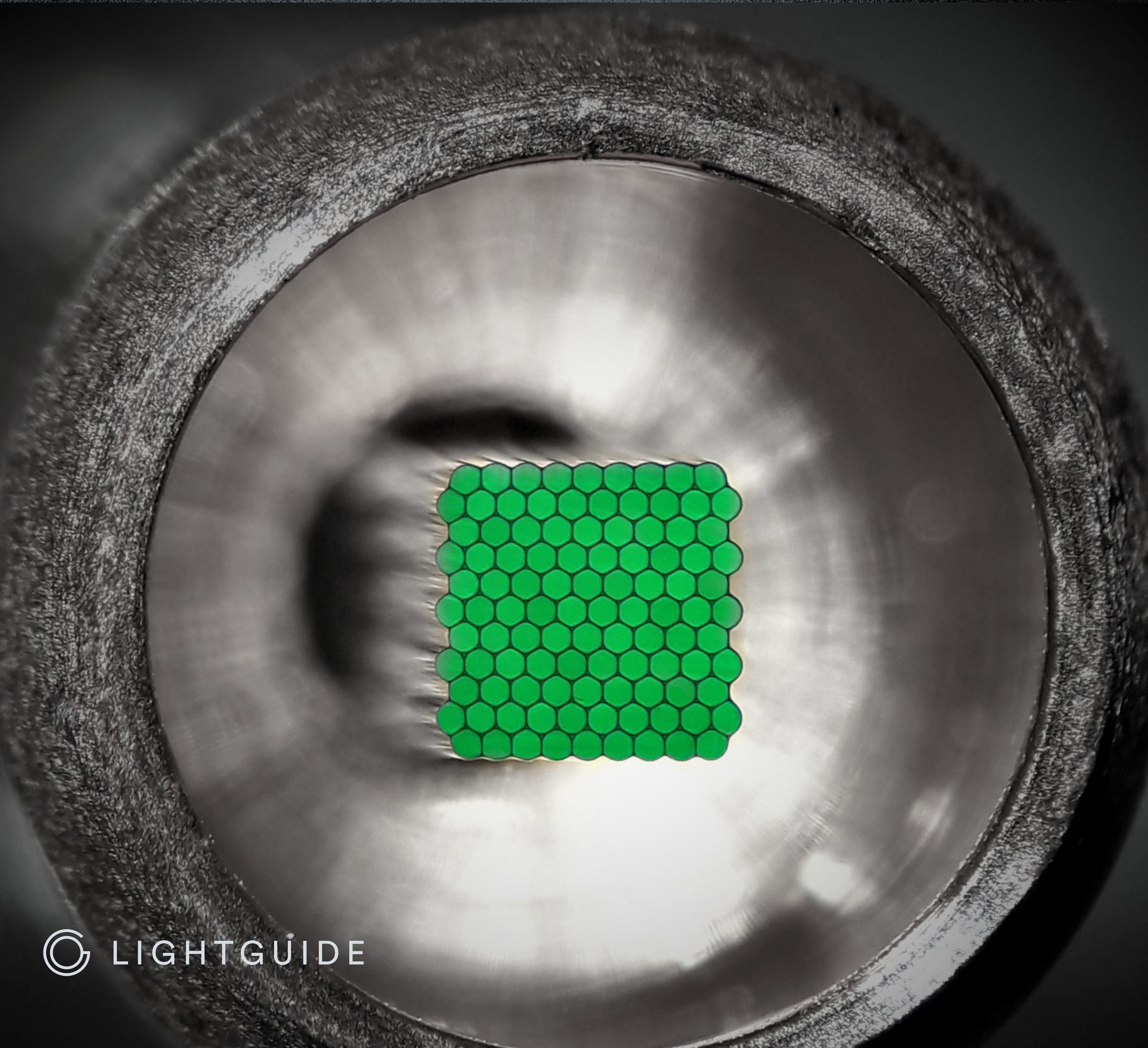
NEW GENERATION OF FIBER BUNDLES

for Medical and Industrial applications



LIGHTGUIDE

Lightguide is technology leader in speciality fiber industry. Our strenght is fiber bundles, cables and laser delivery instruments for industrial, medical and scientific applications.

Fiber Bundles

Optical fiber bundles are critical components in many applications such as spectroscopy, semiconductor manufacturing, laser delivery, and many more. Conventional fiber bundles are made of many fibers glued together. It is a reasonably easy technology that many companies can produce. There are just a few companies that can make fused bundles that embody many benefits over conventional glued bundles. Several of these benefits are better transmission, higher laser damage threshold, and applications in harsh environments.

