How to Speak "Fiber Geek"
Article 4: Single-Mode Optical Fiber Geometries

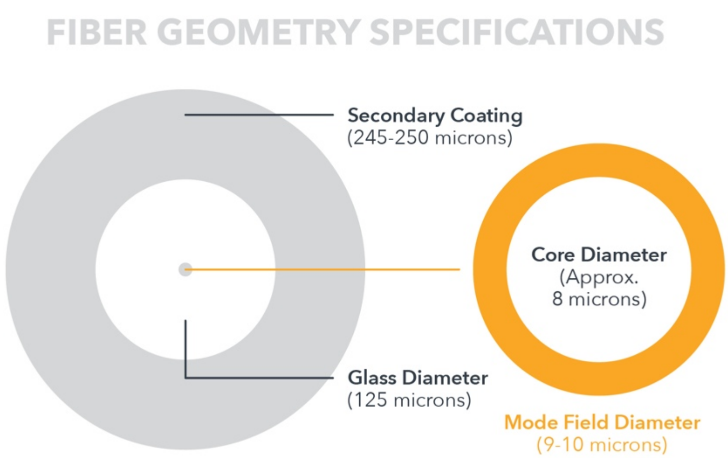
Welcome back, Fiber Geeks!

The first article in this series highlighted some bandwidth demand drivers and introductory standards information. Article 2 then focused on attenuation and Article 3 followed with a focus on dispersions. This next article, the fourth in the series, will focus on single-mode fiber geometries.

First, let's define fiber geometry as to how that term will be used and discussed here. Fiber geometry in this article will highlight specifications such as the various diameters, concentricities and fiber curl in single-mode fibers.

The primary impact of fiber geometry occurs in the splicing and connectorization processes. Fibers with good and consistent geometry tend to have lower splice and connectorization losses than do other fibers. However, as highlighted earlier in article 3, fiber concentricity is also extremely important for polarization mode dispersion (PMD) performance. In 2018, we sometimes take fiber geometry for granted since it has been very good for a long time. However, this has not always been the case...

We'll work our way through a typical fiber specification, highlighting the importance of various single-mode fiber geometry specifications.



Cladding (Glass) Diameter - 125.0 ± 0.7 µm

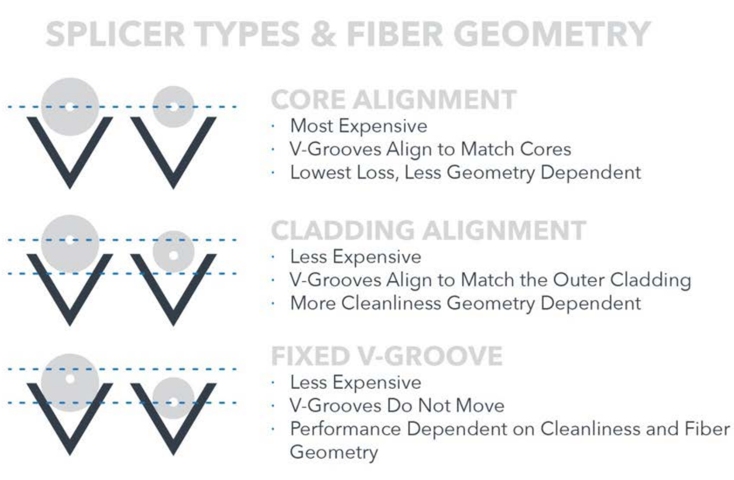
Cladding diameter is the outer diameter of the glass portion of the fiber. For telecommunications fibers, this diameter has been 125 microns (µm) for a very long time. On the other hand, the diameter tolerance has not always been 0.7 µm.

During the 1980s, optical fibers had outer diameter tolerances as high as +/- 3.0 µm. As you can imagine, matching up fiber cores ranging from 122 to 128 µm in diameter could result in extremely high loss. This situation is why fusion splicing machines required additional technology to help align the fiber cores. This extra technology increased the price of the splicing units.

As the industry matured, single-mode fiber diameters remained the same at 125 µm. However, over the same time period, the specification tolerance declined to 0.7 µm with typical meter-to-meter variability becoming even tighter.

From a manufacturing perspective, this diameter and tolerance were not easy to achieve. When fiber was first invented, the developers had to create manufacturing methods along with ways to measure fiber diameter. When manufacturing to tolerances of tenths of a micron, inputs such as stray air currents, vibrations or particulate in the glass can cause significant diameter variability. These factors require top-tier fiber manufacturers to have very tight control over their processes and procedures.

