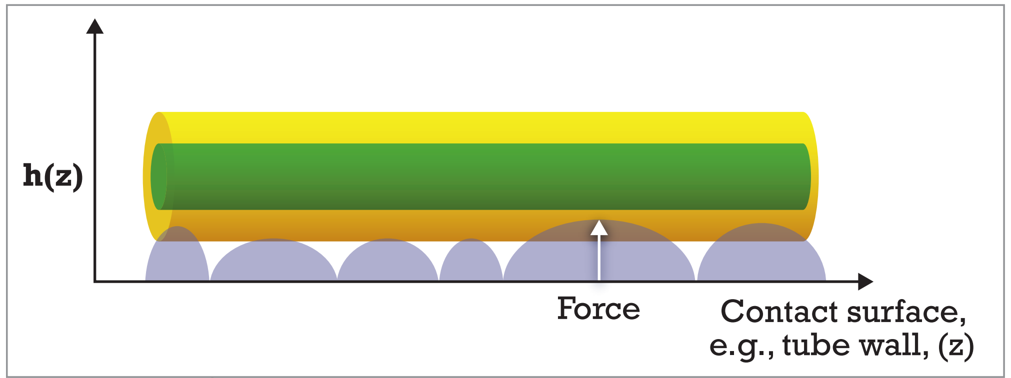

FIGURE 1. Schematic representation of microbending.

The bends that cause microbending are typically < 1 mm in radius and are commonly described as a random variable with a distribution of spacing and amplitude. The parameters of the random variable's power spectral density (PSD) along with the fiber geometry and refractive index profile determine the fiber's microbending sensitivity.

To understand microbending physically, consider measuring a fiber contact surface roughness by dragging a stylus along the surface to measure the heights of the "bumps" along the test surface length. A Fourier transform of the surface-height profile produces the spectrum of spatial periods presented of the test surface. An example is shown in Figure 2. The left-hand plot is the surface height profile, i.e., the measured distribution of size and space of the surface perturbations. The right-hand plot is the PSD of the data in the left-hand plot after Fourier transform.

Microbending is different from macrobending, another familiar mechanism for attenuation increase with bending. Long period perturbations (> 1 mm) do not provide the right resonance to couple light