Lightguide is a company that is a few steps ahead in fused bundle technology. In this short article, we want to present what innovations we have made and how customers can benefit.

Currently, we distinguish between 4 different types of fiber bundles in our portfolio:

- Glued Bundle (GB)
- Hexagon Fused Bundle (HFB)
- Clad Fused Bundle (CFB)
- Monolith Fused Bundle (MFB)

We want to briefly describe each of these bundles to show the benefits of the new technologies.

Glued Bundle

This bundle is a simple technology where many fibers are glued together with epoxy glue. Fibers have gaps between them and the typical fiber packing coefficient is around 0.85. Many companies can produce them in different degrees of quality. This is a cost-effective solution when maximum coupling is not required for the bundle outputs.

Hexagon Fused bundle (HFB)

This technology was developed around 25 years ago in order to increase the packing coefficient up to 0.93, achieve better transmission and make bundles more applicable in harsh environments. Fibers are aligned together within a silica tube and fused together This makes them more resistant against higher temperatures and harsh environments. After fusing, fiber clads are melted together (no gaps between fibers) and take the shape of a hexagon (honeycomb packing).

New generation of fiber bundles

In recent years Lightguide has made a significant innovation in fused-bundle technologies. It results in two new types of fused bundles where the silica tube is removed and any shape is possible. Compared to HFB, there are several VERY SIGNIFICANT benefits:

1. Any shape is possible with maximization of coupling with a light source
2. Smaller bundle diameter
3. Higher precision of bundle
4. Higher NA
5. High power applications

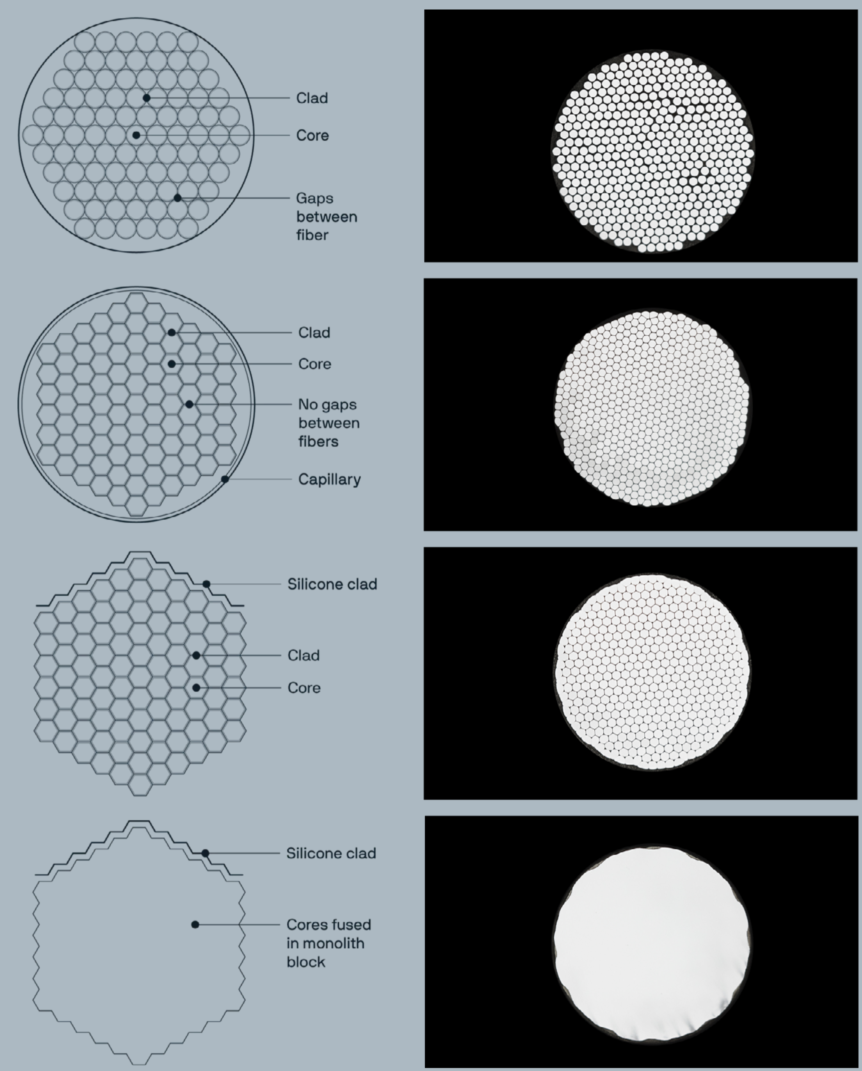
Clad Fused bundle (CFB)

Similarly, as in HFB, during the fusing process, the fiber clads are fused together and gaps between fibers are removed but there is no silica tube required. Elimination of the silica tube gives complete freedom in the bundle end geometry (square, triangle, rectangle etc.) Another advantage is that the face of the metal connector absorbs incoupled light. In the case of HFB incoupled light travels through a silica tube and may cause the failure of the bundle.