As diameter variability has decreased, splicing machines have reduced the alignment technologies needed. And while there has been a significant decrease in the price of these machines, there has been no corresponding substantial increase in splice loss. While core alignment splicing machines still provide the best performance, smaller "fixed V-groove" machines with lower prices and limited alignment capability have significantly closed the performance gap. The typical splice loss for AllWave®+ Zero Water Peak (ZWP) Optical Fiber, spliced using a core alignment splicing machine, is roughly 0.03 dB, whereas the same fibers spliced with a fixed V-groove machine have an average loss of approximately 0.05 dB. In an absolute sense, that's a significant difference. However, this difference is actually pretty insignificant in the context of most fiber optic network applications.



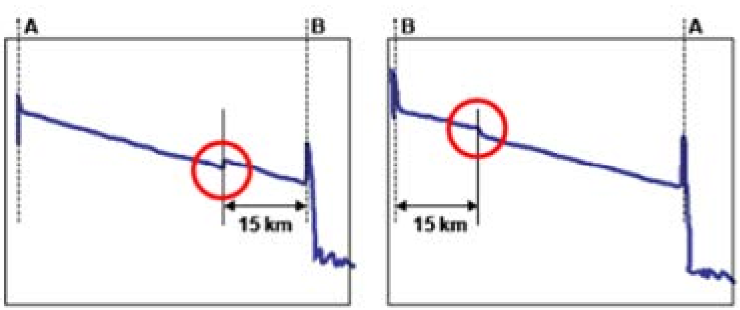
Enabled by tighter fiber geometry, the reduced cost of splicing machines is one of the factors that have contributed to the overall decrease in the cost of building fiber networks. In fact, this change has ultimately enabled fiber to the home to become a reality.

Mode Field Diameter (MFD)

Mode field diameter (MFD) is another specification related to fiber geometry. In a typical G.652.D-compliant single-mode fiber, not all of the light travels in the core; in fact, a small amount of light travels in the fiber cladding. The term MFD is a measure of the diameter of the optical power density distribution, which is the diameter in which 95% of the power resides.

MFD is important for two main reasons. The first reason is that fiber bending loss is typically correlated with MFD. As the MFD increases, bend loss also increases, and vice versa. Historically, fibers with smaller mode field diameters are less bend sensitive. That being said, modern process technology has enabled Tier One fiber manufacturers to make G.657.A1 bend insensitive, single-mode fibers with a nominal mode field diameter of 9.2 µm.

Second, when two fibers of different mode field diameters are spliced together, the two fibers have different backscattered light properties. In this case, the OTDR will errantly show either a power gain, known as a "gainer", or elevated loss, depending on in which direction the measurement is taken. When measured from the larger MFD into the smaller, a gainer is produced. When measured from the smaller MFD into the larger, an elevated loss is seen, as shown below. This is an artifact of the OTDR measurement method and does not affect transmission properties. Breaking and re-splicing the fibers will typically not change the result, unless there's a bad cleave or some other anomaly at the splice interface. The correct way to measure splices overall is bi-directionally, which is even more important for fibers with MFD mismatches.



OTDR Splice "Gainer" and Elevated Loss

This fact shows why innovations such as OFS AllWave+ ZWP Single-Mode Fiber are so important. AllWave+ Fiber meets or exceeds the ITU-T G.652.D and G.657A.1 recommendations. This allows an extra measure of bend insensitivity, while maintaining a nominal 9.2 µm MFD to reduce gainers when spliced to the installed base of 9.2 µm MFD single-mode fiber.

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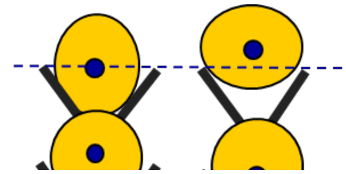
Clad Non-Circularity of d 0.7 %



Cladding
Non-Circularity

Clad non-circularity measures a fiber's deviation from perfectly round, and is measured as a percentage difference versus perfect. Fiber is "round", and the more round that a fiber is, the better it is. Similar to other fiber properties, better cladding non-circularity can result in improved splicing and connectorization performance.

