

LARGE CORE OPTICAL FIBERS FOR MEDICAL APPLICATIONS

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SUMMARY

Medical procedures using high power lasers to alter or vaporize body tissues are increasingly common. Popular lasers in these procedures include Nd:YAG, diode and Ho:YAG lasers. Large core hard polymer clad optical fiber (HPCF) is becoming the choice for fiber optic assemblies that are used to deliver laser energy. While proper fiber design, fiber termination and end face preparation are critical to the power performance of a fiber optic assembly, the type of laser source and the laser launch conditions both have an impact. For medical product development engineers, the key to project success is to develop a close relationship with an experienced fiber supplier in the early stage of product development. This not only shortens the development cycle but also saves time and reduces cost when the project moves into the production phase later.

INTRODUCTION

Medical procedures using high power lasers to alter or vaporize body tissues are increasingly common. Some examples include BHP or enlarged prostate surgery, laser lithotripsy or stone fragmentation, endovenous laser therapy, and laser angioplasty. Less common are laser trabeculectomy, TMR, and dental/oral surgeries.

Typical lasers used in the medical procedures are Nd:YAG lasers (1064nm), frequency doubled Nd:YAG lasers (532nm), diode lasers (800nm ~ 850nm ~ 980nm), and Ho:YAG lasers (2.1 μm). For these common lasers, pure silica core step index multimode optical fiber can be a good choice as it transmits light well at visible and IR wavelengths up to 2.1 μm. CO₂ lasers at 10.6 μm and Er:YAG laser at 2.9 μm are also used for high power medical applications. However, silica core fiber does not work for these two lasers due to high attenuation. Instead, silica based hollow waveguides¹ optimized at the relevant wavelengths can be employed. For excimer lasers emitting UV light at 308nm, optical fiber must be specially processed or treated to provide good and stable transmission. It is important to select a proper fiber for specific lasers at specific applications.

In medical procedures, laser energy is delivered through an optical fiber assembly. Use of optical fiber is beneficial to patients and medical doctors and also reduces medical expense. Since the fiber is thin and flexible, it can be easily and tightly bent. Therefore, only a small incision or cut is required to insert the fiber into the body and deliver the light energy to the target tissue. Thus, medical procedures using fiber optic delivery are minimally invasive. The patient recovers faster from the procedure. In practice, patients have shorter hospital stays, often an outpatient visit, which will result in medical cost reduction. As laser energy can be delivered through fiber to a target area without damaging the surrounding tissue, the procedure has high efficacy. Bleeding is reduced during procedures because of the small incision and coagulation characteristics of some lasers. The procedures provide patients a less traumatic experience as a result.

OPTICAL FIBER

Pure silica core step index multimode optical fibers have several advantages over telecom fiber. First, the fiber is capable of handling high power. The large core diameter, often >0.1 mm, enables the fiber to transmit more light. High numerical aperture (NA) gives the fiber a wider angle of light collection and thus enables more light to be coupled into the fiber. High core to clad ratio enables the fiber to transmit maximum light power for the same fiber core diameter while its flexibility is maintained. In addition, the fiber is capable of transmitting higher laser power because pure silica material has a higher melting temperature and damage threshold than doped silica. A second benefit is lower cost, with a minimal amount of expensive dopant materials used in a pure silica core fiber. Also, the fiber has high mechanical strength and flexibility. Fiber is proof tested in line up to 150kpsi and has a small bend radius. Other benefits include ease of termination and the ability to sterilize these fibers using standard methods including autoclave and ETO.

Silica fiber with polyimide, hard clad and silicone coating or buffer is common in medical

applications. Polyimide works at temperatures up to 400°C. As this coating is tough and thin, polyimide coated fiber is a good option for bundles and often require no extra buffer or jacket in practice. Hard clad, an optical polymer with a lower refractive index than silica, can also be used as cladding material. It provides extra mechanical strength to the fiber, as well as facilitates quick cleaving and easy field termination. Silicone has a high temperature rating up to 200°C. A rubbery material, silicone is an excellent choice for applications requiring minimal micro-bending loss. Secondary coatings are typically extruded onto the fiber for additional mechanical protection. Common materials are Tefzel®, nylon and Teflon®. As a fluoro-polymer, Tefzel® and Teflon® are chemically inert while nylon is often used in cases where the jacket needs to be glued to the connector.

Hard polymer clad fiber (HPCF) is popular for medical applications. From a viewpoint of fiber configuration, there are single-clad HPCF and dual-clad HPCF. Examples of single clad and dual clad HPCFs are shown in Figure 1 and Figure 2, with example configurations listed in Table 1 and Table 2. Custom sizes and configurations are also available. Dual clad differs from single clad in that dual clad has an extra thin fluorine doped silica glass layer between the pure silica core and outer hard polymer coating. The additional hard polymer coating in dual clad HPCF acts as a secondary cladding so that additional light can be guided in the silica cladding. The dual clad HPCF has a higher power damage threshold and covers a broader wavelength range, up to 2.1 μm in infra-red. However, the dual clad has lower NA (0.22NA versus 0.37 or 0.48NA for single clad) and costs moderately more than single clad. Single clad is generally recommended for an application before dual clad is considered.