Monolith fused bundle (MFB)

This bundle in terms of transmission, is as close to single plastic clad fiber transmission as possible. Here the main difference is that fiber clads are removed and the fiber cores are fused together making one monolith body. There are no individual fibers that can be recognized. This type of fused bundle has the same advantages as CFB, however, there is a difference. MFB gives homogenous far and near field beam profiles. MFB is ideal for low power applications, while utility at higher powers need to be studied.

Comparison of Glued (GB), Hexagon Fused (HFB), Clad Fused bundle (CFB) and Monolith fused bundle (MFB).



With the glued bundle technology (GB), many fibers are glued together with an epoxy resin adhesive.

With the Hexagon Fused Bundle Technology (HFB), the fibers are held together in a glass capillary and then fused together.

The Clad Fused Bundle technology (CFB) is similar to the HFB. During fusing process fiber are deformed into a hexagonal structure. A glass capillary is not used here.

This type of bundle in terms of the transmission are similar to the single fiber. It is called Monolith Fused bundle (MFB).

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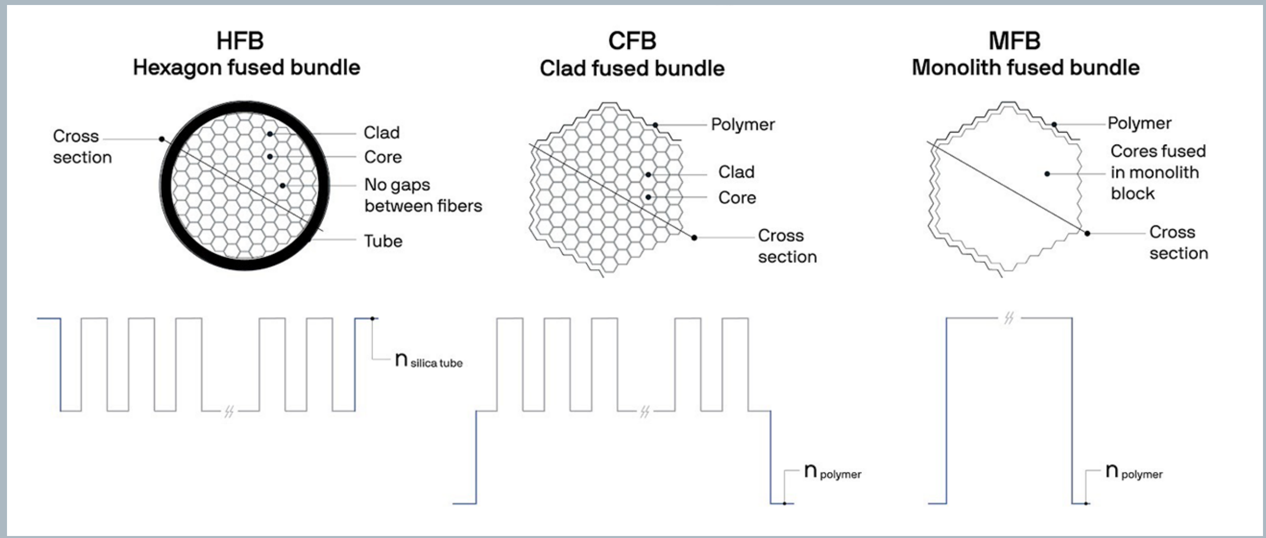
Optical characteristics of HFB, CFB, and MFB

Lightguide has chosen to use a refractive index profile (RIP) approach to deliver optical principles in the three different fiber bundles. Fibers in HFB, CFB and MFB are fused, eliminating the free spaces between individual fibers. The fibers change their outer shape and altogether create a honeycomb-like structure with no gaps between any fibers. It is possible to provide RIP for cross-sections of different fiber bundles.