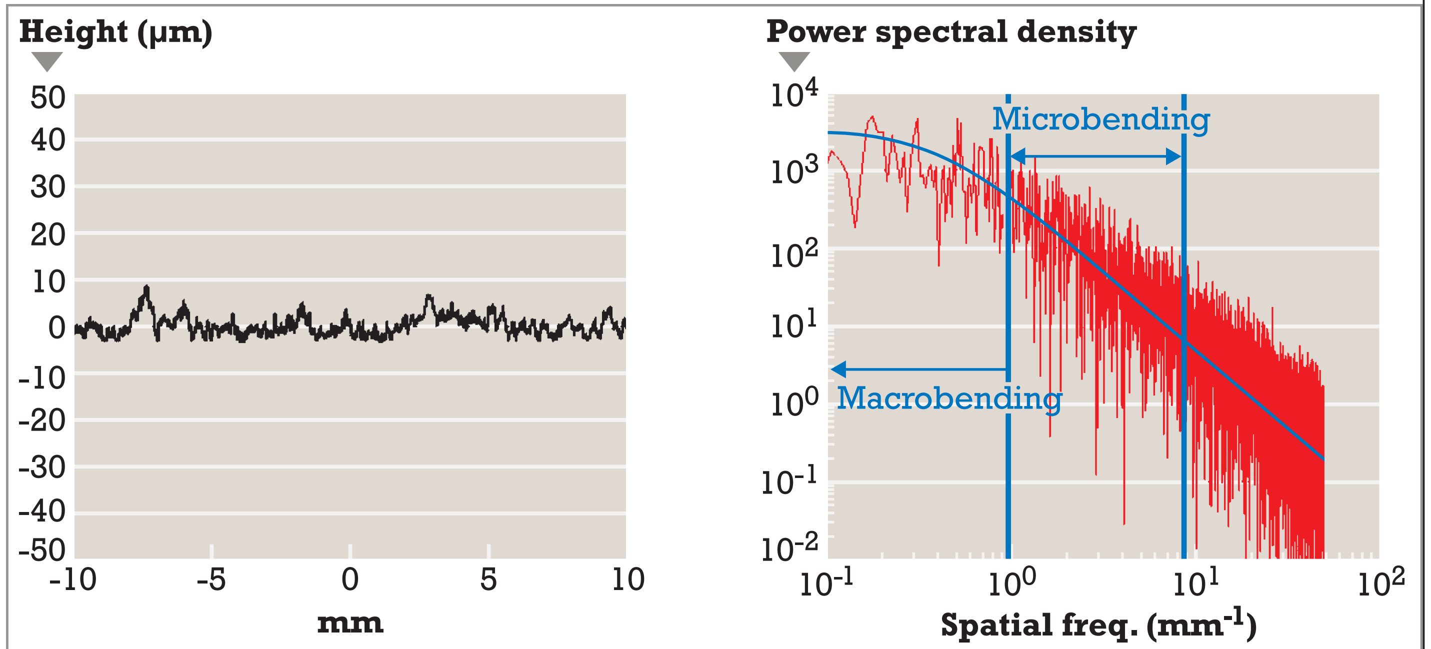

FIGURE 2. The plot on the left is an example surface profile measurement. The plot on the right is a Fourier transform of the plot on the left, plotted as the power spectral density of the data.

to the cladding modes via microbending, but can cause macrobending. Short period perturbations (< 200 μm) are spanned by the fiber and typically have little impact on attenuation. Spatial periods between 0.2 and 1 mm are the most critical for microbending because they can interact with the cladding modes and deform the optical core.[3]

Fiber parameters and attributes affecting microbending

The next equation shows several design options to improve optical fiber resistance to microbending.[4]

$$Y = N\langle h^2\rangle \frac{a^4}{b^6\Delta^3}\left(\frac{E}{E_f}\right)^{3/2} \quad (1)$$

where γ is the microbending induced attenuation increase, *N* is the number of bumps of average height ⟨*h*⟩ per unit length, *b* is the total fiber diameter, *a* is the core radius, Δ is the fiber refractive index difference, and E_f and *E* are the elastic moduli of the fiber and the fiber surrounding material (i.e., coating), respectively.

As equation (1) shows, the core radius and refractive index difference strongly affect the fiber microbending sensitivity. An example is shown in Figure 3. The blue squares present wire mesh drum microbending test results for a commercially available singlemode fiber compliant with ITU-T Recommendation G.652 Table D. The red diamonds present results for an ITU-T Recommendation G.657. A1-compliant fiber. The abscissa is the "MAC-value," the ratio of the mode field diameter and cutoff wavelength in common units.[5]

The refractive index profile designs of two fibers are very similar; the Rec. G.657. A1 fiber has a smaller core radius and larger refractive index difference, thus a lower MAC value. As predicted in equation (1), the Rec. G.657.A1 fiber has improved microbending resistance. This relationship has also been noted in the literature.[6]

There are practical limitations to improving microbending using core radius and refractive index profile, however. They determine the design optical properties of the fiber and for a given fiber type or product, they are bound by industry standards. For example, ITU-T Recommendation

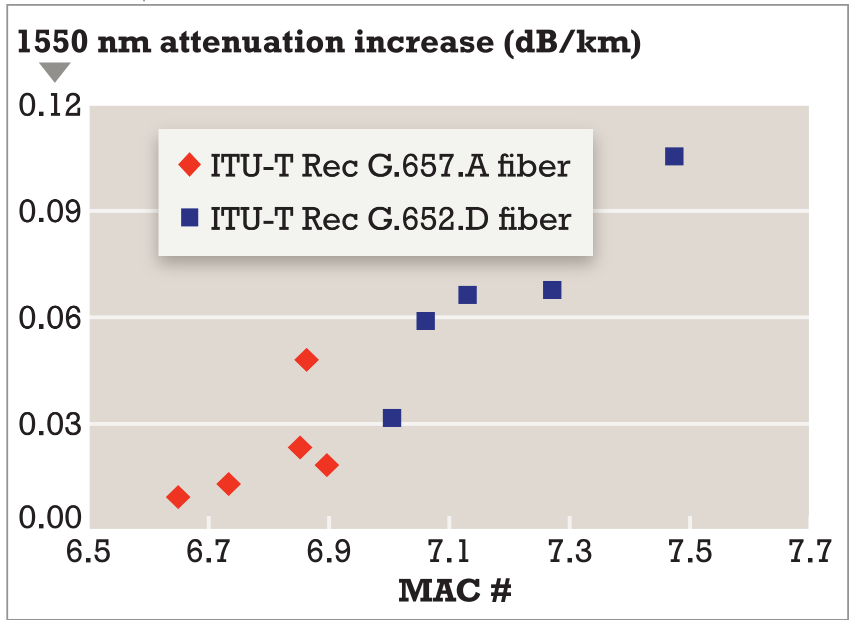

FIGURE 3. Microbending results for ITU-T Recommendation G.652- and G.657-compliant fibers.

G.652 specifies dispersion, mode field diameter, and cutoff wavelength such that the ability to modify *a* and Δ in equation (1) and stay compliant to that product standard is limited.