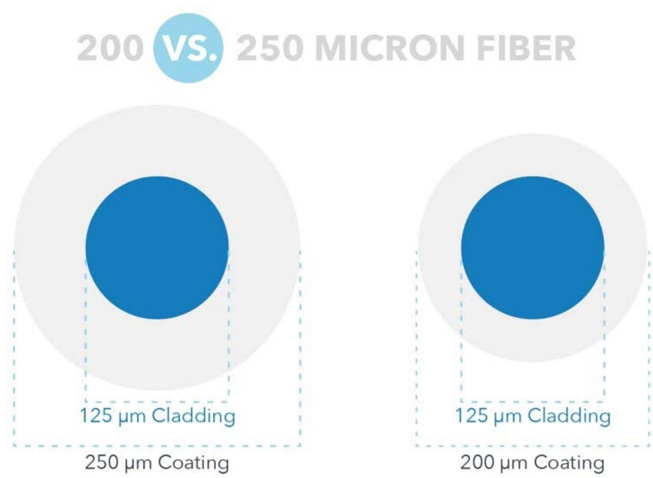
Core/Clad Concentricity Error (Offset) of d 0.5 ¼m, < 0.2 ¼m typically

Core/clad concentricity error (CCCE) measures how well the core is centered in the fiber. CCCE is measured in microns and, of course, the closer the core is placed to perfect center, the better it is

Core/Clad
Concentricity Error

While coating specifications are not as stringent as glass specifications, they are also extremely important. The two main parameters are Coating Diameter (Uncolored) 237 - 247 µm and Coating-Clad Concentricity Error (Offset) d 12 ¼m.

For roughly the first 30 years of single-mode fiber manufacturing, a coating nominal diameter of approximately 245-250 µm was standard in the industry. However, in 2014, OFS launched a 200 µm fiber in response to the need for higher fiber density in fiber optic cable designs.

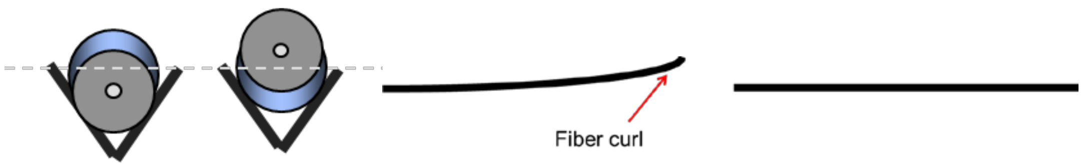


Although the difference between 200 and 250 µm is not tremendously large, smaller diameter fibers can enable twice the fiber count in the same size buffer tube, while also still preserving long-term reliability. This fact has led to many new cable designs, including extremely small microcables, loose tube duct cables and all-dielectric, self-supporting (ADSS) aerial cables. As the demand for higher fiber density continues to increase, we can expect to see even more cable designs taking advantage of 200 µm coating.

Besides inherent size, coating diameter control is extremely important. Coating diameter can affect the size of the overall bundle in fibers. If the coating is too thick, the overall bundle may incur strain sooner than expected. If, on the other hand, coating concentricity is not good, there can be additional concerns particularly when splicing ribbons.

Fiber Curl

The final parameter we will discuss is fiber curl.



Fiber curl assesses the non-linearity of bare glass. In other words, fiber curl measures how straight the glass fiber is when no external stressors are present. If imbalanced stresses are frozen into a fiber during the draw process, curl can result. This curl can show up during the splicing of fiber optic ribbons or when fixed V-groove splicing machines are used.

If curl occurs, the two ends of the fiber will not be straight or match up during the splicing process. This situation leads to both high losses and difficulty splicing. Curl is measured in meters of curl, with a typical specification being > 4m. When optical fiber comes out of the fiber draw, it is annealed during the manufacturing process to reduce the effects of curl. As a result of this process, for users of top-quality fiber, fiber curl poses no concern for typical telecom applications.

Fiber geometry is often taken for granted by end users, primarily because it has been very good for so long. However, it has taken hard work and the contributions of innumerable people over many years for fiber geometry quality to reach its current level.

So the next time you obtain a 0.00 dB splice loss or very low connector loss, first pat yourself on the back, and then raise a glass to those who have paved the way to bring fiber geometry to where it is today.

In closing, fiber geekdom is a journey, not a destination, and there's always more to learn. OFS has multiple decades of experience with fiber optic networks. Please contact your local OFS representative if you would like additional information regarding any of the items in this article.