The upper row picture schematically explains the differences of different fused end fiber bundle technologies. In contrast, the bottom row shows RIPs of corresponding fiber bundle cross-sections. The main difference between conventional HFB and the new fused end fiber bundle technologies CFB and MFB is the absence of the silica tube.

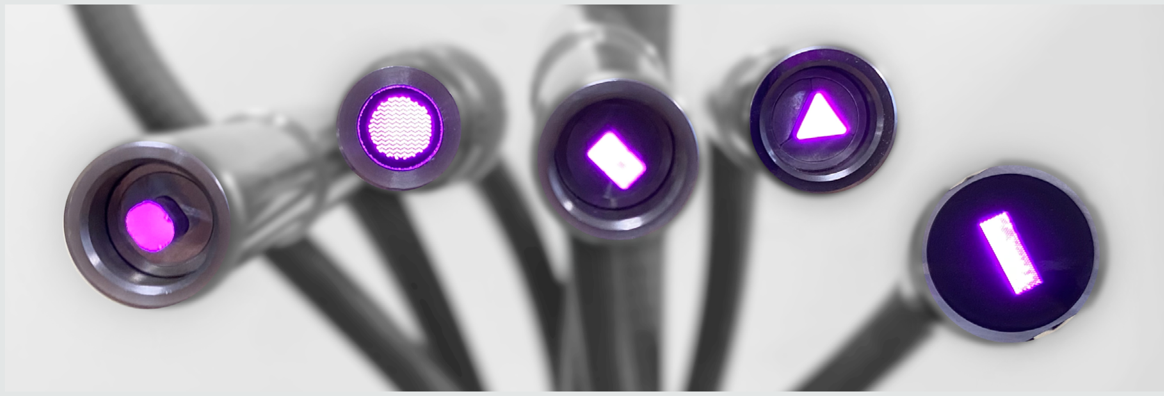
In the HFB design, the refractive index of the silica tube is higher than F-doped silica cladding of the individual fibers. In the CFB and MFB designs the fused fibers have a high refractive index cores and the outer layer of bundle is made of a low refractive index polymer or air.

Almost every shape is possible

In recent years Lightguide has made significant innovations in fused bundle technologies. It results in two new types of fused bundles where the silica tube is removed, and any shape is possible. Compared to HFB, there are several significant benefits:

Any shape is possible which leads to maximization of coupling with a light source. Smaller bundle diameter can be realized, which requires less space for the bundles. Higher precision of the bundle can be realized. Higher NA can be achieved due to the outer polymer cladding. Furthermore, the bundles are suited better for high-power applications.

Bundle Type	NA	Abstraction In the article
Glued bundle	0.22	GB
Standart fused bundle	0.22/0.37	HFB
New fused end technology	0.37	CFB
New fused end technology	0.37	MFB



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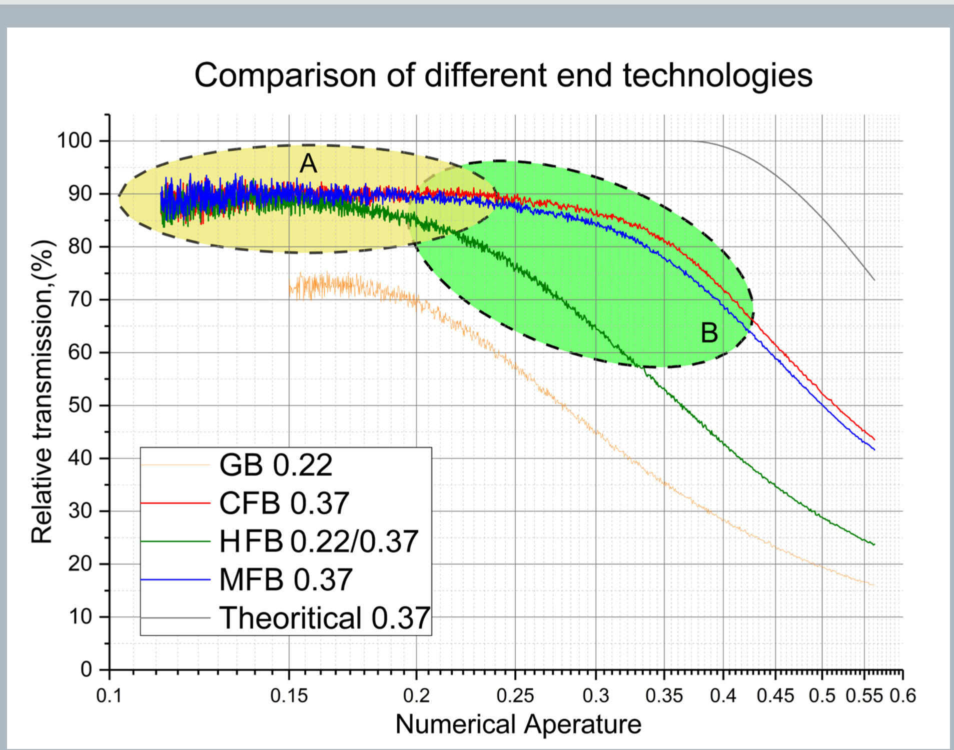
Transmission comparison of bundle technologies