The fiber coating presents the next opportunity to improve microbending performance. From equation (1), the obvious approach is to increase the coating diameter. In fact, large changes in coating diameter have a profound effect on microbending performance.

Figure 4 presents results of microbend testing on singlemode fibers with coating diameters of 250 μm, 500 μm, and 900 μm. As a load was applied to the fiber samples, the attenuation increased much more rapidly for the smaller coating diameter samples.

Industry standards again limit this approach, however. IEC and ITU-T fiber standards specify an uncabled coated fiber diameter of ~ 250 μm.

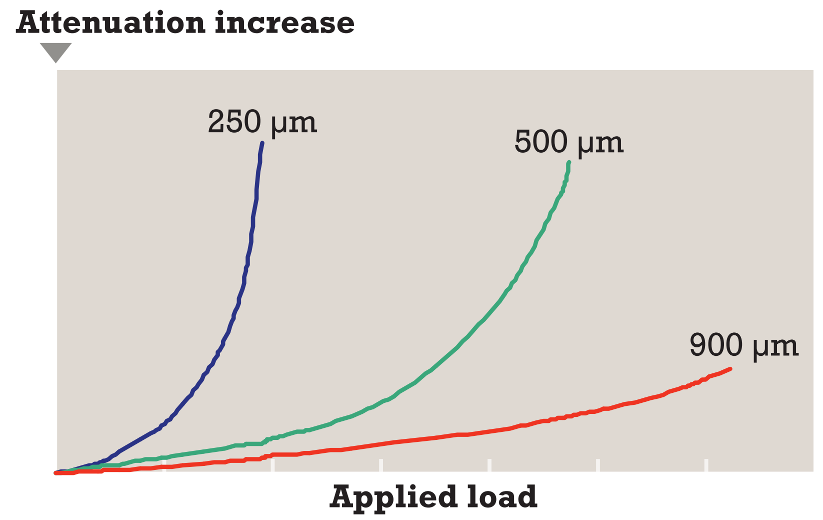

FIGURE 4. Microbending vs. coating diameter. The microbending sensitivity reduces as the coating diameter increases.

It is common for an optical cable manufacturer to take a 250-μm diameter optical fiber and buffer it to 900 μm. The directional microbending improvement seen in Figure 4 between 250 μm and 900 μm diameter products would be expected in this case.

The next opportunities to improve fiber microbending presented in equation (1) are the elastic moduli of the fiber and the fiber coating. Current commercial telecommunications-grade optical fibers are all silica; thus, the parameter E_f is not available for design. This leaves E, the elastic modulus of the fiber coating; and, indeed, it has been shown that by using a lower coating elastic modulus, microbending-induced attenuation can be reduced.[7] The most common approach is to lower the inner-primary coating modulus, i.e., the material that surrounds the glass fiber.

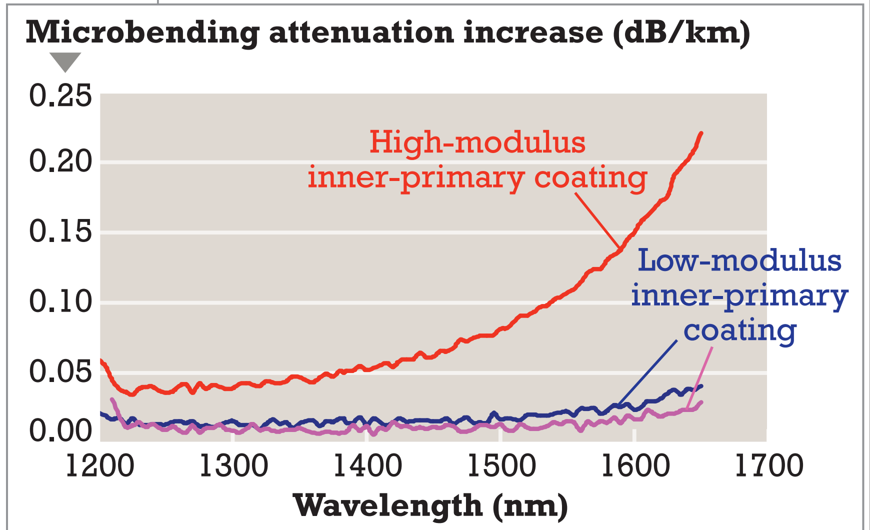

FIGURE 5. The effect of coating modulus on microbending for ITU-T Rec. G.652-compliant fibers.

The effect of changing the modulus of the inner-primary coating is illustrated in Figure 5, which shows microbending test results of ITU-T Recommendation G.652-compliant fibers with high and low inner-primary elastic modulus coatings. Note that small differences around a nominal diameter do not affect microbending performance. The better performing fibers in Figure 5 are 242 μm in diameter; the other is 245 μm.