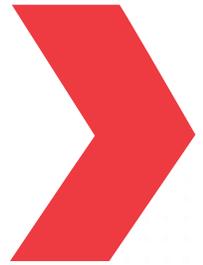




Figure 1. Single Clad HPCF Construction

HPCF: Hard Polymer Clad Fiber

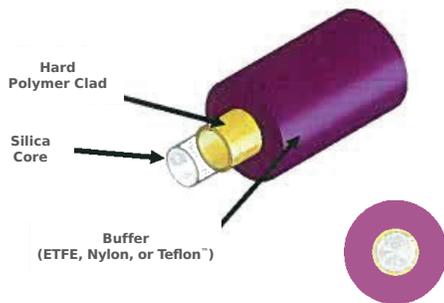


Figure 2. Dual Clad HPCF Construction

Hard polymer coating also acts as secondary clad

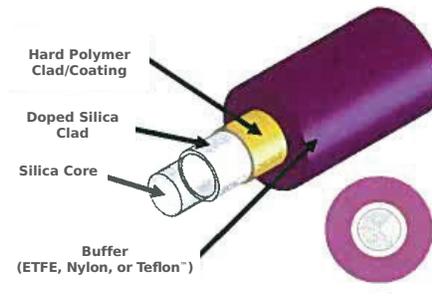


Table 1. Examples of Single Clad Fiber

Silica Core Dia (µm)	Hard Polymer Clad Dia (µm)	Tefzel Buffer Dia (µm)	Proof Test Level (kpsi)
200	230	500	150
300	330	650	150
600	630	1040	75
1000	1035	1040	125

*Fibers with other sizes and configurations are available from Polymicro Technology, LLC

Table 2. Examples of Dual Clad Fiber

Silica Core Dia (µm)	Primary Silica Clad Dia (µm)	Hard Polymer Clad Dia (µm)	Tefzel Buffer Dia (µm)	Proof Test Level (kpsi)
200	240	260	375	150
365	400	430	730	150
550	600	630	1040	100

*Fibers with other sizes and configurations are available from Polymicro Technology, LLC.

FIBER OPTIC ASSEMBLY

Fiber optic assemblies which deliver laser light consist of a fiber with two prepared ends, proximal and distal terminations. Compared with ST, FC and connectors of other types, SMA is the most popular. The SMA connector, with some custom variations, interfaces with the medical laser at the proximal end of an assembly. For example, a mechanical or electronic interlock can be integrated into the connector for authorized operation of medical lasers and eye safety. The distal end of optical fiber is simply cleaved, polished, or even sculptured to generate an emitting light pattern for specific applications. Examples are side-firing sculptured tips within a protective glass enclosure, ball lens tip, and diffuser tips. A side-firing tip emits light at an angle close to 90 degrees from the end of fiber, and has found applications in, for example, BPH where laser energy evaporates prostate tissue on the side of fiber. Diffuser tips are widely used in photodynamic therapy of cancer where optical power is guided through the fiber and illuminates uniformly within the tumor tissue.

Options for preparation of a fiber end face include cleave, mechanical polish and laser thermal polish. If done properly, a cleave can provide a mirror surface with minimal edge chipping, although the surface is less flat than a polish. A cleave is cost effective and especially ideal for field termination. Mechanical slurry polish down to 0.3µm is typical, yielding a flat surface which can be angled. The polish process can be automated in bulk quantity and is, as a result, cost effective for mass production. Laser polish is an advanced technology that creates a less flat but pristine surface which is capable of withstanding high power input. It is often used jointly with glass sleeves in high power terminations. However, this technology is not suitable for bulk process and is more costly.

POWER HANDLING

Medical laser system design engineers often ask which power level a fiber or an assembly is capable of handling. The answer really depends on many factors in practice. Some of them are related to the assembly and fiber used in the assembly. They include fiber geometry, core and clad material, fiber design (single clad, dual clad, etc), fiber termination, surface quality, end face contamination, and other parameters. In general, dual clad HPCF handles more power than the single clad. A laser polish based high power termination offers much higher power capability. The power performance of the assembly also depends upon the laser source and laser-fiber coupling through laser parameters (wavelength, continuous wave, pulsed, pulsed energy, repetition) and laser launch conditions (NA, alignment, stability, beam spot homogeneity).

In general, the light induced damage threshold of pure silica fiber is about 1 GW/cm for pulsed laser and about 2 MW/cm² for continuous wave laser at 1064nm. To reach these power levels, extreme care must be taken of the coupling of light into and out of a fiber. For example, applications exist where over 30W of cw laser power at 532nm is transmitted in single clad HPCF (0.3mm core diameter), over 80W of pulsed laser power at 1064nm, and more than 50W pulsed laser power at 2.1µm in dual clad HPCF (0.55mm core diameter). Further, it is known that over 2000W of cw Nd:YAG at 1064nm has been transmitted down a dual clad HPCF fiber, however this would be for industrial material processing applications in cutting or weld of metal.

SUMMARY

In order to improve the likelihood of project success, medical product development engineers should develop a close relationship with an experienced fiber supplier in the early stage of product development. By working together in the early stage, the fiber supplier and the medical system developer can develop an in-depth understanding of each other's requirements before commencement of a full-scale project development. This not only shortens the project development cycle but also likely saves time and reduces cost when the project moves into the production phase.

¹ Hollow silica waveguides are available from Polymicro Technologies.

For more information please contact Polymicro Technologies, a Subsidiary of Molex at polymicrosales@molex.com or by phone at (602) 375-4100.