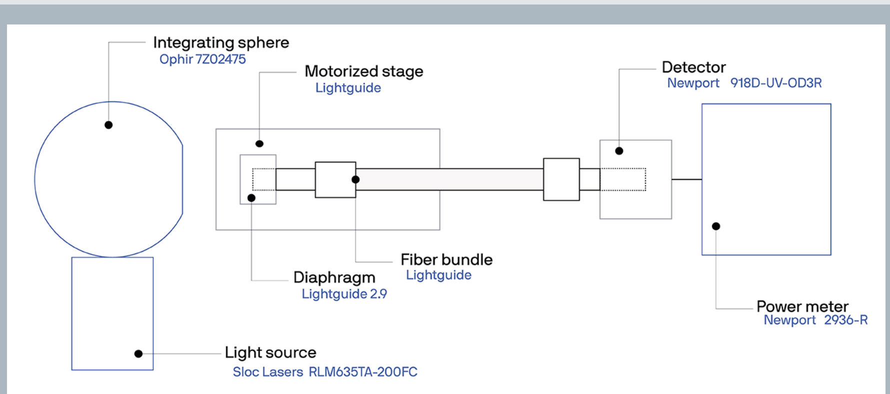
Numerical aperture was calculated from the integrating sphere opening dimensions and distance to bundle. Relative transmission curves are displayed in the graph comparison of different bundle end technologies, and for convenience, an added theoretical transmission curve of an ideal fiber bundle with NA=0.37.



Used experimental setup. At first synthetic quartz glass rod was measured as reference. The NA was measured through the opening of the integrating sphere with known distance to the bundle.

Fiber bundles with identical outer designs have been tested but with different end treatment technologies to obtain relative transmission curves for further studies.

Each fiber bundle has been tested in a setup by changing the distance between integrating sphere and diaphragm. Distance power and position changes were recorded. To obtain relative transmission curves of the different fiber bundles, measurement of a pure synthetic silica rod was used as reference.



Reflective index profiles of the different Fiber bundle technologies.

As it was expected, traditional glued fiber bundle technology GB (GB 0.22 line in the graph) shows the least performance, determined by the low packing factor of fibers, interstitial spaces, and glue layer between individual fibers. This solution satisfies applications where cost is a consideration along with a sufficient transmission rate that is acceptable.

Conventional fused fiber bundle in silica tube HFB (HFB 0.22/0.37 curve in the graph) technology shows significantly better results if compared with GB. Pressed together, the fibers are deformed creating a solid silica honeycomb structure, which is made from cores and F-doped reflective claddings of the individual fibers. The leap in the transmission is driven by peculiarity, that this technology allows eliminating free spaces between individual fibers, fusing and pressing them together. This technology is common with a high repeatability rate and will be a perfect fit for applications where the max required NA is 0.22...0.24, and circular shape active end can be useful and fulfill expectations of performance.In the new fused end technology, CFB (CFB 0.37 curve in the graph) fibers are fused together without a silica tube, giving freedom of active area shapes. For this technology fiber cores and F-doped reflective claddings create a honeycomb structure. The performance of this technology for numerical apertures up to 0.22 does not differ much from conventional HFB technology. However, for higher numerical apertures than 0.22..0.24, we can observe a significant gain in transmission because the outer layer of this bundle end is made from low refractive index polymer reflective coating. Obtained results allow us to conclude that new fused end technology - CFB (Clad Fused Bundle) shows superior performance once compared with traditional glued end fiber bundle and conventional fiber bundle with fibers fused in a silica tube. Innovation of new fused end fiber bundle technologies open additional opportunities to utilize fiber bundles with specially treated ends in applications where they are required:

- high NA;
- high power;
- hight temperature threshold;
- large active areas;
- unusual shape of the active area at input or output.