A low-modulus, inner-primary coating alone is not sufficient to protect against microbending, however. Poor coating design, chemistry, or application can squander the benefits of low elastic modulus. Figure 6 shows wire mesh drum microbending test results for an experimental fiber drawn with the same experimental coating formula to three different configurations. The same coating that delivers superior performance on Sample A performs poorly on Samples B and C, where the final product is not designed correctly.

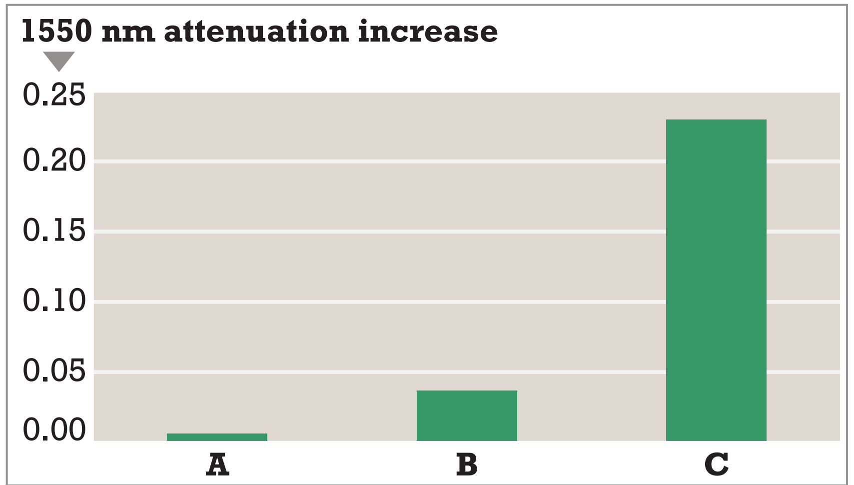

FIGURE 6. The effect of coating geometry on microbending.

In the end, all variables at hand—optical fiber design, coating selection, manufacturing, and cabling—must be optimized to protect the fiber attenuation from microbending while in service. This is seen in Figure 7, where wire mesh drum microbending test results are shown for several fibers and coatings. These contain the

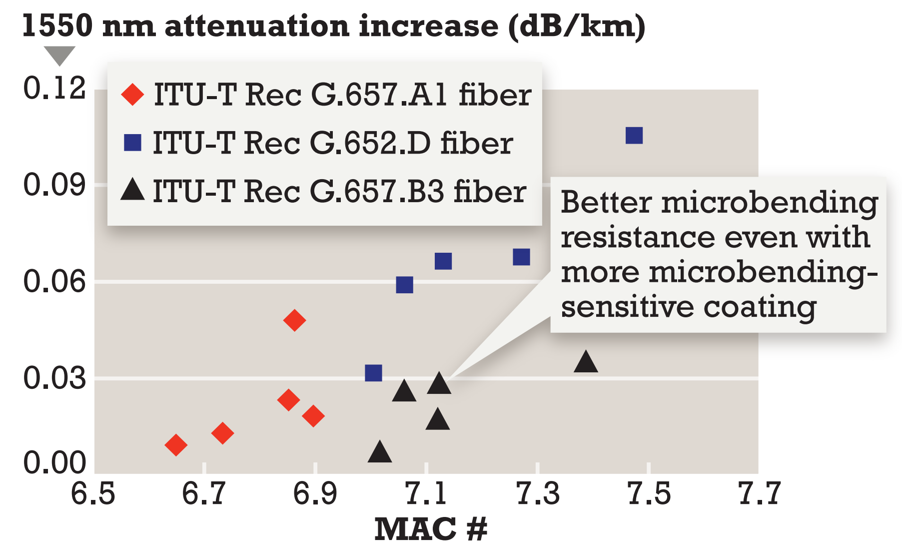

FIGURE 7. Wire mesh drum microbending testing of various ITU-T fiber types with different coatings.

same data as Figure 3, except a third data set is added that reports results for an ITU-T Recommendation G.657.B3-compliant (5-mm bend radius) fiber, which actually has a legacy coating more sensitive to microbending than the samples in Figure 3. Yet, in this case, the robust microbending resistance of the Rec. G.657.B3 refractive index profile design compensates for a more microbending-sensitive coating to produce a more microbending-resistant optical fiber.

The whole is greater than the sum

Understanding and controlling attenuation change with bending is critical to preserving the superior initial attenuation of the optical fiber. Microbending is a crucial means by which bending can increase the attenuation of an optical fiber. Providing a product with strong microbending resistance is more than simply specifying an optical fiber coating; it requires an optimized glass and coating product designed, produced, and tested with the highest level of technology. ◈

References

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