CFB technology will be the best fit for high NA applications and applications where unusual shape active ends at the inputs or outputs are required.

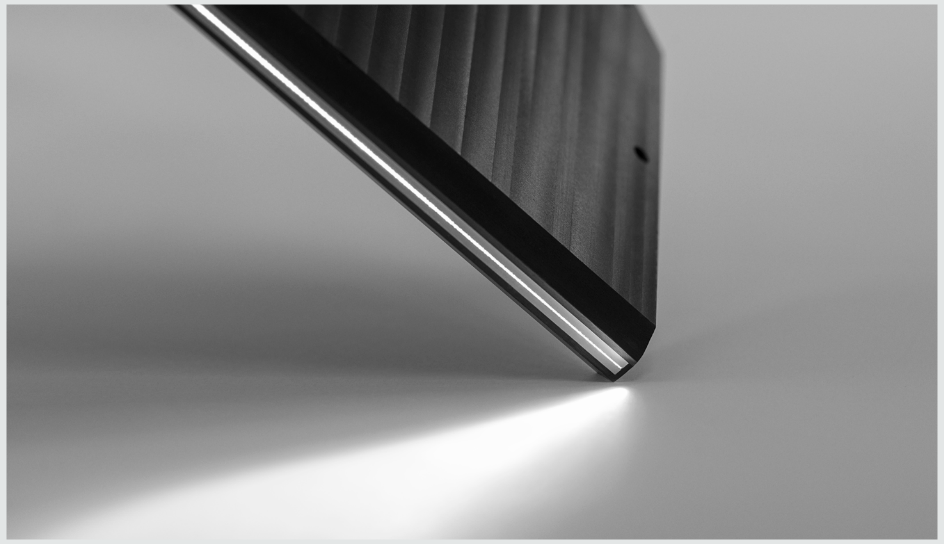
MFB bundles are still under development. The packing density is close to 1. Due to this fact, the transmission is highly comparable to HFB bundles. In contrast to HFB, they are not suitable for high power applications as the cladding is made of polymer with limited temperature resistance. One of the primary applications is illumination.

Opens countless new applications

In the two paragraphs above, Lightguide suggests using HFB (A area in graph) or CFB (B area in the graph) technologies. There is some overlap between those technologies about numerical aperture 0.22...0.24. CFB to be selected if there is an unusual shaped optical end required or it is desired to use fiber bundles at high powers.

The new fused end technology MFB (MFB 0.37 curve) is intended to fuse fibers without an F-doped silica reflective cladding, creating a monolith block covered with a low refractive index polymer. MFB technology might be useful for low power illumination applications, while utility at higher powers needs to be studied further.

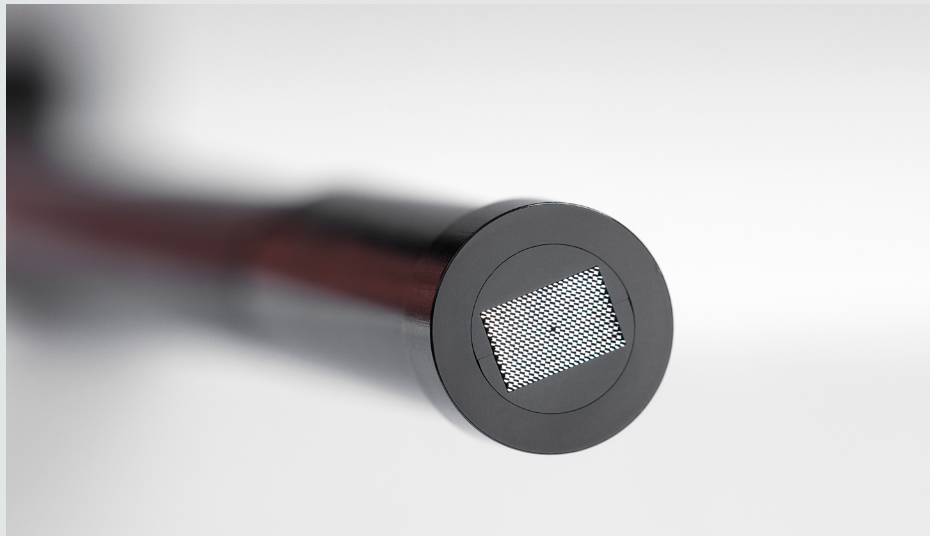
Industrial applications



Light delivery

Laser delivery

Spectroscopy



Sensing applications

Semiconductor

UV curing

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